بسم الله الرحمن الرحيم

ضَ جم ٣١٣
جيولوجيا المياه الجوفية

EHG 313
GROUNDWATER GEOLOGY

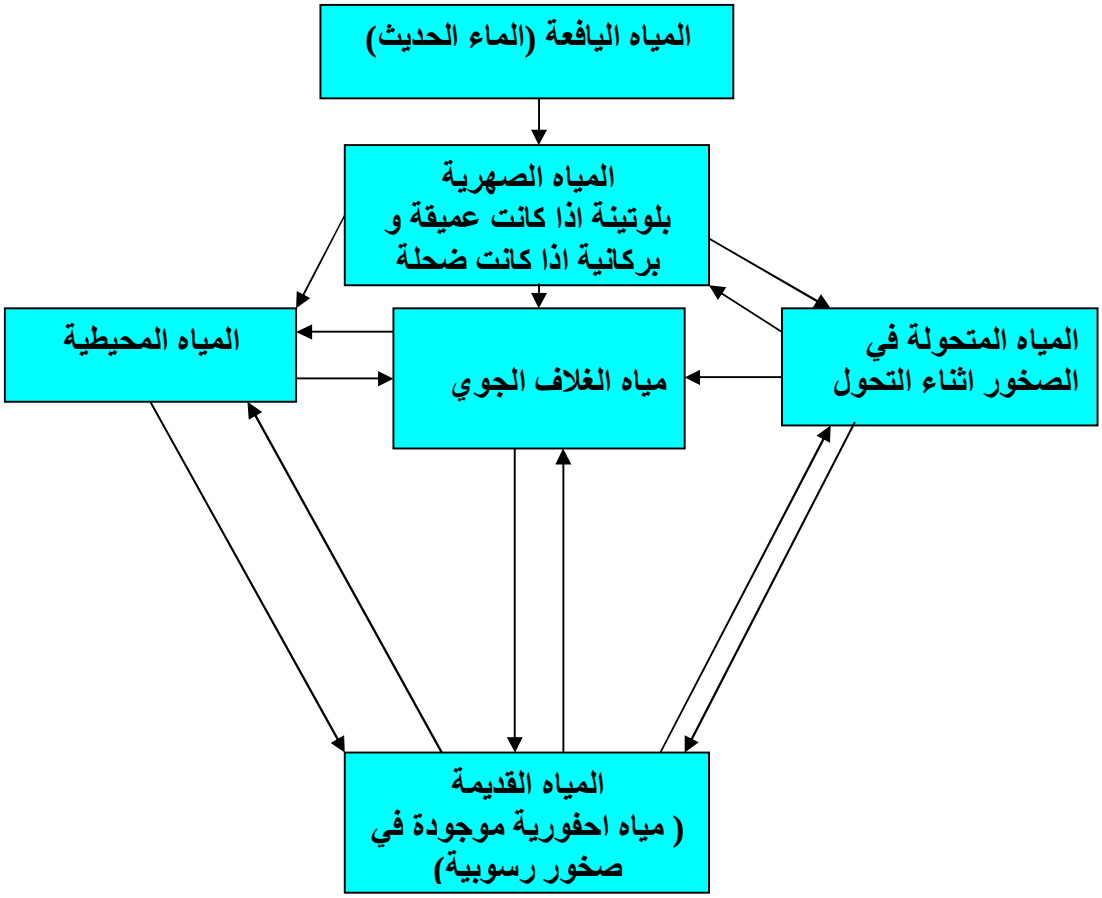
CONTENTS المحتويات

توزيع الدرجات

١- اختبارات دورية 45 %
٢- Essay 15 %
٤- امتحان نهائي ٤٠%

Origin and Age of Groundwater
اصل وعمر المياه الجوفية

How does groundwater originate?



1- Juvenile Water ذات أصل صهيري او فضائي ولم تكن سابقا جزءا من الدورة المائية
2- Connate Groundwater e.g fossilized water (احفورية) المياه الحبيسة تشمل مياه قديمة
3- Meteoric groundwater (Rainwater Recharge) مياه الغلاف الجوي
4- Magmatic Groundwater e.g comes out from volcanoes and traps in rocks مياه صهرية
5- Metamorphic groundwater e.g trapped during rock-forming processes مياه متحولة
6- Marine Water مياه المحيطات والتي تسربت الى التكاوين المائية

Groundwater age almost determine by environmental isotope, such as H^3 and C-14.

التوزيع العامودي للمياه الجوفية
Vertical Distribution of Groundwater

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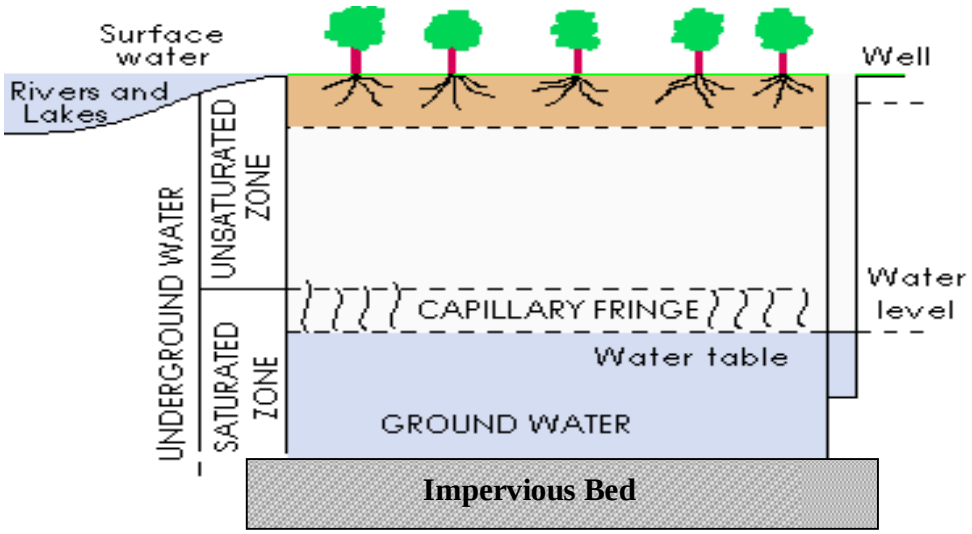


Two main parts
1- Unsaturated zone (Aeration Zone)
- Soil zone
- Intermediate zone
- Capillary fringe

2- Saturated zone (phreatic Water)

تواجد المياه الجوفية في التكوينات الجيولوجية
OCCURRENCE OF GRONDWATER IN THE GEOLOGICAL FORMATIONS

تنقسم التكوينات المائية الى اربعة اقسام وهي كما يلي:

1- AQUIFER التكوين المائي (الخزان المائي)

It is a natural formation or a geological structure saturated with water which has good hydraulic conductivity to supply a reasonable quantity of water to a well or spring. Such as unconsolidated sedimentary formations like gravel and sand. Fractured igneous and metamorphic rocks and carbonate rocks with solution cavities also form good aquifers.

2- AQUITARD المعوق المائي (شبه منفذ)

It is a formation having insufficient permeability to make it to a source of water supply but allows interchange of groundwater in between adjacent aquifers due to vertical leakage. Therefore, aquitards serve as semi-confining layers. Examples are those of silt and shale.

3- AQUICLUDE العازل المائي

This is a confining formation which is impermeable like unfractured crystalline rocks, clays and shales in nature, truly impermeable formations are rare as every geological unit has some hydraulic conductivity.

4- AQUIFUGE التكوين المسا ك

This is a confining formation which is impermeable such as unfractured crystalline rocks.

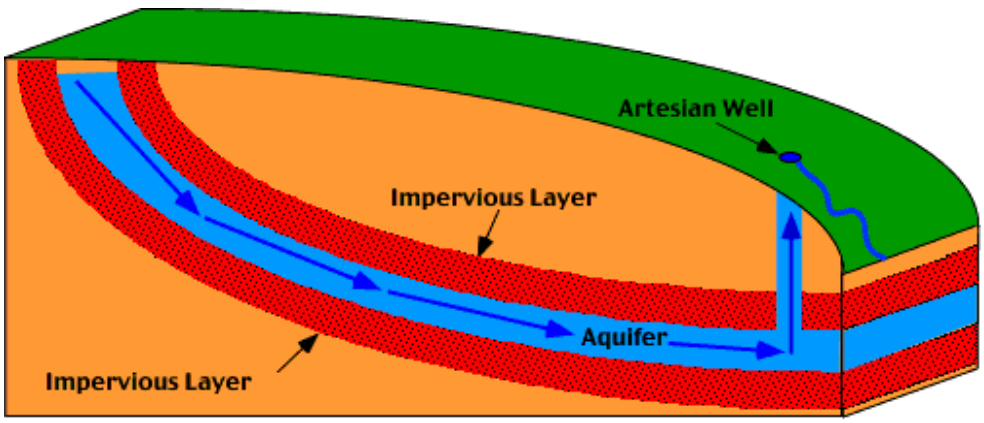
Types of Aquifers

تصنف الطبقات الحاملة للمياه والمعتمدة على الخواص الهيدروليكية الى ثلاثة انواع:

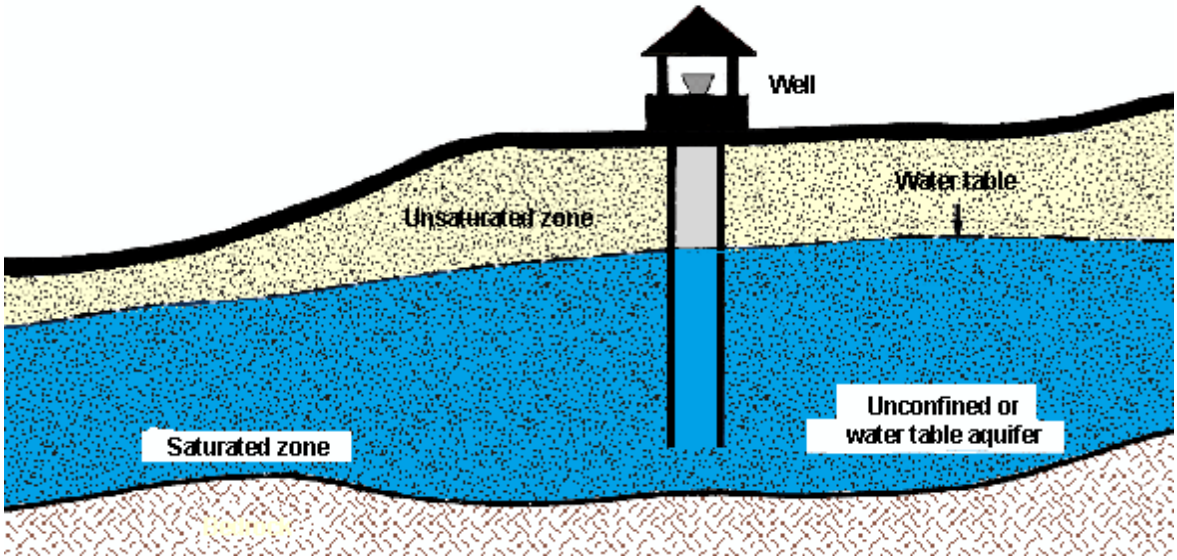
(1) Confined aquifer(تكوين مائي محصور): A confined aquifer, also known as an artesian aquifer, is overlain and underlain by a confining layer.

(2) Unconfined aquifer(تكوين مائي غير محصور) : An unconfined aquifer is exposed to the surface without any intervening confining layer, but a confining layer underlies it. It is partially saturated with water; the upper surface of saturation is termed water-table which is under atmospheric pressure .These are illustrated below

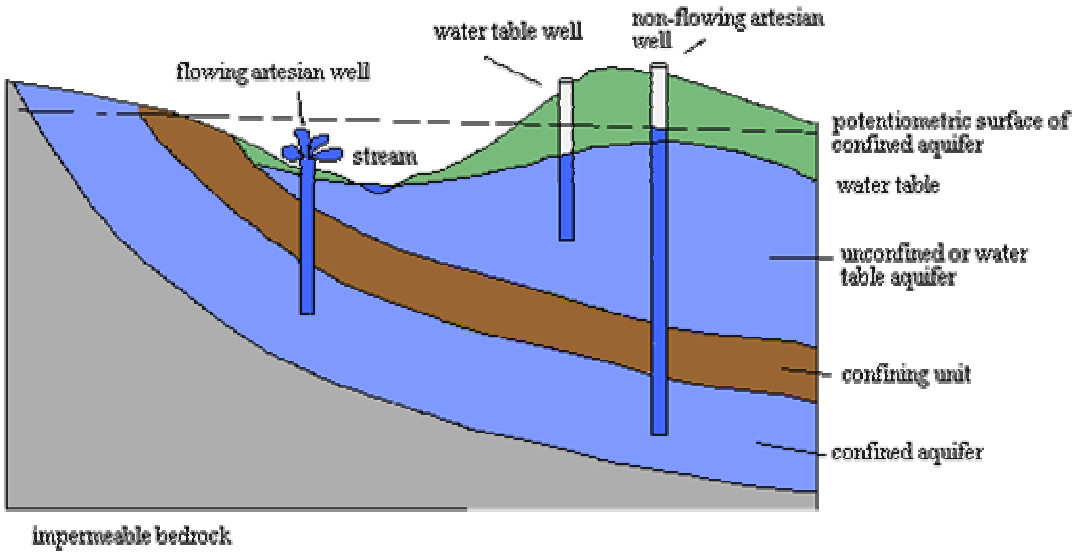
(3) Leaky or semi-confined aquifer(تكوين مائي راشح) : In leaky aquifers, aquitards form the semi-confining layers, through which vertical leakage takes place due to head differences across it.



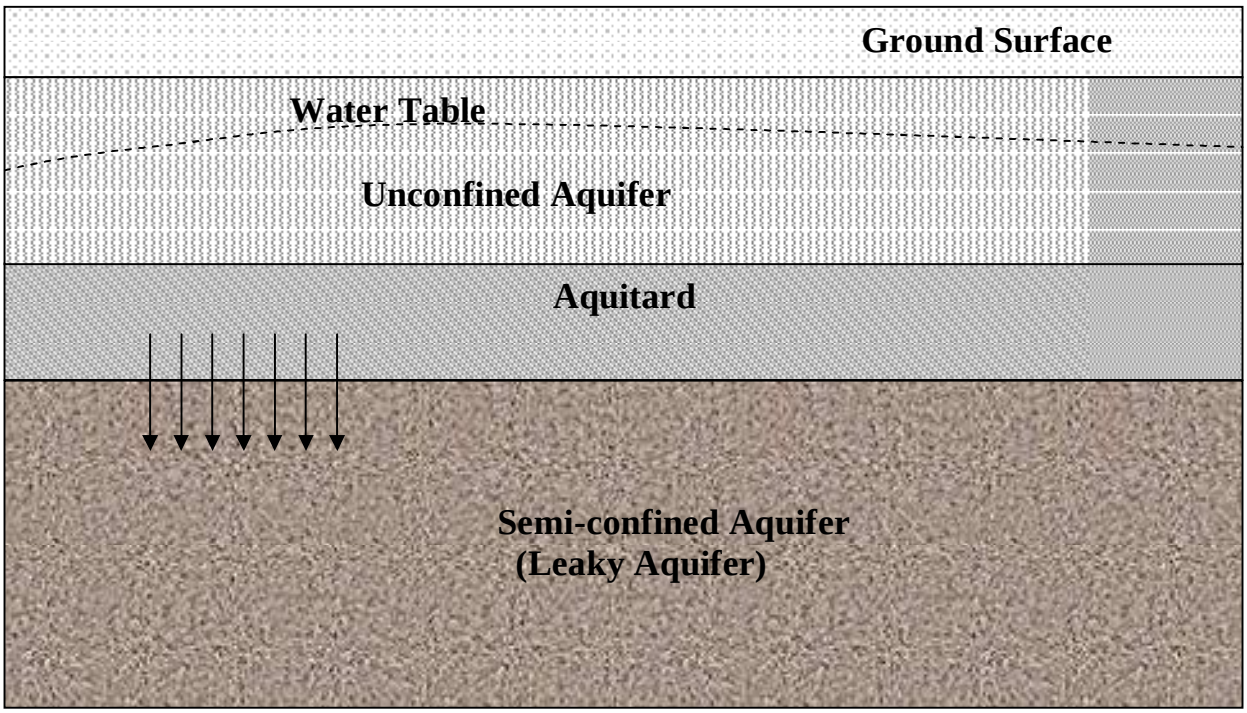
Confined groundwater and the development of an artesian well.



Unconfined groundwater



Confined and unconfined aquifers.



Leaky Aquifer (semi – confined Aquifer)

The differences between confined and unconfined aquifers

Property	Confined	Unconfined
Stratigraphy	Closed to atmosphere	Open to atmosphere
Storativity	0.001 to 0.0000001	0.1 to 0.01
Water Level (Topographic)	Does not reflect topography	Reflects topography
Water Level (Pump)	Pressure response (fast, wide)	Drainage response (slow, local)
Water Level (Evapotranspiration)	Does not respond diurnally to ET	May respond to evapotranspiration
Water Level (Rain)	Does not respond to rain events	Does respond to rain events
Water Level (Load)	Responds to load	Does not respond to load

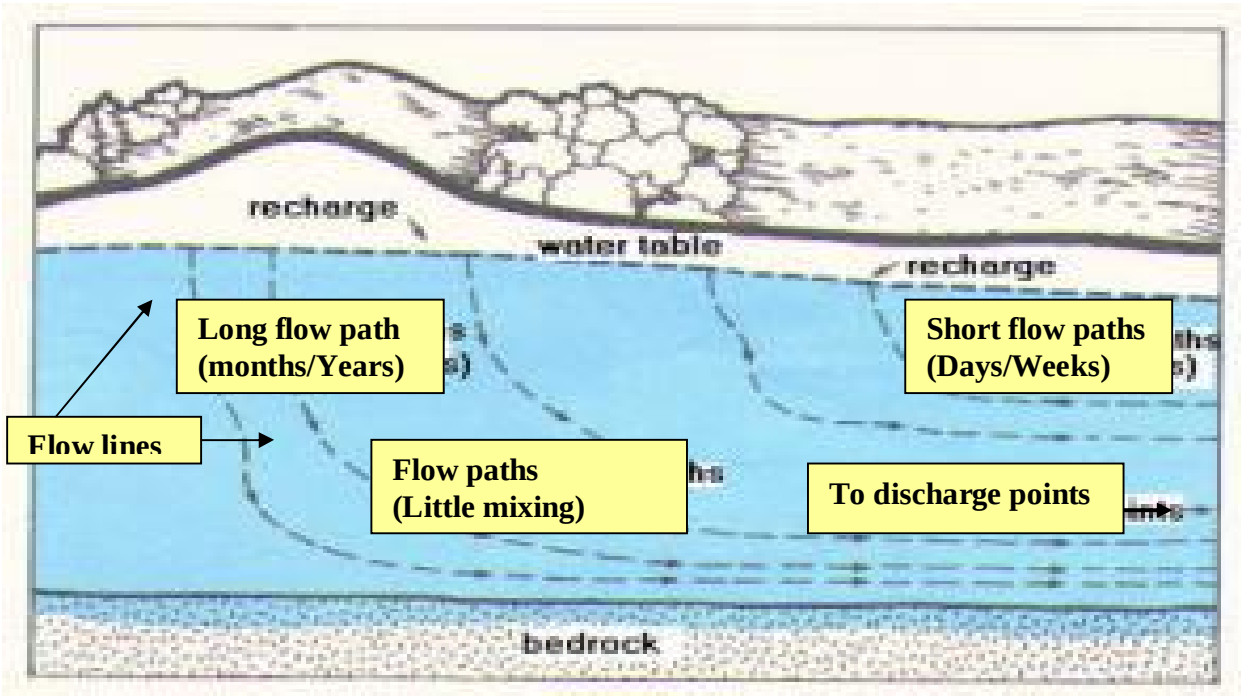
حركة المياه الجوفية
GROUNDWATER MOVEMENT

1- Local موضعي
2- Regional اقليمي

Groundwater Flow Rates معدل حركة المياه الجوفية

Groundwater moves very slowly from recharge areas to discharge points. Flow rates in aquifers are typically measured in feet per day. Flow rates are much faster where large rock openings or crevices exist (often in limestone) and in loose soil, such as coarse gravel. It may take years, decades or even centuries for groundwater to move long distances through some aquifers. However, ground-water may take only a few days or weeks to move for a short distance through loose soil. Groundwater typically moves in parallel paths (i.e., layers) with little mixing, due to the slow movement of groundwater, which does not create sufficient turbulence to cause mixing to occur. This becomes an important factor in the location and movement of contaminants that enter the groundwater.

هنالك عوامل تؤثر على حركة المياه الجوفية منها (١) الطبوغرافية في حالة تجانس المتكون (٢)جيولوجية منطقة تواجد المياه الجوفية بمعنى عدم تجانس المتكون المائي



تذبذب مستويات المياه الجوفية
GROUNDWATER LEVELS FLUCTUATION

اهمية دراسة تذبذب المياه الجوفية
يكمن في معرفة التغيرات في مخزون المياه اما نتيجة عمليات التغذية او الضخ المستمر وانواعه:

التقسيم الزمني لتغيرات مستويات المياه الجوفية

(1) Short – Variation (Daily Fluctuation) تذبذبات يومية

(2) Long – Variation تذبذبات طويلة الاجل

(3) Seasonally Variations تذبذبات موسمية

العوامل المؤثرة في تذبذب المياه الجوفية

Factors affecting Groundwater Fluctuations

1- Precipitation
2- Surface Runoff
3- Evapotranspiration
4- Ocean Tides
5- Earthquakes
6- Artificial Factors

الينابيع
SPRINGS

What is a spring?

Definition of Spring: Springs are place where a concentrated discharge of groundwater flows at the ground surface.

Also

1- A spring is a water resource formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of ground water at or below the local water table, below which the subsurface material is saturated with water.

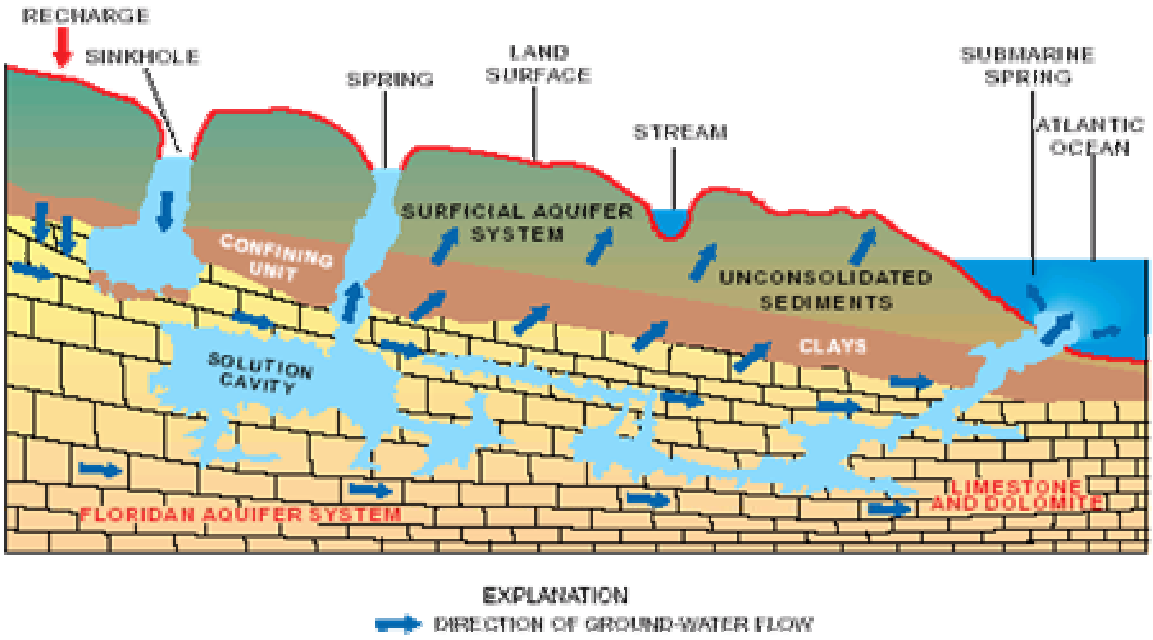
2- A spring is also the result of an aquifer being filled to the point that the water overflows onto the land surface. They range in size from intermittent seeps, which flow only after much rain, to huge pools flowing hundreds of millions of gallons daily.

Springs are not limited to the Earth's surface, though. Recently, scientists have discovered hot springs at depths of up to 2.5 kilometers in the oceans, generally along mid-ocean rifts (spreading ridges). The hot water (over 300 degrees Celsius) coming from these springs is also rich in minerals and sulfur, which results in a unique ecosystem where unusual and exotic sea life seems to thrive.

How are springs formed?

Springs may be formed in any sort of rock. The largest springs are formed in limestone and dolomite in the karst topography. Both dolomite and limestone fracture relatively easily.

When weak carbonic acid formed by rainwater it enters to these carbonate rocks, when it reaches a horizontal crack or a layer of non-dissolving rock such as sandstone or shale, it begins to cut sideways, forming an underground stream. As the process continues, the water hollows out more rock, eventually admitting an airspace, at which point the spring stream can be considered a cave. This process is supposed to take tens to hundreds of thousands of years to complete.

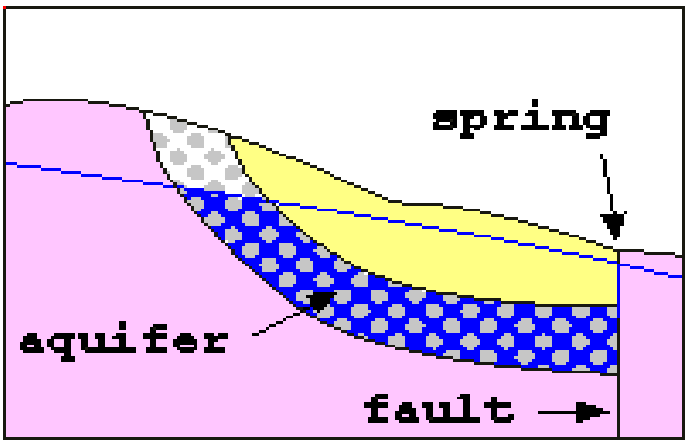


: Springs Mechanism

Water infiltrates into the ground to become groundwater. It flows slowly through porous rock or sand (aquifer), under the influence of gravity . It eventually discharges to the surface lower in the landscape via springs. Springs occur where there is a pathway for the water to escape and where the watertable (or groundwater pressure) is above ground level.

Changes in Spring Flows

Aquifers are topped up during the Wet season, raising watertables. Spring flows are at a maximum at that time. As the Dry season proceeds groundwater drains out of the aquifer via springs and the watertable progressively falls. If the watertable falls below ground level at the spring it will stop flowing. Some springs are permanent but the majority dry up at some time before the next Wet season. Even some apparently permanent springs can dry under extended drought conditions. The example below shows stream flow in a river that is spring fed in the Dry season.



TYPES OF SPRINGS

The following diagram showing types of gravity springs
(a) Depression Spring
(b) Contact Springs
(c) Fracture artesian spring
(d) Solution tubular spring

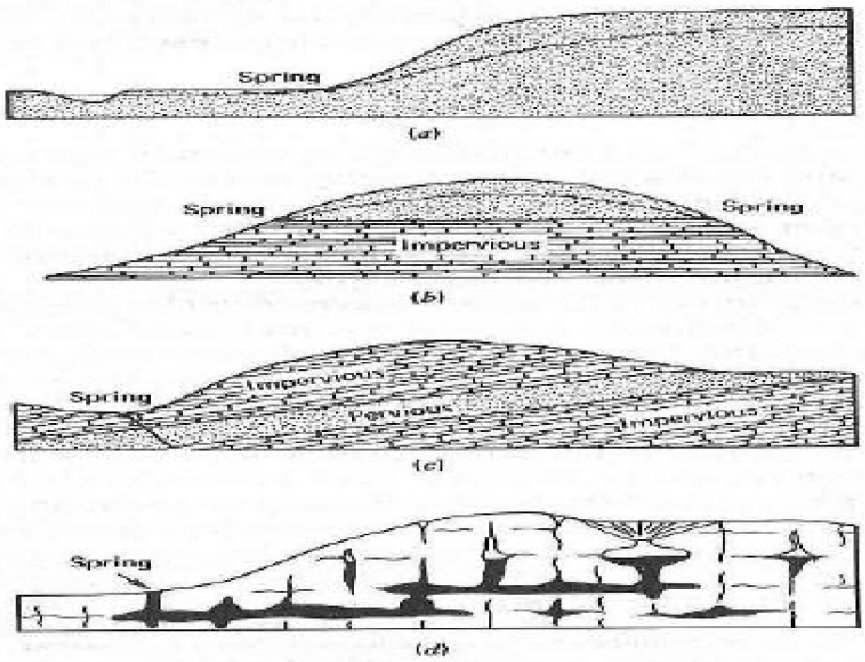
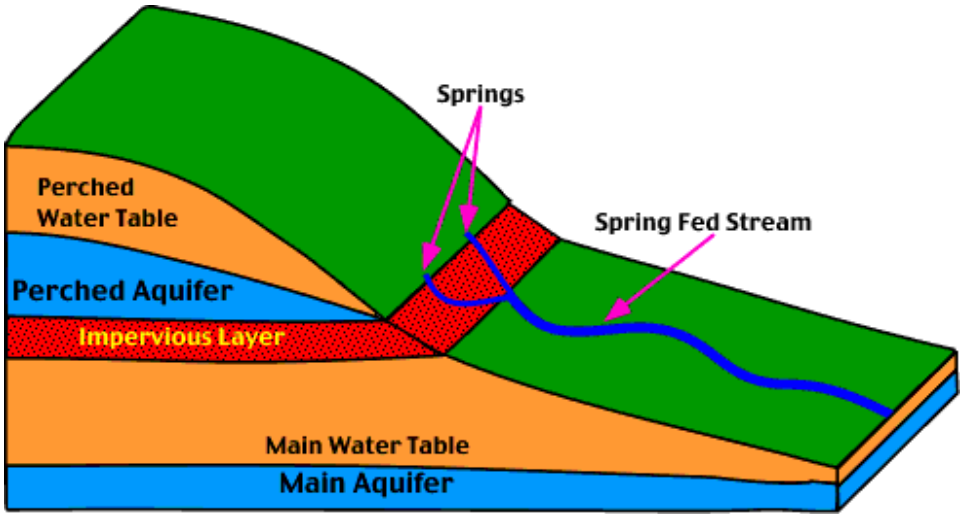


Fig. 2.15 Diagrams illustrating types of gravity springs. (a) Depression spring. (b) Contact springs. (c) Fracture artesian spring. (d) Solution tubular spring (after Bryan[6]; copyright © 1919 by the University of Chicago Press).

The presence of an impermeable layer beneath this type of groundwater can cause the formation of a perched water table. These features are elevated some distance above the surface's main water table. Springs that flow from underground to the Earth's surface are often formed when a perched water table intersects the surface.



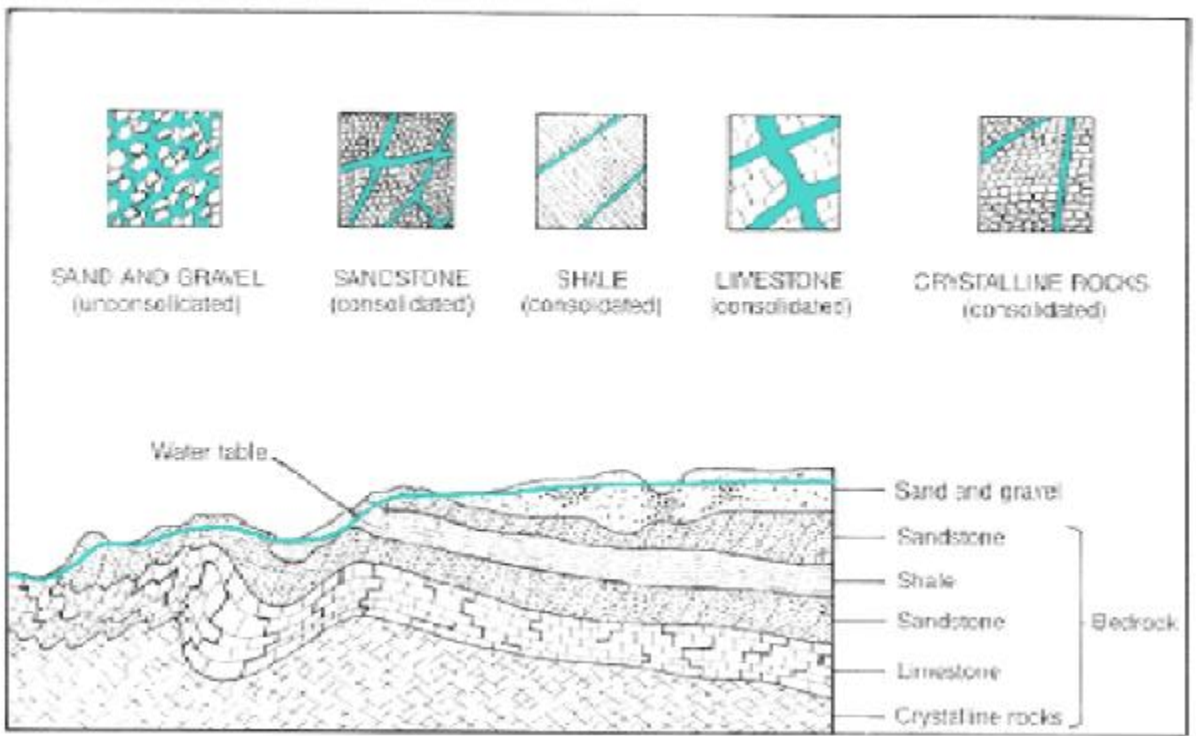
Unconfined groundwater, perched water tables and the development of springs

تواجد المياه الجوفية في الصخور الرسوبية
Occurrence of Groundwater in Sedimentary Rocks

تقسم الصخور الرسوبية إلى عدة أنواع :

١- صخور رسوبية حتاتية مثل الحجر الطيني – الحجر الرملي – الكونجلوميريت
٢- صخور رسوبية كيميائية النشأة مثل الحجر الجيري والدلومايت
٣- متبخرات مثل الجبس والانهبدرايت والهاليت
٤- صخور رسوبية عضوية النشأة مثل الفوسفات
٥- الفحم والليجنايت

يشكل النوع الأول مانسبتة ٥٠ % من الحجم الكلي للصخور الرسوبية. كما يختلف عطاء هذه الصخور باختلاف مسامية ونفاذيتها والشكل يوضح بعض هذه الصخور.



تواجد المياه الجوفية في الرواسب الغبر متماسكة
Groundwater in Non-indurated Sediments

تنقسم الرواسب الغير متماسكة الى:

١- الرواسب النهرية Alluvium
٢- الرواسب الجليدية Till
٣-الرواسب الريحية Loess
٤-الكثبان الرملية Sand dunes
٥- رواسب المنحدرات Colluvial deposits
٦- رمال وطين البحيرات والخلجانLacustrine sands and clay

وغالبا ما يفضل البحث عن المياه بتلك الرواسب للأسباب التالية

١- سهولة الحفر
٢-غالبا ما توجد هذه الرواسب في الأودية حيث يكون مستوى الماء الجوفي قريب من السطح
٣-تتميز بعطاء نوعي عالي مقارنة بغيرها من المواد
٤- النفاذية في هذه الرواسب مرتفعة عن غيرها باستثناء الأحجار الجيرية المحتوية على تجاويف

المياه الجوفية فى الصخور النارية والمتحولة
Groundwater in Igneous and Metamorphic Rocks

Fracture Characteristics Controlling Ground Water Availability

Igneous and metamorphic-rock aquifers

The principal water-yielding aquifers of Western part of Saudi Arabia can be grouped into five types:

1- Unconsolidated and semi consolidated sand and gravel aquifers;

2- Sandstone aquifers and carbonate-rock aquifers; and

3- Aquifers in igneous and metamorphic rocks. Igneous and metamorphic-rock aquifers can be grouped into two categories:

(a) crystalline-rock aquifers

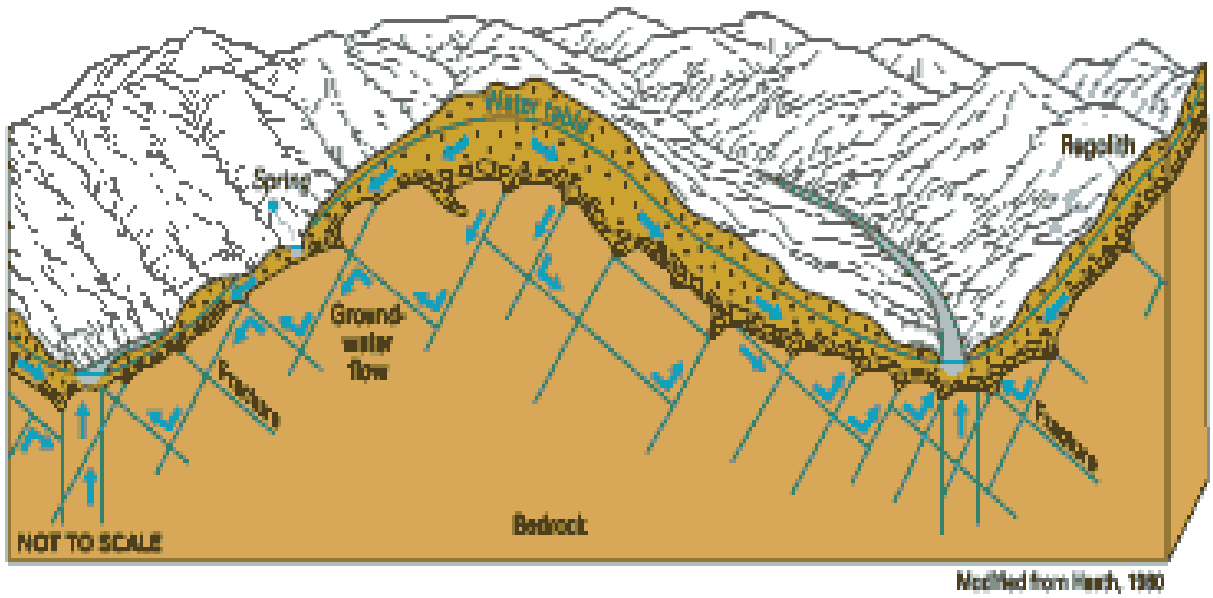
(b)volcanic-rock aquifers.

Large areas of the western and northwestern Saudi Arabia are underlain by crystalline rocks.

porosity is insignificant. These igneous and metamorphic rocks are permeable only where they are fractured, and they generally yield only small amounts of water to wells. However, because these rocks extend over large areas, large volumes of ground water are withdrawn from them, and, in many places, they are the only reliable source of water supply.

NOTES

Although crystalline rocks are geologically complex, movement of water through the rocks is totally dependent on the presence of secondary openings; rock type has little or no effect on ground-water flow.



How much water is stored in hard rock?

The volume of water stored in fractured hard rocks near the surface is estimated to total less than 2 percent of the rock volume. This percentage decreases with depth as fractures become narrower and farther apart. The total amount of water in storage in the rocks surrounding a hard rock well is small, so that groundwater levels and the well's yield can decline dramatically during the summers of dry years. The volume of water stored in many alluvial soils can amount to 10-25 percent of the volume of the alluvium.

How much water will your well yield?

Half of all hard rock wells yield 10 gallons per minute or less, which is only enough for individual domestic supplies. When conditions are good, wells drilled in fractured rock may yield several hundred gallons per minute when pumped. Good conditions include:

• large amounts of fractures;
• good interconnection between fractures;
• wide, large, clean fractures;
• a source of recharge;
• a large quantity of water in storage; and
• proper installation of the well, including removal of granular debris that may clog the fractures. Some wells may be dry if the above conditions are not met

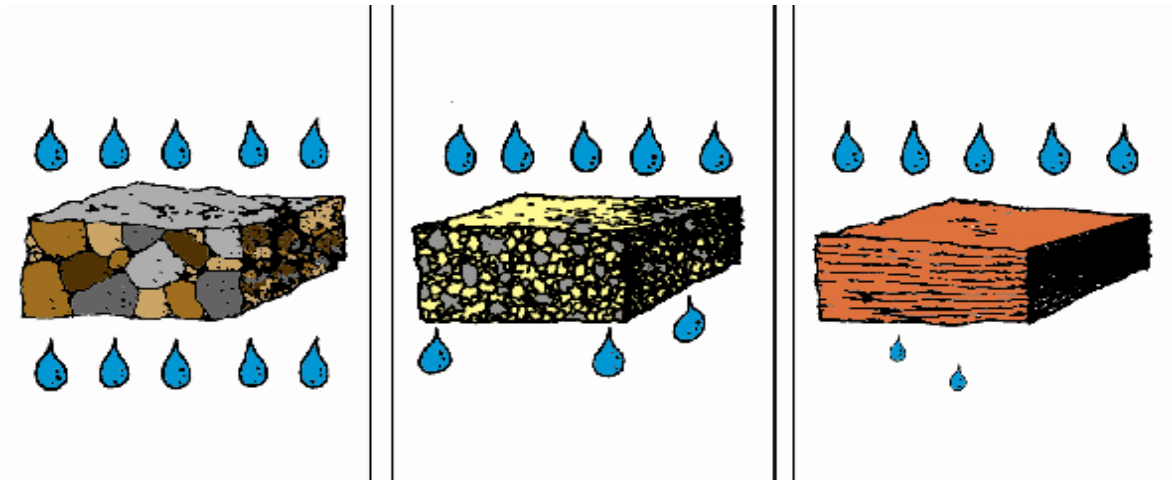
المسامية والنفاذية للصخور الرسوبية والنارية
Porosity and Permeability of Sedimentary and Igneous rocks

Permeability النفاذية

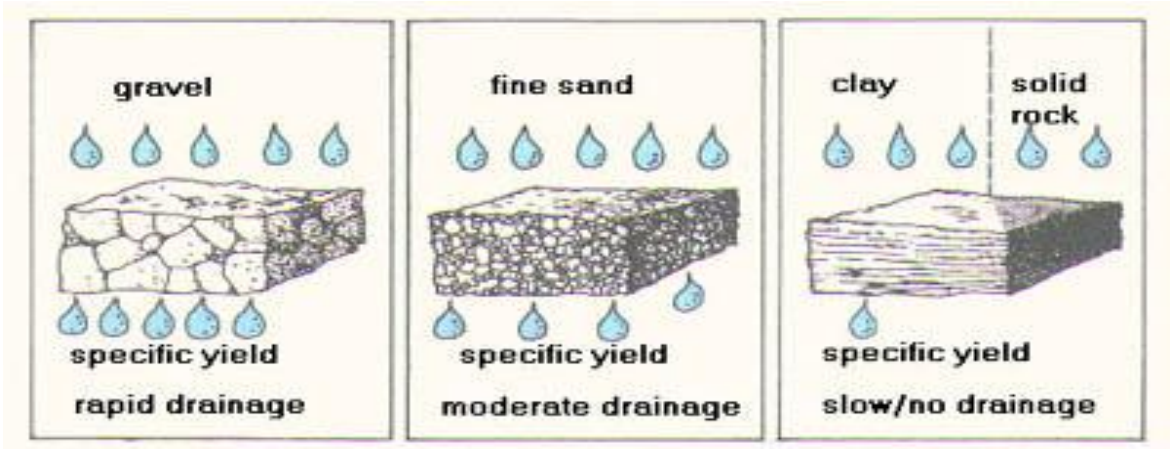
Permeability is a measure of how fast water will flow through connected openings in soil or rock. Low permeability refers to soil or rock that restricts the movement of water through it .

The specific yield is the actual amount of water that will drain out of saturated soil and rock by gravity flow. It does not drain out completely because some water forms a film that clings to soil and rock, which called specific retention.

Permeability is critical for water supply purposes; if contained in soil or rock will not drain out, it is not available to water wells.



GRAVEL **FINE SAND** **CLAY**
Rapid drainage **Moderate drainage** **Slow drainage**



Hydraulic Conductivity Range in (cm/s) for Sediments

well-sorted gravel	10^{-2} to 1
well-sorted sands	10^{-3} to 10^{-1}
silty sands, fine sands	10^{-5} to 10^{-3}
sands, till	10^{-6} to 10^{-4}
clay	10^{-9} to 10^{-6}

Porosity المسامية

The capacity of soil or rock to hold water is called porosity.

Saturated sand contains about 20% water;
gravel, 25%;
and clay, 48%.
Saturated bedrock commonly contains less than 1% water.

Note
Clay is not a good water source despite its high water content, or porosity, because the extremely small size of the openings between microscopic particles creates friction that effectively halts water movement. Saturated clay is virtually impermeable.

Diagram below showing several types of rock intensities and the relation of rock texture to porosity.

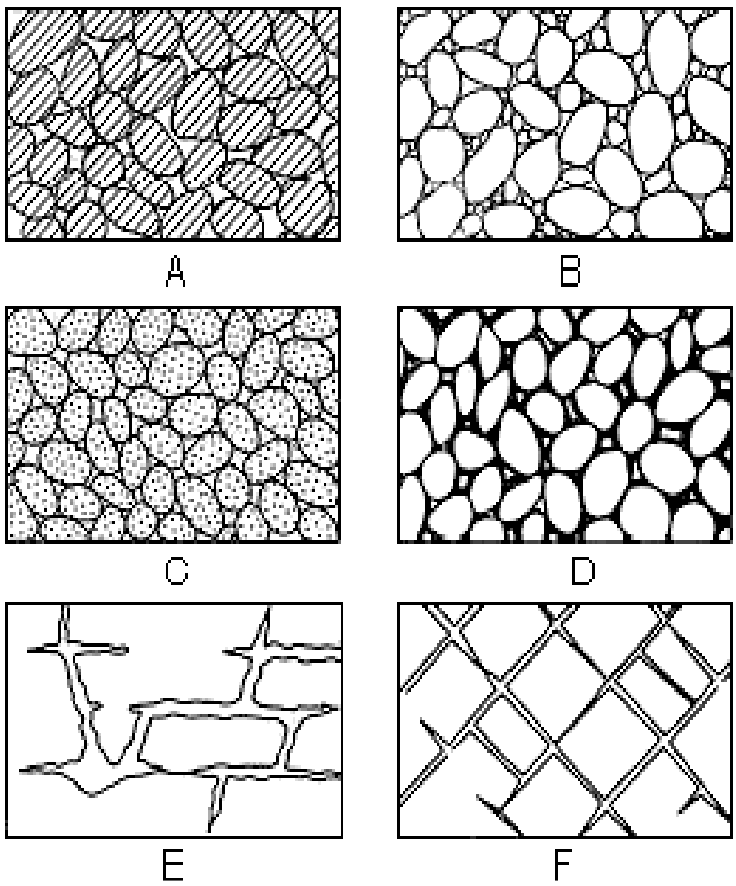


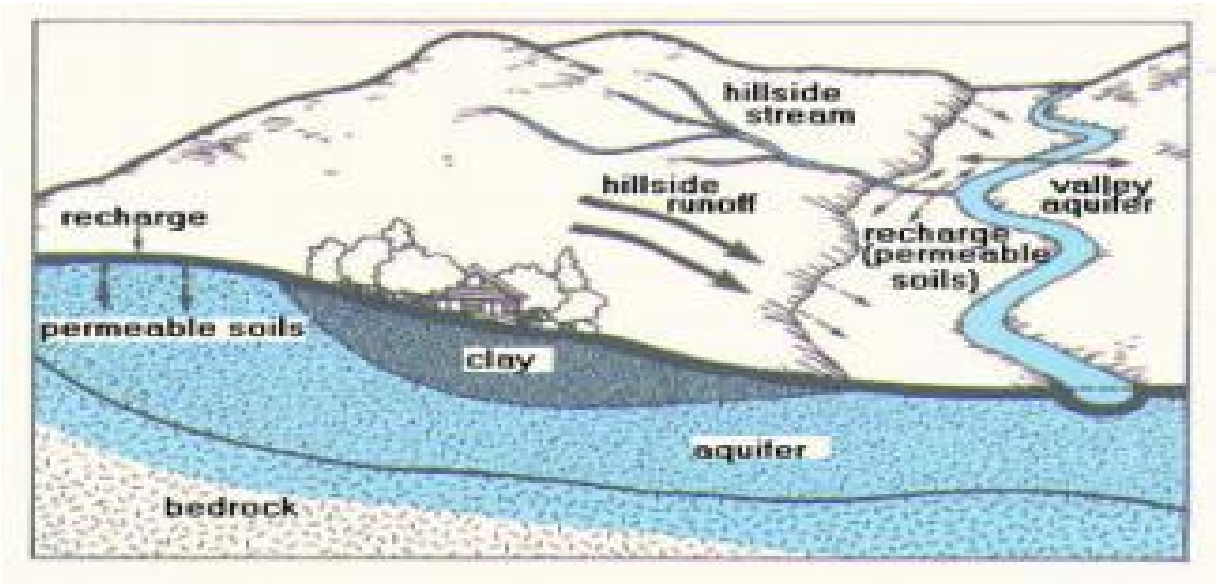
Fig. A. Well-sorted sedimentary deposit having high porosity;
Fig. B. poorly sorted sedimentary deposit having low porosity;
Fig. C. Well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity;
Fig. D. well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices;
Fig. E. rock rendered porous by solution;
Fig. F. rock rendered porous by fracturing.

تصريف وتغذية المياه الجوفية
GROUND WATER RECHARGE AND DISCHARGE

Recharge is the process by which ground water is replenished. A recharge area is where water from precipitation is transmitted downward to an aquifer.

Most areas, unless composed of solid rock or covered by development, allow a certain percentage of total precipitation to reach the water table. However, in some areas more precipitation will infiltrate than in others. Areas which transmit the most precipitation are often referred to as "**high**" or "**critical**" **recharge areas**.

As described earlier, how much water infiltrates depends on vegetation cover, slope, soil composition, depth to the water table, the presence or absence of confining beds and other factors. Recharge is promoted by natural vegetation cover, flat topography, permeable soils, a deep water table and the absence of confining beds.



Discharge areas are the opposite of recharge areas. They are the locations at which ground water leaves the aquifer and flows to the surface. Ground water discharge occurs where the water table or potentiometric surface intersects the land surface. Where this happens, **springs** or **seeps** are found. Springs and seeps may flow into fresh water bodies, such as lakes or streams, or they may flow into saltwater bodies.

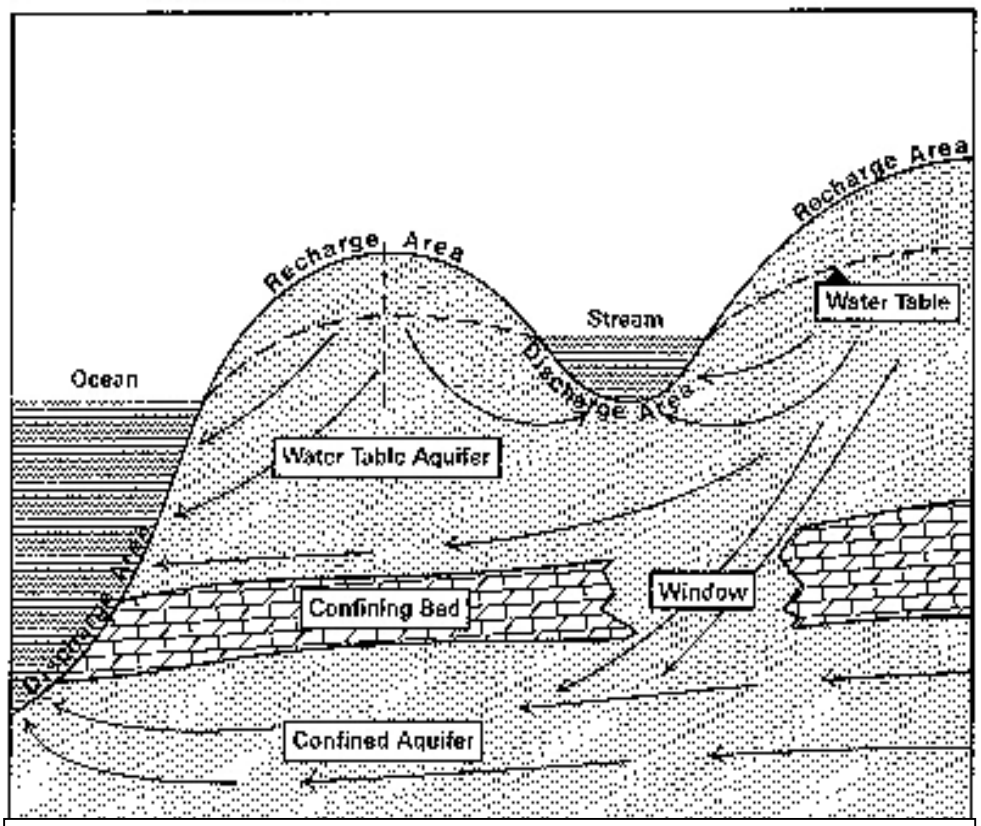
Under the force of gravity, ground water generally flows from high areas to low areas. Consequently, high areas-such as hills or plateaus-are typically where aquifers are recharged and low areas-such as river valleys-are where they discharge. However, in many instances aquifers occur beneath river valleys, so river valleys can also be important recharge areas.

Groundwater Discharge Points

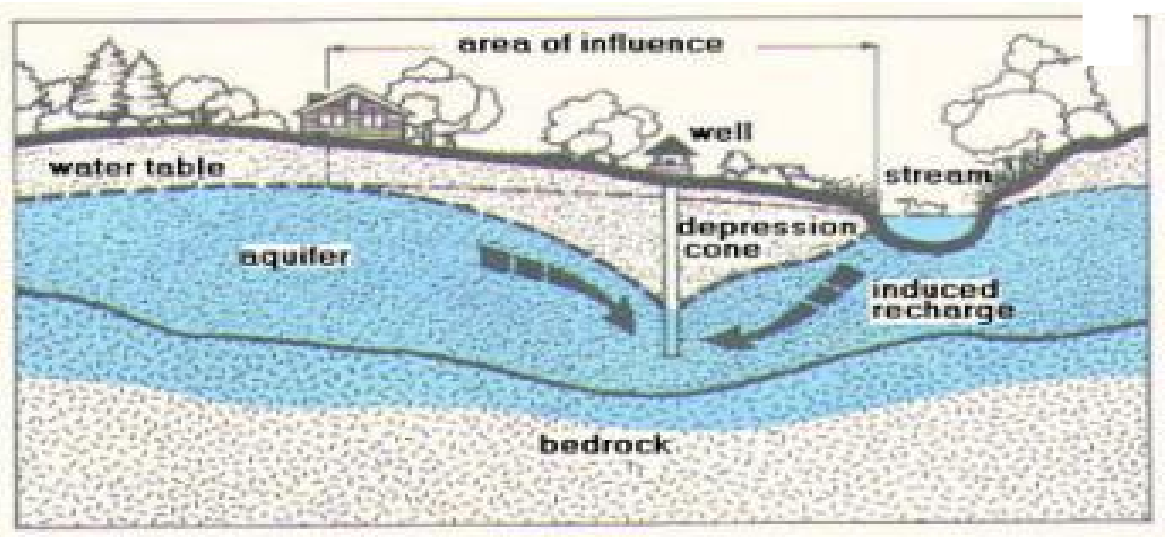
Groundwater enters the ground in recharge areas and leaves the ground at discharge points. Discharge is continuous, as long as sufficient water is present above the discharge point. Discharge points typically occur as seepage into wet-lands, lakes and streams. Springs are visible discharge points at the land surface. If the water table is close to the land surface during the growing season, large amounts of groundwater may be withdrawn by plant transpiration. Typical recharge and discharge areas are depicted in Figure below.

Wells: Induced Recharge

The cone of depression from a pumping well may extend to a nearby stream or lake. This lowers the adjacent water table below the steam or lake level. As a result, the stream or lake begins to lose water to the adjacent groundwater aquifer in the vicinity of the well. This is known as induced recharge. Streams and wetlands have been completely dried up by induced recharge from well pumping.



Recharge and Discharge Areas



Wells: Induced Recharge

عطاء الآبار
Well Yields

-

١- الصخور الرسوبية

يتراوح عطاء الآبار في الصخور الرسوبية

النصف متماسكة من ١-٥٠٠ جالون /دقيقة.
الصخور دقيقة التحبب يقل العطاء عن ٥ جالون/دقيقة
الحجر الرملي ٥-٢٠٠ جالون/دقيقة
الحجر الجيري المتميز بوجود التجاويف يزيد عن ٢٠٠٠ جالون/دقيقة

٢- الرواسب الغير متماسكة
تتفاوت في عطائها معتمدة على حجم الحبيبات ورجة التصنيف وغيرها من الدلائل

٣- الصخور النارية والبركانية

يتروح عطاء الآبار المحفورة في الصخور النارية والمتحولة على تواجد التشققات وكثافتها بينما الصخور البركانية مثل البازلت (Basalt)وحجر الخفاف فيعتمد على الفراغات التي تتركها الغازات والتي تعتبر أماكن تخزين المياه.

نوعية المياه الجوفية في التكاوين الجيولوجية المختلفة
Groundwater Quality In Different Geological Formations

Introduction

Factors Effect Groundwater Chemistry

1- Chemical Weathering of silicate Minerals.
2- CO_2 Dissolved.
3- Precipitation and Dissolution of Carbonate Minerals.
4- Intensive Evaporation Processes.
5- Ion Exchange.

Sedimentary Rocks الصخور الرسوبية

نوعية المياه الجوفية تعتمد اساسا على التركيب المعدني للرواسب والصخور المختلفة. في الصخور الرسوبية مثل الاحجار الجيرية ($CaCO_3$) يغلب على نوعية المياه ارتفاع عنصر الكالسيوم بينما الابار المحفورة في صخور الدلومايت ($Ca.Mg\ (CO_3)_2$) فيغلب على نوعيتها ارتفاع عنصري المغنسيوم والكالسيوم. كما هو موضح في المعادلات التالية

$$Ca\ CO_3 + H_2\ O + CO_2 \hat{U}\ Ca + 2HCO_3$$

Calcite

$$CaMg\ (CO_3)_2 + 2H_2\ O + 2CO_2 \hat{U}\ Ca + Mg + 4HCO_3$$

Dolomite

Igneous Rocks الصخور النارية

تجوية المعادن السيلكاتية الداخلة في التركيب المعدني للصخور تساهم وبشكل كبير في تحديد نوعية المياه الجوفية في هذا النوع من الصخور وتتفاوت في تركيز العناصر التي تحررها نتيجة عمليات التجوية الكيميائية كما هو موضح في المثال لتفاعلات نتيجة التجوية الكيميائية:

$$K\,Mg_3\,Al\,Si_3O_{10}\,(OH)_2\,(s) + 7H_2\,CO_3 + \tfrac{1}{2}\,H_2O \;\hat{U}\; K + Mg + 7HCO_3 + 2H_4SiO_4 + \tfrac{1}{2}\,Al_2\,Si_2O_5\,(OH)_4\,(s)$$

(Biotite) **(Kaolinite)**

$$FeS_2 + 4O_2 \;\hat{U}\; Fe + 2SO_4$$

Pyrite

طرق استكشاف المياه الجوفية
Groundwater Exploration

The following points can help to expiration groundwater :

1- Field Observations
2- Hydrologic Indications
3-Structure geological Maps
4- Geophysical Methods(Seismic and Resistivity Methods