Geophysical Inversion [GPC-516]

Date - 25.07.2024

Lecture Plan :

Textbooks : Menke W., 1989, Geophysical Data Analysis : Discrete Inverse Theory, Academia Press, International geophysical series, vol. 45, 3rd edition Matlab Edition.

Sen M.K., 2013, Global Optimization Methods in Geophysical inversion 2nd Edition.

Reference Books : Scales J.A Smith, ML., Trietal, S., 2001, Introductory Geophysical Theory, Samizdat Press, Golden Colarado, USA

Gubbins, D., 2004, Time series Analysis and Inverse Theory for Geophysicists, Cambridge University Press

Exam : Traditional → Mid-Sem [32 marks] → Descriptive, Numerical, S.A, Proof
End-Sem [100 marks] → " " " "
Quiz - 2 [10 marks each : Duration → 20-30 mins]

Mid-Sem : Introduction :
Elementary concepts / Data, Modes, Models, Norms
Linear Algebra :
Vector, Matrix, Decomposition Technique, SVD
Least Squared - Based ↓ Inversion.
Matrix
Local Optimizations → Gradient Base or Newton, SCG

Environmental Geology [GLO-532]

effects on → Soil, Water, Land, Air
Water → Ground water, Surface water

Reservoir Induced Seismicity (RIS) :
Koyna Dam in Maharashtra

- Most of the Hazards are seasonal in occurance (like volcanic hazards, earthquake etc. can occur again and again)

San Andreas Fault → Here stress is accumulated over a period of time and is subject to earthquake
↓
"Radon" measurement is done to predict the occurrence of Earthquake (Radon count increases prior to earthquake)

- Flood Frequency Curve
- CCP → Carbon Credit Policy

To reduce the emission of carbon govt. are crediting some amount of money in exchange of lowering of carbon emission.

Hazards :
→ Geological / Geogenic : Landslides, Earthquakes Tsunami, Floods, Volcanic Hazards
→ Technological : Floods, RIS ← (caused by Dam Failure)
→ Anthropogenic : Earthquake, Floods Mining Hazards
→ Mixed : Landslides

Just because it causes problem, we cannot stop mining, hence comes the term Sustainable mining

ESID → Ecologically Sustainable Industrial Development
↓
managing environment along with mining activities.

Geophysical Inversion

Date : 26.07.2024

Data - model Introduction :

$d = G m$

data ↳ $d = [d_1, d_2, \ldots, d_N]^T$

model/ model parameter ↲ $m = [m_1, m_2, \ldots, m_N]^T$

G = Kernel function / matrix

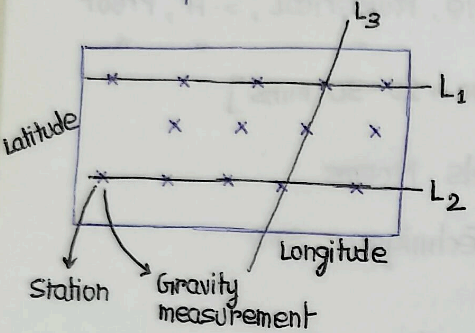
Forward Modelling : (Iterative)

Hypothetical Model → Forward Theory → Predicted Data "Computed Data"

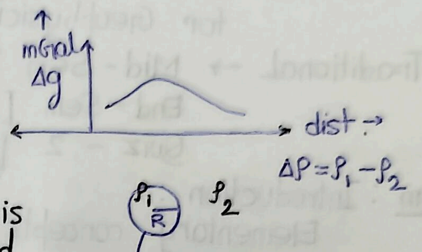
Inverse Modelling

Observation / Data $\xrightarrow[\text{optimization}]{\text{Inversion}}$ Estimated Model Parameter

Gravity Survey :
↓
Data / Observation



From the response we assume the model Hence its Hypothetical

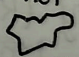


This sphere is the model and ρ and R are the model parameter

"Forward Theory" is the theory based on Physics which provides the relation b/w the model parameters and the quantity (gravity, seismic, logging etc.) we want to estimate

observed function or Loss function = RMSE / MAE $= \sqrt{\frac{\sum (d_{computed} - d_{predicted})^2}{N}}$

↳ We need to minimize this

If geometry is regular then computation theory is easy, but if the geometry is is not regular , then its difficult.

↙ □ or O

Environmental Geology

Environment of Air :

Air Pollution

- Climate change
- Thermal Inversion
- Global Warming
- Greenhouse effect
- Floods or Sea-level change
- Ozone Hole depletion

Flows fast in the atmosphere ↑

Residence time is less for CO than CO_2
Hence CO is more dangerous than CO_2

SO_2, Pb, Cd, Hg → Bio-magnifier (it magnifies the amt. of other poisonous gas, like if we have 10 gm of Pb it will magnify Pb to larger extent)

↓ Carcinogenic

→ These are not greenhouse gases

Aerosol → it can be solid / liquid / gas.

Primary pollutants are anthropogenic in nature.

"Wind cock"

OECD → Oil Exporting Countries

SPM → Suspended Particulate Matter.

→ PM-10 → it is more dangerous

↓ RSPM (< 10 μm)

Respiratory Suspended Particulate Matter

"Water vapour" is most hazardous as it helps in the reaction of the elements to form poisonous gases, like NO, CO, CO_2 etc.

Seismic Data Processing and Interpretation

Date - 29.07.2024

1. Thermodynamics variation creating Pressure variation.
2. Wave equation variation
3. Variation in Amplitude, Phase and Frequency.

Amplitude, Phase, Frequency reveals the informations of lithology and fluid along with anisotropy variation.

* Gadallah (Big one) → Book

Formation Evaluation

Here we would learn about the interpretation of log data.

Formation → a particular geological layer. (named after the location which differ from basin to basin)

The well log data are measured in "Depth domain"

"Fluid pressure" is an important parameter when dealing with production scenario. → so that when evaluating we can know about the fluid flow wheather pressure is low / high within the formations so that we can generate / increase / decrease pressure as and when required.

From 'thin section' we can get an idea about the pore space, grain size and also about the permeability.

Porosity depends on the sorting of the particles within the rock
poorly sorted → less porosity
well sorted → high porosity

Electro-Facies → It comes from the wireline or electrical log

Petrophysical properties → Volume of shale, porosity, water saturation

Permeability → Relevant to flow properties

Books → Bateman
Helander

Geothermics and Geodynamics

4.53 giga annum → Throughout this age, activities have been going under/within
(4530 million years) the Earth continuously throughout the evolution.

Mutual interaction after evolution
↳ means change of momentum → generation of energy leading to release of energy creating Earthquake

In the Alluviam → 300 - 400 m/s (P-wave velocity)

Plume material is directly connected to core-mantle boundary.

Body has released huge amt. of energy itself → Free oscillation of the body leading to vibration

Q-value
Gravity → can be computed from free Oscillation of the Earth

Here more importance is given to gradient than the value itself → wheather it is gradually increasing / moderately increasing or increasing at a faster rate creates a great impact.

Disruption Technique

Inversion layer / Magmatic Ocean
↳ D'/D" layer

Seismic Data processing and Interpretation

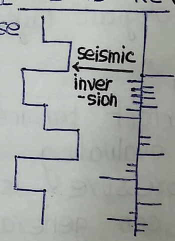
Date - 30.07.2024

$S(t) = W(t) * R(c) + n(t)$

Earth

Polarity : → outcome after study
1. SEG Normal
2. SEG Reverse

AI vs RC (Data)



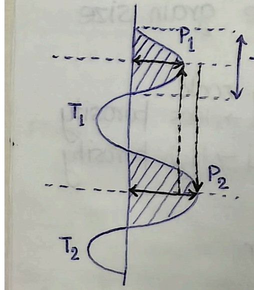
1. Structure
2. Sediments
3. Fluids

A. Characterization of source wavelet
B. Characterization of Refracted / reflected wavelet.

R(c) are layer based information where RC is absent

In Normal pressure condition, SEG Normal has high impedence, high (+)ive amplitude

Wedge, Tuning, Thin are related to amplitude.



Peak to Peak → Resolution

Thickness of the layer (geology) (T_1)

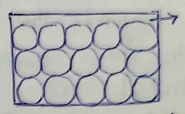
$T_1 = \frac{\lambda}{4}$

SEG normal at zero crossing → + to -
SEG Reverse at zero crossing → - to +

Formation Evaluation

1. Determination of mineralogy from wireline log.
   ↳ From here we can get the information about the Rock-type (Shale / sandstone) or presence of any minerals → Shale clay / Quartz / calcite
2. Induced GR spectrometry tool → Change in water saturation.
3. NMR Tool and application
4. Image log tools and how they can be used for fracture characterization
   ↳ Dip meter log

Porosity depends on → (i) Grain size and shape (ii) Cementing Type (iii) Grain sorting.



Critical Porosity =40%

Total porosity = $\phi_e + \phi_{ne}$

ϕ_t Effective porosity, non-effective

* Pumice stone → has porosity but not interconnected (i.e no effective porosity)

Elastic properties → Rock Physics
- V_p
- V_s
- ρ

- Porosity
- S_W
- V_{sh}

Water saturation :

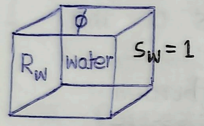
S_W is unitless 0 – 1% 0 – 100%

$$\underbrace{S_o + S_g}_{S_{hy}} + S_W = 100\%$$

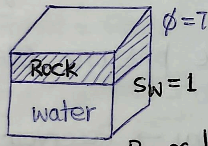
$$S_{hy} + S_W = 1$$

$$\therefore S_{hy} = 1 - S_W$$

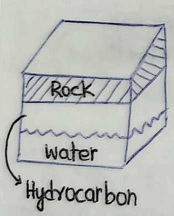
S_{Wi} = Irreducible water saturation.



$R_t \propto R_W$



$R_t \propto \frac{1}{\phi}$



$\phi = 75\%$

$S_W = 70\%$

$R_t \propto \frac{1}{S_W}$

$R_t = R_o \rightarrow$ Wet Rock resistivity $(S_W = 1)$

$$R_t \propto R_W * \frac{1}{S_W} * \frac{1}{\phi}$$

$$\therefore R_t \propto \frac{R_W}{\phi S_W}$$

Formation factor (F)

$$S_W^n = \frac{R_o}{R_t} = \frac{F \times R_W}{R_t} = \frac{a\,R_W}{\phi^m R_t}$$

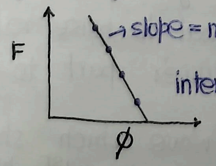
R_W → Direct or Indirect

R_t → Deep Resistivity

ϕ^m ↳ calculate

$$F = \frac{a}{\phi^m}$$

$$\Rightarrow \log F = \log a - m \log \phi$$



Geothermics and Geodynamics

Bode-Titius Rule :

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

↳ This expression gives the distance of the n^{th} planet from the Sun in Astronomical Units (A.U)

The result was found to be true upto Uranus but failed for Neptune and Pluto.

Ecliptic Plane - It related to the rotation of the planet forming a plane

The equatorial plane and ecliptic plane are different for planets
Hence the angle is different (like for earth it is 23.5°)

Terrestrial Planets

Jovian / Great Planets → From Jupiter to Neptune

Pluto is beyond the "Kuiper Belt"

Neptune to some extent and Pluto are under the influence of other gravitational pull, hence can be considered a reason as to why they doesn't follow Bode-Titius Rule.

Seismic Data Processing and Interpretation

Date : 31. 07. 2024

The amplitude, phase and frequency are together combine to form the wave i.e the wave contains all these informations which is related to geological entity (Thickness, Rock properties) and is subjected to techtonic activity leading to the changes of the attributes – (i) Petrophysical properties
(ii) Rock Physics properties (Pore pressure, Overburden pressure)
(iii) Geomechanics

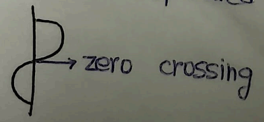
Basin → Deposition → Rock → Tectonic / Sedimentary → Reservoir → Seismic

Peak to Peak or Trough to Trough → means there is homogeneous geology and the resolution has been perfectly

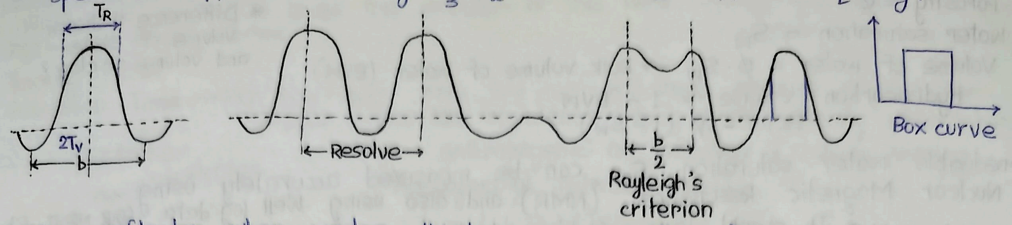
But Peak to Trough or vice versa suggest the geology consist of multiple properties

Resolution :

1. Minimum separation b/w two features.
2. Based on seismic wave these resolution can be identified.
3. Two interface must show separate reflectors (vertical resolution)
4. How far two features are separated in a single interface (horizontal resolution)
5. Resolution can be demonstrated based on signal to noise ratio
6. T reflections lags behind the shallower part to $\frac{2\Delta z}{\lambda}$ of deeper part.
7. There are two waves where arrival of 2^{nd} wave which shows perceptable changes in the appearance of the 1^{st} wave.
8. Rayleigh defined resolvable or separable limit start when two events are separated by half-cycle.



9. For box-curve frequency, the wavelet $\overset{\text{shape}}{\wedge}$ is sinc, Rayleigh frequency spectrum approximated by $\frac{2}{3}V_u$ where V_u = upper frequency.



10. Clear reflector when wedge thickness more than $\frac{\lambda}{4}$ with different velocity from surrounding materials.

11. The wave shape is nearly constant below a thick of $\frac{\lambda}{4}$ where we observe minimum amplitude for constructive interference and single layer can be identified.

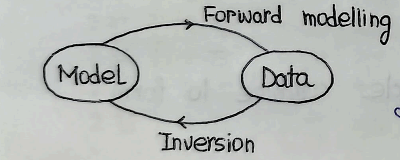
Geophysical Inversion

Forward modelling ↓

Start
↓
Model Initiation (Assume model parameter)
↓
Computing Forward Response
↓
MAE Misfit error = Computed − Observed → L_1 Norm, → L_2, → L_∞

Data
↓
Inversion / Inverse Models
↓
Model parameter
→ Local
→ Global
→ Hybrid

Inversion ↑



$d = Gm$ (d → data, G → Kernel matrix, m → model)

(i) In $d = Gm$ → there is no noise

error $= d - Gm$

$\therefore m^{est} = G^{-1} d$

(ii) g = generalised, e = noise

$d = Gm + e$

$m^{est} = G^{-g}d + G^{-g}e$

$m^{est} = G^{-g}\, G m_{true} + G^{-g}e$

$m^{est} = m^{true} + (G^{-g}G - I)m_{true} \underbrace{- G^{-g}e}_{\text{artifact}}$

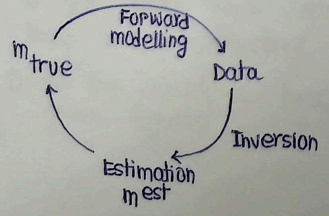
$G^{-g}G = I$

case-1 → $m^{est} = m^{true}$ + artifact

$G^{-g}G \neq I$

case-2 →

$m^{est} = m^{true}$ + Bluring effect + artifact



Formation Evaluation

For clean formation :
Porosity = ϕ
Water saturation = S_W
$\therefore$ Volume of water = $\phi \cdot S_W$ → Bulk volume of water (BVW)
Hydrocarbon volume = 1 − BVW
$HCPV = \phi\,(1 - S_W)$

* Difference between Volume of shale and volume of clay ?

Irreducible water saturation S_{wi} can be measured accurately using Nuclear Magnetic Resonance (NMR) and also using Well log data (GR, NPHI, Rt, DT)

* It should have fluid content in the rock for NMR to work we cannot apply NMR for dry rock.

Ratio plot → Invaded zone saturation $S_{xo} = \dfrac{a\,R_{mf}}{\phi^2 R_{xo}}$ ↓ 1
→ Un-Invaded zone saturation

$$S_W = \frac{a\,R_W}{\phi^2 R_t}$$

$$\therefore \frac{R_{mf}}{R_{xo}} = \frac{R_W}{R_t} \qquad \therefore R_{wa} = \frac{R_{mf} \cdot R_t}{R_{xo}}$$

Minimum 5 points are neccessary to calculate R_W from Ratio plot or R_{wa} technique or Pickett plot.

Geothermics and Geodynamics

Pluto comes in the path of the Neptune, as the revolutional period of Neptune is 248 years, hence there is no problem of meeting each other. So, pluto is not considered a planet as it doesn't have its own path of rotation like the others. (it crosses the path of the Neptune).

Reburying of the debris –
During the ~~Acresion~~ accretion period, the smaller dust particles combine to form planets since the Big bang.
Fusion started for the evolution of the Protosun
Meteorites come from the Asteroid belt and Kuiper Belt
- Chondritic
- Achondritic

The half-life of magnesium - 26, Aluminium - 26 are very short w.r.t the age of the Earth (4.53 giga annum), so the daughter nucleus of them, help in the determination of the age of the planets.

Environmental Geology

Ozone is a secondary air pollutant.
Wind cock is used to know the direction of the wind.
AQI → Air Quality Index
Toxicity factor
Residence Time → For how much time the air pollutants remains in the air.
CO, NO → Has less residence time (kills instantly when inhaled)

CO_2 sequestration
↳ storage

Anthropogenic air pollution → Stubble burning
Peroxyacetyl Nitrate (PAN)
Liquid + Solid = Aerosol
Inorganic
Organic
Radiogenic → Radon (it disintegrates to uranium)

PM
SPM ↗ ↖ RSPM
Suspended Particulate Matter
Respiratory suspended Particulate Matter

Coal Mine Fire → spontaneous combustion of coal
GOAF → Subsidence due to underground coal mine
CO is formed due to incomplete combustion
Composition of fossil fuel → $CH+N+S+O+P$

Mathura Refinery release huge amounts of NO_x, SO_x

Thermal Inversion → Due to the increase in temp. the air pollutants come down from the atmosphere.

Seismic Practical

1. common shot gather
2. common receiver gather
3. CDP gather
4. common offset gather
5. Stack

Question :

Rho 1	Rho 2	V_1	V_2
1.3	1.4	1200	1250
1.8	1.9	1270	1300
1.85	1.95	1310	1330
2	2.2	1370	1390
2.37	2.48	1400	1430
2.56	2.73	1450	1470
2.44	2.45	1500	1510
2.73	2.77	1530	1540

(i) Calculate RC from the following information and plot ρ_1 vs RC, ρ_2 vs RC
Interprete the result.

(ii) Calculate source interval from the following information :
No. of fold = 30
channel = 198

(iii) Estimate the Fresnel zone radius from the following information :
Velocity, v = 1277 m/s
Period, T = 1200 ms
Half - wavelength = 40 ms

(iv) From the given figure try to identify as many seismic figure /events as you can. What are the main primary reflection events. What are the factors affecting the amplitude of seismic events in the figure.

(v) Draw the waveform based on the peak and trough distribution of the given figures.

Date - 01 . 08 . 2024

Geophysical Inversion

Data - Model Relationship and Least - squared Methods :

Let $d = Gm + e$ (error)

$\underset{\text{data}}{d}$, $\underset{\text{Kernel matrix}}{G}$, $\underset{\text{model}}{m}$

$$E = \text{misfit} = \text{Error} = e^T e = (d - Gm)^T (d - Gm)$$
$$= (d^T - m^T G^T)(d - Gm)$$
$$\therefore E = d^T d - d^T Gm - m^T G^T d + m^T G^T Gm$$
$$\frac{\partial E}{\partial m^T} = 0 \Rightarrow 0 - 0 - G^T d + G^T Gm = 0$$
$$\Rightarrow G^T Gm = G^T d$$
$$m = (G^T G)^{-1} G^T d$$
$$m^{est} = \boxed{(G^T G)^{-1} G^T} d$$
$$\underset{G^{-g}}{\uparrow}$$

it is not always squared

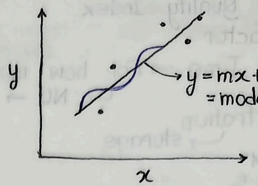
(i) Dimension of G = ?

(ii) Why gravity - magnetic field method is called the potential field model ?

(iii) Cultural Noise ?

(iv) T Remote - reference system ?

'apriori' - when you don't have any idea about the noise being incorporated in the data.



Here the model is a straight line
m , c are the model parameters

Its not that we have to fit the model exactly with the observed points, but to make a model which goes well with the geology and can be explained geologically.

Environmental Geology

One by - product of Thermal inversion is Acid Rain.

AQI → It indicates whether pollutants level in air may cause health concerns or not.

Air Quality monitoring → Collect samples → Analyse samples $\xrightarrow{\text{conduct}}$ Vulnerability Analysis (VA) $\xrightarrow{\text{calculate}}$ Vulnerability Index (VI) $\xrightarrow{\text{prepare}}$ Vulnerability Score Test (VST)

Toxicity Weightage Factor :

Pb 85 → means Pb is 85 times more toxic than other dust particles.

CPCB → That controls air pollution.

$CaO + CO_2 \rightarrow CaCO_3$ (limestone / calcite)

$CaMgCO_3 \rightarrow$ Dolomite

For Sensitive area, AQI < 150 (expected) because people in this area (like hospital) are not assumed to be much healthy, and are subjected to much effect.

UCG → Underground Coal Gas Equation.

Coal Liquifaction.

NPT → Non - Proliferation Treaty.

CBM → unconventional sources of energy.

Seismic Data Processing and Interpretation

Date - 05.08.2024

Tuning and thin bed effect :

1. When bed thic is embedded in a medium of diff properties is $1/4^{th}$ of the wavelength in thickness the refrac from the top and base of the interf is constructively and amplitude increases.
2. Thin bed is less than $\frac{\lambda}{4}$, a destructive interference produces in a case of $V_3 > V_2 > V_1$ (consi triple layer case) shows min amplitude for thin wedge situation whereas for longer thic am produced appro correct reflectivity, however interf with side lobes provides oscilla in the wavelet. Peak to peak or trough to trou provides appro correct thickness (refer the slide of ampli vs thick)
3. $V_3 = V_1 \neq V_2$ cons inter and amplitude increases.

Onboard processing — Data is acquired in segD format

Pre & major processing — processed in segy format.

3592, → processed part

3590 →

EBCDIC

Exa-bite and DLT

Mud Logging : → drilling → released formation fluid.

Formation Evaluation

SPWLA
SEG
SPG
AGU

Importance of drilling mud →
- (i) Well - bore stability (balance pressure b/w borehole and formation)
- (ii) Blowout prevention
- (iii) Cooling down the drill-bit
- (iv) Bringing cutting

Hydrostatic fluid pressure 10 MPa/km

$$= \int_0^2 \rho g h \, dz$$

Geop

The solar wind removed all the gas / dust particles from the solar system.
High melting point → silica ion.
Curray proposed that the moon was formed elsewhere.
Iron is absent in the moon. The core and some parts of the Earth has iron. Hence it doesn't support Curray's observation.

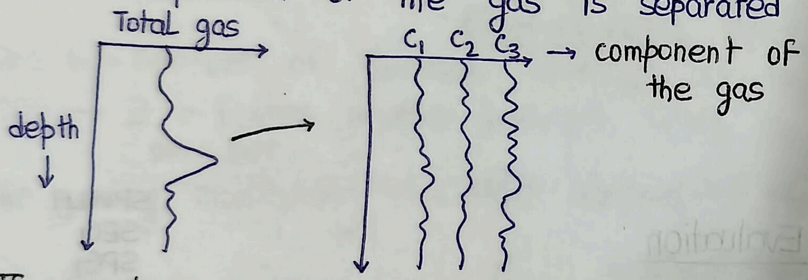
Xenon Retention
Xenon closure
During the giant impact the size / mass distribution was 70 - 80% of the present condition of the Earth.

Siderophile prefers to be present in the metallic state.
Chalcophile prefers to be present in the sulphur form.
Lithophile element lies in the crust.

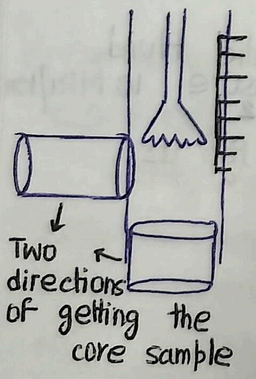
Formation Evaluation

Date - 06.08.2024

Mud logging is the direct method of measurement.
It also gives an idea about the hydrocarbon containing formation as it brings the cutting information.
Each composition of the gas is separated out in chromatography.



If we have calcite then when reacting with H_2S, forms bubbles, hence helps in its identification.
Core derived information are accurate measurement of physical properties.



The measurement in the form of core sample in the horizontal direction gives information along the bedding.
But when measuring in the vertical direction we get to know about the different formation.

Length : Diameter ratio of core sample is 2 : 1

Geothermics and Geodynamics

Short-lived and Long-lived isotope
Gravitational Collapse
Self-adiabatic compression tell us about the increase of temp. till the core by 900°C.

$$\left(\frac{dT}{dP}\right)_{adiabatic} = \frac{T\alpha}{\rho C_p}$$

The diurnal variation increased from 4-5 hrs to 24 hrs in the present situation due to "Tidal effect".

$$\text{Heat Flux} = \frac{J}{\text{sec. Area}} = \frac{W}{\text{Area}}$$

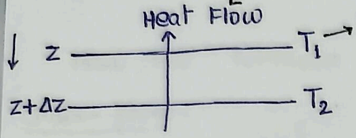
for Earth we consider $\frac{mW}{m^2}$

$$\Delta Q = KA\frac{T_2 - T_1}{L}\Delta t$$ → Conduction Equation

Lowrie Tables
Pg. No. - 221
228

$$\frac{dT}{dh} = \frac{\gamma}{\gamma - 1}\frac{GM}{R}$$

Adiabatic lapse rate.



→ Surface of the Earth

$T_2 > T_1$

$$\frac{\Delta Q}{A \times \Delta t} = q_z = -K\left(\frac{dT}{dz}\right)$$

$$Q_p = 95.2\,C_U + 25.6\,C_{Th} + 0.00348\,C_K$$

$\frac{MW}{kg}$ ← Unit ← C_U ↓ conc. of Uranium; C_{Th} ↓ Conc. of Thorium; C_K ↓ conc. of Potassium

$$Q_p = 95.2 \times 4.6 + 25.6 \times 18 + 0.00348 \times 33000$$

Date: 07.08.2024

Seismic Data Processing and Interpretation

Objective of Seismic Data processing:

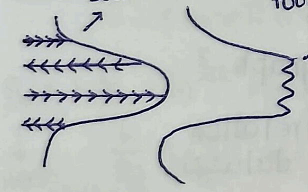
(i) $S(t) = W(t) * R(c) + n(t)$
↳ Reducing this i.e noise

(ii) Enhancing the Resolution / capturing bed based on Resolution S(t)

Resolution is important for proper acquisition and Quantitative Interpretation.

such smoothness is not found

we get this variation



Demultiplexing provide allocation and amplitude variation.

Interpreting seismic we have to get to Reservoir seismic from the whole seismic section by characterizing amplitude, phase and frequency from the UTM locations of the source and receiver. because the trace developed in a receiver for a particular formation will differ from place to place, hence locations are important.

Reservoir seismic ← means characterizing fluids based on amplitude variation

wiggle, variable density and variable wiggles

Geophysical Inversion

Digital Filter Designing :

Example of seismic-signal deconvolution ;

Let a(t) and b(t) are two signals. They are related by convolution process such as,

$$\underset{\text{Signal}}{a(t)} = \underset{\text{filter}}{f(t)} \underset{\text{convolution operator}}{*} \underset{\text{signal}}{b(t)}$$

In integral form we can write,

$$a(t) = \int f(\tau)\, b(t-\tau)\, d\tau$$

In summation : In discrete form we can write

$$a_i = \Delta t \sum_{j=1}^{p} f_j \, b_{i-j+1} \qquad \text{Here } b_i = 0 \;;\; i<0,\; i>p$$

p = length of filter signal

Δt = sampling interval

In Linearised Inverse Problem, we can write

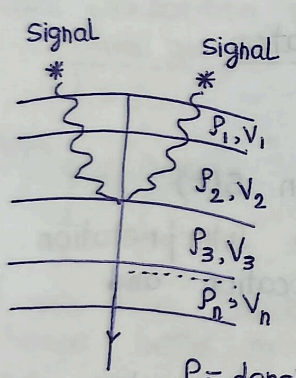
$$d = Gm \quad [m = \text{model parameter}]$$

$$G = \Delta t \begin{bmatrix} b_1 & 0 & 0 & 0 & 0 & \cdots\cdots & 0 \\ b_2 & b_1 & 0 & 0 & 0 & \cdots\cdots & 0 \\ b_3 & b_2 & b_1 & 0 & 0 & \cdots\cdots & 0 \\ \vdots & & & & & & \\ b_n & b_{n-1} & b_{n-2} & \cdots & \cdots & \cdots & b_K \end{bmatrix}$$

$K = n-p+1$

when $n>p \rightarrow$

$n<p \rightarrow$



ρ = density

V = velocity

Reflectivity series ?

(i) Nature

(ii) How to generate Synthetic seismograph ?

- Random → there will be list correlation b/w subsequent dataset.
- Stochastic → Here a part is deterministic and the other part is random
- Chaotic

Formation Evaluation

Advantages of mud-logging :

(i) Evidence of hydrocarbon
(ii) Rock type (Litho-facies)
(iii) Fracture detection (indirect)
(iv) Type of hydrocarbon
(v) In-situ stress
(vi) Porosity of formation
(vii) Pore pressure
(viii) Texture, grain size
(ix) Sorting of grains

Cross-plot : Relationship / correlation between two physical properties

Overlay plot, Histogram, cross-plot, Line plot (Triple combo-plot) Scatter plot, Box plot.

Quick Log Analysis : (Cross - plot)

Why we need to know about the lithology ?

It is very important for famation evaluation :

Like in the calculation of NPHI we need to know about the limestone for its calibration.

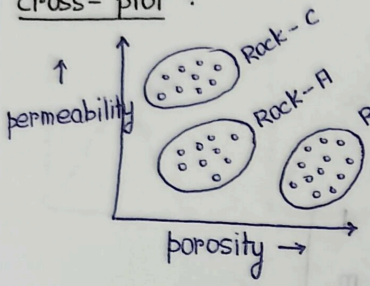
$$\phi_D = \rho_{ma} - \rho_b$$

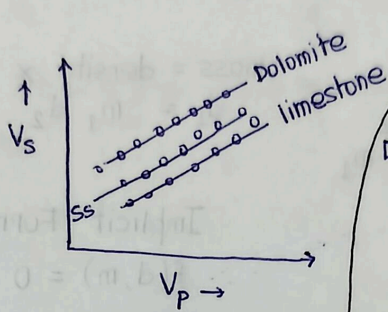
↳ we need to know the density of the matrix.

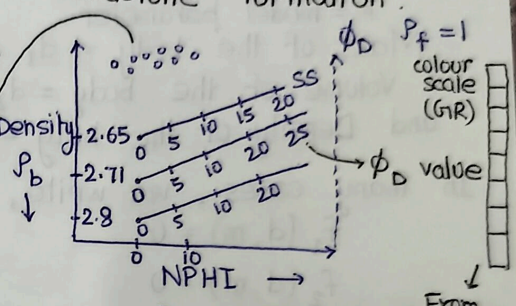
$$F = \frac{a}{\phi^m} \; ; \; \left.\begin{aligned} F &= \frac{1}{\phi^2} \\ &= \frac{0.81}{\phi^{2.15}} \end{aligned}\right\} \rightarrow \text{Different relation for different formation.}$$

Also the formula for saturation S_w is applicable for limestone or sandstone formation.

<u>Cross- plot</u> :







↓ From here we can get the lithology

for gas bearing it will go up i.e low density

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Let $\rho_{ma} = 2.71$ (limestone)

$= 2.65$ (Sandstone)

<u>Geothermics</u> <u>and</u> <u>Geodynamics</u>

$S_p = 1.01 \times 10^{-11}$ W/kg for granite

↓ Heat produced

$$\frac{W}{kg} \times \frac{kg}{m^3} = \frac{W}{m^3}$$

and for Earth, it $\frac{mW}{m^3}$

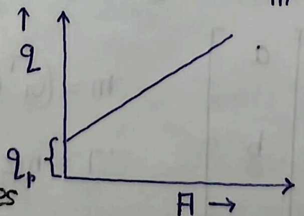
Page- 229, 238, 241, 242

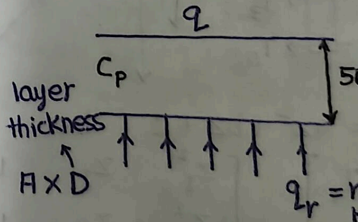
In continental,

Heat flow = 65 mW/m^2 → These are the mean values

In oceans, ↑

Heat Flow Heat flow = 100 mW/m^2





= reduced heat flow coming from the base

$$\therefore q = q_p + AD$$

↓ Heat production

^ Value is highly scattered for oceans, hence high standard deviation and vice versa for continental [Page - 242]

The processes responsible for heat flow inside the Earth :

(i) Conduction → $\Delta Q = KA \frac{T_2 - T_1}{L} \Delta t$

(ii) Convection

(iii) Radiation

(iv) Advection

Numericals from rigidity modulus

Flexural rigidity

Page - 111

Rheological → Flexural rigidity
Physical → Density of minerals
Chemical → composition of minerals (Olivine, pyroxine)

} Parameters

Moho- discontinuity → Chemical boundary.

Conduction dominates in the lithosphere and in small amout in the Inner core.

Geophysical Inversion

Date - 08.08.2024

Data- Model Relationship :

Implicit - Explicit Form :

Let d = data
m = model parameter
Mass of the body = d_1
Volume of the body = d_2
and Density of the body = m_1

mass = density × volume
$d_1 = m_1 d_2$

In many cases, we write,

$$f_1(d,m) = 0$$
$$f_2(d,m) = 0$$
$$f_3(d,m) = 0$$
$$\vdots$$
$$f_L(d,m) = 0$$

L = No. of equations

Implicit Form :

$$f(d,m) = 0 = F \begin{bmatrix} d \\ m \end{bmatrix}$$

$m \to M$
$d \to N$

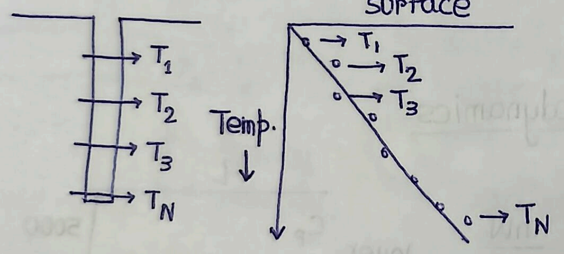
Explicit
Implicit

$$\therefore F = \begin{bmatrix} +I & 0 \\ 0 & G \end{bmatrix}$$

$$0 = d - \frac{L \times (M+N)}{g(m)}$$

$$\therefore 0 = d - Gm$$

Borehole - Temperature :



$$\begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_N \end{bmatrix} = \begin{bmatrix} z_1 & 1 \\ z_2 & 1 \\ \vdots & 1 \\ z_N & 1 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix}$$

$$T = a\underset{\downarrow}{z} + b$$

depth parameter

If $T = az^2 + bz + c$ then,

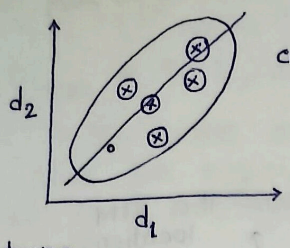
$$\begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_N \end{bmatrix} = \begin{bmatrix} z_1^2 & z_1 & 1 \\ z_2^2 & z_2 & 1 \\ z_3^2 & z_3 & 1 \\ \vdots & \vdots & \vdots \\ z_N^2 & z_N & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

$$m = (G^T G)^{-1} G^T \cdot d$$

$$T = mz + c$$

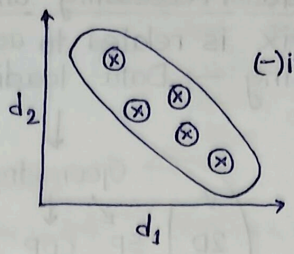
Error Deviation :

MSE
MAE
R = Pearson's Correlation coefficient
R^2 = Coefficient of Determination.

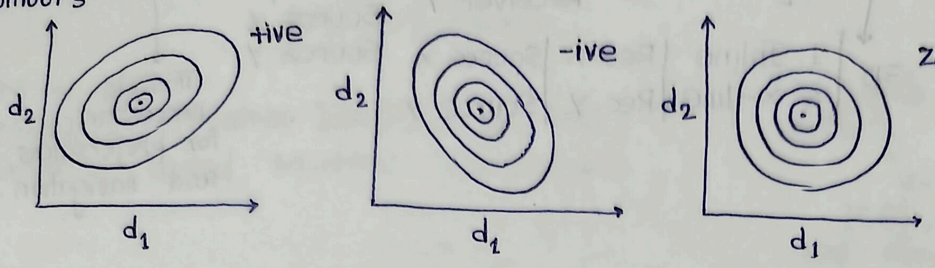


correlation coefficient = +

$$R = \begin{bmatrix} 0 & -1 \\ -1 & +1 \end{bmatrix}$$



Contours



zero / unconrelated

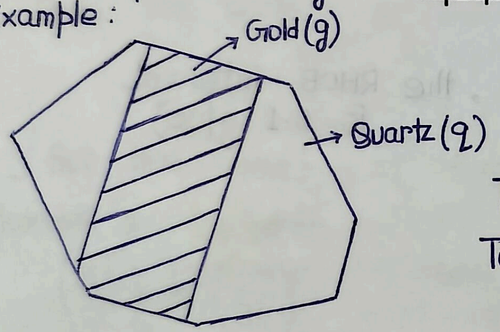
Limitation of potential field theory in Inverse theory.

$m = 0.3\ m_1 + 0.5\ m_2 + 0.7\ m_3$

Geophysical Inversion

Date- 09.08.2024

Linear Explicit Theory :
Example :



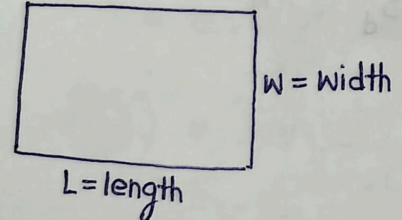
Volume : V_g = volume of gold , V_q = volume of quartz
ρ_g = density of gold , ρ_q = density of quartz
Mass :

$$\text{Total } (V) = V_g + V_q$$
$$\text{Total mass } (M) = \rho_g V_g + \rho_q V_q$$

Formulate the Inverse problem using Linear explicit Theory / Relation / Least - squared Inversion

Given , V = Total volume of geological body.
$= 24\ cm^3$
M = Total mass
= 17 gm
Find ρ_g , ρ_q → 2.65 g/cc
↓
19.3 g/cc
$d = Gm$
$G = ?$

Example 2 :



Given : C = cincumference
eg. - 5 cm
A = area
eg. - 6 cm^2

$C = 2L + 2W$
$A = L \times W$

Find out length (L) and width (W)
Using Explicit / Implicit Theory / Least squared Inverse approach.

Seismic Data Proccessing and Interpretation

Date : 12.08.2024

Conversion, Geometry and matrix is related to acquisition → Acquisition

Multiplexing ⟶ De-multiplexing ⟶ Data loading → Processing

↓

Geometry

FFID → Field File ID

True Amplitude Recovery

2D [SP CDP | Receiver X, Receiver Y → Means the UTM locations ↑ Source X, Source Y

3D [1. Inline, 2. X-line | Rec. X, Rec. Y | Source X, Source Y

Means the UTM locations → This is neccessary for projections and navigation.

Formation Evaluation

$\rho_b = 1.9$ to 3 g/cc (In the NPHI - RHOB cross-plot, the RHOB interval is 0.1 g/cc)

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

$\rho_f = 1.0$ g/cc

ρ_{ma} (limestone) = 2.71 g/cc

ρ_{ma} (sandstone) = 2.65 g/cc

ρ_{ma} (dolomite) = 2.87 g/cc

$\phi_N = -0.05$ to 0.45

Limestone = $\phi_N \simeq \phi_{NL}$

Sandstone → $\phi_{N_{SS}} - 0.04$

Dolomite → $\phi_{N_{DL}} + 0.04$

(Plot RHOB vs ϕ_N)

Shale → Clay → Kaolinite, → Salt; Shale → Silt

Shale is of different types hence it's not plotted in the Neutron-Density cross-plot.

ρ_b	ϕ_{D_L}	$\phi_{D_{SS}}$	ϕ_{D_d}	ϕ_N
1.9	0.474	0.455		
2	0.416	0.394		
2.1	0.357	0.334		
2.2	0.298			
2.3	0.239			
2.4	0.181			
2.5	0.122			
2.6	0.064			
2.7	0.006			
2.8	-0.053			
2.9	-0.111			
3	-0.169			

The cross-plot of Sonic and NPHI with the help of Depth colour bar is useful in getting an idea about the lithology.

$V_P = f(DT_{matrix}, \phi, \rho_f)$

$DT_{max} = 47.5\ \mu s/ft$

↳ This value is applicable when the regions has 100% Limestone

But if it contains 60% limestone and 40% dolomite then, D_T becomes $= 0.6 \times 47.5 + 0.4 \times 43$

Our motive is to find the porosity not the fluid content which affects the value of ϕ_D when there is a present of gas in the formation.

- M-N plot
- MID plot (Matrix Identification Plot)
- Inversion based Mineral Composition

The three combination cross-plots namely RHOB – NPHI, RHOB – DT, and NPHI – DT provides or predict different lithology so, we should combine the three logs to interpret which we would see in this three methods.

Geothermics and Geodynamics

Adiabatic temp. gradient inside the Earth :

From the surface to the earth → 10 to 30 °c /km and 0 °c in the permafrost and ocean floor.

So, with this calculation till we reach the core the temp. would become 6371 km × 10 °c = 63710 °c.

But the temp. at the core is 6000 °C, then what happens here?

Self-adiabatic compression increases the temp. of the core by 900 °c.

Maxwell's Equation :

$$\left(\frac{\partial T}{\partial P}\right)_s = \left(\frac{\partial V}{\partial s}\right)_P$$

$$= \left(\frac{\partial V}{\partial T}\right)_P \cdot \left(\frac{\partial T}{\partial s}\right)_P$$

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P \quad \therefore \left(\frac{\partial V}{\partial T}\right)_P = \alpha V$$

$$\therefore = \alpha V \cdot \left(\frac{\partial T}{\partial s}\right)_P$$

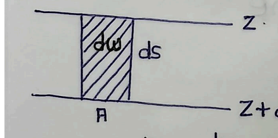
again, $dq = T\,dS$

$$\Rightarrow m C_P\, dT = T\, ds$$

$$\frac{dT}{ds} = \frac{T}{mC_P} = \frac{T}{\rho V C_P}$$

$$\therefore \left(\frac{\partial T}{\partial P}\right)_s = \alpha V \cdot \frac{T}{\rho V C_P}$$

$$= \frac{T\alpha}{\rho C_P} \Rightarrow \left(\frac{\partial T}{\partial z}\right)_s \cdot \frac{1}{\rho g} = \frac{T\alpha}{\rho C_P} \Rightarrow \left(\frac{\partial T}{\partial z}\right)_s = \frac{T\alpha g}{C_P}$$



$dP = \rho g\, dz$

$dP = \frac{dw}{A}$

Qu. In the lower mantle at a depth of 1500 km, $g = 9.9\ m/s^2$, $C_p = 1200\ J/kg/K$, $\alpha = 14 \times 10^{-4}\ K^{-1}$, $T = 24000\ K$. Calculate the temp. gradient.

$$\rightarrow \left(\frac{\partial T}{\partial z}\right)_s = \frac{24000 \times 14 \times 10^{-4} \times 9.9}{1200} = 0.027\ K/Km$$

Qu. $C_p = 700$ J/kg-K , $g = 10.1$, $\alpha = 14 \times 10^{-6}$, $T = 4000$ K . Find the temp. gradient.

$$\rightarrow \left(\frac{dT}{dz}\right)_s = \frac{4000 \times 14 \times 10^{-6} \times 10.1}{700} = 8.08 \times 10^{-4} \text{ K/m}$$

Qu At 50 km in the mantle , $g = 9.9$ m/s^2, $\alpha = 17 \times 10^{-6}$ K^{-1} , $T = 1800\text{ K} + 100 = 1100$ K

$C_p = 1400$ J/kg-K (Take $C_p = 1250$ J/kg-K)

$$\rightarrow \left(\frac{dT}{dz}\right)_s = \frac{1000 \times 17 \times 10^{-6} \times 9.9}{1400} = 1.2 \times 10^{-4} \text{ K/m}$$

When you approach the moho-depth the $\left(\frac{dT}{dz}\right)_s$ decreases suddenly.

Pg - 223 , fig - 4.13 Stacy (1992) ↘ The different parameters where developed in this paper

Seismic Data Processing and Interpretation

Date - 13.08.2024

Data loading

1. It is possi to obtain single stress (offset) section from multichannel sei data.
2. A single stress secti is almost identical with single except offset value b shot and recei is non-zero
3. Bandpass filter and gain control ; then single stre secti is simply formed by plo the same offset for each shot gather (FFID)
4. Generally one of the very first channel of each shot is selected because of the arrival times of reflection incre with the increase in the offset due to NMO and single str sec geometry prepa from one of the channel closed to the source location.
5. Signal to noise ratio of a single stress section is signi low when compared to the stack section. However to check the stress sec this single str sec is equally important for customizing the proce flow / modification.

Geometry definition (Ref. slide 16 & 17) :

1. Position of source - receiver , generally done by using real geophysical co-or source and group centres for each channel for each shot position.

2. Important geometry parameters :
(i) Shot and group interval ; shot and streamer depth (for marine)
(iii) Absol dist for each individual stress from the shot points.

3. Geometry definition needs acquisition information and these parameters are recorded in OB logs (OB logs provides information about layouts, source / navigation etc

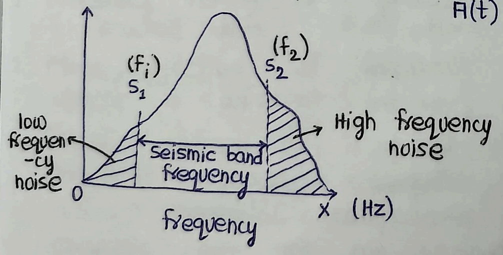
4. OB log for 2-D seismic is simple and basic information is stored . For 3D it is more informative and consisting with auxiliary information like GPS / streamer gun array separation , QC result (shot and channel

5. UKOOA (United Kingdom offshore Operation Association) File / P190 or 92 format is the industrial file format for navigation or raw navigation file

6. After loading the next processing sequences may be initiated.

QC in Ge loading
A proper geometry of the seismic data is requi to be defined during proce ; NMO correction , CDP shot , veloci analy ampli recov , these few steps are required when defining the geometry is crucial

QC of geometry after loading into stress header can be achieving through following steps :
(i) Checking stress header
(ii) Calculating propa vel from the shot gather.
(iii) Checking the database
(iv) Analysing bookstack



$A(t) = 1 \quad f_1 < f < f_2$
$= 0$

Formation Evaluation

Multi-mineral Composition :

$$\text{Sandstone} = f(\underset{\text{Quartz}}{\underset{\downarrow}{V_1}}, \underset{\text{Feldspar}}{\underset{\downarrow}{V_2}}, V_3) \hookrightarrow \text{silt}$$

MID plot :

$$\phi_{ND} = \frac{\phi_N + \phi_D}{2}$$

M-N plot is a cross-plot consisting of the three logs $- \rho_b, \phi_N, DT$

Seismic Data processing and interpretation

Date - 14.08.2024

Filter : Bandpass
1. Structural orientation
2. Frequency content : Signal and noise

Complex Fourier Transform :
1. Continuous
2. Periodic } Time to frequency

1. Discrete
2. Aperiodic } Frequency to time

Fourier Transform
Continuous
Aperiodic } For both time to frequency and frequency to time.

For → $F(j\omega) = \int_{-\infty}^{+\infty} f(t) e^{-j\omega t} dt$

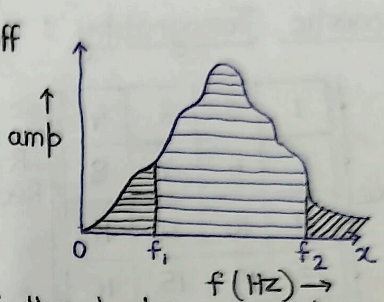
Inv → $f(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} F(j\omega) e^{j\omega t} d\omega$

Mother Conversion :

1. $A(t) = 1$, $f_1 < f < f_2$
$= 0$, other

f_1 and f_2 both are cut-off

2. $A(t) = \text{sinc}(t)$
$= \frac{\sin(t)}{t}$ (Sinc function)

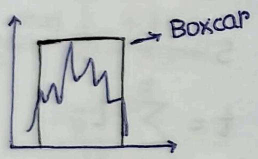


The Petroleum System Model gives us the information of the hydrocarbon present in the sub-surface

Source, Reservoir, Migration, Trap, cap, Seal → Components of Petroleum System

if any of the components is made zero, then there is a possibility that we wouldn't get hydrocarbon.

Geo-chemical survey gives us the information of carbon concentration.

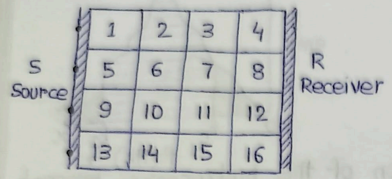


Bandpass Filter (Ref. slide from 19)

1. Frequency filtering is a process of directly modifying the amplitude spectrum of seismic data.
2. Main objective of frequency filtering is to separate signal and noise amplitude appear in different frequency component.
3. Seismic traces are composed of several sinosoid those have different amplitude, phase, frequency; decomposed these traces into different sinosoidal components of different frequency using spectral analysis. Then we can remove undesired freq amplitude components and specifying the band after using specific filter operator; The frequency band that frequency filter keeps is called passband and defined by low frequency (f_1) and high frequency (f_2) cutoff.
4. Frequency filter are designed to characterize the pass band region

Seismic Inversion

Acoustic Tomography :



$$\begin{cases} t_1 = h \times S_1 + h \times S_2 + h \times S_3 + h \times S_4 \\ t_2 = h \times S_5 + h \times S_6 + h \times S_7 + h \times S_8 \\ t_3 = h \times S_9 + h \times S_{10} + h \times S_{11} + h \times S_{12} \\ t_4 = h \times S_{13} + h \times S_{14} + h \times S_{15} + h \times S_{16} \\ t_5 = h \times S_1 + h \times S_5 + h \times S_9 + h \times S_{13} \\ t_6 = h \times S_2 + h \times S_6 + h \times S_{10} + h \times S_{14} \\ t_7 = h \times S_3 + h \times S_7 + h \times S_{11} + h \times S_{15} \\ t_8 = h \times S_4 + h \times S_8 + h \times S_{12} + h \times S_{16} \end{cases}$$

Tomography Travel - time (t)

= Length (h) × slowness (s)

= h × S

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \\ t_5 \\ t_6 \\ t_7 \\ t_8 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \\ S_7 \\ S_8 \end{bmatrix}$$

$$S \xrightarrow{L_{ij}} R \qquad L_{ij} \rightarrow \text{path length}$$

$$t = \sum_{j=1}^{p} \frac{L_{ij}}{V_j}$$

V = velocity

$$t = \sum L_{ij} C_j$$

C = slowness

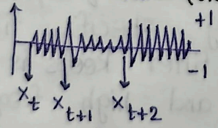
Signals , Noise :

$d = g(m) + e$

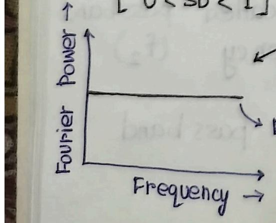
$$\text{Noise} \rightarrow \begin{cases} \text{Uncorrelated (Purely Gausian)} \\ \text{Corelated Noise} \end{cases}$$

Corelated Noise → Red Noise, Pink Noise, Blue Noise } → These depend on the frequency hence have colour

$$\begin{bmatrix} -1 < SD < +1 \\ \text{or} \\ 0 < SD < 1 \end{bmatrix} \leftarrow$$



Corr. coeff. = (R) = (x_t , x_{t+1})



→ Flat spectrum or white noise (Because it has noise of all frequency hence white)

$$\text{signal} \longrightarrow \underset{\text{(apply filter)}}{\text{F.T}} \longrightarrow \text{Inverse F.T} \longrightarrow \overset{\text{This is devoid of noise}}{\text{Signal}}$$

Formation Evaluation

Multi-mineral Composition Analysis :

↳ why ? → In petrophysics, for model development in rock physics, we need matrix information.
Also to calculate porosity, saturation we should have an idea about the composition of the minerals.

matrix $\xrightarrow{\text{sandstone}}$ Quartz (70%)
Clay (30%)

$\rho_b = \phi \times \rho_f + (1-\phi)\rho_{ma}$

$\rho = 2.65$ g/cc is not applicable for complex formation consisting of quartz and clay.
↓
sandstone

Harmonic average
$\frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3} + \ldots\ldots$

Elastic Properties
V_p, V_s, ρ_b ⟵ [Rock Physics] ⟶ Petrophysics
ϕ, V_{sh}, S_w

acts as a bridge to get the petrophysical properties from Elastic properties

The problem with the direct way of determining mineral composition (Laboratory) → it is very contly and also when we have a lot no. of wells then using spectrometry, XRD methods application are difficult to implement in different wells | in all the wells.

Least Squared Inversion Method :

$$\rho_b = \rho_q * V_q + \rho_{ca} * V_{ca} + \rho_{cl} * V_{cl} + \phi * \rho_f$$

$CV = L$
$V = C^{-1}L$

c contains the petrophysical information

$y = mx + c \quad , \quad y = f(x)$

$r = |(y - f(x))|^2$

$r = |CV - L|^2$

our work is to reduce this value

non-negative least square error

$\frac{dr}{df} = 0$ → will provide the solution.

$V = (C^T C)^{-1} C^T L$

Geothermics and Geodynamics

L = latent heat

$dS = \frac{mL}{T}$ ↳ heat energy required to transform solid into liquid, corresponding Volume change $(V_L - V_s)$

$$\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$$

$$\left(\frac{\partial P}{\partial T}\right) = -\frac{1}{\frac{V_L - V_s}{mL}} \cdot \frac{1}{T_{mp}}$$

$$= \frac{-1}{(V_L - V_s)} \cdot \frac{mL}{T_{mp}}$$

$$\Rightarrow \frac{dT_{mp}}{dz} = \left(\frac{\rho_s}{\rho_L} - 1\right)\frac{gT_m}{L}$$

(Page - 224 - fig 4.14)
** ↳ is important and its interpretation

solidus → melting point variation temp.

$$\left(\frac{dT}{dz}\right)_{adiabatic} = \frac{T\alpha g}{C_p}$$

↳ 0.7 - 0.8 K/km
(in the core - mantle bounding) is less than the melting point temp.

Environmental Geology

Sequestration → is to deposit in such a way that it remains safely stored and not released to the atmosphere.

CO_2 $^{3/4}H_2O$
Clathrate

Sinks
- Natural
  - Abandoned deep seated coal mines
  - Used Petroleum Reservoir
  - Oceans
  - Plants
- Artificial
  - Technologic conversion
  - Mineral Sequestration (making into a solid from liquid)

waste to resource → CH_4

Trap → Structural Trap
→ Stratigraphical Trap

CO_2 gas ↓ $CaCO_3 \rightarrow$ Calcite

CO_2 ↓ $CaMgCO_3$ (Dolomite)

Ground level ozone is good but not atmosphere level ozone, it leads to ozone hole.

Carbon Credit Policy (CCP)

Recycling of greenhouse gases

Seismic Inversion

Data, Systems, Noises

Data - 16.08.2024

Process :
(i) Deterministics
(ii) Stochastics
(iii) Random

$d = g(m) + e$ [Error Factor]

Forward Theory : $d_{predicted/computed} = g(m)$ Forward Theory

data (d) $|d_{obs} - d_{pred}|$ = Norm = Loss function

Stability of the Algorithms / Noise Analysis

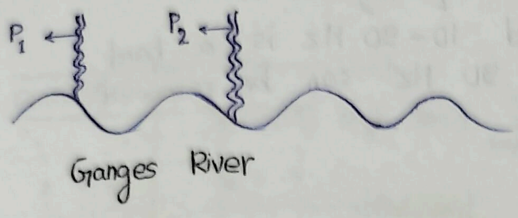
Noise
- Random Noises (Gaussian) (Uncorrelated)
  Mean ~ 0
  Variance ~ 1.0
- Correlated Noises (Non-random Partially)
  $X_t = A \times (t-1) + \varepsilon_t$
  ↳ Stationary time-series data
  ε_t = Purely Random Noise
  A = Maximum Likelihood Estimation (MLM)

Algorithm :
- Fast
- Robust → It is the property of an algorithm which represents insensitive to the outlier / Noise.

Environmental Geology

Kimberlites got its name from Kimberly.

LULC → Land Used Land Covered
Benches ↔ Bench heigh = 12 m
986 MRL and 486 MRL ↳ Mean Reduced Level
↳ it will have top benches
LULC → Mass Wasting / Mass movement, eg : Subsidence / Landslides etc.



BOD → Biochemical Oxygen Demand

In the Indo-gangetic alluvial planes there is Arsenic contraimination of Ground water.

Land use changes emissions of Carbon

The main cause of Coal-mine firing is spontaneous combustion.

EIA ⟶ EMP ↳ Environment Management Plan
↓
Environmental Impact Assessment.

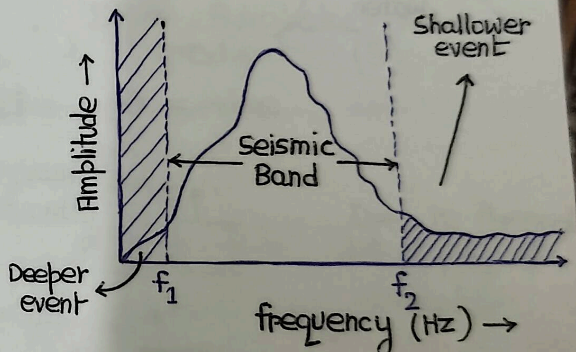
{ Over exploit
Over draw

IF draw doon → Coastal Area
is greater than percolation

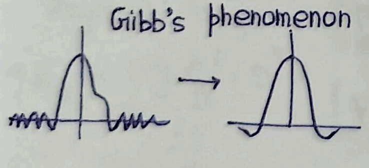
Seismic Data processing and Interpretation

Date-19.08.24

Max. lower frequency content in the deeper event is seen.
How to perfectly decide the value of f_1 ?



$A(t) = 1 \quad , f_1 < f < f_2$
$\quad\;\; = 0 \quad , \text{others}$ } Other why ?



More the content of the dominant

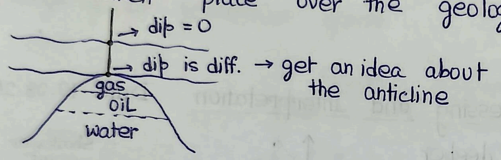
High-pass frequency :
Remove freq which is higher than the cutoff (f_1) ; High freq cut-off (f_2) is the Nyquist frequency
Band pass
Keep specific frequency band between f_1 and f_2
Notch : 50 - 60 Hz removal. In marine high freq random and low freq swell noise both will be removed based on proper filtering

All the amp. of different frequency components are useful

Raw seismic data
while some ampli corresponds signals and other's are noise.
Desired ampli components are restricted within the frequency content which is bandwidth.
Eg - 1 → Effective bandwidth tends to 10-140 Hz, sampling frequency is 1 ms. Nyquist frequency = ?
Eg - 2 (Ref. slide 21) → for Land record 10 - 90 Hz is a band limited data and more than 90 Hz can be removed as high frequency noise

Formation Evaluation

Dip - meter log :
We need the information of dip to map the structure.
How structurally they are formed and how the tectonic activities have taken place over the geological time.



Formation
Micro - resistivity
UBIT TooL

Temp. at the lower mantle boundary = 3500 K
$C_p = 700 \ J/kg\,K$ $\quad \alpha = 15 \times 10^{-6} \ K^{-1}$ $\quad , g = 10.3 \ m/s^2$
L = Latent heat of fusion of iron = 7×10^6 J/K ; $\rho_s = 13000 \ kg/m^3$
$\rho_L = 11000 \ kg/m^3$

For liquid iron phase calculate ;

$$\rightarrow \left(\frac{dT}{dz}\right)_{adiabatic} = \frac{T\alpha g}{C_p} = \frac{3500 \times 15 \times 10^{-6} \times 10.3}{700} = 7.725 \times 10^{-4} \ K/m$$

$$\left(\frac{dT_{mp}}{dz}\right) = \frac{T_{mp}}{L}\left(\frac{\rho_s}{\rho_L} - 1\right) g = 9.36 \times 10^{-4} \ K/m$$

Derivation, Numerical and Interpretation of the graph

Conduction :

Convection → Thermally Induced buoyancy force leads to the initiation of the process of Convection.

Radiation →

Advection → Pressure Induced Force
↳ Takes place due to the pressure differences

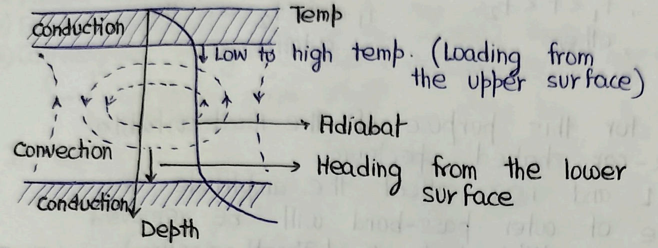
Red band or Infrared band.

Chemical Differentiation

$K_P = \frac{16}{3} \cdot \frac{\pi^2 \sigma T^3}{e}$ ← conductivity due to radiation

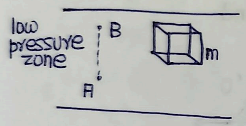
n = refractive index

e = Degree of absorption = opacity of the medium



Explain the Convection process with respect to the adiabatic process or adiabats or adiabatic temp. gradien-t.

If the real temp. gradient is more sharper (i.e larger drop of temp.) then the temp. at B is more, hence the packet with move up (towards the shallower region) due to buoyant force.



$$\left(\frac{dT}{dz}\right)_{real} - \left(\frac{dT}{dz}\right)_{adiabatic} = \text{Super Adiabatic Temp. gradient } (\theta)$$

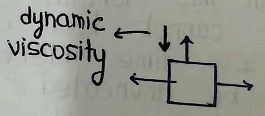
for convection to happen θ = +ive

$\Delta m = \rho \Delta V$

$= \rho \alpha V \Delta T$

$\because \alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$

$\Delta F = \Delta m \times g = \rho \alpha V g \Delta T$ ← Buoyancy force



Due to thermal diffusivity of conduction, the amt. of hea will be removed from the body.

$R_a = \frac{\rho \alpha g V \Delta T}{R\eta}$ ↳ Rayleigh No.

$\nu = \frac{\eta}{\rho}$ → dynamic viscosity; ν ↓ Kinematic viscosity

$R = \frac{K}{\rho C_P} = \frac{m^2}{sec}$

$\eta \times R = Pa\text{-}sec \times \frac{m^2}{sec}$

$= force$

$\Rightarrow R_a = \frac{\alpha g \frac{\Delta T}{D} \cdot D^4}{\frac{R\eta}{\rho}}$ $\quad [V \simeq D^3]$

$= \frac{\alpha g \theta D^4}{R\upsilon}$

Date : 20 . 08 . 2024

Seismic Data Processing and Interpretation

Filter Operator in reference to FT and CFT :

1. Band limited wavelet is used to filter the seismic data which is known as Filter operator in time domain. Amplitude samples of these operator is known as coefficient.
2. Most feasible on practical filter operator in frequency domain can be designed through Fourier Transformation.
3. Primary objective,

$$A(t) = 1 \quad , f_1 < f < f_2 \qquad f_1 \text{ and } f_2 \text{ are the cutoff.}$$
$$= 0 \quad , \text{others}$$

$$A(t) = \text{sinc}\,(t) = \frac{\sin(t)}{t}$$

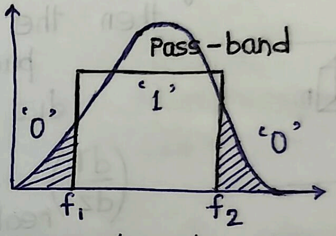
The amplitude spectrum for this purpose of the most suituible operator filter is box-car shaped spectrum.

It will be multiplied by 1 and never affect the amplitude of pass-band. The amplitude of outer pass-band will be removed completely, as it is multiplied by 0 (Theotherically)

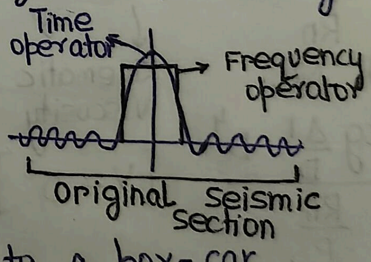
Challenges :

$$\left.\begin{aligned} A(t) &= 1 \;, f_1 < f < f_2 \\ &= 0 \;, \text{other} \end{aligned}\right\} \text{Frequency Domain}$$

$$A(t) = \text{sinc}\, t = \frac{\sin(t)}{t} \rightarrow \text{Time Domain}$$



The counter part of box-car function is time domain sinc function. The issue in this function has amplitude in ±∞ time interval. filter operator cannot have coefficient, upto infinite number for filter, for ±∞ time interval. Hence in practice it is required to be truncated in both end to get finite time series before applying seismic data whereas after truncation in time domain it is no longer representing the box-car function spectrum in frequency domain.

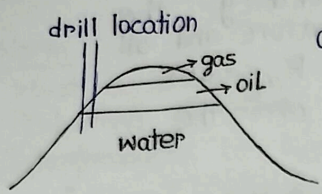


The real amplitude function looks pingy due to the fluctuations (nature) / fractions (values) which is known as Gibbs effect.

This arises due to appro to a box-car using finite no. of coeff in time domain

Oscilla obser as a Gibbs effect in frequency domain, to avoid such oscillation, a trapezoid operator ~~which~~ with ~~moves~~ smooth inclination is designed. Oscillation ~~process~~ passes amplitude of rejected band as well to design trapezoid filter operator, few non-zero filter coefficient in time-domain is considered

Formation Evaluation



Over - pressure

fluid pressure = $\int_0^z \rho_w g \, dz$
↓
10 MPa/Km

With respect to the relative position, the tool can be on the high side or low side.

(i) Pattern recognition
(ii) Fourier Transform
(iii) Correlogram Analysis

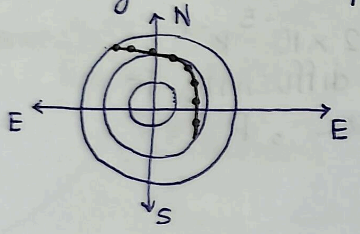
} To find the dip of the bedding plane when using dip- meter log tool.

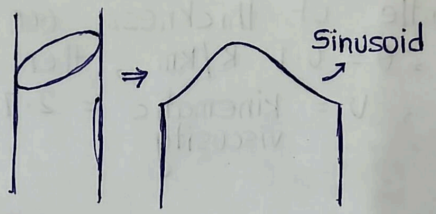
↳ 1. Correlation ~~angle~~ length.
2. Maximum dip angle

If dip angle = 30° ; Hole diameter = 12 inch

$\therefore$ search angle = 12 × cos 30°
= $6\sqrt{3}$ inch = 6 × 1.732 = 10.392 inch.

Distribution of the data i.e in which orientation are the maximum dip falling → Polar plot



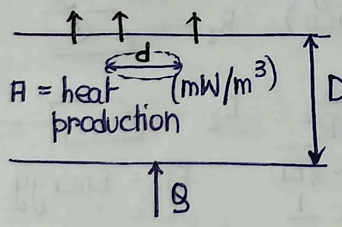


Geothermics and Geodynamics

$R_a = \frac{\alpha \theta g}{K \upsilon} D^4$ - (1)

Upper Mantle
Lower Mantle
Whole Mantle

Order matters i.e at what resolution the work is being done. like $\eta = 10^{13}$ Pa - sec, if 10^{12} is added to it then not much effect is observed, so order is important.



$\therefore A \times D = \frac{\mu W}{m^3} \times m = \frac{\mu W}{m^2}$

$\therefore q_z = -K \frac{\Delta T}{\Delta z}$

$\therefore \frac{\Delta T}{\Delta z} = - \frac{q_z}{K}$
↳ θ

$\frac{d}{D}$ = aspect ratio

$\therefore$ From (1) we get,

$R_a = \frac{-\alpha \cdot q_z g}{K \upsilon K} D^4$

Convection is initiated when the Rayleigh No. exceeds a critical value (R_{ac}) which is dependent on the geometry of the flow and the boundary condition on the upper and lower surfaces.
↳ Stress free or not
and the dimension i.e the d : D ratio (aspect ratio)
because the lateral dimension (d) of the convection shell will not be the same

1. For no shear stress on the upper and lower boundary, the upper boundary held at a constant temperature and all heating from below i.e $A = 0$, in that case, $R_{a_c} = 658$ at this Rayleigh No. the horizontal dimension of the shell is 2.8 D.

2. For no slip on the boundary the upper boundary held at a constant temperature and all heating from below, i.e $A = 0$, the $R_{a_c} = 1708$, the dimension of shell is 2.0 D

3. For no slip on the boun, a cons heat flux across the upper boun and all heating from within the fluid i.e $Q = 0$ and $A \neq 0$, in that case $R_{a_c} = 2772$ and the dimension of the = 2.4 D

4. For no shear stress on the boundary, a constant heat flux across the upper boundary, and all heating within the fluid where $Q = 0$ then $R_{a_c} = 868$, dimension = 3.5 D

Numericals :

For the upper mantle of thickness 600 km, $\alpha = 2 \times 10^{-5} K^{-1}$, $\rho = 3700 \ kg/m^3$, $\theta = 0.1 \ K/km$, then thermal diffusivity is $1.4 \times 10^{-6} \ m^2/sec$, ν = kinematic viscosity $= 2.7 \times 10^{17} \ m^2/sec$, $R_a = ?$

→ $R_a = \frac{\alpha \theta g D^4}{\kappa \nu}$

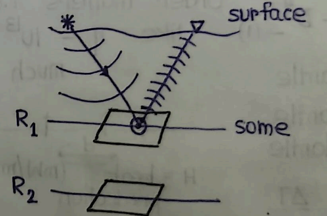
Seismic Data Processing and Interpretation

Date: 21.08.202

Gain Recovery : (Before Brute stack)

- TAR
- AGC

Reasons (mostly)
→ Spherical Divergence
→ Absorption (Phase; frequency distortion)



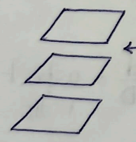
$s(t) = a(t) \cdot g(t)$ $\quad g(t) = t^P$

$ED \propto \frac{1}{R^2}$

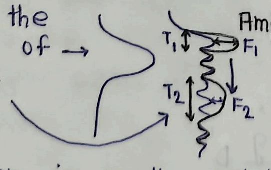
$Amp \propto \sqrt{ED}$
$\propto \frac{1}{R}$

ED = Energy density

$\alpha = \frac{\pi f}{Q V}$ → Dynamic Frequency, → velocity



Due to these features, the variation of → becomes



$F_2 > F_2 \quad T_2 > T_1$

Rock Quality Designation is mostly related to Interpretation.

Geophysical Inversion

Norm :

What is Norm ?

Properties of Norm ?

Interpretation of Norm and Applications

" Size " " Length "

Linear Algebra :

Scalar

Vector

Matrix ⟶ Data and Noise

Definition of Misfit

The selection of Norm for data interpretation

' Norm ' is a function from spaces of vectors on to s sculator's , denoted by $\| \cdot \|$

It satisfies the properties

α = scalars

$u, v \rightarrow$ vectors

(i) $\|v\| > 0 \quad , v \neq 0$

$\|v\| = 0 \Leftrightarrow v = 0$

(ii) $\|\alpha v\| = \|\alpha\| \|v\|$

(iii) $\|u+v\| \leq \|u\| + \|v\|$

$$\|x\|_{L_p} = \left(\sum_{i=}^{n} |x_i|^p \right)^{1/p} \quad p \geq 1$$

L_p = Norm of order p

p = order

$p=1$ L_1 Norm $\quad \|x\|_{p=1} = |x|$

$p=2$ L_2 Norm $\quad \|x\|_{p=2} = \sqrt{x^T x}$

$p=3$ L_3 Norm

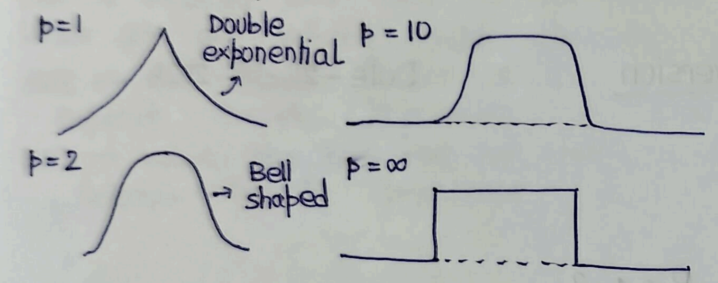
$\vdots$

$p=\infty$ L_∞ Norm $\quad \|x\|_{p=\infty} = Max|x_i|$

Interpretation → How to select the order of the Norm in optimization

$\|Gm - d\|$ = Misfit

Generalised Gaussian probability distribution function (pdf)



$$\rho_p(x) = \frac{p^{1-\frac{1}{p}}}{2\sigma_p \Gamma\left(\frac{1}{p}\right)} \exp\left(\frac{-|x-x_0|^p}{p(\sigma_p)^p} \right) \quad p=1$$

σ_p ↓ variance

Γ ↳ Gamma function

p = order of the Norm

Formation Evaluation

Cross-correlation of electrode pairs 1 and 3 and 2 & 4 helps us to find the displacement H_{13} and H_{24}

$\therefore \tan\alpha = \frac{H_{13}}{Caliper_{13}}$ and $\tan\beta = \frac{H_{24}}{Caliper_{24}}$

Strike = dip direction - 90°

Determination of Dip direction :

Geothermics and Geodynamics

Numerical Solution :

$$\rightarrow R_a = \frac{\alpha \theta g D^4}{K \nu} = \frac{2 \times 10^{-5} \times 0.1 \times 10 \times (600)^4 \times (10^3)^4}{1.4 \times 10^{-6} \times 2.7 \times 10^{17} \times 10^3} \qquad \frac{\frac{1}{K} \cdot \frac{K}{km} \cdot \frac{m}{s^2} \cdot m^4}{\frac{m^2}{s} \cdot \frac{m^2}{s}}$$

$\downarrow$

Unitless $\quad = 6857.14 \qquad (g = 10 \ m/s^2)$

In this condition at the base of upper mantle, 40 mW/m^2 of heat is coming from the lower mantle, thermal conductivity 6.7 W/m-K. Calculate the upper mantle's Rayleigh No.

$$\rightarrow R_a = \frac{\alpha g D^4}{K \nu} \cdot \frac{Q}{k} \quad [A = 0]$$

$$= \frac{6857.142}{\theta} \cdot \frac{40 \times 10^{-3}}{6.7} = \frac{6857.142 \times 10^3}{0.1} \cdot \frac{40 \times 10^{-3}}{6.7}$$

$R_a \downarrow \qquad = 409381.66$

Upto 10^3 the convection is initiated and beyond that it will be vigorous activity

Movement of the continent happened 130-140 million years ago

Lowrie
(Page - 249 → fig - 4.8)

Home Assigment :

Geophysical Inversion

Date - 22.08.2024

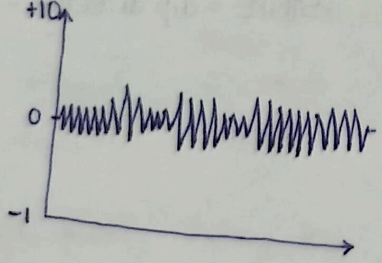
1. Let $x = \begin{bmatrix} 9 \\ -12 \end{bmatrix}$

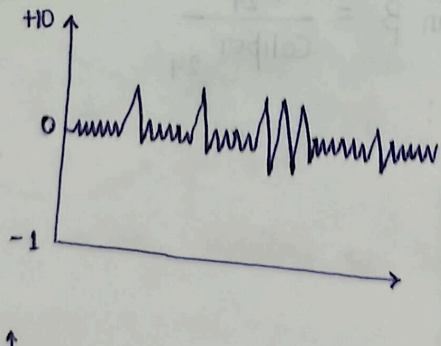
   Compute $\|x\|_1, \|x\|_2, \|x\|_\infty$

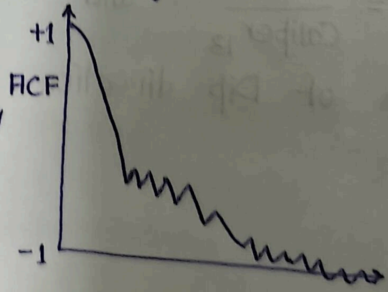
2. What happens to the L_p norm if $P < 1$?
   For example $\left(\sum_{i=1}^{n} |x_i|^{1/2} \right)^2$ a norm ?

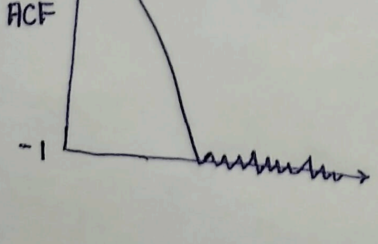
3. " Random " and " Uncorrelated " are the same thing

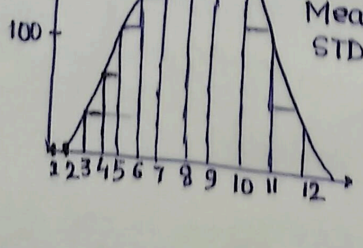
4.

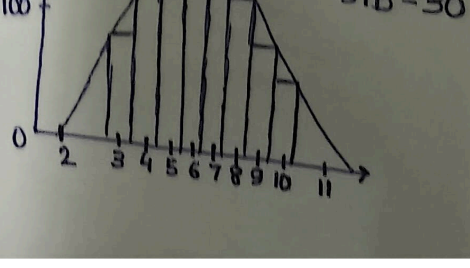












Suppose we took some of the samples from any of the time series and sorted them according to the size. Would it preserve the bell-shaped curve?

5. Correlation length ?
6. What is exponential co-variance matrix
   - STD = Standard Deviation
   - ACF = Auto - Correlation Function.
7. What is random noise ?
8. What is uncorrelated noise ?
9. What is correlated noise ?
10. How do we identify the types of correlated noise in a time series/sequence?
11. How do we examine the level (%) of noises in the real / field observation
12. "Random", "Uncorrelated", "White Noise" are the same thing ?

Seismic Data Processing and Interpretation

Date: 22.08.2024

Gain Recovery :

$s(t) = g(t) * a(t)$ → Automatic Gain Control

For different formation, N no. of lithology / litho- facies, N no. of rock type due to density variation, we have variation of velocity, → $g(t)$ need to be designed.

Due to lithology and fluid we can differentiate b/w the velocity variation
When we are talking about spherical divergence we mean amplitude decay.

AAI → the minimum value is 0
Amplitude Acoustic Impedence
RAI → value can be +ive or -ive
Relative Acoustic Impedence.

For marine we consider the RMS amplitude and onshore we consider the median value of the amplitude