REMOTE SENSING & GIS IN WATER RESOURCES

Paper code: 08MTRS32

<u>Units–3, 4 & 5 : Groundwater, Crystalline and Sedimentary Aquifer Systems</u>

Dr. K. Palanivel
Assistant Professor

Centre for Remote Sensing, Bharathidasan University

Tiruchirappalli

08MTRS-32: REMOTE SENSING & GIS IN WATER RESOURCES

1. **Surface Water Resources:** Hydrological Cycle: (Rainfall, Infiltration, Runoff, Evapotranspiration) – Global distribution of Surface Water bodies – Surface Water Budgeting/Quantification using Satellite Infrared data – Spectral Response Pattern of Water.
2. **Drainage morphometric analysis:** Drainage mapping and analysis (from Satellite data, Automated Drainage Mapping using DEM, Drainage Morphometric Analysis) Water Quality Mapping and Monitoring using Remote Sensing.
3. **Groundwater :** Basic Principles of Groundwater Hydrology
4. **Crystalline Aquifer Systems:** Characteristics, Mapping of Crystalline Aquifer Systems, Lithological, Regolith and Fracture Pattern Mapping and Modelling, Geophysical Surveys and GIS based Geospatial modelling of Crystalline Aquifer System
5. **Sedimentary Aquifer Systems:** Characteristics, Artesian and suberising conditions, Mapping Techniques using Geoinformatics.
6. **Geomorphic Aquifer System:** Hydro geomorphic mapping through Satellite Raw and Digitally processed data – Ground water quality (Rock – water interaction, pollution etc).
7. **Natural and Artificial Recharge:** Site Selection for Natural and Artificial Recharge on Geological criteria, Detection of Site Specific Mechanism for recharge through GIS Applications)
8. **Groundwater Modelling:** Geospatial Modelling of Groundwater Systems – Stochastic – Flow – Linear – Finite - element Modelling.
9. **Integrated Watershed Development and Management:** Conjunctive analysis of Surface and Groundwater – GIS based Watershed wise Water budgeting – Integrated Watershed Planning – Water Resources Information System.
10. **Case studies:** Remote sensing and GIS in water resources – Case studies.

Units-3, 4 & 5 : Groundwater, Crystalline and Sedimentary Aquifer Systems

3. Basic Principles of Groundwater Hydrology: Groundwater Origin & Occurrence. Sources of Groundwater – Classification of Groundwater. Aquifer Types**:** Crystalline Aquifer, Sedimentary aquifer, Unconsolidated Sedimentary Aquifer, Geomorphic aquifer - Pump tests**.**

4. Crystalline Aquifer Systems: Characteristics, Mapping of Crystalline Aquifer Systems, Lithological, Regolith and Fracture Pattern Mapping and Modelling, Geophysical Surveys and GIS based Geospatial modelling of Crystalline Aquifer System

5. Sedimentary Aquifer Systems: Characteristics, Artesian and suberising conditions, Mapping Techniques using Geoinformatics.

Groundwater Origin, Occurrence Sources & Classification of Groundwater

Meteoric water: Groundwater of atmospheric origin that has been geologically recent (tens of thousands of years) part of hydrological cycle.

Connate water or **Fossil water:** Much older groundwater that is still of atmospheric origin but that has been isolated from the hydrological cycle for millions of years. This water was already present in the geological formation when it was formed (Connate = born together). E.g. Water in which alluvial material was deposited.

Juevenile water or **Primary water:** Groundwater that has never been part of the hydrological cycle. It was formed within the earth itself and is of **magmatic** origin. This includes, **volcanic** (shallow) and **plutonic** (deep) **water.**

Juvenile water can move up in the earth's crust with volcanic activity. It is high in mineral content, but insignificant as a water resource.

Metamorphic water is water that was in rocks during the period of metamorphism.

Marine water is water that has moved into aquifers from oceans.

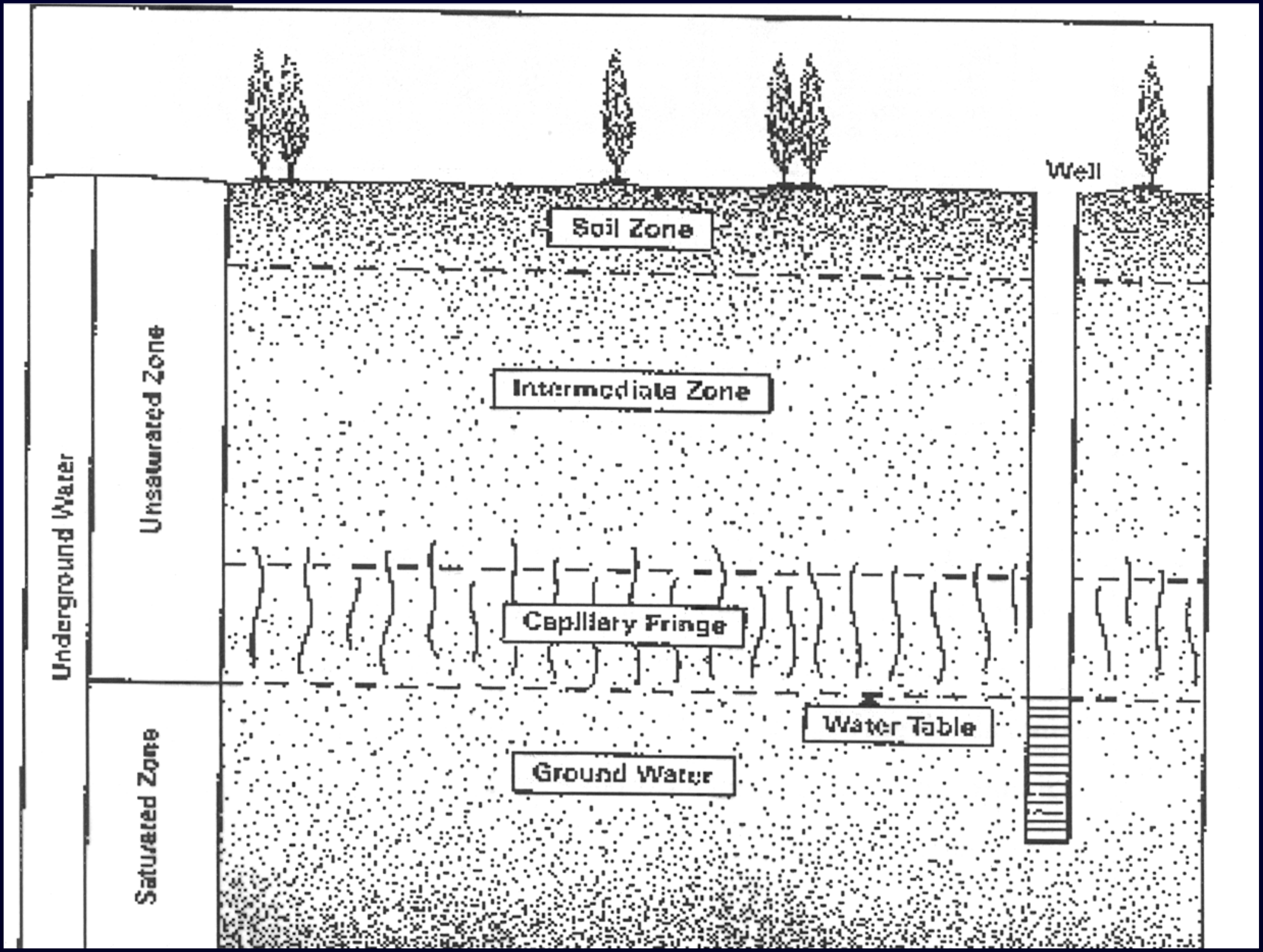
The **Age** of groundwater may range from a few years or less to tens of thousands of years or more.

Much older **Meteoric groundwater** dated back to 5000 to 30,000 years calculated with the help of carbon 14 dating technique, formed during previous climatic periods with higher rainfall.
Cosmic water is water that comes in from space with meteorites, a rare one.

Rejuvenated water is the water returned to the terrestrial water supply by geologic processes of compaction and metamorphism – is called water of compaction.

Internal water is water occurring at a very great depth underneath the surface within the zone of disconnected openings.

VERTICAL DISTRIBUTION OF GROUNDWATER



Subsurface water occurs in two different zones.

One zone, located immediately beneath the land surface in most areas, contains both water and air in the voids. This zone is referred to as the **unsaturated zone**.

Other names for the unsaturated zone are **zone of aeration** and **vadose zone**.

The unsaturated zone is almost always underlain by a second zone in which all voids are full of water.

This zone is defined as the **saturated zone**. Water in the saturated zone is referred to as **ground water** and is the only subsurface water available to supply wells and springs.

c. *HORIZONTAL (WORLD'S) DISTRIBUTION OF GROUNDWATER*

Very vast.

It occurs in different formations with varying quantity and quality as,

GW in Glaciated Mountainous Regions

GW in Glaciated Central Plains Alluvial Basin GW

Mountain Range GW

GW in Sedimentary Plateau and Upalnds

GW in High plains

GW in Floodplains

Desertic GW

<u>Deltaic GW</u>

Coastal Plain GW, etc.

But,

Out of the estimated distribution of world's water, the groundwater occurs about only 0.625%. In that,

Vadose water	-	67,000 km3	=	0.005%
Gw within depth of 0.8 km	-	4,200,000 km3	=	0.31%
Gw between 0.8 and 4 km depth	-	4,200,000 km3	=	0.31%
Total	**-**	**8,400,000 km3**	**=**	**0.625%**

Aquifer Types: Crystalline Aquifer, Sedimentary aquifer, Unconsolidated Sedimentary Aquifer, Geomorphic aquifer

AQUA - WATER in Latin
FER - to yield

An **aquifer** is a saturated geologic formation that will yield a usable quantity of water to a well or spring. Underground zone or layer which is the source of water.

It may be,

- a gravel deposit
- sand
- sandstone
- highly shattered or cracked or a cavernous limestone, etc.

Aquifer is also called as **Underground reservoir** or **Water bearing stratum** or **Water bearing bed** or **Water bearing deposit** or **Water bearing layer** or **Water bearing formation.**

- RESERVOIR ROCKS
    - PERMEABLE
        - POROUS
            - FLUVIALS
                - ALLUVIALS
                    - FANS
                    - FILLS
                - DEPOSITS
                    - DELTAS
                    - COASTALS
            - SAND DUNES
            - GLACIALS
                - ESKERS
                - KAMES
            - SEDIMENTARIES
                - CLASTIC
                - NON-CLASTIC
        - FRACTURED
        - KARSTIC
    - IMPERMEABLE
- NON-RESERVOIR ROCKS

AQUIFER CLASSIFICATIONS / TYPES

- UNCONFINED or WATER TABLE AQUIFERS or PHREATIC WATER or FREE GROUNDWATER AQUIFERS

In which water table varies in undulating form and in slope.

The water within the aquifer is not confined and exposed to atmosphere, i.e. not held under pressure by an overlying impermeable layer – Unconfined Aquifer

The upper limit of the aquifer is defined by the water table itself.

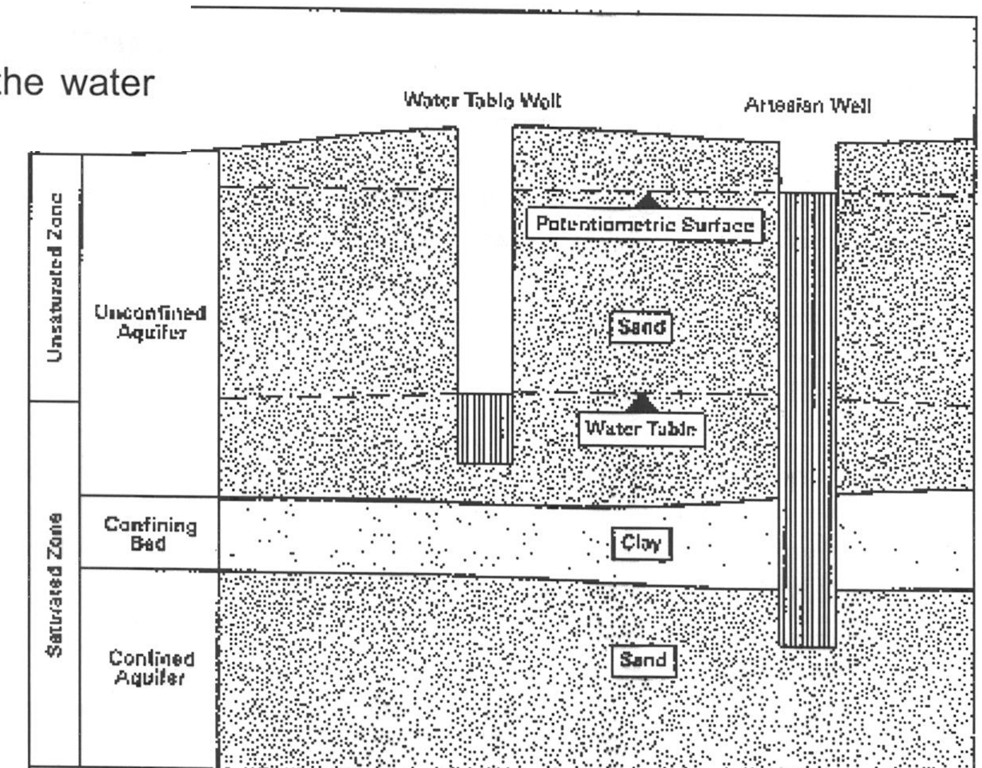


Figure 2.3 Aquifers and Confining Beds

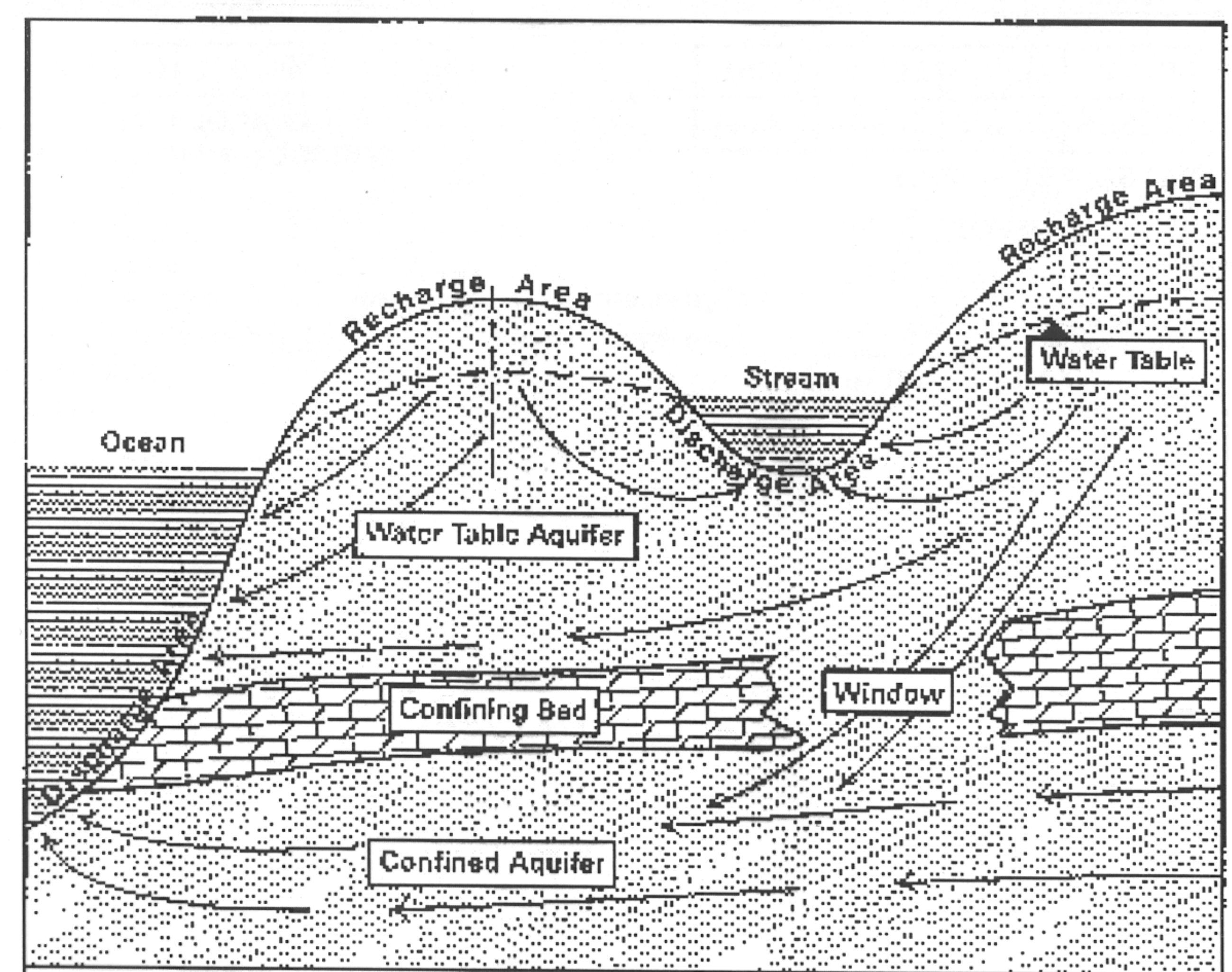


Figure 2.4 Recharge and Discharge Areas

Influent and effluent Streams

If the stream receives water from groundwater table for its flow, then the stream is known as influent stream.
On the contrary, if the stream supplies water to the groundwater table by percolation, then the stream is known as effluent stream.

As a rule, groundwater flows at a low incline into the rivers and lakes (receiving bodies of water) and infiltrates into them (**effluent conditions**; Fig. a).

In times of flood water water surface is situated above the groundwater. During that time bodies of water infiltrate into groundwater (**influent condition**). This is known as **bank-filtered water** (Fig. b).

If in the neighborhood of these surface waters groundwater is discharged, e.g. through wells, so that the phreatic surface drops below the level of that body of water, the surface water infiltrates into the groundwater as bank-filtered water, too (Fig. c).

The **groundwater velocity of flow** in Berlin is about 10 to 500 m p/a, depending on groundwater incline descent and the permeability of the aquifer. However, near well facilities, these low flow velocities can increase significantly.

Fig. a: Groundwater infiltrates into bodies of water

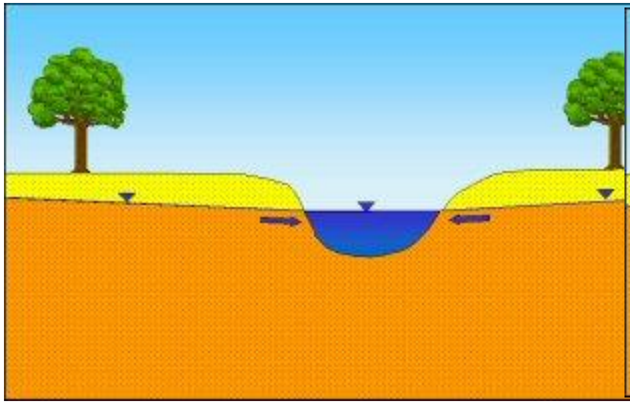


Fig. b: Bank-filtered water caused by flood water: bodies of water infiltrate into groundwater

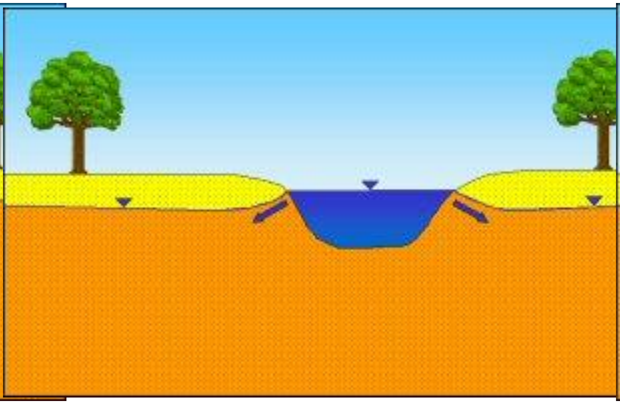
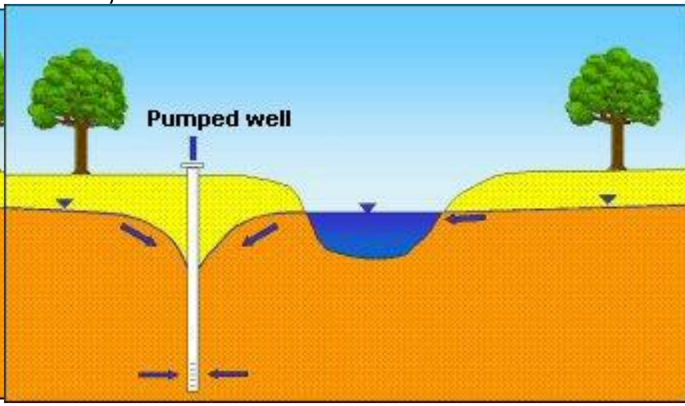


Fig. c: Bank-filtered water caused by discharge of groundwater: caused by the lowering of the groundwater by wells,



- PERCHED AQUIFER and PERCHED WATER TABLE

If a local impermeable stratum exists between the water table and ground level,

i.e. in the zone of aeration, then instead of percolation, the water gets stored up in a limited area above that stratum – **Perched Groundwater zone** and

the upper surface of this zone is called the **Perched water table.**

- CONFINED or ARTEIAN or PRESSURE AQUIFERS

It occurs where groundwater is confined under pressure greater than atmospheric by overlaying relatively impermeable strata.

A **confining bed** is a geologic unit which is relatively impermeable and does not yield usable quantities of water.
Confining beds, also referred to as **aquitards**, restrict the movement of ground water into and out of adjacent aquifers.

Confined aquifers

- usually occur at considerable depth and
- may overlie other confined aquifers.
- often recharged through cracks or openings in impermeable layers above or below them.
- complex geological formations may be exposed at the land surface and can be directly recharged from infiltrating precipitation.
- can also receive recharge from an adjacent highland area such as a mountain range.
- Water infiltrating fractured rock in the mountains may flow downward and then move laterally into confined aquifers.

A region supplying water to a confined aquifer is known as a **recharge area.**

The **Piezometric surface** or **potentiometric surface** of an Artesian or confined aquifer is an imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer.

- LEAKY AQUIFERS or SEMICONFINED AQUIFERS

An aquifer bound by one or two semi pervious layer (aquitards) is called a leaky or semiconfined aquifer.

- SEMI UNCONFINED AQUIFER

If the permeability of the fine grained layer in a semi confined aquifer is so great that the horizontal flow cannot be ignored, then such asn aquifer is intermediate between the traditional semi confined aquifer and the unconfined aquifer and may be called a **semi unconfined aquifer.**

Aquifuge (= refuse)

Rocks that refuses to contain or allow to flow water within it. Thus, the formations which are neither porous nor permeable. Eg. Granite, Basalt, Quartz, etc.

Aquiclude (= include)

Rocks that includes water but it will not allow water to flow freely. These rocks porous but impervious. Eg. Clay, Shale, Mudstone, etc.

Aquitard (= retard)

Rocks which are partly impervious and transmit water at a slower rate than an aquifer. These rocks are semi pervious in nature. Eg. Clay lenses interbeded with sand.

AQUIFER An *aquifer* is a saturated formation of earth material which not only stores water but yields it in sufficient quantity. Thus an aquifer transmits water relatively easily due to its high permeability. Unconsolidated deposits of sand and gravel form good aquifers.

AQUITARD It is a formation through which only seepage is possible and thus the yield is insignificant compared to an aquifer. It is partly permeable. A sandy clay unit is an example of aquitard. Through an aquitard appreciable quantities of water may leak to an aquifer below it.

AQUICLUDE It is a geological formation which is essentially impermeable to the flow of water. It may be considered as closed to water movement even though it may contain large amounts of water due to its high porosity. Clay is an example of an aquiclude.

AQUIFUGE It is a geological formation which is neither porous nor permeable. There are no interconnected openings and hence it cannot transmit water. Massive compact rock without any fractures is an aquifuge.

The definitions of aquifer, aquitard and aquiclude as above are relative. A formation which may be considered as an aquifer at a place where water is at a premium (e.g. arid zones) may be classified as an aquitard or even aquiclude in an area where plenty of water is available.

Deep Aquifer

Shallow Aquifer

5. PHYSICAL PROPERTIES OF AQUIFERS

a. **PRESSURE HEAD :** The pressure head of groundwater at a given point in an aquifer is the height to which water will rise in an open, vertical tube (Piezometer) that is inserted down to that point.

The pressure head expresses the gage pressure of the water in terms of the height of a water column – gage pressure is the pressure with respect to atmospheric pressure.

b. **TEXTURE OF UNCONSOLIDATED MATERIALS**

The texture of the material is classified depending on the relative amounts of sand, silt and clay in a soil.

c. STRUCTURE OF CLAY

A soil with predominantly Ca or Mg clay behaves like a coarser-textured soil and has a 'good' structure. – they are more permeable and friable than soils with dispersed clay.

Dispersion or flocculation of clay depends upon how far the individual clay particles are separated from each other by thickness of the layer of absorbed cations surrounding each particle.

Flocculated clay and associated good structure of the soil are preferred for **agriculture.**

d. POROSITY

The percentage of the total volume of the material occupied by pores or interstices is known as porosity.

e. VOID RATIO

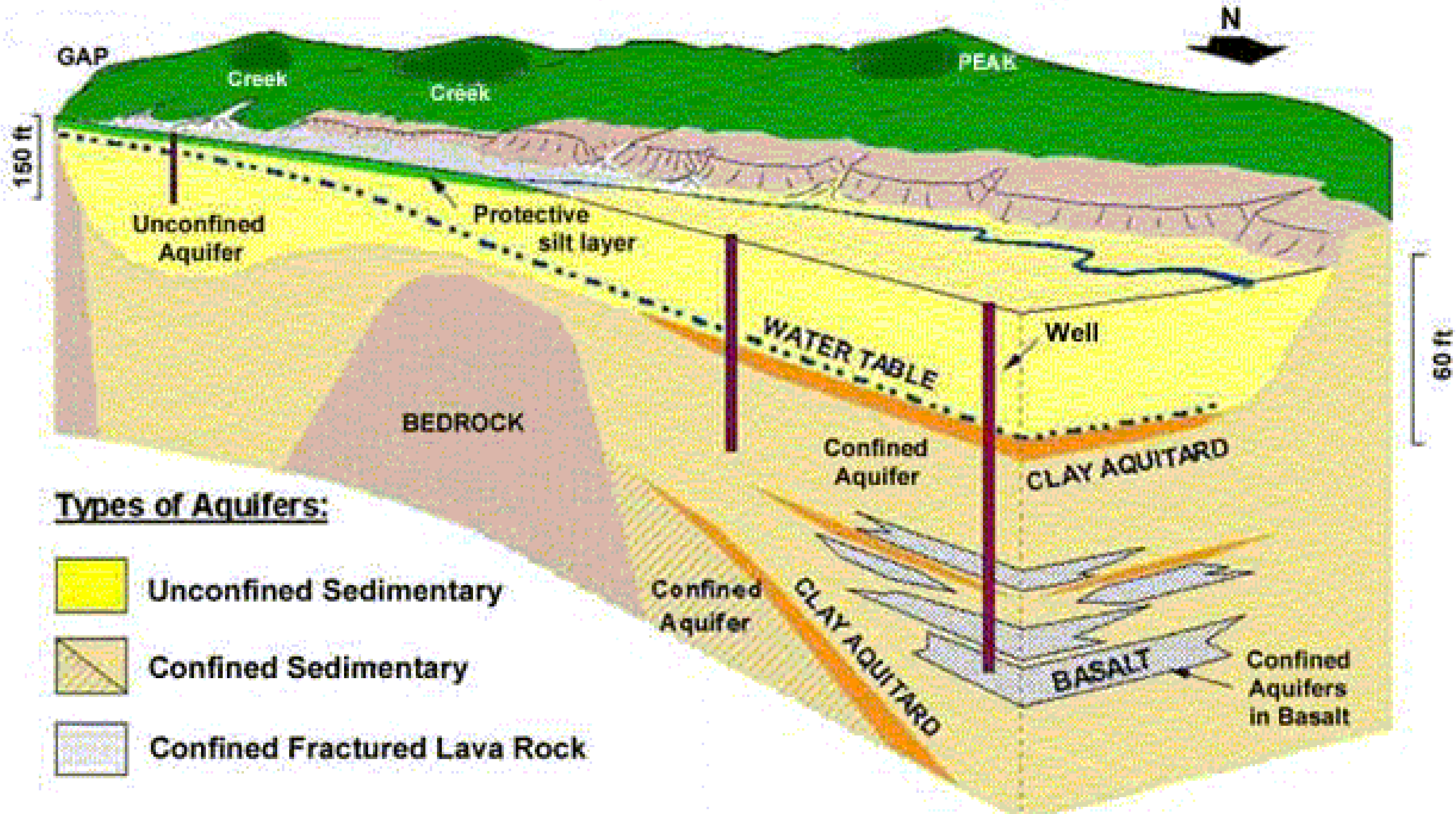
The ratio between pore volume (voids) of the soil and volume of the solids.

Dense sands and gravels = 0.7 ; unconsolidated clays = 1.3.

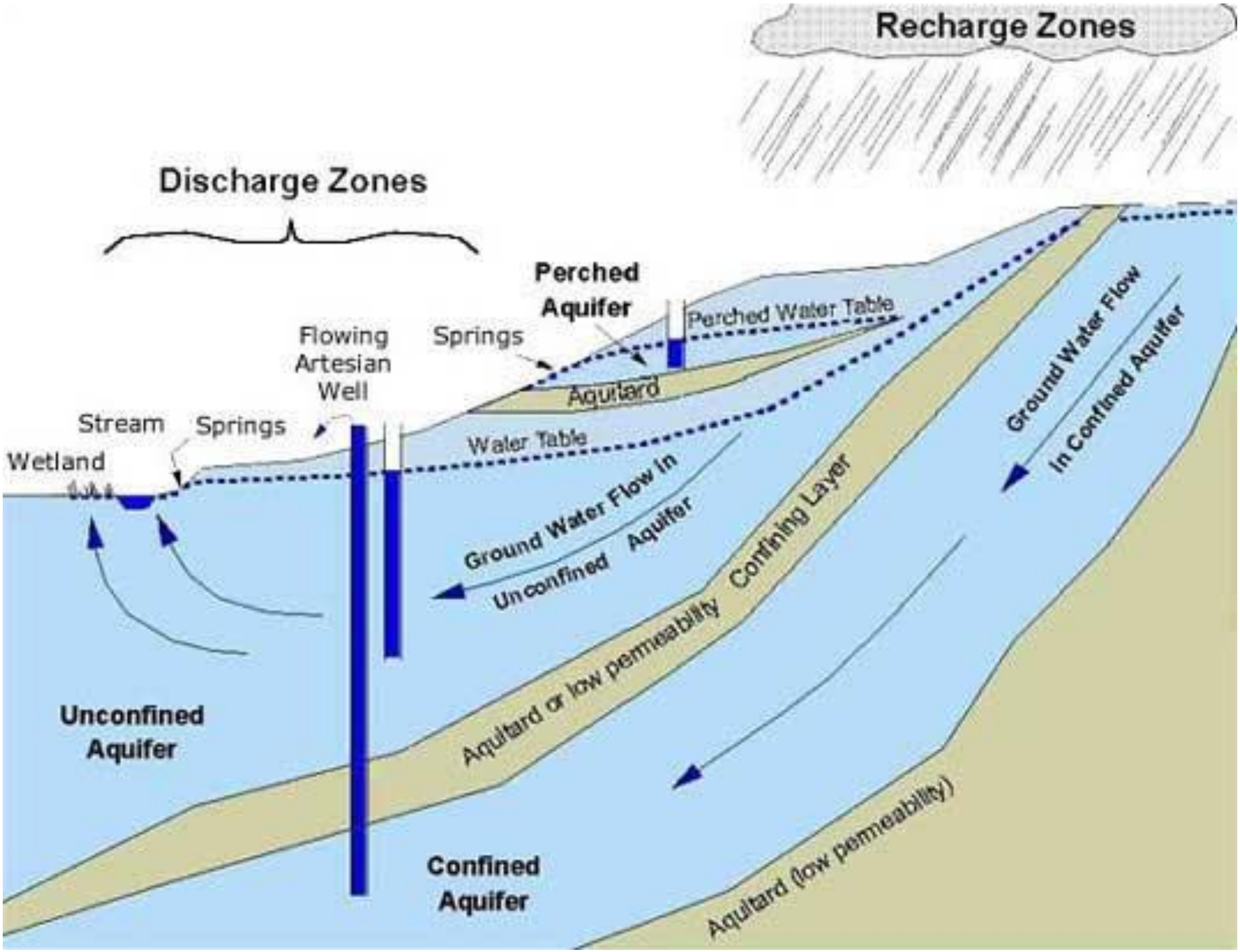
f. BULK DENSITY

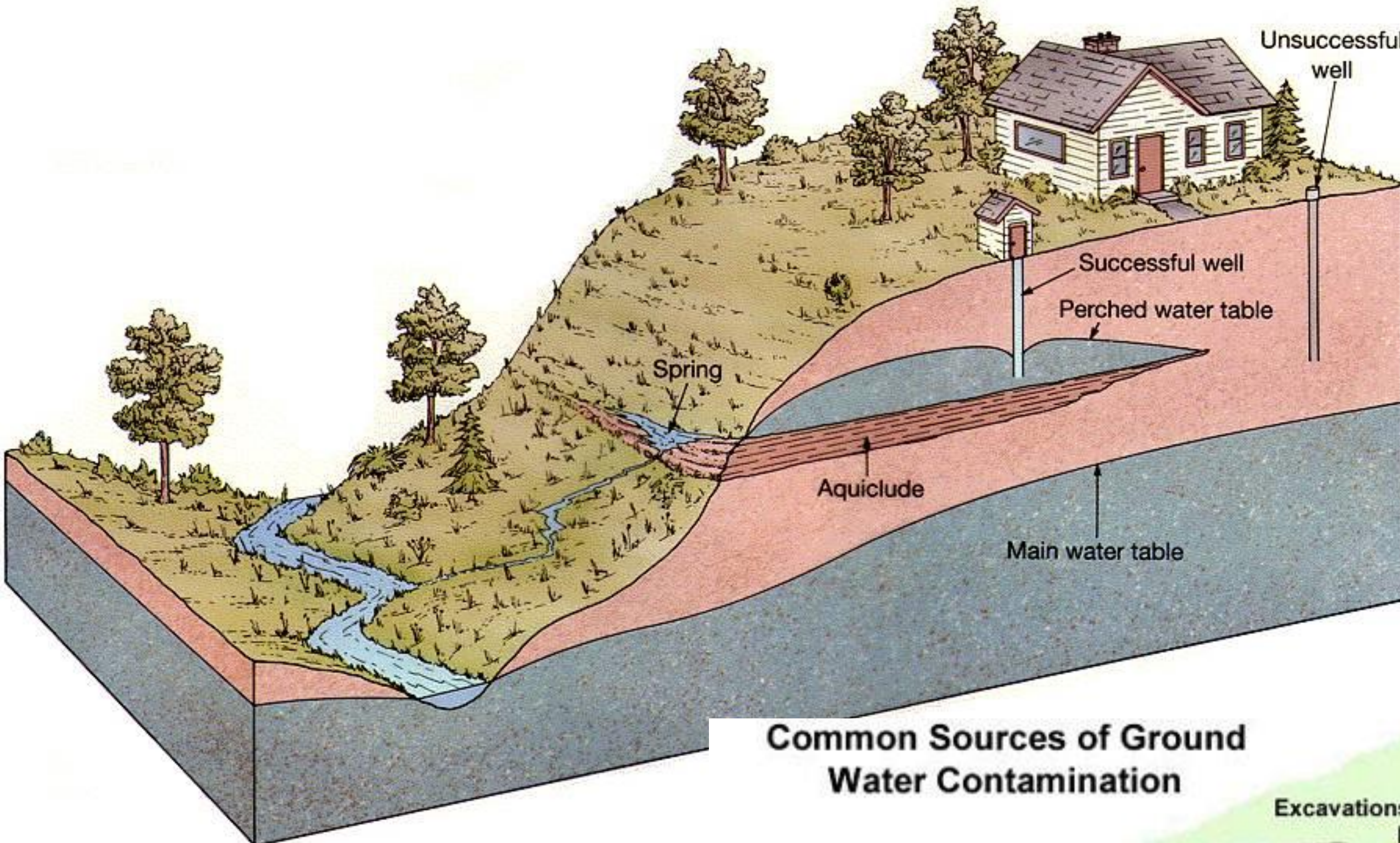
The density of the total soil or rock material, solids and voids after drying is called bulk density.

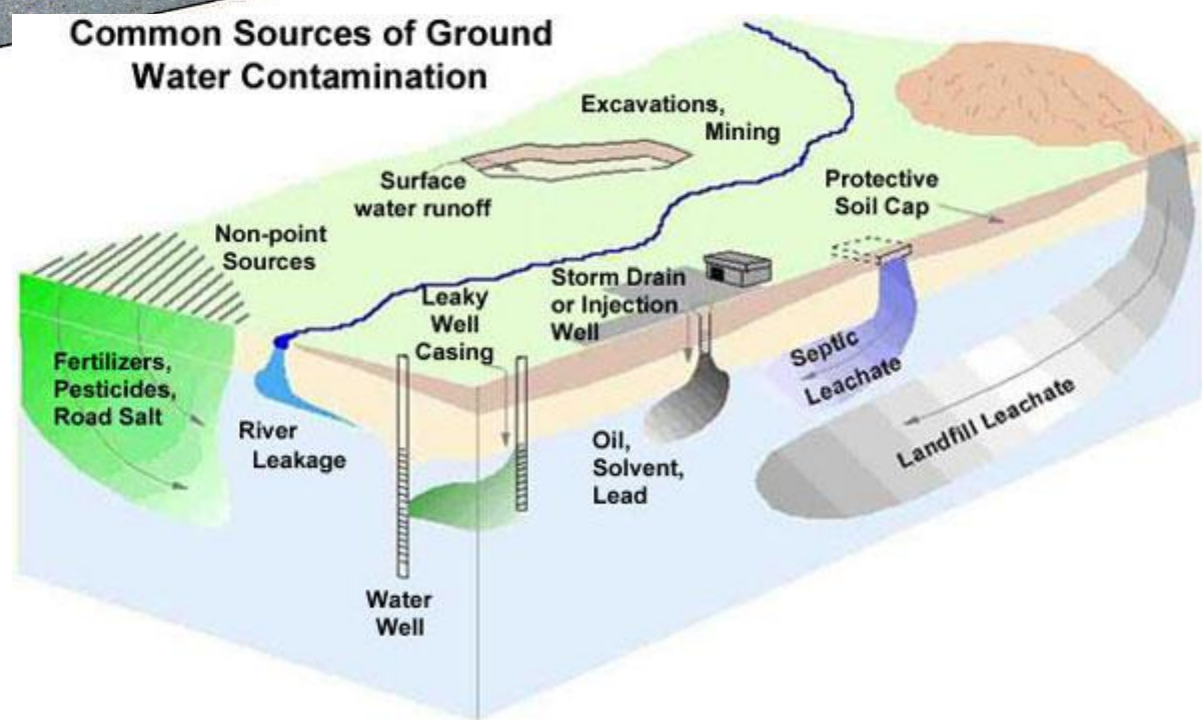
Anatomy of an Aquifer:

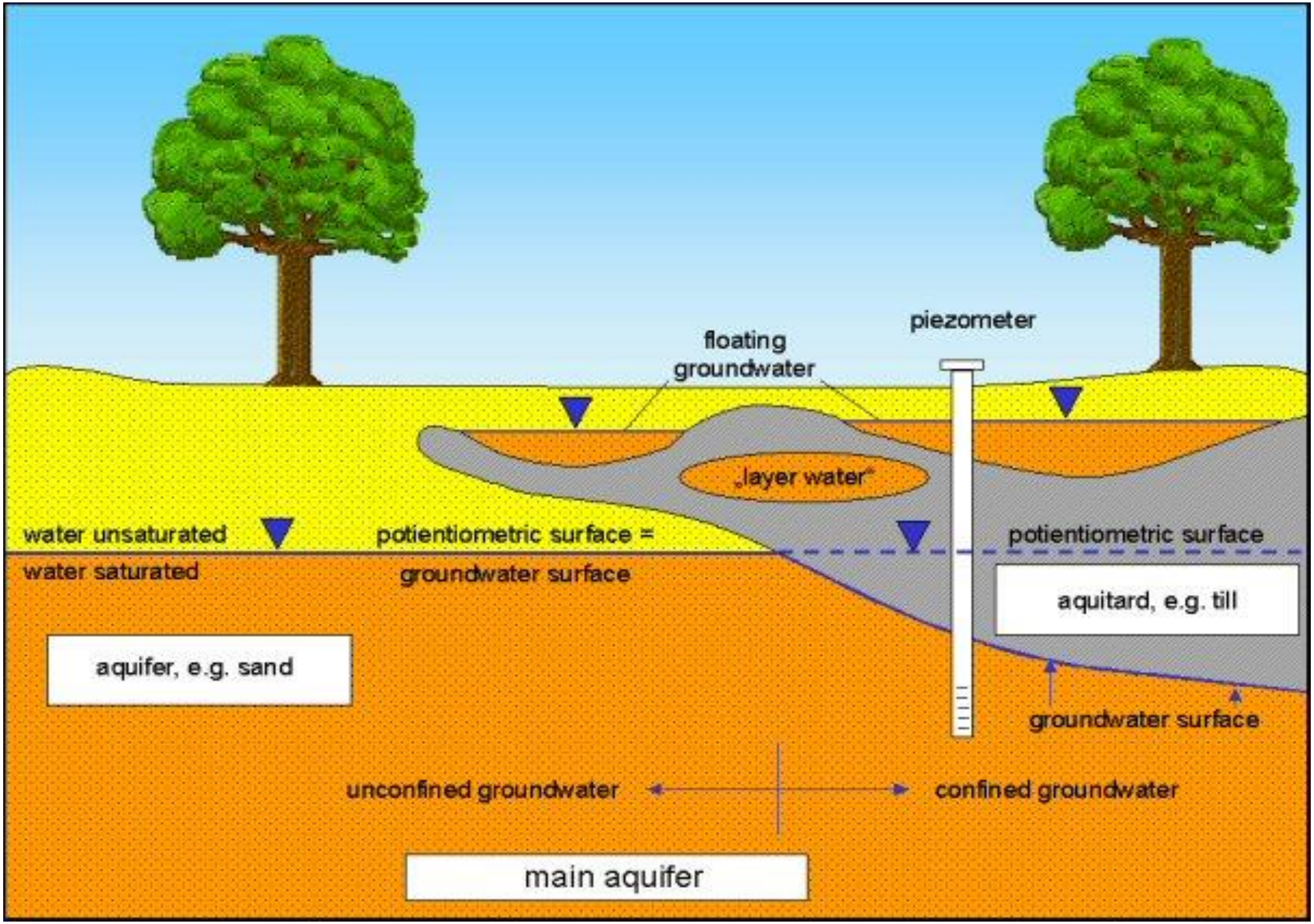


VERTICAL EXAGGERATION = 100:1


Recharge Zones
Discharge Zones
Perched Aquifer
Perched Water Table
Flowing Artesian Well
Springs
Aquitard
Stream
Springs
Water Table
Wetland
Ground Water Flow in Unconfined Aquifer
Ground Water Flow In Confined Aquifer
Confining Layer
Aquitard or low permeability
Unconfined Aquifer
Confined Aquifer
Aquitard (low permeability)


Unsuccessful well
Successful well
Perched water table
Spring
Aquiclude
Main water table


Common Sources of Ground Water Contamination
Excavations, Mining
Surface water runoff
Protective Soil Cap
Non-point Sources
Storm Drain or Injection Well
Leaky Well Casing
Fertilizers, Pesticides, Road Salt
River Leakage
Septic Leachate
Oil, Solvent, Lead
Landfill Leachate
Water Well


piezometer
floating
groundwater
„layer water“
water unsaturated
water saturated
potientiometric surface =
groundwater surface
potientiometric surface
aquitard, e.g. till
aquifer, e.g. sand
groundwater surface
unconfined groundwater
confined groundwater
main aquifer

CRYSTALLINE AQUIFER SYSTEMS

1. INTRODUCTION

a. CRYSTALLINE&METAMORPHIC / HARDROCK AQUIFERS

b. FRACTURED AQUIFERS

2. CHARACTERISTICS OF CAQ / HRAQ

a. FRESH ROCKS

b. WEATHERED ZONES

c. FRACTURED ZONES

➡ FRACTURE MEDIUM

<u>FRACTURE</u> – DISCONTINUOUS PLANAR FEATURE WITHIN ANY ROCK MASS THAT MAY HAVE DEVELOPED AS A RESULT OF PRESSURE AND TEMPERATURE DIFFERENCES DURING AND / OR AFTER THE FORMATION OF THE ROCK.

- OCCUR CHIEFLY IN DENSE XALLINE OR CEMENTED ROCKS
  - FAULTS – GOOD POTENTIAL
  - SHEAR ZONES - -DO-
  - BRECCIA - -DO -
  - REGULAR OPEN FRACTURES – VERY GOOD POTENTIAL
  - IRREGULAR OPEN FRACTURES – GOOD POTENTIAL ZONE
  - FISSURES – MODERATE POTENTIAL

- The direction of large joints and fracture zones can be observed in areas where normal and reverse fault exists.
- Width,
- roughness,
- spacing and
- filling of fractures and
- the kinematic viscosity of water

decides the transmission characteristics of fractured aquifer.

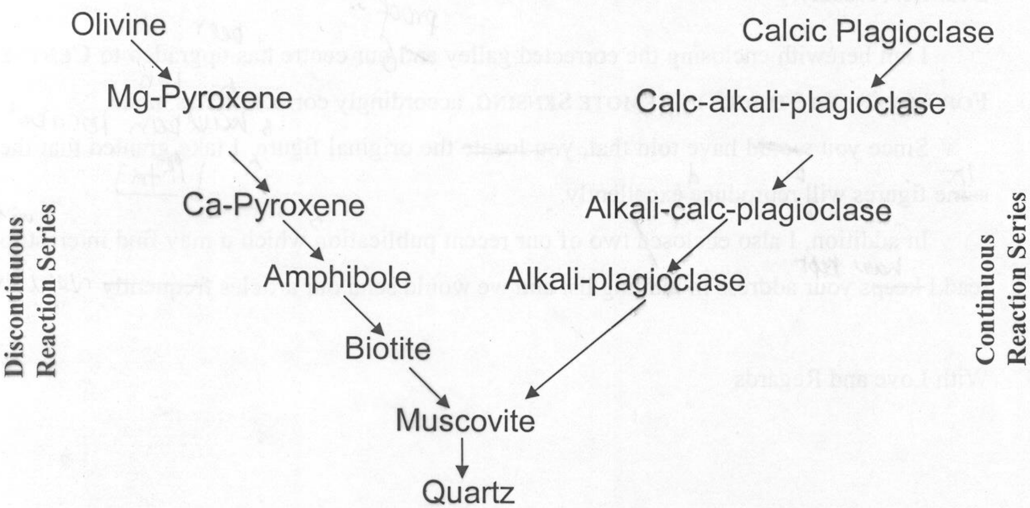
3. LITHOLOGICAL ASSEMBLAGES

	Acidic (over saturated)	Intermediate (Saturated)	Basic (Saturated)	Ultrabasic (Under saturated)
Extrusive (Volcanic)	**Rhyolite**	**Dacite**	**Basalt**	**Phonolite**
Hybabyssal	←-------------------**Porphyries**-------------------→ **Granophyre**	**Aplites**	**Dolerite**	**Tingulite**
Intrusive (Plutonic)	**Granite**	**Granodiorite**	**Gabbro**	**Nepheline syenite**

- INTRUSIVE ROCKS
  - ACIDIC ROCKS
    - BATHOLITHS – More common
      - High pressure & low temperature (1100)
      - Granite, Diorite, Gabbro, Granodiorite, syenite, etc.
      - Hypersthene, Muscovite, Albite, Quartz

- EXTRUSIVE ROCKS
    - BASIC ROCKS
        - SILLS, DYKES, ETC.
            - Low pressure& High temperature (2200)
            - Basalts, Andesites, Rhyolite & volcanic deposits (unconsolidated)
            - Mg pyroxenes, Olivine, Bytownite, Labradorites, etc.

BOWEN'S REACTION SERIES



4. ASPECTS OF WEATHERING

- **IGNEOUS PLUTONS**
    - FRACTURING during cooling of magma
    - REMOVAL OF OVERBURDEN – Sheet joints
        - Close / tight joints
        - Very low gradient of GW movement

- VERITICAL FRACTURES & FAULTS
    - Vertical upliftments
    - Tectonic disturbances
    - Continental adjustments
    - Widening of cracks
    - Rubble zones with broken rocks along fault planes
        - Vertical movement of GW occurs

- DISINTEGRATION / WEATHERING
    - PHYSICAL WEATHERING
        - Chemically competent
        - Break down into pieces
    - CHEMICAL WEATHERING
        - Less resistant minerals – altered or removed in solution
        - Altered and resistant minerals – disaggregated masses at parent site
            - some GW movement
    - COMBINED ACTIONS
        - ACIDIC PLUTONS
            - Both disintegration &
            - Fracturing.

- TIGHT / CLOSE FRACTURES
    - AS THE FORMATION DEEPENS (>200m)
        - LESS PROSPECTS
        - HYDROFRACTURING / BLASTING TECHNIQUES
    - OPEN FRACTURES
        - GOOD PROSPECTS
        - BATTERY OF WELLS

- CARBONATE ROCKS
    - SOLUTION BY RAINWATER
        - PRODUCES SECONDARY POROSITY
        - LARGE YIELDS

- BUT RARELY OCCURS – ONLY IN SHIELD AREAS OF THE CONTINENTS.
-

- **BASIC LAVA FLOWS**

  High porosity and hydraulic conductivity, Primary Porosity, Secondary porosity

  -
  - Individual lava flows – cracks developed on cooling
    - The hardened crust – collapsed on cooling in to empty lava tubes & vesicles and also in alluvial sediments laid down between subsequent lava flows.

    - Vesicles near the top of each flow (<1m)
      - High porosity and hydraulic conductivity
      - Extraordinarily high conductivity if they are interconnected
      - Eg. Snake River Group, Idaho, Washington – 15 million gpd/ft (186,000 m^2 /day).
    - Alluvial deposits formed in between lava flows when there was a substantial time intervals
      - Enhances the storage capacity and
      - Transmissivity
    - Presence of lava tubes
      - Increases storage capacity and
      - Transmissivity

  - INCOMPLETE RIFTING 1 BILLION YEARS AGO
    - LAVA FLOW LIE BENEATH THE SURFACE
    - FEW BROKEN
    - HIGHLY VESICULAR – NO INTERCONNECTION
    - NO ALLUVIAL DEPOSIT
    - POOR RESERVOIR FOR GW.

  - Pyroclastic deposits – Andesite, Rhyolitic – exploding type from volcanic cone
    - Tuff
    - Pumice
    - Ash
    - Scoria
    - Breccia
      - Reservoirs – where fractures developed.
      - High porosity based on
        - big fragment size,
        - sorting and
        - subsequent degree of cementation

5. MAPPING AND MODELING OF FRACTURES

FRAQTA

"FRACTURED AQUIFER SYSTEM OF TAMIL NADU"

6. TYPES OF GEPHYSICAL SURVEYS

7. MODELING THE CHARACTERISTICS OF CRYSTALLINE AQUIFER SYSTEMS

+

"Dual porosity

Or

Double porous system"

SEDIMENTARY AQUIFER SYSTEMS

1. INTRODUCTION

By volume – 5% (meta, igneous 95%)

But by aerial coverage – 75%.

All igneous and metamorphic rocks exposed at or near the Earth's surface are

- in an **unstable** chemical and physical condition &
- **break down** into finer and finer components, transported and deposited over geologic time.

Destruction, redistribution and deposition of rock particles play a significant role in

- producing 3 out of 4 types of aquifers – **alluvial, sedimentary, glacial.**
    - Through 3 agents of erosion – **wind, running water & glacier ice.**

Running water is the **most effective** of these **agents** – because it operates continuously over most land **areas** of the Earth.

- RW – primary agent in creation of alluvial aquifers and
- As a major force in building or altering other types of aquifers.

Before removal of a rock mass – it must be broken down into particles – **Rock weathering processes**.

Weathering

In-situ physical disintegration and chemical decomposition (in response to the environmental conditions) of rocks found at or near the Earth's surface.

Two major types:

Physical (mechanical) & **Chemical** (assisted by organisms - biological) weathering.

Weathering depends upon

1. Earth's tectonism
2. Temperature of Rock formation

    Higher temperature - More unstable – ready to disintegrate
    e.g. Basalt - formed at 2,190°F (1,200°C).
    [High disintegration]

    Lower temperature - More resistant - withstanding longer time
    e.g. Granite – formed at 1,110 °F (600°C).
    [(S)low disintegration]

3. Climatic conditions (seasonal hot & cool)
    (arid / semi arid - humid)
4. Availability of water
5. Rock chemistry
6. Water chemistry (acidic – rainwater – carbonic acid)
7. Rate of movement of water, etc.

2. PROCESS OF SEDIMENTATION

a) EXOGENETIC - ALLOGENIC - EXTRABASINAL

GENERATED OUTSIDE THE BASIN AND CARRIED INTO IT BY WAVES AND CURRENTS – TERRIGENOUS SEDIMENTS AND THE PYROCLASTIC DEPOSITS.

FRAGMENTAL OR CLASTIC ROCKS – CONSTITUENT OF THESE ROCKS ARE EMPLACED IN THE ROCK FABRIC AS SOLID PARTICLES WHICH HAVE BEEN FORMED BY THE FRAGMENTATION OF PREEXISTING MATERIALS.

- Physical distintegration
- Mechanical transportation & deposition
- Product of combined process of physical and chemical disintegration
    - Physical disintegration (daily heating & cooling, ice-crystal growth, wetting & drying, root wedging, etc., as a result – comminution-reduction in size) &
    - chemical disintegration (Oxidation, Hydration, Hydrolysis, Chelating & Solution) and sedimentation
- aerodynamic or hydrodynamic principles govern the accumulation
- framework-pore fabric, cross-bedded.

b) ENDOGENETIC – AUTHIGENIC – INTRABASINAL

FORMED IN THE BASIN – CHEMICAL / BIOCHEMICAL SEDIMENTS EXTRACTED FROM THE BASIN WATERS

AMORPHOUS AND CRYSTALLINE PRECIPITATES FROM SOLUTION - Nonclastic

E.G. ROCK SALT, ANHYDRITE, GYPSUM, COAL, ETC.

- interlocking, crystalline granular fabric.

ENVIRONMENTS

DENUDATIONAL	- More of physical & chemical disintegration
ALLUVIAL	- More of chemical disint., transportation & Deposition – fluvial dominated
SHORE LINE	- Physical & chemical disint. Wave winnowing
MARINE	- Chemical disint. precipitation
INLAND BASIN	- Both physical & chemical disint. & deposition
GLACIAL	- More of physical disint. And transport&depo.

Consolidation – due to compressional pressure, cementation and dehydration.

SEDIMENT	**ROCK**
Angular gravel -	**Breccia**
Rounded pebbles -	**Conglomerate**
Sand & alluvium -	**Sandstone**
Silt -	**Siltstone**
Clay -	**Shale**

ALLUVIAL AQUIFERS

Approx. 30,000 mi^3 (125,000 km^3) of water per year falls as snow and rain

30% of this water returns directly to the oceans by rivers and streams.

Through this process,

- it erodes the landscape,
  - extend their drainage systems both upstream & downstream sides,
  - downcut or aggrade (build up) their channels &
  - widen their valley walls),
- transports the materials,
- deposits sediment such as gravel, sand, silt & clay along the river courses and into the sea.

Aluvial Aquifer Landforms & their GW Prospects:

- Valley fills
- Alluvial fans
- Alluvial cones
- Bajadas

May not be well rounded & – *coarse gravel or sand* – ***Good GWP*** but not as good as River Alluvium

- River colluvium / colluvial fill, Alluvium – **Good GWP**
- Flood plains - *extremely fine silt* – ***High GWP***
- Meander plains
- Point bars /
- Channel bars
- River terraces

- *coarse sediment* – ***Higher yields*** *than FP*

- Buried channels / palaeo channels – - do –
- Deltas - Well sorted & well rounded – **Good GWP**
  - if grain size is so fine – **Not adequate supply**

Wells finished in top/bottom set beds **yields high** than d foreset beds

Hydraulic Characteristics – In General:

Having varying grain size, usually fine grained, rounded and well sorted – Porosity is excellent, but hydraulic conductivity varies.

If the gradient increases – discharge increases & sediment size will become coarser – conductivity will be higher.

Along the sediment boundary – lower hyd. Cond. than in the sediment plains.

In Consolidated sedimentary rocks, uncemented

a. FRESH ROCKS - PRIMARY POROSITY

b. FRACTURED ZONES - SECODARY POROSITY

Unconsolidated sediments

SEDIMENTARY ROCK AQUIFERS

Coastal zone sediments – in continental areas - exposed

Beach sediments

Offshore sediments – clay, finer offshore sand

Warm, Shallow seas – from marine organisms – coral reefs of CaCO3 – if the sea level rises, Oozes – either Ca or Si rich.

Hydraulic properties of sandstone

Sediments laid down by transgressive – regressive seas

Compaction – increased depth of overburden, chemical precipitation or solution (removal) effects within the void spaces of the sediment and Heat from magmatic intrusions.

Some of these changes increase the usefulness of the sediment as storage medium for groundwater, others reduce or even eliminate the storage capabilities of the sediment (e.g. hydrothermal solutions associated with magmas).

Hydraulic properties of clay

Porosity – volume of void space is relatively high in clays – but the actual size of the voids is extremely small, hence, water is strongly attracted to the large surface area of the clay particles – hydraulic gradient is very less.

Chemical precipitation is not important in the cementation of clay particles.

Heat and Pressure – clay changes to shale.

Shale – when exposed to water during drilling, some shales can swell to much larger volumes.

On greater heat and pressure, shale changes to slate – no storage space for gw.

Hydraulic properties of Calcium-rich deposits

Massive inorganic calcium-rich deposits – little void space exists for fluid storage.

Organic calcium deposits (coral reefs) – void spaces occur frequently but are spaced irregularly.

Time and other factors – do make these deposits more rigid and in some cases more dense – limestone – inflexible – can crack when supported unevenly.

Extensive joint or fault systems because of uneven isostatic adjustment and local stresses produced by solution effects and erosion.

Chemical replacement by magnesium from sea water during or after rock formation. – high Mg – Dolomite – toughening of the rock.

They have initially less reservoir storage space.

But once exposed at or near the land surface, limestone and dolomite can undergo remarkable change.

Rainwater absorbs CO2 from air – forms a weak acid, carbonic acid – when enteres cracks and crevices - dissolve small volume of rock.

Over time cracks can be extensive and voids can be created – **Secondary solution cavities** - if they near land surface – collapse and produce ponds and lakes or sink holes – karst topography – **water moves rapidly** – extreme care must be taken to prevent **contamination** of the groundwater.

Glacial Deposits

2nd most important aquifer systems.

Plucking or quarrying – continental glaciers entrain rock debris.

Makes depressions, entrailment of debris in these depressions and deepen valleys to 100s of feet below sea level.

When ice flows toward terminus, bottom melting releases debris – lodgement till – less in thickness- rarely it reaches significant thickness.

Moraine formation – entrain and deposit all sizes of sediment in a single land form – huge rocks may be mixed with clay or fine sand. In somecases, thick clay deposits are found – extremely well sorted.

Outwash deposits – Melt waters carry / entrain gravel sized debris as bed load, i.e., transported along the bottoms of rivers and streams When the river gradient is much reduced, then begin to deposit some of the material in their channels.

Thus, Clay sized particles are carried down stream and deposited from the outwash.

Stratified gravel and sand deposits in front or between of moraines downstream – outwash build up.

Hydraulic properties of glacial deposits

Till - **Lodgement till** (hardpan) – sediment deposited on the ground beneath the ice, compressed clay-rich (Little space for gw) &

Ablation till – Material released through surface melting at the glacier terminus - loosely consolidated, clay poor contains all sized angular to semirounded material. (Substantial volume of gw can move) and

outwash - well-stratified and well-sorted silts, sands and gravels, well rounded, loosely packed and relatively uncemented – (porosities are unusually high).

Loess- Non stratified and unconsolidated sediment consisting of silt-sized particles of quartz and feldspar picked up by wind from outwash plains and deposited downwind side. High porosity – limited hydraulic conductivity - moderate yield .

Valley-train – coarse sand and gravel carried 100s of miles down stream via major river systems – extraordinarily high.

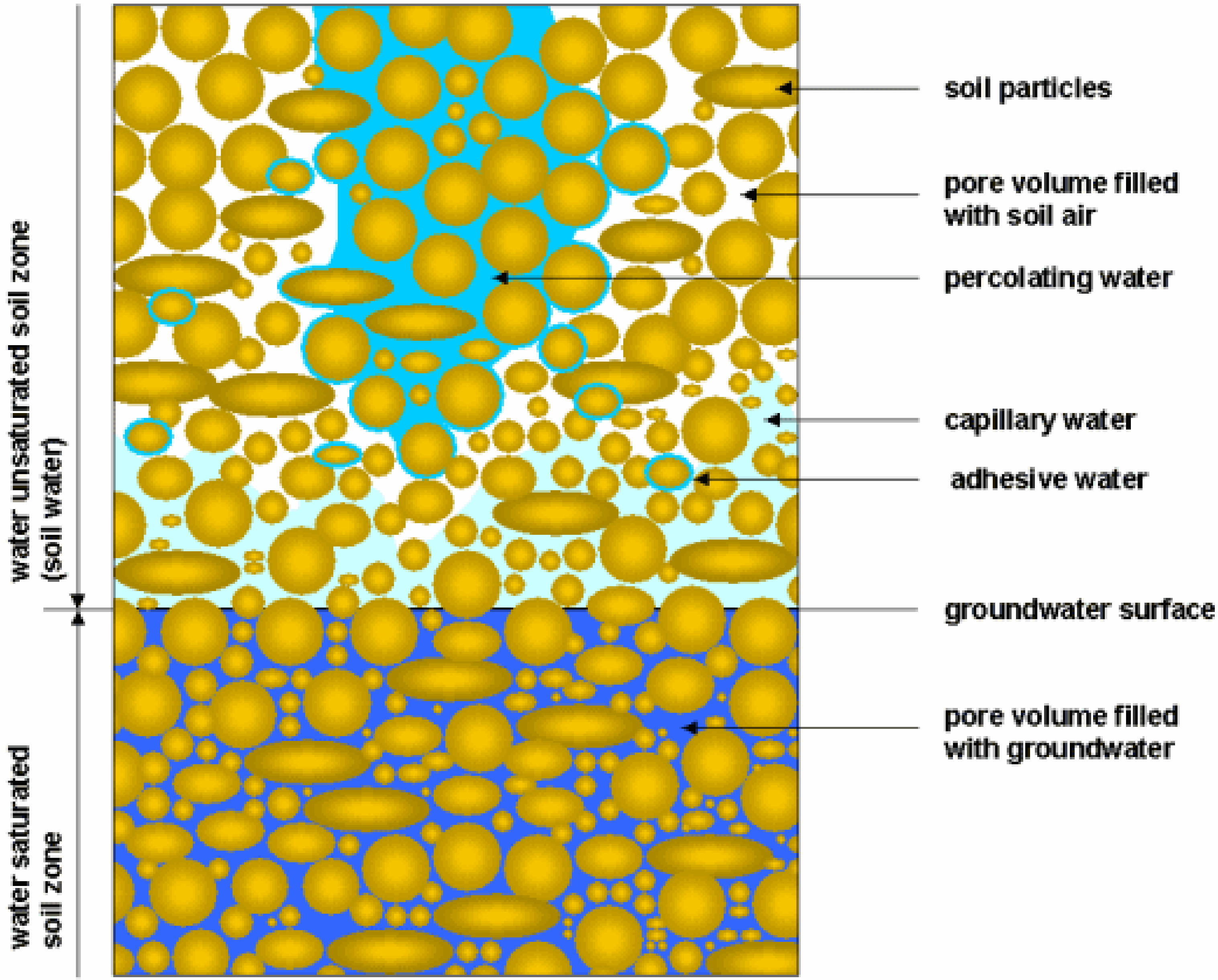
Preglacial valleys – **buried valleys** – high yield wells.

Advantages of Groundwater

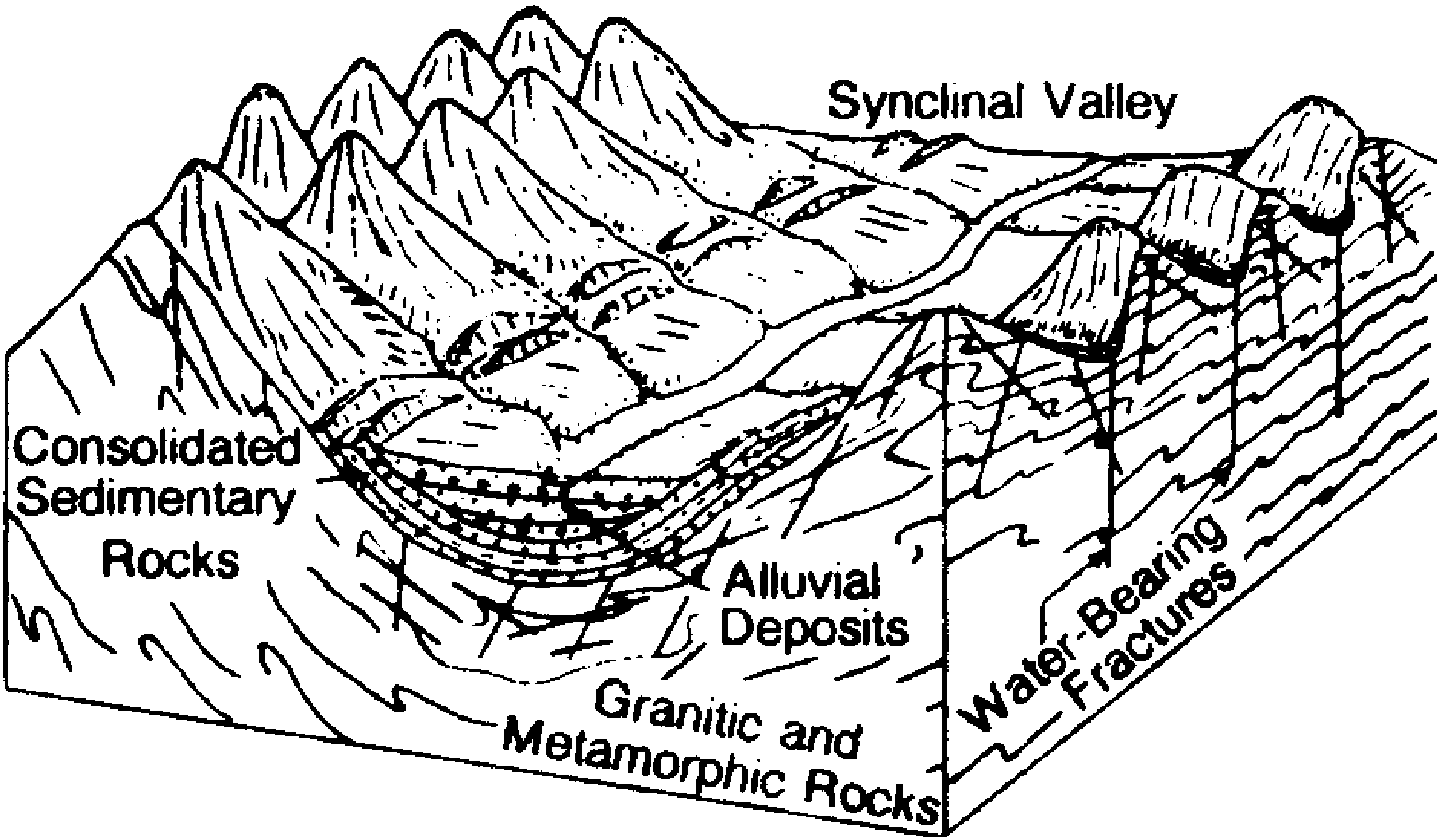
Using Undergroundwater is more advantageous than the surfacewater. Because

1. In some places, the available surfacewater potential may be not sufficient, in such cases, groundwater is the only alternative and dependable source.
2. During Winter season water will flow in the rivers but during summer the river may dry up. In such cases, groundwater is the ony source of water supply.
3. Due to dissolution of minerals the surfacewater quality may be deterioates but at the same time the quality of ground-water is improved through percolation (infiltration) process into the ground.
4. In the case of surfacewater, there is always the threat of pollution. Such possibility is remote in the case of under-groundwater.
5. When compare to surfacewater, the undergroundwater is free from weed seeds, plant organisms, turbidity and bac-terial pollution.
6. When compare to surfacewater, the undergroundwater is more uniform in quality, temperature, chemical composition and soluble mineral content.
7. Dams and Canal systems are needed to store surfacewater and then to distribute the supply. But the Underground storage basin covers wide area throughout, in which wells can be sunk.
8. In the case of surfacewater, the storage reservoirs always face silting problems which gradually decreases their storage capacity. But in underground aquifer such conditions do not exists.
9. Loss of water due to evaporation is possible in the surfacewater reservoirs but in the case of undergroundwater this is not so.
10. In the border areas, the surfacewater reservoir may be liable to destruction by enemy particularly during war time. But the destruction of undergroundwater is not possible.
11. In the surfacewater reservoir there is a possibility of leakage, but in underground reservoir there is no such situation.
12. Due to surfacewater storage, the earthquakes, landslides and unprecedented flood may be created and it is mainly because of storage water pressure, but in the case of undergroundwater storage such a fear does not exist.
13. Large areas are submerged under the impounded surfacewater and lost for cultivation. But the submergence of land surface is not involved in the groundwater storage.

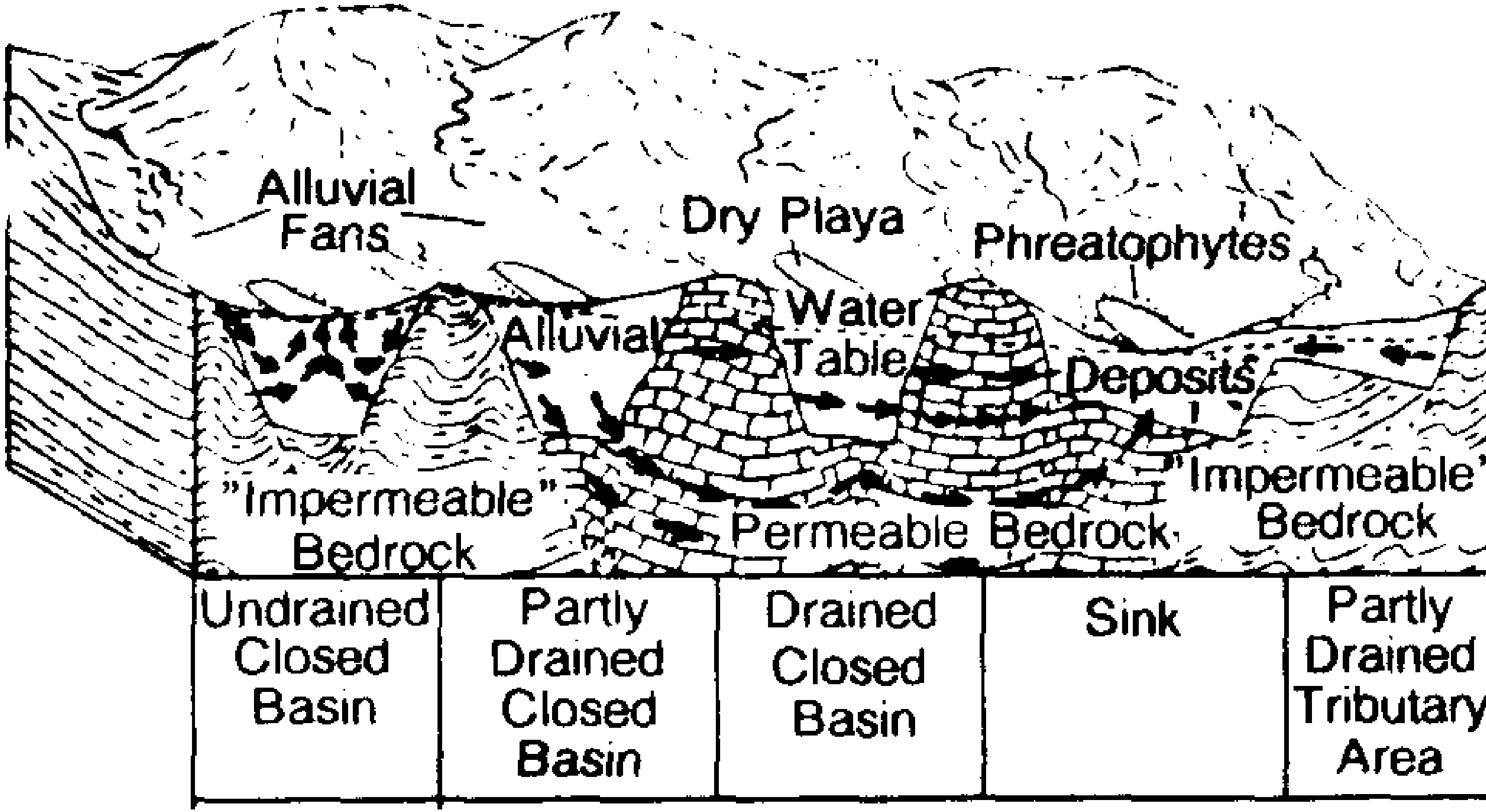
✦✦✦


soil particles
pore volume filled
with soil air
percolating water
capillary water
adhesive water
groundwater surface
pore volume filled
with groundwater
water unsaturated soil zone
(soil water)
water saturated
soil zone

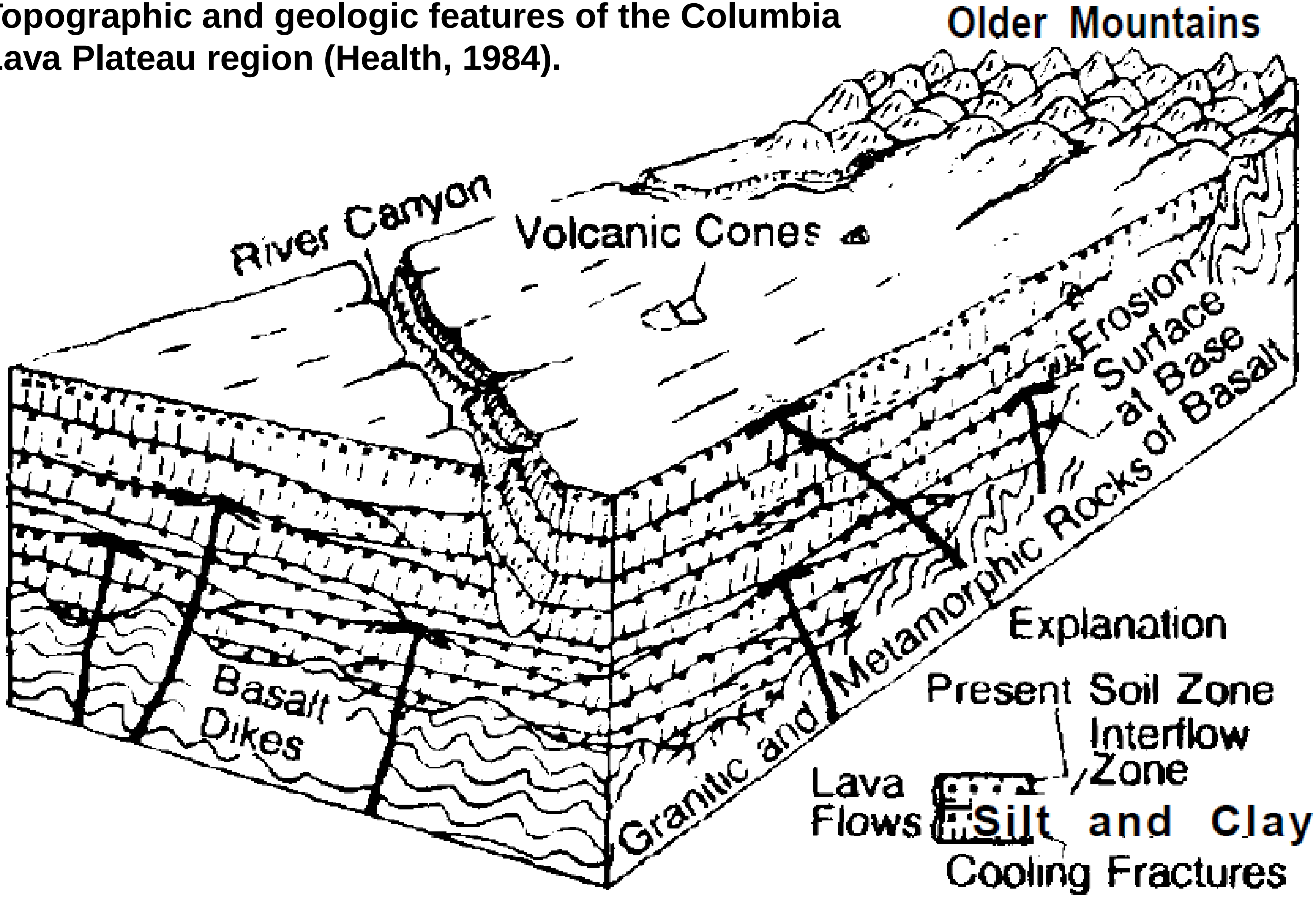
Aquifers / formations derived out of combination of data collected through surveys



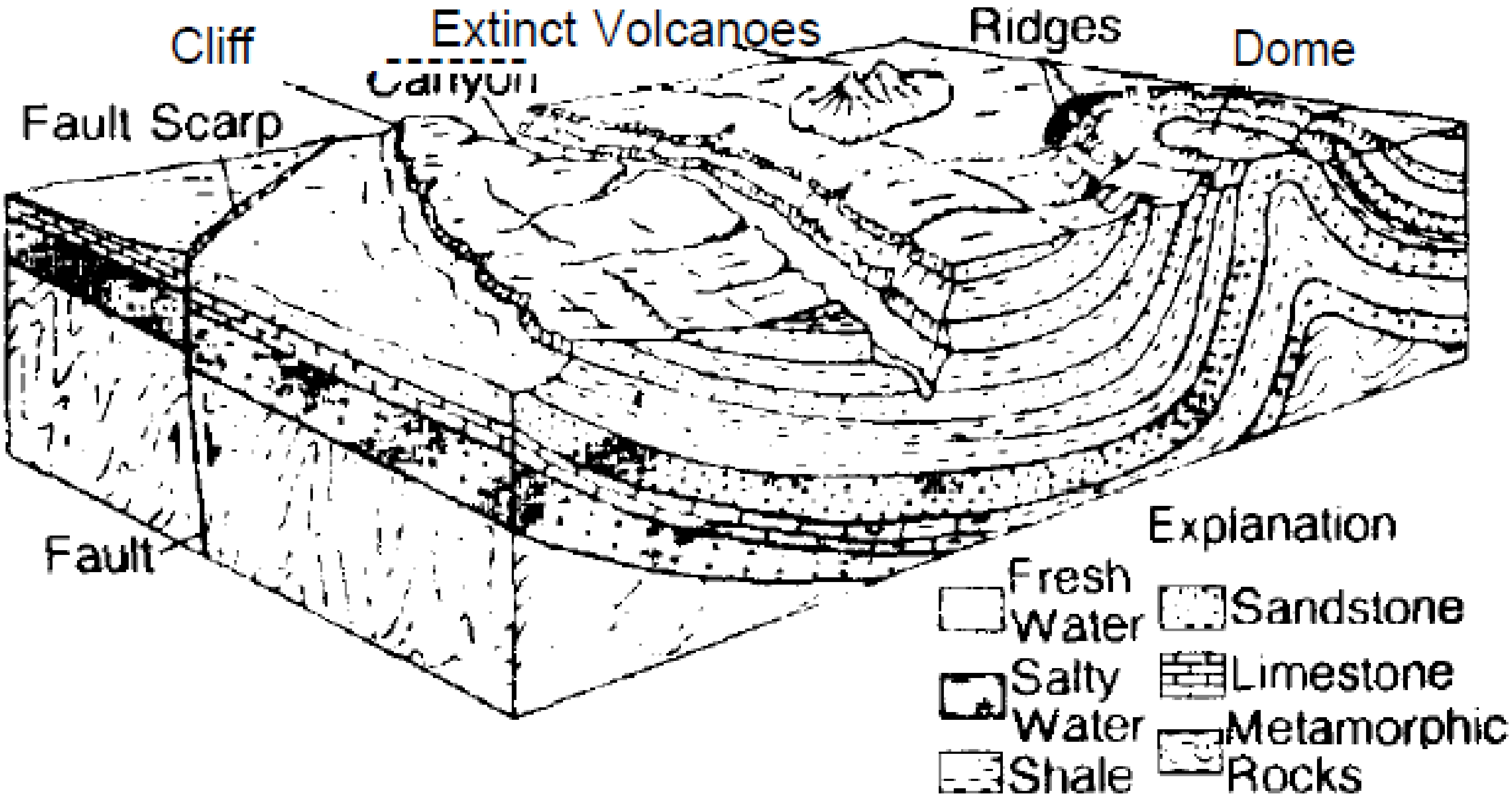
Topographic and geologic features In the southern Rocky Mountains part of the Western Mountain Ranges region (Heath, 1984)


Alluvial Fans
Dry Playa
Phreatophytes
Water Table
Alluvial
Deposits
"Impermeable" Bedrock
Permeable Bedrock
"Impermeable" Bedrock
Undrained Closed Basin
Partly Drained Closed Basin
Drained Closed Basin
Sink
Partly Drained Tributary Area

Topographic and geologic features of the Columbia Lava Plateau region (Health, 1984).

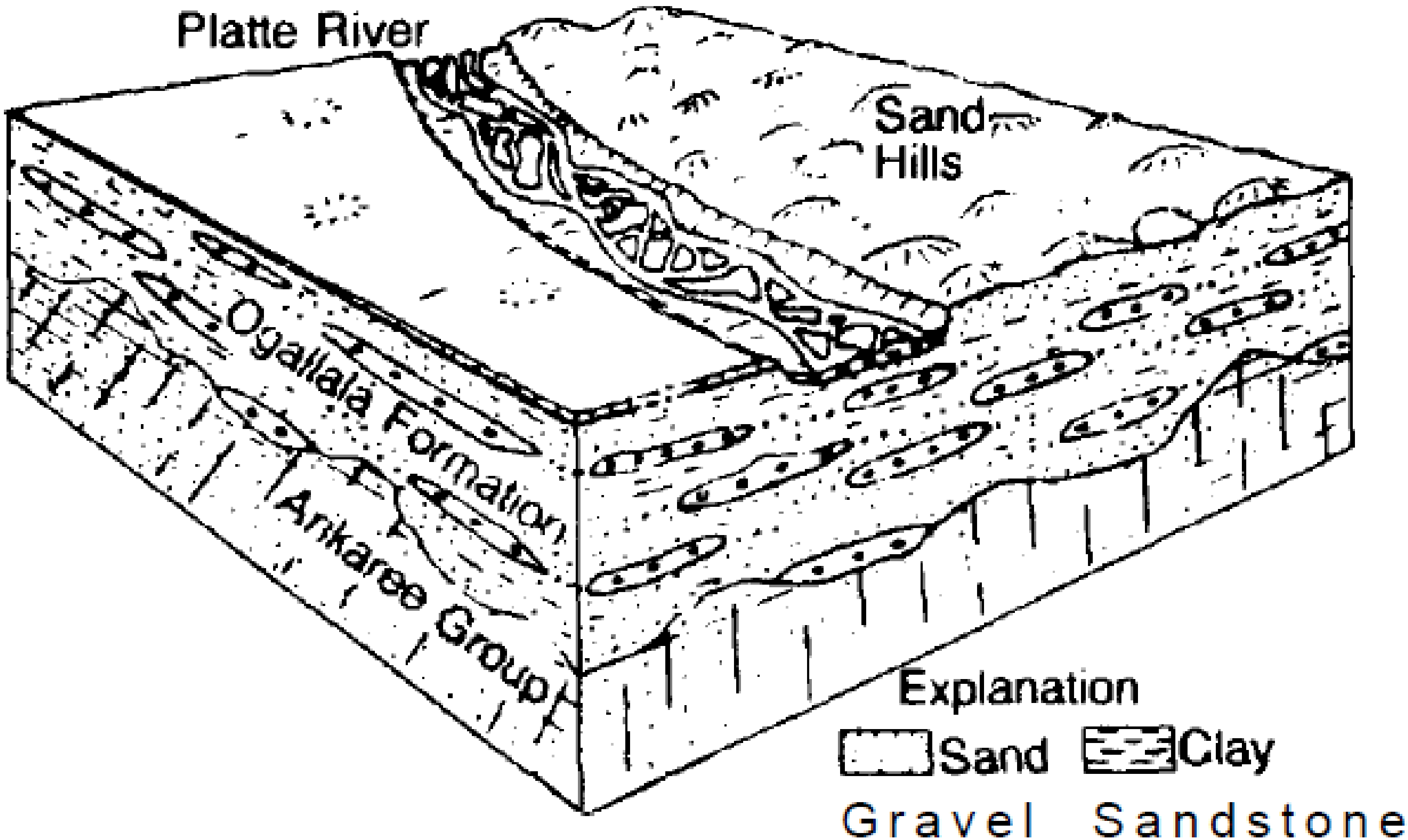


(b)



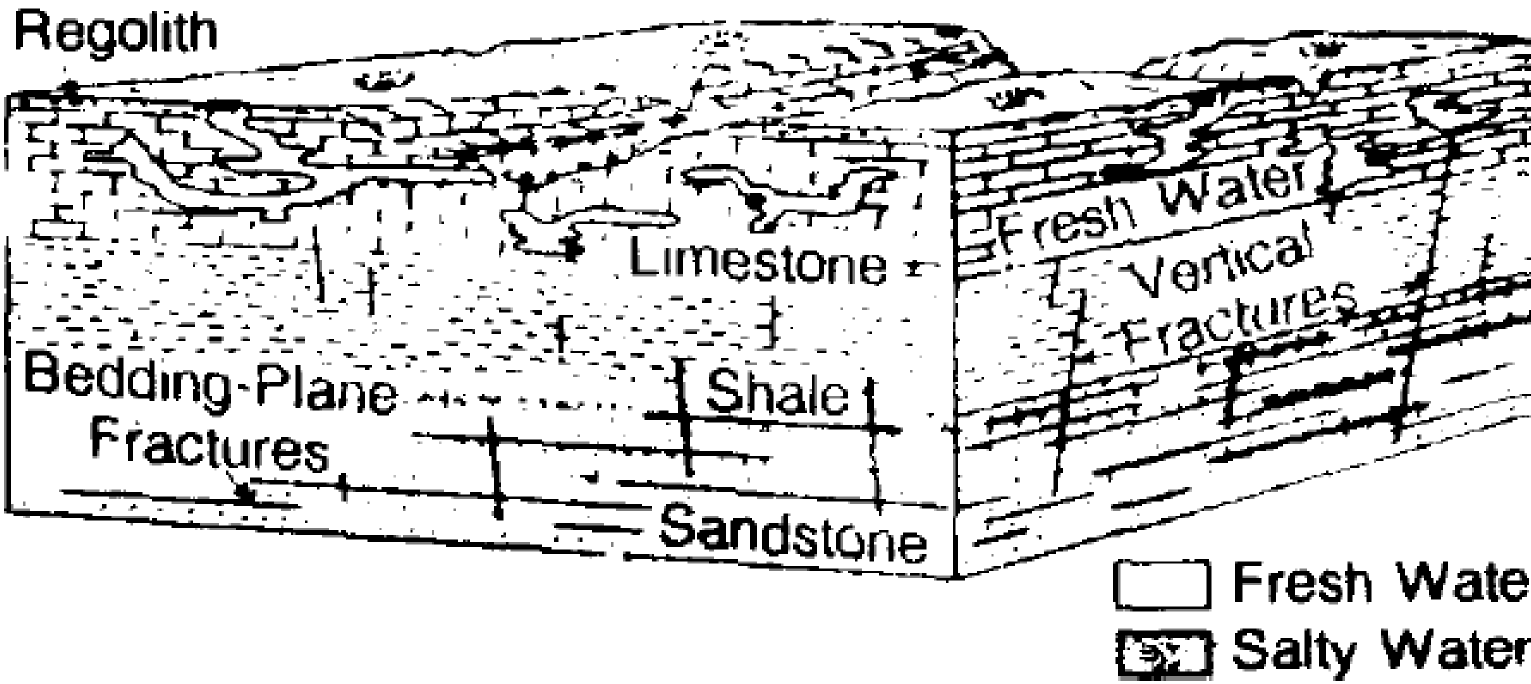
(b)

Figure 5b. Topographic and geologic features of the Colorado Plateau and Wyoming Basin region (Heath, 1984).



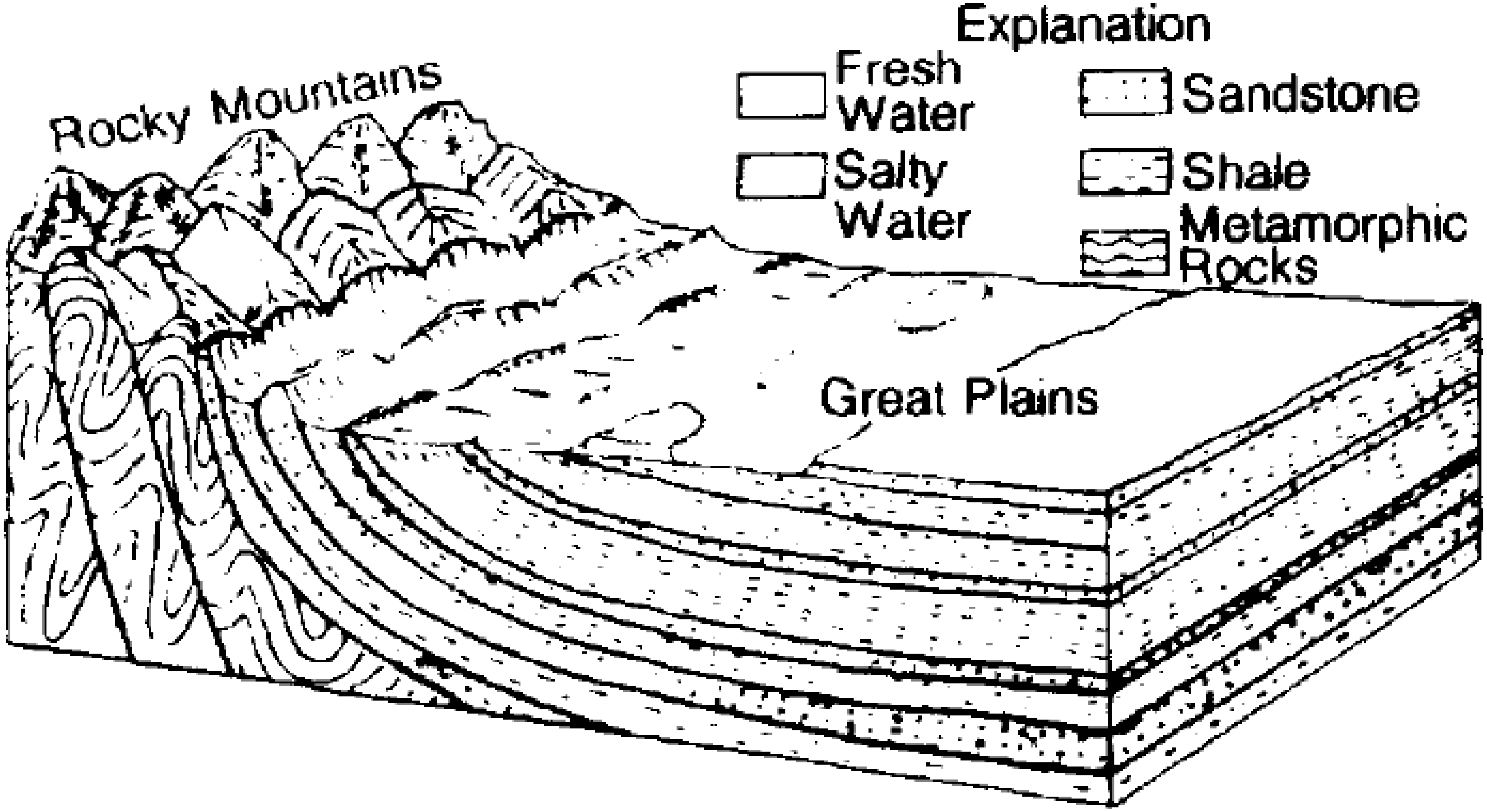
(b)

Figure 6b. Topographic and geologic features of the High Plains region (Heath, 1984).



(b)

Figure 7b. Topographic and geologic features of the Nonglaciated Central region (Heath, 1984).



(c)

Figure 7c. Topographic and geologic features along the western boundary of the Nonglaciated Central region (Heath, 1984).

Case Studies on Crystalline and Sedimentary Aquifer Systems