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ABSTRACT

A group of scientists and science educators at Washington State University has developed and pilot tested an integrated physical science program designed for preservice elementary school teachers. This document includes the syllabus and class materials for the Geology block of the physical science courses developed by the group. Included are diagrams, lecture notes, a list of source materials, laboratory exercises and evaluation materials to be used with the course. Topics include: (1) minerals; (2) rocks; (3) volcanoes; (4) weathering; (5) geologic time and fossils; (6) radiometric time; (7) structural geology; (8) earthquakes; (9) plate tectonics; (10) mineral resources; (11) groundwater; (12) geologic hazards; and (13) earth processes. (CW)

FINAL REPORT

Submitted to the National Science Foundation

A MODEL TO IMPROVE PRESERVICE ELEMENTARY SCIENCE TEACHER DEVELOPMENT

Julie H. Lutz, Principal Investigator
Donald C. Orlich, Principal Investigator

NSF Grant No. TEI-8470609
WSU 145 01 12V 2460 0102
Washington State University
Pullman, Washington 99164-2930
June 15, 1988

GEOLOGY LECTURES AND LABORATORIES

A MODEL TO IMPROVE PRESERVICE ELEMENTARY SCIENCE TEACHER DEVELOPMENT

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Washington State University
Pullman, WA 99164-2812

NSF Grant No. TEI-8470609
Volume IV

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOck

Astronomy 301

Introduction:

Name:	G. D. Webster
Office:	Physical Science 1152
Office Hours:	10:00-11:00, 1:00-2:00, MWF
T.A.:	Erik Weberg, Phy. Sci. 254
Text:	Foster, Physical Geology, 4th Edition
Lab:	N') manual, exercises will be passed out in laboratory. All work to be completed in laboratory.
Laboratory Room:	Physical Science 1149
Grade:	50% Chemistry; 50% Geology

Geology Half:
- Midterm - 25%
- Final, comprehensive, 2/3 on last quarter of semester. - 35%
- Lab - 40%

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

Tentative Lecture Schedule

Date	Lecture	Readg. Assign
Oct. 21	Minerals	Chapter 1, 2
23	"	
26	Igneous Rock, Vulcanism	Chapter 3
28	" " "	
30	Weathering	Chapter 4
Nov. 2	Sedimentary Rocks	
4	Metamorphism and Metamorphic Rocks	Chapter 5
6	" " " "	
9	Geologic Time, Relative	Chapter 16
11	Radiometric Time	
13	Structural Geology, Earthquakes	Chapter 13
16	Plate Tectonics	Chapter 14
18	Midterm Exam, All lectures through Metamorphic Rocks	Chapters 1-5
20	Plate Tectonics, continued	Chapter 15

THANKSGIVING BREAK, NOV. 23-27

Date	Lecture	Readg. Assign
Nov.30	Mineral Resources	Chapter 6
Dec. 2	" "	
4	Ground Water	Chapter 12
7	Geologic Hazzards	Chapter 8
9	" "	
11	Earth Processes	Chapters 7, 8

Dec.18 FINAL EXAM for Geology, comprehensive, 8:00-10:00am

Laboratory Schedule

Oct. 22	Minerals
29	Rocks
Nov. 5	Rocks, continued
12	Geologic Time, Fossils
19	Structural Geology/Plate Tectonics
Dec. 3	Geologic Processes
10	Lab Final

ASTRONOMY 301, GEOLOGY BLOCK

INTRODUCTORY LECTURE

Reasons elementary teachers should take geology:

We live on the earth, we need to understand it to survive as we overpopulate it.

Natural interest - recognition of surroundings; knowledge

Natural hazzards - awareness, safety

Minerals, Rocks - economics, resources, limits, uses, etc.

Fossils - record of past life

Natural Laboratory for field trips -

Show and Tell -

Careers - 120,000 geoscientists in the U. S., in many specialities such as Mining, Ground Water, Petroleum, Paleontology, Geological Engineering, Structural Geology, etc.

Vacations -

Hobbies - largest in U. S. since 1920

ASTRONOMY 301 - GEOLOGY BLOCK

MINERALS

Chemistry Review

Matter - lithosphere, solid portion of earth, made of matter

A. Composition:

1. Atom - minute partical of matter composed of smaller subatomic particles.
    a. Proton - + charged particle
    b. Neutron - neutral particle
    c. Protron + Neutron = nucleus
    d. Electron - - charged particle, form shells around the nucleus; vary from 1 to 8 in outermost shell.
2. Element - a substance consistiing of atoms of one kind only.

Smallest particle of matter that can enter into a chemical reaction.

- +100 elements
- Periodic chart of elements:

1 Hydrogen	14 Oxygen
2 Helium	26 Ferrum (iron)
11 Sodium	47 Silver
17 Chlorine	79 Gold
	82 Lead

3. Atomic Number - number of protons in nucleus; nonvariable

Element		Wt % in Cont. Rx	Wt % in Earth
Oxygen	O	46.4	28
Silicon	Si	28.15	13
Aluminum	Al	8.23	0.4
Iron	Fe	5.63	35
Calcium	Ca	4.15	0.6
Sodium	Na	2.36	<0,1
Magnesium	Mg	2.33	17
Sulphur	S	0.026	2.7
Nickel	Ni	0.0075	2.7
		Greater than 97%	Greater than 99%

4. Ion - atom in which the number of protons is either > or < the number of electrons; atom has gained or lost electrons.

- ions are chemically active
  - 1 or 7 electrons - most active
  - 2 or 6 electrons - next most active
  - 3 or 5 electrons - less active
  - 4 - still less active
  - 8 - very stable, noble gases

a. Anion - (-) charge, excess electrons

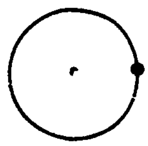
b. Cation - (+) charge, lacking electrons

5. Ionic radii - radius of each ion, depends upon the number of electrons and whether electrons have been lost or gained (lost, contracts slightly; gained, expands slightly).

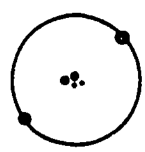
- ionic radii will determine whether certain elements (coupled with their ionic charge) can enter into the formation of some minerals.

Ex. Calcite ($CaCO_3$) and Dolomite $(Ca,Mg)CO_3$

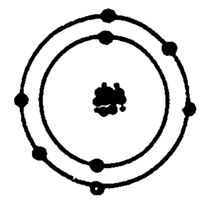
Diagrams of atoms and ions:



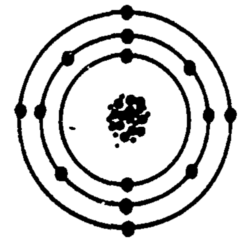
1 proton
1 electron
HYDROGEN (H)



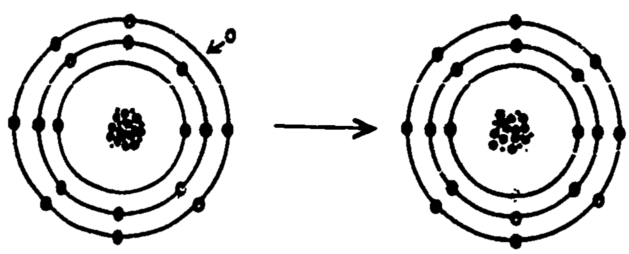
2 protons
2 neutrons
2 electrons
HELIUM (He)



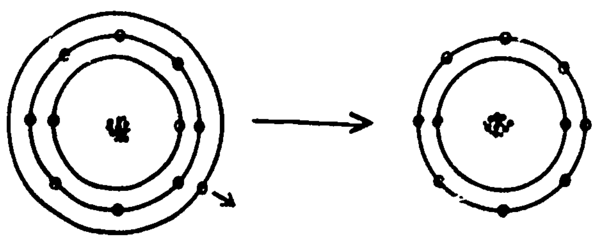
8 protons
8 neutrons
8 electrons
OXYGEN (O)



14 protons
14 neutrons
14 electrons
SILICON (Si)



Chlorine atom (Cl) +1 electron Chlorine ion (Cl^{-1})



Sodium atom (Na) -1 electron Sodium ion (Na^{+1})

6. Isotopes - atoms with the same atomic number but different atomic mass, i.e., have a different number of neutrons

- generally react chemically and physically similar to the normal balanced form

- Some are unstable, thus break down in radioactive decay

a. Radiometric dating:

Uranium 238 -	Lead 206-	4.5 billion yrs, half life
Uranium 235 -	Lead 207-	713 million years h.l.
Thorium 232 -	Lead 208-	13.9 billion yrs, h.l.
Rubidium 87-	Strontium 87	50 billion yrs h. l.
Potassium 40-	Argon 40	1.5 billion yrs h. l.

- Half life - time for 1/2 of parent element to breakdown into daughter products

See overhead for breakdown chain for each of 3 isotopes

- Many isotopes breakdown so rapidly that they are of no value for radiometric dating

7. Molecules - combination of 2 or more atoms whether of the same or different kinds.

- i. e. minerals

a. Ionic compounds or bonding - most common, anions and cations attract one another and bond to reach the neutral electrostatic charge.

- form brittle crystals, i. e. halite

b. Covalent compounds or bonding - sharing of electrons to attain the neutral electrostatic charge

- i. e. diamond, water, methane

c. Metallic compounds or bonding - bonding electrons shared throughout the mass, thus a good electrical conductor

- characteristic of pure metals, Ag, Au, Plat.
- atoms easily rearranged, thus malleable or ductile

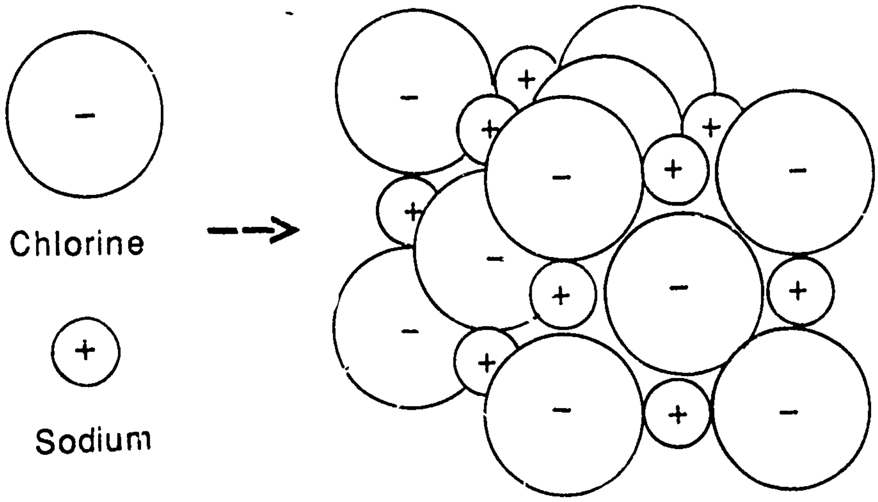
d. Polymorphs - same chemical composition, different chemical structure

- i. e. diamond and graphite

e. Isomorphs - different chemical composition, same structure

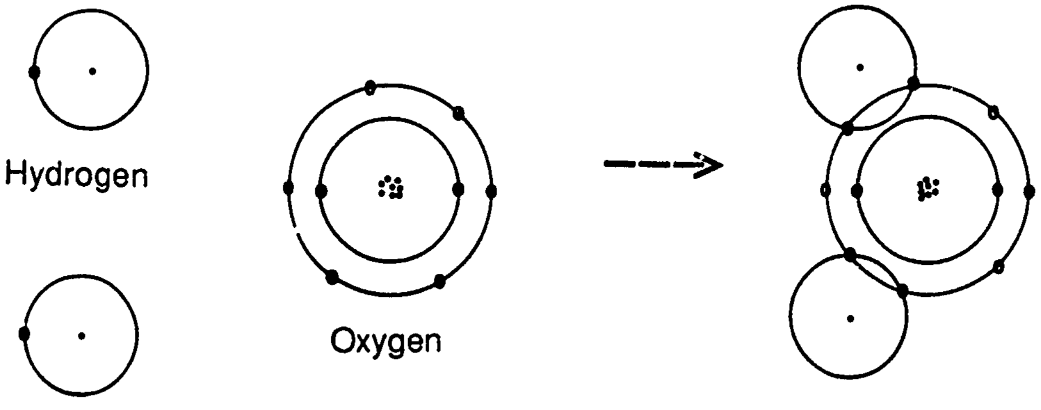
- i. e. Forsterite (Mg,SiO_4) --Fayalite (Fe,SiO_4), isomorphic series

Ionic Bonding



Sodium Chloride (NaCl)

Covalent Bonding



I. Minerals - naturally occurring, inorganic solid possessing a specific internal structure and a definite chemical composition that may vary within specific limits. More than 2,000 known.

Physical Properties:

1. Color - may vary, beware
2. Chemical composition -
3. Crystal form - see diagrams
4. Specific Gravity -
5. Fracture or Cleavage
6. Streak - color of powdered particles
7. Luster - light reflectance, metallic vs non-metallic
8. Hardness - measure of resistance to being scratched

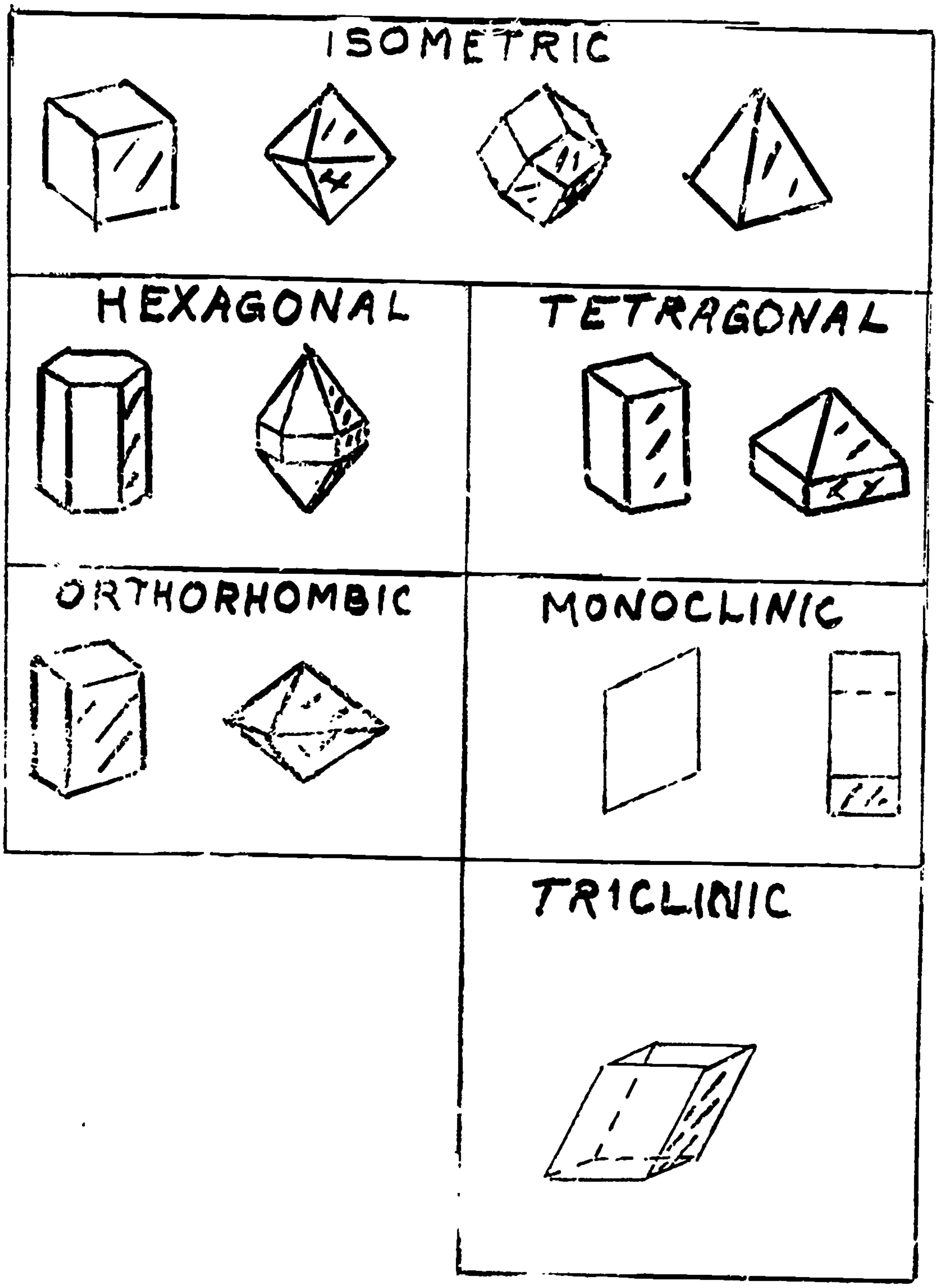
   Moh's Scale

10	Diamond	5	Apatite
9	Corundum	4	Fluorite
8	Topaz	3	Calcite
7	Quartz	2	Gypsum
6	Feldspar	1	Talc

   General Scale

   7 - Glass
   6 - Nail
   3 - Penny
   2-2.5 - Fingernail

9. Acid - reaction to dilute HCl
10. Magnetism - weakly, strongly
11. Taste - good for salts
12. Malleable - or ductile, metals
13. X-ray analysis - pattern developed by deflection of x-rays



Common Crystal Forms

II. Mineral Groups

1. Silicates - make up 95% of all minerals (+2,000) - see diagrams
   a. Silica tetrahedra SiO_4 Olivine $(FeMg)_2SiO_4$
   b. Silica chains Si_2O_6 (single) Pyroxenes
      Si_4O_{11} (double) Amphiboles
   c. Silica sheets Si_6O_{22} 3:11 Micas
   d. 3-D frameworks - Feldspars
   e. SiO_2 Quartz
2. Oxides - compounds of O, Hematite (Fe_2O_3); Magnetite (Fe_3O_4)
3. Sulfides - compounds of S, Galena (PbS); Sphalerite (ZnS)
4. Carbonates - " of CO_3, Calcite, Dolomite
5. Halides - chlorine or fluorine compounds, salts
6. Native elements - Ag, Au, Cu, Pl, diamonds, S
7. Phosphates - compounds of phosphate

III. Relative abundances: minerals are building blocks of rocks

20 minerals make up 95% of all rocks; 10 make up most rocks, with silicates leading the way.

Igneous Rocks - feldspars, micas, amphiboles, pyroxenes, olivene, & quartz

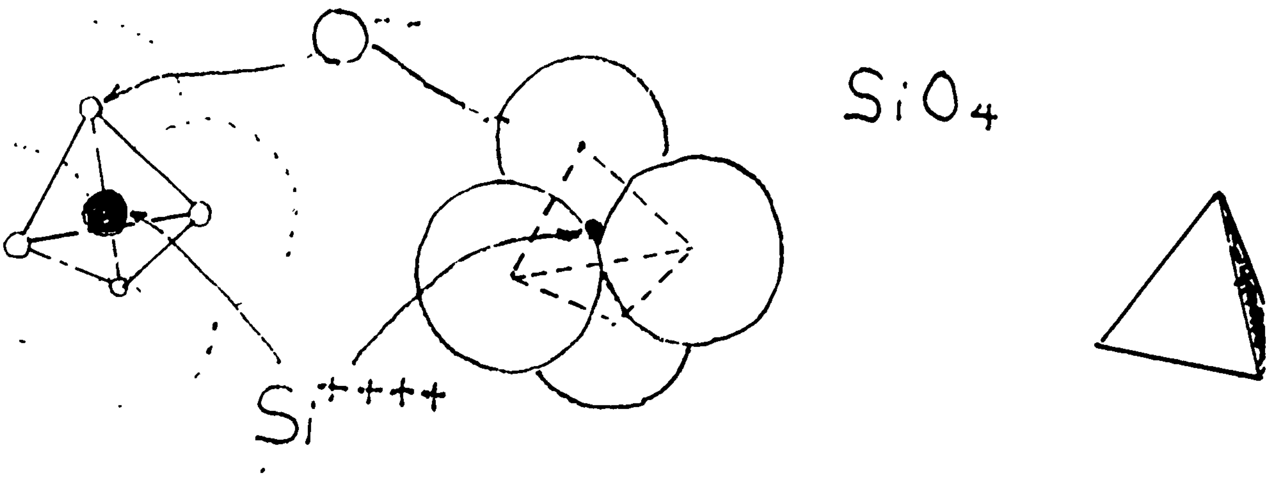
Sedimentary Rocks - quartz, calcite, dolomite, clays, and feldspars

Metamorphic Rocks - quartz, feldspars, amphiboles, pyroxenes, micas, & chlorite

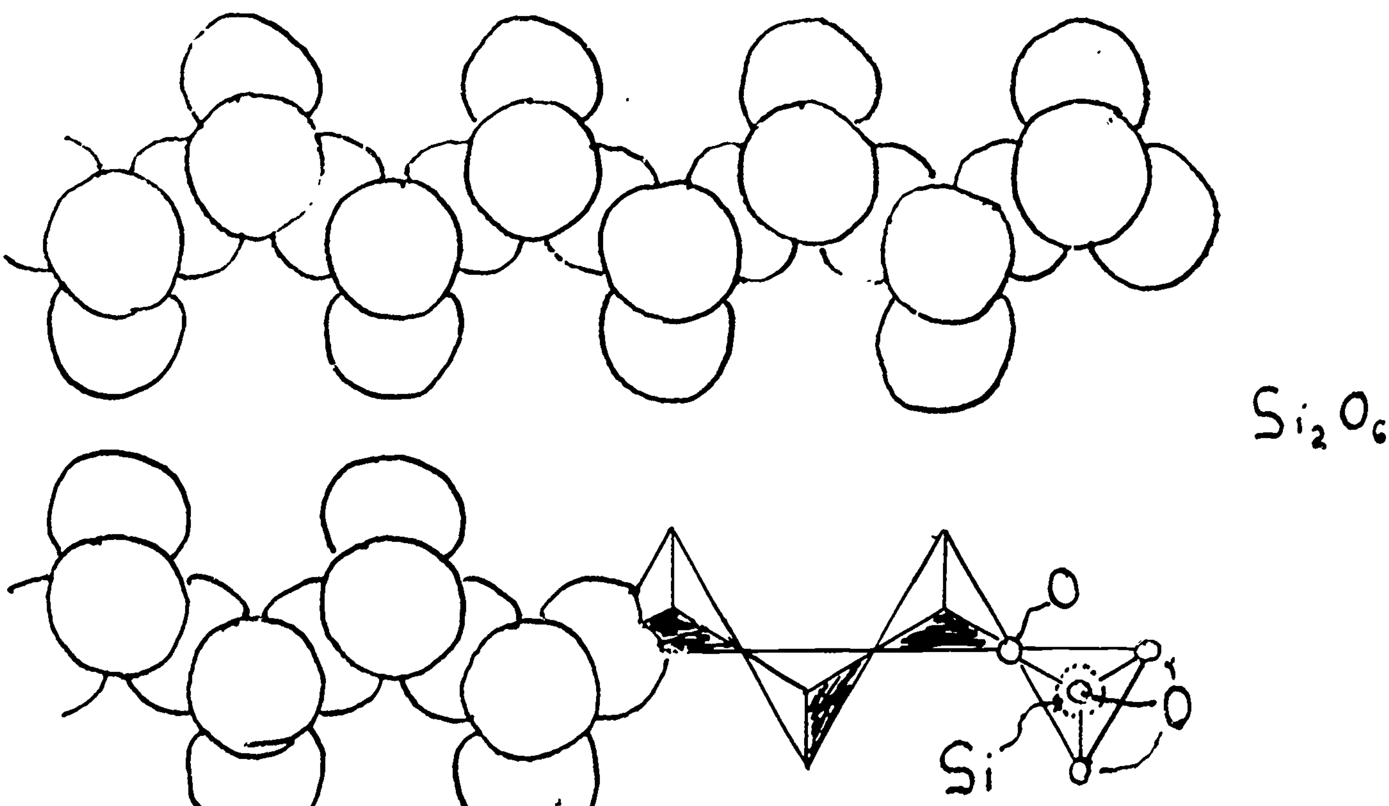
IV. Historical Uses of Minerals

A. Primitive Man - stone age, used rocks as well as minerals
   - flaking or flint knapping of tools and weapons
   - charms

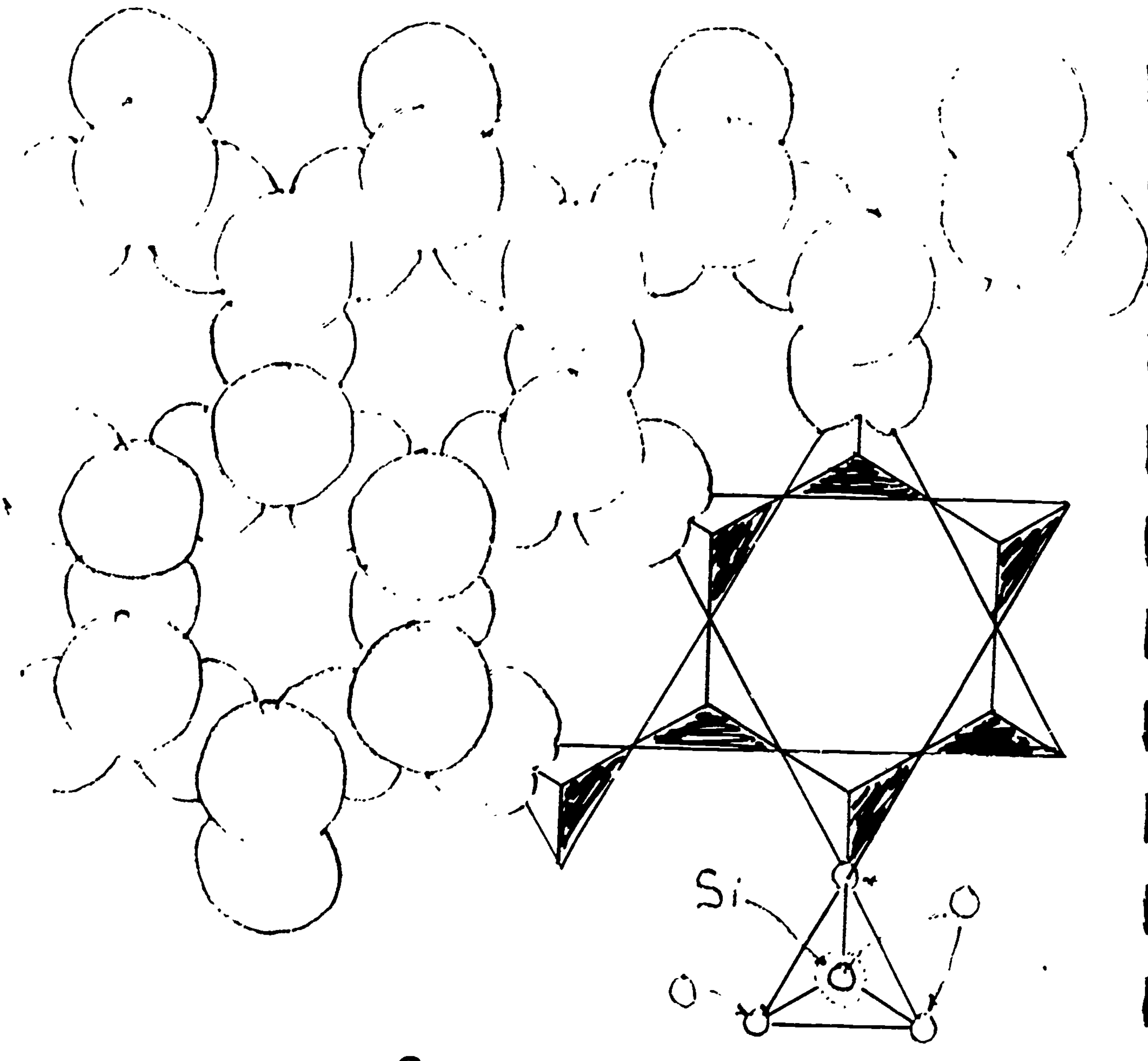
B. Age of Metal: Bronze Age - 3500 B.C. to Iron Age - 1000 B. C.



Silica Tetrahedra



Silica Chains



Si_6O_{22}

Silica Sheets

Parts of Europe and Asia

1. Gold - ornament, softness and color
2. Copper - implements and receptacles, softness and color
   - Michigan, Keeweenawan Peninsula
3. Bronze - copper + tin
4. Oxides - paint pigments and cosmetics, iron
5. Clays - ceramics
6. Medicines - silver, gems, other minerals
7. Gems - color and shape

C. Classical Times -

1. Greeks - 384 B.C to 44 B.C., several writings & treatises on minerals, metals, and their uses.
2. Romans - Pliny the Elder, 4 books of 37 devoted to mineral substances in *Encyclopedia of Natural History.*

D. Dark Ages - Christ to 1100 A.D., several *Lapidaries* were written, based on fancy and religous dogmas of the times, useless.

E. Modern Mineralogy - commences with Georg Bauer (1494-1555), wrote under name of Georgius Agricola:

De Natura Fossilium, 1546 - first text of mineralogy

De Re Metallica, 1556 - a classic

V. Gemstones

A. Attractiveness -

1. Purity and deepness of color -

1st - crystal, red, green, blue,

2nd - purple, orange, brown, black

2. Can change with fashion or salemanship

Black - fashionable in 1800s, lost out, now returning.

Opal - Queen Victoria considered it an evil gem

Pearls - come and go

B. Durability - measure of hardness

Topaz - splits with a soft blow

Jade - composite of minute crystals

Diamond - very hard, but can be shattered with a solid blow

C. Rarity - naturals vs synthetics

- Andalusite - Brazil
- ruby
- emerald
- sapphire
- diamond

D. Size - the bigger the better if no blemishes.

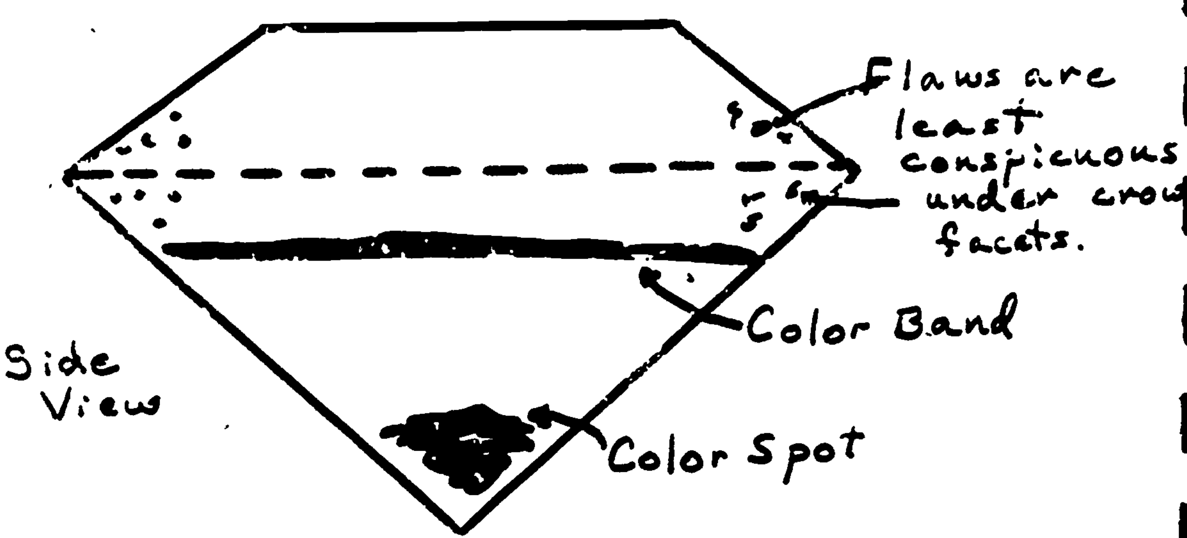
E. Cuts: way the gem is faceted or shaped - see diagrams

1. Brilliant
2. Step Cut
3. Cabochons: thickness 1/3-1/2 width, must be centered or will give an offcentered star. Also must be perfectly domed, if asymmetrical will give a lopsided, offcenter star.

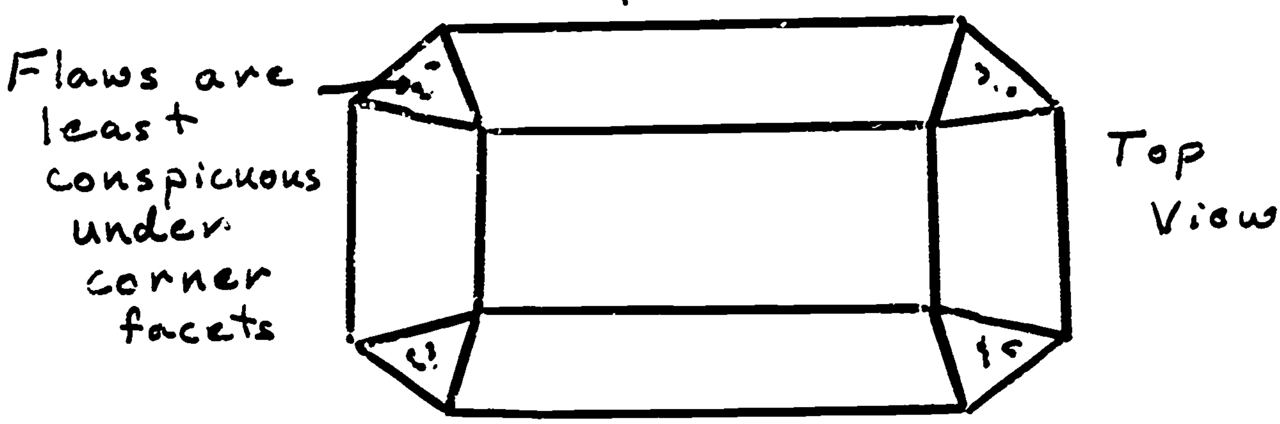
a. Catseye Cut

b. Stars

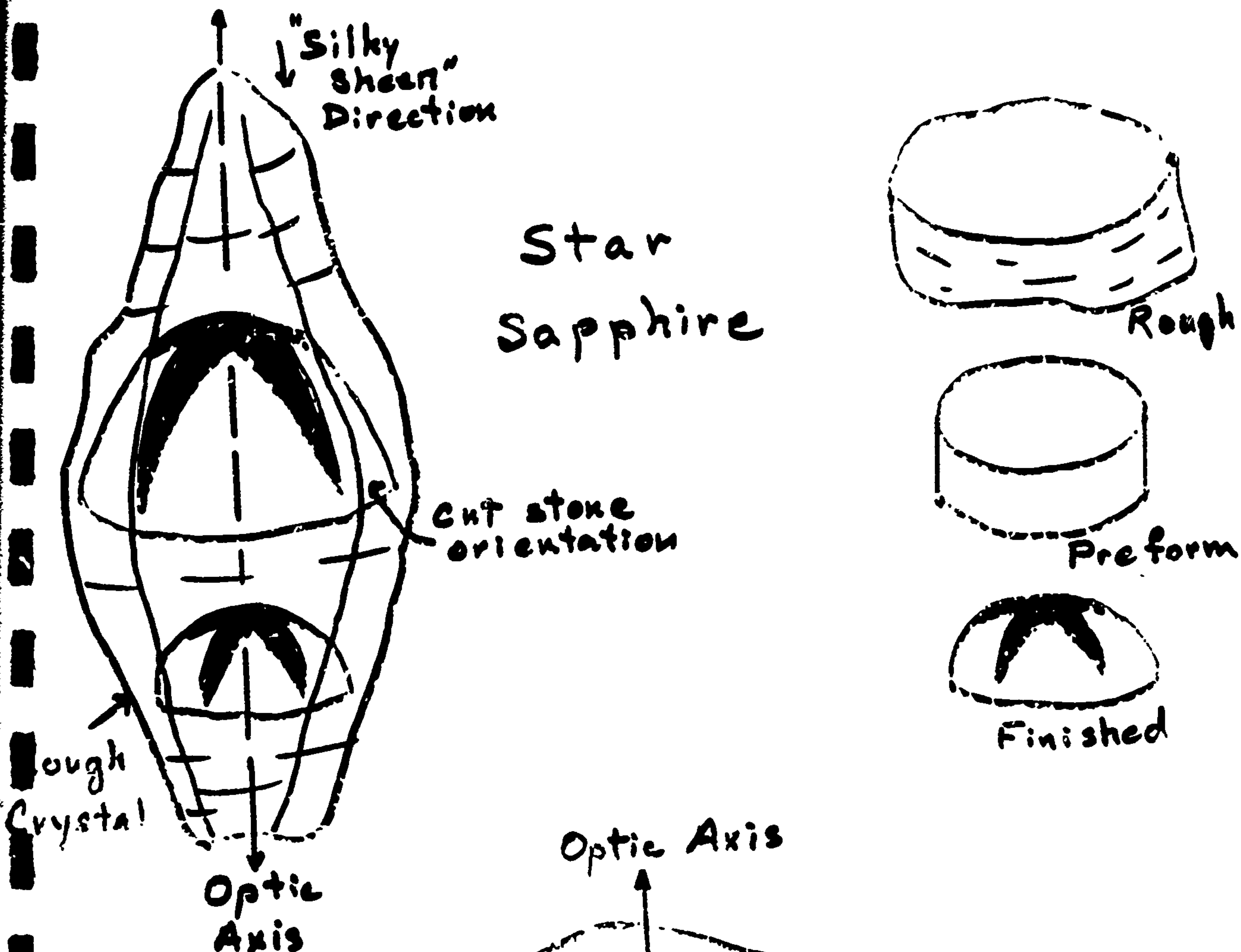
Brilliant Cut

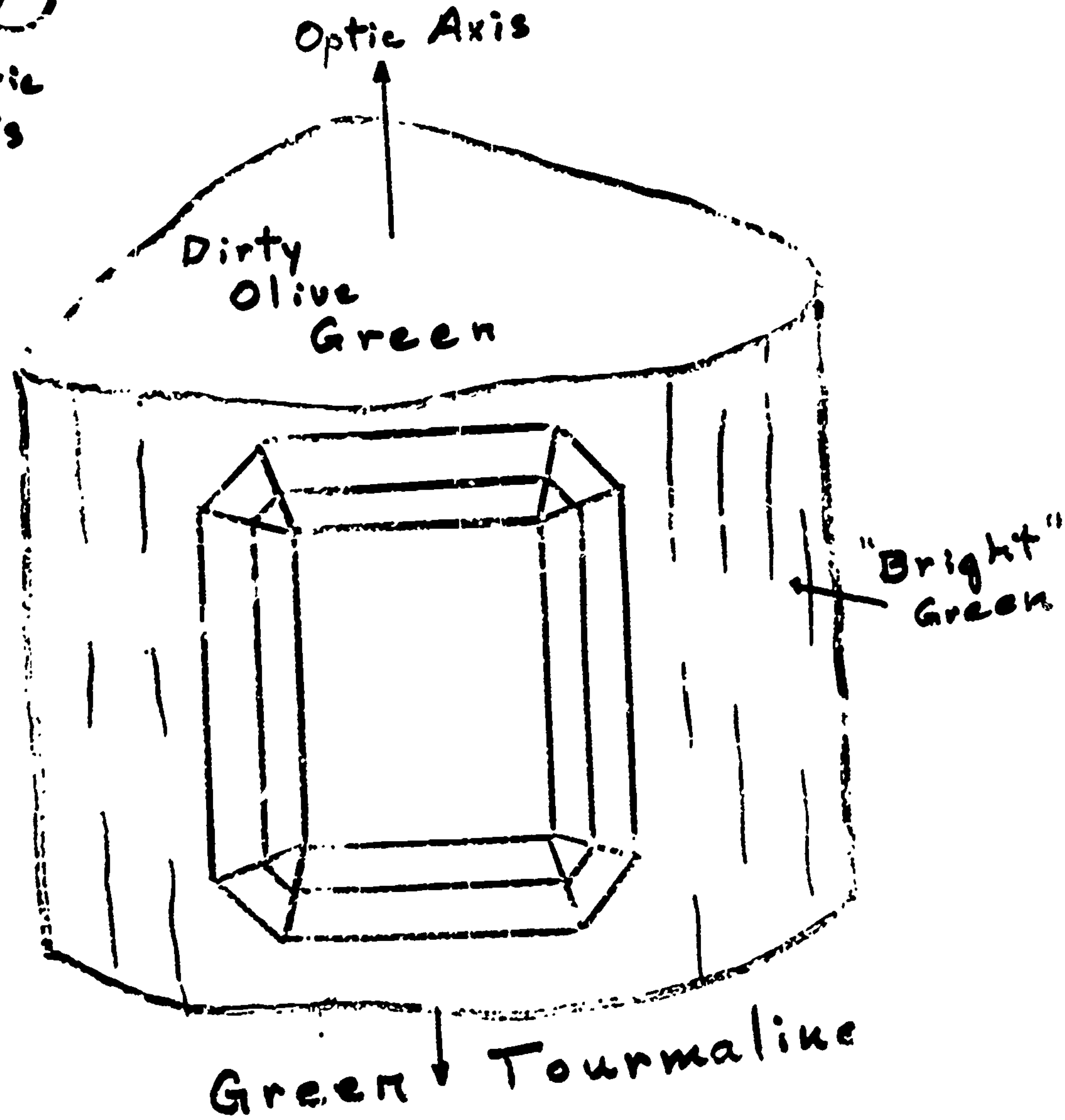


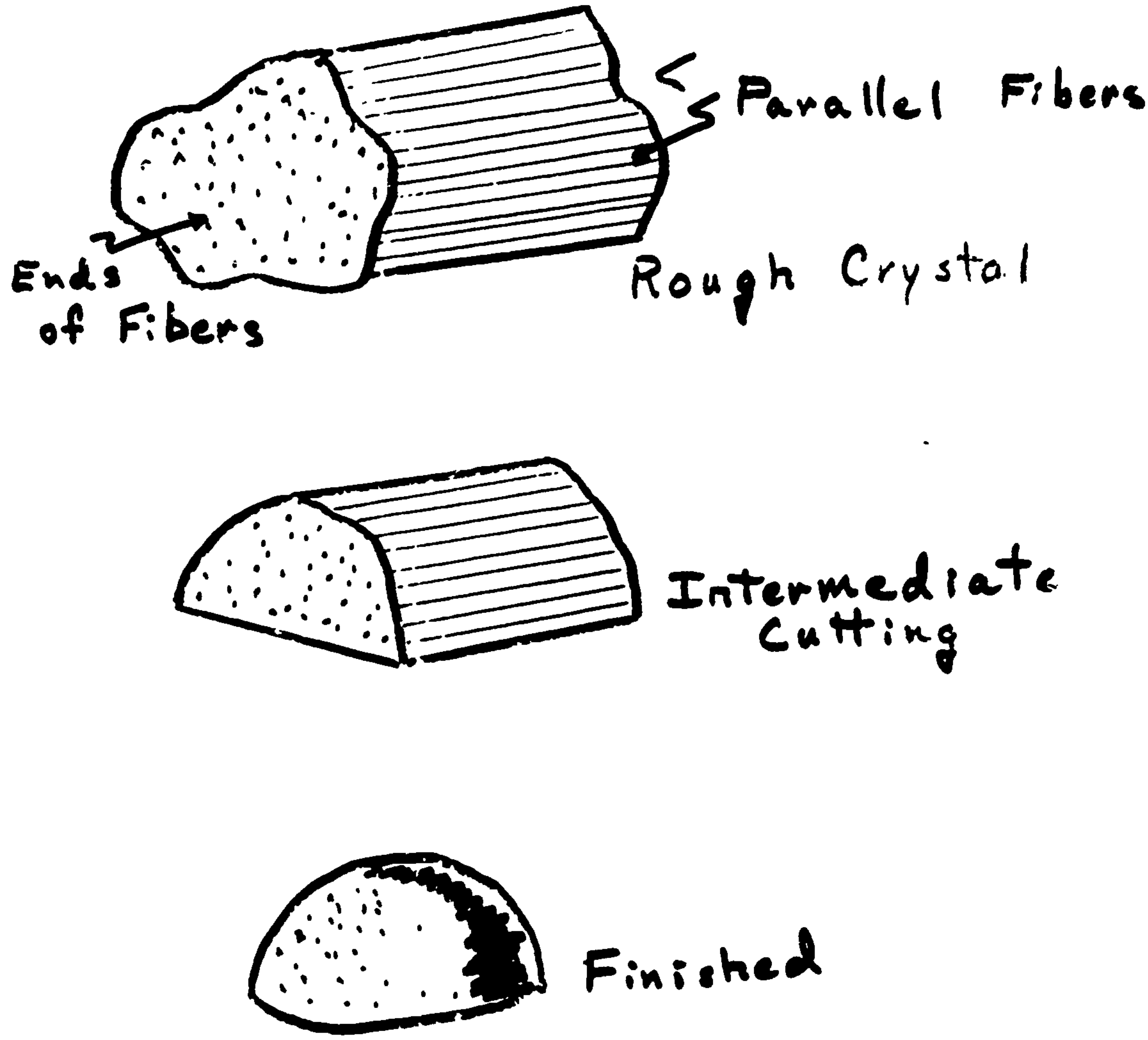
Step Cut



Diamonds


"Silky Sheen" Direction
Star Sapphire
Rough
Preform
Cut stone orientation
Finished
ough Crystal
Optic Axis


Optic Axis
Dirty Olive Green
"Bright" Green
Green Tourmaline


Parallel Fibers
Ends of Fibers
Rough Crystal
Intermediate Cutting
Finished

Catseye Cut

F. Organic Gems:

1. Pearl
2. Amber
3. Mother of Pearl
4. Coral
5. Tortoise Shell
6. Ivory - tusk, teeth (whales, walrus, elk)

G. Prices - whatever the buyer and seller agree upon depending upon the factors discussed above and market conditions.

ROCKS

Definition: a consolidated aggregate of one or more kinds of minerals

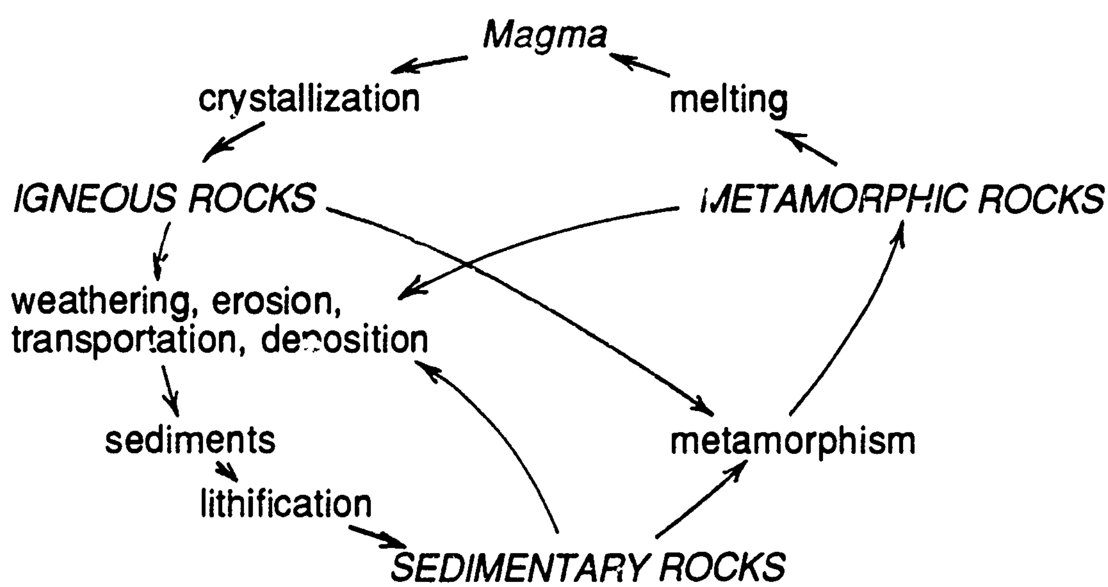
Exceptions:

Coal - organic

Conglomerate - aggregate of other rock fragments

Obsidian - volcanic glass, no minerals crystallized

Rock Cycle - a part of the geologic cycle



IGNEOUS ROCKS

I. Kinds - formed from the consolidation of liquid magma

A. *Extrusive* - formed on the earth's surface by crystallization from magma (*Volcanic*).

- lava flows
- includes volcanic bombs, tephra, etc.

B. *Intrusive* - formed beneath the surface of the earth by crystallization from a magma (*Plutonic*).

II. Crystallization of a magma:

A. Magma composition:

1. Mafic - *basic*, *Sima*, contains relatively lower amounts of silica

   ex. - basalt

2. Sialic - *acidic*, felsic, *Sial*, contains relatively higher amounts of silica

   ex. - granite

3. Composiiton of any two magmas, although similar, are virtually never identical. Usually vary in the kinds and amounts of trace elements.

B. Sequence of crystallization - N. L. *Bowen's Reaction Series:*

1200°C Total melt

	Discontinuous Series	Continuous Series
1125°C	Olivine $(Fe,Mg)_2SiO_4$	Calcic Feldspar $CaAl_2Si_2O_8$
	Pyroxene $Ca(Mg,Fe,Al)(Si_2O_6)$	Calc-sodic
	Amphibole $K,Ca,Mg,Fe,Al(Si_6O_{22})$	Sodic-calc
	Biotite K, Mg, Fe, $Al(Si_3O_{10})$	Sodic Feldspar $NaAlSi_3O_8$
600°C	Potassic Feldspar $KAlSi_3O_8$	
	Muscovite $KAl_3Si_3O_{10}(OH)_2$	
	Quartz SiO_2	

1. Gives order, if all elements present in magma, allowing compete sequence to develop (not common) and magma cools gradually.
2. *Discontinuous series* - ferromagnesium silicates
   a. Note change in silicate structure, more complex downward, tetrahedra to sheet.
   b. General decrease in Mg downward and an increase of Fe and Ca
   c. Replacement of the Mg by Fe and Ca and Al is within the lattice; melting and recrystallization.
3. *Continuous series* - plagioclase family - there is a solid state repalcement of Na for Ca in the crystal lattice, with no solution of previously formed minerals.
4. Ionic radii of K is much larger thatn Ca and Na, therefore a great change takes place between Na and K feldspars.
5. Explains *Magmatic Differentiation* - separation of crystallized part of the magma from the remainder of the magma

before crystallization completed.

6. Explains the mineral associations as we find them in igneous rocks
7. Shows us that the original composition of magma differs, one from another.

C. Rate of crystallization:

1. Rapid - little time for magmatic differentiation and crystallization to occur. Smaller crystals develop.
2. Slow - greater time for magmatic differentiation and crystallization to occur. Larger crystals develop.
3. Variations are reflected in *Porphyries*

   Phenocrysts - large crystals

   Ground Mass - smaller crystals

IV. Texture - characteristics and appearance in reflected light as determined by size, shape and arrangement of the minerals in the rock.

A. Factors affecting grain size:

1. Silica content of the magma:
   a. High - very liquid, longer time to solidify, coarse grain
   b. Low - mud-like, less time to solidify, fine grain.
2. Gas content of magma:
   a. Great amount - longer time to solidify, coarse grain
   b. Small amount - shorter time to solidify, fine grain
3. Time:
   a. Long - coarse grain
   b. Short - fine grain
   c. Very short - very fine grain, glassy (Obsidiian)

d. Two periods - results in 2 sizes of grains (porphyry)

B. Grain Shapes:

1. Euhedral - can see all or most crystal faces
2. Subhedral - can see poorly developed or few crystal faces
3. Anhedral - no crystal faces present

C. Type of textures:

1. *Glassy* - looks like glass
2. *Aphanitic* - fine-grained, need hand lense to see grains
3. *Phaneritic* - coarse-grained, see crystals with naked eye
4. *Porphyritic* - 2 different sizes of crystals, phenocrysts in ground mass

V. Composition: See classification diagrams.

A. Acidic - sialic, felsic - commonly light colored, contain orthoclase feldspar and quartz

B. Basic - sima, mafic - commonly darker colored, contains plagioclase feldspar and ferromagnesian minerals.

Get a progression from light to dark, so beware, color is not always reliable.

VI. Common Plutonic Rocks: see classification diagrams

A. Granite

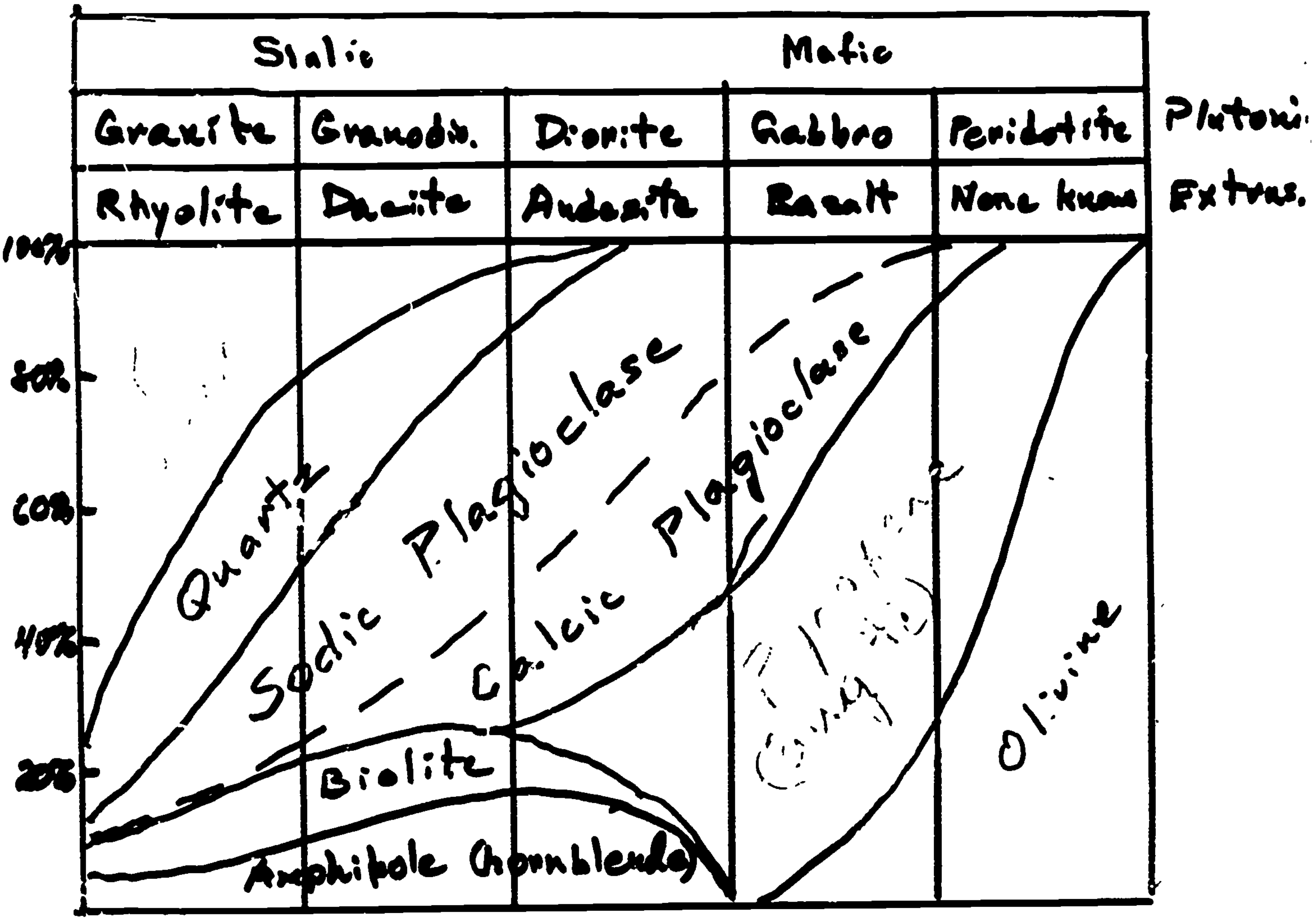
B. Syenite

C. Granodiorite

D. Diorite

E. Gabbro

F. Porphyry


Sialic
Mafic
Granite
Granodi.
Diorite
Gabbro
Peridotite
Plutoni.
Rhyolite
Dacite
Andesite
Basalt
None know
Extrus.
100%
80%
60%
40%
20%
Quartz
Sodic Plagioclase
Calcic Plagioclase
Biolite
Amphibole (hornblende)
Olivine

Color	w/ quartz	w/out quartz	kind of Feldspar
Light	Granite	Syenite	mostly orthoclase
Medium	Granodiorite (w/ s/ orthoclase) Quartz Diorite (w/out orthoclase)	Diorite	mostly sodium Plagioclase
Dark	Quartz Gabbro	Gabbro	mostly calcium Plagioclase

Plutonic Igneous Rocks

INTRUSIVE BODIES

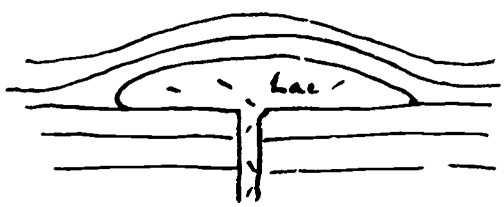
Pluton - any intrusive body, irrespective of size or shape

I. Deep Seated - form at depth below the earth's surface.

- A. Batholith - greater then 40 sq. mi. in surface area
- B. Stock - less than 40 sq. mi. in surface area.
- C. Features:
  1. Halo - aureole of metamorphic rocks
  2. Generally coarse grained
  3. Common in mountainous belts of world
  4. May cut across or parallel the grain of the country rock
- D. Problems:
  1. What happened to the country rock?
  2. Use geophysics to define boundaries at depth.
  3. Origin, formed as a result of plate tectonics.

II. Intermediate Depth - hypabyssal rocks

- A. Dike - discordant tabular bodies that cut across the grain of stratification in the form of a sheet.
- B. Sill - Concordant tabular bodies
- C. Laccolith - toad-stool shaped, concordant but lift overlying strata.



- D. Lopolith - basin shaped, both floor and roof sag downward.
- E. Features:
  1. Rocks may be finer-grained because of faster cooling
  2. rocks may be coarse-grained
  3. Porphyrys are common in these rocks

4. May be rich in particular minerals, eg. beryl, quartz, etc
5. Most common in mountainous belts

IV. Hazzards:- Associated with vulcanism, see hazzards under vulcanism

VULCANISM

I. Introduction

A. Swedes - go to Mount Heckla

B. Folklore - legends or myths of volcanoes are second only to the legends of a universal deluge among primitive peoples. Many primitive peoples offered human sacrifices to the "deities or demons who lived" in the nearby volcanoes.

C. Klamath legend:

Llao - chief of the Below World - Mt Mazama, Oregon

Skell - chief of the Above Wrold - Mt Shasta, California

Battle of hurling rocks at each other in the darkness.

Mt. Mazama collapsed under Llao precipitating him back into his underworld domain leaving a huge hole which filled to form a lake - Crater Lake.

Describes formation of the caldera at Crater Lake which occurred 6,600 yrs b.p.; scandals found in ash

Were Shasta and Mazama active simultaneously?

Last eruption of Shasta may be only 200 yrs old

D. Modoc Indians - southern Oregon & northern California

Chief of sky spirits found it too cold in Above World so he drilled a hole in sky with rotating stone and pushed snow and ice to form a mound. He stepped through and formed trees, rivers, animals, fish and birds.

Brought his family to dwell in mountain and sparks and smoke from their hearth fire flew out the hole in the top of the lodge.

Throw a log on fire, sparks higher and earth trembled.

He put out fire and went back to live in sky.

Describes an active volcano.

E. Nisqually legend:

Mt Rainier moved to east side of Puget Sound to escape crowding of fast growing mountains on (.,ic Peninsula.

She bacame a monster, sucked in all creatures that approached to close.

Changer came in shape of Fox and defied her to swallow him. He was tied to another mountain.

Rainier sucked in vain, burst a blood vessel and expired.

No recent lava flows but a mud flow once poured 45 miles down the White River to lowlands west of Tacoma and spread into a lobe 20 miles long, 3-10 miles wide. Wood in this is age dated at ~5,000 yrs b.p.

F. Note these examples have related primitive man's interpretation of something that was not understood. Also this relates Earth Science to early man and mythology.

II. Definition - activity of molten rock whether intrusive or extrusive in the crustal region of the earth.

III *Volcano* - conical shaped hill or mountain formed around an opening (vent) in the earth's surface through which hot rock fragments, gases, and lava are ejected..

A. Types:

1. *Cinder cones* - steep sided, gases common, composed of angular fragments ejected in mild to violent explosions; sides slope 25° - 30°. Form in rift and subduction zones. Ex. Paricutin - 200 miles west of Mexico City; started in

CLASSIFICATION OF VOLCANOES

Character of Eruption	Volume of Pyroclastics & Gases	Lava Flows	Lava Fluidity	Volcano Form	Example
Explosive -- sudden, violent and multiple explosions	abundant hot gases, especially water; nuées ardentes; blocks, bombs, lapilli, ash, pumice (breccia, tuff)	minor to moderate amount of lava - obsidian or rhyolite	thick, pasty	conical incl. 25°-30° - - - - - - - - - - - caldera	Krakatoa Pelee Mazama
Intermediate -- less violent; alternately explosive & effusive; composite cone	ash, cinders, bombs; nuées ardentes are uncommon	principally andesite; some basalt and rhyolite	less thick	composite or strato-cone incl. 10°-25° - - - - - - - - - - - seldom a caldera - just a crater	Vesuvius Mt. Rainier Mt. Hood
Quiet -- relatively little explosive activity	very little pyroclastics and gas	abundant basalt flows	thin, very fluid	shield volcanoes; incl. <10°, broad - - - - - - - - - - - craters & fissures	Hawaii
Quiet, fissure eruptions	no pyroclastics	tremendous volume of basalt of uniform composition	thin, very fluid	no cone; horizontal flows; great thickness; plateaus - - - - - - - - - - - fissure-fed; no calderas or craters	Central Washington Deccan, India Argentina Iceland Ethiopia

1943 in a corn field; 1400' high one year later, active until 1951.

2. *Shield or Lava cones* - very flat, sides slope at 2° - 10°, formed by repeated lava flows, calm eruptions. of basalt Form over hot spots.

   Ex. Mauna Loa - 30,000' high, mostly under water

3. *Composite or Strato cones* - formed by alternating lava flows and explosive eruptions; sides slope 10° - 25°, andesite or rhyolite. Form in subduction zones.

   Ex. Mt. St. Helens, Rainier, Vesuvius

4. *Fissure Eruptions* - lava flows from a linear opening, which may be tens of kilometers in length

   Ex. Lava flows on columbia Plateau

B. Features:

1. *Vent* - opening in earth's crust through which material is poured or blown onto surface, passes through the throat.
   a. *Crater* - circular vent at summit of volcanic cone
   b. *Fissure* - linear vent, few meters to tens of kilometers in length, may be quite narrow, a very few meters
2. *Caldera* - a large pit resulting from an explosion or collapse of the central part of a cone; miles in diameter

   Ex. Crater Lake Oregon, 3 miles diameter, 3,000' walls
3. *Volcanic plug* or neck - solidified magma in throat
4. *Spine* or Needle - exposed plug

C. Activity classificaiton:

1. Active
2. Dormant

3. Extinct

D. Products of vulcanism:

1. Gases
   a. Steam   b. CO_2 c. Nitrogen
   d. Sulfur   e. H_2S f. Oxygen
   g. Carbon monoxide   h. Sulfur dioxide

2. *Fiery Cloud* - Nuées ardentés - composed of gases, quite lethel
   Ex. Mt Pelee, Martinique Island, West Indies; town of St. Pierre wiped out in 1902, 25,000 to 40,000 lives lost, 2 survivors.

3. Debris
   a. *Pyroclasts* - fragments ejected from a volcano
      1, *Ash* - < 2 mm
      2, *Lapilli* - 2 - 64 mm
      3, *Bombs* - rounded fragments >64 mm
      4, *Blocks* - angular fragments > 64 mm
   b. *Tephra* - unconsolidated deposits of pyroclasts.

4. Lavas
   a. Acidic - siliceous
   b. Basic - ferro-magnesians
   c. Pillow lavas - crystallized under water
   d. Pahoehoe - ropey lava, smooth upper surface
   e. Aa - blocky lava, angular
   f. Textures
      1, Glassy - ex. obsidian, crystallizes very quick
      2, Glassy with holes - ex. pumice; gas bubbles

3, Non-glassy with holes - ex. scoria; gas bubbles

4, Amygdaloidal - non-glassy with holes filled secondarily

E. Distribution: (approximately 475 active in world)

1. Circle of fire - ring around the Pacific Ocean; caused by subduction along tectonic plates.
2. Cross - Mid-Atlantic Ridge , Mediterranean to West Indies Caused by upwelling or plate collision: i.e. plate tectonics.

F. Causes - plate tectonics, to be discussed in a later section

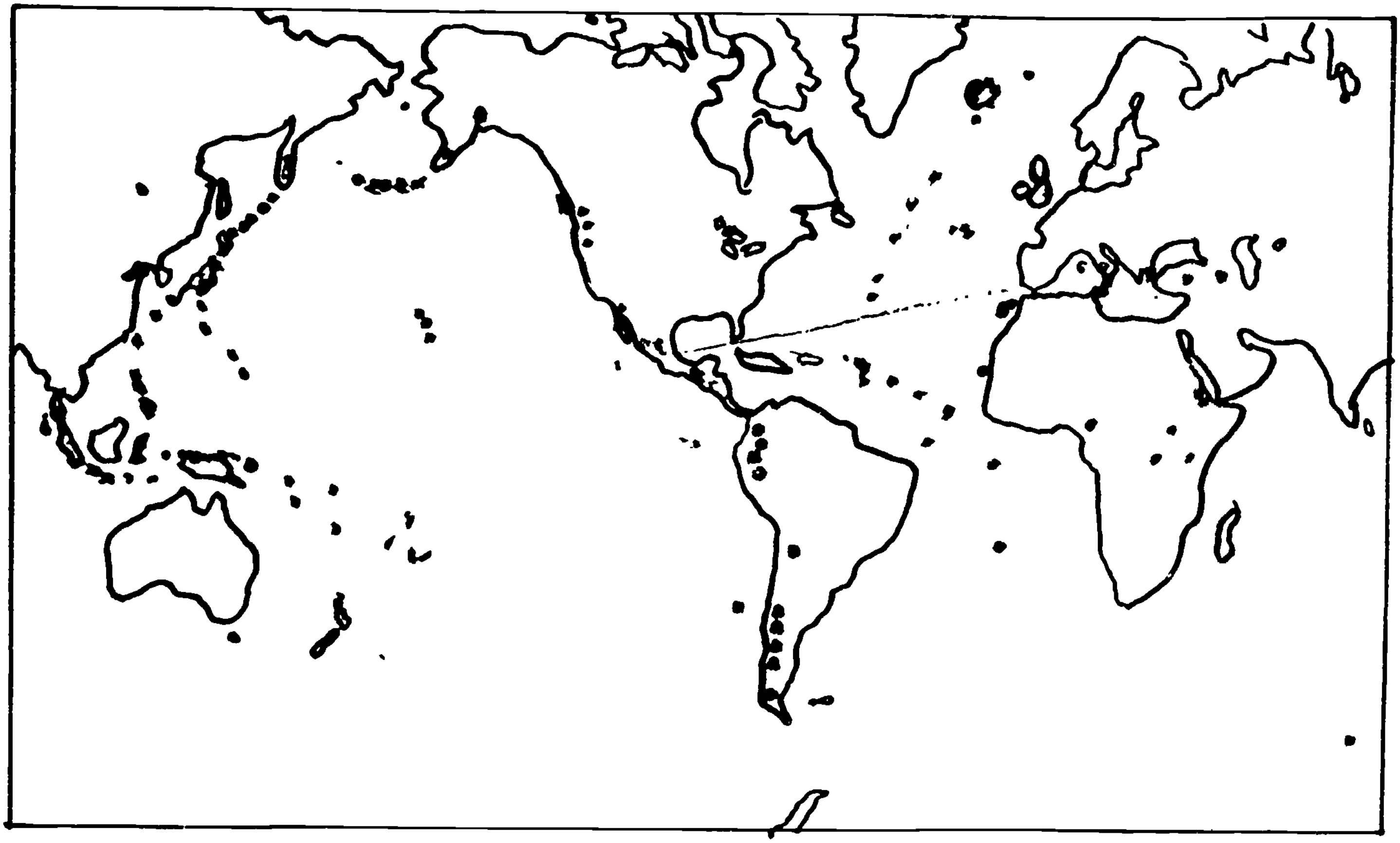
- heat from the molten outer core of the earth

G. Economic uses:

1. Steam for generation of electricity or heat
2. Fertile soil
3. Mineral porducts - $NaCO_3$, NH_3CO_3

H. Hazzards:

1. Earthquakes - to be discussed later
2. Lava flows - small ones may be diverted, otherwise get out of the way
3. Ash falls- small ones may be an inconvenience and ruin certain crops; large ones can be devastating
   Mt. St. Helens or Mazama as an example
4. Mudflows - get out of the way
   Fossil example at Mt. Rainier
   Modern example in the Andes
5. Global temperature - cooling effect from volcanic ash in the atmosphere, Krakatoa as an example



Active Volcanoes of the World

Comp. / Text	Felsic or Acidic K spar to 50% Plag 0 - 10% Qtz to 40% Fe, Mg to 30%	Mixed Plag > K spar Qtz 0 to 10% Fe, Mg to 40%	Mafic or Basic Plag = Fe, Mg approx.	Ultramafic Fe, Mg only
Phaneritic, porphy.	Granite " Porphy.	Diorite " Porph	Gabbro " Porph.	Peridotite Dunite
Aphanitic porphy	Rhyolite " Porphy	Andesite " Porph	Basalt " Porph	—
Glassy	Obsidian		Trachylite	
Vessicular	Pumice		Scoria	
Pyroclastic	Tuff (particles <2mm)			
	Lapilli Tuff (part. 2-64mm)			
	Agglomerate (rdd. part. >64mm)			
	Volcanic Breccia (ang. part. >64mm)			

Could these cause the major extinctions in the geologic past?

SEDIMENTARY ROCKS

I. Introduction

A. Detrital Rocks Formation

1. Weathering - produces fragments of previously existing rocks - sediments
2. Transportation - movement of sediments from one location to another
3. Deposition - the accumulation and settling out of sediments in a temporary or permanent resting place
4. Compaction - decreasing the void spaces between the sediment particles; may involve rotation and alignment of some particles; lithification
5. Cementation - lithification by infilling the void spaces with a cement.
6. Detrital Sedimentary Rock - end product of the above processes!

   Ex. Sandstone, conglomerate, etc.

B. Chemical Rock Formation

1. Solution of pre-existing rocks
2. Transportation of materials in solution to a lake or ocean
3. Evaporation -

   Sea water - 1,000 m yields 15 m of chemical sediments

   Sequence - $CaCO_3$ - $CaSO_4$ (75% evaporation), NaCl (90% evaporation), bittern salts
4. Decrease in CO_2 in solution - travertine and tufa, $CaCO_3$

   Carbonate compensation depth - ~4,000 m, increase in

CO_2, water becomes slightly acidic, holds $CaCO_3$ in solution.

5. Chemical Sedimentary Rocks - product of these processes!

   Ex. - Salt, Gypsum, Limestone

C. Biochemical Rocks formation

1. Solution of pre-existing rocks
2. Precipitation of materials in solution by organisms to build shells, bones, etc.
3. Accumulation of organic matierial in one of several ways, i.e., current action, organic buildup of a reef, wind, etc.
4. Biochemical Rocks - products of above processes!

   Ex. Limestone - shell accumulations with carbonate mud

   Coquina - shell accumulation

   Coal - plant accumulation; Peat - Lignite - Bituminous - Anthracite - Graphite

II. Importance -

A. Cover - 75% of earth's surface covered by sedimentary rocks

   65% mud rocks

   20-25% sandstones

   10-15% carbonates (limestone and dolostone)

   1% conglomerates and breccias

B. Thickness - quite variable, veneer to >15,000 m

C. Economics - exhaustable

   Fossil fuels -oil and gas, coal

   Building materials - stone, limestone for cement, clays for ceramics, gypsum for plasterboard, etc.

   Mineral products - silica for glass, iron, salts, etc

III. Sites of formation

A. Non-marine:

Valleys and rivers flood plain

Lakes

Deserts

Plateaus

Glaciers

B. Marine

Near shore - continental shelf

Off shore - continental slope

Abyssal areas

IV. Laws of sedimentary sequences

A. Law of original horizontality - Steno 1669; primary dip

B. Law of superposition- Hutton, late 1700s; first recognized but not stated by Steno

V. Characteristics of sedimentary rocks:

A. Textural features:

1. Grain size:

Boulders	>256 mm
Cobbles	64-256 mm
Pebbles	2-64 mm
Sand	0.0625-2 mm
Silt	0.002 - 0.0625 mm
Clay	<0.002 mm

2. Roundness

Angular - subangular - subrounded - well rounded

FIG. 176

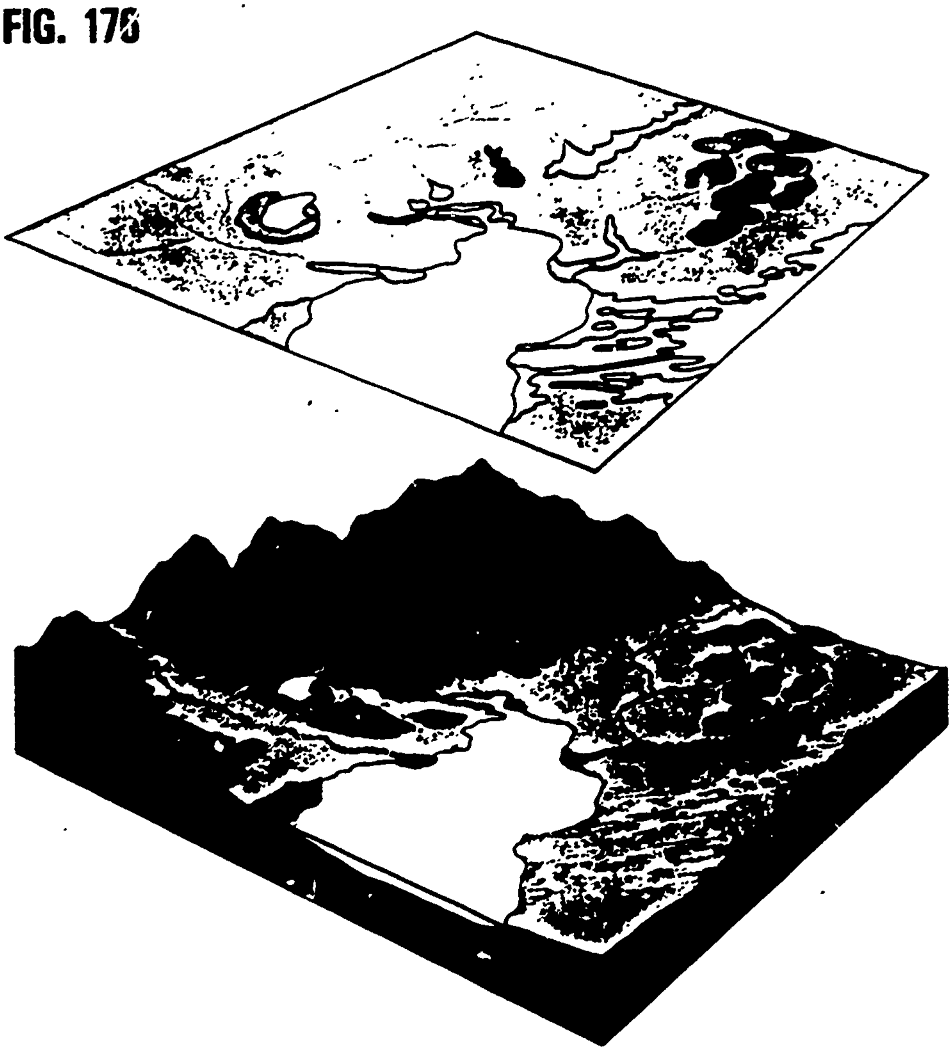


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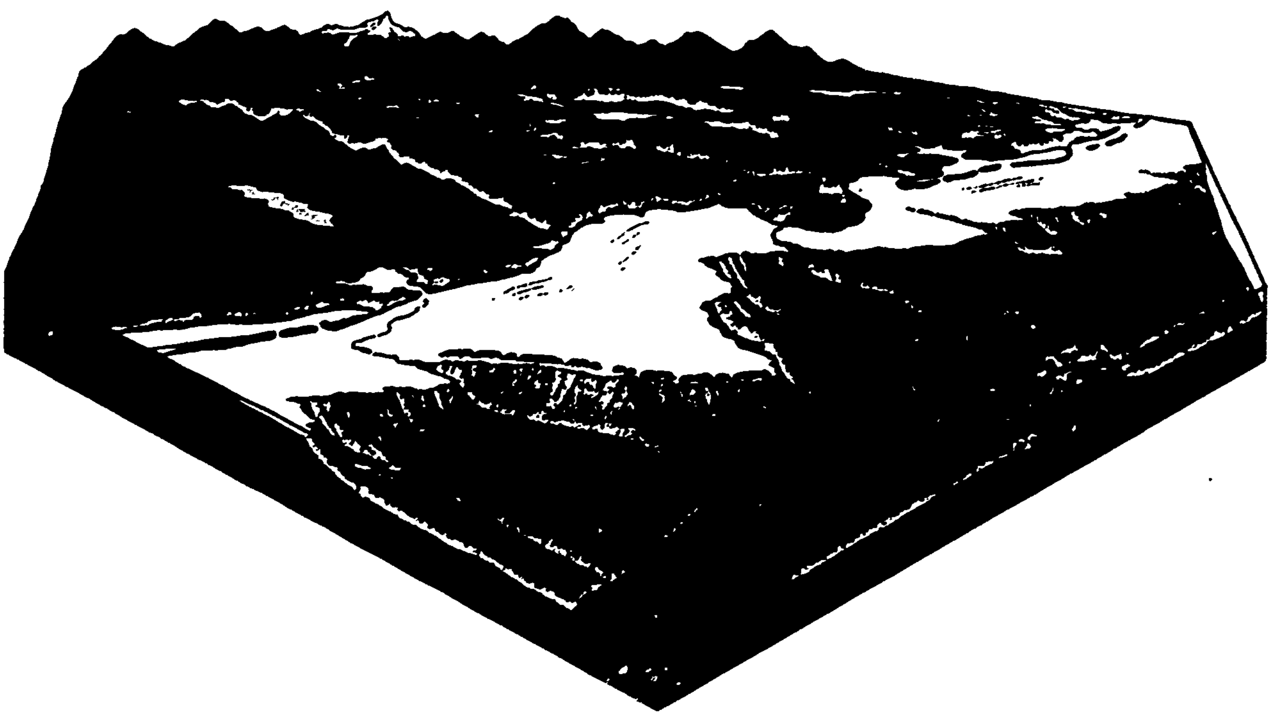
FIG. 98



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3. Sorting

    Poor - moderate - well

B. Factors affecting textural features

1. Origin and nature of parent rock

    ex. Granite vs basalt

    ex. Sedimentary vs metamorphic terranes

2. Physiography of land area

    High - coarser

    Low - finer

3. Amount and type of transportation

    Water vs wind

    High mountain stream vs low flood plain

4. Climate

    Moist - more material

    Dry - less material

    Seasonal

5. Energy

    Strong - coarser

    weak - finer

C. Porosity - void spaces

    Intergranular

    Vuggy

D. Compaction - loss of voids

    Loss of fluids

    Reorientation or alignment of grains

E. Cementation -

1. Precipitated minerals

Quartz, Calcite, Dolomite, etc ($CaSO_4$, Fe)

2. Matrix minerals

Clay

F. Stratification - bedding, laying down in layers

1. Bedding plane
2. Cross-bedding

Water vs wind

Directions of deposition, one or more

3. Laminae - very thin
4. Nature of surfaces -

Regular vs wavy

Irregular

Planar

G. Special features

Mud cracks

Fossils

Hard parts

Tracks and trails

Ripple marks - current and swash

Graded beds

Cut and fill

Rain drop impressions

Slumps

Flame structures

Sole markings

Nodules - different composiition than surrounding rock

Concretions - concentration of cementing material

Geode- hollow center, may be crystal lined

Etc.

VI. Classification of Sedimentary Rocks - see overhead

A. Detrital - based on grain size first and composition second;

- also use angularity in very coarse rocks

B. Chemical - based on mineral composition

C. Biochemical -based on textural features (ratio of mud to fossils) and composition.

D. Problematic -

Marl

Bauxite

Origin	Texture		Rock Name
Detrital	Grain Size	>2.0 mm	Conglomerate (rdd clasts) Breccia (ang clasts)
		0.0625 – 2 mm	Sandstone Arkose (>10% feld) Graywacke (>25% rk frags, clay mtrx) Orthoquartzite (~ pure qtz)
		0.002–0.0625 mm	Siltstone
		<0.002 mm	Claystone
Chemical	Mineral Comp	Halite	Rock Salt
		Gypsum	Rock Gypsum
		Microxln Qtz	Chert
Biochemical	Textural Features	<10% fossils	Limestone
		<90% Megafos.	Fossiliferous Ls
		>90% Megafos	Coquina
		>90% Micofos	Chalk
		Dolomite	Dolostone
		Plant Debris	Coal

Sedimentary Rock Classification

METAMORPHIC ROCKS

I. Metamorphism -Greek, from meta (beyond, over, change) and
   morpho (form); hence - change in form
   Make up 15% of rocks in earth's crust.
   Relate back to rock cycle
   A. Formation of new minerals - marl goes to garnet and wollastonite
   B. Readjustment or rearrangement of existing minerals - limestone to marble, small crystals to large crystals of calcite
   C. Crystalline rocks derived from sedimentary rocks - shale to slate

II. Agents of metamorphism
   A. Heat - probably the most important
      1. Degrees reached will determine the minerals formed
         a. Chlorite - complex silicate, low grade 150-250°C
         b. Epidote - Ca,Al,Fe silicate
         c. Garnet - complex silicate, middle grade 250-450°C
            Biotite in or adjacent to this grade
         d. Staurolite - Fe,Al silicate, (cross crystalls)
         e. Sillimanite -Al_2SiO_5, high grade 450-700°C
            (also Kyanite and Andalusite found here) or 800°C
      2. Source of heat
         a. Geothermal gradient - increases with depth
         b. Given off from a pluton
         c. Friction, faulting
   B. Pressure - often works in conjunction with heat
      1. Increases wtih depth ~60,000 psi at 40,000' depth

2. Source

a. Faulting - stress

b. Overburden - increases with depth

C. Chemical fluids - includes aquaeous gases and hydrothermal fluids; may be aided by fluids in pore spaces of rocks

Source: - Hydrothermal fluids given off of a crystallizing magma

III. Metamorphic Facies - an assemblage of minerals that reached equilibrium during metamorphism under a specific set of conditions.

A. Amphibolite facies - high grade, 450-800°C

1. Original rock shale - common minerals sillimanite, kyanite, and andalusite

2. Original rock basalt - common minerals plagioclase and hornblende

B. Epidote facies - middle grade

1. Original rock shale - common mineral garnet

2. Original rock basalt - common minerals plagioclase and hornblende

C. Greenschist facies - low grade

1. Original rock shale - common minerals chlorite, epidote and biotite

2. Original rock basalt - common minerals plagioclase, epidote and chlorite

IV. Types of metamorphism

A. Dynamic - formed from pressure

Rocks highly brecciated, fractured

B. Thermal or contact - heat and chemical fluids

Rocks recrystallized, coarser grained

C. Regional - heat and pressure with or without chemical fluids

Rocks recrystallized, some solution, precipitation, foliation, neocrystallization; coarser grained

D. Hydrothermal - chemical fluids mainly

Rocks formed by solution and precipitation, extensive changes in composition and mineralogy.

V. Characteristic features of metamorphic rocks

A. Foliation - leaved or leafy, Latin

1. Slaty - planes of parallel rock cleavage, quite lengthy, can't see minerals with naked eye
2. Phyllitic - flakes of rock cleavage, thicker than slaty, minerals weakly visible with naked eye.
3. Schistose - flakes of rock cleavage, thicker than phyllitic, minerals visible to naked eye
4. Gneissic - not a true foliation at times (banded), but when a foliation, coarser than schistose

B. Banding - produced by alternating layered composition; has flowed from pressure

C. Nonfoliated or crystalline - formed by recrystallization or formation of new minerals

VI. Types of metamorphic rocks - see overhead

Foliation	Texture or Composition	Rock Name
Non-foliated	Calcite or Dolomite	Marble
	Grains >2mm	Metaconglomerate
	Qtz grns 0.0627-2.0mm	Metaquartzite
	Xls micoscopic, comp. var.	Hornfels
Foliated	Slaty cleavage	Slate
"	Phyllitic "	Phyllite
	Schistose	Schist
	Gneissic	Gneiss

Classification of Metamorphic Rocks

EXAMPLES OF EVENTS IN TIME

I. Catastrophic events

A. Sodom and Gomorrah - see overhead diagram

Genesis 19, v. 28: "And he looked toward Sodom and Gomorah and toward all the land of the plain and beheld the smoke of the country went up as smoke of a furnace"

Biblical scholars believe that Sodom & Gomorrah are inundated under the south end of the Dead Sea. Two other towns involved Admah and Zeboim located in the Vale of Siddim, on the south edge of the Dead Sea, approximately 2,000 B. C.

Jordan Valley - Long straight-sided graben

- Jordanian plateau on east; plateau on west
- Numerous hot sulfur springs
- Earthquakes are common, an active area today
- Bitumen (heavy crude tars) seeps, sulfurous odors

Dead Sea - South end is tilting, as measured in recent years; submerged islands becoming lower elevations.

- Submerged forest, 20 m below surface
- North end several hundred m deep

Postulations:

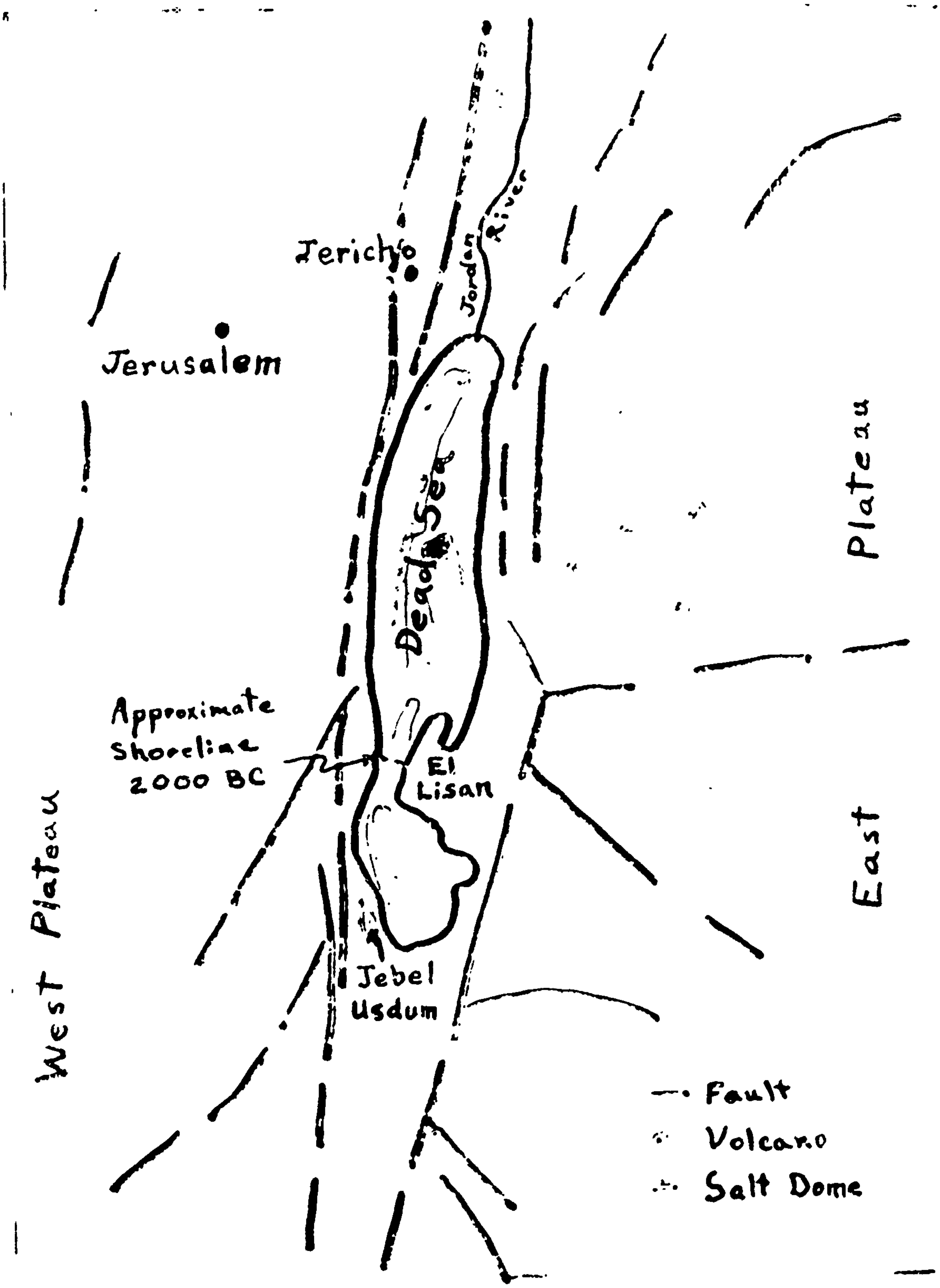
A large earthquake occurred, possibly during a thunder storm (thus appears to come from heaven)

Area was down dropped, inundating south end of Dead Sea

Fires started around oil seeps or in homes (most likely) where bitumen was used in wall construction and for fires.

The salt dome (Jebel Usdum) represents Lot's wife

The bible records the first described earthquake


Jericho
Jordan River
Jerusalem
Dead Sea
East Plateau
West Plateau
Approximate
Shoreline
2000 BC
El
Lisan
Jebel
Usdum
Fault
Volcano
Salt Dome

B. Santorini or Thira - volcanic caldera (ring of islands) between Greese and Crete, 400 m deep; eruptions have occurred since 200 B.C., 1707 one famous

Sediments in eastern Mediterranean contain 2 buried ash layers, both of which thicken towards Santorini: dated by C^{14} method

Younger ash 1400 B.C. - 10 m, thins to SE

Older ash 25,000 y.b.p. - 10 m, thins to SE

Note rate of accumulation:

20 m in 21,600 years or 0.0009 mm/yr average

Crete: eastern half covered by ash fall of 1400 B. C.; archeological records show dispersal of population to small western villages about 1400 B. C. and loss of higher level of civilization.

Postulations:

1. Tsunamies probably occurred which wiped out great Cretan coastal cites such as Knossus (survivors moved west because they could not till the ash covered land)
2. Tsunamies were the Greeks "mythical" 9 day Deucalion flood
3. Ash cloud caused the sun to become dark like the moon and tsunamies caused the 9 days or flooding recorded in the 18th Dynasty (1400 B. C.). This was also the reason that they dispaired the cesation of Creton cedar and oils used in the mummification process
4. Santorini is the lost continent of Atlantis

C. Krakatoa - volcanic island, 2,600' above sea level, located in the Sundra Straits, between Java and Sumatra (Malayan archipeligo)

Most violent explosive eruption in recorded history, 1883.,

26 August --British ship Charles Bal sailing in the area recorded that the mountain was consumed in a ball of smoke, associated with several large explosions, bits of ash falling on deck, St. Elmo's fire in the riggings.

27 August-- 4 explosions, 5:30, 6:44, 10:02 (biggest) and 10:52. Heard at Alice Springs (central Aurtralia) Manila and Rodriguez (SW Indian Ocean)..

Picked up by barometers throughout the world.

Shock wave went around the world 7 times

Ash cloud rose an estimated 50 miles, going into the jet stream and around the world in 13 days.

5 cubic miles of material blown from sea floor, leaving a hole 300 m deep, and three small islets along rim

Associated tsunamies killed an estimated 35,000 people in 300 coastal villages. Tsunamie 120' maximum height.

D. Mount Pelee - active volcano 5 miles north of St. Pierre (settled in 1635, 28,000 population in 1902) on the Island of Martinique, French West Indies, Caribbean area.

23 April, 1902 - began a new series of activity

4 May - hot steam, mud and lava broke through the crater wall, killing 4, arousing the populace who moved into St. Pierre from farms, etc.

8 May, 7:45 a.m. - top of mountain disappeared in a flash and a

fiery cloud rolled down the mountain hitting St. Pierre. Killed an estimatd 30,000 people. Temperatue of cloud >650-700°C as glass melted but <1058°C as copper did not melt.

18 ships in harbor, 1 escaped.

The Roraima was coming into port, 25 of the 68 crew members survived, with the ship set afire and the masts blown off.

2 survivors in town, one in the cellar dungeons, the other an exception.

Spire commenced to rise from the top of Mt. Pelee and continued up to 1,000' above its base, gradually disintegated, gone by mid 1903.

II. Rates of Sedimentation

A. Introduction - U. S. rivers carried an estimated 1 billion tons of sediment to the oceans per year prior to the construction of dams throughout so much of the U. S.

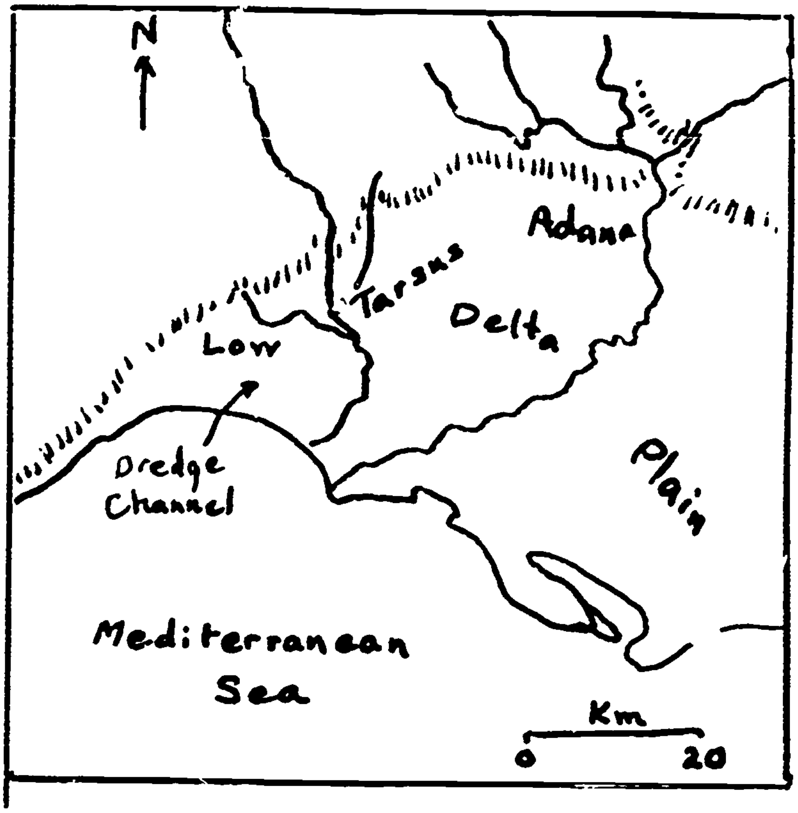
Man has increased the rate of erosion ~ 3 times

B. Eastern Mediterranean: - see overhead

Tarsus - city of Paul the Apostle; located only a short dredge channel from the sea in biblical times. Today it is 12 km inland, a farming community.

Miletus - principal port of Ionian Confederacy, on a promotory in Bufa Gulf, 200,000 + inhabitants. Today , a small town, 8 km inland.

Ephesus - vied with Smyrna and Pergamum in early days of Christianity for first city of Asia. As the swampy conditions increased, malaria became a real killer and city abandoned. Today 10 km inland.


N
Adana
Tarsus
Delta
Low
Dredge
Channel
Plain
Mediterranean
Sea
Km
0
20


Menderes R.
N
Selcuk
Ephesus
Aegean
Samos
Priene
Sea
Mt Latmos
Heraclea
Km
0
20
Miletus

Thus 8 to 12 km (lateral distance) of infilling in ~2,000 yrs

0.004 km (4 m) to 0.006 km (6 m) per year infilling.

C. Fertile Cresent - Mesopotamian region - see overhead

This area was the breadbasket of the the area (world) 8,000 years ago. Temperature was probably still modified by retreating glacial conditions in Europe.

Marine transgression 4,000 to 5,000 B. C. Was this caused by uplift of the Zagros Mountains and downwarp of the adjacent plain?

Since 3,000 B. C. the Tigrus-Euphrates delta has advanced 175 km (100 miles); this is 35 m per year.

Today it advances 25 m per year.

Was the transgression Noah's Flood??

D. Mississippi River - carries 700 million tons of sediments per year.

- 0.34 cu. km delta growth per year.

III. Erosion Rates -

A. North America - being lowered at an average rate of 0.3 m or 1' per 10,000 yrs.

Therefore 10 to 20 million years to reduce all of North America to sea level.

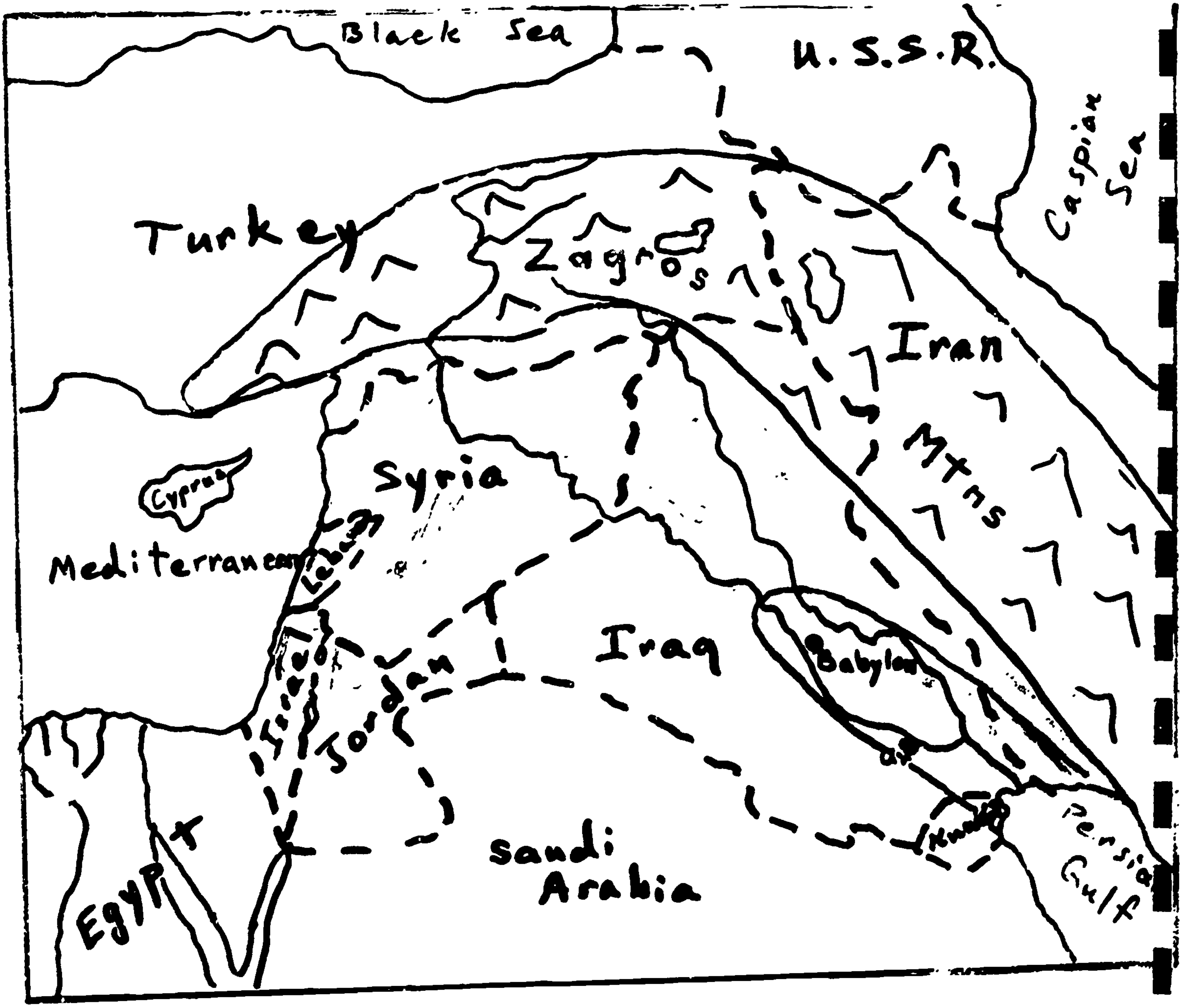
B. Grand Canyon - 2,000 m deep, cut in 3 m.y. to 10 m. y.

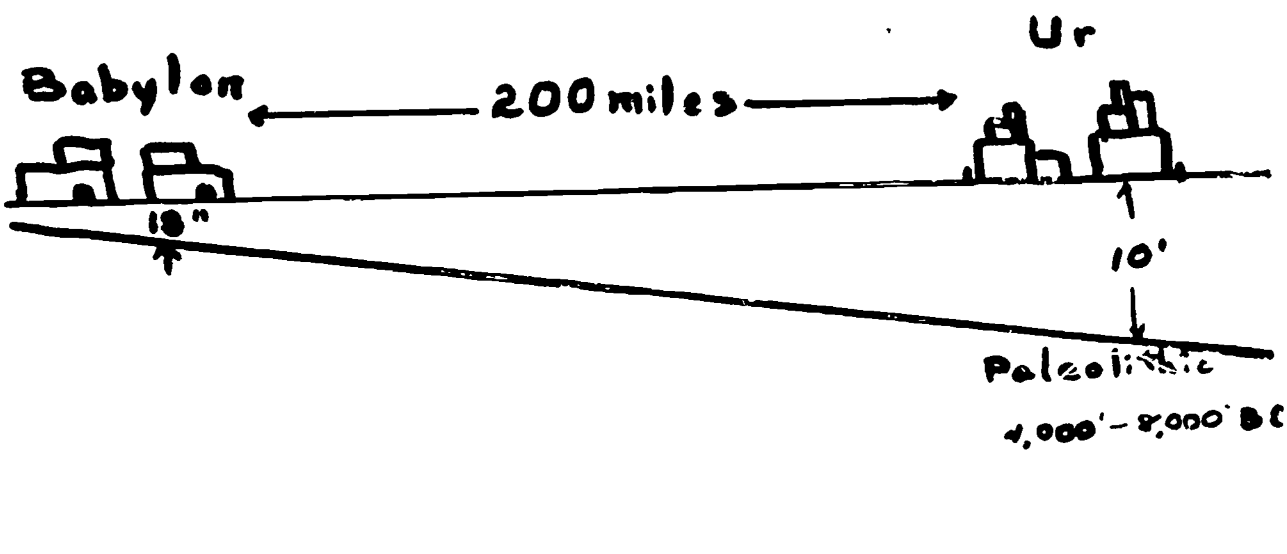
This is an erosion rate of 0.000666 to 0.0002 m per yr.

2/3 to 1/5 of a mm per yr.

C. Roman road - Via Prenestina (Rome to Palestrina) built ~200 B. C., flush with hillside. Roadbed of basalt blocks; hillside of lithified volcanic ash.

Today the road is a low mound 1 m above hill surface; 5 mm/yr


Black Sea
U.S.S.R.
Caspian Sea
Turkey
Zagros
Iran
Mtns
Cyprus
Syria
Mediterranean
Iraq
Jordan
Babylon
Ur
Persian Gulf
Saudi Arabia
Egypt


Ur
Babylon
200 miles
18"
10'

IV. Uplift: - tectonics, with earthquakes

A. Southern California - 200 m in 1,000,000 yrs , 0.3 mm/yr to

San Gabriel Mtns - 4' uplift in earthquake of Feb. 1971

Some data 4,000 m (12,000') in 1.5 million years

= 1 m/375 yrs, or 2.7 mm/yr

Other data 1 m/133 yrs = 7.5 mm/yr

B. Lateral movement along San Andreas Fault

200 km in 50 million yrs = 1 cm/yr in discontinuous jumps

V. Sea Level Changes:

A. Glacial melt - 100 m in 20,000 yrs = 0.005 m or 5 mm/yr;

Therefore 10,000 yrs to raise 50 m

What if 100 m in 10,000 yrs = 0.0l m or 10 mm/yr

then only 5,000 yrs to raise 50 m.

During last glacial maximum sea level would have been 300' lower than today

Average rise of 100 cm /century from 17,000 to 6,000 B.P.

" " 12-15 cm/centruy from 4,000 to present

Between 1890-1950 sealevel rose 1.2 mm/yr or 70 mm in 60 yrs

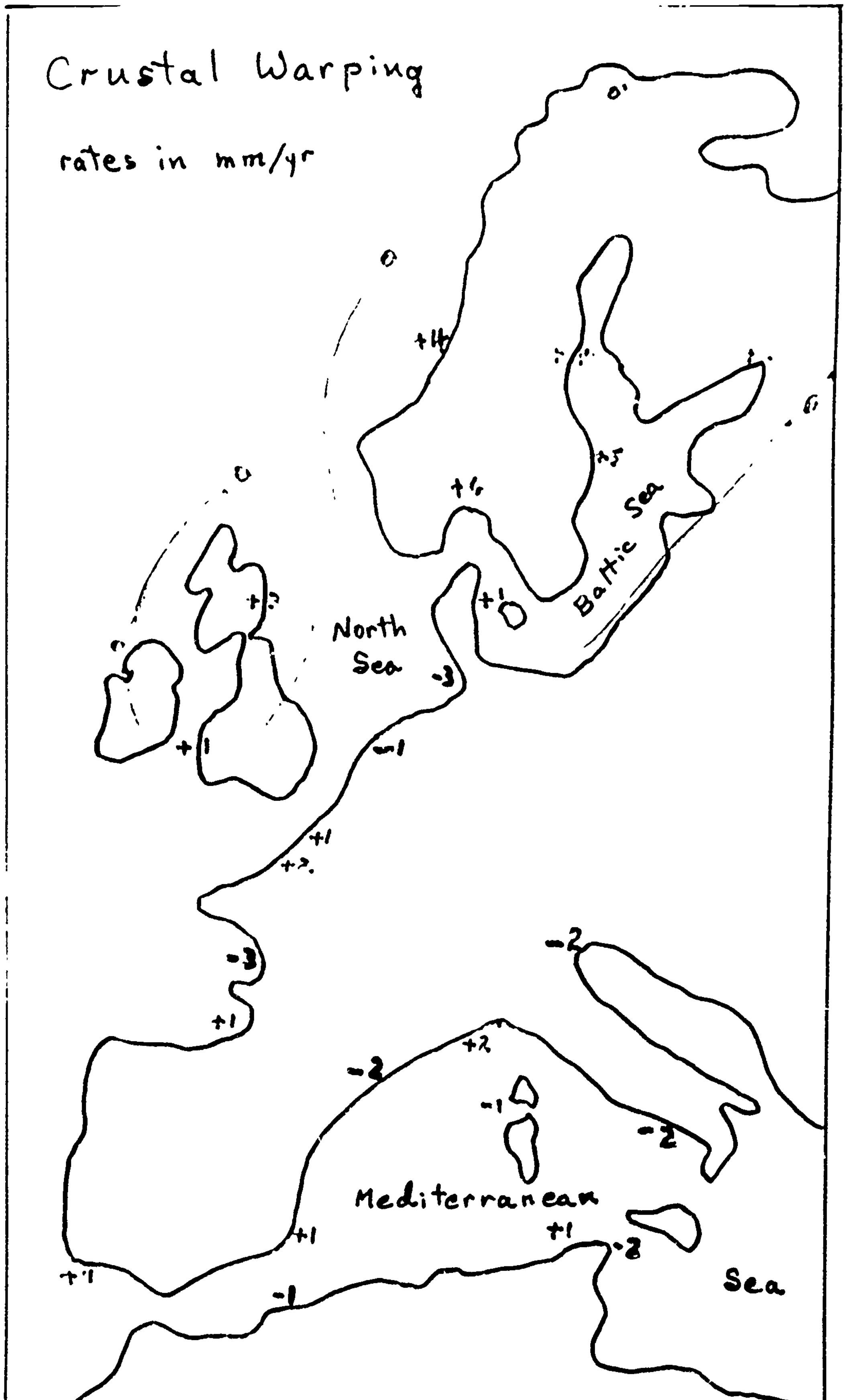
Melt glacial ice and sea level would rise ~50 m

Memphis, Tenn. and Montreal, Canada become sea ports.

Seattle, Portland, Los Angels, Washington D.C., New York, Boston, etc inundated (Most major cities of the world).

B. See overhead for changes in Europe, rates of mm/yr

VI. Floods - every few years to every century or two, frequent to infrequent in human life scale but geologically very frequent.


Crustal Warping
rates in mm/yr
North Sea
Baltic Sea
Mediterranean
Sea
-3
-1
+1
-3
+1
-2
+2
-2
-1
-2
+1
+1
-1

GEOLOGIC TIME

I. Types of time

A. Relative - relationship of events with one another in sequence of occurrence

B. Radiometric - based on radioactivity. Certain elements have a greater number of neutrons in the nucleus which leaves them unstable. The loss of neutrons and other particles to balance them occurs at regular rates which may be used to date the rocks.

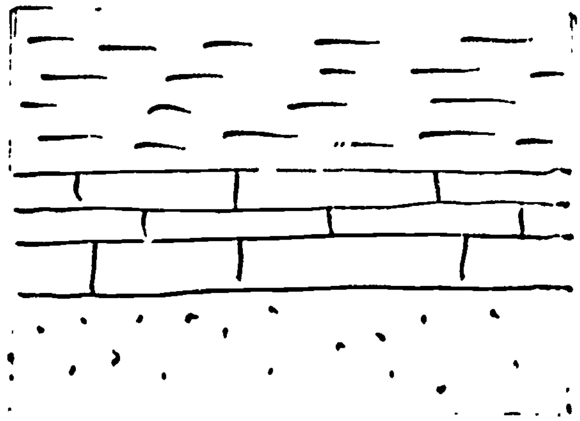
II. Relative time

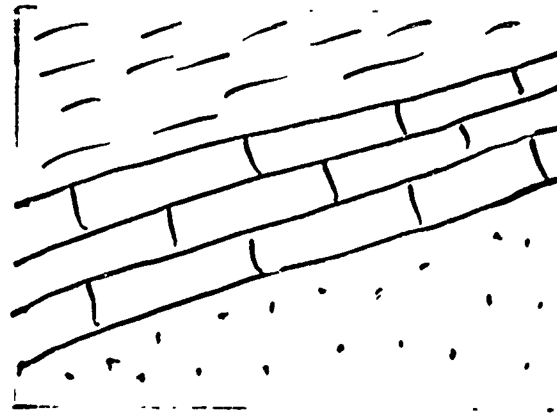
A. Physical evidence

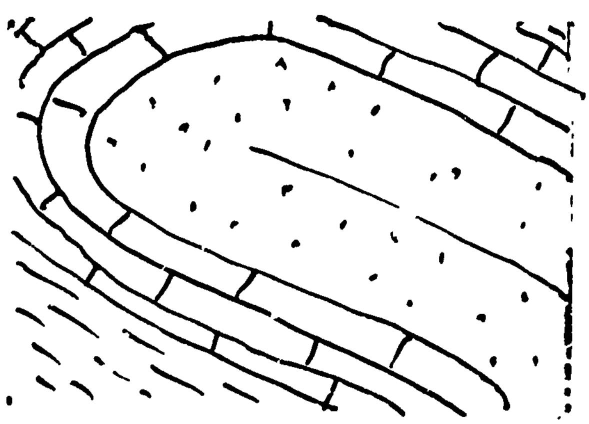
1. Law of original horizontality - lateral continuity
2. Law of superposition - used in layered rocks, youngest on top unless overturned
3. Law of cross-cutting relationships- cut rock is youngest; used on intrusives, faulting and folding
4. Law of inclusions - rock bearing inclusions youngest
5. Unconformities
6. Erosion rates
7. Deposition rates
8. Glacial melt rates
9. Crustal warping rates
10. Movement of plates in plate tectonics

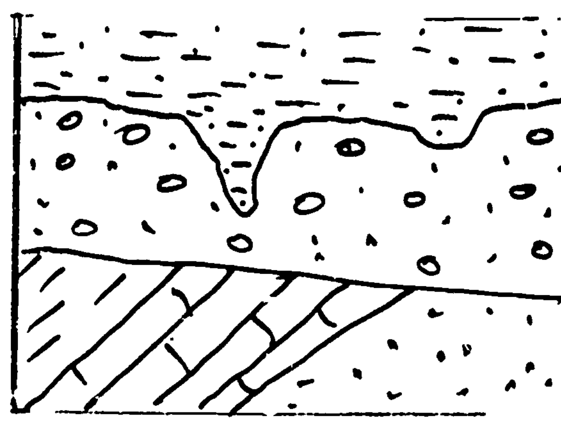
B. Organic evidence

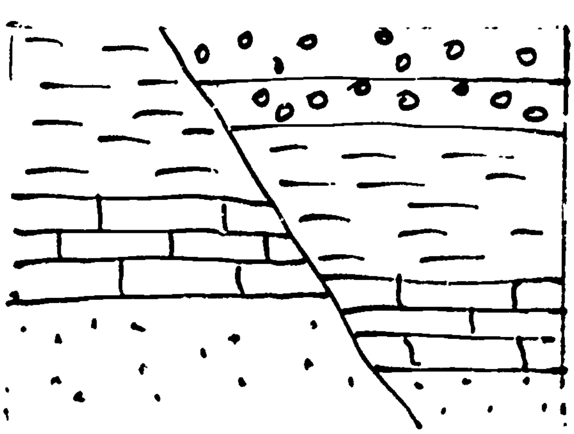
1. Law of faunal assemblages - like assemblages indicate like ages for rocks bearing assemblages
2. Evolution as shown in the fossil record

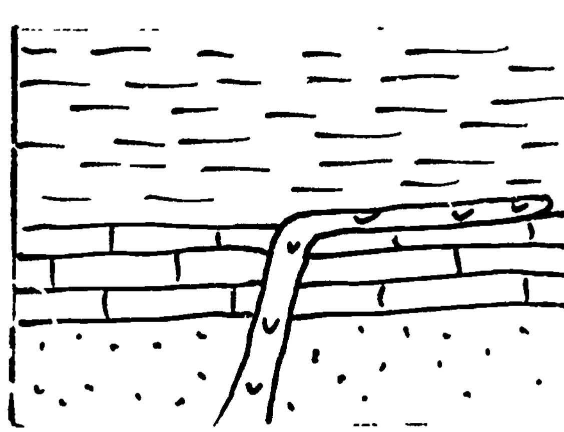












a. Beringer - Germany, lying stones

b. Wm Smith - England, surveying for canals

c. Sir Charles Lyell - England, percentage of living forms

d. Charles Darwin - England, evolution concepts

3. Cautions - reworking of fossils, stratigraphic leaks

C. Time scale - see overhead

III. Radiometric time - measured on a time clock of whatever scale, day, week, year, etc.

A. Radioactivity

1. Atomic number - number of protrons, determines element

2. Mass number - number of protons + neutrons will react as element (number of protrons)

3. Isotope - has excess neutrons to protons, unstable

i.e. U^{238} - 92 protons (Atomic #) + 146 neutrons = mass number 238.

U^{235} - 92 protons (Atomic #) + 143 neutrons = mass number 235

4. Half-life - time for 1/2 of original material to break down into daughter products (more stable) by emmission of alpha and/or beta products. This is a constant rate not affected by heat, pressure or chemical changes

a. Alpha emmission - 2 protons and 2 neutrons, changes atomic and mass number, new element formed

b. Beta emmission - 1 electron lost from a neutron forming a proton, changes atomic number but not mass number; new element formed

B. Radioactive elements - these are trapped in crystals with

[illegible] Time Scale

Era	Period		Epoch
	Neogene	Quaternary	Recent
	Neogene	Quaternary	Pleistocene
	Neogene	Tertiary	Pliocene
	Neogene	Tertiary	Miocene
	Paleogene	Tertiary	Oligocene
	Paleogene	Tertiary	Eocene
	Paleogene	Tertiary	Paleocene
	Cretaceous		
	Jurassic		
	Triassic		
	Permian		
	Carboniferus	Pennsylvanian	
	Carboniferus	Mississippian	
	Devonian		
	Silurian		
	Ordovician		
	Cambrian		
Precambrian			

crystallization

U^{235}	7 alpha and 3 beta emmissions	Pb^{207}	0.713 b.y.
U^{238}	8 alpha and 6 beta emmissions	Pb^{206}	4.51 b.y.
Th^{232}	6 alpha and 4 beta emmissions	Pb^{208}	13.9 b.y.
K^{40}		Ar^{40}	1.3 b. y.
Ru^{87}		St^{87}	47.0 b. y.

C. To calculate age:

$$Age = C \times D/P$$

where : C = decay constant for element dating

D = amount of daughter product

P = amount of parent product

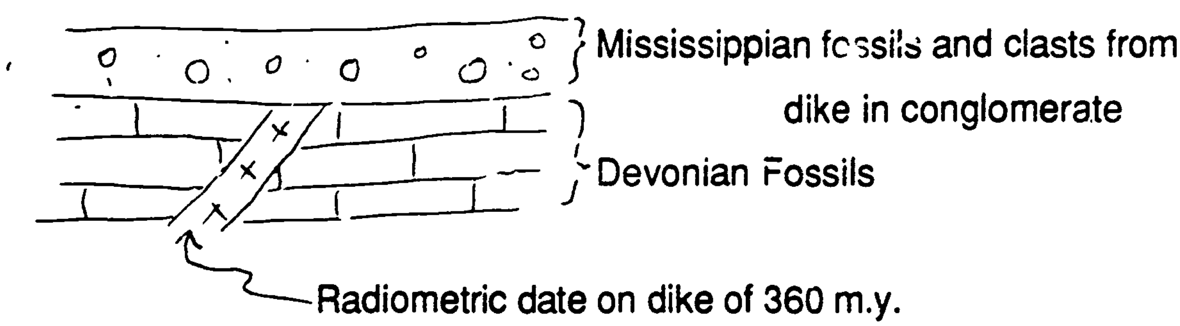
D. Carbon-14 dating

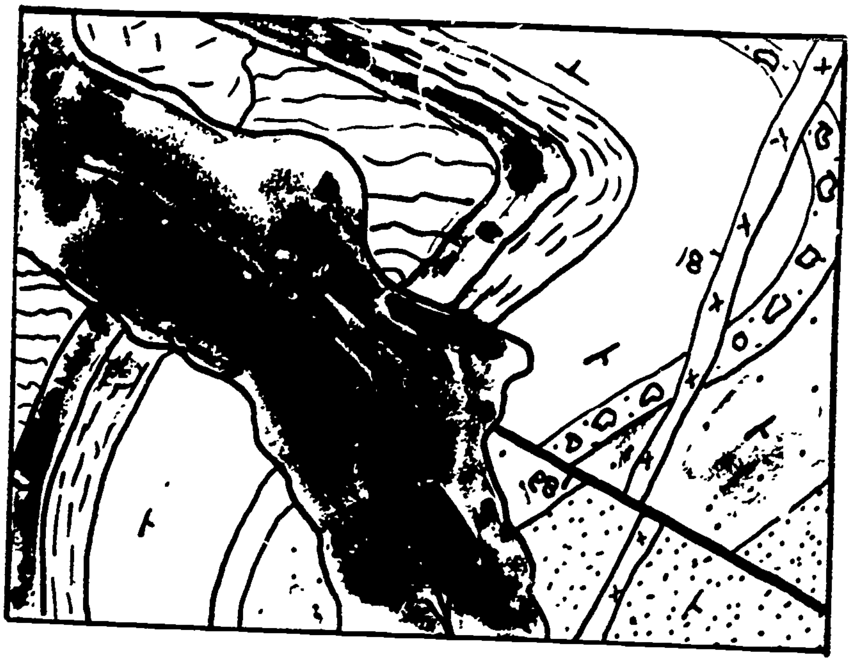
1. Neutron hits nitrogen atom in outer atmosphere, knocking 1 proton from nucleus which forms an atom of C^{14}; rate of formation approximately constant, affeacted by sunspot activity
2. C^{14} reacts with O forming CO_2, circulates to earth's surface;
3. CO_2 taken in during life cycle of organisms and fixed, constant ratio of C^{14} toC^{12} in organism while living
4. Organism dies and no more CO_2 intake; decay of C^{14} begins; half -life of 5,730 years
5. Picks up proton to convert back to Nitrogen
6. Calculate time by comparing amount of C^{14} in fossil and compare to normal ratio in living organisms
7. This method good back to 50 000 years, best up to 25,000 y.

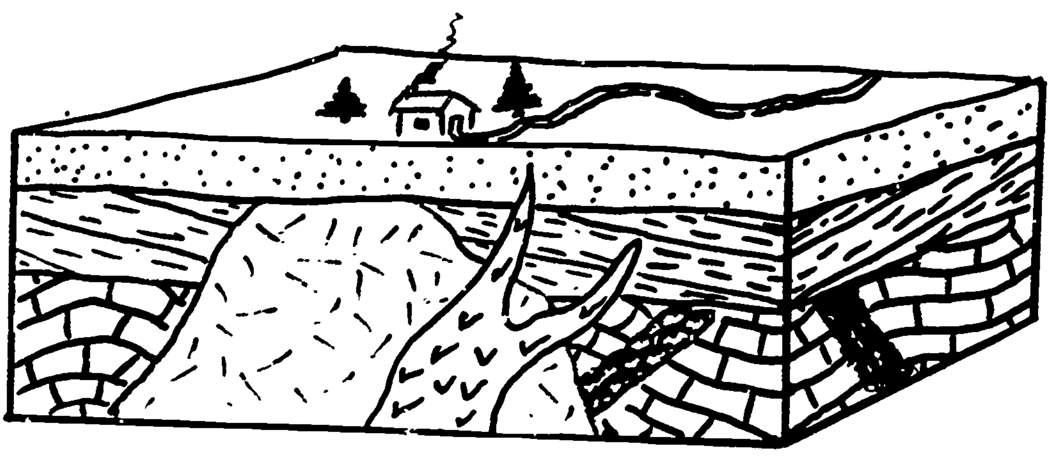
   i.e Wood from Wisconsin, last glacial advance - 11,350 years old.

i.e. Ash with associated artifacts in cave on shore of Great Salt Lake, Utah - 10,000 years old.

Example of use of absolute and relative age dating:







STRUCTURAL GEOLOGY

I. Formation of the Earth - most prevailing current theory

A. Big bang followed by condensation from a gaseous cloud. As the condensation occurrs there is heating from the friction and perhaps some from radiation. Forms a molten mass which begins to cool and crystallize. As crystallization begins magmatic differentiation occurs with heavy elements (Fe, Ni) sinking toward the center and lighter elements (O, Si, etc) rising toward the exterior. Differentiation could also have occurred during condensation.

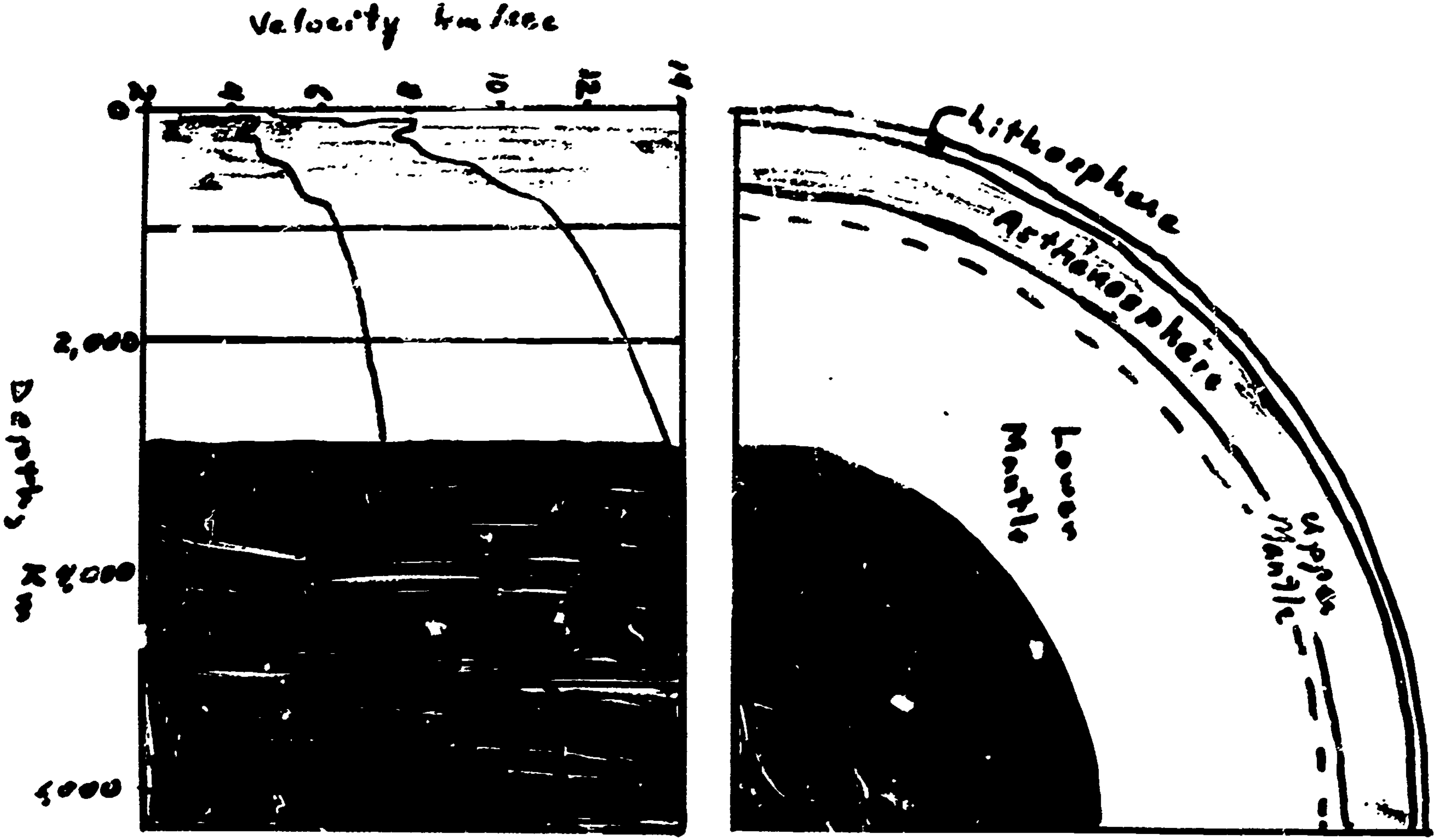
Some people have proposed that there was no melting, it all occurred as a cool process.

B. With either concept ultimately get Earth in cross-section as: (see diagram)

Lithosphere	**Crust**	5-56 km thick, thinner under oceans
	Mohorovicic discontinuity	
Asthenosphere	**Mantle**	2,900 km thick
	Liquid outer core	2,200 km thick
	Solid inner core	1,216 km radius

C. Geophysical data to verify:

1. **Earthquakes** occur when rocks in the earth's crust rupture under stress. This process is called faulting. The point at which it occurs in the crust is called the **focus.** The area on the surface of the earth immediately above the focus is called the **epicenter.** Energy is released when the rupture occurs and it is expressed in three types of


Velocity km/sec
0
2,000
Depth km
4,000
6000
Lithosphere
Asthenosphere
Lower Mantle
Upper Mantle

waves. (see diagrams)

a. **P wave** -Primary or compression waves. Travel the fastest, therefore arrive first after an earthquake occurs. Travels through solids or liquids.

b. **S wave** - Secondary or shear waves. Travel slower, arrive second, vibrate in a sideways manner, thus shear. Travels through solids only.

c. **Surface Waves** - Slowest moving of the three, move like waves on a pond, a ground motion and complex. Forms when P and S waves reach the surface of the earth.

d. See cross-section diagrams to explain movement of waves and how they are used to determine the cross-section of the earth.

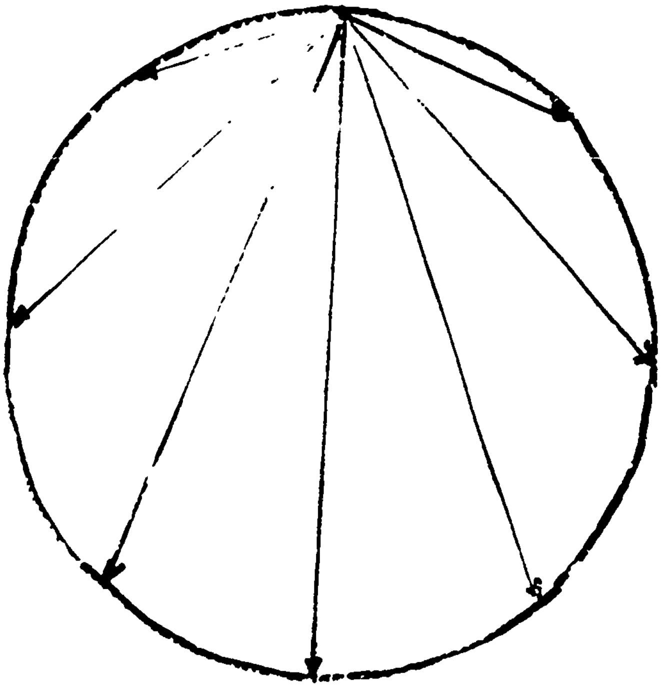
e. Seismographs - show how they work.

f. Location of epicenters - three point

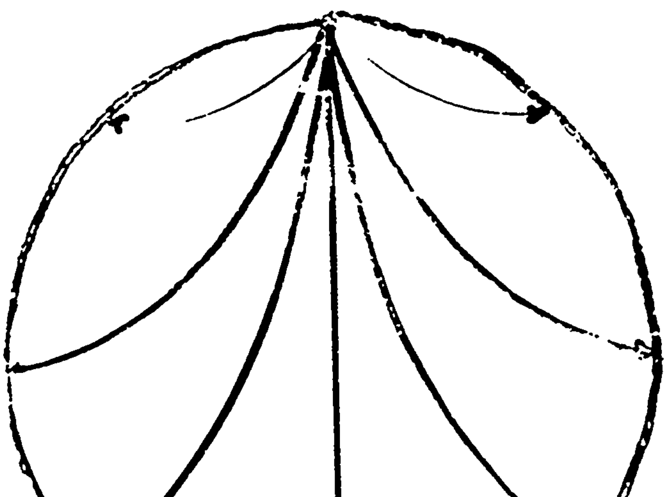
g. Magnitude scale of an earthquake

    1, Richter magnitude scale - 10 units

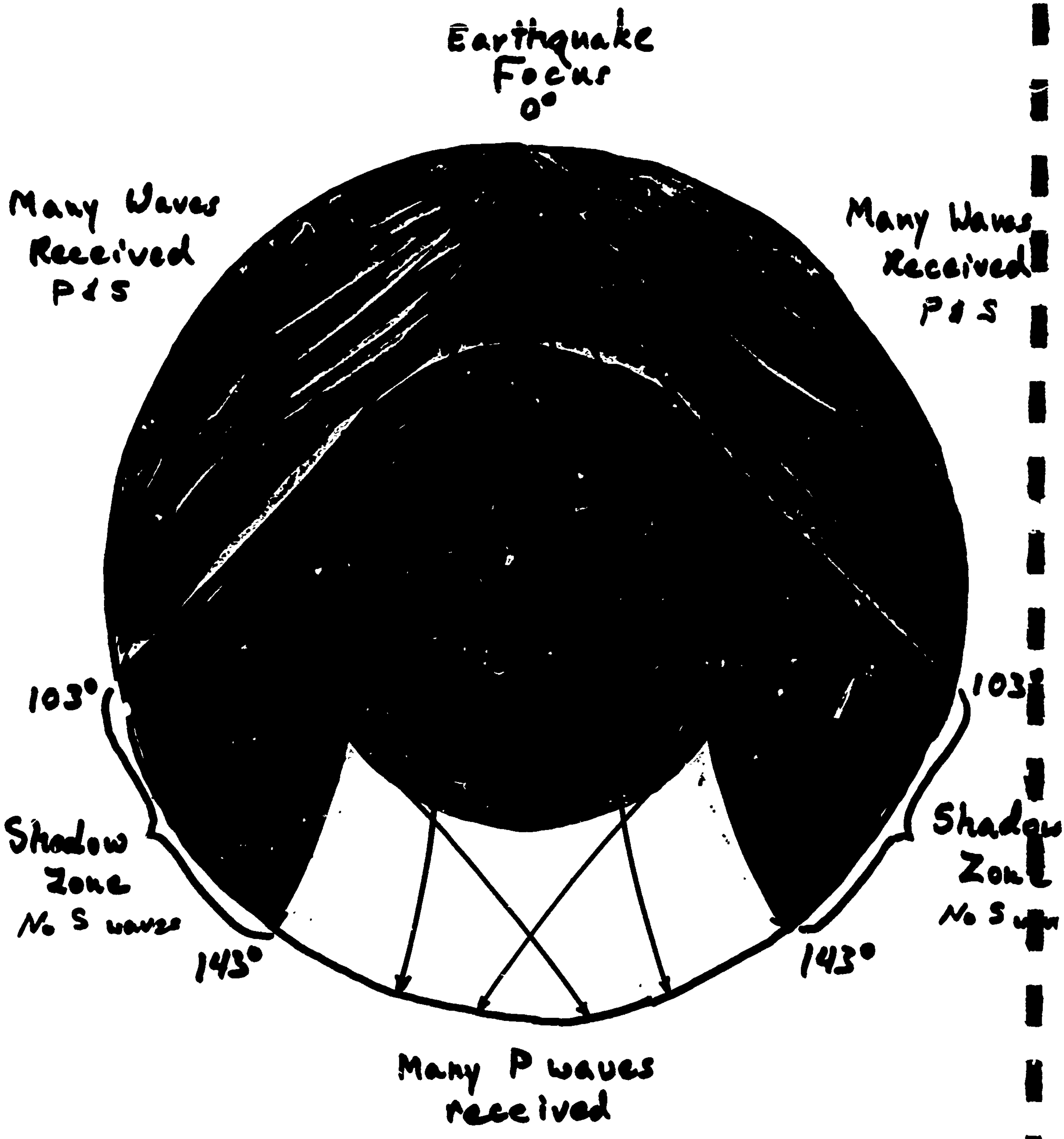
    2, Modified Mercalli Intensity - 12 units



Homogeneous Planet



Differentiated Planet


Earthquake
Focus
0°
Many Waves
Received
P & S
Many Waves
Received
P & S
103°
103
Shadow
Zone
No S waves
Shadow
Zone
No S
143°
143°
Many P waves
received

II. **Plate Tectonics** - General title or label applied to Continental Drift and referring to the vertical and lateral movements of the lithosphere, includes vulcanism.

A. General introduction - The crust of the earth is formed of plates which are moving about. Cause of the movement is probably convection within the mantle as plumes of molten material extend into the mantle from the liquid outer core.

First proposed by European geologists in the 1800s and accepted by most European geologists by the early 1900s. Not accepted by most American geologists until late 1960s.

Paleomagnetism shows that plates have changed their positions through time.

Use Magnetite crystals: - see diagrams

Declination - angle from true N to magnetic pole

Inclination - angle horizontal towards pole

B. Major features of plate boundaries:- see diagrams

1. **Divergent Boundaries** - areas where new crust is formed by pushing the adjacent plates apart. New crust is basalt and shows magnetic reversals (explain). **Sea Floor Spreading.** (see diagrams)

a. **Ridges** - relatively narrow, i.e. .Mid-Atlantic Ridge

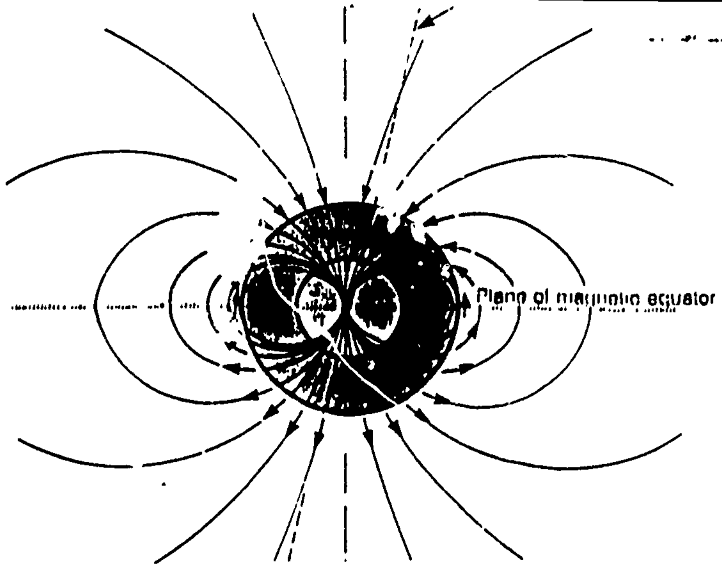
b. **Rises** - relatively wide, broad, i.e. Mid Pacific Rise

c. **Rifts** - occur within continents., i.e. East Africa

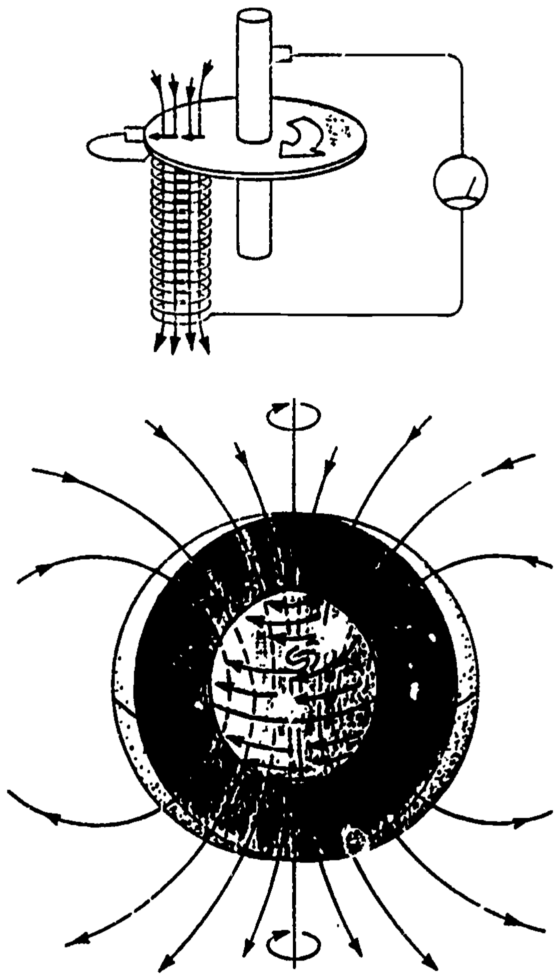
d. Process accompanied by:

1, Abundant earthquakes and faulting

2, Earthquakes shallow and mostly small

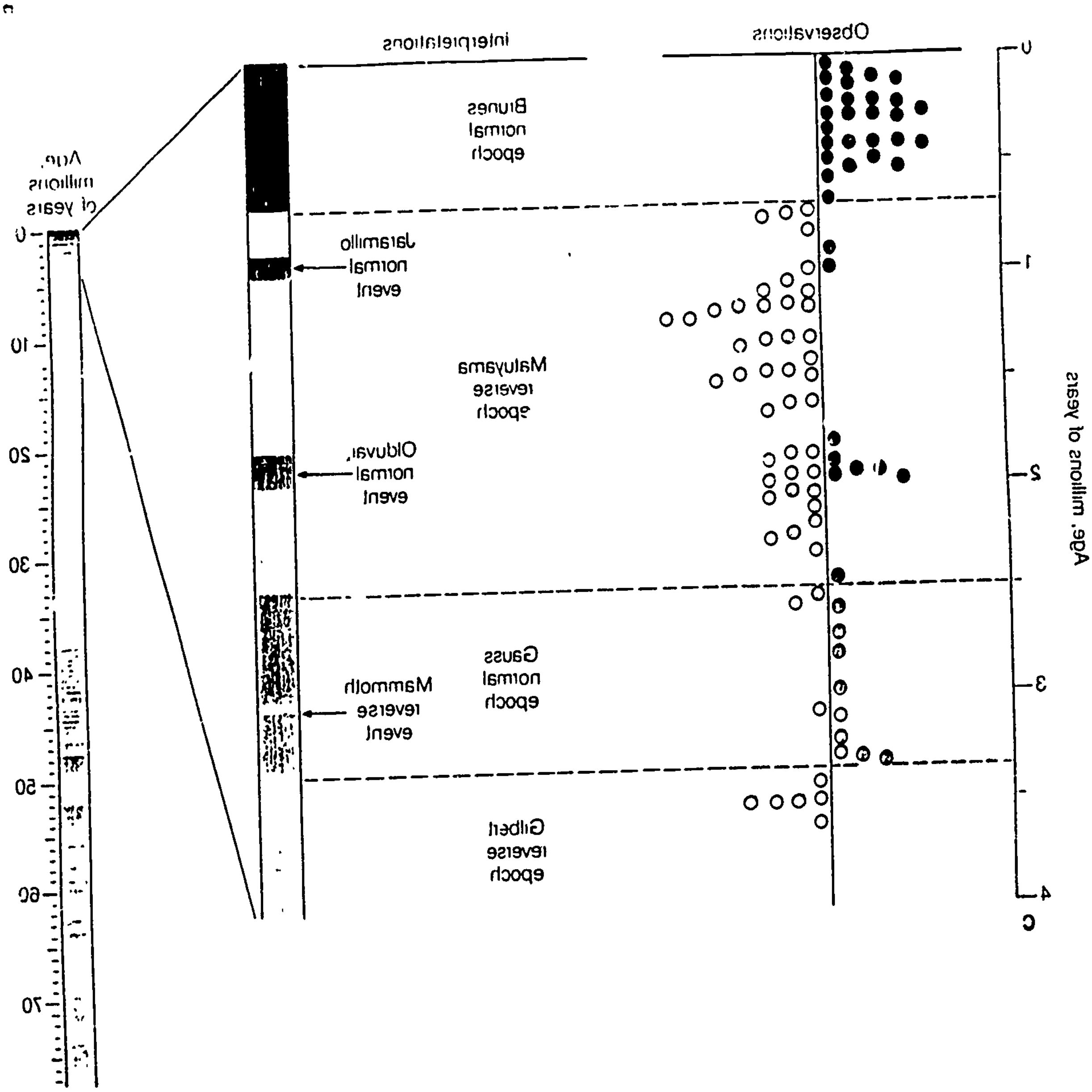


(A) Lines of force in the earth's magnetic field are shown by arrows. If a magnetic needle were free to move in space, it would be deflected by the earth's magnetic field. Close to the equator, the needle would be horizontal and would point toward the poles. At the magnetic poles, the needle would be vertical.

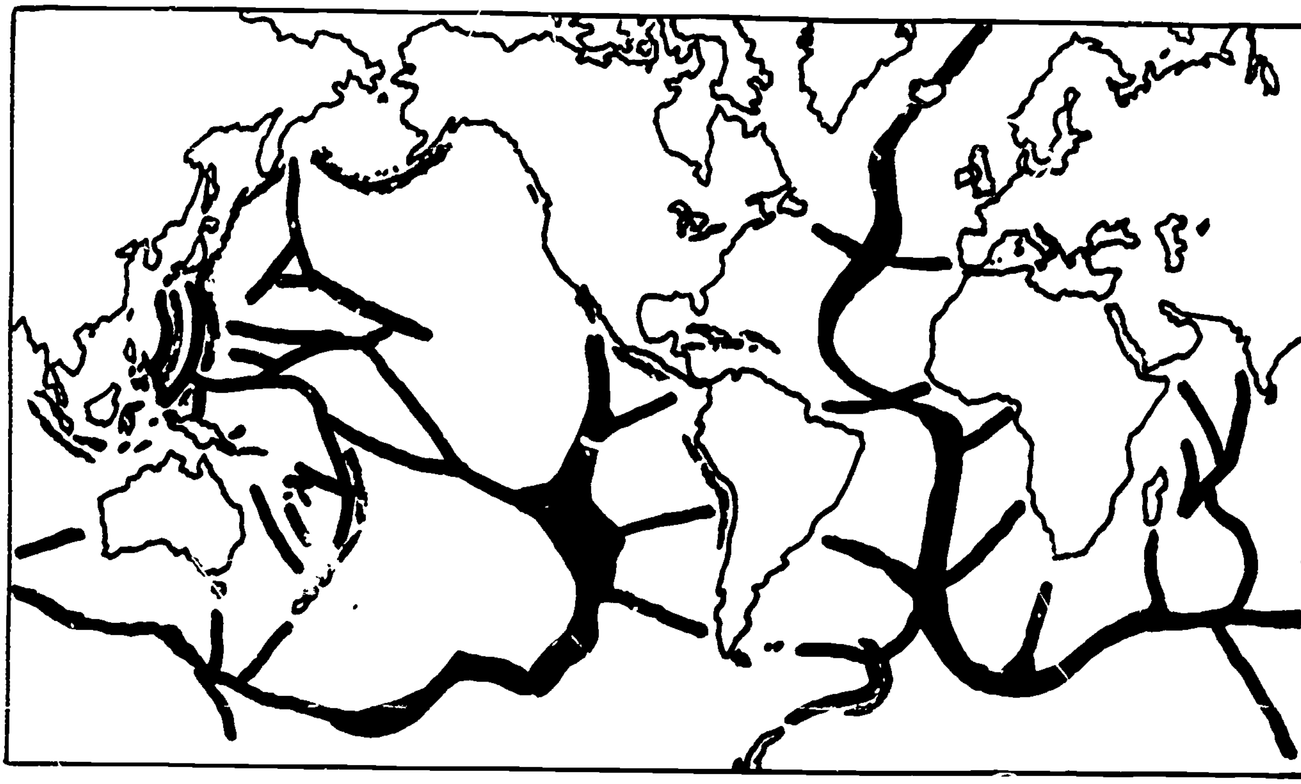


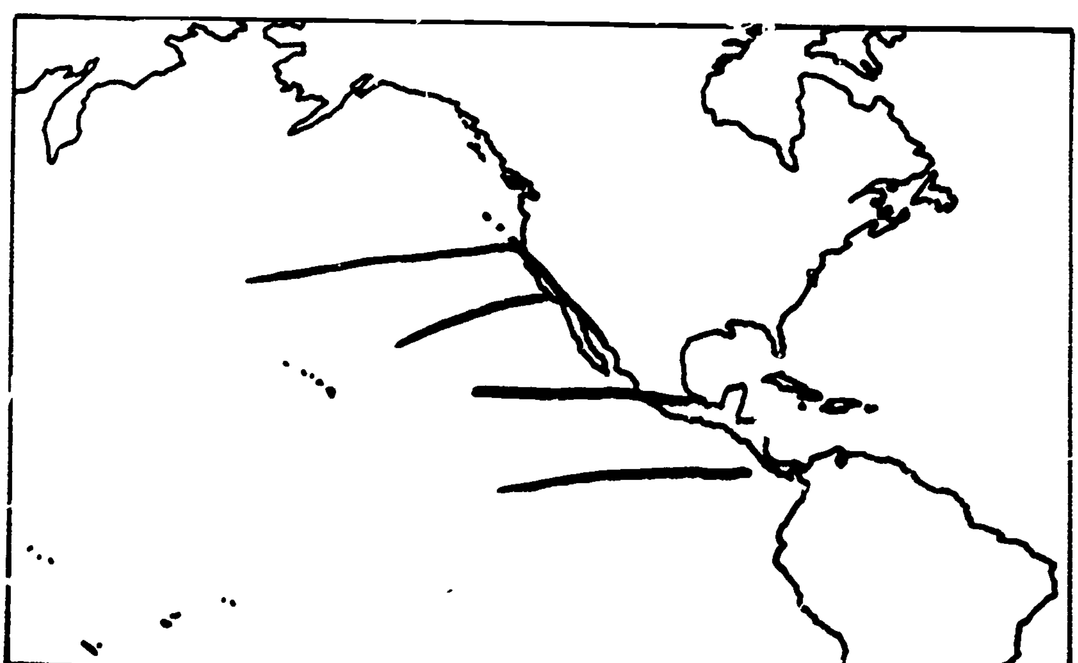
(B) Theoretically, convection in the earth's core can generate an electrical current (in a manner similar to the operation of a dynamo), which produces a magnetic field.

Figure 17.7 The earth's magnetic field is like that of a simple bar magnet. The temperature in the core and mantle, however, is far too high for permanent magnetism. The earth's magnetism must therefore be generated electromagnetically.



Age, millions of years
0
10
20
30
40
50
60
70
Interpretations
Observations
Brunes normal epoch
Jaramillo normal event
Matuyama reverse epoch
Olduvai normal event
Gauss normal epoch
Mammoth reverse event
Gilbert reverse epoch
Age, millions of years
0
1
2
3
4





3, Many transform faults

4, Vulcanism, shield type cones and fissure flows

2. **Convergent Boundaries** - plates collide, consumption areas, oceanic crust is subducted (recycled) back into the mantle. (see diagrams)

   a. **Ocean-Ocean** - subduction, trenches. SW Pacific, Australian plate with Pacific plate.

   b. **Continent-Ocean** - subduction, trenches. West coast of North and South America

   c. **Continent-Continent** - welding together. Himalayas

   d. Process accompanied by:

      1, Numerous earthquakes and faulting

      2, Earthquakes shallow to deep, small to large

      3, Vulcanism, magma of mixed types

      4. Mountain building and metamorphism

3. **Fault Boundaries** - **Transform Faults** - two plates laterally sliding past one another. Earthquakes shallow to moderately deep, small to large.

C. Plate pattern :

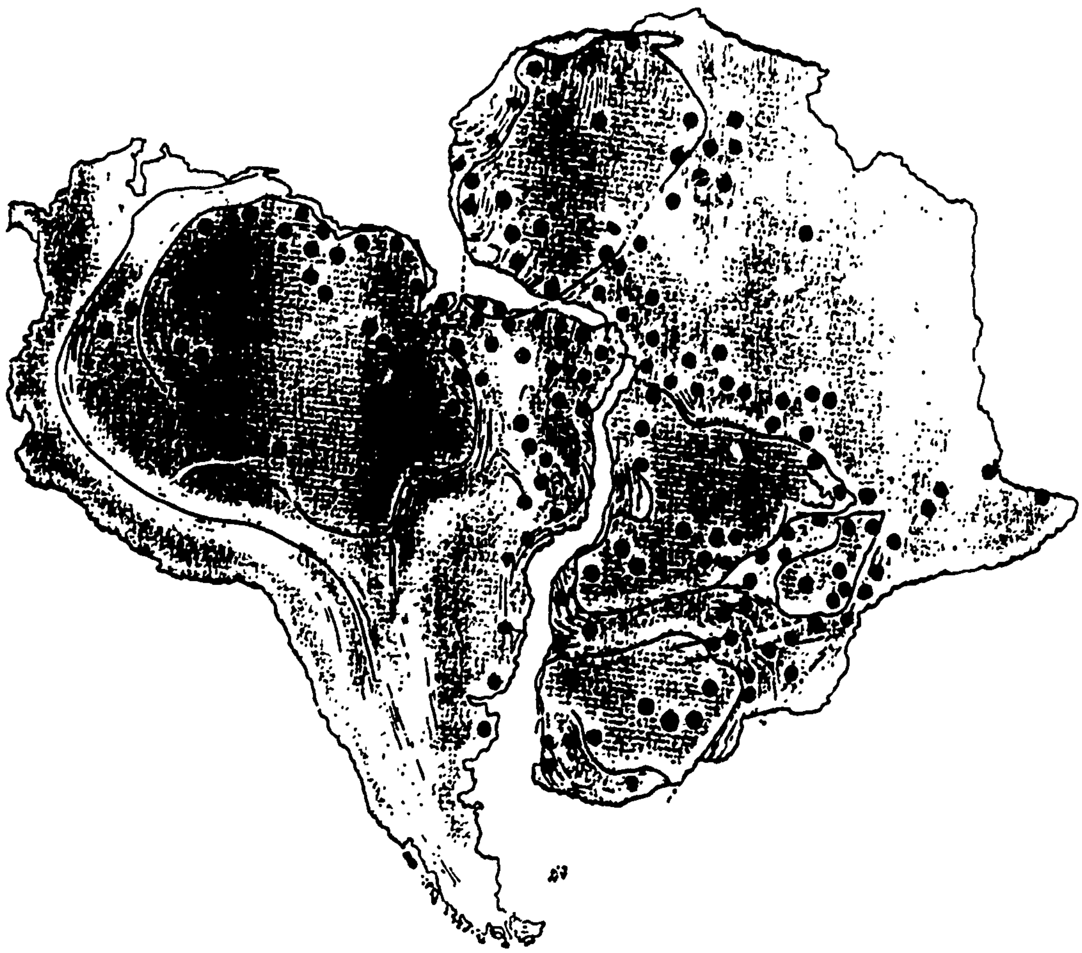
1. As recognized today - see diagram

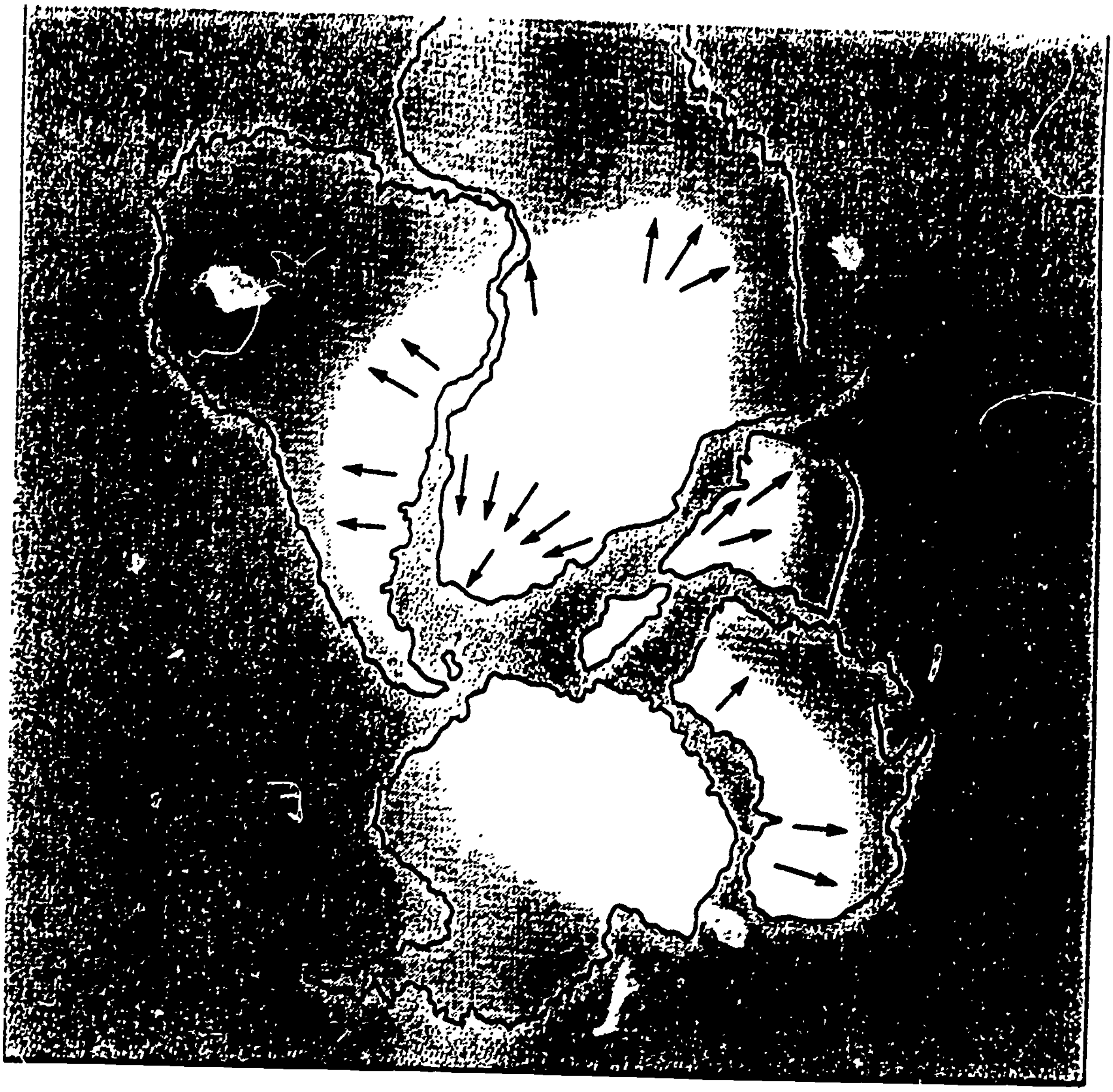
2. As it existed ~200,000,000 years ago - see diagram

D. Summary

1. The basic concepts of Plate Tectonics are established; many details remain to be worked out, including the driving mechanism.

2. Explains how new crust is formed from the asthenosphere





(B) If the continents were restored to their former positions according to Wegener's theory of continental drift, and if the former South Pole were located approximately where South Africa and Antarctica meet, the location of late Paleozoic glacial deposits and the directions in which the ice flowed would be explained nicely.

Figure 17.5 Distribution and flow direction of late Paleozoic glaciers provide further evidence of continental drift.

3. Explains where lithosphere is consumed
4. Explains metamorphism
5. Explains mountain building
6. Explains volcanism type and pattern
7. Explains earthquake patterns
8. Explains rock associations and patterns as seen on the earths surface today and can be interpreted to have occurred in the past.

III. Deformation Structures - rocks will yield under pressure. As the stress builds the rocks will bend; when the stress becomes to great they rupture. The bending process is called **folding**, and the rupture process **faulting**. Several types of folds and faults are recognized based on the geometry of the structures.

A. Folds - see diagrams

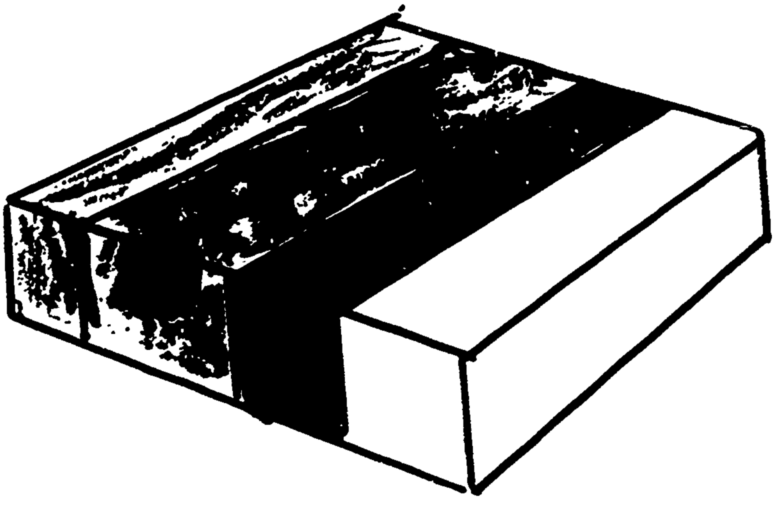
1. **Antiforms** - positively elevated in the center
   a. Anticline -linear
   b. Plunging anticline
   c. Doubly plunging anticline
   d. Dome

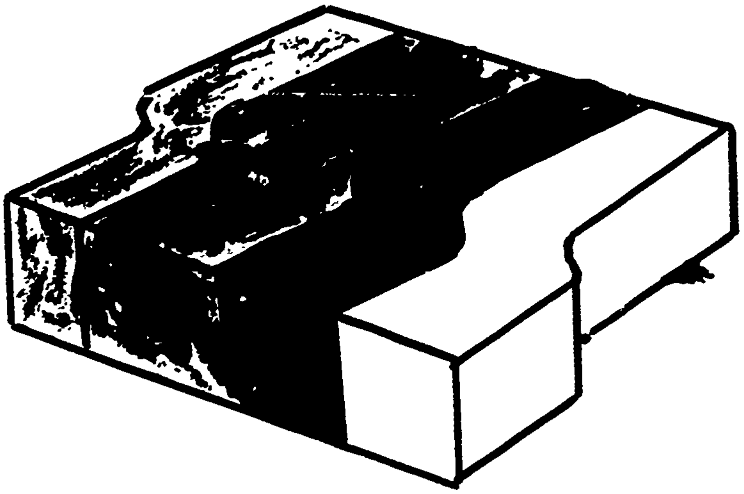
2. **Synforms** - depressed in the center
   a. Syncline
   b. Plunging syncline
   c. Doubly plunging syncline
   d. Basin

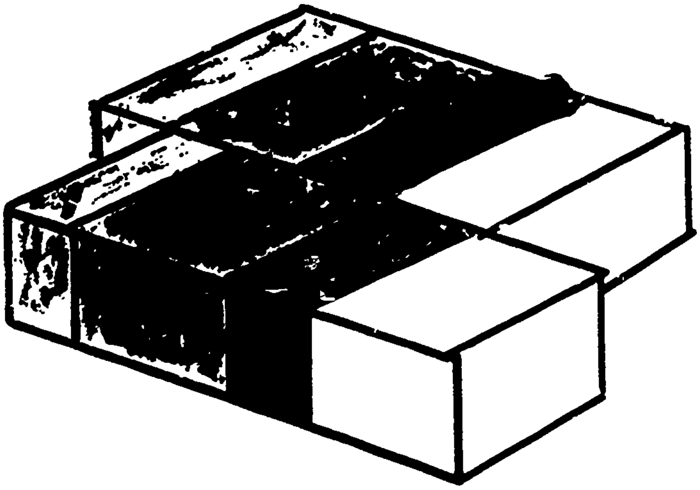
3. Other descriptors and their significance
   a. Symmetrical
   b. Asymmetrical
   c. Overturned
   d. Open vs closed
   e. Gravity folding

B. Faults - see diagrams

1. Vertical or dip slip movement
   a. Vertical fault plane - no crustal shortening or lengthening







b. Normal fault - tension, crustal lengthening

c. Reverse fault - compresion, crustal shortening

d. Thrust fault - low angle, much shortening

2. Horizontal or Strike slip movement - blocks slide past one another

   a. Right lateral -

   b. Left lateral -

3. Oblique or diagonal movement - both vertical and horizontal components

4. Other fault terminology

   a. Slickensides -

   b. Drag -

MINERAL RESOURCES

I. Earth composition:

A. 15 elements make up all but 0.1% of the earth

B. Comparison of percentages in the crust and overall makeup of the earth. See diagram

C. Distribution of elements in the crust is not uniform and has been changing through time as the crust has evolved with plate tectonics. It will continue to change in the future. (overhead) U.S. is dependent on other countries for many of our metal supplies. We produce an excess of relatively few (Molybdenum, Magnesium). Many metals that we export we import the ores to process (aluminum).

D. Man's search for metals and other earth resources continues to increase and outstrips the availability of some products.

1. Iron example:

1/3 on the earth is iron, yet **crust only 1/18** where it is the 4th most abundant element.

An ore is minimally 30-35% Fe, some are 50-55%; thus an ore is **concentrated 5.3 times** the average.

World average use of Fe is 98 kg/person/year

U.S. average use of Fe is 590 kg/person/year

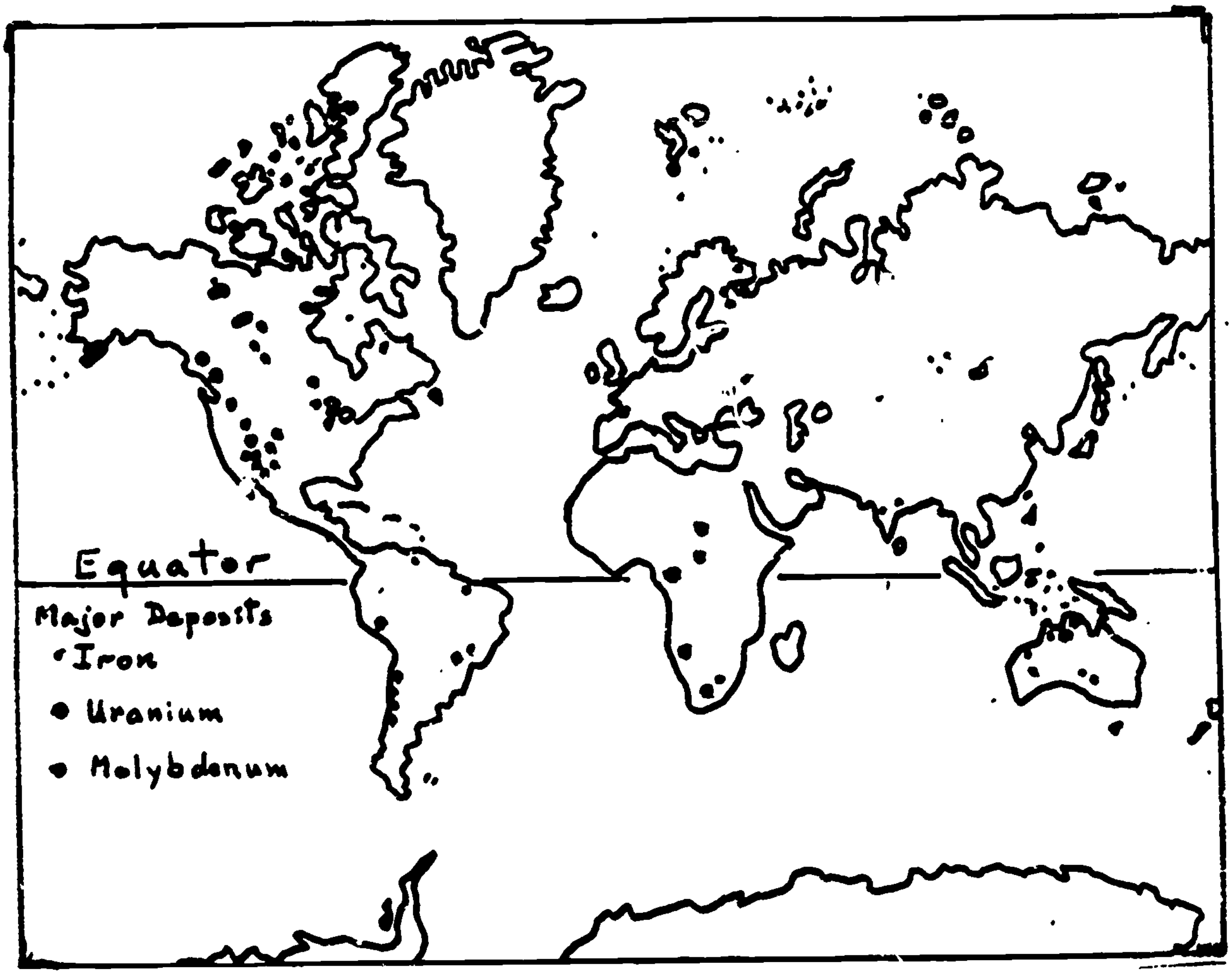
If by 2,000 A.D. everyone in world were to use Fe at rate of U.S today it would take 6X the current production

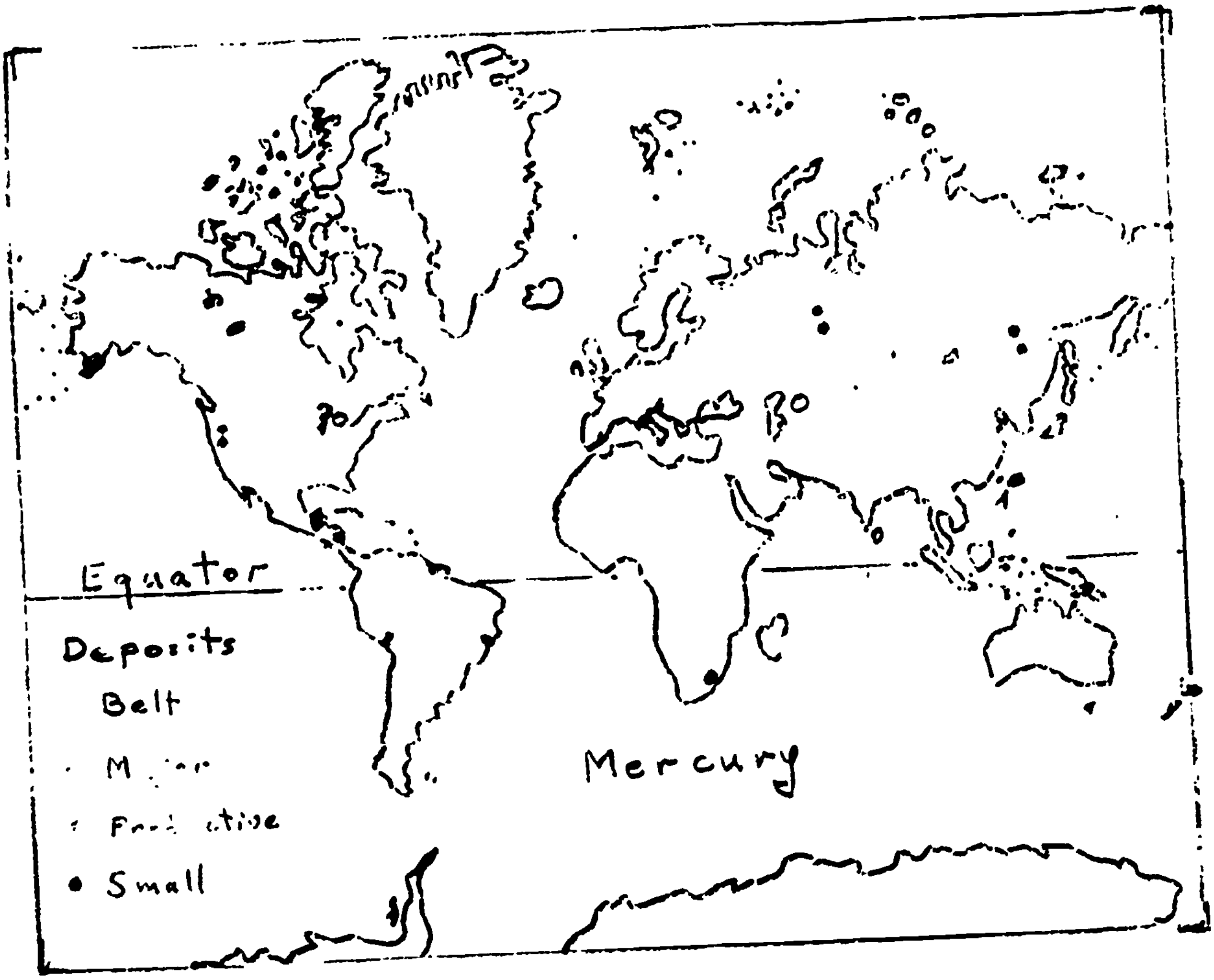
However, increasing population may require another 2X current needs; thus we are now at 12X current use

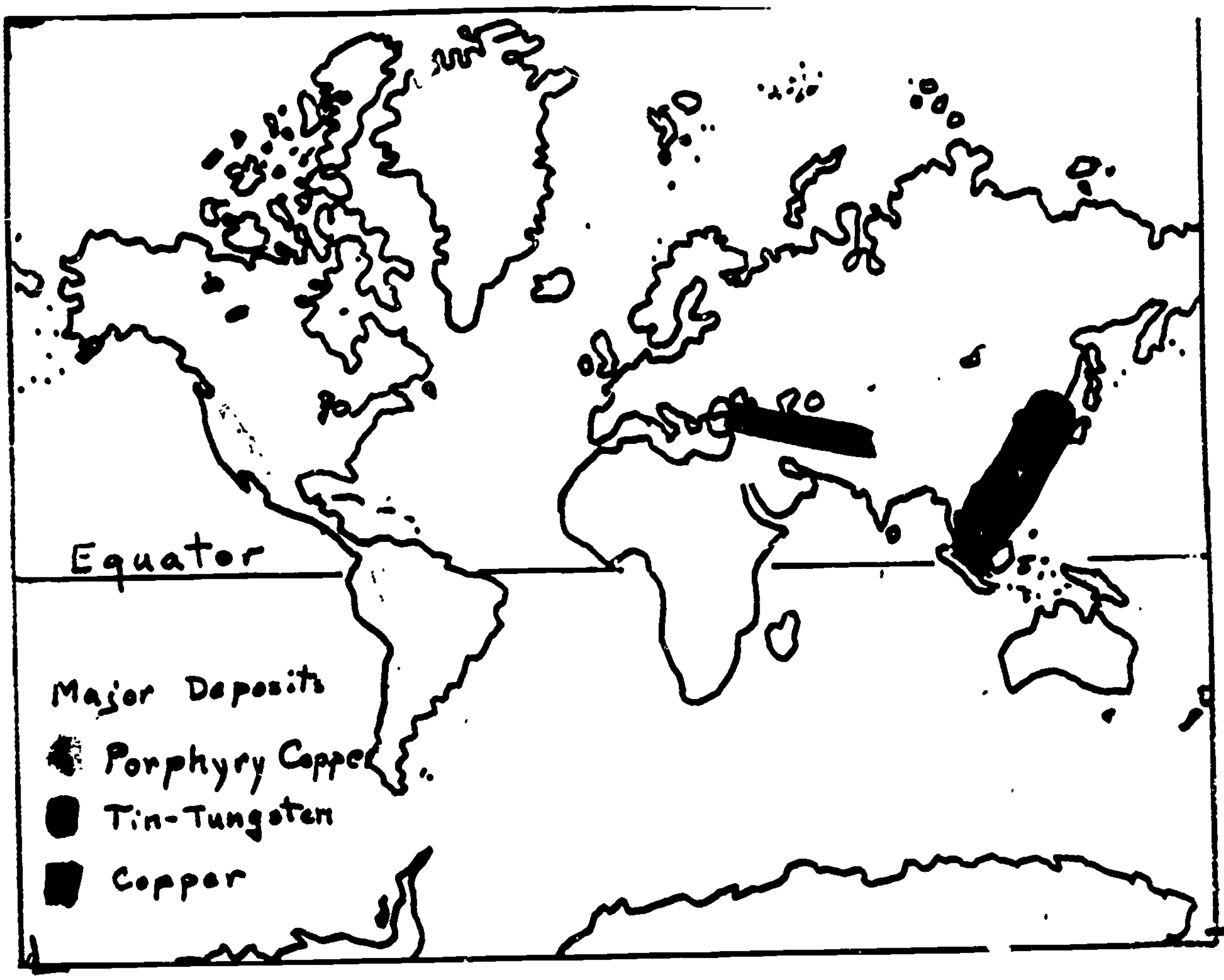
There are insufficient higher grade ores so we go to

Element	% World	% Crust
Iron	[illegible]	5.63
Oxygen	[illegible]	46.40
Silicon	[illegible]	28.15
Magnesium	[illegible]	2.33
Nickel	[illegible]	0.0075
Sulfur	[illegible]	0.026
Calcium	[illegible]	4.15
Aluminum	[illegible]	8.23
Sodium	0.57	2.36
Chromium	0.26	0.01
Cobalt	0.13	0.0025
Phosphorus	[illegible]	0.105
Potassium	0.07	2.09
Titanium	0.05	0.57
Manganese	0.22	0.095

Weight percent of 15 most abundant elements in the Earth compared to their percentage in the continental crust.


Equator
Major Deposits
Iron
Uranium
Molybdenum


Equator
Deposits
Belt
Small
Mercury


Equator
Major Deposits
Porphyry Copper
Tin-Tungsten
Copper

lower grade ores, if so we could be talking another 1.5 to 1.7X the amount of ore which is equal to 18 to 20X the current amount of ore required to meet our needs. This is not including recycling.

Results 18 to 20X: more miners

more smelters and pollution

more energy needed for smelters

more environmental damage

more transportation of ore and products

etc.

With recycling and the ore reserves of the world we could come close to supplying the world needs as calculated.

1982 data from U.S. Bureau of Mines:

Consumption of Fe in U.S. 60 million long tons

Price $32.25-$32.78 per ton of 51.5% ore

Production: 7th in world after USSR, Australia, Canada, others

Mines - 35 million long tons

Imports - 15 million long tons

Exports - 2.9 million long tons, 36% deficit

Recycled - all refined iron and steel, not ores.

12 mines operated by 8 companies, 90% of prod.

Minnesota 68%

Remainder from 10 other states

8,000 employees at mines and concentrating plants

2. Copper:

1/70th most abundant elemetn

Use **11 kg/person/year** in U.S.

Need **1% minimum for an ore** in copper porphyries and higher percentages from hydrothermal veins to be commercial.

Thus an accumulation of **140X** or higher in ores.

Using the same reasoning as used for Fe to supply everyone in the world at the U.S. usage by 2,000 A.D. it would take approximately **50X** the current production.

There are insufficient ores to do this.

3. Other elements are even less abundant and require higher concentrations to be an ore.

II. General terms

A. **Mineral Resource** - any product coming from the earth

B. **Mineral deposit** - any concentrated mass of a potentially economical mineral product.

- any valuable mass of ore

- once produced the deposit is **exhausted**

C. **Ore** - rock or soil bearing sufficient quantites of desired mineral products to earn a profit.

D. **Ore grade** (concentration) - high, low, marginal, noneconomic (today's tailings may be tomorrow's ore)

III. Origin- where concentrated when formed

A. Plate tectonics - see diagram

l. Spreading centers - metal oxides and sulfides

2. Subduction zones - metals

B. Associated with igneous rocks

1. **Disseminated** - product scattered through the igneous body; may be in small concentrations but if price is high enough it is commercial. i.e. gold, copper , diamonds

2. **Differentiation** - settling out of crystals of product as the magma cooled. i.e. chromite

3. Late stage crystallization (a form of differentiation) - crystals are among the last to form as the magma crystallizes and the minerals formed are developed in cracks adjacent to or along the edges of the pluton. i.e. magnetite (Some pegmatites may form here)

C. **Metamorphism** of regional or contact type - fluids in magma react with the country rock and ore deposits are formed in the country rock adjacent to the magmatic body. i. e. galena, silver, pyrite, gold, copper. May be igneous associated.

D. **Hydrothermal** - hot fluids circulating through the crustal materials, perhaps near an intrusive body, leach elements from the rocks as they pass through and then deposit them in adjacent areas where they cool. i.e. pyrite, galena, gold.

E. **Sedimentary processes** -

1. Evaporites - direct precipitation of the evaporites . i.e. halite, etc.

2. Deposition - currents transport and deposit fragments and waste products of aquatic organisms to form limestone and phosphate

3. Placers - heavy metals, such as gold and platinum,

are concentrated where the current slows down. Products originated elsewhere, by other processes.

4. Deep Sea deposition - nodules rich in manganese, iron, and some copper and other metals are formed around grains of sand on the sea floor at some depth. These apparently form very slowly but are commercial. Also contain much silica which is harder to process.

ENERGY RESOURCES

I. Fossil Fuels - exhaustible!! - derived from solar energy

A. Oil and Gas - derived from organic life which is buried in sediments, undergoes a transformation to the fluid hydrocarbon stage, migrating into a reservoir rock in a trap. (overhead)

1. World production figures and areas - see overheads
2. Proven reserves - see overhead
3. U.S. imports - see overhead

B. Coal - accumulation of plant material which is transformed into coal by heat and pressure, which concentrates the fixed carbon content

Peat - lignite - bituminous coal - anthracite coal - graphite

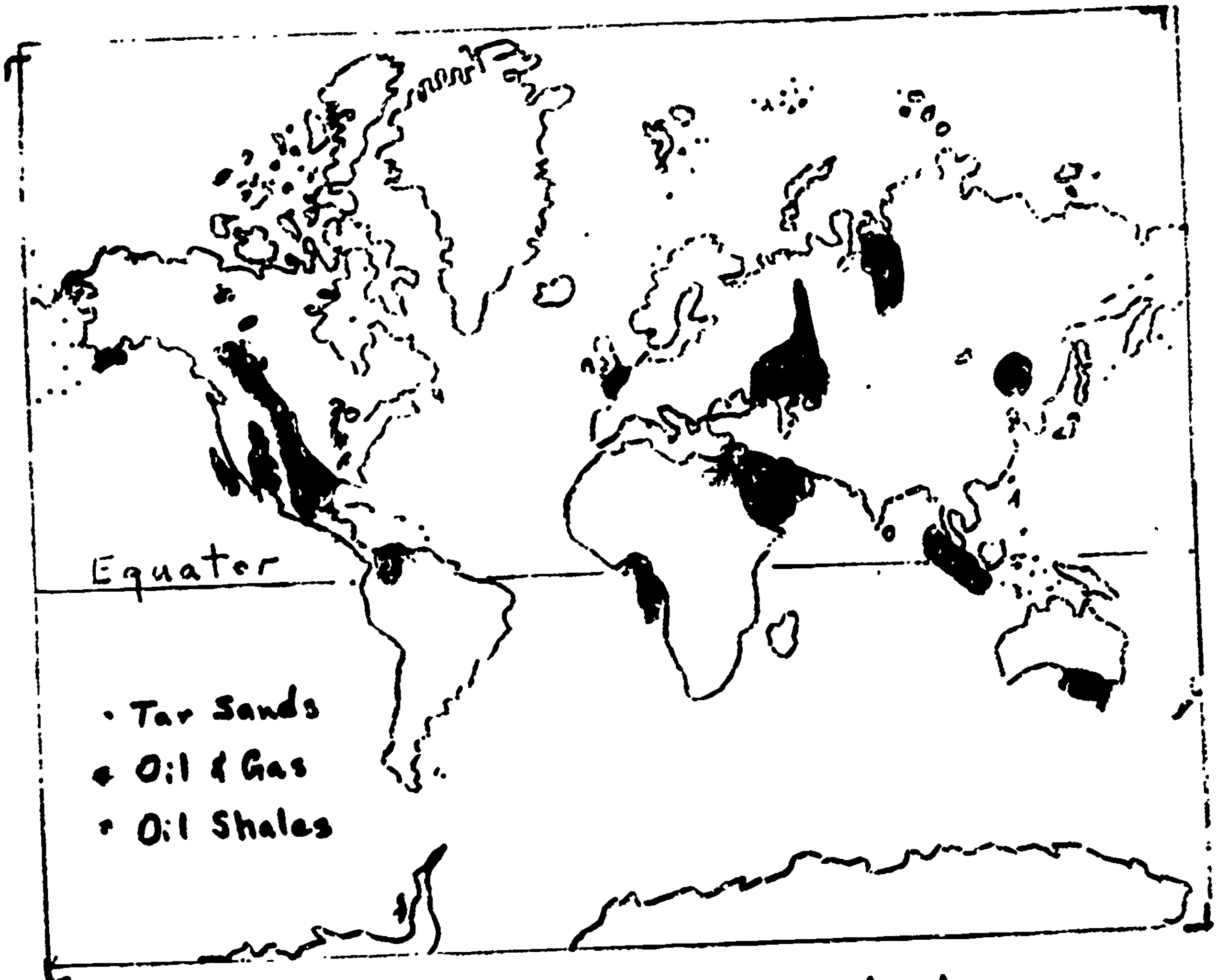
Overhead to show world reserves distribution

II. Solar energy - direct radiation from the sun

III. Nuclear energy - use of fission of uranium and thorium; need method of harnessing fusion.

IV. Geothermal energy - utilize steam to generate electricty or directly as heat

V. Tidal - use daily tidal flux to generate electricty



Areas of major hydrocarbon production

Time ↑

4 Accumulation in Trap

↑

3. Migration into Reservoir Bed

↑

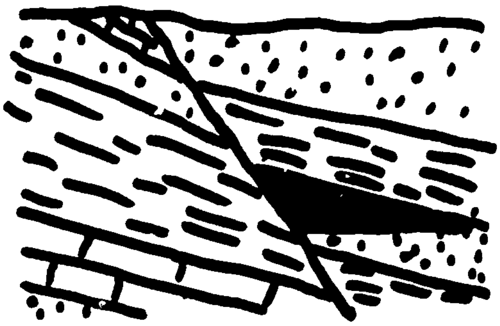
2. Generation of Hydrocarbons

↑

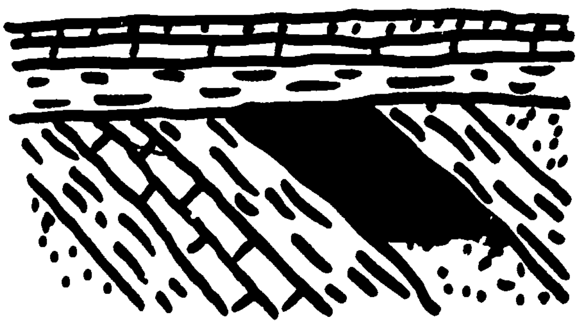
1. Deposition of Source Bed

Essentials of Hydrocarbon Production

Anticlinal Trap

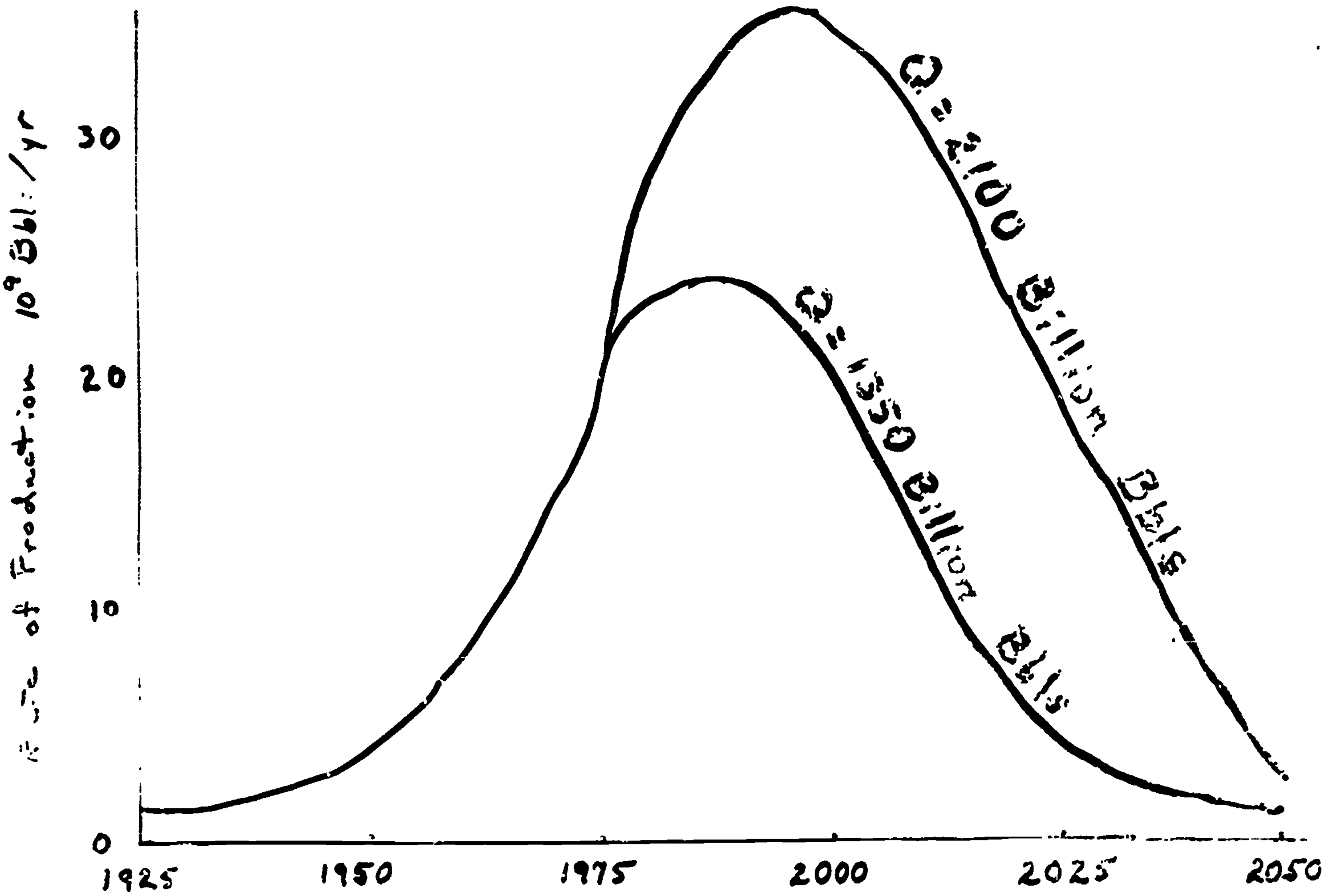


Fault Trap

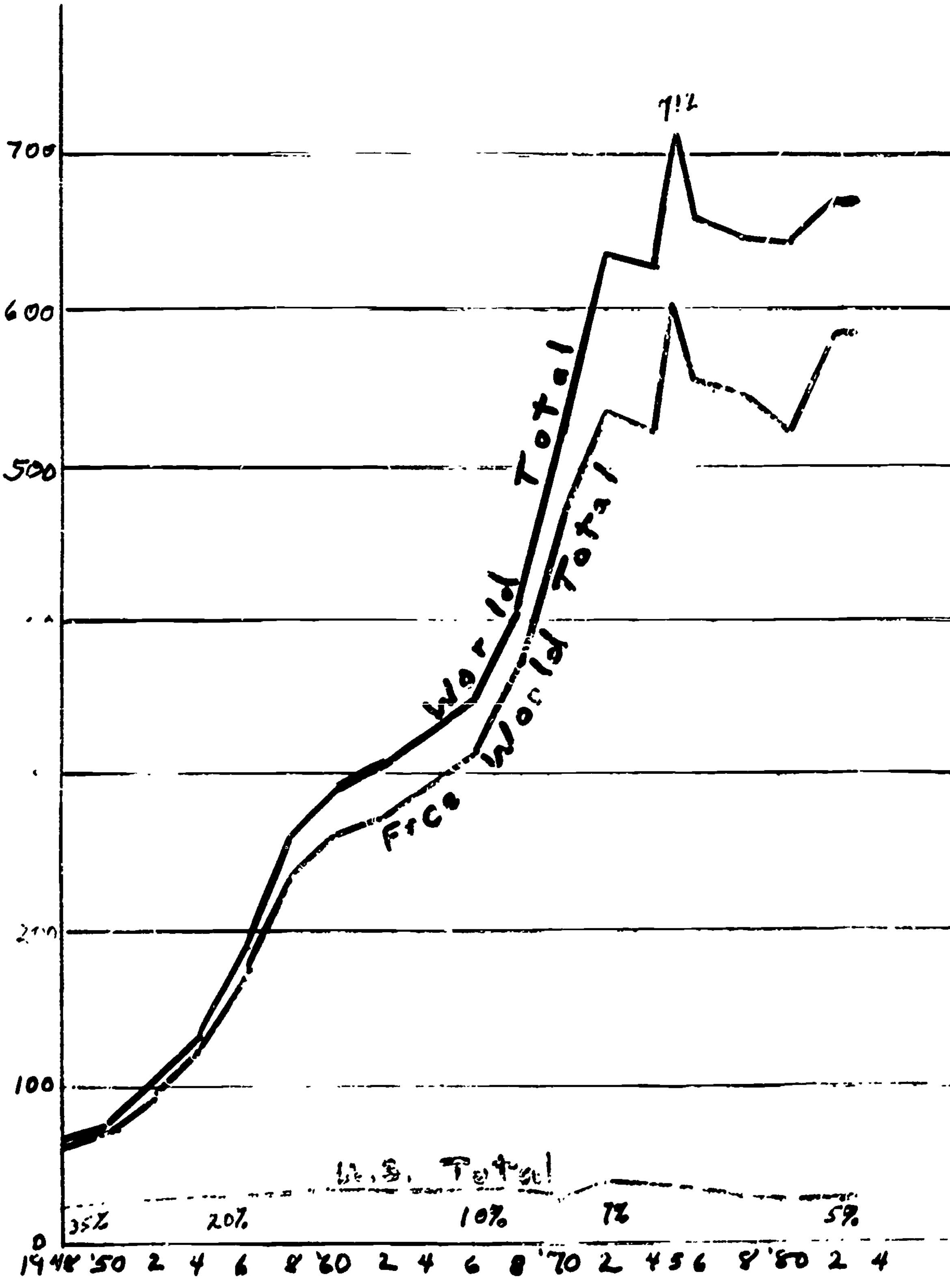


Unconformity Trap

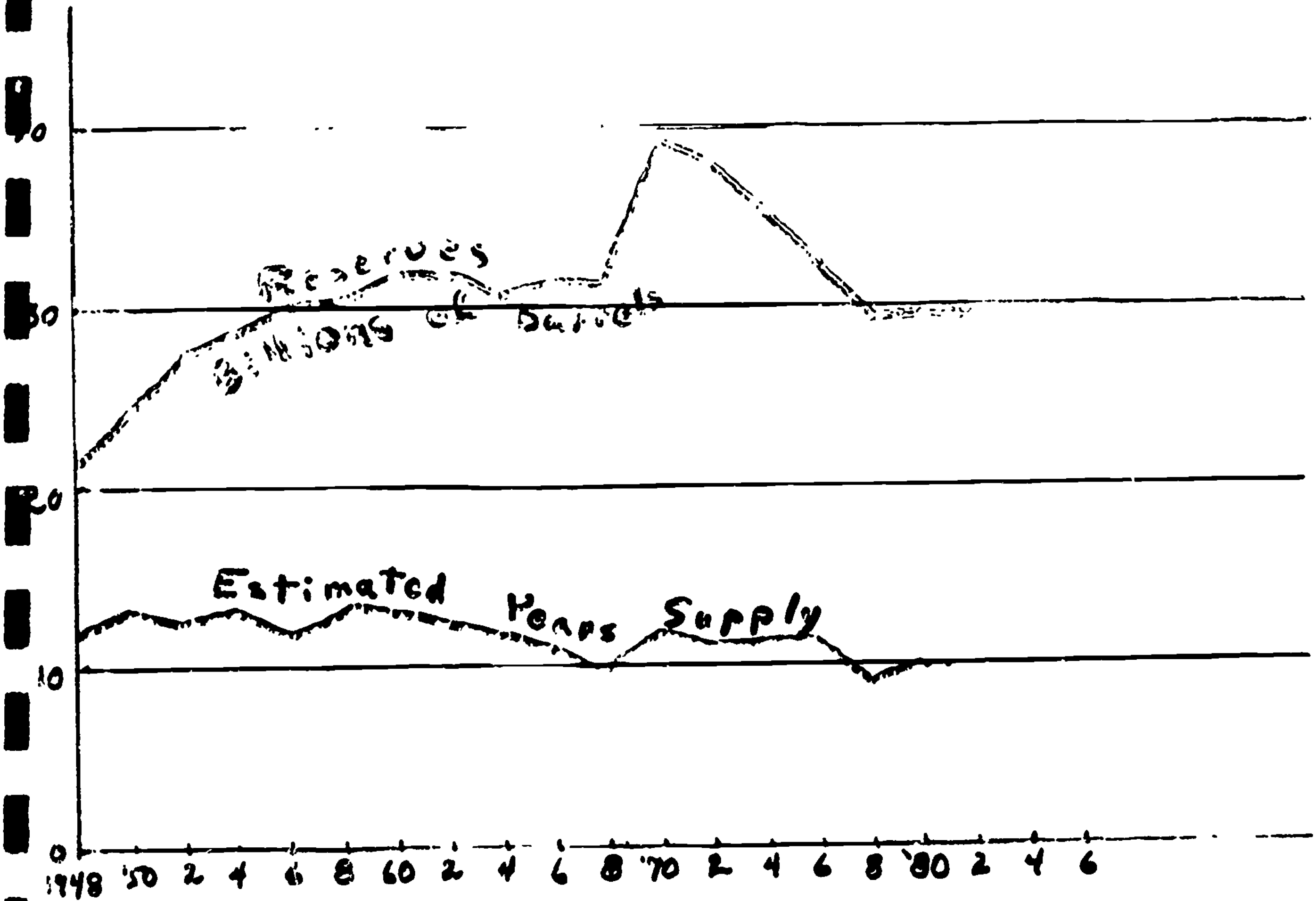
All views cross-sections within Earth's crust



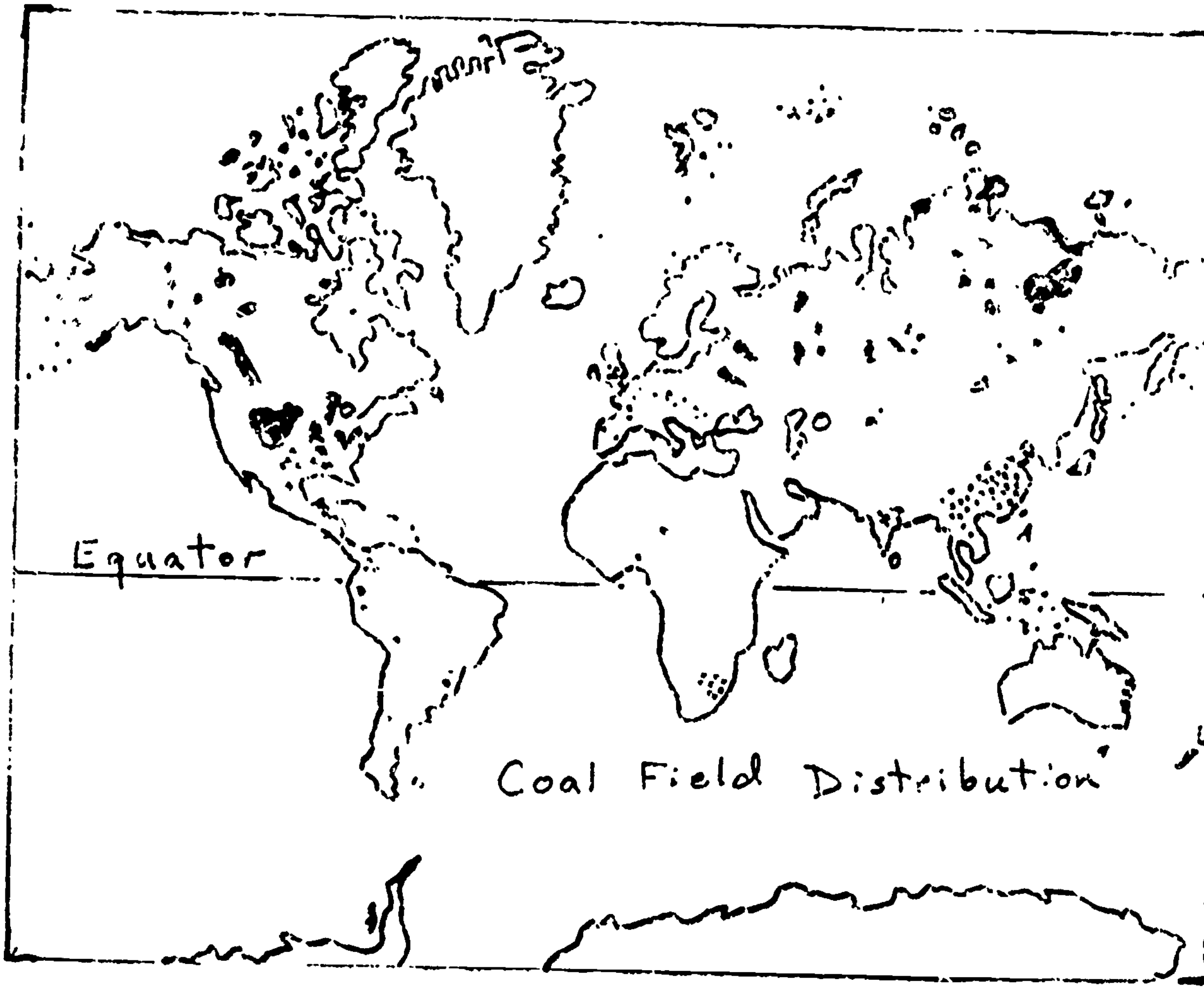
Cycle for world petroleum production.

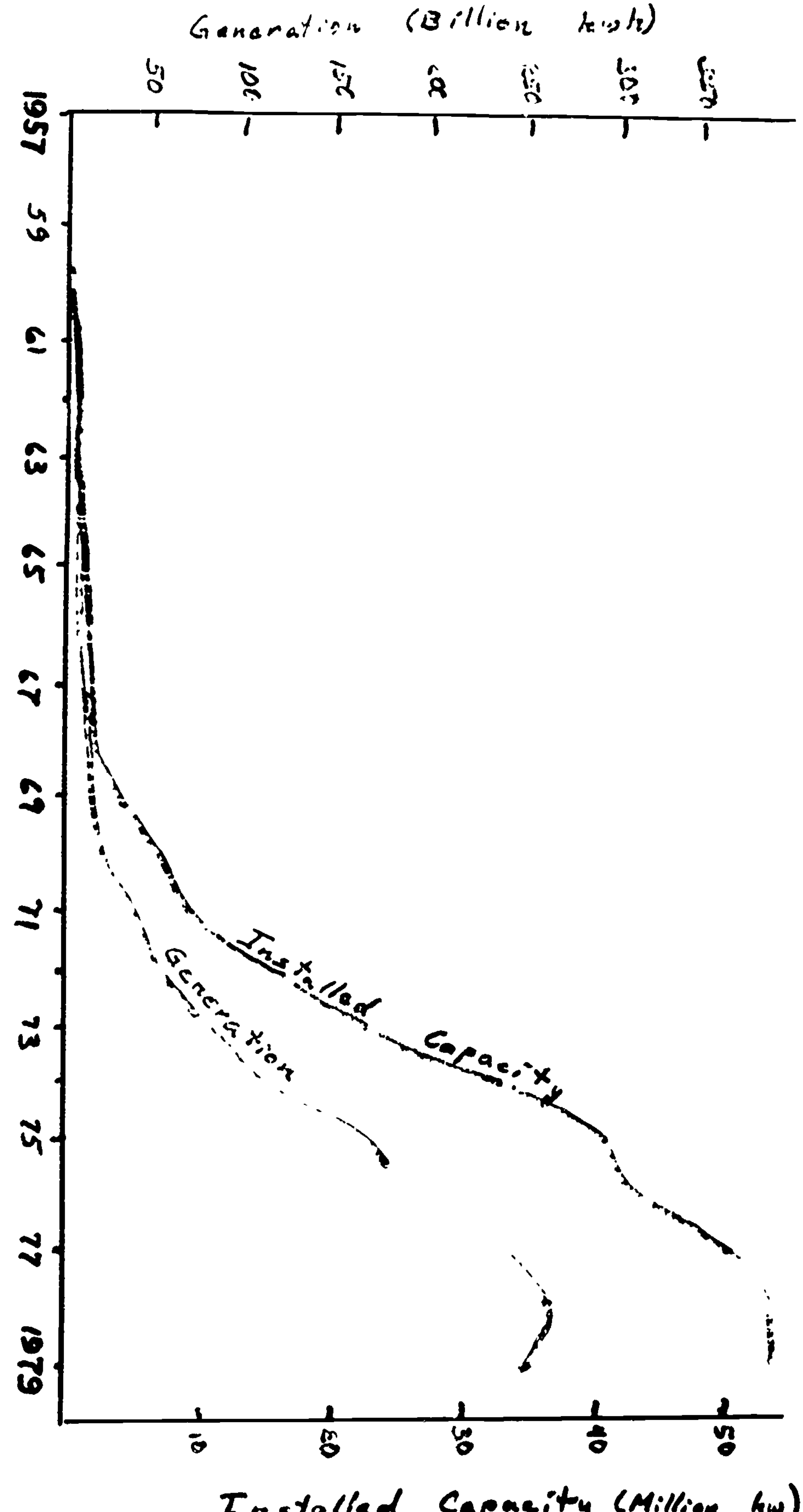


Estimated Proved Crude Oil Reserves
(Billions of barrels)



Proved Reserves of U.S. Crude Oil
& Estimated Years Supply


Equator
Coal Field Distribution



U.S. nuclear power plant capacity & annual generation.

GROUND WATER

I. Introduction - water recycles in the hydrologic cycle (big cycle involving water from the oceans to clouds to rain and snow to glaciers, streams, lakes, and ground water back to the oceans).

Runoff = precipitation - evaporation - transpiration - infiltration

Runoff - water carried to oceans by streams

Ground water -water that infiltrates into the pore spaces and crevices in consolidated and unconsolidated materials in the earth. This water amounts to more than 66 times the amount of water in the streams and lakes of the earth.

Man's use of this natural resource is depleteing it faster than it is being recharged in many areas and pollution is contaminating it in many other areas. As the population continues to increase our demand for this water will increase. We must conserve it and prevent the pollution of it.

II. Occurrence

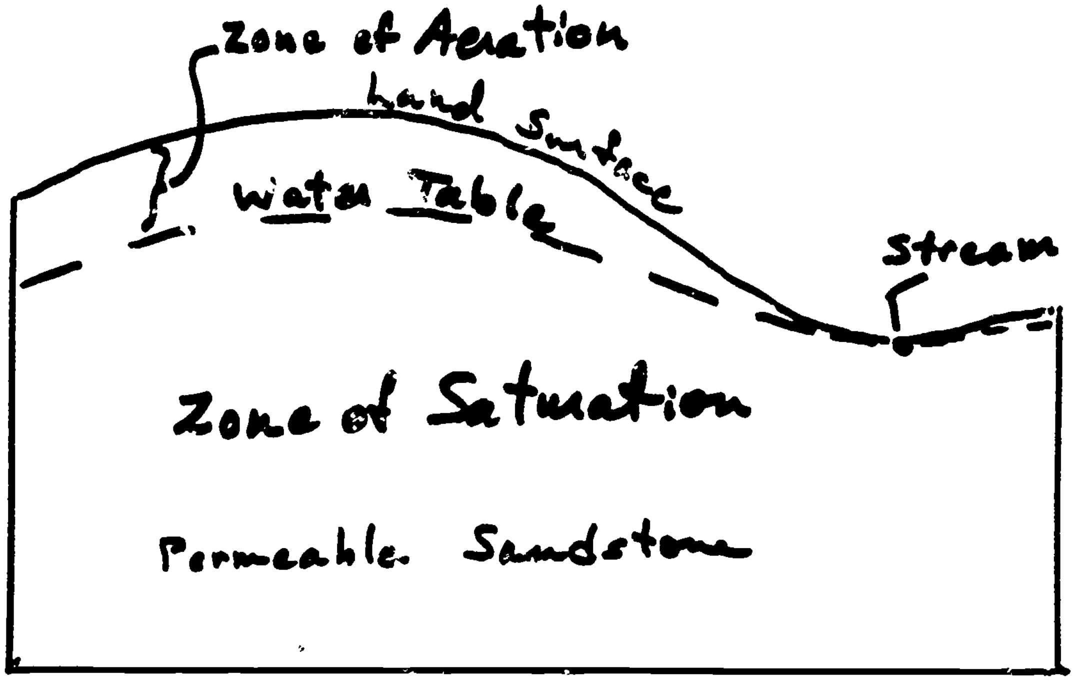
A. **Porosity** - void spaces in earth materials

B. **Permeability** - measure of the interconnectability of the void spaces.

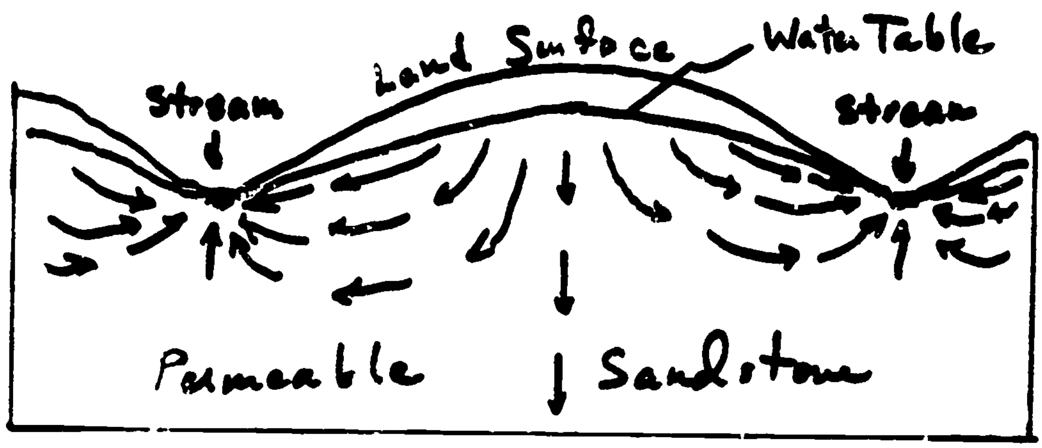
C. Relationship - there must be void spaces in earth materials for water to be there. The voids must be interconnected for the water to move from one to the other, to be recharged, and for man to retrieve it.

D. Zones: (see overhead)

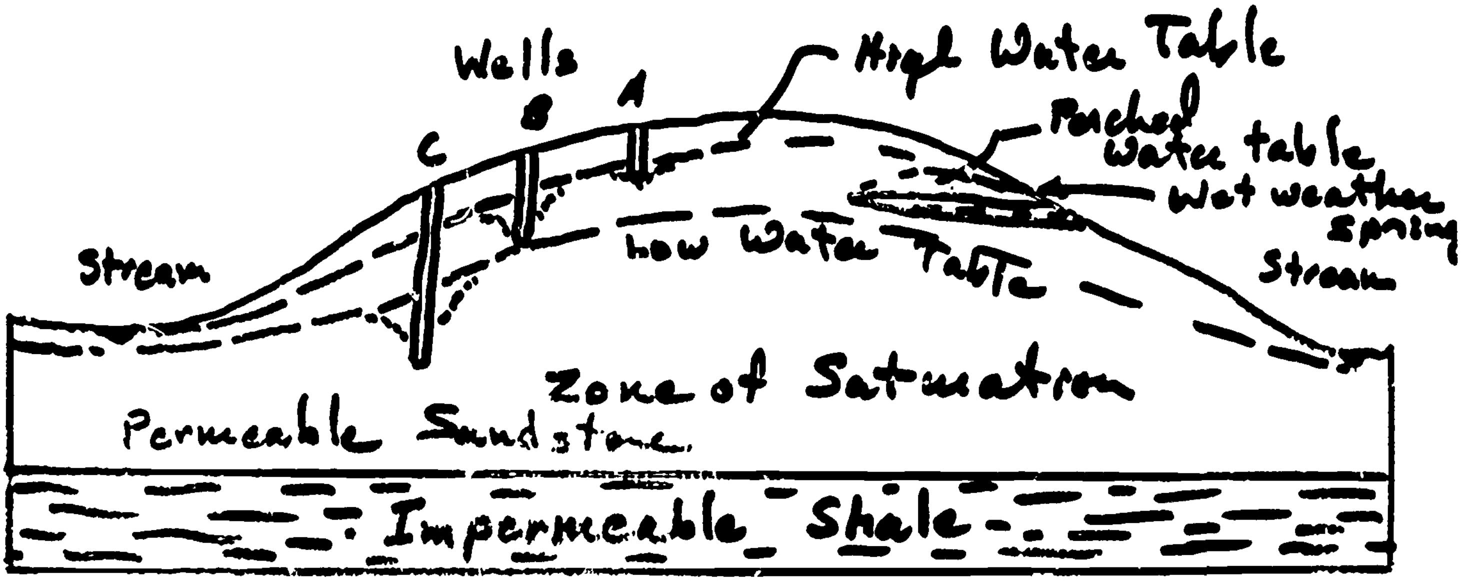
1. **Zone of Aeration** - belt of earth material which ground water passes through from the surface of the earth to the



Zone of Aeration
Land Surface
Water Table
Stream
Zone of Saturation
Permeable Sandstone



Land Surface
Water Table
Stream
Stream
Permeable Sandstone



Wells
C
B
A
High Water Table
Perched water table
Wet weather spring
Low Water Table
Stream
Stream
Zone of Saturation
Permeable Sandstone
Impermeable Shale

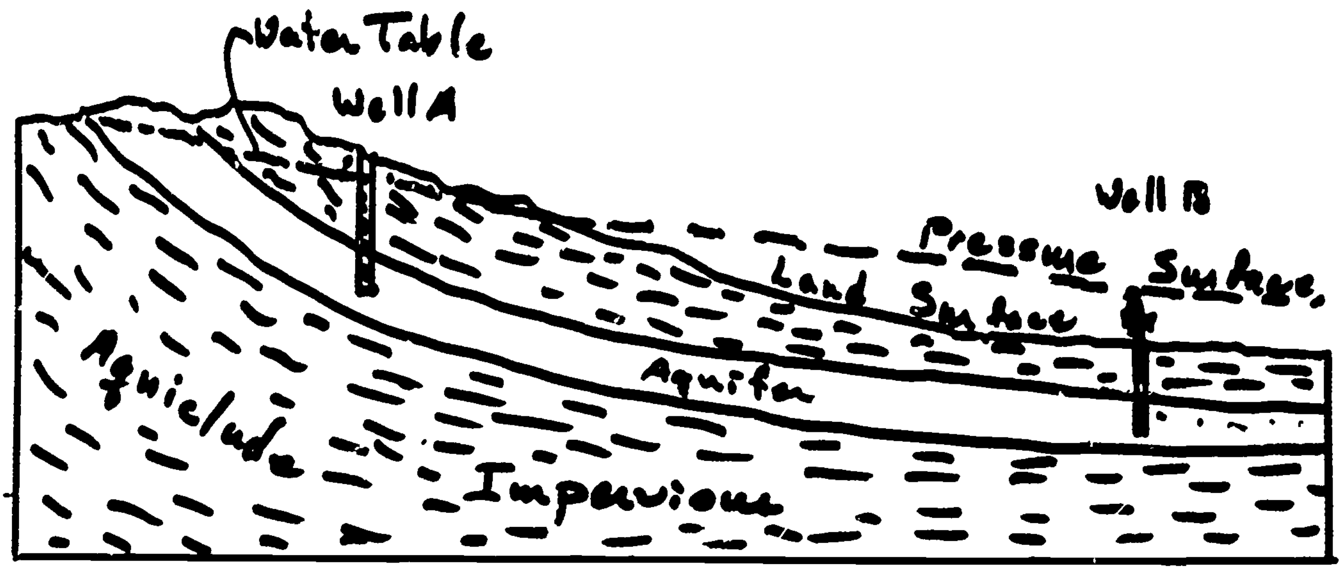
zone of saturation. The molecular attraction of water and rock materials and the molecular attraction of the water molecules themselves will cause some of the water to remain in the zone of aeration as suspended water where void spaces are mixed with air and water.

a. **Soil moisture belt** - upper part of Zone of Aeration, water in this belt is used by plants, evaporated back to the atmosphere, and moves through and lateral during recharge periods (rainfall and snow melt).

b. **Intermediate Belt** - water held here by suspension and will move down or lateral during periods of recharge.

c. **Capillary fringe** - lower belt of Zone of Aeration, above Zone of Saturation, water held in voids by molecular attraction.

2. **Zone of Saturation** - belt in the earth materials where voids are filled with ground water.
3. **Water Table** - surface between Zone of Aeration and Zone of Saturation; irregular surface which will fluctuate level as water supply fluctuates with amounts of precipitation. (see overhead)
4. **Perched Water Table** - occurrence of a water table above the Zone of Saturation, usually a local feature which will not be present during periods of draught. Has an impermeable layer below it and above the main water table.


Water Table
Well A
Well B
Pressure Surface
Land Surface
Aquifer
Aquiclude
Impervious

E. **Recharge** - infiltration of water during and after rainfall and snow melt.

III. Springs, wells. and gysers

A. **Spring** - occurrence of the intersection of the water table and the surface of the earth materials (may be under water in a lake or the ocean).

B. **Well** - man dug opening across the zone of aeration into the zone of saturation.

C. **Aquifer** - permeable earth material confined by impermeable units, i.e. sandstone between shales. If the aquifer intersects the surface of the earth water may infiltrate and charge it .

D. **Artesian Water** - water flowing under pressure from the aquifer to a level above the aquifer; may come out onto the surface from a spring or a well.

E. **Thermal springs** - springs flowing water which is at temperatures above normal earth temperatures in that region. The water is normally heated by cooling magmas in the subsurface.

F. **Gysers** - thermal springs where the water temperatures are such that part of the water comes out as steam.

IV. Caves and karst

A. **Caves** - many caves are formed by ground water infiltrating along joints and fractures in rocks and then dissovling parts of limestone layers. If the cave is above the water table some of the dissolved materials may be precipitaed to form stalagmites, stalactites and other features in the caves.

B. **Karst** - areas underlain by limestone or other rock which is undergoing or has undergone solution in the past. The solution results in subsidence pits as the soil and rock overlying the dissolved units collapse.i.e. Florida.

GEOLOGIC HAZZARDS

Introduction - awareness of our environment is making us aware of the potential dangers of natural or induced hazzards. Geologists offer the potential of identifying potential hazzards and thus preventing or avoiding much loss of life and property values. Unfortunately man, the optimest and the greedy, prefers to ignore many of the obvious potential hazzards and likes to or is willing to live in many areas that are the most hazzardous.

A. Definition - any hazzard resulting from a geologic phenomenon. This may include intervening work of man. Size may vary from a small localized feature such as rocks falling off of a cliff to subsidence of vast areas of land under ocean waters. Causes are variable and event may be repeated frequently or infrequently.

Types of Hazzards -

A. Volcanic associated - discussed under volcanoes; we cannot prevent the volcano but we are able to predict some eruptions and with more study will probably be able to predict all eruptions in the future.

1. Earthquakes
2. Lava flows
3. Ash falls
4. Mudflows
5. Global temperature changes

B. Earthquakes - we can identify the most likely areas of occurrence and given time may be able to predict when an earthquake will occur.

1. P and S waves set up vibrations which if of sufficent intensity can cause collaspse of buildings and other structures resulting in the loss of life and property Engineeris can design buildings

to withstand the vibrations but the greater the intensity, the greater the cost. We cannot prevent the earthquake, what is our cost limit.

2. Waves may be generated in water as a tsunami (tidal wave) or seich (wave generated in lake) which can cause inundation of ships and boats and striking shore, vast damage to seaside structures. Again we cannot prevent these phenomena but we can build our ports and towns in areas the tsunami or seich is not likely to hit.

3. Earthquake induced features include landslides, rockfalls, slumps, and related features. In these instances the condition has developed by weathering and erosional processes over a period of time and the earthquake is the triggering mechanism. This includes features such as rockslides into lakes which cause a wave to crest the dam holding the lake and the subsequent flood down valley.

C. Gravity Events - events which are developed by weathering and erosional processes and ultimately trigged when the gravitational pull exceeds the tensional bonds. Rockslides, slumps, earthflows, rockfalls, etc. These features are most common in areas of relief, especially high relief of mountainous areas and may be aided by saturated moisture conditions. When they occur they leave obvious scars which will generally be coved by vegetation in time. Areas with potential for gravity event hazzards can usually be easily identified. Some events can be prevented by proper construction and agriculture practices.

D. Floods - Streams are the natural runoff channels for the hydrologic cycle. Excess water will be channeled down them whenever large storms or above average moisture conditions occur. The floodplain in a valley is the natural place for the excess water to flow when the flood conditions occur. The floodplain is also the breadbaset of the world. Man generally does not need to live on the floodplain but can live adjacent to it or on higher terraces above the current floodplain and still till the floodplain. Man must accept that there will be the flood when the right conditions are met and a crop may be lost as a result. If man must live on the floodplain (in the case of exceptionally large rivers with vast floodplains, such as the lower Mississippi Valley, etc) a home should be built on an artifical elevation (earth mound) high enough to be above the high flood level.

E. Ground Water -

   A. Solution and collapse

   B. Lowering of ground water table and dessication of sediments with subsidence of land areas resulting.

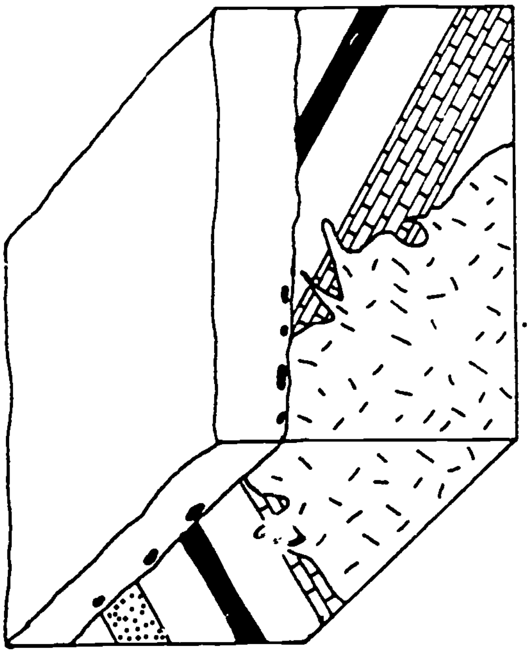
   C. Pollution - this is a critical one for future needs.

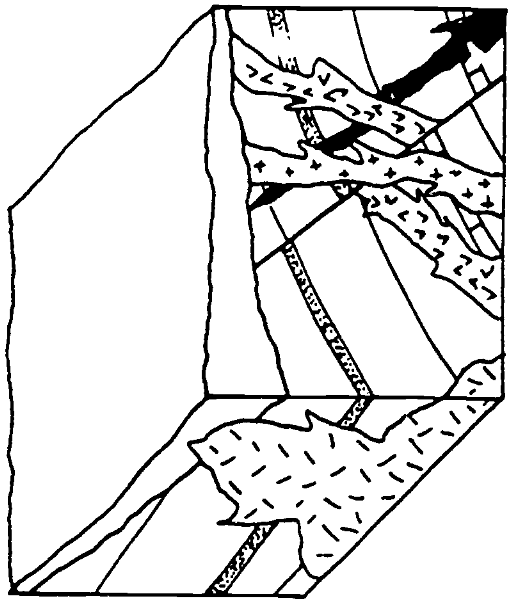
   D. Triggering mechanism, such as lubrication or increased weight, for some gravity events.

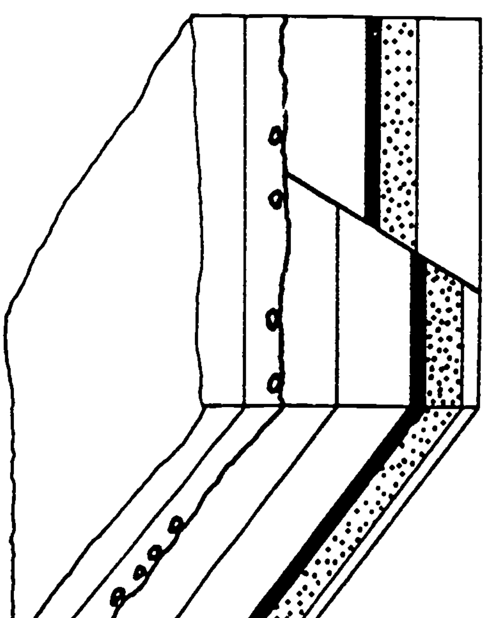
F. Glacial advances - needs more study, can't prevent or predict at present.

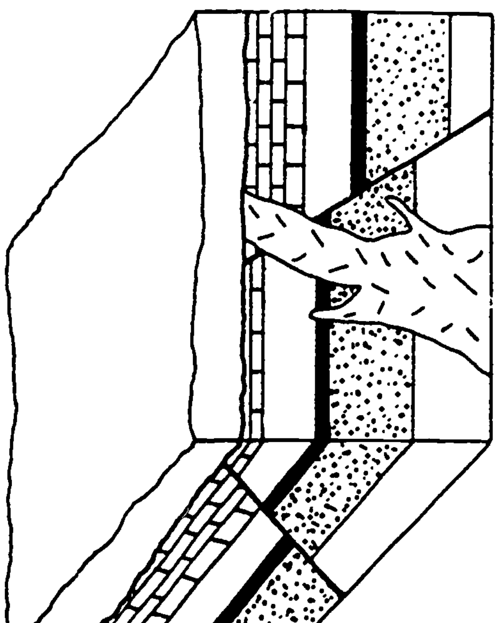
G. Wind storms - cyclones, tornadoes, hurricanes, monsoons, and other wind storms are meteroric features which we will not discuss but list as potential hazzards which are dependent on the local climatic conditions.

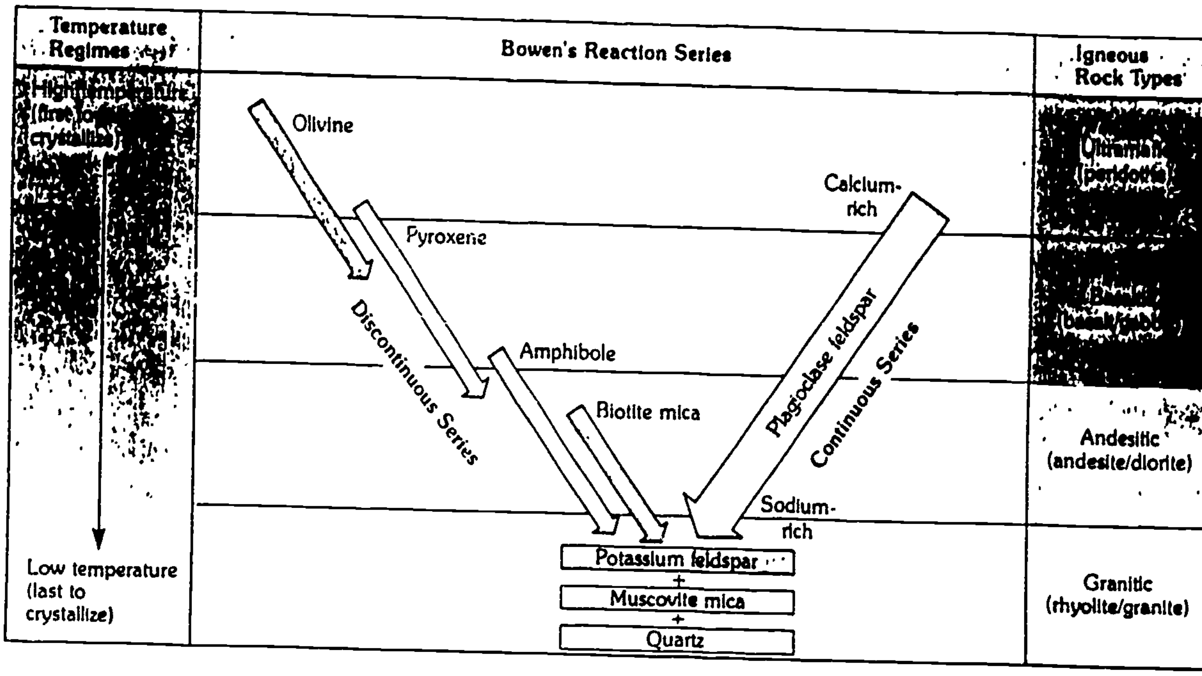
Lab pass outs, not in exercises.











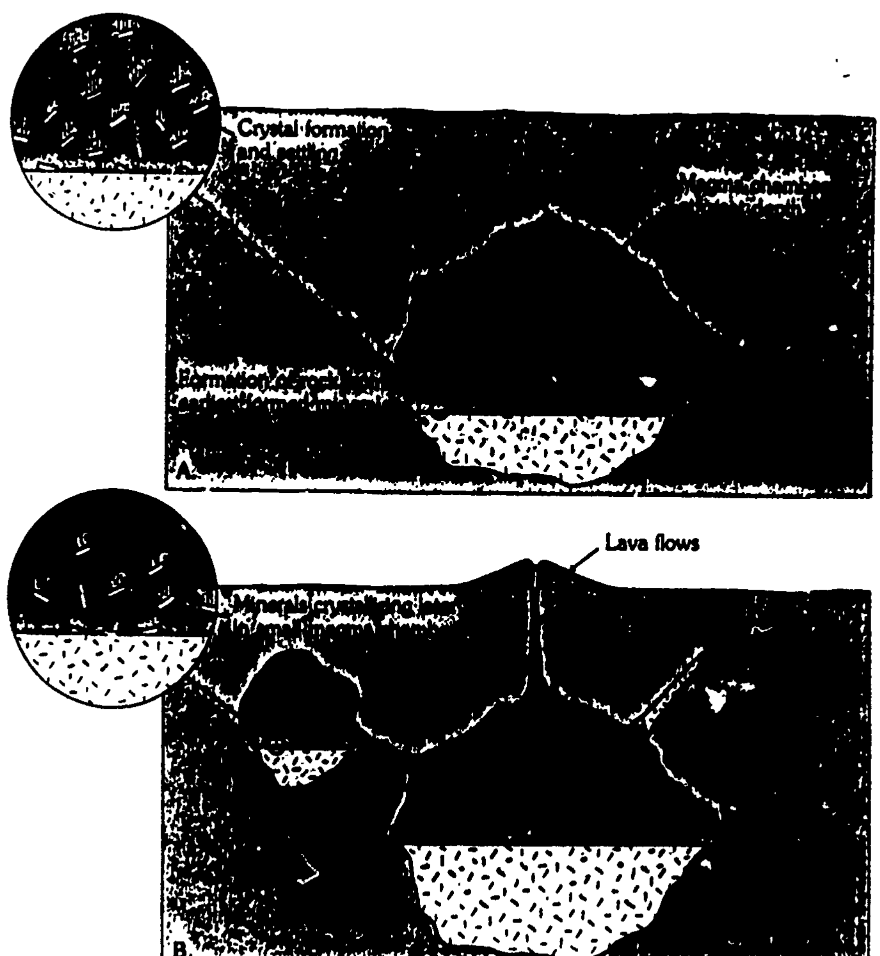
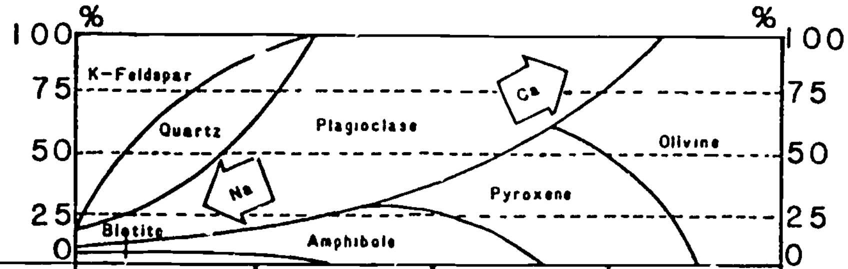


FIGURE 3.7
Separation of minerals by fractional crystallization. A. Illustration of how the earliest formed minerals can be separated from a magma by settling. B. The remaining melt could migrate to a number of different locations and, upon further crystallization, generate rocks having a composition much different from the parent magma.

MINERAL COMPOSITION



Rock Name	Extrusive Aphanitic	rhyolite	andesite	basalt	
	Intrusive Phaneritic	GRANITE	DIORITE	GABBRO	PERIDOTITE
Color		Light ⟶		Dark ⟶	

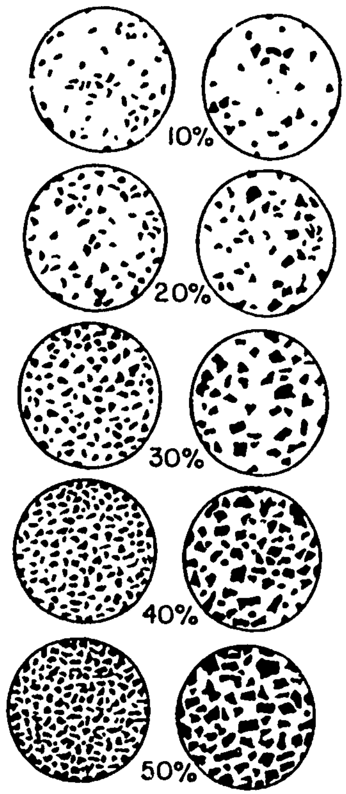


Figure 4.3 - Igneous Rock Classification

Three igneous rock types don't fit into the above classification scheme.

Obsidian- a massive volcanic glass exhibiting a near-perfect conchoidal fracture pattern. Obsidian's chemical composition is similar to granite or rhyolite.

Pumice- generally light colored and highly vesicular. Glassy shards can often be seen with the aid of a hand lens.

Tuff- a very fine-grained pyroclastic rock composed of friable volcanic ash. The individual grains feel gritty when rubbed between the fingers.

The following table lists common minerals by luster and hardness. It may help you get stsrted on the mineral identitification.

Non-Metallic (light)		Non-Metallic (dark)		Metallic	
Talc	1	Biotite	2-3	Galena	2.5
Gypsum	2	Hematite	1.5-5	Chalcopyrite	4
Halite	2-2.5	Limonite	1.5-5	Hematite	5-6.5
Muscovite	2-3	Sphalerite	3.5-4	Magnetite	6
Calcite	3	Amphibole	5-6	Pyrite	6-6.5
Fluorite	4	Pyroxene	5-6		
Orthoclase	6	Olivine	6.5-7		
Plagioclase	6	Garnet	6.5-7.5		
Quartz	7				

Sandra Bushnell
Sheryl Gillis
Kelly Willis
Linda Warner

Astronomy 301 Geology Section Lab Exam December10, 1987 Erik Weberg

NAME ____________________

Identify the ten samples and answer the questions. 2 points each.

1 a)
b) What is this used for?

2 a)
b) Where was this rock deposited?

3 a)
b) Is this plutonic or volcanic?

4 a)
b) What chemical elements are abundant in this rock?

5 a)
b) Why don't we find this mineral in clastic sedimentary rocks very often?

6 a)
b) Why is color a poor criteria for identifying this mineral?

7 a)
b) What conditions were necessary to form this rock?

8 a)
b) Where may this rock have been deposited?

9 a)
b) What feature best allowed you to identify this mineral?

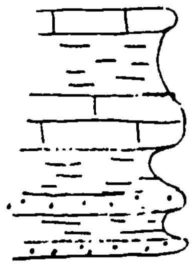
10a)
b) What chemical elements are in this rock?

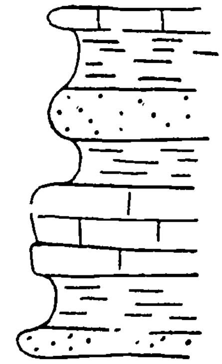
11. Why does a porphyritic rock have both large and small crystals? (4 pts)

12. What is it about halite which may interest one of your students? (2 pts)

13. Your third-grader brings you a rock that his/her dad/mom found on a river bank during their vacation in Arizona. Your student wants to know what it's made of, how it formed, and how it came to be where it was. What are ya gonna' do now? This is a question you may be faced with when you get a class to teach. (5 pts)

14. The following rock exposures were found a great distance apart. Correlate the rock layers to reconstruct how the layers may have looked before erosion. (3 pts)



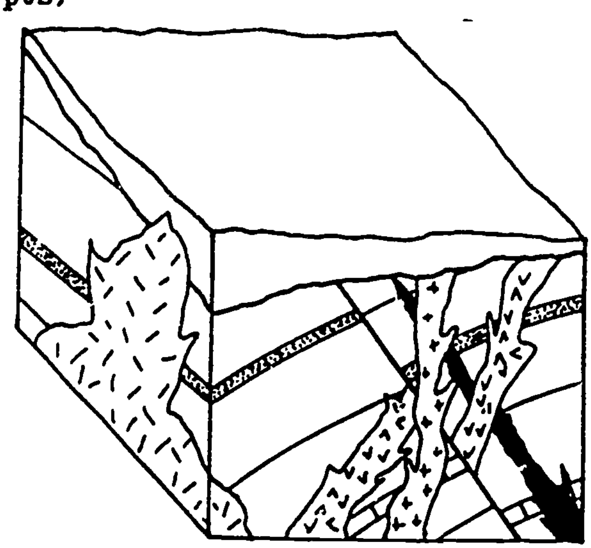


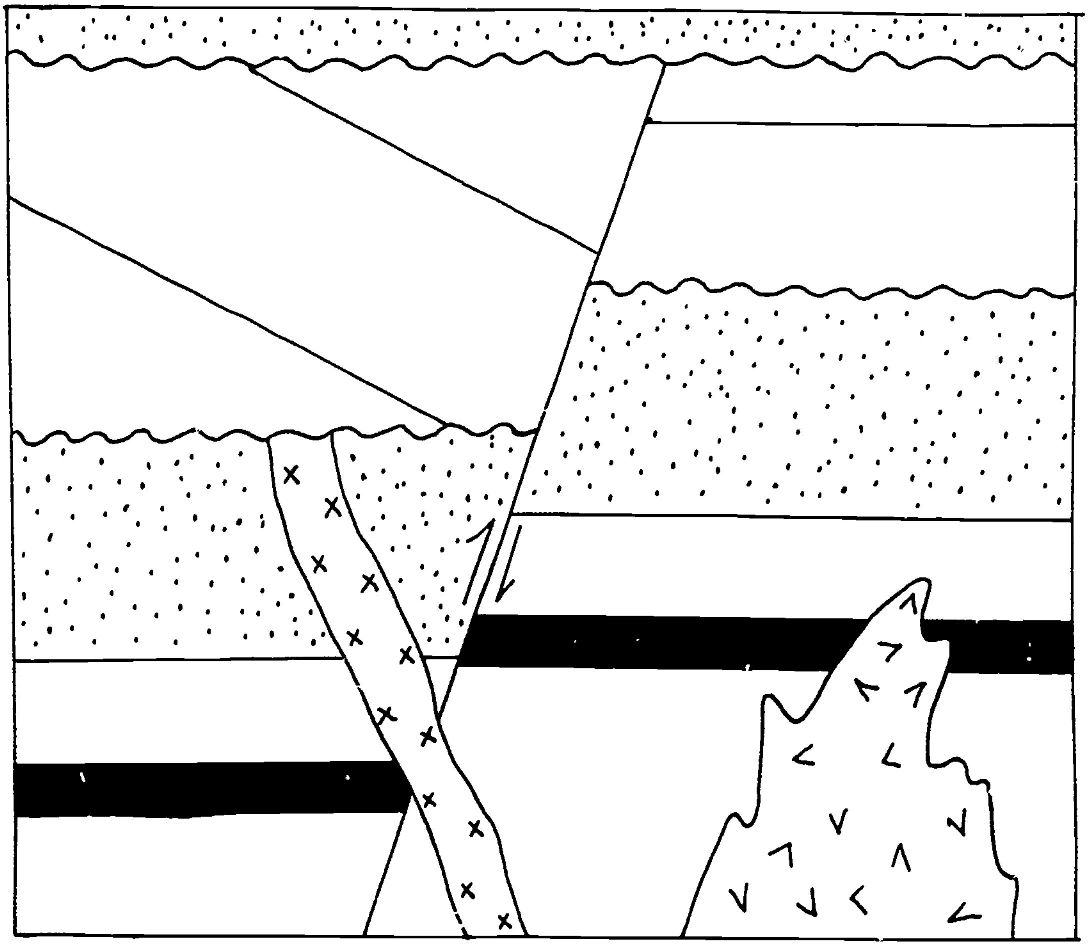
15. What structure is drawn here? (1 pt) Label the axis. (1 pt)

16. How do you know that these rocks have been structurally deformed and not just deposited this way? (2 pts)

17. What type of fault is shown here and what led you to that conclusion? (2 pts)

18. Study the following block diagram. Use complete sentences to list the proper sequence of events after you have labeled the rock layers as to their ages with 1 being the oldest. (5 pts)





A B

Which igneous rock is older, A or B? ______. How did you determine that or why can't you tell? (2 pts)

There are three thihgs wrong with this cross section. Prepare a well written paragraph describing the mistakes in this cross section. Use complete sentences and read your paragraph to yourself to make sure it makes sense. Use the back too if necessary. (3 pts)

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

Source Materials for Geology

Source materials for geology are numerous and widely scattered. New materials are being developed daily as the public awareness of geologic hazzards increases.

Primary and secondary teachers should ask friends, neighbors, the chamber of commerce, museums, professional geologists, professional geological societies, and city and state agencies for information concerning locally available collections and displays of geological materials as well as speakers.

Rock hounding has been the largest hobby in the U.S. for several decades. There are several hundred rock hound clubs in the U.S. Their members have collections and are often willing to give a talk on them and are usually proud to show some of their specimens. Sometimes they will lead a local field trip to good collecting sites.

State geological surveys are an excellent source of literature on the local geology and many have publications of general interest on mineral and fossil collecting. State geological employees are often available for talks.

The daily newspaper is an excellent source of current geologic events, such as earthquakes, mud slides, volcanic eruptions, etc. for daily discussions.

Field guides, following major highways and local roads to features of major geologic significance, have been made for most parts of the U.S. by professional geologists. New guides are prepared for geological meetings each year. Most guides are published by regional or state geological societies and in short runs. Many are out of print within a year or two. Libraries at universities with good geology departments are the best source for guide books.

Computer software is rapidly being developed for earth science. Some programs are available from the following firms.

Projected learning programs, Inc., P.O. Box 2002, Chico, CA 95927

Cambridge Development Lab. Inc., 1696 Massachusetts Avenue, Cambridge, MA 02138

General geologic teaching materials, relief maps, overhead transparencies, 8mm film loops, film strips, 35mm slide sets, lab supplies, etc. are available from:

Ward's Natural Science Establishment, Inc.
P.O. Box 1712, Rochester, NY 14603 or
P.O. Box 1749, Monterey, CA 93940

Hubbard, P.O. Box 104, Northbrook, IL 60065

Journals. There are several journals published for the non-specialist and general public. Most of these should be in the public library of any major city and school system.

Earth Science - Published by American Geological Institute, Dept. E503, 4220 King Street, Alexandria, VA 22302-1507 (topical articles for the public).

Journal of Geological Education - Published by National Association of Geology Teachers c/o Allen Press, Inc., P.O. Box 368, Lawrence KS 66044. Articles on teaching techniques, new book reviews, teachers column, supply and equipment advertisements, etc.

Geotimes - Published by American Geological Institute (5205 Leesburg Pike, Falls Church, VA 32041). Provides a summary of developments in geology, current geologic events, new publications, new films, etc.

Rocks and Minerals - Heldref Publications, 4000 Albermarle Street, NW, Washington, DC 20016. Collecting localities, museum displays, mineral shows, book reviews, etc.

Scientific American - Published by W.H. Freeman Co., 660 Market Street, San Francisco, CA 94104. Excellent summary articles on major topics.

Films. Numerous geology films are available, however most are made for grades 7-12. Two major sources are available for films.

1. Ladd, G.T., and Snyder, P.B., 1978, Selected films on geology. Available from American Geological Institute. Provides a brief description of each film, intended audience, running time, and year of production.

2. National AudioVisual Center, Information Services, EQ., Washington, DC 20409. The National Audio-Visual Center sells and rents films produced by many government agencies. Vidiocassette copies may also be purchased at modest prices.

35mm Slides. Collections of 35mm slides are available from a number of sources. Individual slides and topical slide sets may be purchased from the follcwing agents.

Ward's Natural Science Establishment, Inc.
P.O. Box 1712, Rochester, NY 14603 ‹r
P.O. Box 1749, Monterey, CA 93940

JLM Visuals, 1219 12th Avenue, Grafton, WI 53024

Earth Slide by John S. Shelton, W.H. Freeman Company, 41 Madison Avenue, New York, NY 10010. (500 slides, many aerial views, illustrate most physical geology topics).

Slides for geology by D.A. Rahm, McGraw-Hill Book Co., 330 West 42nd Street, New York, NY 10036 (321 slides, many different topics of physical geology).

Geology Slides by D. Tasa, Tasa Graphics, 5230 W. 73rd Street, Minneapolic, MN 55435 (Many slides are of full color line drawings).

Physical Geology by W. Hamilton, W.H. Freeman Co., 41 Madison Avenue, New York, NY 10010 (150 slides on most topics of physical geology).

Mineral, Rock and Fossil specimens. The best source of rock, mineral and fossil specimens is:

Ward's Natural Science Establishment, Inc.
P.O. Box 1712, Rochester, NY 14603 or
P.O. Box 1749, Monterey, CA 93940
Specimen quality is good and service is gcod.

Fossils of high quality and good service may be obtained from:

Geological Enterprises, Inc., Box 996, Ardmore, OK 73401

Malicks' Fossils Inc., 5514 Plymouth Road, Baltimore, MD 21214

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

Lab Exercise - Minerals

Introduction. Without minerals Earth would not exist as we know it. Most of Earth is formed of crystalline solids called minerals. Minerals form rocks and are the source of our inorganic natural resources. A few minerals occur widely, whereas most are restricted to local areas. Some are rare, occurring in only one or two locations worldwide. Of the approximately 3,000 known minerals less than 25 are considered common.

Minerals are formed in a variety of ways. Many minerals are formed by crystallization from molten matter called magma. These minerals have formed at high temperatures. Other minerals form at lower temperatures by precipitation from ion-saturated sea and ground water. Some minerals result from evaporation of sea and ground waters.

Man's utilization of minerals continues to increase, whether it is for use as gems, chemicals, building materials, precious metals, etc. The quest for minerals has caused wars and today is an environmental concern.

Minerals that form inorganic natural resources of economic importance are called ore minerals. Most of these are limited and at our present rate of consumption will be exhausted within a few hundred years.

Principles to be learned.

1. Recognize the physical properties of minerals.

2. Using the physical properties identify some of the common rock forming and ore minerals.

3. Economic uses of the ore minerals identified.

Terms.

Cleavage - the splitting of a mineral along planes determined by the crystal structure of the mineral.

Color - the visual property of a mineral, apart from its form, dependent upon a response to light.

Crystal habit - the regular polyhedral form, bounded by plane surfaces, reflecting the periodic or regularly repeating internal arrangement of atoms.

Fracture - the manner of breaking and resulting appearance of a mineral.

Hardness - measure of the resistance of a mineral to being scratched.

Luster - the character of the light reflected by a mineral.

Mineral - a naturally occurring crystalline, inorganic substance with a chemical composition of limited range.

Specific Gravity - ratio of the mass of a body to the mass of an equal volume of water at a given temperature.

Streak - colcr of a powderized mineral.

PART I - Physical Properties

The first physical properties that are observed when looking at a mineral are color, luster, crystal form and cleavage. Sometimes the mineral can be identified from the combination of these characters but usually simple tests must be conducted to determine other physical properties of the specimen before the mineral can be correctly identified. These commonly include tests for hardness, streak, solubility and specific gravity, less often tests are made for taste and magnetism.

Your instructor will demonstrate the physical property tests. As you learn to recognize and test for each of the physical properties observe the examples provided by your instructor.

Color & Translucency. The color of a mineral may be unique, or more often, the color may vary depending upon trace amounts of impurities in the specimen. The intensity of the color may also vary. Always observe the specimen in direct light to determine its color. Most minerals are opaque, that is they will not transmit light. Other minerals will allow some light to pass through them, these are called translucent. Often the translucent part may be a thin edge of the specimen. Minerals that allow light to pass through them are called transparent. Most transparent minerals are colorless or show a very light intensity of a particular color.

Never rely upon color alone when identifying a mineral. Use color in combination with other physical properties.

Luster. The luster of minerals varies from the brilliancy of gem stones to the dull earthy tones of some ore minerals. No tests are required to determine the luster since it is a physical property that is observed. Many terms are used to describe luster. The most common are given below.

Adamantine - the brilliant sparkle of diamonds or other gems.

Vitreous - the appearance of the broken edge of a clear or colored bottle or pane of glass.

Metallic - the dull to bright sheen of a metal.

Earthy - the dull appearance of dirt or dark soil.

Pearly - the satiny glow of a pearl or interior of an oyster shell.

Waxy - the shiny wax appearance.

Nonmetallic - any luster lacking the sheen of a metal.

Crystal Habit. The crystal habit (Fig. 1.1) of a mineral is determined by the internal arrangement of the atoms that the crystal is made of. All crystals form in one of six crystal systems, which are based on symmetry. There are many forms in each crystal system. A perfect crystal grows in unrestrained space. Since most minerals develop in confined space they are not perfect. Crystals are recognized by the planar symmetry of the faces that develop as they grow. Crystals commonly have multiple faces; they may have as few as four faces or many faces. A mineral may occur in more than one crystal form. Many different minerals occur in the same crystal habit.

Often minerals lack crystal form or the crystals are so small that they can be recognized only when observed with a microscope or by X-ray analysis. Crystal habit should be used in combination with other physical properties.

Cleavage and Fracture. The way that a mineral breaks is described as cleavage or fracture. This depends upon the internal arrangement and bonding strengths of the atoms forming the mineral. Cleavage is a regular planar break that develops along surfaces of weak bonding strengths (Fig. 1.2). Perfect cleavage produces a smooth planar surface in reflected light. Poor cleavage produces a step effect. Some minerals have more than one cleavage. The number and angles between cleavage directions are important physical properties for identification of many closely related minerals.

Fracture is any irregular breaking surface of a mineral. Self-explanatory terms to describe fracture include hackly, fibrous or splintery. A conchoidal fracture is the rounded,

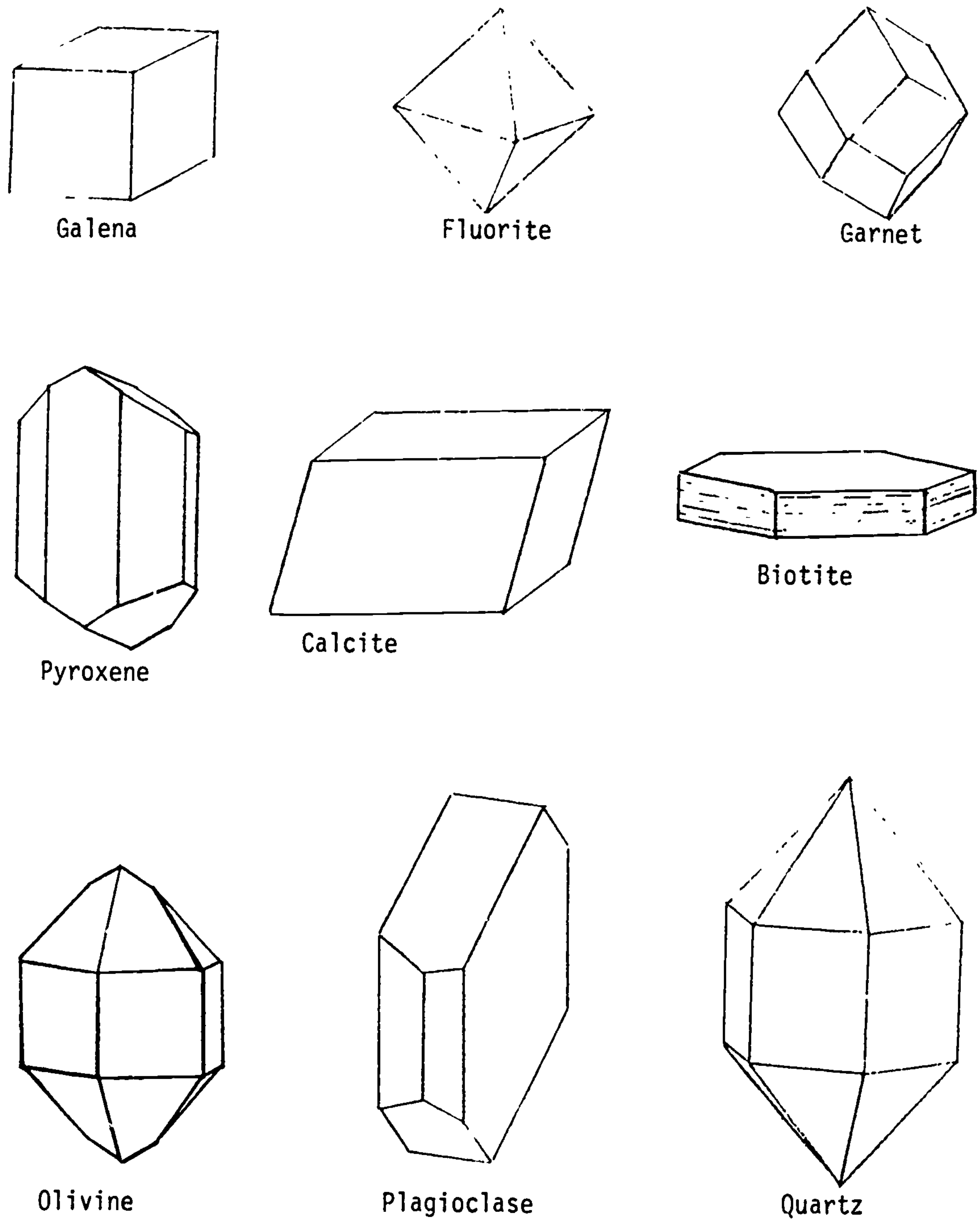


Figure 1.1. Some common crystal habits of some of the minerals studied.

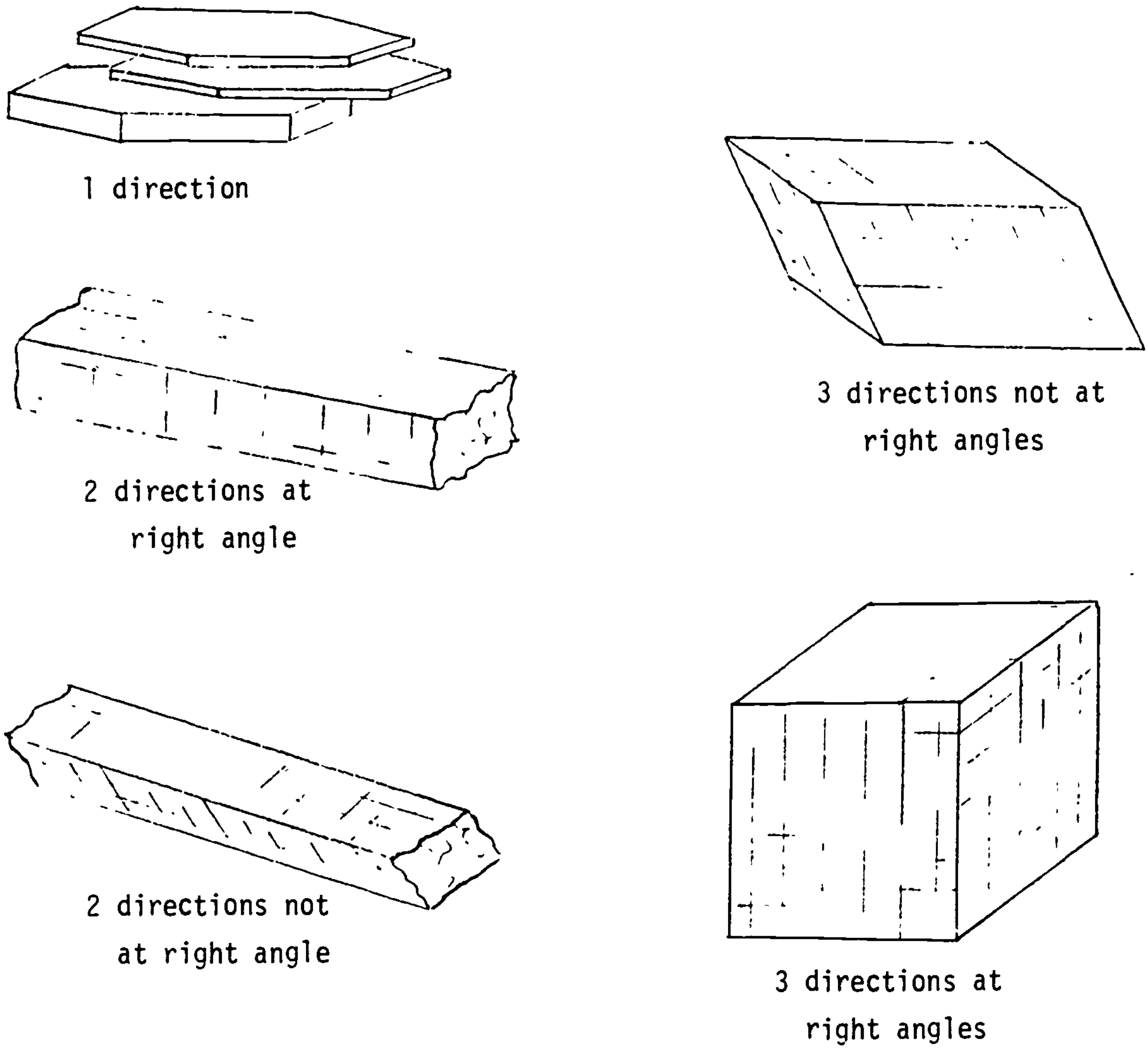


Figure 1.2. Cleavage diagrams showing five different types recognized.

shallowly concave, or convex concentrically banded break that occurs in glass.

Streak. To determine the streak of a mineral drag an edge or corner across an unglazed porcelain plate, powderizing a small part of the specimen. Blow off the excess. Check to make sure that you did not cut into the porcelain plate which will happen if the specimen being tested is harder than the porcelain. Now observe the color of the powder. The color of the powder can be significantly different or the same as the color of the specimen. The streak will always be one color for a particular mineral.

Hardness. The hardness of a mineral is a measure of its resistance to being scratched.

The standard reference set for comparing the relative hardness of a mineral is called Mohs´ Scale of Hardness. The minerals and their relative hardness are given below.

1. Talc (softest)	6. Orthoclase
2. Gypsum	7. Quartz
3. Calcite	8. Topaz
4. Fluorite	9. Corumdum
5. Apatite	10. Diamond (hardest)

The relative difference of hardness between adjacent minerals on the scale is not the same. For example, the difference between corumdum and diamond is much greater than the difference between corumdum and topaz.

To determine the relative hardness of an unknown specimen use a sharp corner and see which of the minerals in the Mohs´ Scale of Hardness can be scratched. The hardness is the point at which it will scratch a softer mineral but not scratch the next harder mineral. Now rotate your specimen and try another corner. Some minerals have different degrees of hardness on different edges because of the internal atomic arrangement in the crystal. Be careful not to mistake the powderized streak of your specimen for a scratch.

The hardness of some common items that may be used in place of the minerals in the Mohs´ Scale are provided.

Glass or knife blade - approximately 5.5-6 (depends upon impurities in the glass and type of steel in the knife blade)

Nail - 5-6 (depends upon the type of iron)

Penny - 3.1

Fingernail - 2.2-2.5 (may vary with the individual or fingers of an individual)

Specific Gravity. A measure of the relative weight of a substance is referred to as its specific gravity. To determine the specific gravity one must take the ratio of the mass of a substance compared to the mass of an equal volume of water at a given temperature. Often the laboratory equipment necessary to do this is not available. An estimate of the specific gravity can be made with a little practice. We all refer to an object as being light or heavy depending upon its size and weight. The same relative comparison may be applied to mineral specimens. Many metallic minerals are relatively heavy compared to the nonmetallic minerals. Among the metallic minerals some, such as gold, lead or mercury, are heavier than the copper bearing minerals. Although not as obviously different as the examples just cited, differences among the nonmetallic minerals may be recognized with practice.

Taste. A few minerals are easily dissolved in water. These minerals also have distinct salty or bitter tastes when touched with the tongue. The test is obvious. The common example is halite which we usually call salt.

Solubility in acid. Diluted hydrochloric acid is used to test the solubility of a group of minerals called carbonates. This test is made by dropping one or two drops of the acid on the specimen to see if it effervesces (gases are given off as it dissolves in the acid). Calcite reacts quickly whereas dolomite has to be powdered (increasing the surface area) to react moderately rapid. Be careful not to get the acid on your clothes, body or personal items as it is quite corrosive. Do not apply it indiscriminately and wipe it off with a paper towel immediately after you have made the test.

Magnetism. The test for magnetism is to use a small magnet and see if it will adhere to the specimen. Only a few minerals are magnetic.

Other Physical Properties. Special equipment may be required to make tests for some minerals. These include ultraviolet light to check for fluorescence and Geiger counters to check for radioactivity. Although some of the minerals that you will be studying are fluorescent we will not check for these physical properties. Thin plates of a few minerals are flexible. Some minerals are malleable, that is, they can be hammered into thin sheets. This group includes gold, silver and copper.

PART II. Mineral Identification

Minerals are identified by the recognition of their characteristic physical properties. Rarely can this be done on the basis of one physical property, usually it is a combination of three or more physical properties. Although different methods are used by some geologists to identify minerals one of the most frequently used techniques is to begin with luster, color, crystal habit (if present), cleavage or fracture, streak, and hardness. Specific gravity, magnetism, reaction to acid, taste, and other less common physical properties are determined when the mineral cannot be identified by the earlier determined physical properties. Occasionally the more unique physical properties are obvious when the specimen is first handled or observed, i.e. greasy feel, higher specific gravity, flexibility, transparency.

For each numbered specimen determine the physical properties filling in the appropriate blanks on the exercise sheet. Then identify the specimen using the mineral charts provided (Tab. 1).

Spec. #	Color	Luster	Crystal Form	Cleavage	Streak	Hardness	Spec. Gravity	Solubility in acid - Taste Magnetism	Mineral Name
1.									
2.									
3.									
4.									
5.									
6.									
7.									
8.									
9.									
10.									
11.									
12.									
13.									

Table 1
Physical Properties of Common Minerals

Amphibole Na,Ca,Mg,Fe,Al Silicate	Dark greenish black to black, luster vitreous, may be splintery, H. 5-6, 2 cleavage planes at 60o & 120o, Sp. Gr. 2.9-3.2, prismatic crystals. Common in igneous rocks.
Azurite $Cu_3(CO_3)_2(OH)_2$	Azure blue, luster vitreous to dull earthy, streak pale blue, H. 4, commonly occurs massive, fibrous fracture, Sp.Gr. 3.77, effervesces with HCl, ore of copper, gem stone.
Biotite K,Mg,Fe,Al Silicate	Dark brown to black, luster pearly to vitreous, streak colorless, H. 2.8-3.2, 1 perfect cleavage, commonly occurs in "books" or foliated blocks, translucent & flexible in thin plates. Accessory mineral in igneous rocks.
Calcite $CaCO_3$	Colorless, white, yellow, luster vitreous to earthy, streak colorless or white, H. 3, 3 cleavage planes rhombohedral, translucent to transparent, shows double refraction if transparent, strong reaction to cold dilute HCl, common in limestone. Used in cement.
Chalcopyrite Cu,Fe,S_2	Brass yellow, luster metallic, tarnishes purple, streak greenish black, H. 3.5-4, tetragonal crystal form, but usually massive, uneven fracture, Sp.Gr. 4.2. Ore of copper.
Chlorite Mg,Fe,Al Silicate	Green to greenish black, luster vitreous, streak colorless to faint green, H. 2.25, perfect basal cleavage, thin sheets flexible. Occurs as foliated blocks or small flakes. Metamorphic mineral. No commercial use.
Fluorite CaF_2	Variable color, often yellow, green, purple, luster vitreous, streak colorless, H. 4, perfect 4 cleavage planes (octahedral), Sp.Gr. 3.2, often transparent to translucent. Used in steel-making, glass, hydrofluoric acid.
Galena PbS	Lead gray, luster bright metallic, streak lead gray, H. 2.5, perfect cubic cleavage, Sp.Gr. 7.4-7.6. Ore of lead.

Garnet Fe,Mg,Ca,Al Silicate	Variable, often reddish brown or yellowish green, luster vitreous to resinous, streak none H. 6.5-7.5, cubic crystals, uneven cleavage, Sp.Gr. 3.5-4.3, may be massive, often crystalline. Metamorphic mineral. Used as a gem & abrasive.
Graphite C	Steel gray, luster metallic to earthy, streak gray-black, H. 1.5, perfect basal cleavage, greasy feel, occurs in foliated masses. Metamorphic mineral. Used in lubricants, pencils, electrodes.
Gypsum $CaSO_4.2H_2O$	Colorless to white, luster vitreous, streak white to colorless, H. 2, good cleavage in one plane, conchoidal fracture in one direction, may be fibrous, massive or crystalline, Sp.Gr. 2.3, evaporitic mineral. Used in wall board, cements, plaster.
Halite NaCl	Colorless, white, gray, highly variable, luster vitreous, H. 2.5, 3 perfect cleavage planes at right angles (cubic) often translucent to transparent, Sp.Gr. 2.2, salty taste, thin sheets flexible. Evaporitive mineral. Common salt.
Hematite Fe_2O_3	Black, steel gray, or red; luster earthy or metallic, streak red, H. 6, Sp.Gr. 5.2, irregular fractures, ore of iron, common accessory, in many rocks.
Limonite $Fe_2O_3.nH_2O$	Yellow, orange, brown black, luster earthy, streak yellow brown, H. 1.5 (appears softer), earthy masses amorphous, Sp.Gr. 4.37, not a true mineral. Ore of iron, paint pigment.
Magnetite $FeOFe_2O_3$ or Fe_3O_4	Black, streak black, luster metallic, H. 6. Sp.Gr. 5.17, strongly magnetic. Ore of iron. Accessory in many igneous rocks.
Muscovite K,Al Silicate	Colorless to white, luster pearly to vitreous, streak white, H. 2-2.5, 1 perfect cleavage, commonly occurs in "books" or foliated blocks, transparent & flexible in thin plates. Accessory mineral is acidic igneous rocks. Used in insulation, lubricants, paints, & wall paper. Commercial occurrences in metamorphic rocks.
Olivine $(Mg,Fe)_2SiO_4$	Glassy green, luster vitreous H. 6.5-7, Sp.Gr. 3.2-3.4, subconchoidal fracture, poor one plane cleavage. Common in mafic igneous rocks.

Opal $SiO_2.H_2O$	Variable color, commonly white, luster dull to waxy, streak colorless, H. 5.5-6.5, conchoidal fracture, Sp.Gr. 2-2.3, may be translucent in clear varieties. Amorphous masses, occurs in veins & fractures. Gemstone when brilliant colors present.
Orthoclase Feldspar $K(AlSi_3O_8)$	White, pink, green, luster vitreous, streak white, H.6, 2 cleavage planes nearly at right angles, no striations on cleavage faces, Sp. Gr. 2.6, common in acidic igneous rocks. Used in ceramics & enamelware.
Plagioclase Feldspar $Na(AlSi_3O_8)$ to $CaAl_2Si_2O_8$	White to blue gray, luster vitreous, streak white, H. 6, 2 cleavage planes nearly at right angles, striations on cleavage faces, Sp.Gr. 2.7, common in mafic igneous rocks. Some use in ceramics.
Pyroxene Ca,Mg,Fe,Al	Dark Greenish black to black, luster vitreous, H. 5-6, 2 cleavage planes nearly at right angles, Sp.Gr. 3.2-3.6, prismatic crystals short. Common in mafic igneous rocks.
Pyrite FeS_2	Brass yellow, luster metallic, streak greenish or brownish black, H. 6-6.5, cubic crystal form, massive or crystalline, Sp.Gr. 5.0. Source of sulfur used in sulfuric acid. Fool's Gold.
Quartz SiO_2	Colorless, white, gray, pink, purple; luster vitreous streak none, H. 7, conchoidal fracture, hexagonal prismatic crystals, Sp.Gr. 2.65. Common in acidic igneous rocks, some metamorphics, and sandstones. Used in glass making & electronics.
Sphalerite ZnS	Yellow brown, to black, luster resinous, streak white to reddish brown, H. 3.5-4, cubic crystals, usually massive, cleavage perfect 6 planes, Sp.Gr. 3.9-4.1. Ore of zinc.
Talc $Mg_3Si_4O_{10}(OH)_2$	White, greenish white, silvery white, grey green, luster pearly, streak white, H. 1, perfect basal cleavage, greasy feel, massive forms do not show cleavage. Metamorphic mineral. Used in paints, ceramics, paper, talcum powder.

MINERALS - Questions:

1. How do you identify a mineral?

2. Which minerals are common mafic rock forming minerals?

3. Which minerals are common acidic rock forming minerals?

4. Given pyrite and chalcopyrite. What are three physical properties common to both?

   What physical properties, other than chemical composition, distinguish them from each other.

5. Biotite and muscovite are both called micas. What physical properties are used to distinguish them?

6. Given calcite, fluorite, gypsum and halite. What are three physical properties common to all four minerals?

   What physical properties are used to distinguish them from one another?

7. Why is color not a good physical property to use alone when identifying quartz?

8. Given plagioclase and potassium feldspar specimens. What are four physical properties common to both?

What are the physical properties you can use which distinguish these two minerals?

9. Given specimens of amphibole and pyroxene. What are four physical properties common to both?

Explain how you use cleavage to distinguish them?

10. What mineral is used as:

An ore of copper -

To make glass -

To color paint -

To make wallboard -

To make cement -

An ore of iron -

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

Lab Exercises - Rocks

Introduction. A ROCK is a lithified aggregate of minerals of one or more kinds. Rocks are classified into one of three categories based on their origin.

IGNEOUS ROCKS - formed by crystallization from magma (molten material).

SEDIMENTARY ROCKS - formed from lithified particles of other rocks that are deposited by wind, water, or glacial processes or precipitated from aquatic solutions.

METAMORPHIC ROCKS - formed from previously existing rocks that are altered by heat, pressure and chemical fluids, usually heat and pressure.

Each of the next three exercises will study one of the rock types.

Principles to be learned.

1. Physical properties of each of the three rock types.

2. Recognition of and Classification of each of the three rock types.

3. Uses of rock types studied.

Terms.

Rock

Igneous Rock

Sedimentary Rock

Metamorphic Rock

PART I - Igneous Rocks

Introduction. According to currently accepted theories the Earth formed more than 4.5 billion years ago. Heat from friction and radioactivity in a gaseous cloud produced a molten mass which differentiated into layers with the heavier elements like iron and nickel sinking to the interior and the lighter elements, including silica and oxygen, moving toward the exterior. Thus the first Earth rocks to form crystallized from magma.

Terminology.

Acidic

Aphanitic

Basic

Bowen's Reaction Series

Felsic

Glassy

Mafic

Phaneritic

Phenocryst

Porphyritic

Pyroclastic

Tephra

Vessicular

Ultramafic

Classification. Igneous rocks are classified on the basis of (1) chemical composition and (2) texture. The chemical composition is reflected in the minerals that crystallize from the magma to form the rock. Texture is a measure of the size of the minerals grains, occurrence of gas bubbles, or depositional medium of the rock.

Composition. Igneous rocks may be observed in the process of formation by visiting an active volcano, such as Kilauea in Hawaii, during an eruptive phase. At the Hawaiian Islands, magma formed by heat and pressure in the mantle flows through the oceanic crust, out the vent of the volcano onto the surface as lava where it cools and crystallizes. Other magmas are forming along plate margins, such as where two plates are colliding (Fig. 2.1). Many will crystallize at depth, others will flow to the surface, sometimes partially crystallizing as they move, to vent through volcanoes, before completely crystallizing. The composition of the magma and the crystallizing process will determine the ultimate mineral composition of the rock or rocks formed.

A MAFIC or BASIC magma forms in the mantle or oceanic crust. It is rich in iron, magnesium, and sodium; it lacks excess

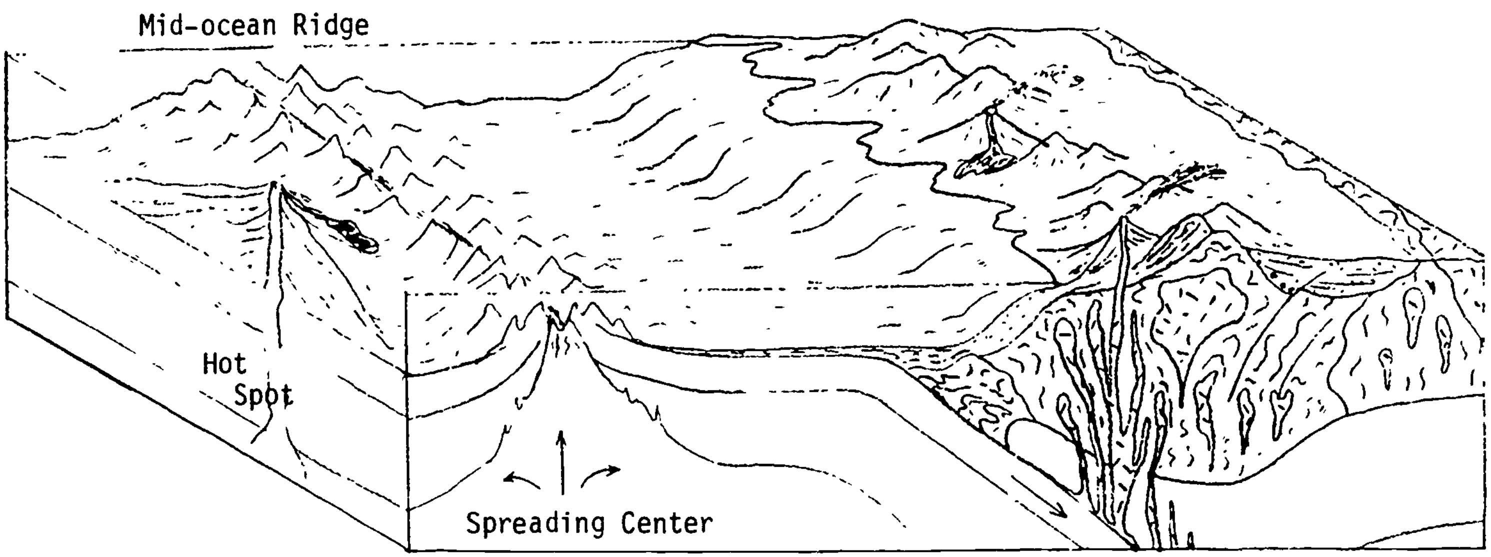


Figure 2.1. Diagrammatic illustration of the origin of igneous rocks. Lava flows extend from the active volcanoes. Melting occurs along the subducting oceanic crust producing intrusive bodies.

silica. An ACIDIC or FELSIC magma forms in the continental crust and is rich in potassium with excess silica. Magma formed at the boundary of the continental and oceanic crust or one formed in the mantle or oceanic crust and moving up into the continental crust, incorporating some continental crustal material, will have a mixed composition.

The first and last minerals to crystallize from a magma depend upon the original composition of the magma. As a magma cools the minerals crystallize in an orderly manner as shown in Bowen's reaction series (Fig. 2.2). Remember, if a magma is basic in composition minerals in the lower temperature range of the reaction series will not form. If the original magma is deficient in sodium, calcium and ferromagnesium cations then the ferromagnesium minerals and plagioclase feldspars will not be present in the crystallized rock.

Based on composition, igneous rocks may be subdivided into four categories.

ULTRAMAFIC - ferromagnesium minerals only.

Mafic or basic - rich in ferromagnesium and plagioclase minerals.

Mixed - formed by the combination of basic and acidic minerals.

Felsic or acidic - rich in potassic feldspar and quartz.

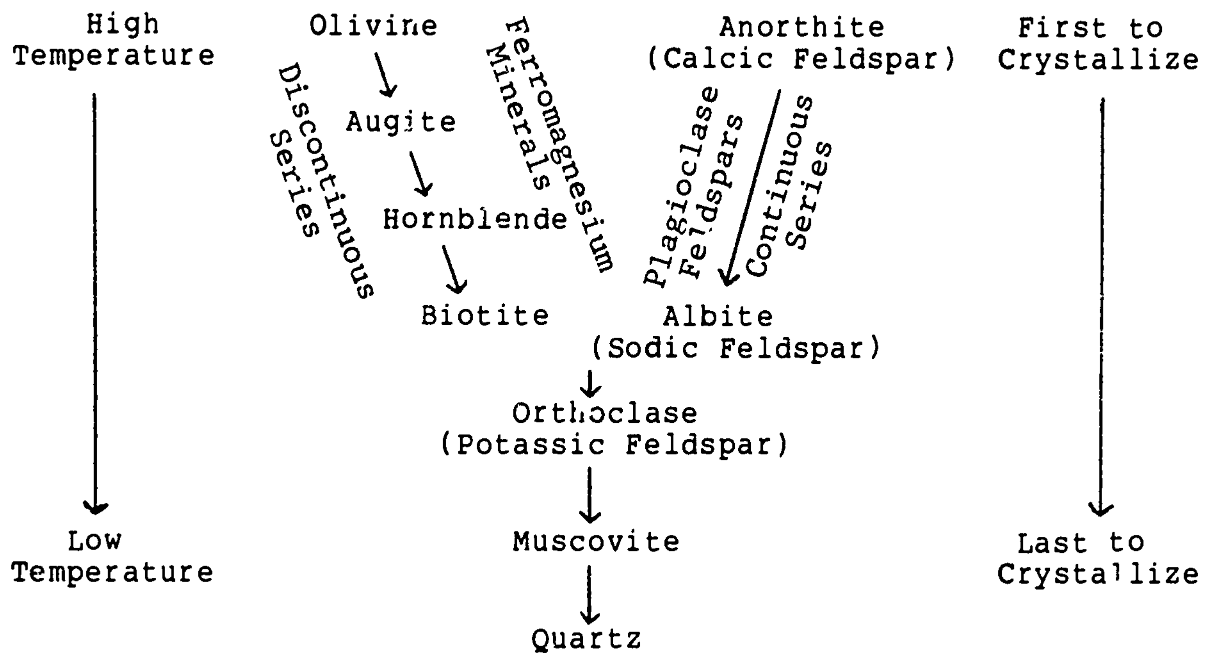


Fig. 2.2. BOWEN'S REACTION SERIES, showing order of crystallization in magmas.

Texture. As a magma cools minerals begin to crystallize. The ultimate size of the minerals depends upon the rate of cooling. Large crystals require greater lengths of time to form than small crystals. Four textures are recognized in the igneous rocks based on the size of the crystals.

GLASSY - amorphous, non-crystalline. Rate of cooling so fast crystals did not have time to form. A conchoidal fracture occurs on these rocks.

APHANITIC - finely crystalline. Rate of cooling moderately rapid, crystals may be identified with a hand lens.

PHANERITIC - crystals large enough to be seen and identified with the naked eye. Rate of cooling slower, below the surface of the earth.

PORPHYRITIC - mixed crystal sizes with PHENOCRYSTS (phaneritic size crystals) embedded in an aphanitic or phaneritic matrix. Crystallization occurred in two phases, slow at depth and rapid at or near the surface of the earth.

Most magmas contain some gases which are given off to the atmosphere as the magma crystallizes. If a magma cools so rapidly that the gases do not escape, then gas bubbles are trapped in the rock. The gas bubbles are called vessicles and give the rock a frothy or porous appearance called a VESSICULAR texture.

In some volcanic eruptions magma is blown into the atmosphere where it crystallizes and subsequently settles to earth. The particles formed are called TEPHRA. Tephra less than 2 mm in diameter are called ash, 2-64 mm are called lapilli and greater than 64 mm are called bombs if rounded and blocks if angular.

Size sorting of tephra occurs when it is blown out of the volcano and by wind currents once it is in the atmosphere. Rocks resulting from the deposits of tephra are often poorly lithified and classified on the basis of particle size. As a group they are referred to as PYROCLASTICS.

Your instructor will demonstrate the different types of composition and texture.

Rock Identification. For each of the specimens present identify the minerals (where possible) and determine the texture. Then classify the rock according to the Igneous Rock chart (Fig. 2.3).

	Minerals Present	Texture	Classification
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			

Uses. Some varieties of the phaneritic and aphanitic igneous rocks are used as ornamental and building stones. Some varieties are also used for sculpture works. Obsidian was extensively used by early man for projectile points and knife blades. Today surgeons are using obsidian scapels. Pumice is used as a scouring abrasive and insulating material. The pyroclastic rocks have been used to a minor degree for building stone.

Fig. 2.3. Classification of Igneous Rocks.

Composition / Texture	Felsic or Acidic	Mixed	Mafic or Basic	Ultramafic
	Potassium Feldspar to 50% Plagioclase none to 10% Quartz to 40% Accessory ferromagnesium minerals to 30% (usually light colored)	Plagioclase > Potassium Feldspar Quartz none to 10% Ferromagnesium minerals to 40%	Plagioclase & Ferromagnesium minerals approximately equivalent (usually dark colored)	Ferromagnesium minerals only
Phaneritic, porphyritic	Granite Granite Porphyry	Diorite Diorite Porphyry	Gabbro Gabbro Porphyry	Peridotite Dunite
Aphanitic, porphyritic	Rhyolite Rhyolite Porphyry	Andesite Andesite Porphyry	Basalt Basalt Porphyry	———
Glassy	Obsidian		Trachylite	———
Vessicular	Pumice		Scoria	———
Pyroclastic	Tuff (particles 2 mm)			
	Lapilli Tuff (particles 2-64 mm)			
	Agglomerate (rounded particles > 64mm)			
	Volcanic Breccia (angular particles > 64 mm)			

Rocks - Questions

1. Why does a gabbro have no quartz in it?

2. Why does a granite have little plagioclase feldspar in it?

3. Given a light gray gabbro or basalt. What mineral(s) could produce the color in the rock?

4. What mineral generally controls the color of a granite?

5. Explain how a diorite porphyry forms?

6. What minerals would be expected to form the phenocrysts in a diorite porphyry or andesite porphyry?

7. What minerals would be expected to form the penocrysts in a rhyolite porphyry?

8. Why might a diorite be referred to as having a salt and pepper texture?

9. Give three areas where igneous rocks are forming today.

a.

b.

c.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

GEOLOGIC TIME AND FOSSILS

Geologic Time

Introduction. The age of the earth has intrigued man for centuries. Until the discovery of radioactivity in the late 1800s and radiometric dating ir the early 1900s the age was estimated in several ways.

One idea was that the oceans were originally fresh water and gradually became saline as salts were dissolved from rocks on land and washed into the oceans. Based on this concept J. Joly in 1899 calculated the age of the earth to be 90 million years. It was later shown that this could not be correct because many factors were not considered and it is now thought that sodium has been in equilibrium in the oceans and on land since much earlier geologic time.

A second idea was that sediments accumulate at an average rate in depositional basins. If the total thickness of sediment were measured and divided by the average rate of accumulation the age of the earth could be determined. Figures ranging from 3 million years to 1.5 billion years were calculated using this method. Again problems with the assumptions disproved the attempts.

The rate of cooling of the earth from a molten mass was another concept which was used to date the age of the earth. An estimate of 100 million years was made by Lord Kelvin in the late 1800s. Again it has been proven incorrect.

Geologists used rates of evolution and uniformitarianism (the present is the key to the past, or stated in another way, processes occurred on the earth in the past as they occur today). Although the estimates were not always precise and they could not be proven, they ranged from tens of millions of years to a few billion.

Principles to be learned:

1. Determination of relative time

2. Determination of radioactive time

Terminology.

Angular Unconformity

Cross-cutting Relationships

Cross-section

Erosional Unconformity

Half-life

Inclusions

Original Horizontality

Relative Time

Radiometric Time

Superposition

Unconformity

RADIOMETRIC TIME - Radiometric dating is based on the constant decay rate (HALF-LIFE) of radioactive elements. These elements are trapped in or are part of the chemical composition of minerals when they crystallize in a magma. They break down with time into daughter products which are trapped in the mineral structure. The measurement of the ratio of daughter to parent products provides the age. This technique will give ages within the limits of the chemical methods used. It is not applicable to all rocks or minerals.

The formula to calculate the age of a rock by the radiometric method may be given as:

$$A = C\left(\frac{D}{P}\right)$$

where A - age
C = decay constant (half-life) for the specific element measured
D = amount of daughter product present today
P = amount of parent product present today

For example: If the D/P ratio is 1/8 and the decay constant is 4.5 billion years, then the age of the rock would be calculated:

$$A = 4.5 \times 1/8 = 0.5375 \text{ billion years}$$

RELATIVE TIME - Establishing the sequence of events as interpreted from the rock record at any one locality is reconstructing RELATIVE TIME. The actual number of years or exact time of occurrence is not put on the individual events, they are simply related in sequence of occurrence with one another. Four principles or laws are used to establish the sequence of events.

1. ORIGINAL HORIZONTALITY - Sedimentary strata are deposited at or near a horizontal position. Deformation of the earth's crust may contort and deform the strata at a later time.

2. SUPERPOSITION - Younger strata are deposited on older strata This principle applies to all sediments and volcanic rocks being deposited on the earth's surface. However, tectonism may distort and overturn a sequence after it has been deposited.

3. CROSS-CUTTING RELATIONSHIPS - Any rock body cutting another rock body is younger than the rock it cuts. This principle also applies to faulting and folding, that is, the fault or fold is younger than the rocks cut or folded.

4. INCLUSIONS - A rock body containing fragments of another rock must be younger than the unit whose fragments it contains. This applies to sedimentary and igneous rocks.

Study of relative time and reconstruction of the sequence of events as they occurred is generally made from CROSS-SECTIONS. Cross-sections are lateral views of a part of the earths crust. They may represent the rocks seen in a mountain side or canyon wall where erosion has removed tne adjacent materials as the mountain or canyon was formed or they may be constructed from drill hole data.

Remember when observing cross-sections that they are a vertical slice of the rock record. The rock record is not complete at any one locality. It represents time and gaps in the record are called UNCONFORMITIES. Unconformities represent time when sediments were not deposited or erosion removed earlier formed strata from the area of study.

Study each of the provided examples (Figs. 3.1-3.6) of the 4 principles. When you understand the examples then work the exercise set (Figs. 3.7-3.3) and answer the questions.

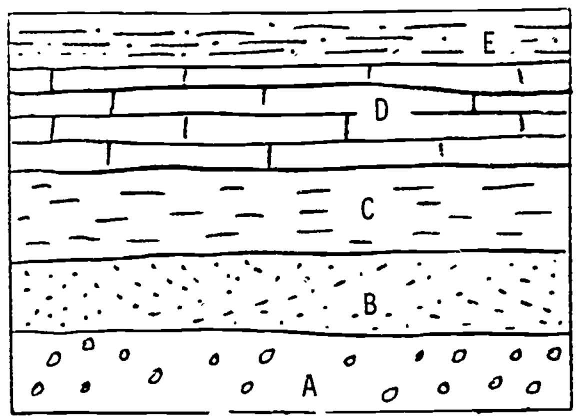


Figure 3.1 Cross-section view illustrating ORIGINAL HORIZONTALITY and SUPERPOSITION. Although the sandstone (dot pattern) shows cross-bedding the layer boundaries are at or near horizontal. In sequence, A was deposited before B, B before C, C before D, and D before E. Therefore A is oldest and E youngest.

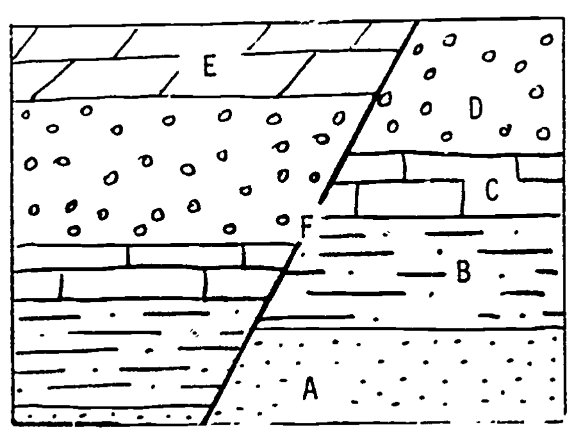


Figure 3.2 Cross-section view illustrating ORIGINAL HORIZONTALITY and CROSS-CUTTING RELATIONSHIPS. The fault F has cut the older units A through E and is therefore younger. Note the superposition of units A through E.

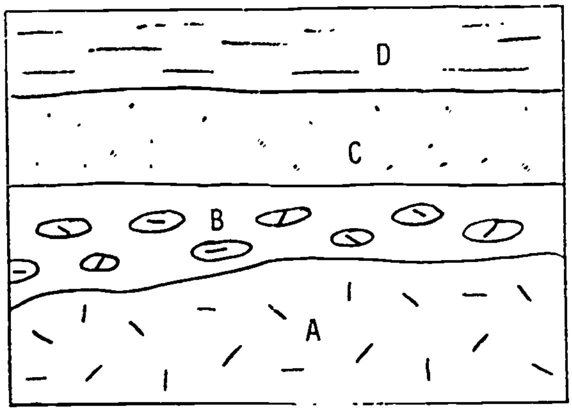


Figure 3.3 Cross-section view illustrating an UNCONFORMITY and concept of INCLUSIONS. A is an older intrusive or extrusive body that was eroded before B was deposited. B contains inclusions of A, therefore B is younger than A. What concepts or laws are illustrated by C and D?

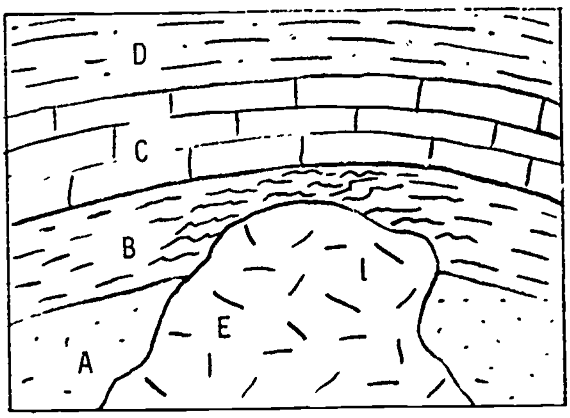


Figure 3.4 Cross-section view illustrating CROSS-CUTTING RELATIONSHIPS. The intrusive body E has intruded, gently folded and metamorphosed the earlier deposited layers A through D. Therefore E is younger. The metamorphism is most intense adjacent to the intrusive. Since the folding occurred after the units were deposited it is younger. The folding accompanied the intrusion and is of the same age. If a radiometric age were determined for the intrusive it would provide a limiting age for the sedimentary rocks.

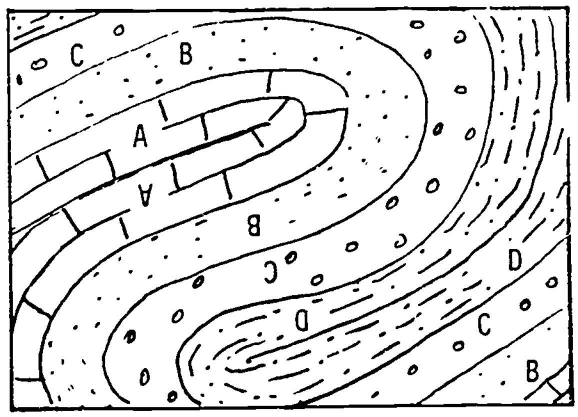


Figure 3.5 Cross-section view illustrating how folding has inverted strata originally deposited at or near horizontal. The inverted units are in the central part of the diagram. The lower right and upper left parts of the diagram have tilted strata in the proper sequence of SUPERPOSITION.

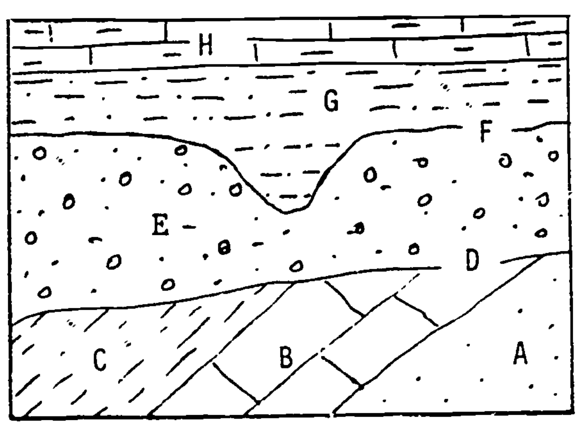


Figure 3.6 Cross-section view illustrating two UNCONFORMITIES and SUPERPOSITION. Strata A through C were deposited and then tilted and eroded along unconformity D. This is called an ANGULAR UNCONFORMITY. Unit E was deposited above the unconformity and then eroded along unconformity F. This is called an EROSIONAL UNCONFORMITY or DISCONFORMITY. Strata G and H were then deposited.

Exercise.

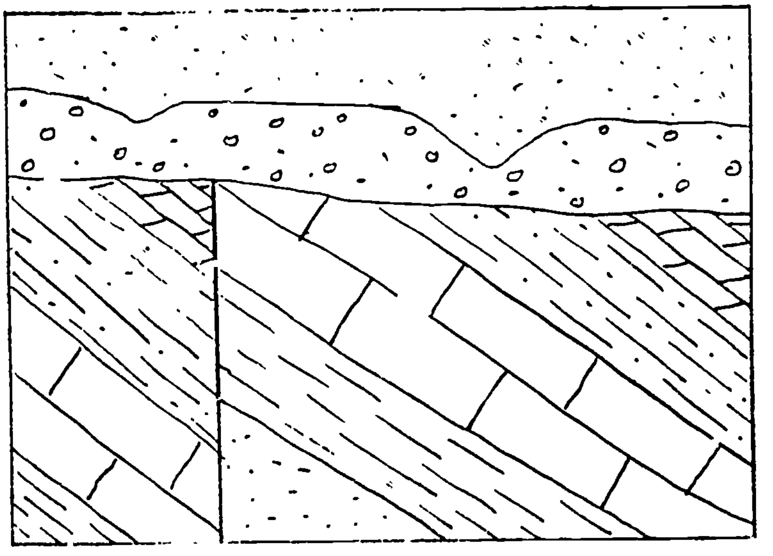


Figure 3.7. Cross-section view, for questions 1 through 6.

1. Using numbers, label the oldest (1) to youngest (7) strata.

2. Between which two urits did tilting occur? _____ & _____

3. Label the fault F. Did faulting occur before or after the tilting?

   ____

4. Label the two unconformities on the diagram: A(oldest) and B(youngest).

5. What type unconformity is A? _________

   What type unconformity is B? _________

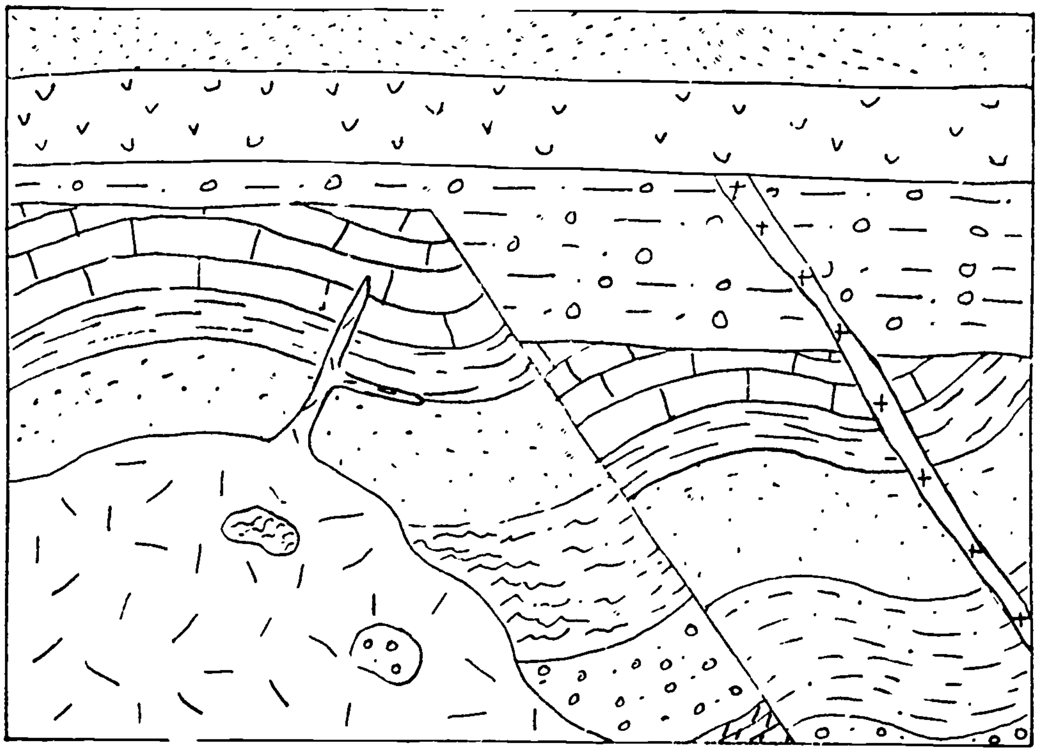


Figure 3.8. Cross-section view for questions 7 through 11.

7. Which occurred first faulting or folding?

____

8. Which intrusion occurred first the one with the plus (+) symbol or that with straight lines at various angles?

____

9. The intrusion with straight lines at various angles contains blocks of two other lithologies. What does this mean?

10. Label the two unconformities A(oldest) and B(youngest). What type of unconformities are they?

A__________ B__________

11. Label the rock units including the intrusives in sequence of occurrences. In outline form reconstruct the sequence of events represented in the diagram. Do not omit the unconformities, folding, faulting, and metamorphism.

12. Given: a daughter to parent ratio of 1/4 and a decay constant of 1.2 billion years, what would be the ages of the rock yielding the daughter and parent products?

If this is the age of intrusion containing the inclusions what can be said about the age of the intrusion with the plus (+) symbol?

Fossils

<u>Introduction</u>. Fossils are our record of past life. They occur in many parts of the world and have fascinated mankind for centuries. The earliest fossils known are over 3 billion years old. They are one-celled organisms found in metasediments in Australia.

Fossils may be used to determine the ages of the rocks that they are found in, to determine the environment of deposition of the enclosing rocks, establish evolutionary lineages, and show paleogeographic distribution patterns reflecting plate tectonics among many other applications.

<u>Principles to be learned</u>.

1. How a fossil is formed
2. Recognize some common fossil forms
3. How fossils are used to date rocks
4. How to correlate strata with fossils

<u>Terminology</u>.

Bivalve

Carbonization

Coral

Fossilization

Gastropod

Impressions

Molds

Permineralization

Replacement

Trace Fossils

Trilobite

FOSSILIZATION. A fossil is any trace or remains of past life. This may include bones, teeth, shells, leaf imprints, molds, etc. The process of forming a fossil is called fossilization. Most organisms are not fossilized. In order for a fossil to form an organism should have hard parts & be rapidly buried in fine-grained sediments after it dies. Exactly when the organism becomes a fossil is difficult to determine because there are many processes to preserve the fossil. The following processes are common.

PERMINERALIZATION - Many organisms have void spaces in their shell, bone or cell structure. When a mineral is added into the void space by ground water percolating through the entombing sediments the process is called permineralization. This often strengthens the original structure which could have been otherwise destroyed. It may occur slowly or rapidly anytime after the organism was buried.

REPLACEMENT - This process occurs when the original shell or bone is replaced by another mineral. The replacement occurs after burial with ground waters percolating through the sediment. A common example is quartz replacing calcite. Less common is pyrite replacing calcite.

CARBONIZATION - Some organisms, such as plants, are compacted after burial with the weight of overlying sediments. As compaction continues volatiles are given off as gases or carried away in solution by ground water. Gradually the volatiles are entirely removed and only a carbon film or residue remains. This process is called carbonization. Coal is formed in this manner. It could be considered very low grade metamorphism.

TRACE FOSSILS - Trace fossils include tracks trails, burrows, feeding traces, and any other structure recorded in the sediment by the life processes of organisms. Since the sediment is soft when these are formed they are often destroyed by other organisms and sedimentological processes. In the past many of these structures were not recognized to be of organic origin. Much study of these remains to be done.

MOLDS - In many sandstones and some dolostones fossil shells have been leached away by ground water. The entombing sediment is left with the internal and external impressions of the shell. These are called molds. They may be formed a few years or millions of years after the shell was buried.

IMPRESSIONS - When a leaf or stem of a plant is washed or dropped onto soft clay or silt it may be impressed into the sediment. It is subsequently removed by solution or other processes. The resulting preservation, often distorted, of the configuration of the plant material is termed an impression. This process is gradational with that of a mold.

Other rare types of fossilization occur, such as freezing and dessication (drying out in an arid environment). Materials preserved in this way are not common and usually destroyed by subsequent processes.

Observe the numbered specimens provided. Using your knowledge of mineralology, the preceding discussion and your instructor's presentation determine the type of fossilization for each. Place your answers in the appropriate space on the exercise sheet.

Common Fossils. An introductory study of the diverse types of fossils would require two or three semester courses. Therefore only a few of the more common types will be presenced.

GASTROPODS - The gastropods or snails are a common animal on land, in streams and lakes and in the oceans. Their coiled conch is easily recognized. Different types of coiling, ornamentation, and size make them of interest. Although most gastropods are herbivores some are carnivorous. They are found from elevations of over 5,000m to the greatest depths in the oceans. The earliest gastropods known are nearly 600 million years old.

BIVALVES - Bivalves or clams are an important food source for mankind. They are exclusively aquatic occurring to elevations exceeding 5,000m and to the greatest depths in the oceans. Many plough through soft sediment looking for food whereas others burrow into the sediment or attach to rocks and extend siphons to suck in water carrying the microscopic organisms they eat. The largest one known lives in the southwest Pacific and is nearly 1.5 meters long, weighing 600 pounds. Their fossil record extends nearly 600 million years. They are recognized by their two valves which are mirror images of one another or nearly so.

CORALS - Corals may occur as solitary individuals or as a colony. The solitary form resembles a horn with radial partitions internally. Colonies are grouped individuals. The living animal lived on top of the solid corallite which was precipitated to keep the soft parts above the sediment surface and anchor it to a firm substrate. Currents brought the microscopic organisms that the animal ate. Today most colonial corals live in shallow warm water in the equatorial belt, between approximately 30°N and S latitudes. Many solitary corals live to greater depths in cooler water farther from the equator. The fossil record is abundant and extends back approximately 550 million years.

TRILOBITES - The trilobites are an extinct group related to the modern crabs and lobsters. They have bilateral symmetry and a shiny chitinous carapace. They lived from 600 million to 250 million years ago. Most were scavengers like their modern counterparts. They may have become extinct as the fish evolved and preyed on them.

VERTEBRATES - The first vertebrate, primative fish, evolved about 550 million years ago. They gave rise to the earliest bony fish (forerunners of today's most common fish) about 400 million years ago. Also they gave rise to the amphibians about 400 million years ago. The amphibians gave rise to the reptiles about 350 million years ago and the first birds and mammals followed about

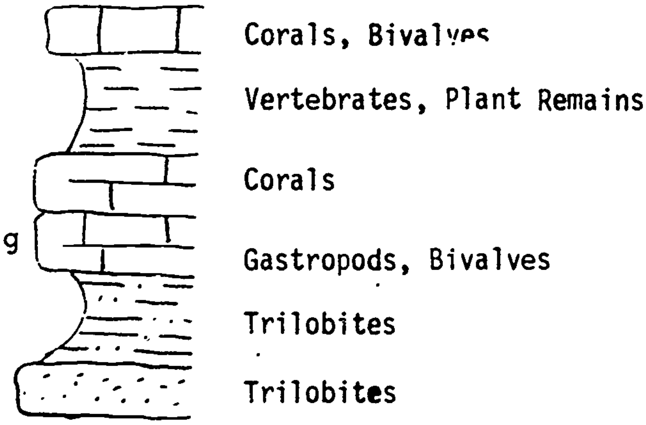
240 million years ago. Man is a late comer in the vertebrates with a record of only 3 to 4 million years. Bones and teeth are the most common fossil remains of the vertebrates. It is not common to find complete skeletons. Vertebrates occur on land, and in fresh and marine waters.

PLANTS - Primitive vascular plants first occurred approximately 425 million years ago. The conifers did not evolve until approximately 275 million years ago and the flowering plants, grasses and landwoods about 125 million years ago. The cellular structure, leaves and woody texture are the features used to recognize plant fossils. They are often preserved as carbonized films and impressions. Most vascular plants live on land. Locally abundant in the oceans they are not as diverse and must live in shallow water where light penetrates.

Observe the identified fossil specimens. Then identify each of the number specimens that you used when identifying the type of fossilization. Place your answer in the appropriate space on the exercise sheet.

In any sequence of strata where fossils are present the law of superposition applies to the fossils as well as the strata (Fig. 3.9). That is, fossils in the first formed strata are older than those in later formed strata. This concept was recognized in the late 1700s and early 1800s. It has since been expanded as discoveries from various parts of the world have shown that many groups of fossils have no living representatives, i.e. trilobites and dinosaurs. Actually the dinosaurs began to evolve as the trilobites became extinct. There are hundreds of examples of extinction of some forms and development of unrelated new forms of life among the different kinds of organisms.

Figure 3.9. A sequence of strata listing the types of fossils found in each unit. Oldest fossils in the basal unit, succeedingly younger fossils in the overlying unit.



Today we recognize that any rock containing trilobites is old, whereas rocks yielding dinosaurs are younger and rocks yielding horse fossils are younger yet. In order of appearance in the fossil record the oldest vertebrate fossils are fish, followed by amphibians, reptiles, and mammals. The diversity of the living forms of life reflects the evolution within each group of organisms.

The orderly sequence of different kinds of life as represented in the fossil record has been demonstrated to occur at many different places in the earth. This has led to the law of FAUNAL SUCCESSIONS. That is, like assemblages of fossils from two different areas indicate a like age for the rocks containing them.

The geologic time scale (Fig. 3.10) was developed during the past 250 years by using the laws of physical relationships (original horizontality, superposition, etc.) and faunal successions. Radiometric dates were not added until the 1900s. As new radiometric dates are determined the time scale is modified accordingly.

Fig. 3.10 Geologic Time Scale
Based on G.S.A. 1984

Era	Period	Epoch	Derivation of Name	Duration x 10^6 years	
Cenozoic		Recent		0.01	66
		Pleistocene	Most recent	2	
	Neogene	Pliocene	More recent	3	
		Miocene	Less recent	19	
	Paleogene	Oligocene	Little recent	13	
		Eocene	Dawn of recent	21	
		Paleocene	Early dawn of recent	8	
Mesozoic	Cretaceous		Chalk	[illegible]	179
	Jurassic		Jura Mts., Europe	[illegible]	
	Triassic		Three-fold division (Germany)	37	
Paleozoic	Permian		Province of Perm, Ural Mts., USSR	21	325
	Carboniferous:		Abundant coal		
	Pennsylvanian			36	
	Mississippian			40	
	Devonian		Devonshire, England	48	
	Silurian		An early British tribe	30	
	Ordovician		Another early British tribe	67	
	Cambrian		Roman name for Wales	65	
Proterozoic					1400?
Archeozoic					2500?

Geologic time to scale

0	
	Cenozoic era
65	
	Mesozoic era
225	
	Paleozoic era
570	
	Proterozoic era (Algonkian)
2000	
	Archeozoic era (Archean)
3500	Oldest fossils
? 4500	Formation of earth's crust

Fig. 3.10 Geologic Time Scale
Based on G.S.A. 1984

Era	Period	Epoch	Derivation of Name	Duration x 10^6 years	
		Recent		0.01	
		Pleistocene	Most recent	2	
	Neogene	Pliocene	More recent	3	
Cenozoic		Miocene	Less recent	19	66
	Paleogene	Oligocene	Little recent	13	
		Eocene	Dawn of recent	21	
		Palcocene	Early dawn of recent	8	
	Cretaceous		Chalk	78	
Mesozoic	Jurassic		Jura Mts., Europe	64	179
	Triassic		Three-fold division (Germany)	37	
	Permian		Province of Perm, Ural Mts., USSR	21	
	Carbon.ferous:		Abundant coal		
	Pennsylvanian			36	
	Mississippian			40	
Paleozoic	Devonian		Devonshire, England	48	325
	Silurian		An early British tribe	30	
	Ordovician		Another early British tribe	67	
	Cambrian		Roman name for Wales	65	
Proterozoic					1400?
Archeozoic					2500?

Geologic time to scale

0	
	Cenozoic era
65	
	Mesozoic era
225	
	Paleozoic era
570	
	Proterozoic era (Algonkian)
2000	
	Archeozoic era (Archean)
3500	Oldest fossils
? 4500	Formation of e[redacted]h's [redacted]ust

Today we still use relative time when reconstructing sequences of geologic events. Where possible we add radiometric dates to provide limiting or confining ages (Fig. 3.11).

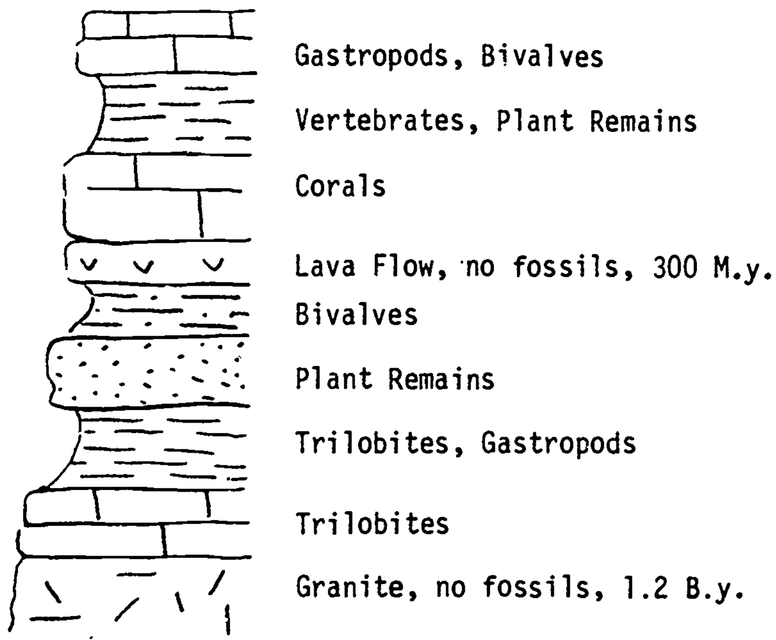


Figure 3.11. A sequence of strata listing the types of fossils found in each unit. We can reconstruct the sequence of events for the rock column applying the law of physical relationships. The radiometric ages determined for the two igneous rocks provide confining ages for the fossils in the strata between them. Also a maximum age of 300 million years is provided for the fossils in the strata above (younger than) the lava flow.

Most sediments are ultimately deposited in basins on land or in the ocean. Individual rock units are recognized on their unique lithology and may extend for a few meters or a few hundred kilometers laterally. Only rarely are canyons cut into these rock units where one could actually trace an individual layer across its total lateral extent. Usually we find intermittent exposures in canyons, valleys or mountain ranges. Thus we try to establish the sequence of events for each exposure and relate the sequences to one another. This is called CORRELATION.

Correlation is based on like lithologies, like sequences of strata, and like assemblages of fossils. Figure 3.12 illustrates two sequences of strata, correlated on (1) lithology, and then (2) fossils and lithology.

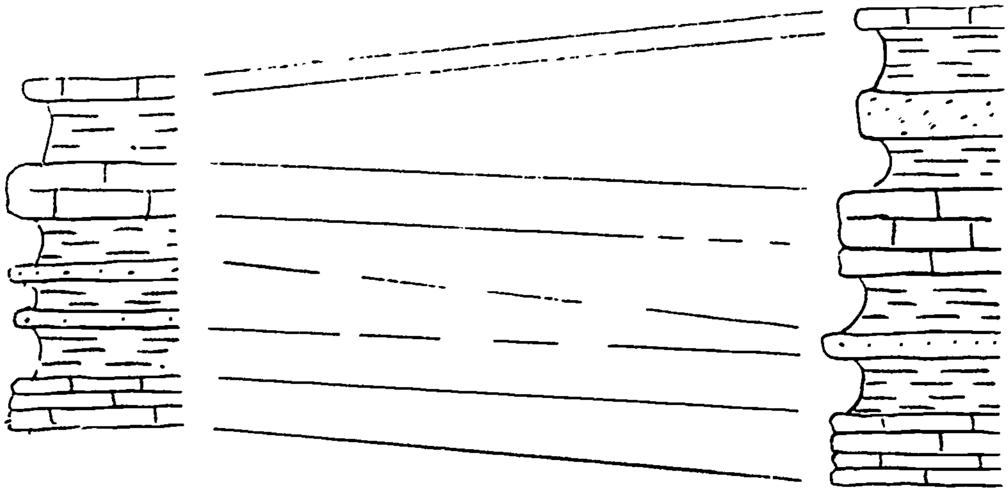


Figure 3.12.1. Correlation of two sequences of strata separated by 20 kilometers of cover. The upper diagram is correlated on lithology and lithologic sequence whereas the lower diagram has fossils added to the correlations.

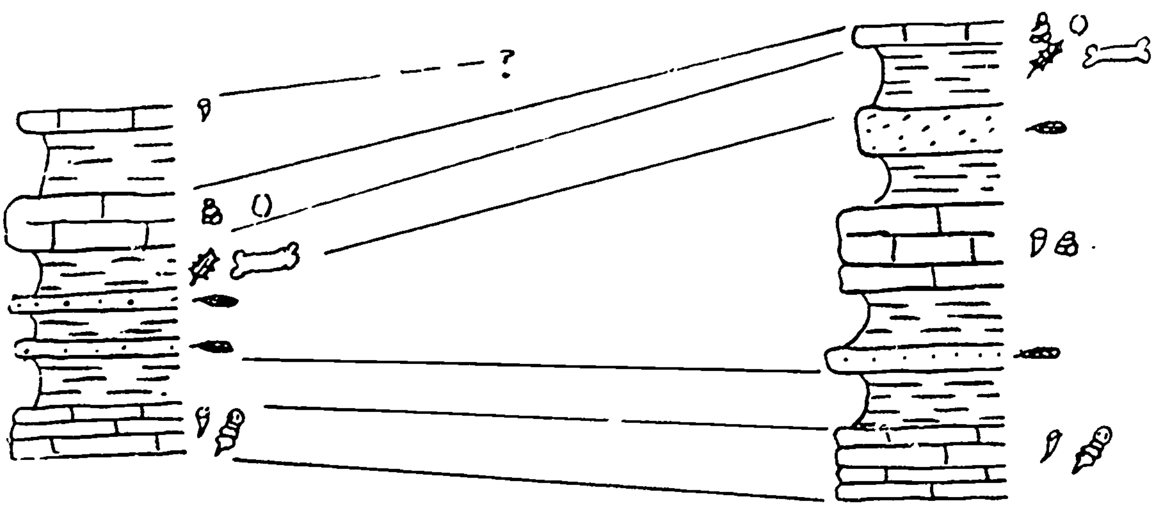


Figure 3.12.2

Exercise:

I. Identify the type of preservation and kind of fossil for each specimen provided.

	Type of Preservation	Kind of Fossil
1.	________________	________________
2.	________________	________________
3.	________________	________________
4.	________________	________________
5.	________________	________________
6.	________________	________________
7.	________________	________________
8.	________________	________________
9.	________________	________________
10.	________________	________________

II. Correlate the two columns of Figures 3.13 and 3.14.

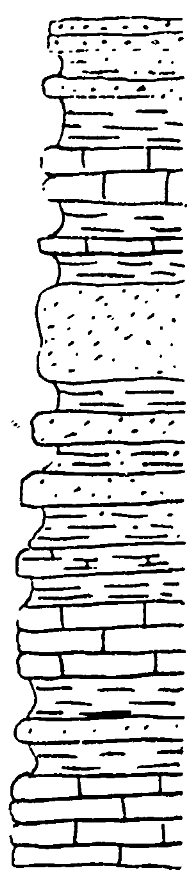
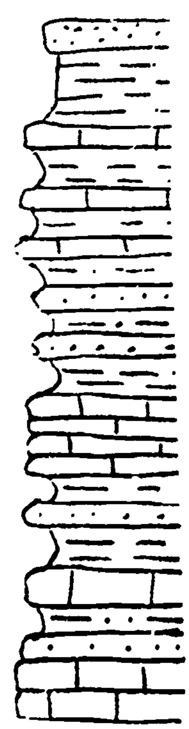


Figure 3.13



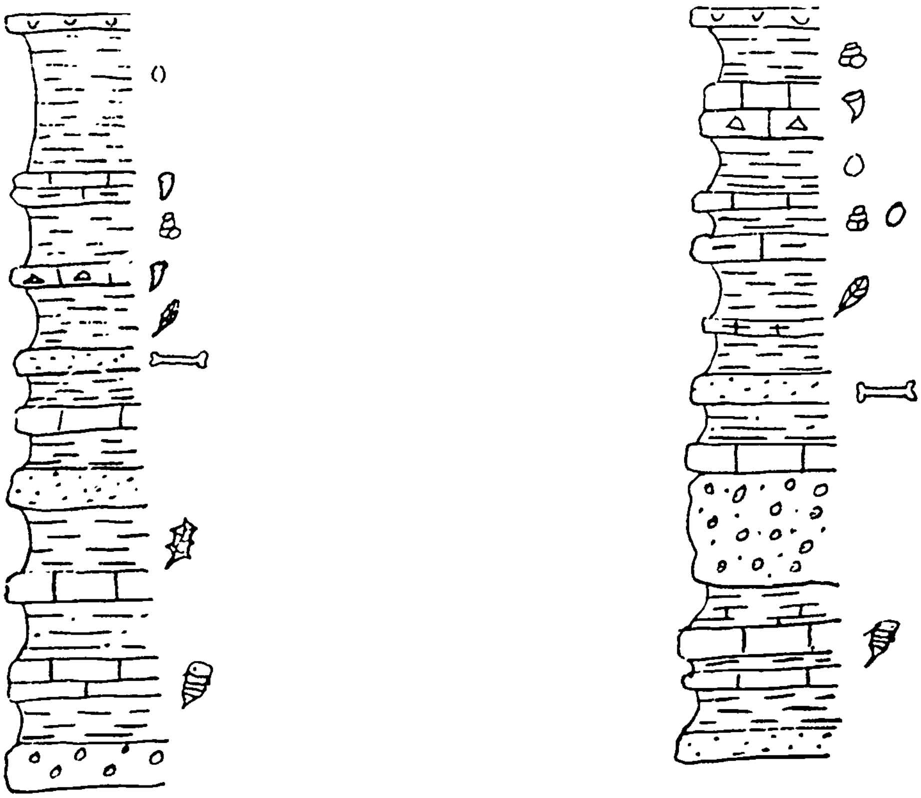


Figure 3.14

PHYSICAL SCIENCE FOR EL' .NTARY EDUCATION TEACHERS
GEOL . BLOCK

Lab Exercise - Structural Geology

Introduction. Structural geology is the study of the three-dimensional arrangement of the rocks of the earth. This includes study of the processes of folding and faulting and plate tectonics. Originally our data were derived from mapping the distribution and attitude of rocks on the earth's surface. Today these surface data are supplemented with data from geophysical studies (electronically derived information) and drill hole data (includes rock samples and electronically derived information). Geologists compile the data onto geologic maps, cross-sections and block diagrams. We will use only cross-sections and block diagrams to learn to interpret geologic structures. Block diagrams are used to represent a portion of the earth which may be viewed on all sides as well as the top and the bottom if desired. The sides are cross-sections. The top usually represents the surface of the earth and the bottom a cross-sectional view of a plane below the surface.

Purpose.

1. To learn to interpret different types of geologic structures.
2. To learn three-dimensional perspectives of rock layers.

Terminology.

Attitude - see orientation section

Antiform - an upfold in which the sides or limbs are inclined away from the central part of the structure.

Dip angle - see orientation section

Dip direction - see orientation section

Normal Fault - a fault in which the fault block above the inclined fault plane or surface has moved down relative to the block beneath the fault plane.

Plunge - the acute angle from horizontal of the trend.

Reverse Fault - a fault in which the block above the inclined fault plane or surface has moved up relative to the block beneath the fault plane.

Strike - see orientation section

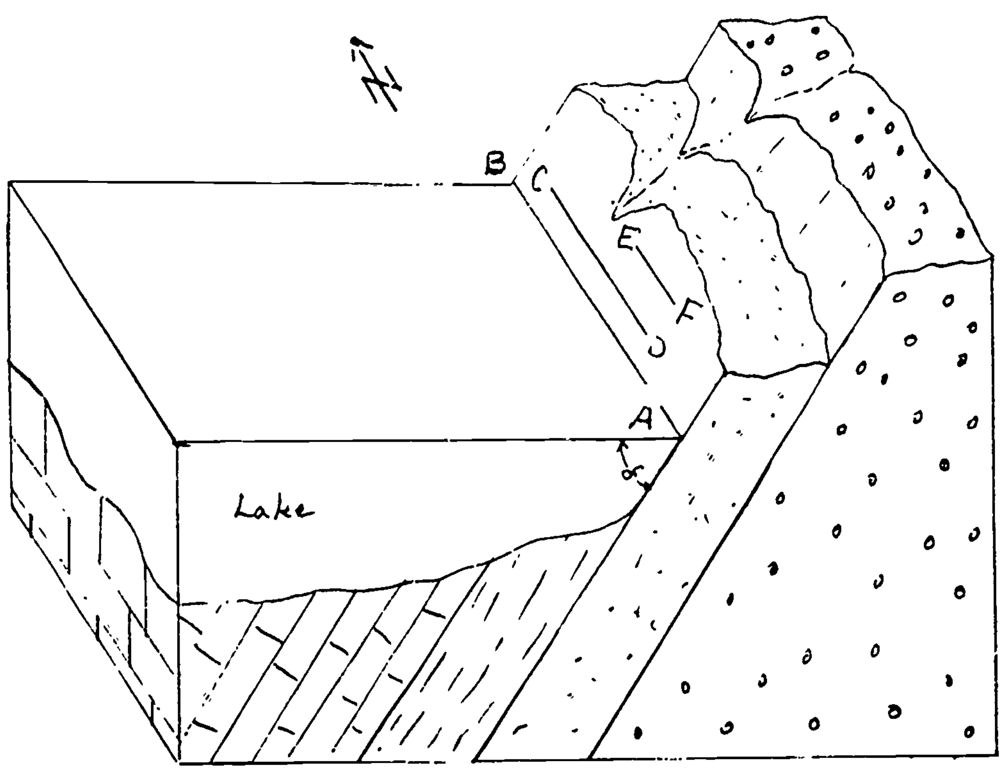
Strike-slip fault - a fault in which the relative movement is horizontal with the two blocks sliding laterally to one another.

Synform - a down fold in which the sides or limbs are inclined toward the central part of the structure.

Trend - the compass direction of the inclination of a linear structure, antiform axis or synform axis.

Vertical fault - a fault in which the fault plane is vertical and the relative movement of the two blocks is vertical.

Orientation. Because strata may be folded or faulted into various configurations within the earth they must be oriented for understanding. The geometrical orientation is called ATTITUDE. Laterally it may remain constant over vast distances or change rapidly. Attitude is described using two components, strike and dip. STRIKE is the compass direction of the line formed when a horizontal plane intersects an inclined layer, fault or other planar feature. In figure 1 the inclined sandstone layer is intersected by the surface of the body of water along AB. Line AB is the strike line. The two parallel lines CD and EF are also strike lines. These lines are referred to north and the strike is usually given as North "so many" degrees east or North "so many" degrees west. In figure 1 it would simply be North.



Figu 1. Block diagram

The DIP DIRECTION is the compass direction in which the layer is inclined (downward), perpendicular to the strike. In figure 1 the dip direction is west. The DIP ANGLE is the acute angle "∡", perpendicular to the strike, which is measured from the horizontal surface down to the inclined surface.

Strike and dip are shown on maps and surface panels of block diagrams by the use of the symbols as follows:

30 inclined strata striking North, dipping 30° East.

vertical strata

horizontal strata

Types of structures. The types of structures were reviewed in lecture and will not be reviewed here. However, the terms are defined and may be reviewed in the terminology section.

Exercise. All questions refer to the block diagrams of figures 2 through 9. To construct the block diagrams trim them with a paper cutter using the guide lines extended away from the diagram. Do not cut out the blank corners. After trimming, place the diagram face down and fold 4 times, following the 4 lines along the sides of the central panel of the diagram as guides. The blank corners should be tucked under the block at 45° and provide finger holds when handling the block. Do not glue or staple the corner blanks as you will want to flatten the diagram out to place arrows or complete panels as you work through the exercise.

Question 1-4 refer to figure 2.

1. What is the attitude of the strata? Place the symbol on the top panel.

2. What is the attitude of the dike?

3. Why is the bank of sandstone wider on the top view of the block than on the side views?

4. Complete the blank panel of the diagram.

Questions 5-8 refer to figure 3.

5. What is the direction of strike of the structure?

6. What are the attitudes of the blank unit of the two limbs of the diagram?

North limb ________________

South limb ________________

7. Complete the two blank panels.

8. What type of structure is this?

Questions 9-13 refer to figure 4.

9. How does this structure differ from figure 3?

10. What type of structure is this?

11. Using the attitude symbol show the strike and dip directions of the blank unit on the two limbs of the structure.

12. What is the approximate angle of dip of the limbs of the structure?

13. Complete the two blank panels of the diagram.

Questions 14-17 refer to figure 5.

14. What type of structure does this block diagram represent?

15. Complete the two blank panels of the diagram.

16. What is the approximate angle of plunge of the structure?

17. Place the attitude symbols on the upper panel showing the strike and dip directions for the limestone unit. There should be three symbols.

Questions 18-20 refer to figure 6.

18. What type of structure does this block diagram represent?

19. Place the 3 attitude symbols on the upper panel showing the strike and dip directions for the blank unit.

20. Which direction does the structure trend?
At what approximate plunge angle?

Questions 21-26 refer to figure 7.

21. What is the attitude of the strata in this diagram Show the symbol on the central panel of the diagram.

22. Three faults are present. Place arrows along the sides of the fault in the side panel to show the relative movement for each fault.

23. Why can the arrows not be placed on the top panel?

24. Name each of the faults, placing the name along the fault on the upper panel.

25. Which fault shows the greatest amount of movement?

26. Complete the blank side panels of the diagram.

Questions 27-31 refer to figure 8.

27. What is the attitude of the strata? Show this placing the strike and dip symbol on the proper panel.

28. Complete the east panel of the diagram.

29. Why are the bands of claystone closer together along the left sides than the right sides of the top and south panels?

30. When looking at the south panel the fault on the left is a ____________________ fault and the one on the right is a ____________________ fault.

31. Place arrows on the south panel to show the relative movement of each fault.

Questions 32-28 refer to figure 9.

32. What is the attitude of the strata?

33. What is the attitude of the dike?

34. Complete the east and north panels of the diagram.

35. Show the relative movement of the fault in the south and north panels of the diagram by placing arrows along the sides of the fault.

36. Place arrows showing the relative movement along the sides of the fault on the top panel of the diagram.

37. Why are the arrows of question 35 incorrect?

38. What type fault is this?

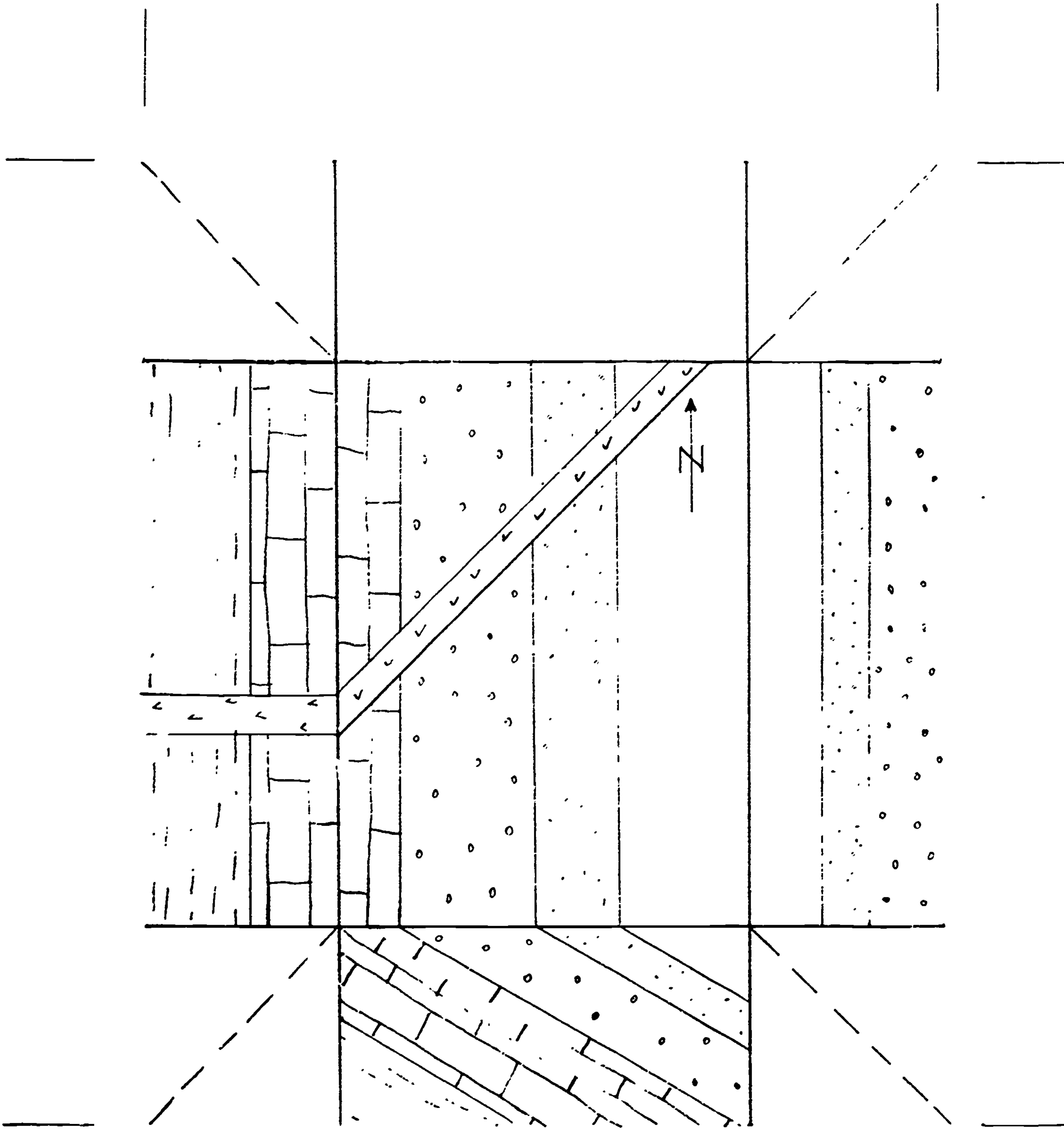


Figure 2

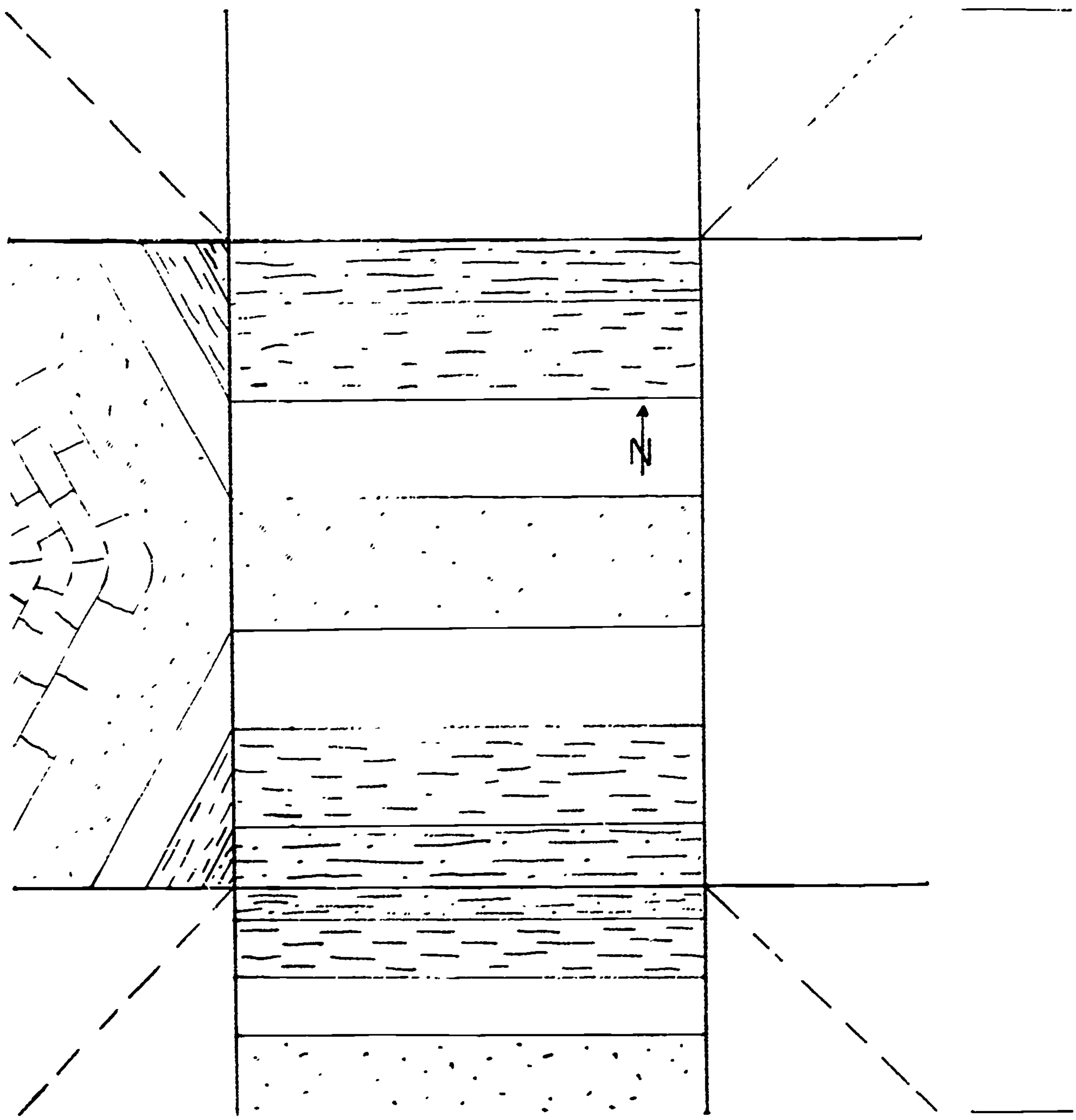


Figure 3

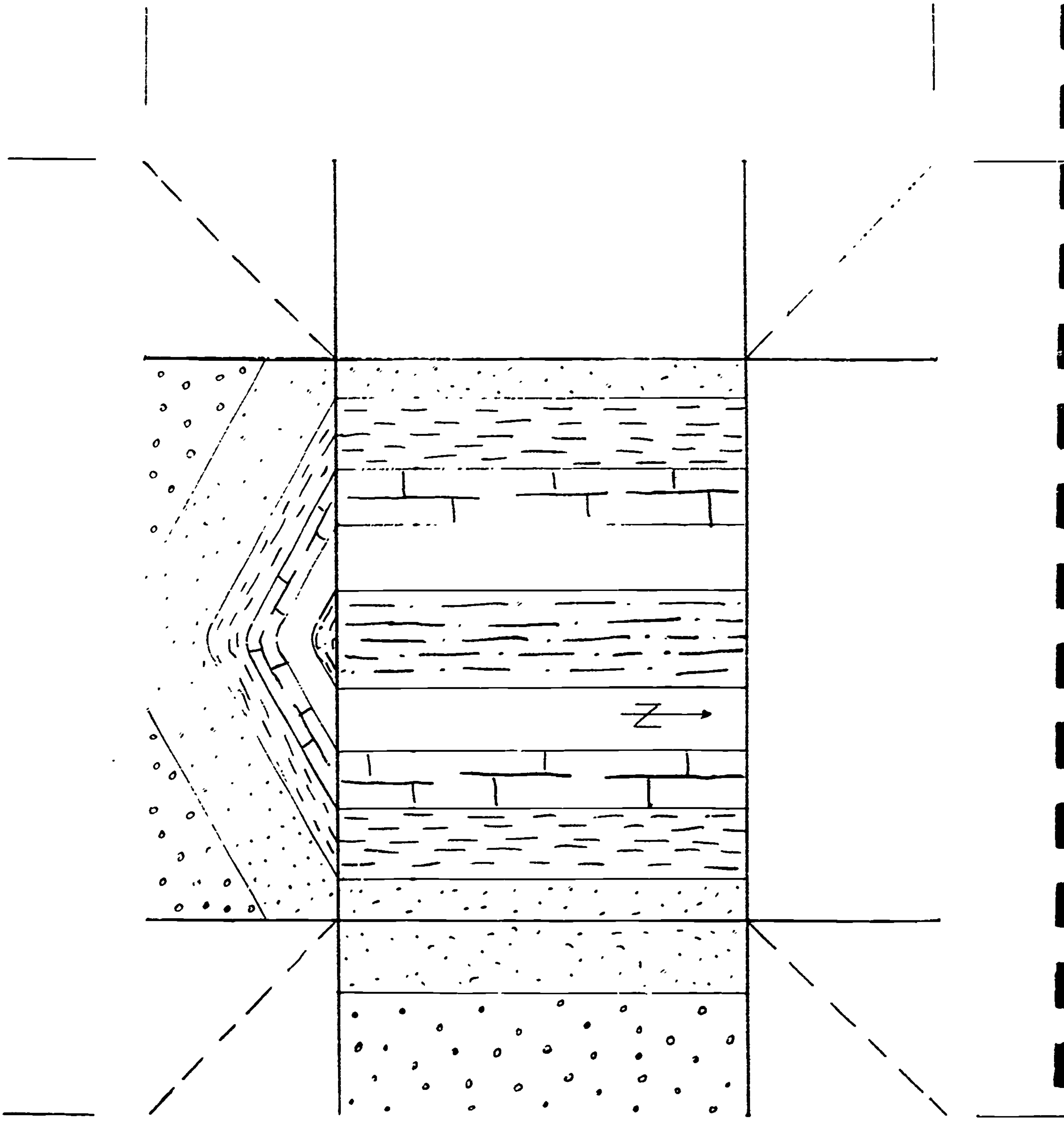


Figure 4

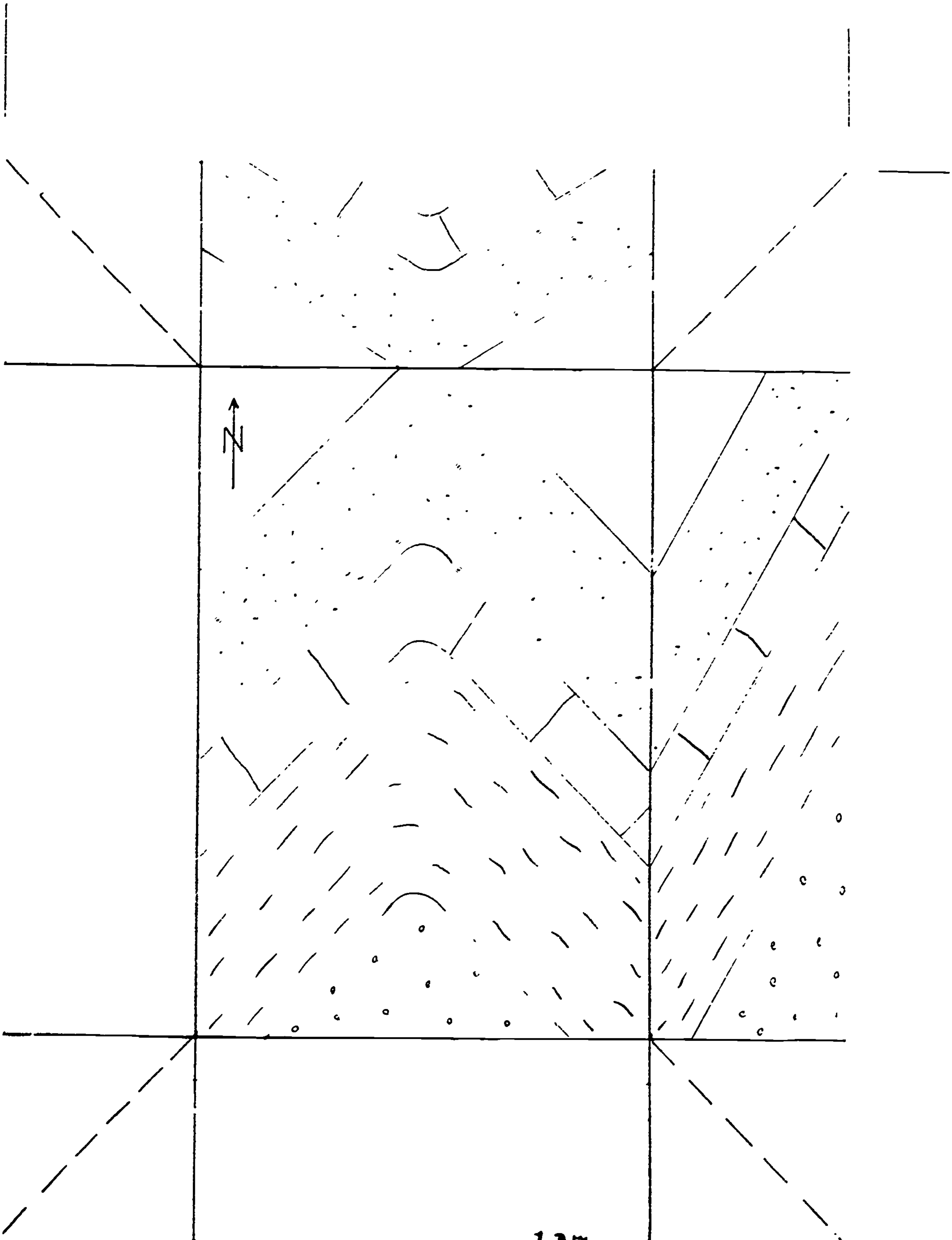


Figure 5

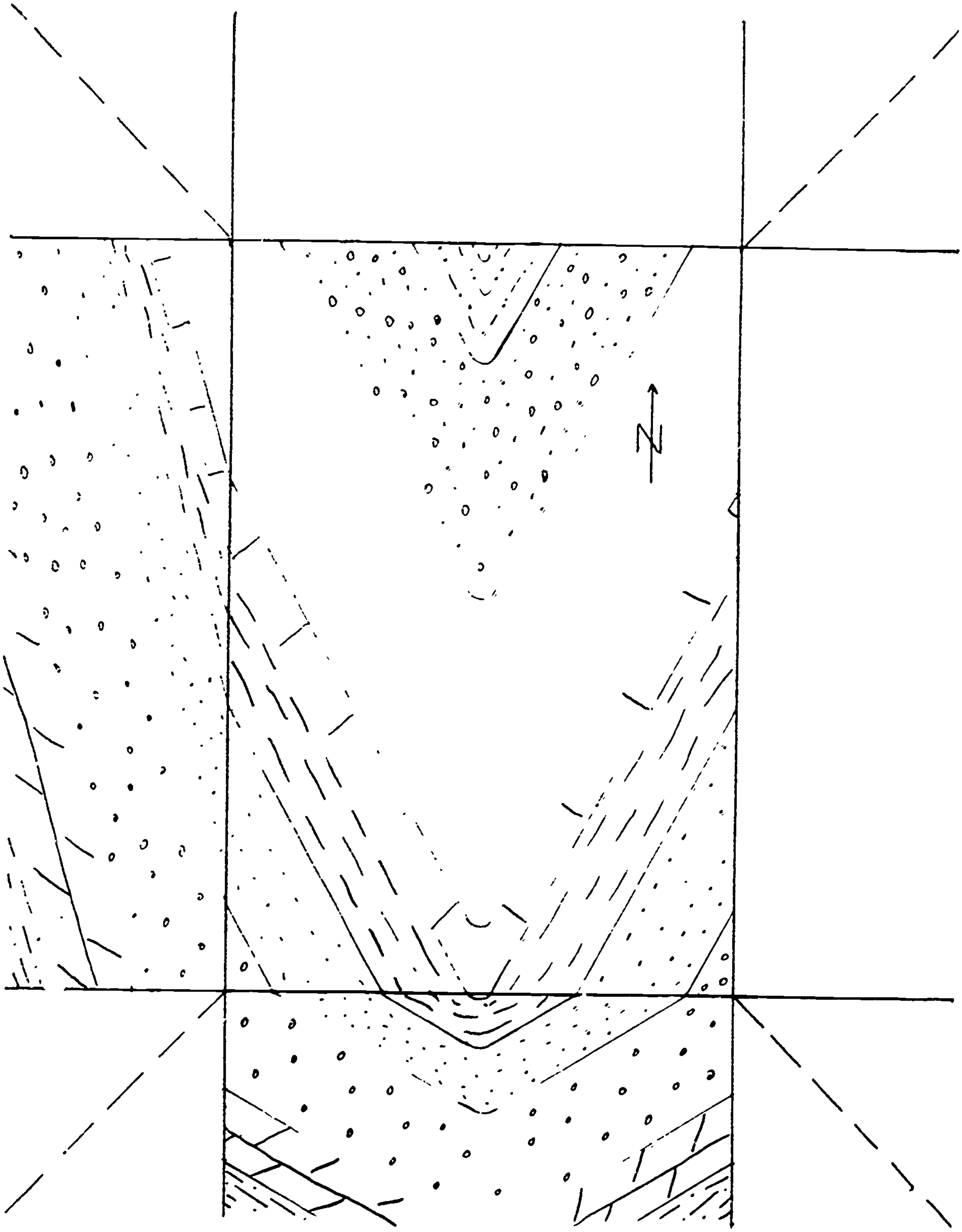


Figure 6

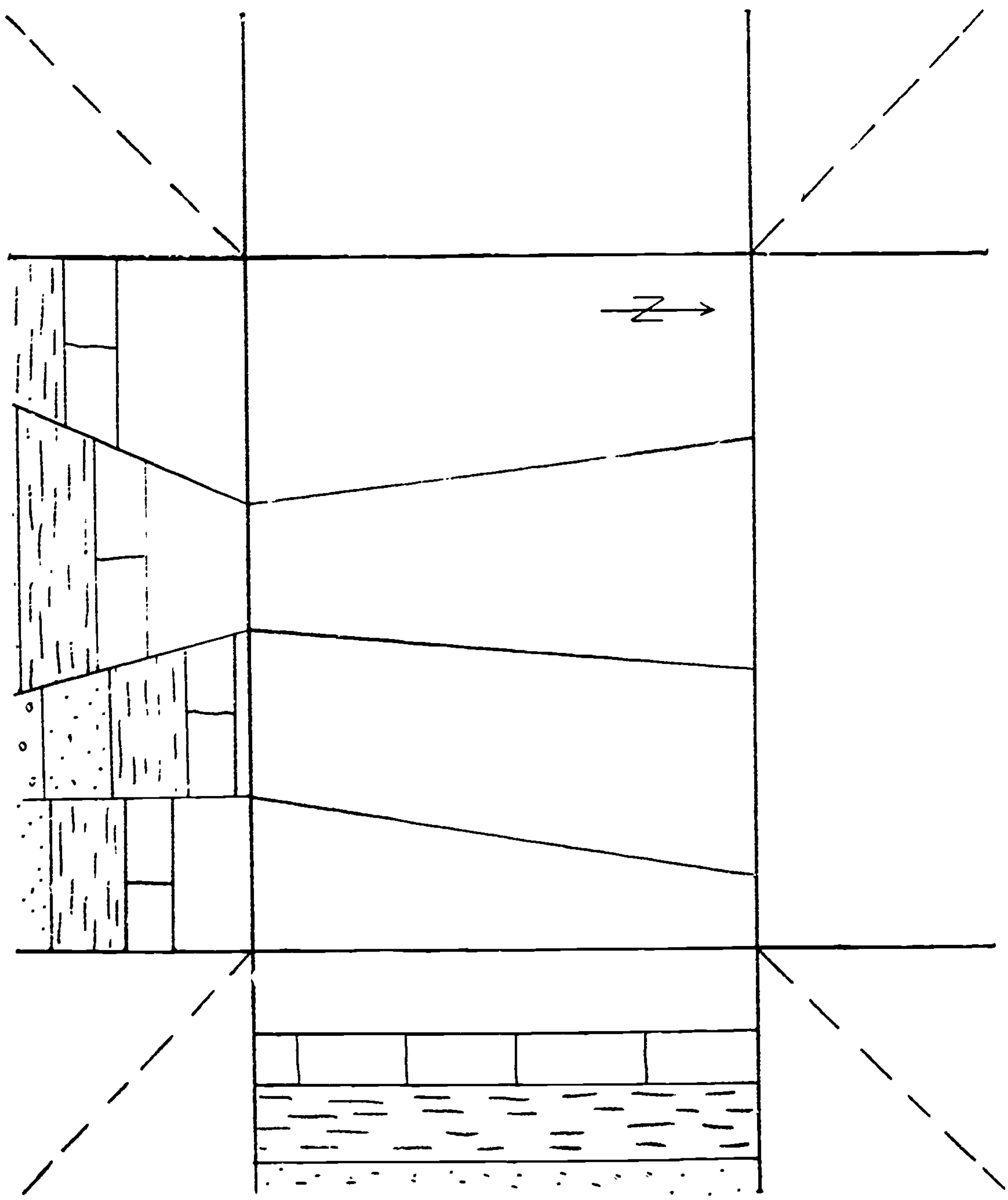


Figure 7

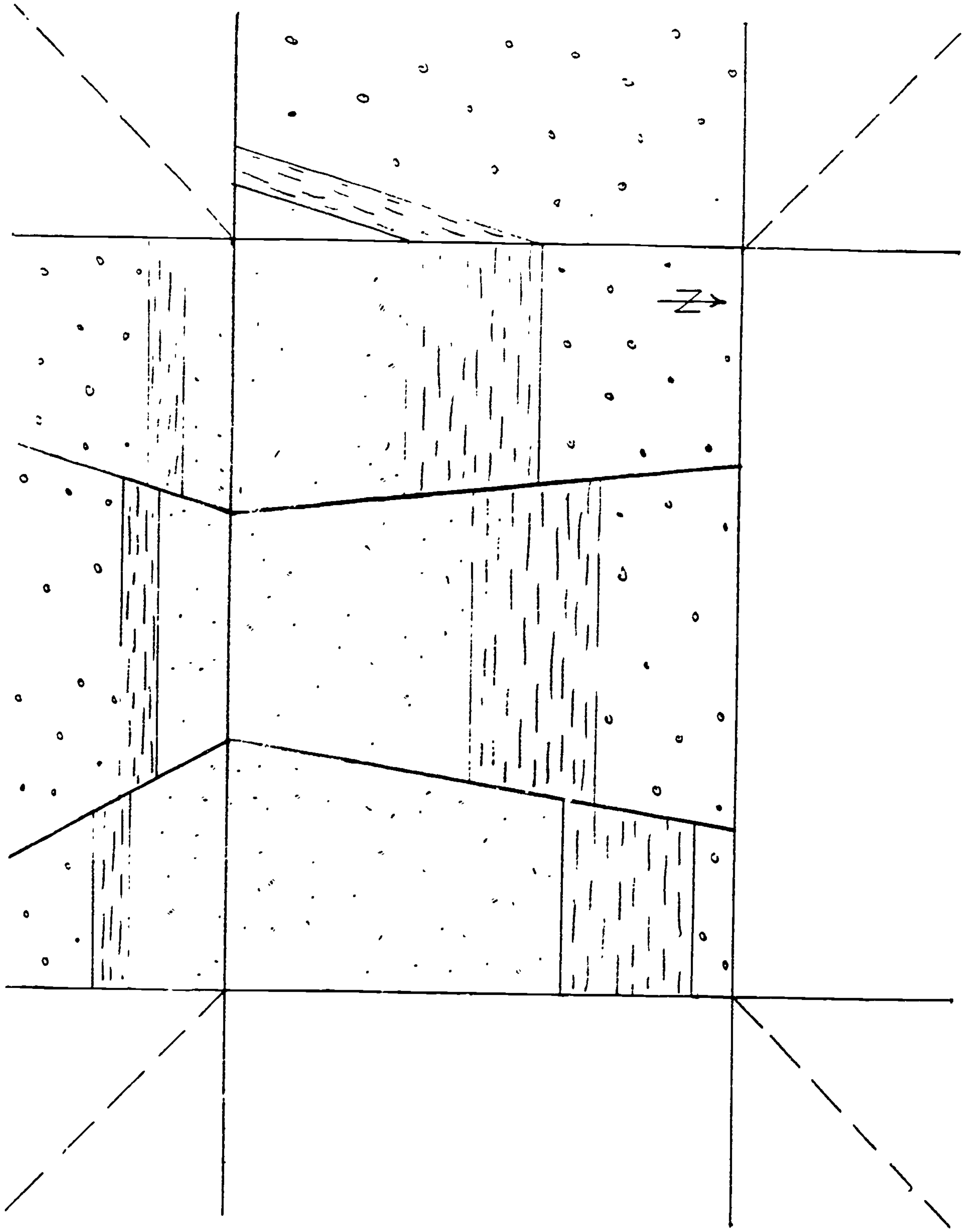


Figure 8

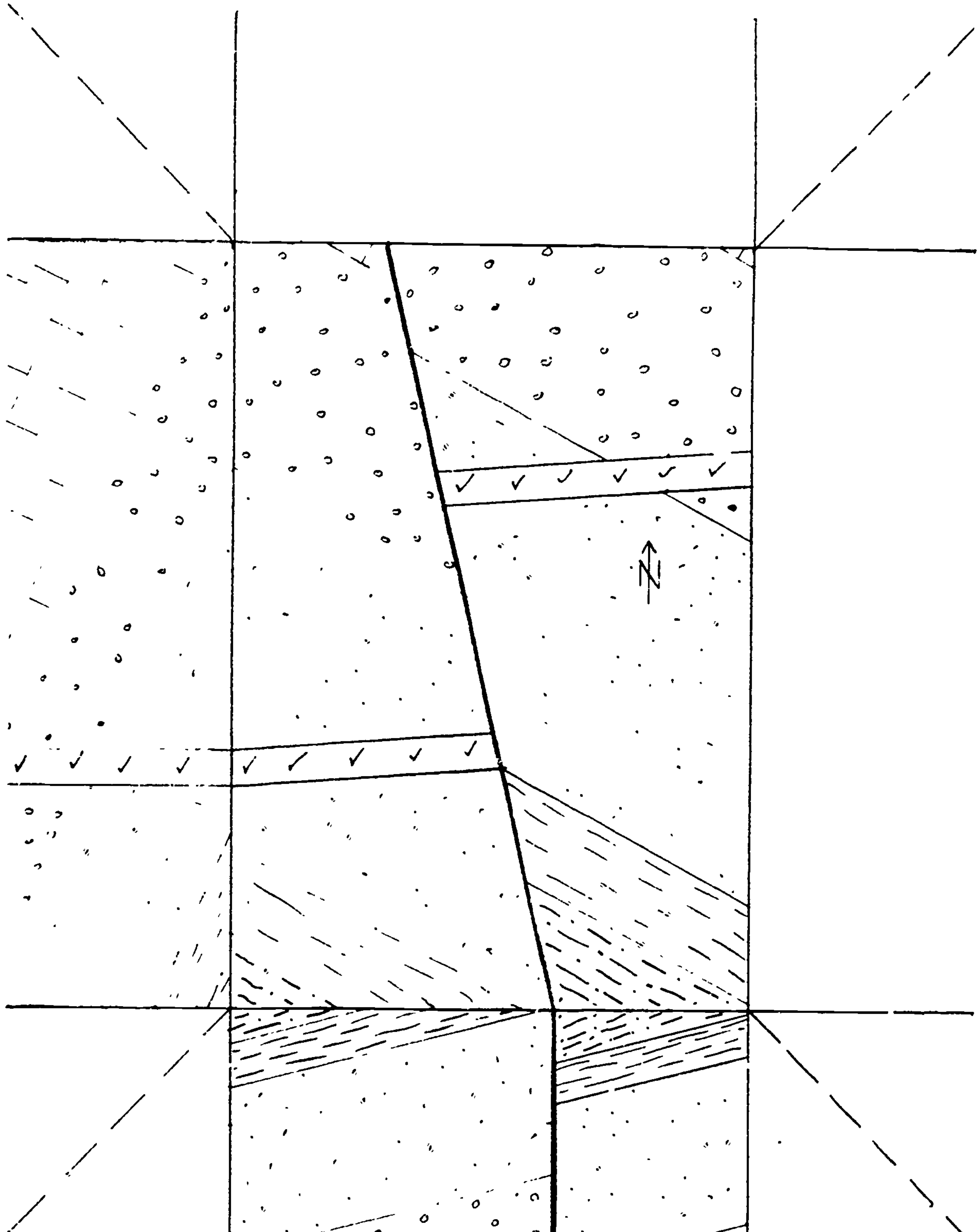


Figure 9

Name: ______________________

ASTRONOMY 301 - GEOLOGY SECTION

Midterm

I. Fill in each blank with the appropriate word or words. (2 pts each)

Igneous rocks are classified principally on ______________________ and ______________________, whereas metamorphic rocks are classified on ____________________________ and ____________________________.

A coarsely crystalline basic igneous rock is called ______________ whereas the finely crystalline equivalent is called ________________.

The chief agents of metamorphism are ________________, ______________, and ______________________________. In a mineral, cleavage is the result of ____, which is determined when the mineral is formed. Minerals are identified by the recognition of a combination of their ____________________________.

II. Define each of the following terms; be as concise as possible. (2 pts each)

Sial -

Rock -

Chert -

Porphyry -

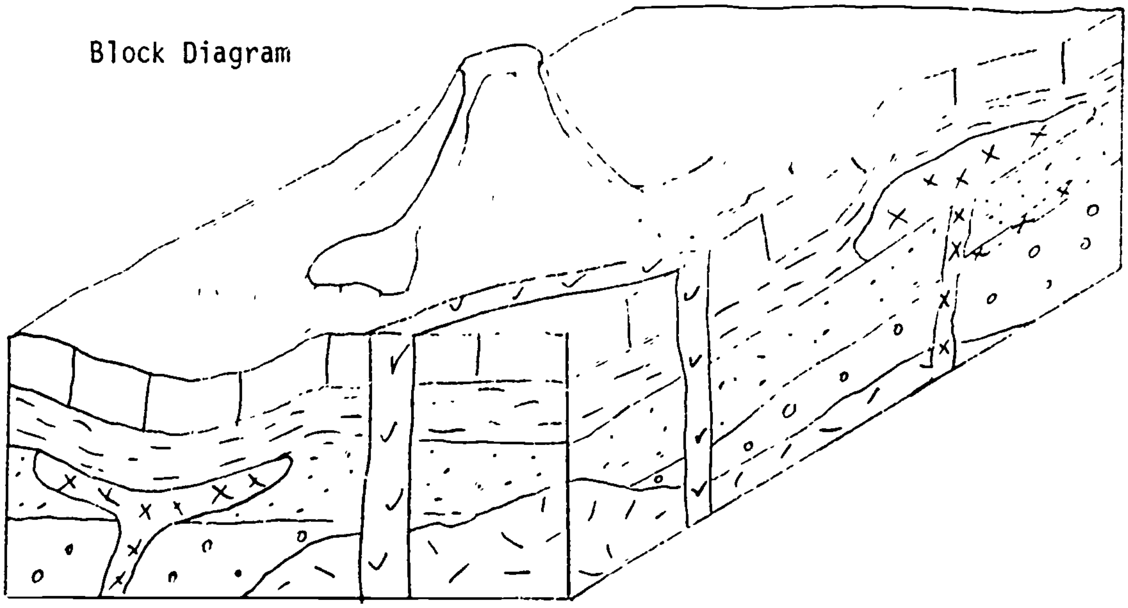
Mafic -

III. What controls the crystal size in a cooling magma? (10 pts)

IV. How is grain size used in the classification of sedimentary rocks? (10 pts)

Name:____________

Block Diagram



V. On the diagram above, using the numbers in front of each of the features, label the following: (2 pts each)

1. Laccolith
2. Dike
3. Batholith
4. Crater
5. Sill
6. Lopolith
7. Intrusive igneous rock
8. Extrusive igneous rock
9. Volcanoe

VI. Explain the significance or meaning of Bowen's Reaction Series as it applies to igneous rocks. (10 pts)

VII. I know nothing about rocks. I have come to you as my teacher with a rock specimen that you tell me is a sedimentary rock. I reply "What is a sedimentary rock?". Explain what a sedimenary rock is. (10 pts)

Name:____________________

VIII. Give the rock cycle. (10 pts)

Name: ________________

ASTRONOMY 301 - GEOLOGY SECTION

Final Exam

1. Fill in each blank with the appropriate word or short phrase (2 pts. each).

Of the two most prominent waves generated when an earthquake occurs the ____________ wave travels the faster, arrives ______________ and will propagate through ______________, whereas the ______________ wave will not propagate through the same medium. The ________________ of an earthquake is the area on the surface of the earth immediately above the ___________________.

Radiometric dates are based on the __________________ of isotopes of radioactive elements such as _________________ and _________________.

Three laws which help establish time relationships are the laws of __________________, ______________________, and _________________________.

A mixed suite of rocks associated with the subduction zone is called a ___________________.

The __________________ of a mineral is a measure of its resistance to being scratched.

The __________________ of a mineral is the color of the powder of the mineral.

2. Explain the difference between a cinder cone and a shield volcano. Use diagrams if they would be helpful. (10 pts)

3. Why do maps showing earthquake occurrences and volcanoes show similar distribution patterns on the earth? (10 pts)

4. What information or data support and confirm plate tectonics? (10 pts)

5. What is the difference between a reverse fault and a strike-slip fault? (10 pts) Use diagrams if helpful in explaining your answer.

6. In each of the boxes sketch a cross-section view of the structure or feature corresponding to the caption. (5 pts each)

Normal Fault

Asymmetrical Anticline

Spreading Center

Angular Unconformity

Symmetrical Syncline

Subduction Zone

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

Part II - Sedimentary Rocks

Introduction. Sedimentary rocks cover approximately 2/3 of the land area of the earth. Yet they make up only about 5% of the volume of the outer 15 km of our planet. In some areas such as western Minnesota and along the edges of many mountain ranges they are thin, forming a veneer over older metamorphic and igneous rocks. In other areas, such as the central part of Michigan and the Texas Gulf Coast, they are thousands of meters thick. Although generally thin in the oceans, sedimentary rocks cover much of the ocean floor.

Sedimentary rocks are formed from previously existing rocks of all types and may form on land or in the oceans (Fig. 2.4). When rocks are broken down by weathering and erosion processes, the fragments formed are called **SEDIMENTS** and some material may be dissolved to go into solution. Glaciers, rivers, ocean currents and the wind transport these materials to their site of deposition. Often the transporting medium forms characteristic structures such as ripple marks, cross-beds and stratification in the sediments as they are deposited. After deposition sediments are **LITHIFIED** by compaction and **CEMENTATION**. **COMPACTION** is the process of reducing the voids in the sediment by rotation of grains and squeezing fluids out of some particles such as clays. Common cements are calcite and quartz, which fill in the void spaces between the grains.

Material that has gone into solution may be precipitated by organisms in their biological processes or by evaporation. Included in the biological processes is the accumulation of plant debris and its subsequent alteration into coal. Technically coal is not a mineral and therefore not a rock, although most geologists include it in the sedimentary rocks.

Sedimentary rocks are significant because we obtain most of our fossil fuels and ground water, as well as many economic products from them.

Terminology.

Biochemical Sedimentary Rocks

Cementation

Chemical Sedimentary Rocks

Compaction

Detrital Sedimentary Rocks

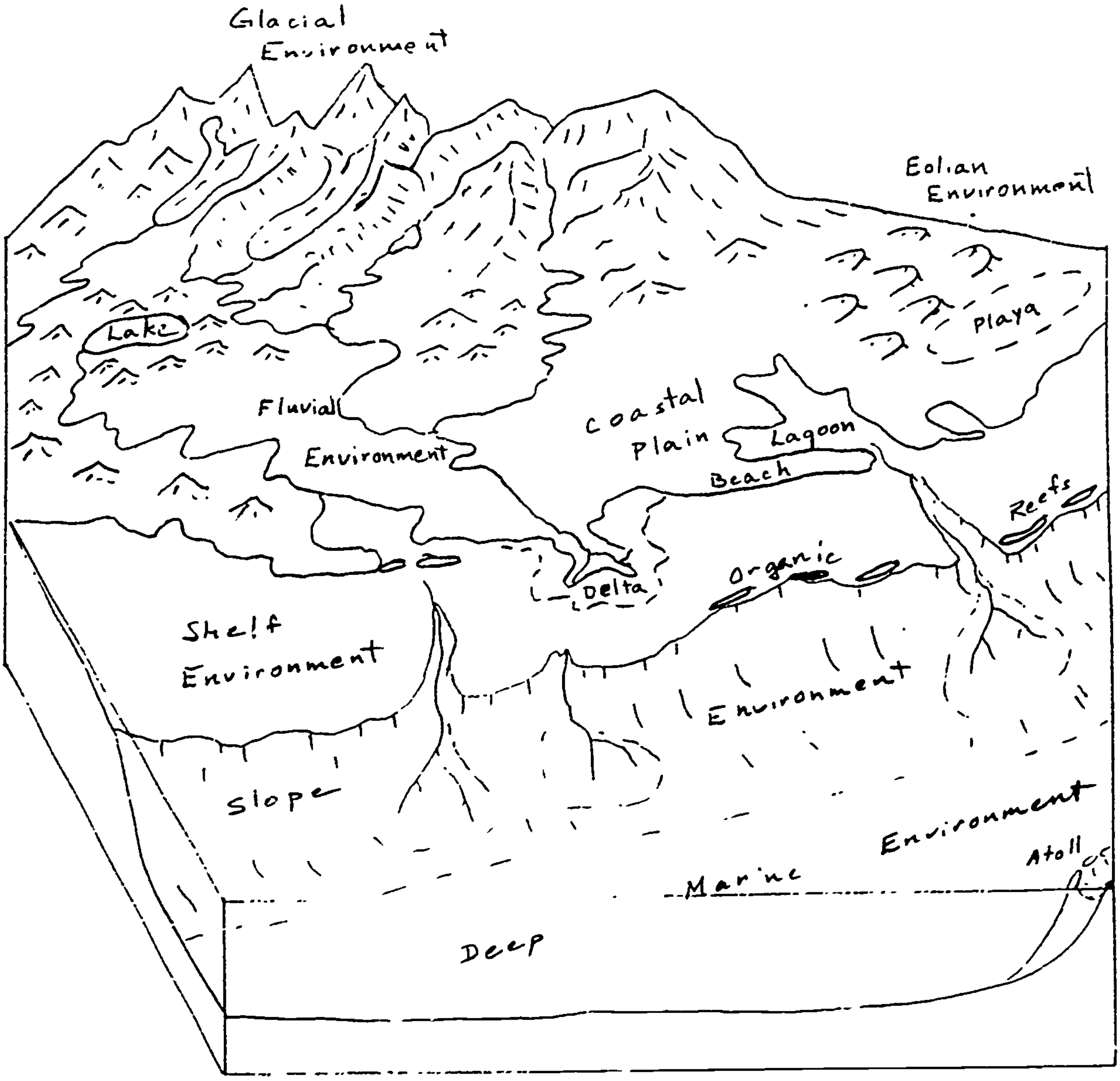


Figure 2.4. Idealized diagram illustrating major sedimentary environments.

Lithification

Microfossil

Megafossil

Sediments

Wentworth size scale

Classification. Sedimentary rocks are subdivided into three groups based on their origin. These are:

1. DETRITAL SEDIMENTARY ROCKS - formed by the lithification of particles of previously existing rocks.

2. CHEMICAL SEDIMENTARY ROCKS - formed by precipitation from or evaporation of aqueous solutions.

3. BIOCHEMICAL SEDIMENTARY ROCKS - formed by the accumulation and alteration of organic debris.

Detrital sedimentary rocks are recognized by the fragments and particles that they contain. These particles are subdivided on the basis of size (Table 2).

Sediment	Grain Size
Boulders	256 mm
Cobbles	64-256 mm
Pebbles	4-64 mm
Granules	2-4 mm
Sand	0.0625 - 2 mm
Silt	0.002 - 0.0625 mm
Clay	0.002 mm

Table 2. **WENTWORTH SCALE** of sediment particle sizes

When lithified or cemented together the sediments form rocks. The rocks formed are given in the sedimentary rock classification (Fig. 2.5).

Chemical sedimentary rocks are formed by precipitation or evaporation from non-biological processes. Part of these rocks are often called evaporites. Sometimes chemical precipitation may involve replacement of previously existing rocks such as chert replacing limestone.

Biochemical sedimentary rocks are recognized by their fossil content. Organisms secrete the carbonate or silica that forms their shells and tests. When the organisms die their shells and tests accumulate on the floor of lakes or in the ocean where they are cemented together to form rock. Since coal consists of the organic remains of accumulated plants it is included in this category. Mega fossils are larger than 2mm and visible with the naked eye. Microfossils are less than 2mm and not visible with the naked eye.

Your instructor will demonstrate the textures of detrital grains and how to determine if the rock contains detrital grains or non-detrital grains.

When identifying sedimentary rocks follow these steps:

1. Grains of detrital origin, go to 2.
   Grains of chemical or biochemical origin, go to 7.

2. Grains larger than 2mm, go to 3.
   Grains smaller than 2mm, go to 4.

3. a. Grains rounded - Conglomerate

   b. Grains angular - Breccia

4. Grains between 0.0625 and 2.0 mm in diameter, go to 5.
   Grains less than 0.0625 mm in diameter, go to 6.

5. This is the sandstone group.

   a. Feldspar content greater than 10% - Arkose

   b. Rock fragments greater than 25% and clay matrix - Graywacke

   c. Nearly pure quartz grains and quartz cement - Orthoquartzite

   d. Mixed composition fitting none of the above - Sandstone

6. a. Grains between 0.002 mm and 0.0625 mm in diameter (will grit on your teeth) - Siltstone

   b. Grains less than 0.002 mm in diameter (will not grit on your teeth) - Claystone

7. Rock made of halite, gypsum or microcrystalline quartz, go to 8.
Rock made of calcite, dolomite, or plant material, go to 9.

8. These are the chemical sedimentary rocks.

   a. Rock composition halite - Rock Salt

   b. Rock composition gypsum - Rock Gypsum

   c. Rock composition microcrystalline quartz - Chert

9. Rock mineralogy calcite or dolomite, go to 10.
Rock of plant debris - Coal

10. a. Rock mineralogy dolomite - Dolostone

    b. Rock mineralogy calcite, go to 11.

11. Megafossils (visible with unaided eye), go to 12
Microfossils (not visible to unaided eye), go to 13.

12. Megafossils make up 10 to 90% of rock - Fossiliferous Limestone
Megafossils make up more than 90% of rock - Coquina

13. Fossils < 10%, rock dense, may contain microfossils - Limestone
Microfossils make up 90% of rock, rock soft and punky - Chalk

For each of the numbered specimens complete the data sheet where applicable and identify the rock type.

Origin	Grain Size	Mineral Composition	Fossil Type & %	Rock Name
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
16.				
17.				
18.				
19.				
20.				
21.				
22.				

Fig. 2.5 Classification of Sedimentary Rocks

Origin	Texture		Rock Name	Use
Detrital	Grain Size	>2.0mm	Conglomerate (rounded clasts)	Building Stone, may bear economic minerals
			Breccia (angular clasts)	Building Stone, may bear economic minerals
		0.0625-2mm	Sandstone	Building Stone
			Arkose (>10% feldspar)	Building Stone
			Graywacke (>25% rock frags & clay matrix	Building Stone
			Orthoquartzite (nearly pure quartz grain)	Building Stone, glass
		0.002-0.0625mm	Siltstone	Building Stone
		<0.002mm	Claystone	Bricks
Chemical	Mineral Composition	Halite	Rock Salt	Salt, chemical industry
		Gypsum	Rock Gypsum	Wallboard
		Microcrystalline Quartz	Chert	Wetstone
Biochemical	Textural Features	<10% fossils	Limestone	Cement
		<90% megafossils	Fossiliferous Ls	Cement
		>90% megafossils	Coquina	Cement
		>90% microfossils	Chalk	Cement, chalk
		Dolomite	Dolostone	Cement
		Plant Debris	Coal	Fuel

Part II - Sedimentary Rocks - Questions

1. How do you tell detrital sedimentary grains from non-detrital sedimentary grains?

2. If a conglomerate is made up of sediments of cobble size what should it be named to show the clast size?

3. Using a similar philosophy as that used in question #2, if a sandstone contains approximately 10% mica what should it be named to show this feature?

4. Similarly if a sandstone has calcite cement, what should it be named to show this?

5. How can it sometimes be determined that a chert has replaced a limestone?

6. What are each of the following sedimentary rocks used for?

   Limestone -

   Coal -

   Orthoquartzite -

   Claystone -

Chert -

Fossiliferous Limestone -

Rock Gypsum

7. Sandstones & Limestones are the rocks we find oil in. How could a rock retain oil?

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

Part III - Metamorphic Rocks

Introduction. Metamorphic rocks are formed as a result of heat, pressure and chemical action on previously existing rocks of any type. Heat and pressure are the two major agents causing the change. These agents are generated where plates are colliding or sliding past one another. Heat may be given off of cooling magma or generated by radioactive decay.

When metamorphism affects wide areas it is referred to as REGIONAL METAMORPHISM. This occurs around a large intrusive body of magma associated with mountain building episodes in plate tectonics. Rocks closest to the magma are more intensely metamorphosed than those at greater distances from it (Fig.2.6). The gradational sequence away from the magma is referred to as METAMORPHIC FACIES. The degree of metamorphism at any one place is determined by the minerals formed, since different minerals will form at higher temperatures than at lower temperatures. The minerals formed also depend upon the composition of the original country rock invaded by the magma.

CONTACT METAMORPHISM affects a small area or narrow band or rock adjacent to a dike sill, lava flow or fault. It may be a few mm or a few meters in width.

Terminology.

Contact Metamorphism -

Foliation -

Metamorphic Facies -

Regional Metamorphism -

Schistosity -

Gneissic Folition -

Slaty Cleavage -

Phyllitic Foliation -

Classification. Metamorphic rocks are classified into two groups based on the present or absence of FOLIATION. Foliation is the laminated structure in a rock resulting from parallel alignment of minerals when the parent rock was subjected to metamorphic processes. Foliation develops best when the parent rock contains clays or sedimentary rocks of differing mineral composition.

Foliated metamorphic rocks are further subdivided on the degree or type of foliation. These grade from the lowest, SLATY CLEAVAGE to PHYLLITIC to SCHISTOSE to GNEISSIC FOLIATION, the highest grade. The increase in intensity of foliation is accompanied by an increase in grain size.

Non-foliated metamorphic rocks are subdivided on mineral composition and grain size. They do not reflect the degree of metamorphism as readily as the foliated metamorphic rocks.

Your instructor will introduce the types of foliation and other textural features of the metamorphic rocks.

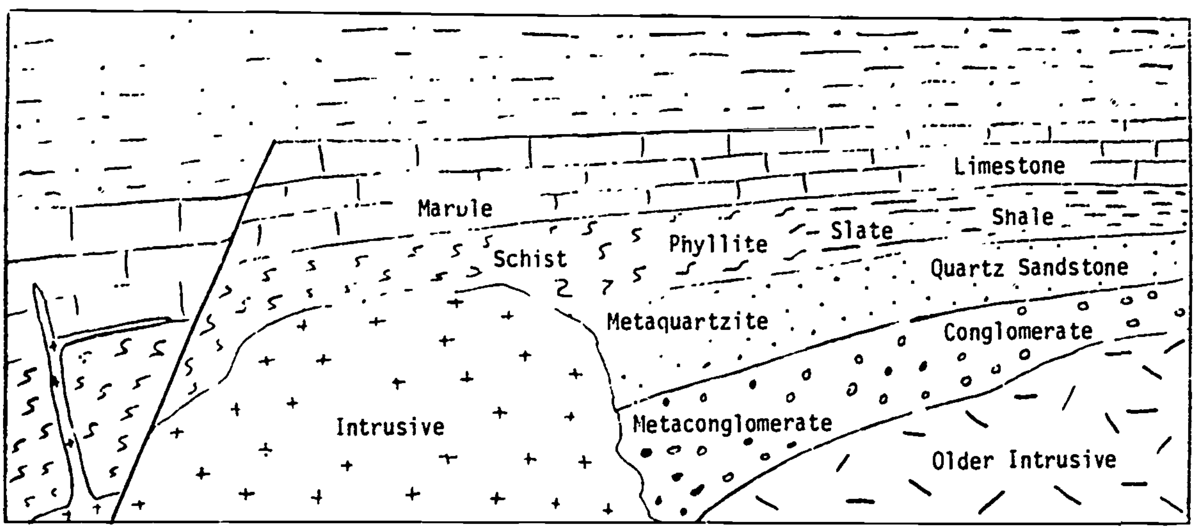


Figure 2.7. Generalized diagram to illustrate metamorphic facies developed around an intrusion producing regional metamorphism. The highest grade metamorphism would be closest to the intrusion with lower grade farther away. Contact metamorphism could be developed along the dike and sill as well as the fault in the left part of the diagram.

Key to identify metamorphic rocks.

1. Rock foliated, go to 2.
   Rock non-foliated, go to 5.

2. Rock fine-grained, go to 3.

   Rock coarse-grained, go to 4.

3. Slaty cleavage present - Slate

   Phyllitic foliation present - Phyllite

4. Schistose foliation present - Schist

   Gneissic foliation present - Gneiss

5. Crystals commonly microscopic but variable, composition variable, usually dark color - Hornfels

   Grains or crystals recognizable with naked eye, go to 6.

6. Crystals of calcite or dolomite - Marble

   Grains greater than silt in size, go to 7.

7. Grains of sand size, quartz with quartz cement - Metaquartzite

   Grains larger than sand size - Metaconglomerate

5. Crystals commonly microscopic but variable, composition variable, usually dark color - Hornfels

Grains or crystals recognizable with naked eye, go to 6.

6. Crystals of calcite or dolomite - Marble

Grains greater than silt in size, go to 7.

7. Grains of sand size, quartz with quartz cement - Metaquartzite

Grains larger than sand size - Metaconglomerate

Exercise. For each numbered specimen provided, fill in the appropriate information and identify the rock type using the key and metamorphic rock classification (Fig. 2.7).

Foliation	Mineral Composition	Grain Size	Rock Name
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			

Fig. 2.7 Classification & Use of Metamorphic Rocks

Foliation	Texture or Composition	Rock Name	Use
Non-Foliated	Calcite or dolomite	Marble	Cement, sculpture, building stone
	Grains > 2mm	Metaconglomerate	Building stone
	Grains 0.0627-2.0mm	Metaquartzite	Building stone, glass
	Crystals microscopic composition variable	Hornfels	None
Foliated	Slaty cleavage, Very Fine-Grained	Slate	Roofing material
	Phyllitic, Fine- to Medium-Grained	Phyllite	May bear economic minerals
	Schistone, Fine- to Coarse-Grained	Schist	May bear economic minerals
	Gneissic, Fine- to coarse-Grained	Gneiss	Building & ornamental stone

PART III - Metamorphic Rocks - Questions

1. How does slatey cleavage differ from phyllitic foliation?

2. How does schistosity differ from gneissic foliation?

3. How does a calcareous marble differ from a limestone?

4. How does an orthoquartzite differ from a metaquartzite?

5. If regionally metamorphosed, what would each of the following rocks become?

	Metamorphic grade low	high
Claystone -		
Fossiliferous Limestone -		
Cobble Conglomerate -		
Chalk -		
Granite -		
Slate -		

6. What is the use of each of the following metamorphic rocks?

Metaquartzite -

Marble -

Gneiss -

Slate -

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
GEOLOGY BLOCK

Lab Exercise - Structural Geology

Introduction. Structural geology is the study of the three-dimensional arrangement of the rocks of the earth. This includes study of the processes of folding and faulting and plate tectonics. Originally our data were derived from mapping the distribution and attitude of rocks on the earth's surface. Today these surface data are supplemented with data from geophysical studies (electronically derived information) and drill hole data (includes rock samples and electronically derived information). Geologists compile the data onto geologic maps, cross-sections and block diagrams. We will use only cross-sections and block diagrams to learn to interpret geologic structures. Block diagrams are used to represent a portion of the earth which may be viewed on all sides as well as the top and the bottom if desired. The sides are cross-sections. The top usually represents the surface of the earth and the bottom a cross-sectional view of a plane below the surface.

Purpose.

1. To learn to interpret different types of geologic structures.

2. To learn three-dimensional perspectives of rock layers.

Terminology.

Attitude - see orientation section

Antiform - an upfold in which the sides or limbs are inclined away from the central part of the structure.

Dip angle - see orientation section

Dip direction - see orientation section

Normal Fault - a fault in which the fault block above the inclined fault plane or surface has moved down relative to the block beneath the fault plane.

Plunge - the acute angle from horizontal of the trend.

Reverse Fault - a fault in which the block above the inclined fault plane or surface has moved up relative to the block beneath the fault plane.

Strike - see orientation section

Strike-slip fault - a fault in which the relative movement is horizontal with the two blocks sliding laterally to one another.

Synform - a down fold in which the sides or limbs are inclined toward the central part of the structure.

Trend - the compass direction of the inclination of a linear structure, antiform axis or synform axis.

Vertical fault - a fault in which the fault plane is vertical and the relative movement of the two blocks is vertical.

Orientation. Because strata may be folded or faulted into various configurations within the earth they must be oriented for understanding. The geometrical orientation is called ATTITUDE. Laterally it may remain constant over vast distances or change rapidly. Attitude is described using two components, strike and dip. STRIKE is the compass direction of the line formed when a horizontal plane intersects an inclined layer, fault or other planar feature. In figure 1 the inclined sandstone layer is intersected by the surface of the body of water along AB. Line AB is the strike line. The two parallel lines CD and EF are also strike lines. These lines are referred to north and the strike is usually given as North "so many" degrees east or North "so many" degrees west. In figure 1 it would simply be North.

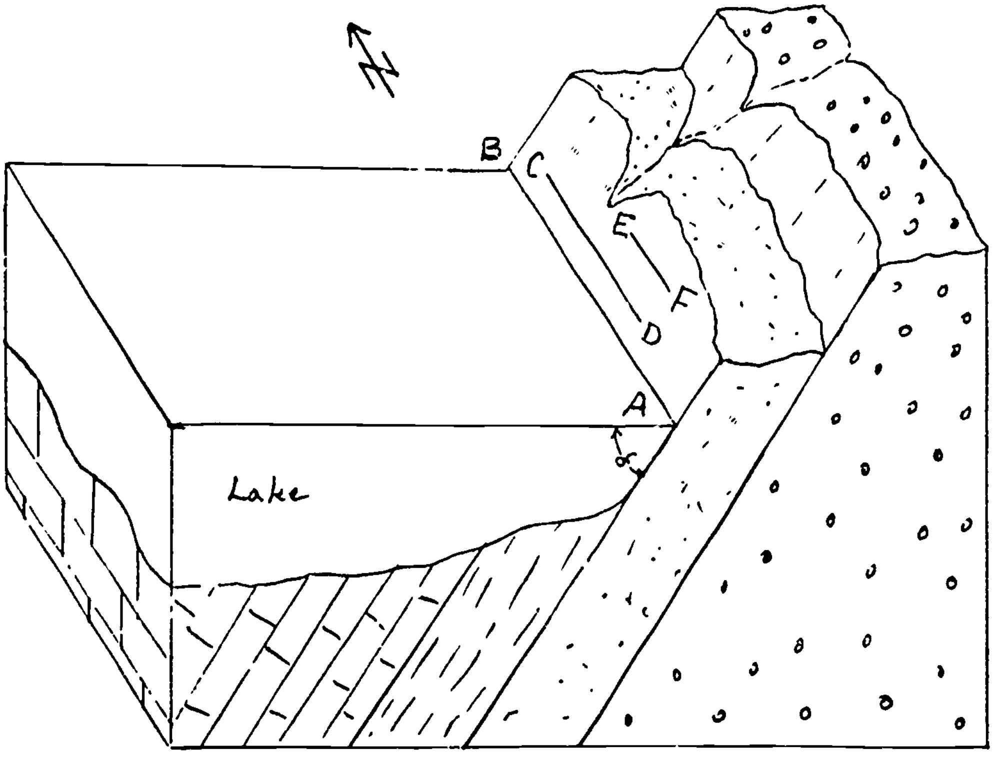


Figure 1. Block diagram

The DIP DIRECTION is the compass direction in which the layer is inclined (downward), perpendicular to the strike. In figure 1 the dip direction is west. The DIP ANGLE is the acute angle "α", perpendicular to the strike, which is measured from the horizontal surface down to the inclined surface.

Strike and dip are shown on maps and surface panels of block diagrams by the use of the symbols as follows:

inclined strata striking North, dipping 30° East.


vertical strata


horizontal strata

Types of structures. The types of structures were reviewed in lecture and will not be reviewed here. However, the terms are defined and may be reviewed in the terminology section.

Exercise. All questions refer to the block diagrams of figures 2 through 9. To construct the block diagrams trim them with a paper cutter using the guide lines extended away from the diagram. Do not cut out the blank corners. After trimming, place the diagram face down and fold 4 times, following the 4 lines along the sides of the central panel of the diagram as guides. The blank corners should be tucked under the block at 45° and provide finger holds when handling the block. Do not glue or staple the corner blanks as you will want to flatten the diagram out to place arrows or complete panels as you work through the exercise.

Question 1-4 refer to figure 2.

1. What is the attitude of the strata? Place the symbol on the top panel.

2. What is the attitude of the dike?

3. Why is the bank of sandstone wider on the top view of the block than on the side views?

4. Complete the blank panel of the diagram.

Questions 5-8 refer to figure 3.

5. What is the direction of strike of the structure?

6. What are the attitudes of the blank unit of the two limbs of the diagram?

   North limb ________________

   South limb ________________

7. Complete the two blank panels.

8. What type of structure is this?

Questions 9-13 refer to figure 4.

9. How does this structure differ from figure 3?

10. What type of structure is this?

11. Using the attitude symbol show the strike and dip directions of the blank unit on the two limbs of the structure.

12. What is the approximate angle of dip of the limbs of the structure?

13. Complete the two blank panels of the diagram.

Questions 14-17 refer to figure 5.

14. What type of structure does this block diagram represent?

15. Complete the two blank panels of the diagram.

16. What is the approximate angle of plunge of the structure?

17. Place the attitude symbols on the upper panel showing the strike and dip directions for the limestone unit. There should be three symbols.

Questions 18-20 refer to figure 6.

18. What type of structure does this block diagram represent?

19. Place the 3 attitude symbols on the upper panel showing the strike and dip directions for the blank unit.

20. Which direction does the structure trend? At what approximate plunge angle?

Questions 21-26 refer to figure 7.

21. What is the attitude of the strata in this diagram? Show the symbol on the central panel of the diagram.

22. Three faults are present. Place arrows along the sides of the fault in the side panel to show the relative movement for each fault.

23. Why can the arrows not be placed on the top panel?

24. Name each of the faults, placing the name along the fault on the upper panel.

25. Which fault shows the greatest amount of movement?

26. Complete the blank side panels of the diagram.

Questions 27-31 refer to figure 8.

27. What is the attitude of the strata? Show this placing the strike and dip symbol on the proper panel.

28. Complete the east panel of the diagram.

29. Why are the bands of claystone closer together along the left sides than the right sides of the top and south panels?

30. When looking at the south panel the fault on the left is a ____________________ fault and the one on the right is a ____________________ fault.

31. Place arrows on the south panel to show the relative movement of each fault.

Questions 32-28 refer to figure 9.

32. What is the attitude of the strata?

33. What is the attitude of the dike?

34. Complete the east and north panels of the diagram.

35. Show the relative movement of the fault in the south and north panels of the diagram by placing arrows along the sides of the fault.

36. Place arrows showing the relative movement along the sides of the fault on the top panel of the diagram.

37. Why are the arrows of question 35 incorrect?

38. What type fault is this?

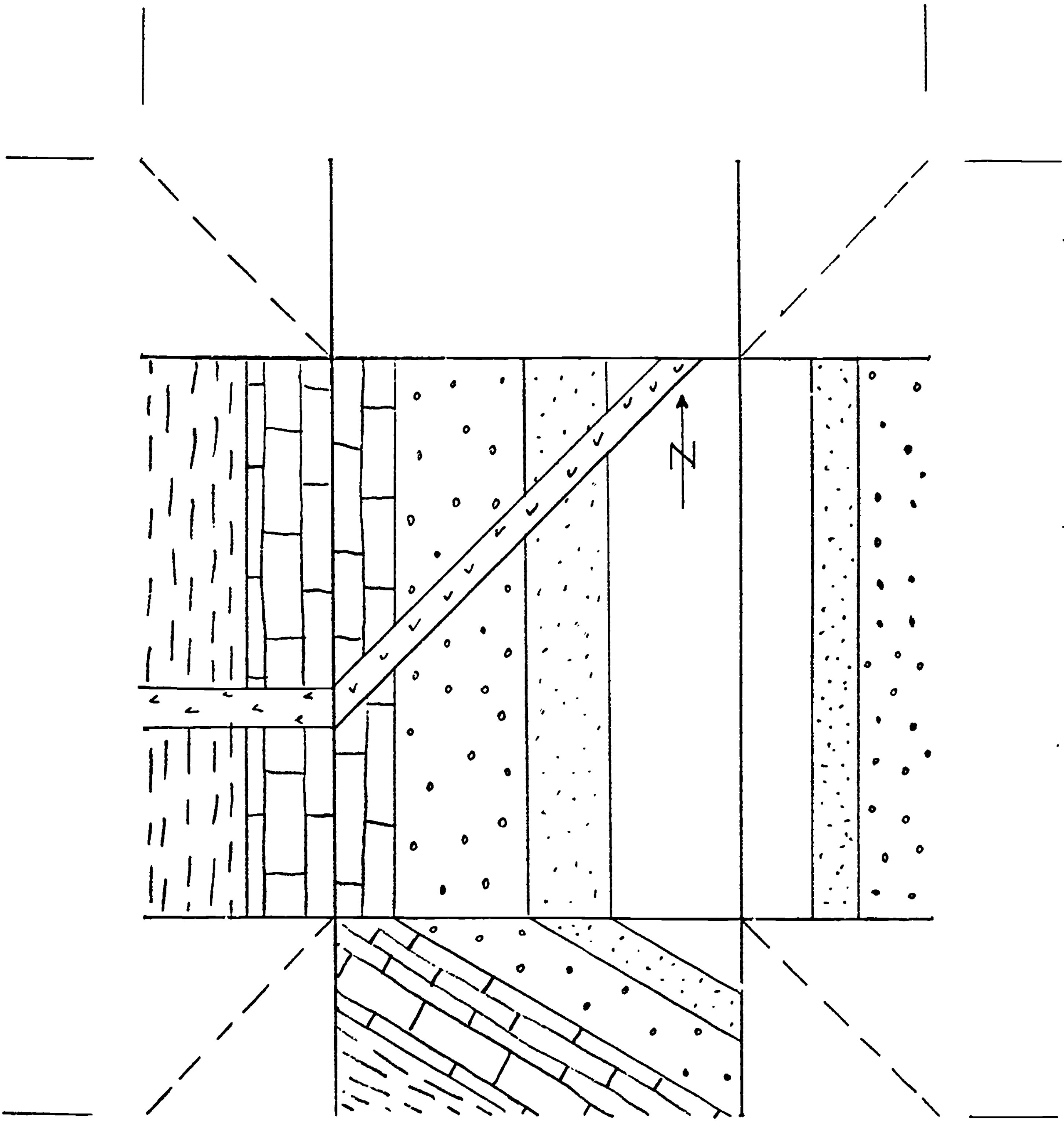


Figure 2

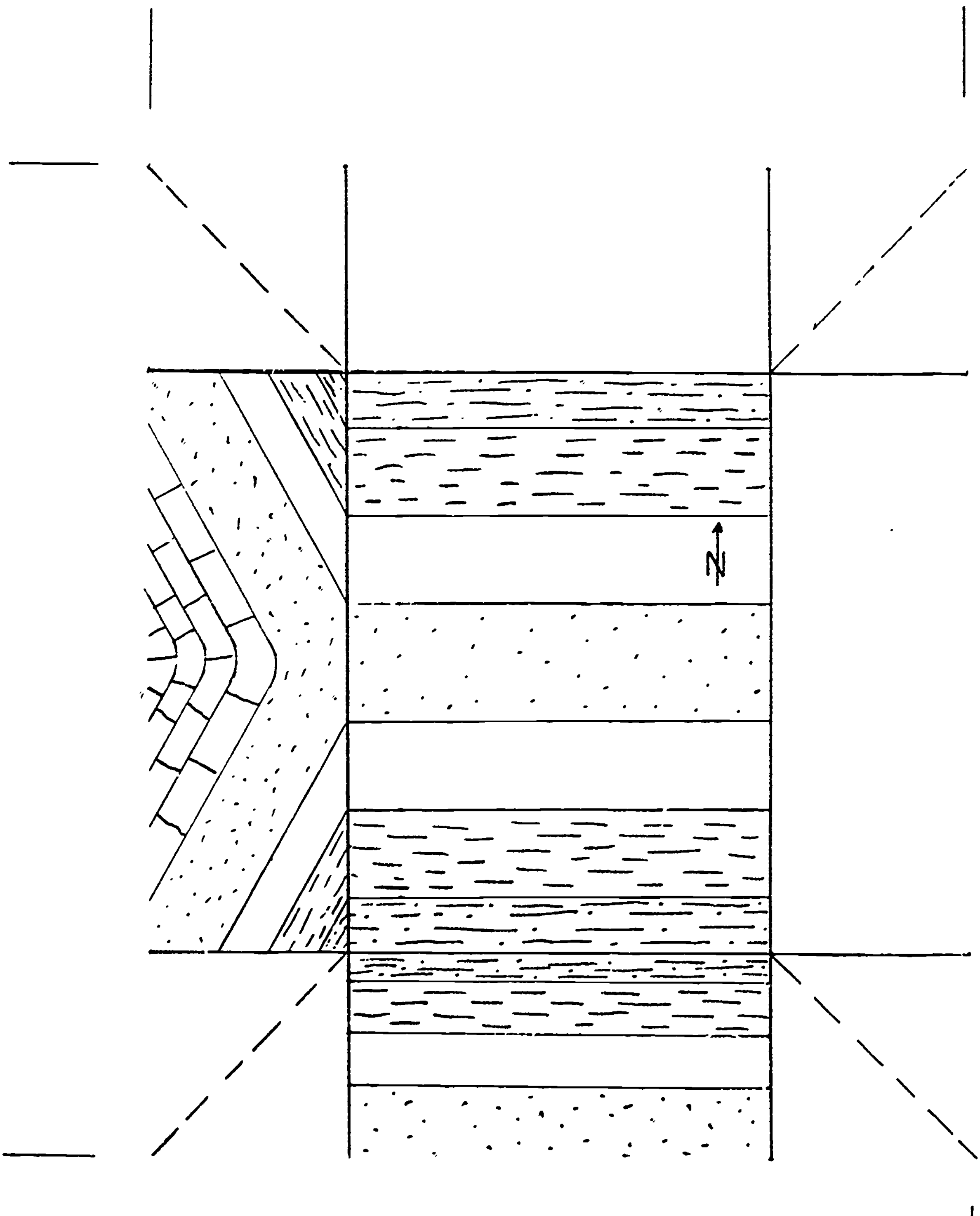


Figure 3

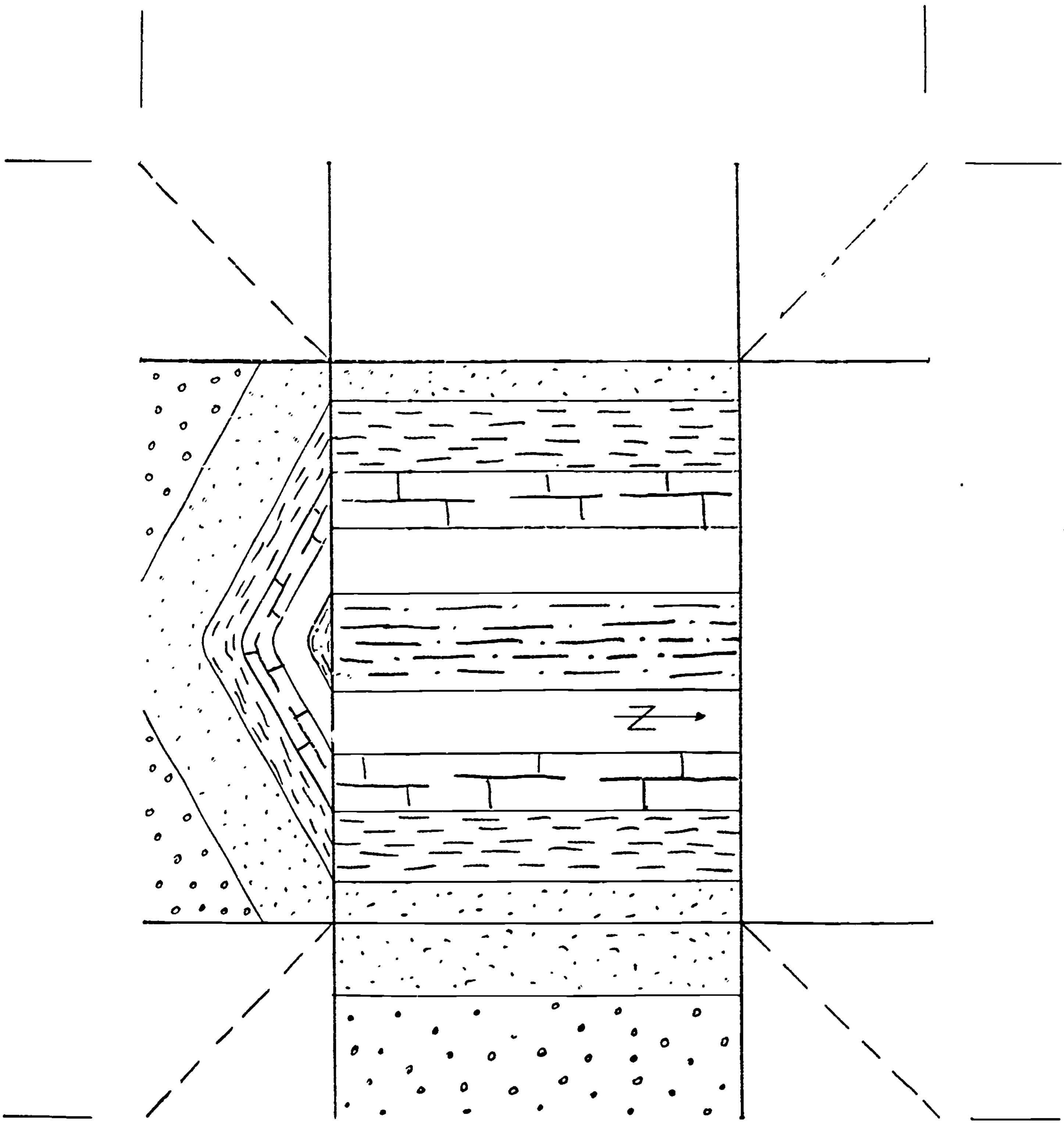


Figure 4

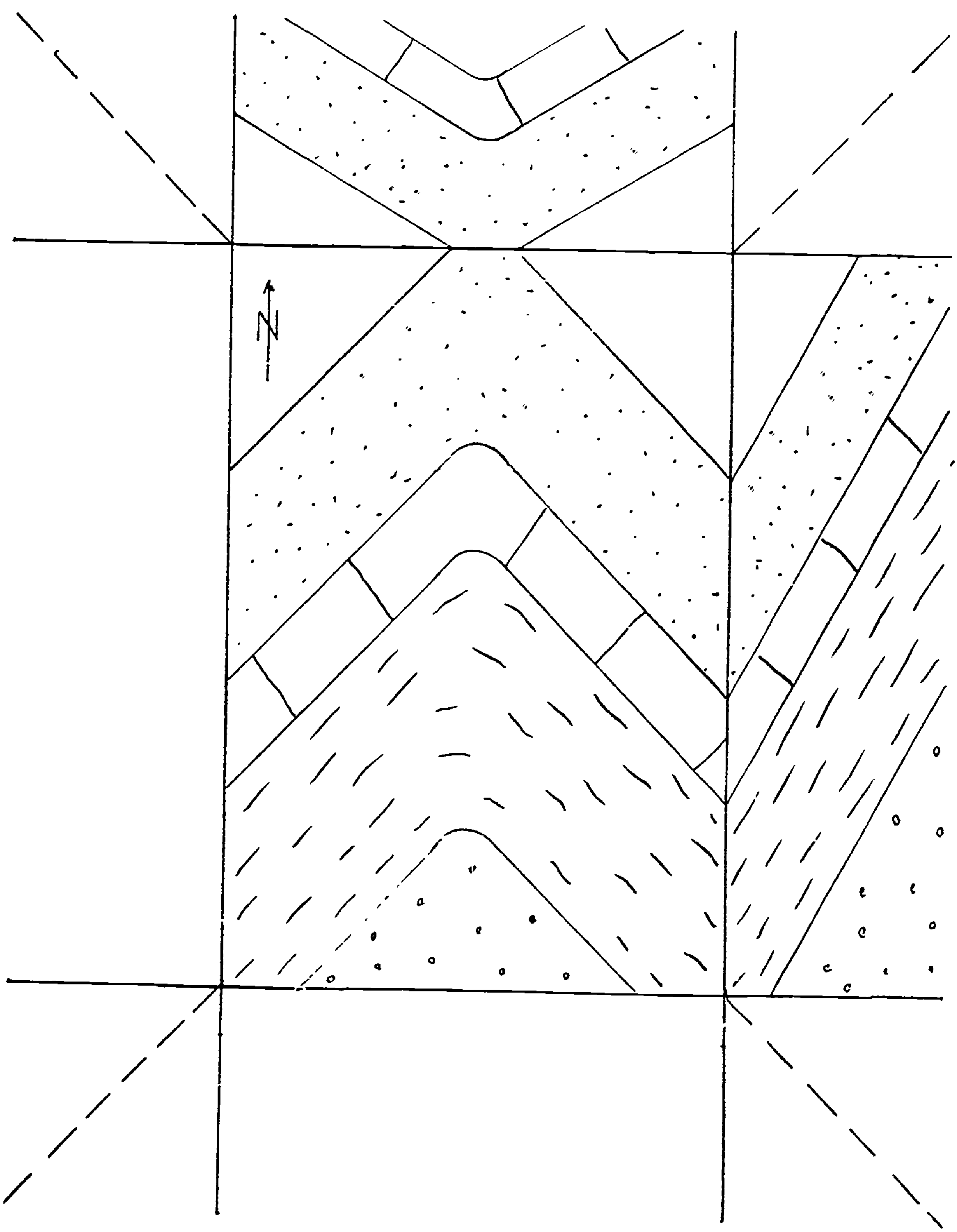


Figure 5

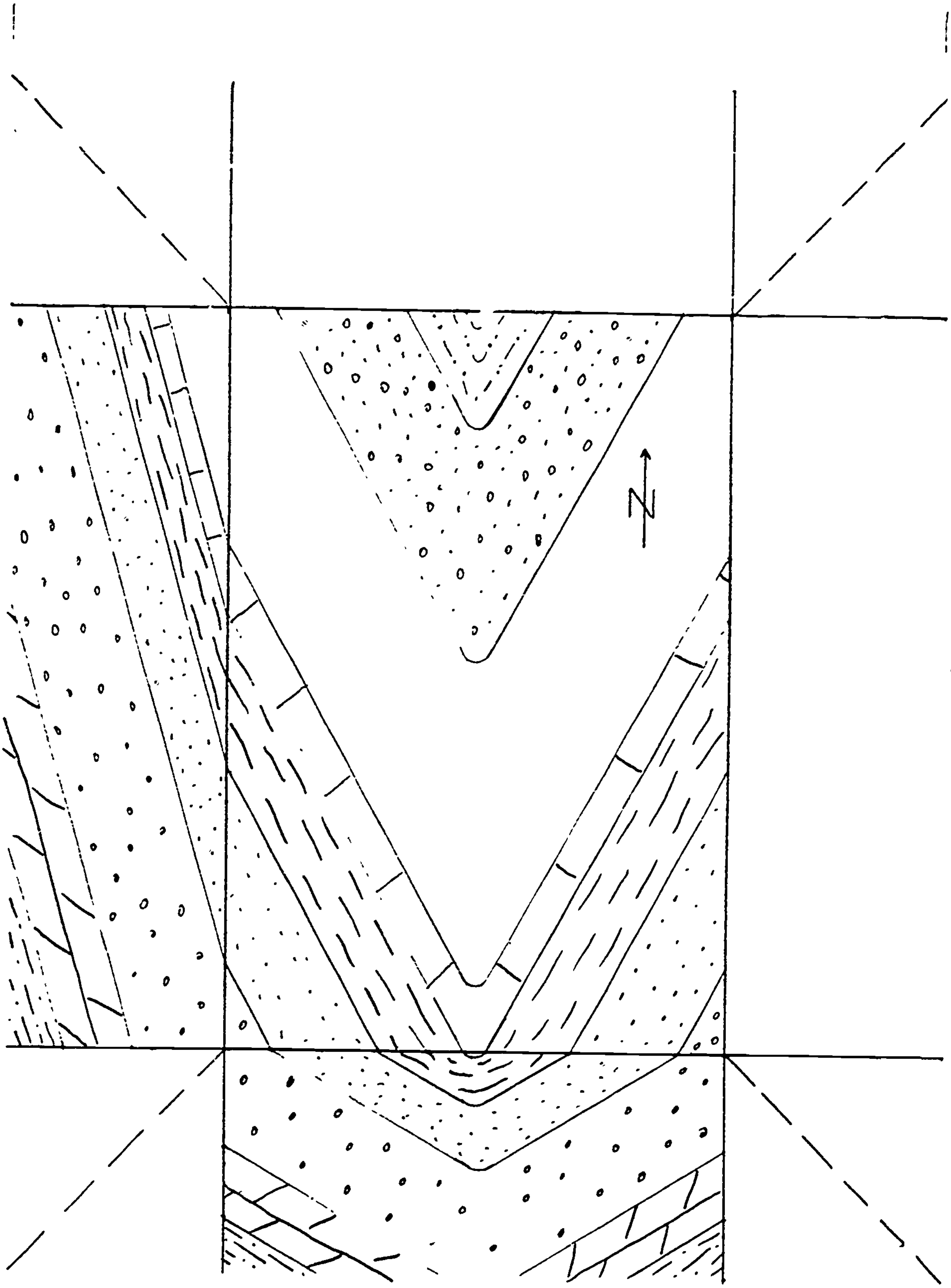


Figure 6

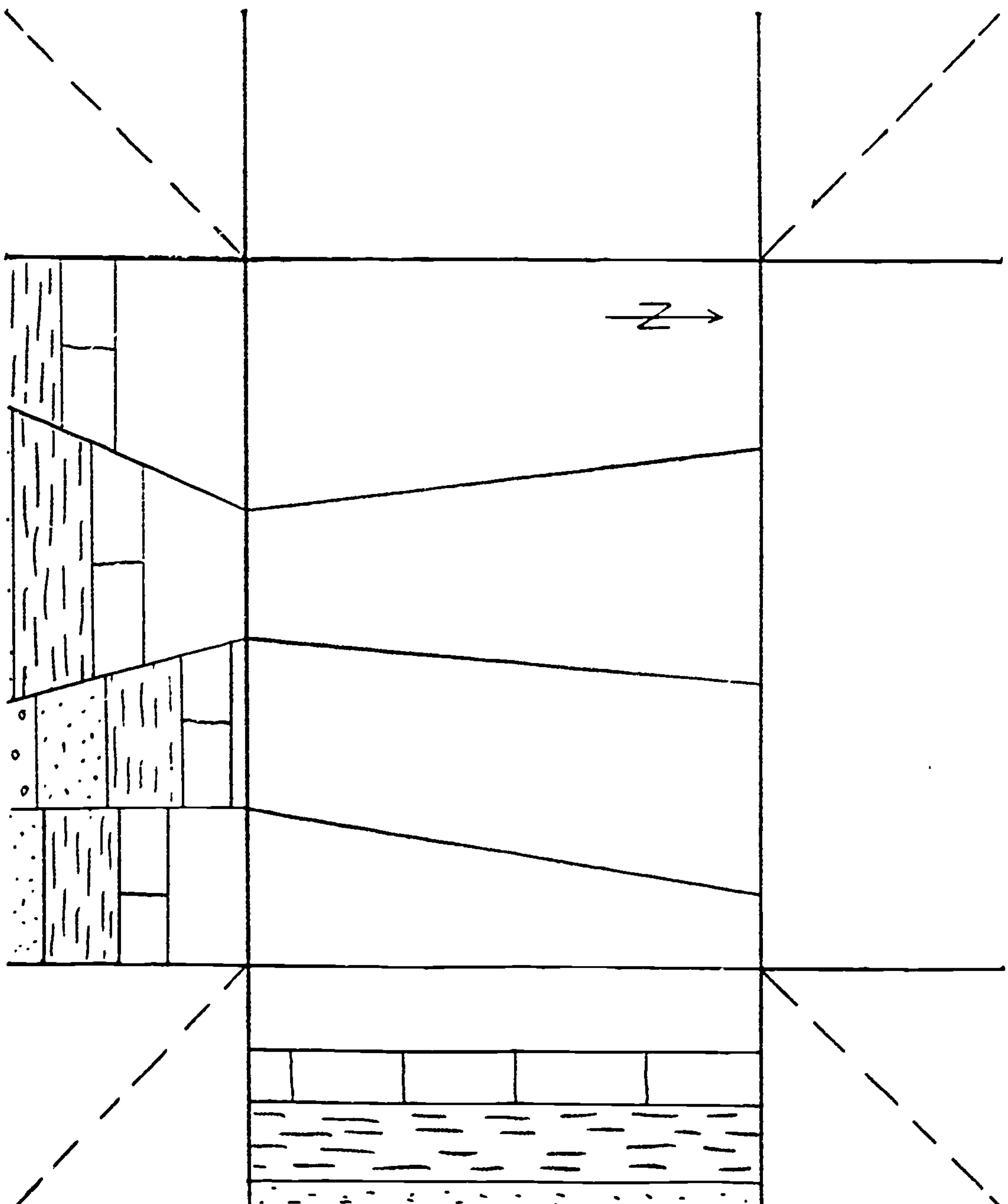


Figure 7

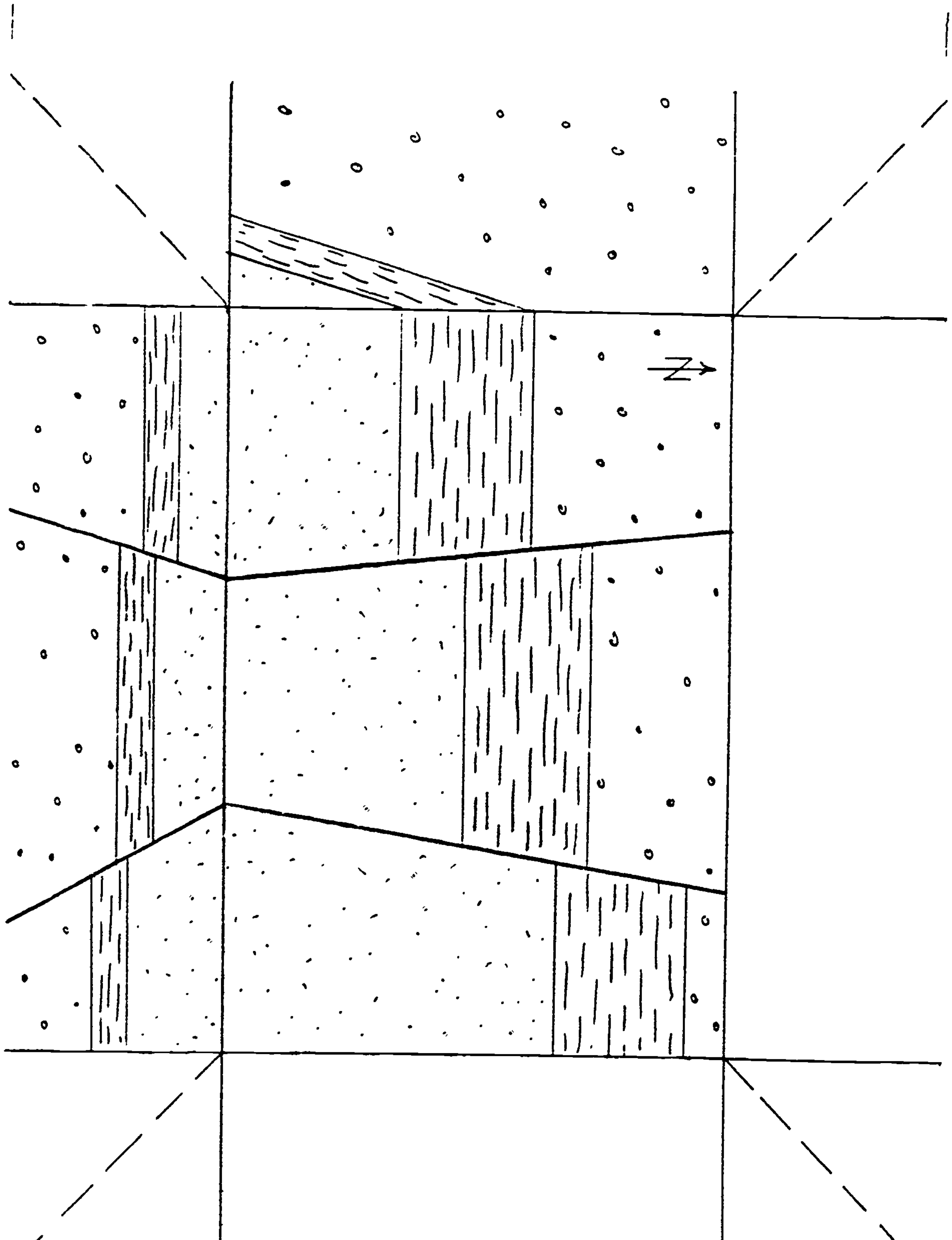


Figure 8

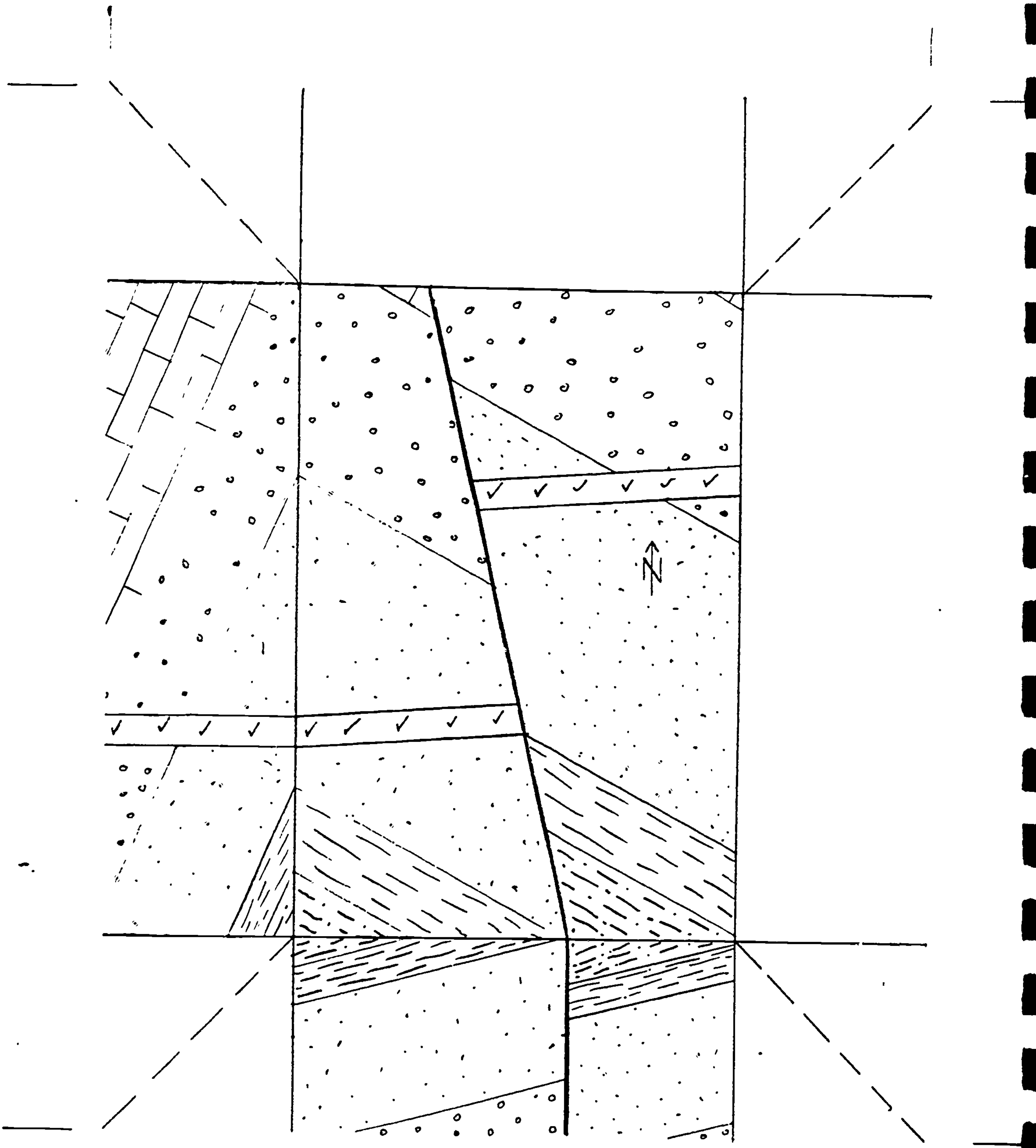


Figure 9

Astronomy 301 Geology Section Lab Exam December 12, 1986 Erik Weberg TA

Name: ______________________________

Identify the eight samples and answer the questions:(2 points for each sample)

1 a)
b)What is this used for?

2 a)
b)Where was this rock deposited?

3 a)
b)Is this plutonic or volcanic?

4 a)
b)What chemical elements are abundant in this rock?

5 a)
b)Why don't we find this mineral in clastic sedimentary rocks very often?

6 a)
b)Why is color a poor criteria for identifying this mineral?

7 a)
b)What conditions were necessary to form this rock?

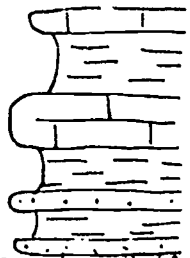
8 a)
b)What rock did this metamorphose from?

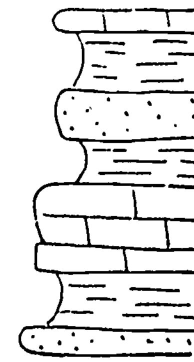
9) Why does a porphyritic rock have both large and small crystals? (4 points)

10)What is it about halite that may interest one of your students? (2 pts)

11) Your third-grader brings you a rock that his/her dad/mom found on a river bank during their vacation in Arizona. Your student wants to know what it's made of, how it formed, and how it came to be where it was. What are ya gonna' do now? Yes, this is a serious question, one you'll likely be faced with before too long. (5 pts)

12) The following rock exposures were found a great distance apart. Correlate the rock layers to reconstruct how the layers may have looked before erosion. (3 pts)



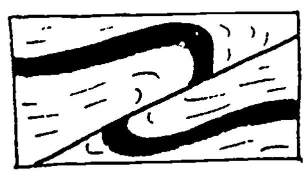


13) What structure is drawn here? (1 pt)

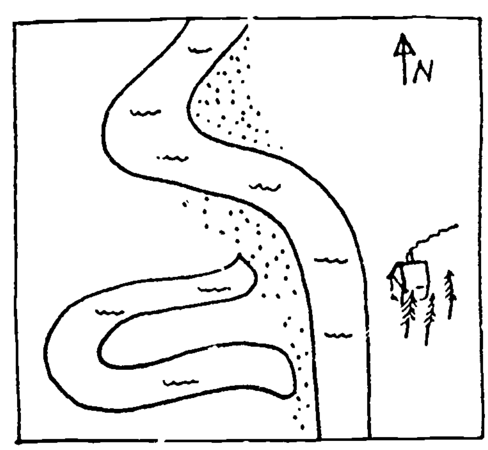
14) Lable the axis.(1 pt)

15) How do you know that these rocks have been structurally deformed and not just deposited this way? (2 pts)

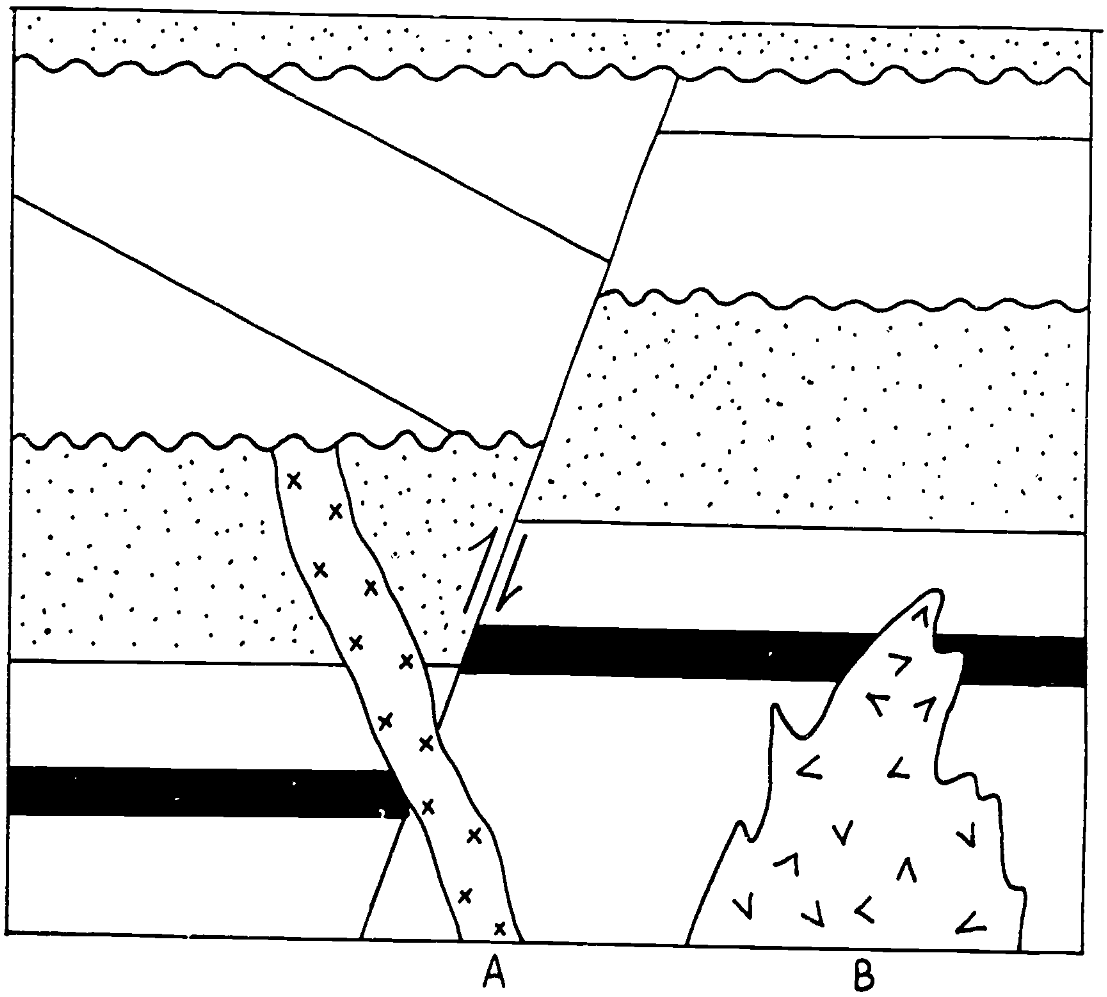
16) What type of fault is displayed here and what led you to that conclusion? (2 pts)



17) The following is a drawing of a map view of a river system. Lable the following items: (6 pts)
where deposition is taking place
where erosion is taking place
where the water is moving fast
where the water is moving slowly
where the river used to flow
What's that last feature called?



18) Explain and draw how an anticline does not necessarily make a hill or how a syncline does not necessarily make a valley. (3 pts)



Which is older, igneous body A or igneous body B? Tell why you decided or couldnt decide. (1 pt)

There are three things wrong with this cross section in terms of seque.ice of events and impossible situations. Describe these three mistakes (4 pts)

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ASTRONOMY 301 - GEOLOGY SECTION

Midterm

I. Fill in each blank with the appropriate word or words. (2 pts each)

Igneous rocks are classified principally on ____________________ and ____________________, whereas metamorphic rocks are classified on ____________________ and ____________________. A coarsely crystalline basic igneous rock is called __________ whereas the finely crystalline equivalent is called __________. The chief agents of metamorphism are __________, __________, and ____________________. In a mineral, cleavage is the result of ____________________, which is determined when the mineral is formed. Minerals are identified by the recognition of a combination of their ____________________.

II. Define each of the following terms; be as concise as possible. (2 pts each)

Sial -

Rock -

Chert -

Porphyry -

Mafic -

III. What controls the crystal size in a cooling magma? (10 pts)

IV. How is grain size used in the classification of sedimentary rocks? (10 pts)

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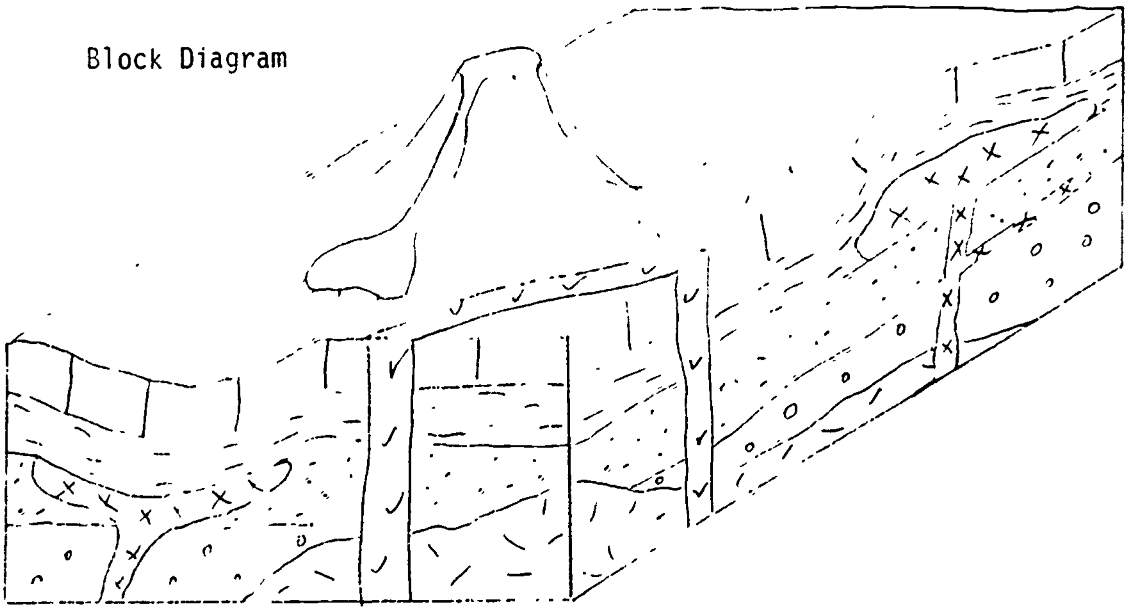
Block Diagram



V. On the diagram above, using the numbers in front of each of the features, label the following: (2 pts each)

1. Laccolith
2. Dike
3. Batholith
4. Crater
5. Sill
6. Lopolith
7. Intrusive igneous rock
8. Extrusive igneous rock
9. Volcanoe

VI. Explain the significance or meaning of Bowen's Reaction Series as it applies to igneous rocks. (10 pts)

VII. I know nothing about rocks. I have come to you as my teacher with a rock specimen that you tell me is a sedimentary rock. I reply "What is a sedimentary rock?". Explain what a sedimenary rock is. (10 pts)

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VIII. Give the rock cycle. (10 pts)

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ASTRO 301 - Geology Midterm

1. Your text says that there are only eight important rock forming minerals yet I gave you ten minerals which make up most rocks. Explain what the difference is and explain why both the eight and ten minerals are the basic rock forming minerals. (15 pts)

2. What are metamorphic facies? (10 pts)

3. What are the three major types of volcanoes? Explain the differences in shape of each in your answer. Use sketches if helpful. (15 pts)

Initials______________

4. Define each of the following terms; be complete but as concise as possible (2 pts each)

Sima -

Phenocryst -

Sill -

Crater -

Pluton -

5. Give and explain each of the parameters used in the classification of the clastic sedimentary rocks. (10 pts)

6. Briefly explain each of the hazzards of volcanoes. (15 pts)

Initials___________

7. Fill in the blank with the most appropriate term or short phrase to complete the sentences. (2 pts each blank)

Minerals are identified on the basis of ______________________ but they are grouped on the basis of ____________________________. A native mineral that can be pounded into thin sheets or pulled into thin strands is said to be ________________. The _________________ of a mineral may be highly varable depending on the trace elements in the _____________________________ of the mineral.

8. Discuss how you could relate the different parts of geology that have been covered in the lecture covereage for this exam in an elementary class. Be specific, that is, what would you use to relate to what. (15 pts)

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ASTRONOMY 301 - GEOLOGY SECTION

Final Exam

1. Fill in each blank with the appropriate word or short phrase (2 pts. each).

   Of the two most prominent waves generated when an earthquake occurs the ____________ wave travels the faster, arrives ______________ and will propagate through ______________, whereas the ______________ wave will not propagate through the same medium. The ________________ of an earthquake is the area on the surface of the earth immediately above the ____________________.

   Radiometric dates are based on the __________________ of isotopes of radioactive elements such as _________________ and ___________________.

   Three laws which help establish time relationships are the laws of ____________________, ______________________, and _________________________.

   A mixed suite of rocks associated with the subduction zone is called a ____________________.

   The __________________ of a mineral is a measure of its resistance to being scratched.

   The __________________ of a mineral is the color of the powder of the mineral.

2. Explain the difference between a cinder cone and a shield volcano. Use diagrams if they would be helpful. (10 pts)

3. Why do maps showing earthquake occurrences and volcanoes show similar distribution patterns on the earth? (10 pts)

4. What information or data support and confirm plate tectonics? (10 pts)

5. What is the difference between a reverse fault and a strike-slip fault? (10 pts) Use diagrams if helpful in explaining your answer.

6. In each of the boxes sketch a cross-section view of the structure or feature corresponding to the caption. (5 pts each)

Normal Fault

Asymmetrical Anticline

Spreading Center

Angular Unconformity

Symmetrical Syncline

Subduction Zone

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Astronomy 301 -Geology Section
Final Exam, Dec. 87

I. Fill in the blank with the word or short phrase which most appropriately completes the sentence (2 pts each blank).

When discussing geologic time, __________________ time is relating events to one another in sequence of occurrence, whereas __________________ time is based on ____________________________. The _____________ wave, which is generated by an earthquake, cannot travel through a ______________ medium. Elongate features in the oceans along which new crustal material is forming are called ______________ or _____________ and are ____________________ plate boundaries. Basalt is an _______________ rock formed largely of hte minerals ___________ and plagioclase feldspars. (20 pts)

2. In the space below draw a cross-section of the earth showing the layers in their proper sequence as they are currently recognized. Be sure to label the layers. (10 pts)

Initials:____________

3. Give and briefly explain each of the geologic hazzards associated with earthquakes. (10 pts)

4. Explain the Law of Superposition, use a sketch if helpful (5 pts).

5. Giving geologic data that you have had presented in this class discuss the fallicies in the following statement: *Mineral resources are uniforminly distributed around the earth and they are in such abundant supply we will never run out of any of them.* (10 pts)

Initials:_______________

6. Draw a cross section of an ocean-continent collision. Label the following features: (15 pts)
   - Trench
   - Subduction zone
   - Continental crust
   - Oceanic crust
   - Magma chambers
   - Volcano

7. Explain the difference between a normal fault and a reverse fault. Use sketches if helpful. (10 pts).

Initials:_______________

8. Explain the difference between an artesian well, an aquifer, and the zone of aeration. Use sketches if helpful. (10 pts)

9. As a student I have brought you a specimen of quartz and a specimen of marble. Explain how each formed and how they may be identified. (10 pts).