STRUCTURAL GEOLOGY (Paper I, Unit 3)

DIP & STRIKE

Objective :- To get information about the 3-D position of rocks.

DIP Angle of inclination of a rock bed with the horizontal plane. Measured in a plane perpendicular to Strike (fig 1)

- angle + direction (eg) 60°, N 45° E
- Angle measured with CLINOMETER
- Direction measured with COMPASS
- (0 – 90°) < 0 (horizontal bed) ⊕ / 90 (vertical bed) ⫫
- TRUE DIP :- Max. angle of dip in a rockbed
  - Dip measured in any other direction is called APPARENT DIP

  Apparent dip < true dip

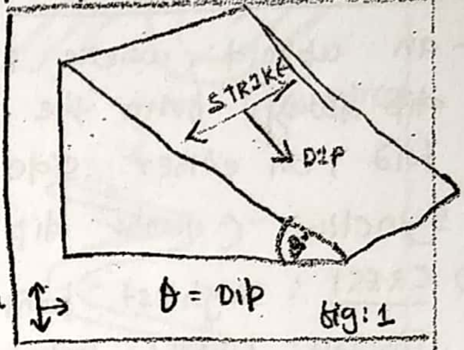


fig: 1

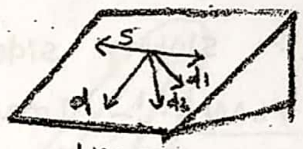


fig: 2

STRIKE

Direction along which an inclined bed intersects a horizontal plane. (scalar quantity) – as only no magnitude.

- Independent of amount of dip.
- Direction measured by compass w.r.t true 'N' & 'S'

(eg) N 30° E (30° east of North)

- True dip is always at right angle to strike

Importance

Important in structural geology

(i) To determine the younger bed & younger beds are always found in the direction of dip.

(ii) CLASSIFICATION and nomenclature of folds, faults & joints and unconformities.

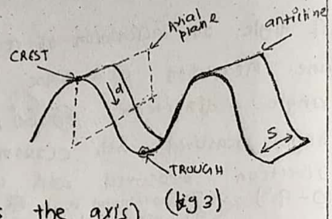
FOLDS

Wavy undulation in the rockbed due to compressional forces acting.

- **ELEMENTS OF FOLD**

(i) Anticline & Syncline

- an upfold, where limbs dip away from the axis of fold, on either side
- Syncline (limbs dip towards the axis)



(fig 3)

(ii) CREST : Highest point on anticline
TROUGH : Lowest point on syncline.

(iii) LIMBS :- sloping sides of the fold from crest to trough

(iv) AXIAL PLANE :- Imaginary plane diving the fold into two halves.

(v) AXIS :- intersection line of axial plane with upper/ Lower surface of constituent beds.

(vi) HINGE :- Line along which amount and/or direction of dip takes place

(vii) CRESTAL PLANE :- The plane / surface formed by all the crests

CLASSIFICATION OF FOLDS → basis
1) Appearance in cross section
2) Symmetry of fold
3) Thickness of limb
4) Interlimb angle
5) Attitude of fold
6) mechanism of folding
7) origin.

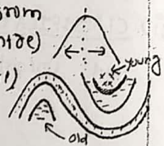
1) Appearance in Cross Section

(i) ANTIFORM :- Any upwardly convex structure

(ii) SYNFORM :- Any upwardly concave structure

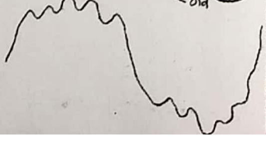
(iii) ANTICLINE :- Convex upward. Limbs slope away from axial plane. (older bed towards centre)

(iv) SYNCLINE - concave upwards. (younger → (centre))

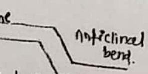


(v) ANTICLINORIUM :- Large anticline with secondary folds of smaller size.

(vi) SYNCLINORIUM :-



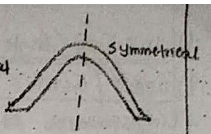
(vii) Anticlinal bend / monocline
Sudden increase in dip of a bed (originally horizonal)



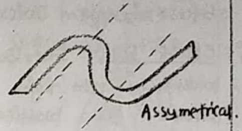
(viii) SYNCLINAL BEND - Local flattening ...

2) Symmetry of Fold

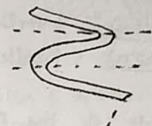
(i) SYMMETRICAL FOLD : Axial plane is vertical and bisects the fold. (upright fold)
- both limbs have same dip
- Either anticlinal / synclinal.



(ii) ASYMMETRIC FOLD : Axis plane has a dip. Limbs have diff dipp.



(iii) Reccumbent fold : An overturned fold inwhich axial plane is horizontal (or nearly so)

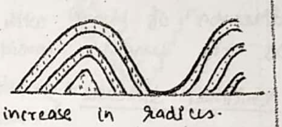


(iv) overturned fold : An assymmetrical fold where one limb has turned past vertical.
- Axial plane inclined
- Both limbs dip in the same direction.
- when amount of dip is same → (Isoclinal)

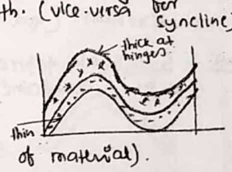
(v) Homocline :- All beds have same amount of dipping in same dir^n.

3) Thickness of LIMB

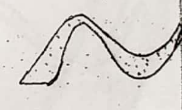
(i) PARALLEL FOLD / Concentric folds
- successive semicircles have a constant centre with gradual increase in radius.
- Thickness of bed does not change with folding
- Anticlines become sharper with depth. (vice-versa for syncline)



(ii) SIMILAR FOLD : shape of fold may vary along the axis.
- Every bed is thinner near limbs & thicker at hinges. (∵ Plastic movement of material).

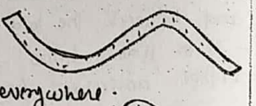


(iii) SUPRATENEOUS FOLD : Thinnest at crest of anticline and thickest at trough of syncline
- differential compaction of sediments around ridges.



4) Interlimb Angle

i) OPEN / GENTLE FOLD



- Limbs meet at bend at an obtuse angle. Thickness remain same everywhere.

(ii) CLOSE FOLD Interlimb angle is <30°

- folding is so tight that incompetant strata flow plastically towards crest & trough.

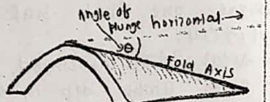
(iii) Tight flow : Interlimb angle < 30°

(iv) Cylindrical : Profile is semicircular

5) Attitude of the FOLD

(i) PLUNGING FOLD : folds having inclined axes

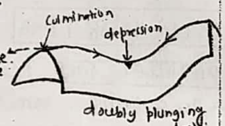
- Angle measured from horizontal. (of plunge)
- nose
- direction of plunge



[PLUNGING ANTICLINE]

(ii) Non Plunging : Axis does not dip in any direction.

(iii) Doubly plunging fold : fold reverses its direction of plunge with in the limits of area under consideration.

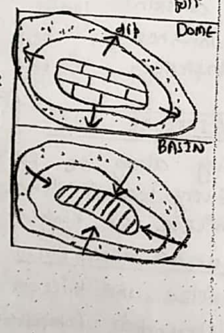


doubly plunging fold

(iv) periclinal structure < dome, basin.

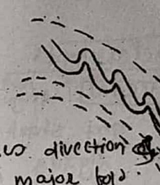
dome: Anticlinal structure, which plunges in all direction (qua qua versal dip) eg. dome

Basin : Synclinal depression with centroversal dip. (centricline.



6) Mechanical FOLDING

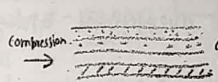
(i) DRAG FOLD :- minor folds developed in incompetant beds due to bedding-plane-slip

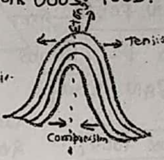


- Parasitic folds
- Pumpelly's rule :- In large number of cases direction & amount of drag fold is the same as major fold.
- Drag folds which comply to this rule - CONGRUOUS FOLD.

(ii) FLEXURE FOLD :-

- True folding
- Compressive force applied on series of flat bed
  - ↳ convex side (Tension)
  - ↳ concave (Compression.

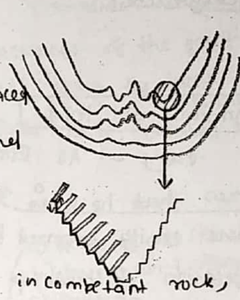




- convex side will elongate, concave → shorten & thicken.
- bending and buckling of competent layer
- sliding of beds past one another.

(iii) SHEAR FOLDING / SLIP FOLDING (GLEIT BRETTER FOLDING)

- minute displacement along closely spaced fractures
- blocks on each side of it, move upward progressively.

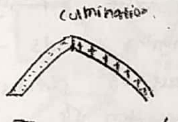


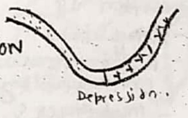
(iv) FLOW FOLDING : occurs in highly incompetant rock, behaving like viscous fluid

7) On basis of ORIGIN

(i) Caused by OROGENIC movement

- subjected to phases of folding
- If 2 anticline belonging to two diff. sets coincide — CULMINATION
- If anticline and syncline coincide - DEPRESSION





(ii) NON TECTONIC

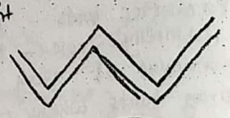
a) Cambering: competant beds form the capping of the hill, overlying incompetant beds
- incompetant beds flow outwards into valley leading to down warping.

b) valley bulging : incompetant material forced up into val.

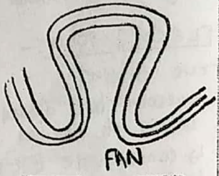
b) Diapiric

8 Special folds

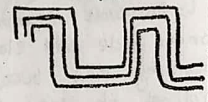
(i) **CHEVRON** :- Angular folds having straight limbs and sharp hinges.
- AKA zigzag / concertina / accordion.



(ii) **FAN FOLD** An upright fold where both the limbs are overturned giving a FAN shape

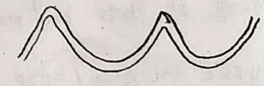


(iii) **Box fold** :- Rectangular in cross section.



(iv) KINK Bands :- narrow bands, where beds assume a dip steeper / gentler than adjacent.

(v) Geosyncline.



Recognition of Fold

- Not easy - All limbs are seldom visible

Features that help in recognizing

(i) where easily inferred by topography → Aerial photography use

(ii) Repetation of outcrop suggest folding

(iii) If fold is open type, reversal of dip direction is enough to identify fold

(iv) In anticline oldest rock bed assumes axial position, vice versa for syncline.

(v) Plunging folds → curved outcrop.

(vi) In case of overturned & isoclinal folds, detailed observation of
- drag fold
- Rock cleavage (developed parallel to fold axis)
- cross bedding
- mud cracks. - Graded bedding

is necessary.

(vii) plotting altitude with dip & strike.

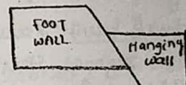
FAULTS

def^n : cracks along which Rock-masses on either side have relative displacement.

Description (parts of fault)

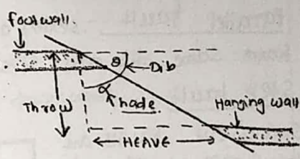
~~(i) FAULT PLANE~~ :-

(i) Foot wall and Hanging wall
block of rock lying above - Hanging wall
block below - Foot wall



(ii) FAULT SCARP :- cliff formed along the upthrow.

Terminologies



i) Hade :- complement angle to Dip.

(ii) throw :- vertical component of displacement of fractured rock.

(iii) HEAVE :- Horizontal component of displacement of the fault

(iv) Net slip :- Total displacement measured along the fault plane

(v) fault zone :- most fault planes associated with crushed and altered rock
- Several parallel fault → shear zone

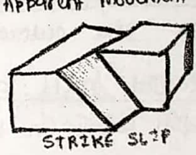
Classification

(1) GEOMETRIC CLASSIFICATION

Based on attitude of faults → basis
- a) Rake of net slip
- b) fault w.r.t adjacent rock
- c) pattern
- d) angle of fault dip
- e) Apparent movement

(a) RAKE OF NET SLIP

(i) Strike slip fault :- Net slip is parallel to the fault plain. Rake of net slip = 0



(ii) Dip slip fault : along dip. Rake of net slip = 90°

(iii) Diagonal slip.
both Strike slip & Dip slip component

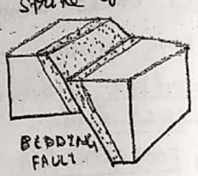
(b) Attitude of fault

(i) Strike fault : Strike of fault is parallel to strike of strata.

(ii) Dip fault :- Strike of fault is parallel to dip of strata

(iii) Diagonal / oblique fault: strikes diagonally to strike of adjacent rocks.

(iv) Bedding fault :- fault plane is parallel to bedding plane of another rock

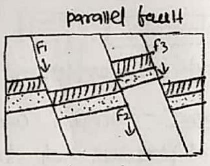


(v) Longitudinal fault: fault strikes parallel to strike of regional structure

(vi) Transverse :- strikes perpendicular to strike of regional structu.

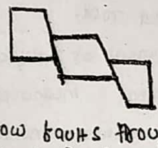
(e) Fault pattern (basis of fault system)

(i) parallel fault : series of faults that have same dip and strike



(ii) Step fault

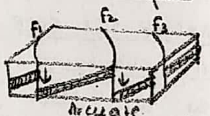
Successive faults are downthrown more and more towards particular direction.



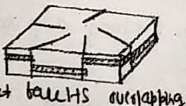
(iii) Graben : Long & narrow faults through bounded by parallel high faults
- 2 parallel normal faults hade towards each other

(iv) HORST :- when 2 parallel normal faults hade away

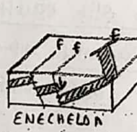
(v) Arcuate / peripheral : circular or arc like outcrop on the level surface



(V) Radial fault : Exhibiting radial pattern on the ground



(vi) Enechelon fault : Relatively short faults overlapping each other.



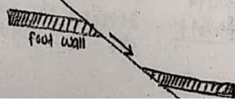
(f) on basis of dip value

(i) High angle fault : dip > 45°

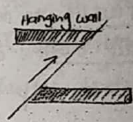
(ii) Low angle fault < 45°

Apparent movement

(g) (i) Normal fault : Hanging was moves apparently downwards.
- normally produced by tension force
- Gravity faults



(ii) REVERSE FAULT Hanging wall appears to have moved upward
- produced by compressional force
- Shortening of earth crust



(3) GENETIC CLASSIFICATION

Based on orientation of 3 principal stresses (One vertical ie gravity / 2, horizontal

(a) Normal faults

(i) max stress — vertical (M_1)

(ii) mean stress — Horizontal (M_2)

(iii) min " — " (M_3)

- hanging wall has moved relatively downwards
- Gravity fault / tensional

(b) Strike slip fault

Horizontal M_1 (max), Horizontal M_3 (min), Vert M_2 (mean.
- parallel displacement (to strike)

2 types < Tear fault (strike of fault is transverse to country rock, displacement along strike
Rift fault
→ strike of fault ∥ strike of adjacent rock.

(c) thrust fault

M_1 (max), M_2 (mean), M_3 (min)
H H V.

hanging wall moves relatively over footwall.

eg Reverse fault (dip > 45°)
· thrust fault (dip < 45°)

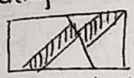
thrust (over thrust
under thrust (foot wall pushed underneath hanging wall)
Nappes
Schuppen. (Several thrust planes develop in parallel sets..
↳ high angle reverse fault formed among them is called Schuppen

Scanned by CamScanner

Effects of faults on outcrop

i) Effect of dip fault : amount of displacement becomes less with increase of dip

ii) Effects of strike fault
- Either to cause repeatation of outcrop or to eleminate some outcrop altogether.



(a) strike fault (b) After denudation

Evidence of faulting

3 criteria sets
- 1) Geological evidence
- 2) Fault plane evidence
- 3) physiographic evidence.

① Geological Evidence on geological maps
- offset of rock units
- Repeatation or omission
- Abrupt termination
- strata out of stratigraphic sequence
- abrupt change in attitude.

2) Fault plane evidence
i) Slickensides :- grooves & striations on one side due to abrasion (along fault plane)
- parallel furrow (mullions)

(ii) Drag :- Local bending caused by fault displacement
- indicates direct'

(iii) Fault breccia & gouge
- Angular fragments embedded in the matrix of finely ground rock (breccia)
- heavy thrust → fine clay powder (gouge)

(iv) Silicification & mineralization : Circulating water percolates and deposits fine grained quartz, causing silicification

(v) Feather joint :- tension fractures due to fault.

Feather joint

③ Physiographic evidence
(i) Fault scarp : steep straight slope (recent origin)
(ii) Fault line scarp : Ridge formed along fault due to unequal erosion
(iii) offset ridge : Resultant rock beds displaced along fault.
(iv) ...

Significance of folds and faults

- major significance to industrial geologists, as they form structural traps for valuable mineral deposits.
  - ⓔ Deposite of minerals like Pb, Sn, Zn in intrusive granite faults
- form channels, through which oil & gas can rise
- In syncline (porous sand beds overlie impermeable clay & shale) ⟶ Artesian well.
- Essential for mining.
  - ⓔ Recumbent folding (Z) and reverse faulting Z allows coal seams to be vertical.
- Problems in engineering geology
  - ⓔ highly crushed or sheared rocks found in faults are dangerous to bridges & tunnels & dams.

JOINTS

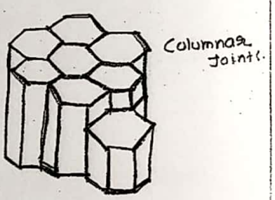
defn :- Fracture in a rock, where there is no relative displacement
- occur in almost every type of rock [↕ ↗ ⟷]
- Result of diastrophism / contraction.

Description
(i) Series of parallel joints → JOINT SET
(ii) Two or more joints intersecting eachother → JOINT SYSTEM
(iii) Two sets of joints at right angles to one another – CONJUGATE syst
(iv) A persistent joint or set – MASTER JOINT.

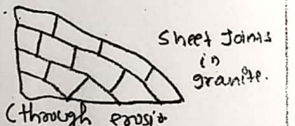
Classification

① According to mode of origin

(i) TENSION JOINT : formed due to tensional force
- Relatively open and have rough, irregular surface
- eg: Columnar joints in lava flow
  Longitudinal joints in anticline.
  mural joint in granite (cubical),
- Also called shrinkage joints
- In igneous rocks → produced due to contraction
- can also be due to deformation.



② SHEET JOINTS develop in sets
- more or less parallel to surface
- due to unloading of rock mass (through erosion)



③ TECTONIC JOINTS / SHEAR
- formed under compression (folding / thrusting)
- conjugate joint system.

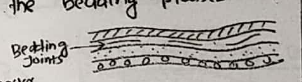
3 types (attitude & geometry)
(i) strike set – Joints parallel to fold axis
(ii) Dip set / Cross joint :- perpendicular to longitudinal joins
(iii) Diagonal / oblique : oblique to both dir...

② Geometric classification
i) STRIKE (ii) DIP (iii) DIAGONAL (refer previous page)

Joints can be
- open
- close / Latent / blind / incipient
  ↳ may become open as result of weathering

Description of common joints

(i) Bedding Joints : oriented parallel to the bedding planes in sedimentary rocks

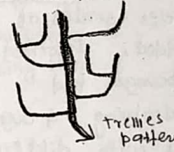


(ii) master joints
The joints which are more strongly developed and extends for longer distance

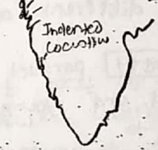
(iii) Primary Joints In igneous rocks, joints are formed during cooling and contraction of magma. Such joints are called primary joints

a) MURAL JOINT : Granite generally show 3 sets of joints mutually at right angle → cubical blocks.
(b) SHEET JOINT : Run in horizontal direction, tensional force.
(c) Columnar Joints :- formed in tabular igneous masses
eg: Sills, dykes, lava flow.

Recognition of Joints in field & their effects on works
- faults without displacement
- wide variation in dimension.
- commonly control the drainage pattern



- Determine shape of coastline by allowing passage of water leading to weathering

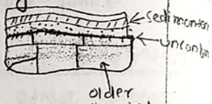


- Pervious to fluids and hence act as acquifer / reservoir
- matters much to miners and engineers.
- Areas of hot spring, are formed when water enters joints
- Localization of some minerals. (molten rock materials to ooze on to earth surface).

UNCONFORMITIES

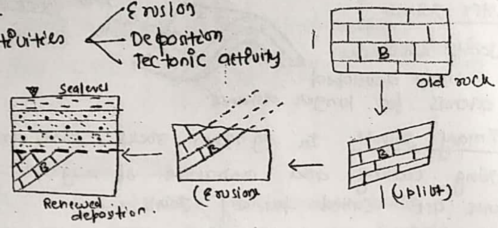
def^n An unconformity is a plane of discontinuity, that separates two rocks, which differ notably in age.

- The younger rock nearly always is sedimentary, deposited on surface of older rock (erosion origin)
- when there is a break in sedimentation, it creates a gap in geological record.



How it forms

Three main activities
- Erosion
- Deposition
- Tectonic activity



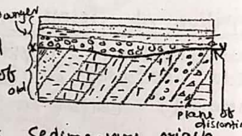
Classification

can be classified on basis of factors

i) Relationship between underlying rock bed and overlying rock
ii) Attitude or underlying and overlying bed.

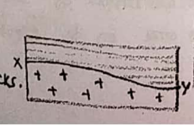
various types.

(a) ANGULAR UNCONFORMITY
- older series of bed have been tilted folded, deformed before deposition of younger bed
- underlying & overlying rocks are of sedimentary origin but with different attitude.

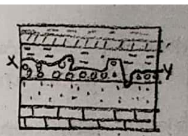


(b) DISCONFORMITY parallel unconformity
- Dip or old and young series with same dip.
- formed due to
  - Lesser magnitude of diastrophism
  - period of nondeposition.
  - period of erosion. or disturbance.

(c) NON CONFORMITY
- older formation made up of PLUTONIC ROCK overlained unconformably by sedimentary rocks.

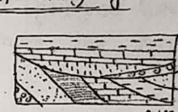


(d) LOCAL UNCONFORMITY
- Non depositional unconformity
- Similar to disconformity, but in local scale.
- Age difference between overlying and underlying bed is very less
- significant in determination of top and bottom of the folded beds.
- A.K.A DIASTEM.

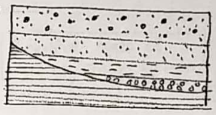


Various types of relationship between overlying & underlying rock

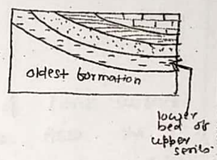
(i) over step :
- formed during marine transgression
- younger series rests progressively on older members.


OVERSTEP

(ii) OVERLAP.
- younger deposition slowly progresses out, encroaching more and more on old gently sloping surface, eventually covering it up entirely.



(iii) off lap : Reverse of overlap
- lower beds (older) extends further than. younger ones.



Recognition of unconformity

- observation in a single outcrop is most satisfactory.
- Reliability in identification increases in proportion to
  - (a) time interval
  - (b) Thickness of beds missing from stratigraphic record.
  - (c) structural discordance
  - (d) topographic relief
  - (e) evidence of weathering.

(i) Evidence of unrecorded interval.
- Gap in palaeontological record : eg: If rocks of upper triassic fossil overlain by lower cretaceous
- Gap in stratigraphic record: local absence of distinctive strata.

(ii) Structural discordance : in group of rocks in either side.

(iii) Topographic irregularity

(iv) Presence of conglomerate : A bed of conglomerate is commonly found at the base of upper series

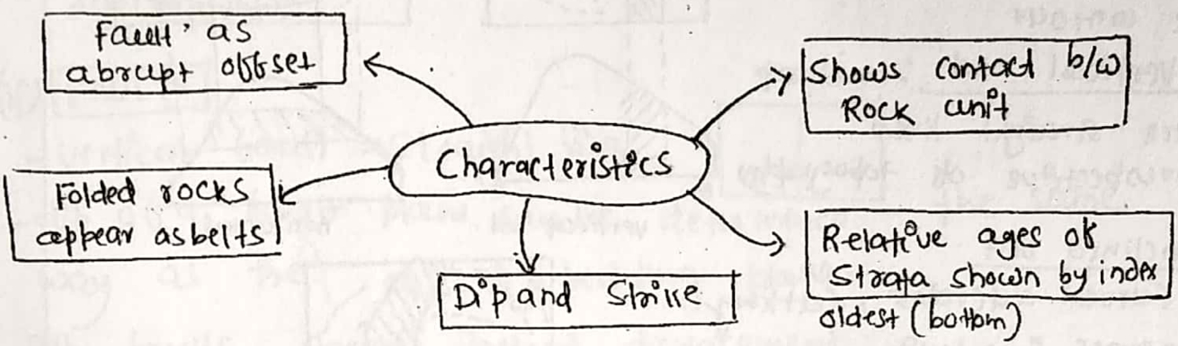
(v) Difference in environment of deposition : formed under

contrasting conditions
(eg) nonmarine beds overlain by marine beds

(vi) Relation with intrusive : concenformities may be recognized by truncation of volcanic ~~tou~~ necks
(vii) Difference in grade of metamorphism : younger series less metamorphosed than older series.
(viii) significant difference in intensity of folding

PRINCIPLES OF GEOLOGICAL MAPPING

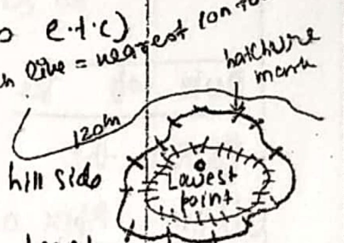
- A geological map shows geological setup of an area in terms of occurence and distribution of various rock types.
- Reveals the attitude and structure of rocks, and their association with topography and drainage.
- Key for understanding structure and geological history.
- Application in mineral prospecting, mining and Civil engineering work.



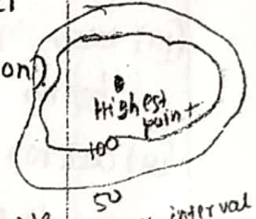
Topographic MAPS

defn: Map showing the configuration of land surface and drainage details of an area. Also the man made features (roads, railways, towns e.t.c) to depict elevations

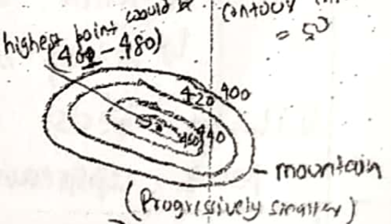
contour lines: - Close depression pits have hatchure/hatch mark on down hill side



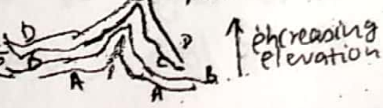
Line on map with same elevation above sea level along it's entire length. (depiction of third dimension)



- Lines bend upstreams. Vs points up the valley
- Form closures near upper part of hills
- Widely spaced on gentle slope and vice-versa.
- Evenly placed → gen uniform slope.
- Do not cross each other. (except at caves / cliffs)
- Inside of circle is always at higher elevation.



- Contour lines make a 'V' when crossing a stream and tip of the V points uphill
- Contour line in opposite sides of valley of ridge always appear in pairs



OUTCROP

def^n: The exposure of rockbed on ground surface is called "outcrop"

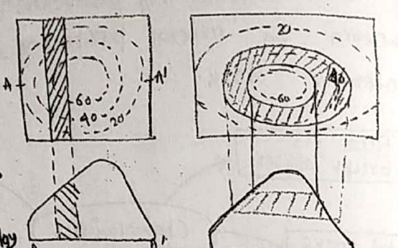
- outcrop pattern determined by < i) Dip and strike; ii) topography of an area.

i) Horizontal ground
- always straight lines, irrespective of dip of strata.

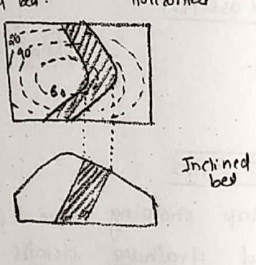
ii) Undulating ground

(a) Horizontal bed: outcrop run parallel to the contour

(b) vertical bed: outcrop are straight lines irrespective of topography



(c) Inclined bed
- Curved outcrops, cutting across contour
- Smaller dip → more sinuous outcrop

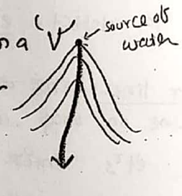


Rule of Vs

(i) When the contour line cross a river they form a 'V'

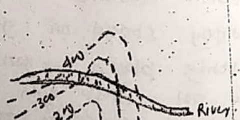
(ii) the Apex of 'V' points upstream / source of water

(iii) near upper part of the hill contour lines form closure

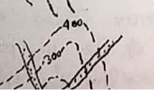


(iv) outcrop of dipping beds also give a 'V' pattern valley
↳ gentle dips (Long Vs)
↳ steep dips (short Vs)

(v) When beds dip up the valley, the 'V' points upstream.



(vi) When beds dip down the valley → 2 cases
a) if angle of dip > valley slope ∃ 'V' points down stream
b) if dip < valley slope ∃ 'V' upstream.

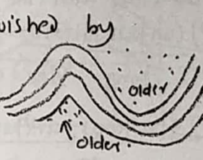


- Compass rose: To locate the North. (eg) → N

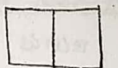
- ~~Tip o'~~

Outcrop pattern & Geological structure

i) FOLDS
- Repeatation of outcrop
- open folding → reversal of dip in successive outcrops
- Anticline & Syncline can be distinguished by relative position of older beds
- Plunging anticline → V shaped outcrop.



(ii) FAULTS
- vertical fault = straight line



- dip of a fault plane can be determined the same way as the dip of bedding plane.
- Dip faults cause lateral displacement.
- younger beds are found on the down throw side and older beds on upthrow.

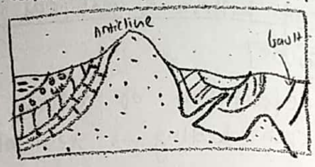
(iii) UNCONFORMITIES
- can be recognized by intersecting boundaries of sedimentary strata.

(iv) IGNEOUS INTRUSION
- Except sills which run parallel to the sedimentary strata, all other igneous intrusion ~~run parallel~~ intersect geological boundaries.

Scanned by CamScanner

Geological cross section

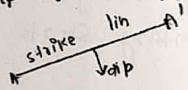
- Geological cross sections are constructed to understand the structure of a region.



- Section represents the conditions to be found at depth.
- Constructed with the help of
  - i) Contour lines :- help in drawing topographic profile along line of section (video - youtube)
  - (ii) Structural attitude of strata : dip computed along the line of cross section.
  - (iii) Thickness of each formation : obtained from drill hole records

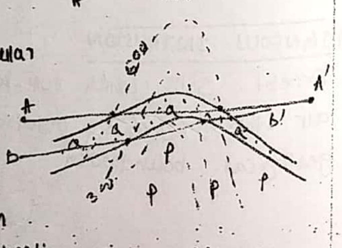
Determination of strike

- Strike line is a line which joins two points of equal elevation on a particular bedding plane. (intersection of bedding plane and horizontal plane)
- Strike lines are at right angles to dip direction. Hence important to get the dip of inclined strata



How to draw

i) Joining the points where particular contour crossed two places.



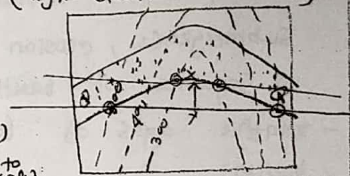
(ii) Altitude same as contour line.

(iii) Where contour lines do not intersect the rock strata, then strike line is drawn connecting any 3 known elevation points (dig).

Del

Determination of Dip

- 2 strike lines are drawn at different altitude on the top boundary.
- To find direction of dip a line is drawn at right angles to the strike. (higher elevation to lower), indicated by arrow.

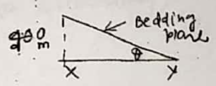


Scale 1cm = 500 m

- Amount of Dip

$$\tan\theta = \frac{\text{vertical drop } (500-300)}{\text{horizontal distance (acc. to scale)}}$$

$$\theta = \tan^{-1}\frac{200}{400} = 26°34'$$



Geological details

DESCRIPTION OF MAP

Geological map come along with detailed description.

i) Introduction
- Scale of the map (eg) 1cm = 200 m.
- look at contour and describe topography eg: Hills / valley.
- Indicate nature and number of various formation.

(ii) Geological Succession
- show sequence oldest → youngest by making an index
- Mention all thicknesses of various beds.

(iii) Geologic structure
- Brief description of various geologic structure
- For inclined beds, give amount and direction of dip ⊢→60
- For folds, give direction of axis and nature of fold.
- For Fault (Nature, direction and down throw).

- unconformities [no of beds present , and structure].
- Igneous body [give geological location].

(iv) Geological History
- Show period of sedimentation, uplift, submergence, erosion, igneous intrusion. & Sequence of faulting
- relative ages of fold fault & igneous bodies.

MAP READING

① Different colours : different type of rocks
- both age and type represented by diff colour

② Each geological units represented by Letter
e J = Jurrassic
K = Cretecious
T = Triassic
JKT (combination)

Lower case — type of rocks
S = shale
gb = Gabro.

③ LINES
i) Thin line for contact (between 2 geological units)
(ii) Fault as thicker line
(iii) Fold

(4) Scale of map
- contour interval.
- Index contour (dark lines → representative)
- North arrow ↑N

(5) Adjoining quadrangle
9 = Present.

⑥ Cross Section
- direction
- elevation → above surface / → below sea level.
- faults, folds, intrusion.

⑦ Text of the map
- Explains the geology
- Stratigraphy.
- Area location (relative to surrounding)
- Specific feature.

⑧ Economic geology
- Formation of coal, NG

⑨ References.

PROJECTION DIAGRAM

STERIOGRAPHIC PROJECTION

What

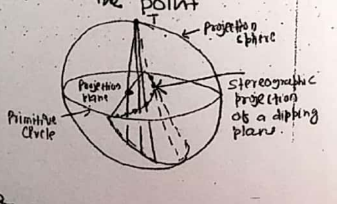
- A powerful method of solving geometric problems in structural geology.
- unlike structure contouring & other map based techniques it preserves only the orientation of lines and planes with no ability to preserve the position relationship.

Stereogram basics

- 2 parts of stereographic projection.
  - i) STEREOGRAM : usually drawn on a tracing paper and represents a bowl-shaped surface embaded in the earth.
  - ii) STEREONET: 3-D equivalent of protractor
    - used to measure angles in the projection.

Principle of stereographic projection

- A line/ plane is imagined to be surrounded by a PROJECTION SPHERE
- A plane intersects the sphere, i.e the great circle.
- A line intersects the sphere in a point
- to image papers on a sheet of paper, these traces and points are projected at the point summit / zenith
- Planes that dip at low angle are presented by significant curvatures



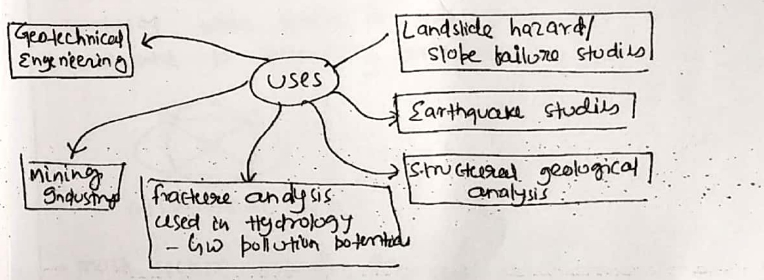
- All vertical planes will project as straight line passing through the centre of stereogram.

Stereonet features

- Stereographic net assists in construction of great circle & points
- Contains family of great circles intersecting at top and bottom
- Every 5th cyclographic trace is bolder, to keep pace of 10° increment
- By rotating the net the great circle can be manoeuvred into any desired strike and dip.
- The small circles help in solving rotation problems and act as scale of pitch angle.

Significance in structural analysis.

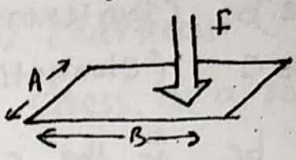
- one of the convenient methods of projecting linear and planar features.
- Engineering geology :- Provides quick and reliable picture of discontinuities and their intersection.
- Estimation of cut slope angle, statistical analysis of joints, for preparation of hazard maps & estimation of safety factors.
- Allows 3-D orientation data to be represented and analyzed in 2-D.



CONCEPT OF STRESS & STRAIN

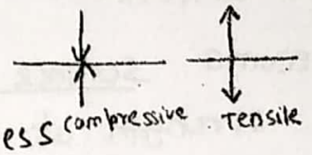
- **STRESS** is force per unit area.
  - Forces exerted by Rock ⇒ $F = m \times a$ eg: weight
  - forces acting on body. Eg: Surface force

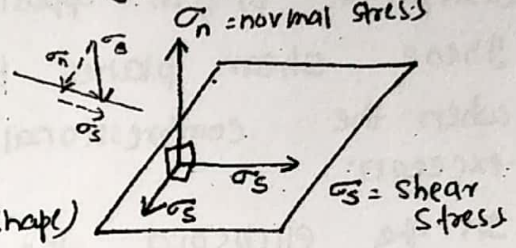
- Stress applied on rock mass can be resolved into 3 mutually perpendicular directions (AXES OF STRESS)
  - Greatest
  - Intermediate
  - Least



$\sigma = \frac{F}{(AB)}$

- **Hydrostatic** :- magnitude of stress of each axis is equal.
  - ↳ under this only the volume changes and not the shape.

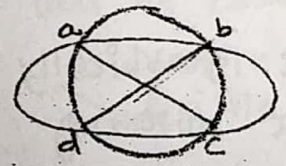




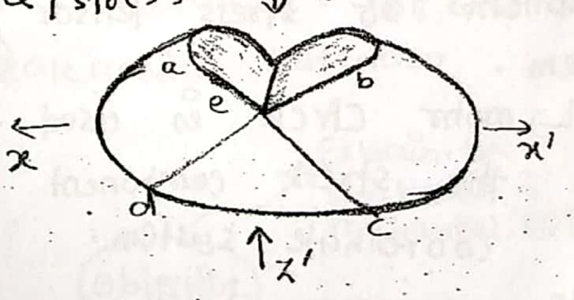
- Application of stress produces **STRAIN** (change in size/shape)
  (2D stress resolved into vector components)
- Distribution of strain along the principal axes ⟶ strain axes.
  - i) **Axis of least strain** : Axis of greatest stress is the axis of greatest compression = least strain.
  - ii) **Axis of greatest strain** : Axis of least stress is axis of least compression → "axis of greatest strain"
  - (iii) Axis of intermediate strain.

STRESS ELLIPSE & STRAIN ELLIPSOID

- STRAIN Ellipsoid is an imaginary figure produced when sphere of homogenous rock is subjected to deforming force/stress.



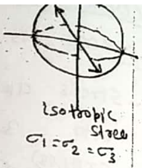
(a) Longitudinal section



(b) Ellipsoid showing plane of shear

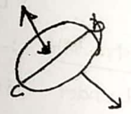
- most section through the Ellipsoid are Ellipse, except the circles with dia ac & bd

- Circular section represent isometric stress i.e no change in shape has taken place along these direction



- Section aeb (shortening)
section bec (elongation)

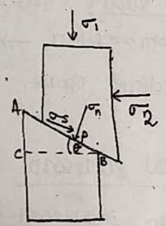
here bc is the surface of shear plane as distribution of stress on either side is in opposite direction.

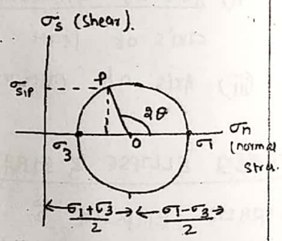


- These shear planes become surface of RUPTURE when the compressional strength of rock has exceeded.
- In the ellipsoid the axis of greatest strain indicates the direction of elongation
- tension fractures form at perpendicular to the greatest axis of strain ellipsoid.

MOHR DIAGRAM

- mohr diagram is graphic representation of state of stress of a rock.





- After performing stress analysis on a material body (assumed as continuum) components of stress tensor, are known w.r.t coordinate system.
  - ↳ mohr circle is used to determine graphically the stress component acting on a rotating coordinate system.
- To represent stress continuously distributed in the body of an object (assumed as continuum)

Significance of mohr dig

i) Relationship between plane orientation and value of normal / shear stress is difficult to determine in stress ellipse. more convenient in MOHR diagram.

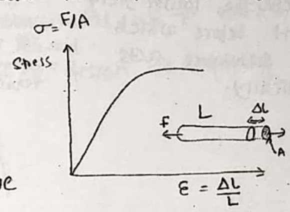
ii) Horizontal axis (normal stress), vertical (shear)

iii) completely represent state of stress at a point in terms of normal & shear.

(iv) 3-D stress can be plotted on mohr dig at 3 mohr circles

STRESS & STRAIN RELATIONSHIP

Relationship between stress and strain is depicted through stress - strain curve



- unique for each material
- found by recording amount of deformation (strain) at distinct intervals of tensile or compressive loading.
- Important to understand mechanical property of material (eg determination of modulus of elasticity)
- Stress and strain curve of various materials vary widely. However some common characteristics of S-S curve can be observed., to categorize materials into. < Ductile / Brittle

Significance

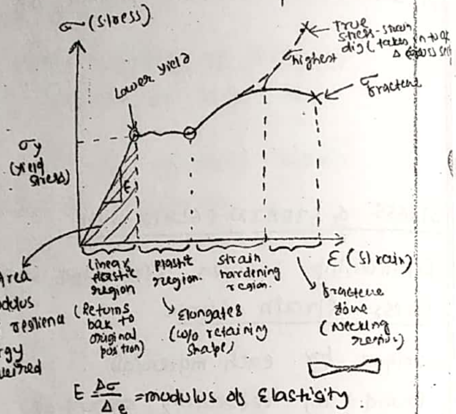
1) Design :- to know max. allowed stress for an equipment or structure (material.

(Objective)
→ Explain the significance of mechanical property
→ Describe the Tension test
→ identify characteristics of S-S curv.

Stress - Strain Curve

I) ELASTIC MATERIAL

- modulus of TOUGHNESS
  area under entire stress-strain curve.
- modulus of Resilience
  Energy required to reach the lower yield point before which the substance acts elastically.



$E = \frac{\Delta\sigma}{\Delta e}$ = modulus of Elasticity.

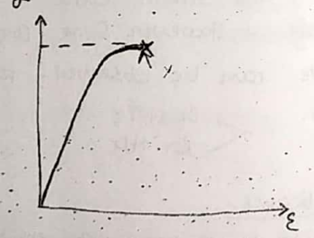
$$\sigma_{applied} = \frac{\sigma_{failure}}{\text{safety factor}}$$

$\sigma = E \cdot \varepsilon$ (HOOKE'S LAW)

eg E = Steel (29000 ksi)
carbon (33000 ksi)

2) Brittle/Plastic material

eg: cast iron, glass, stone
where rupture occurs without any prior noticable change



- Brittle material like concrete or carbon fibre do not have any yield point
  ⇒ Ultimate strength = breaking strength.
- No neck deformation.
- Higher value of max stress → harder material.
- metal is more brittle, when distance from [illegible]

Brittleness

- Property of material: where by it will fracture w/o noticable change.
- opposite to ductile material.
- cast iron, glass
- Important to design mechanical tools
- metals < 5% elongation

Toughness

- Property of metal: to absorb max. energy b4 it fractures.
- calculated from the area under S-S curve
- Enables a material to be twisted, bent or stretched before rupture
- $\alpha \frac{1}{Temp}$
- Desirable for materials to withstand shock/ vibrati

Stiffness

- Resistance to deformation
- modulus of rigidity is the measure.
- opposite to flexibility
-

Resilience

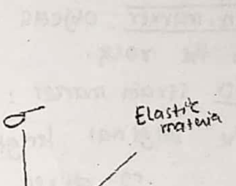
- Property to store energy & resist shocks and impacts.
- Amount of energy absorbed per unit volume in stressing a material up to elastic limit.
- eg. design of spring.

Endurance

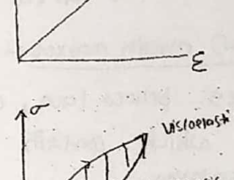
- Ability to withstand varying stresses applied for indefinite times w/o causing failure
  (eg) for steel Endurance limit is about half the tensile strength
  ↳ design of vibrating components

(III) VISCOUS MATERIAL

- viscoelasticity is the property of material that exhibit both viscous & elastic characteristics; while undergoing deformation.



(eg) Honey resists shear flow & strain linearly with time when stress is applied.



- while elasticity is the result of bond stretching along crystallographic plane, viscosity is the result of diffusion of atoms inside an amorphous materia.

- viscocity gives a substance a strain rate dependent on time (purely elastic materials do not dissipate energy when load is applied). viscoelastic substance loses energy when load is applied.
  ↳ The energy lost is derived from the area of the hysteresis loop
- when stress is applied to visoelastic material like polymer, parts of long polymer chain changes position → called CREEP. (but remains a solid material)
- when the original stress is taken away, the back stress will cause the polymer to return to original form.
- measured by Broadband viscoelastic spectroscopy.

STRAIN MARKER'S IN DEFORMED ROCKS

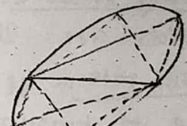
Strain marker: Objects that reveal the state of strain in the rock.

i) 1-D strain marker: objects for which we know the original length
   eg: dikes, linear fossils.

ii) 2-D strain marker:- objects of known initial shape
   eg: pillow lava, conglomerates, breccias, corals.
- or which contain linear marker with variety of orientation.

Finding strain by measuring angular changes

- must know original angle between sets of lines.
- Strain can be estimated from the change in angular relation.
- If 2 originally orthogonal lines remain orthogonal after deformation → they represent the principal strain → orientation of strain ellipsoid



2 methods
- Well man method
- Breddin graph

Behaviour of Rocks under deformation

How material behaves depend on several factors

i) Temperature : At high temp. molecules can stretch & move
   - more ductile (at ↑T)

ii) Confining pressure :- At high confining pressure materials are likely to fracture.

(iii) Strain rate :- At high strain rate, materials tend to fracture. At more strain rate more time is available (↑ ductile).

(iv) Composition :- minerals like Quartz, olivine are very brittle
   - clay, mica, calcite (ductile.

Study of Rock deformation
- Large scale (plate tectonics)
- Small scale (structural geology)

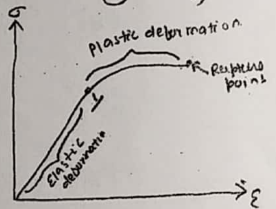


fig: PLASTIC DEFORMATION

Rock characteristics
- more Elastic & brittle near Earth surface
- more plastic & ductile deeper in crust (∵ ↑T, ↑P)

- (eg) most common ductile response - FOLDING
- Rocks
  - competent :- Rock deform under great stress
  - Incompetent :- deform under moderate to low stress
- most common brittle response to stress → FRACTURE
  - ↳ with displacement (Fault)
  - ↳ without " (Joint)

Deformation behaviour of rocks under compression & tension

i) Avg Youngs moduli in tension is smaller than compression

(ii) Avg Poisson's ratio are generally smaller than compress

(iii) Tangent young's modulus in tension reduces with increasing stress

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