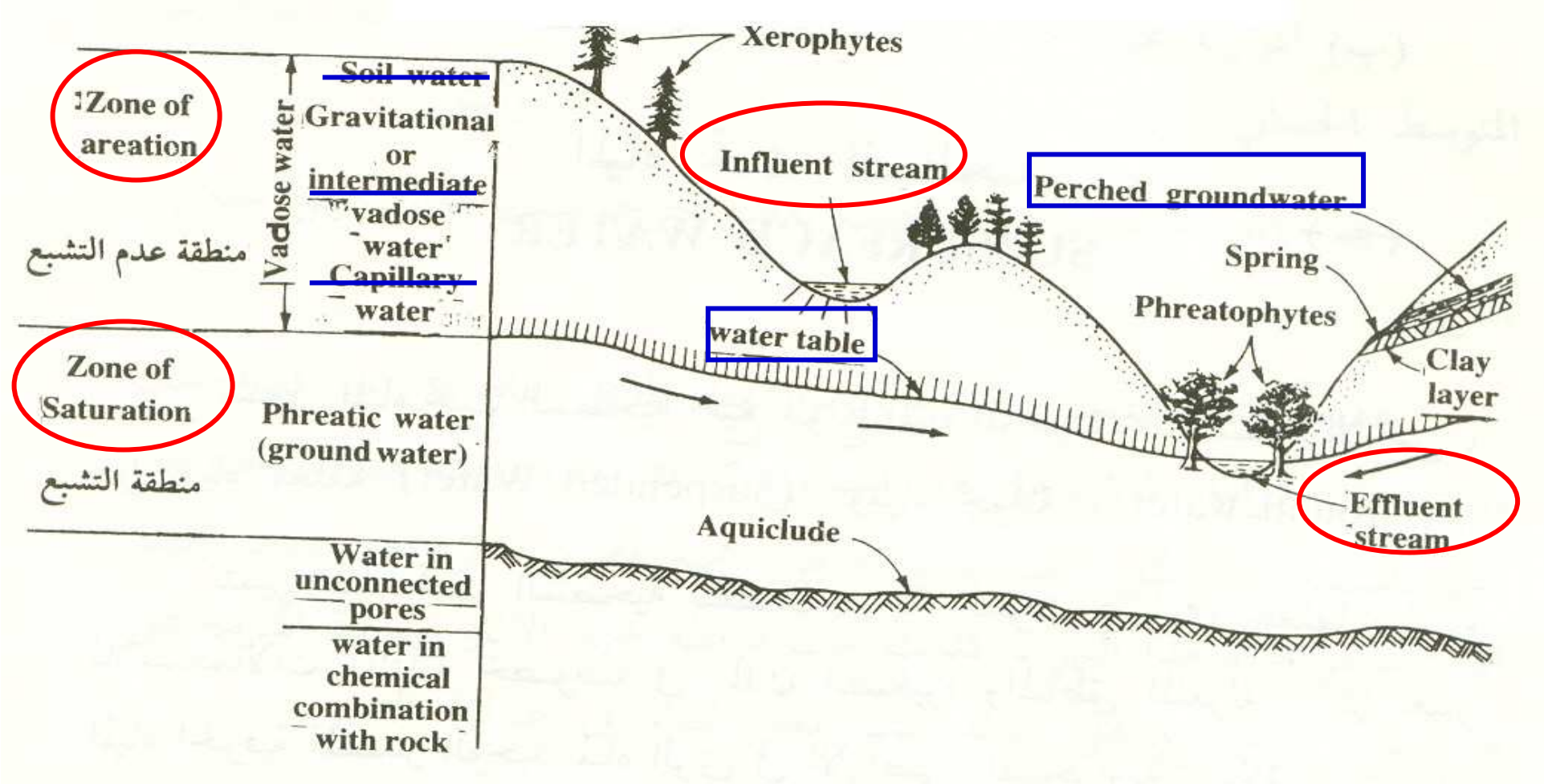
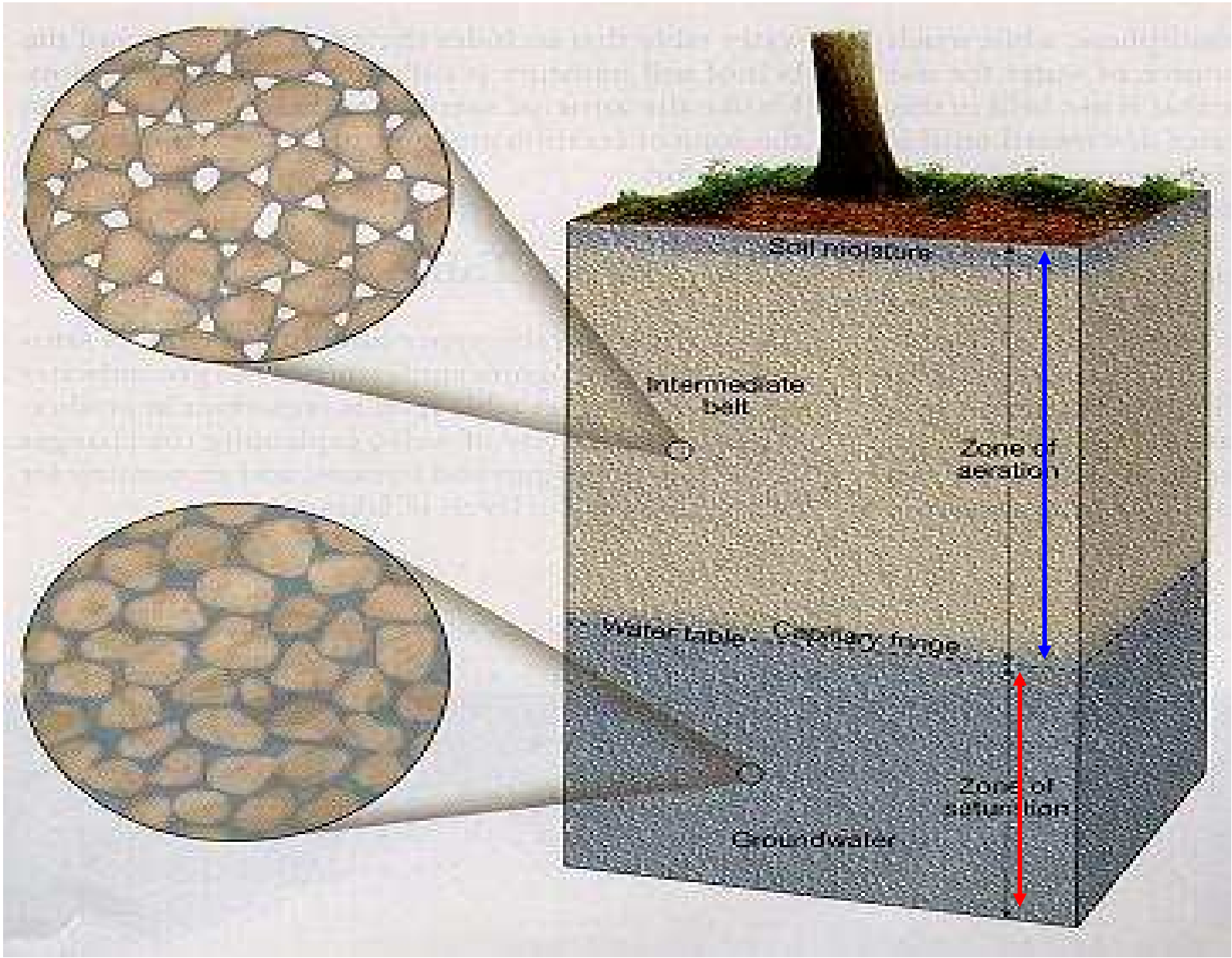
Principals of Groundwater

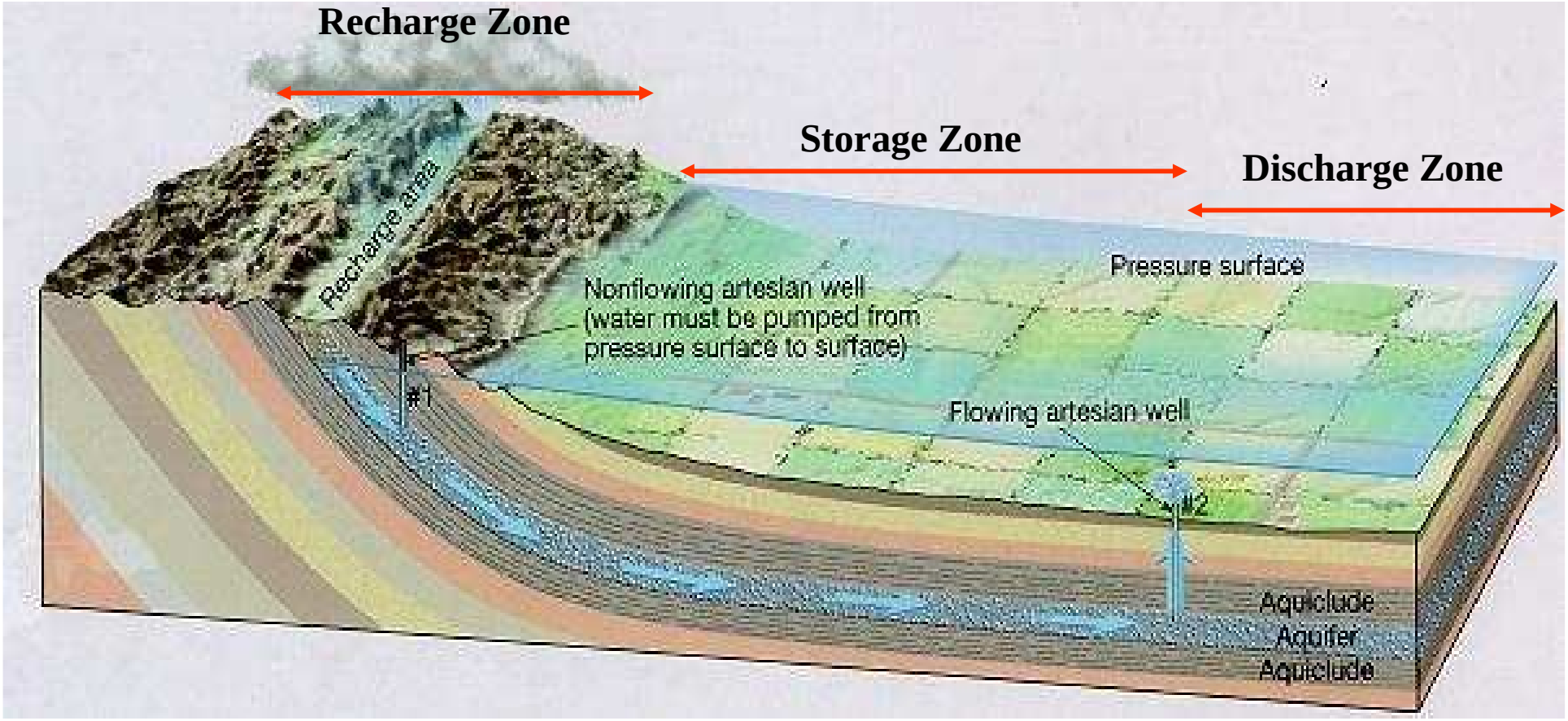
Groundwater: the subsurface water of the saturated zone

Saturated zone: the zone in which, the pores and fissures of the soil and rocks are completely filled with water.



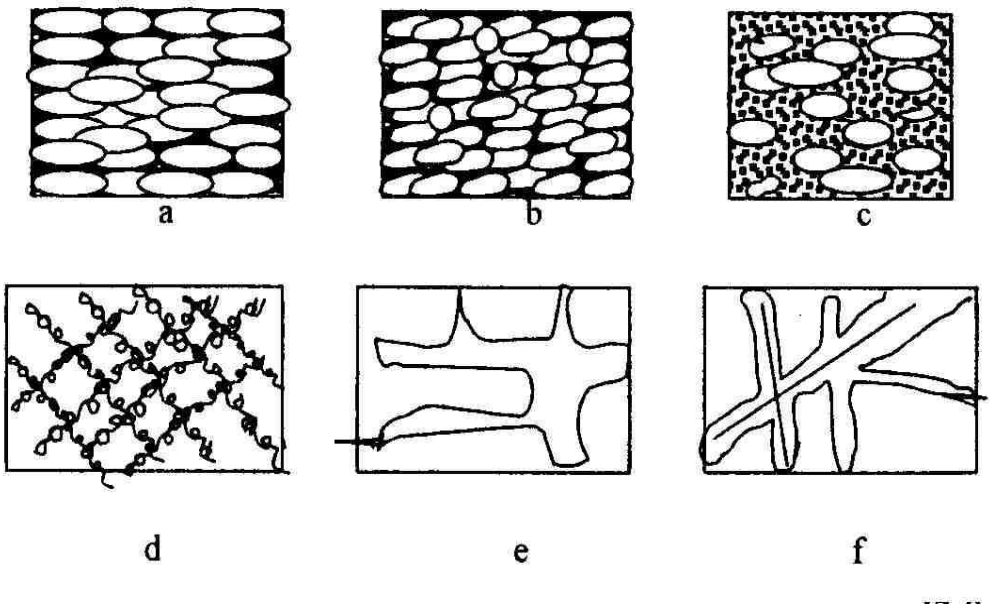

Soil moisture
Intermediate belt
Zone of aeration
Water table
Capillary fringe
Zone of saturation
Groundwater

Occurrence, Amount, Quality of Groundwater are controlled by many factors:

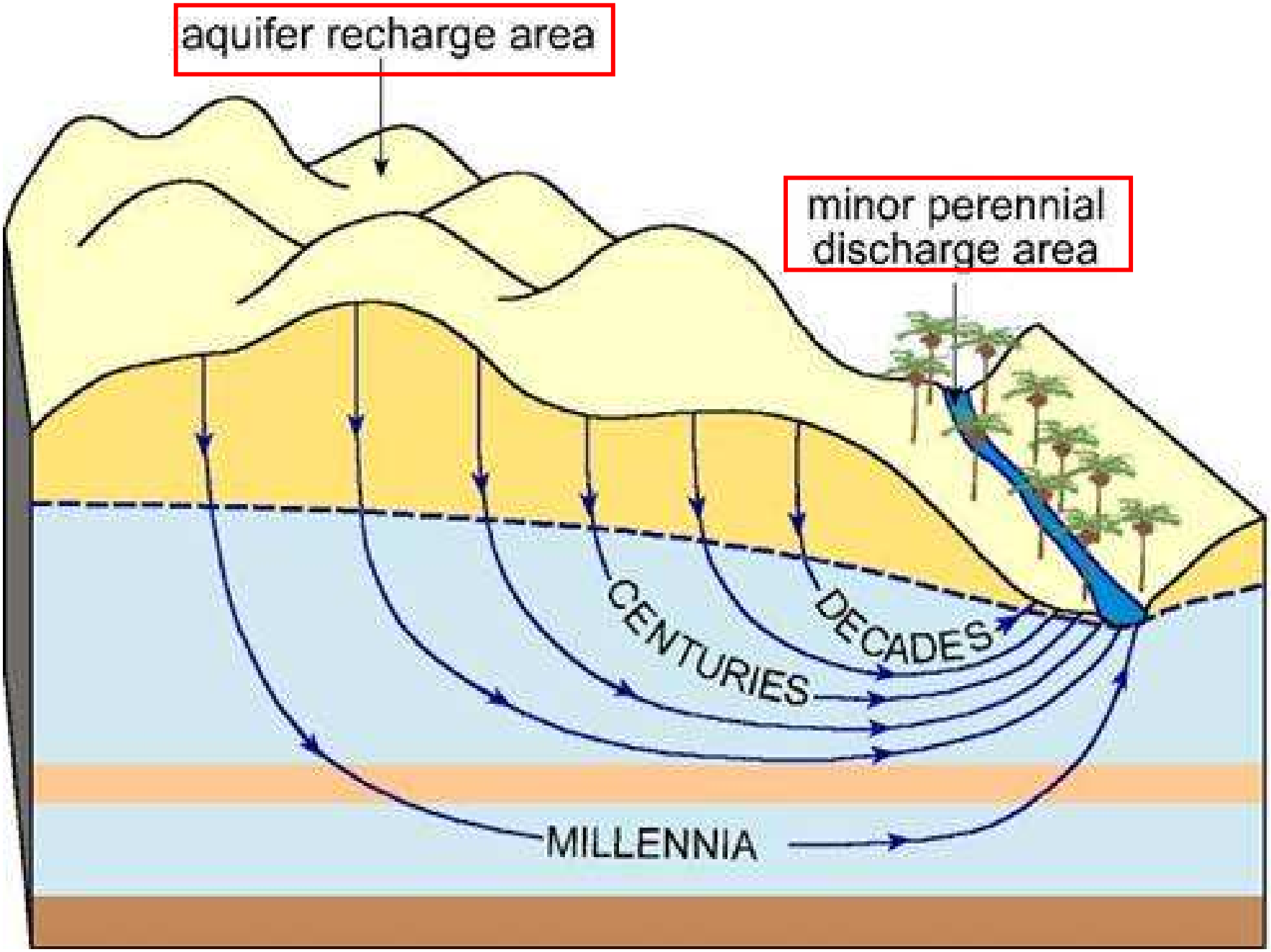


1. Geology (Type of Rocks)
2. Topography
3. Climate and
4. Geometry of Aquifer

Porosity: **It is the ratio of pore space to the total volume of rock**



Permeability: **It is the capability of a rock to pass water or other fluids**


aquifer recharge area
minor perennial discharge area
CENTURIES
DECADES
MILLENNIA

Type of Aquifers:

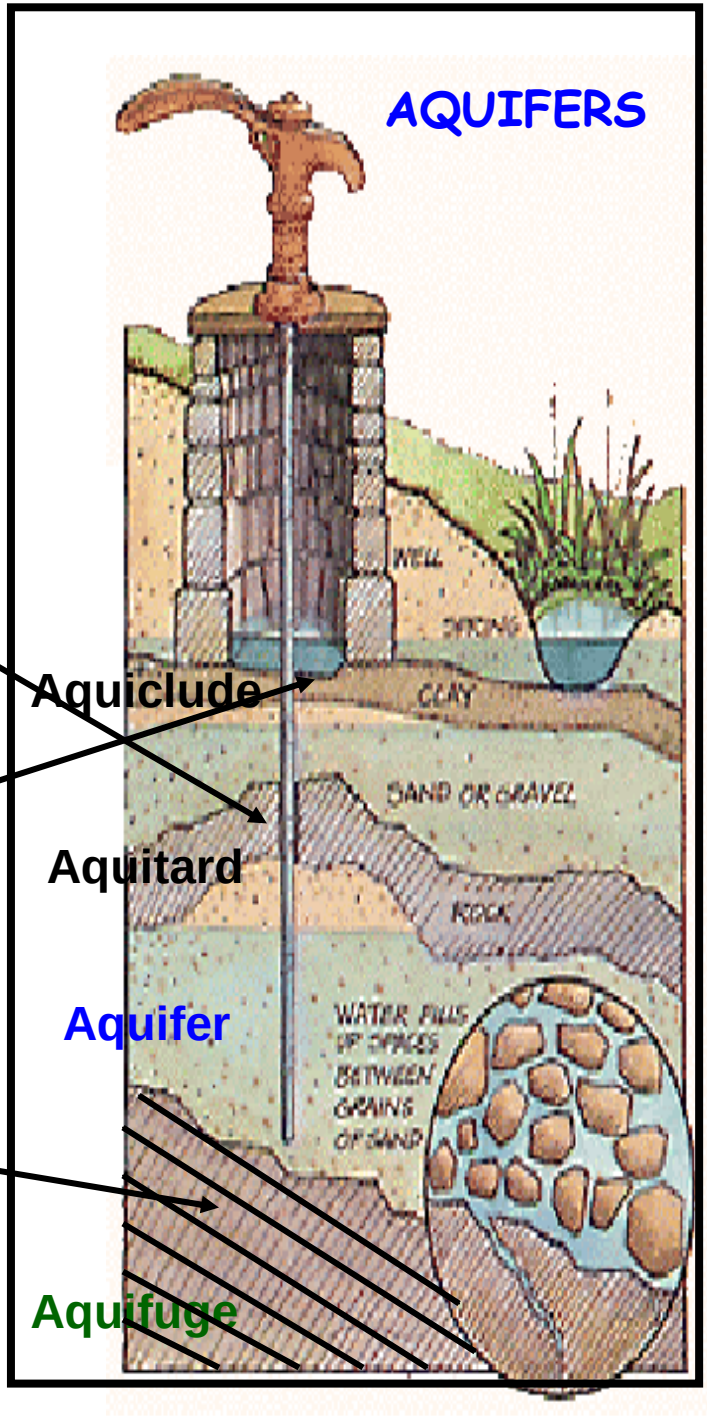
1. **Aquifer:** It is that Rock formation that have the ability to store and transmit substantial quantities of groundwater under ordinary hydraulic gradients.

2. **Aquitard: (Leaky Aquifer)** It is less permeable than aquifer, but may be permeable enough to transmit significant quantities of water.

3. **Aquiclude:** It is that Rock formation that have very low permeability to permit the flow of significant quantities of groundwater

4. **Aquifuge:** It is impermeable formation i.e

   Neither containing nor transmitting water



Unconfined Aquifer:

Confined Aquifer:

Perched Aquifer:

Hydrogeological Characteristics of the rock units in Yemen

Important Aquifers

Good Aquifers

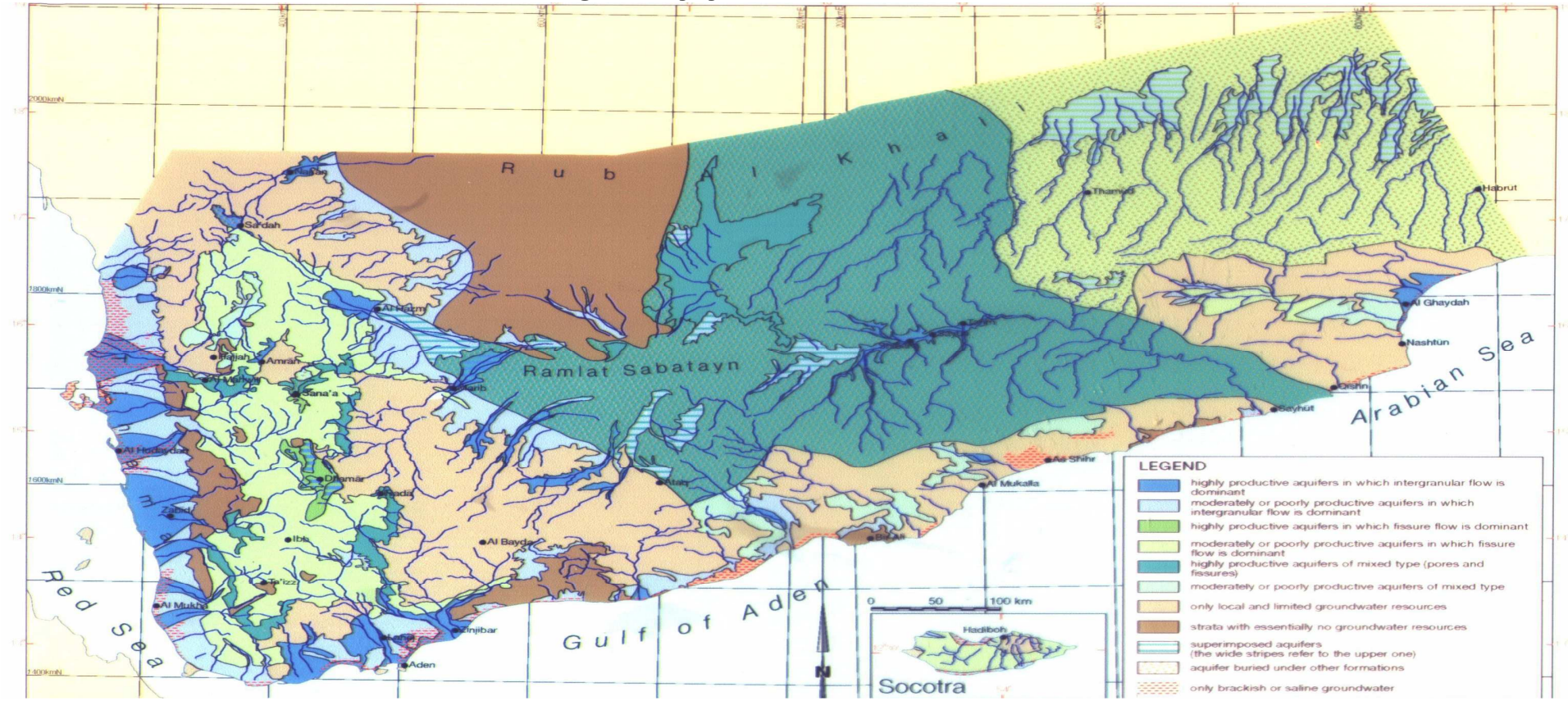
GROUP or FORMATION		LITHOLOGY		GENERALIZED HYDROGEOLOGY	
West	East	West	East	West	East
Quaternary Deposits		sands, gravels, loam, loess, clay, conglomerates, sebkha deposits, marine shell and reef deposits		local and regional porous aquifers, ranging from poorly productive to highly productive; in some zones however, completely dry beds	
Quaternary Basalts (Aden Volcanics)		basalts, tuffs, agglomerates, trachy-andesites, pumice		in general, aquitards or poor aquifers; favourable exceptions in some zones	
Baid	Irqah	shales, limestones, evaporites	gravelly conglomerates	aquitards and other non-aquifer rocks	potential aquifer rocks
	Fuwwah		conglom. & fossiliferous limestones		aquitards
Tertiary Intrusives		granites		non-aquifer rocks	
Yemen Volcanics		basalts, trachy-andesites, rhyolites, pyroclastic rocks		extensive but poorly productive fissure aquifers and aquitards	
	Habshiya	limestones, marls, shales, gypsum		aquitards and poorly productive aquifer rocks	
	Rus	gypsum, anhydride, dolomitic limestones		aquitards and poorly productive aquifer rocks	
	Jiza	shales, fine-grained limestones		non-aquifer rocks	
	Umm-Er-Radhuma	massive marly and dolomitic limestones		poorly to moderately productive aquifers	
Medj-Zir		hard argillites, cross-bedded bioclastic sandstones		aquitards or poorly productive aquifers	
Tawilah Sandstone	Sharwayn	yellow sandstones (Kawkaban member), dark red sandstones (Shibam member) and white clayey sandstones (Thula member)	shales, limestones, sandstones	moderately to highly productive mixed pore/fissure aquifers	aquitards to poor aquifers
	Mukalla		fine/medium sandstones		extensive and very productive mixed pore/fissure aquifers
	Fartaq		calcarenites		aquitards to poor aquifers
	Harshiyat		sandstones with calcareous horizons		poor aquifer rocks
	Qishn		calcarenites, limestones		aquitards
Ahjur		bituminous marly and sandy mudstones		aquitards, aquicludes	
Nayfa		limestones and dolomites		poorly to moderately productive fissure aquifers	
Madbi	Sabatayn	marls and limestones	evaporites and shales		non-aquifer rocks
Shuqra		limestones			
Kohlan Sandstone		sandstones with conglomerate intercalations		poorly productive aquifer rocks	
Akbra Shale		laminated mudstones, siltstones, shales		aquitards/aquicludes	
Wajid Sandstone		cross-bedded sandstones and coarse siltstones		poorly to moderately productive porous aquifers (only productive where hundreds of metres thick)	
Precambrian Basement		igneous rocks, metamorphic rocks, metasediments		generally non-aquifer rocks, but water-bearing in thin weathered zones and in fractured zones	

Spatial Distribution of Regional Aquifers in Yemen

A new small scale schematic hydrogeological map of Yemen was prepared by (Van de Jun et al, 1995)

Based on:

- **the previous hydrogeological maps carried out by Robertson Group, 1991 and the Russian company (zarubezhgeologia, 1992),**
- **Study of numerous reports and**
- **Observation on the field during many years**



In this map the UNESCO classification of aquifer units was followed,

But

in between porousAquifer and fissure aquifer

a category of mixed pore/fissure aquifer is defined.

The following classes of the hydrogeological aquifers in Yemen then resulted:

8 classes

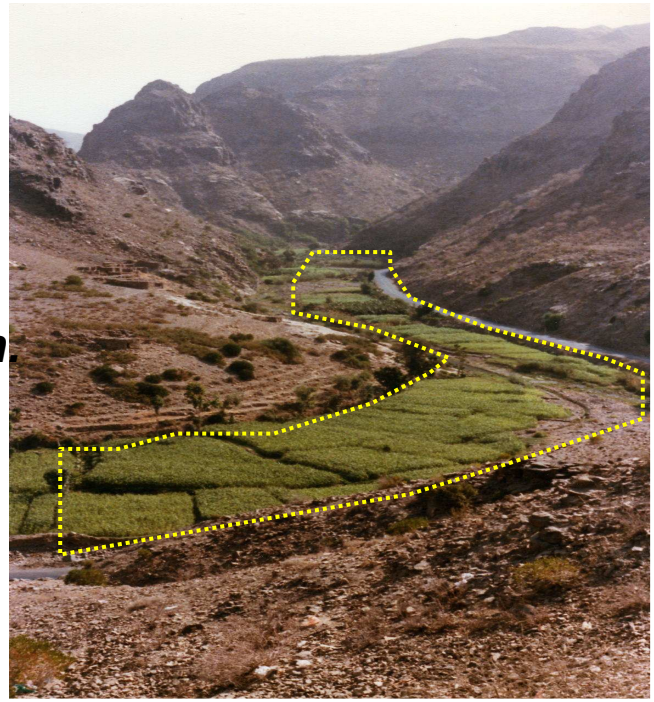
- **1a. Highly productive pore aquifers**
- **1b. Moderately or poorly productive pore aquifers**
- **2a. Highly productive fissure aquifers**
- **2b. Moderately or poorly productive fissure aquifers**
- **3a. Highly productive mixed pore/fissure aquifers**
- **3b. Moderately or poorly productive mixed pore / fissure aquifers**
- **a. Strata with local and limited groundwater resources**
- **4b. Units with essentially no groundwater.**

Principal groundwater systems in Yemen

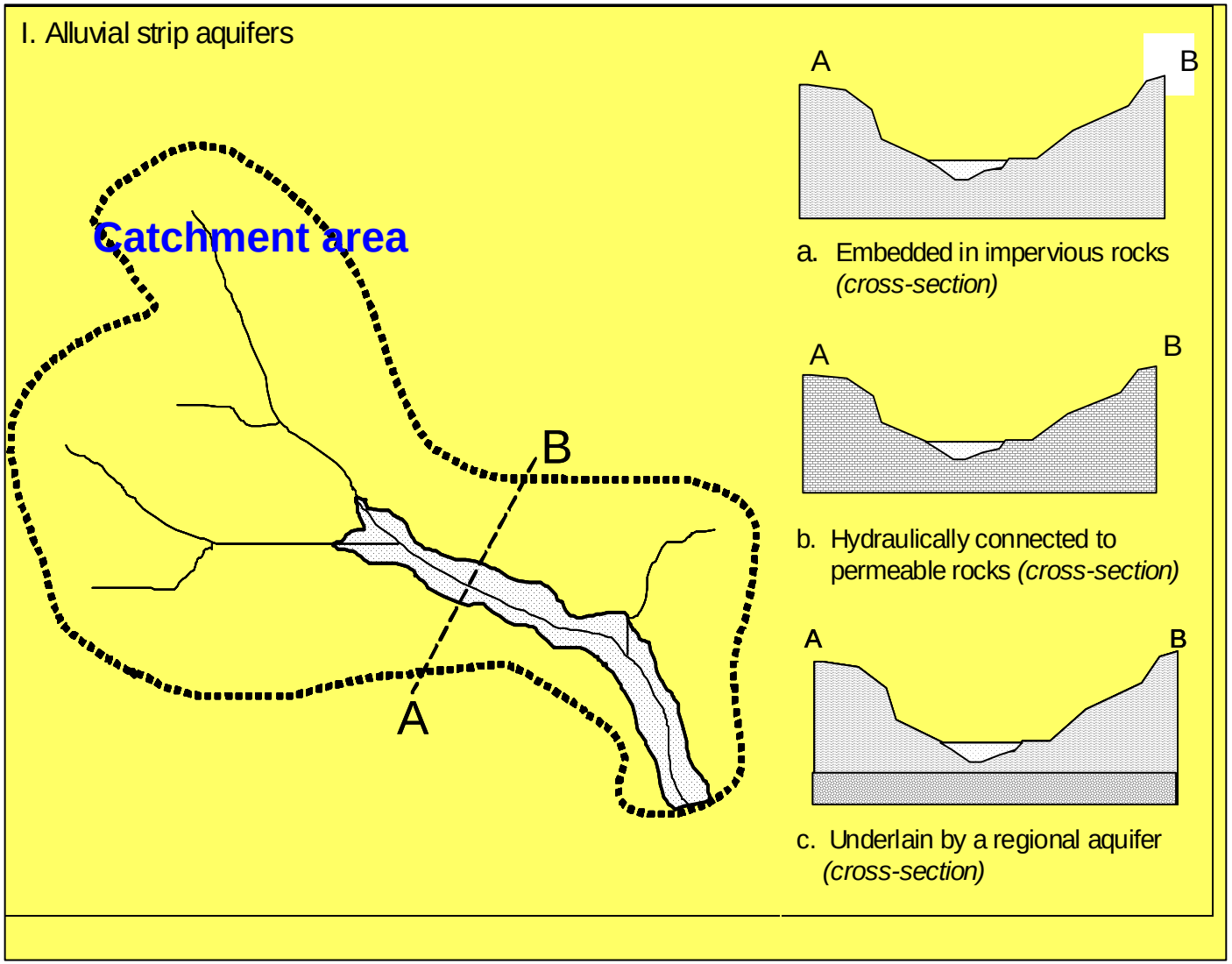
1. Alluvial wadi fills (strip aquifers):

characteristics:

- ***Consist of* Quaternary sedimentary aquifers**
- ***Formed by the wadi (alluvial deposits)***
- ***Recharged by the wadi***
- ***Highly permeable.***
- ***They have a small width compared to their length.***
- ***They were the most convenient places to look for shallow subsurface water***



Example of of wadi (Strip aquifers):



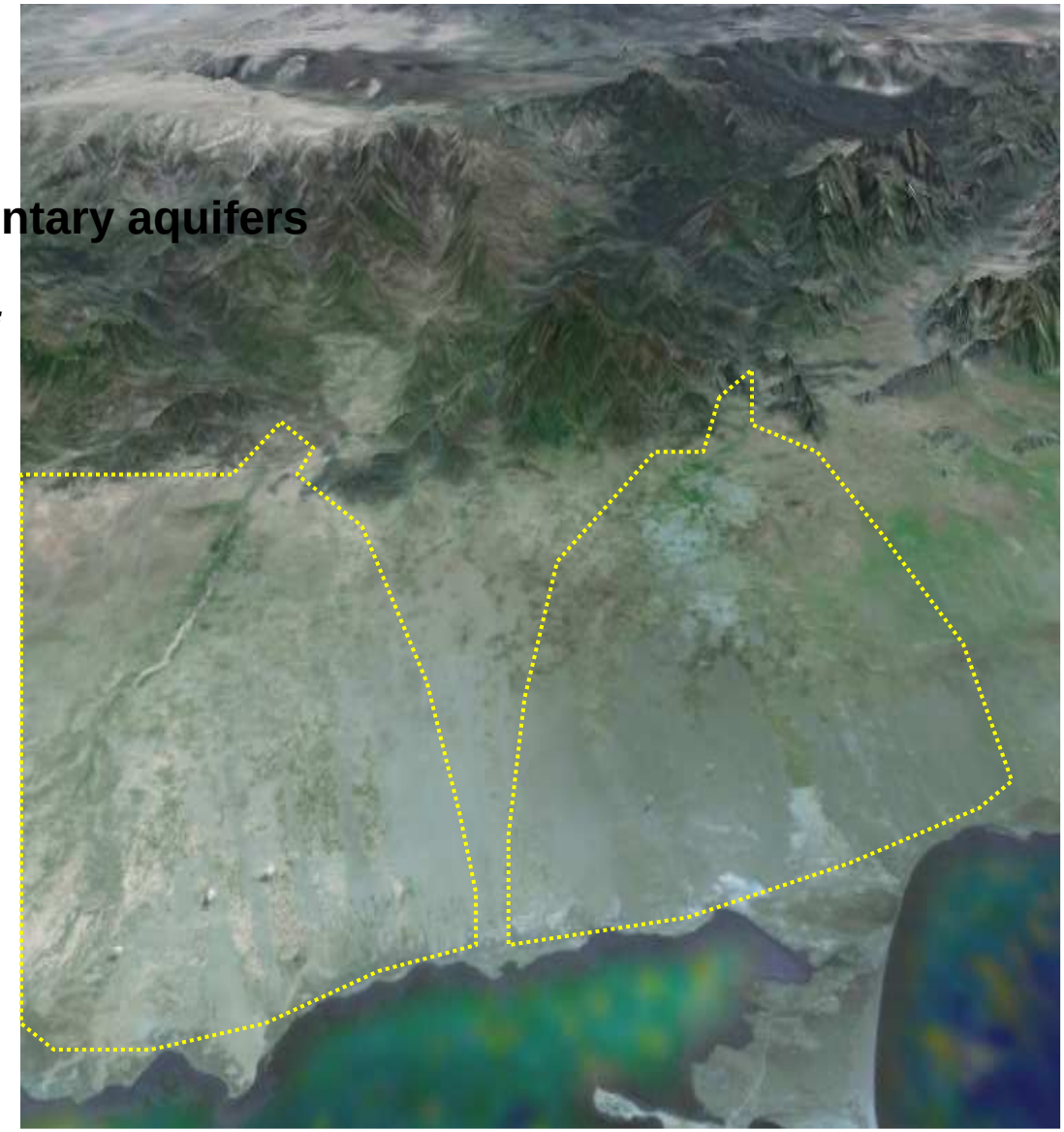
a. Wadi Mawr (Yemen)

b. Wadi Hadhramawt (Yemen)

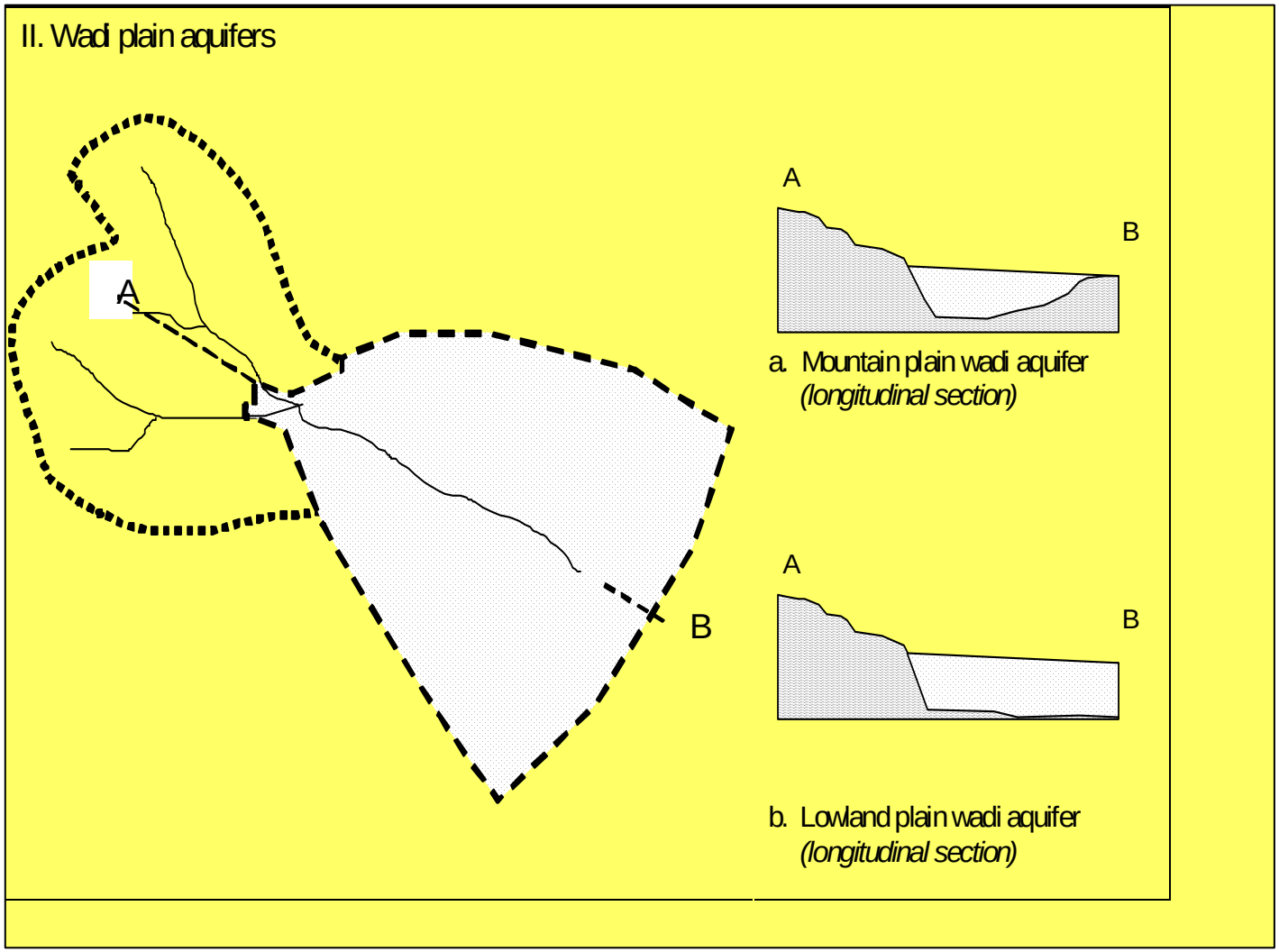
2. Alluvial Wadi Plain (Fans and Delta) aquifers:

Characteristics:

- ***Consist of*** **Quaternary sedimentary aquifers**
- ***Situated at the mouth of wadi***
- ***Recharged by the wadi***
- ***Highly permeable.***



Examples of wadi plain aquifers:



a. Highland Plains (Yemen)

b. Tihama Plain (Y)
Abyan Delta (Y)

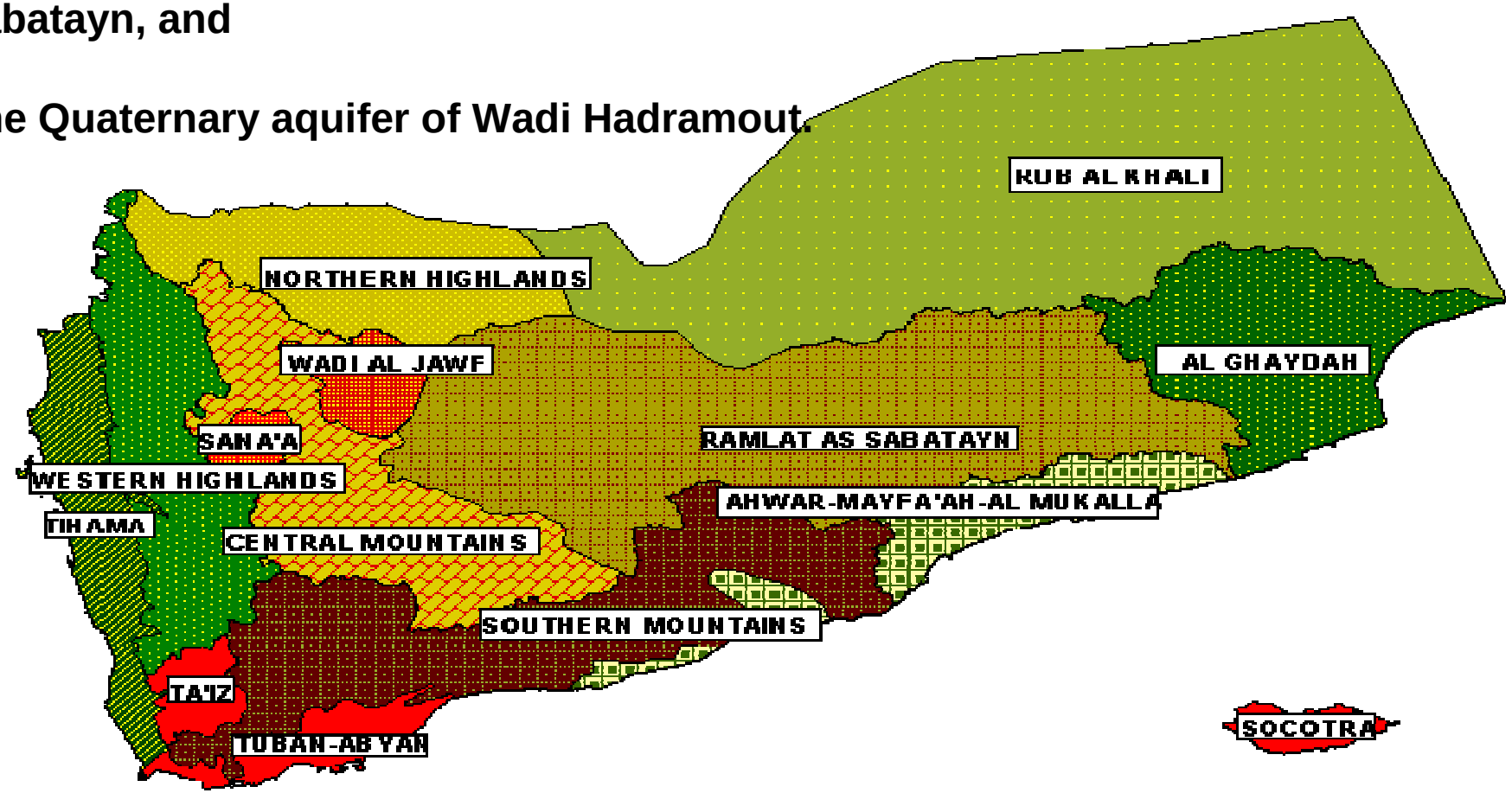
The most important representatives of Wadi Plain aquifers are:

A. The Quaternary aquifer complexes of Tihama plain

B. The Quaternary aquifer of southern coastal plains (Tuban , Abyan, Ahwar & Maif'ah Plain).

C. The Quaternary aquifer at the western and southern edges of Ramlat-as-Sabatayn, and

D. The Quaternary aquifer of Wadi Hadramout.



A. The Quaternary Aquifer System in the Tihama Plain:

- The Tihama coastal plain consists of Tertiary and Quaternary sediment.
- The Tertiary sediments are poorly permeable and containing saline water.
- The Quaternary sediments contain fresh groundwater and extend over more than 400 km along the coast over a width of 30 to 60 km between the escarpment and Red Sea.
- This Quaternary aquifer is recharged by the streams descending from the mountains (Wadis Mawr, Sudud, Siham, Rima, Zabid, rasyan, etc…).

Quaternary Aquifer:

-Thickness: 50 and 250 m.

- Transmissivities: 500 to 3000 m^2/d

- Groundwater flow: from E to W

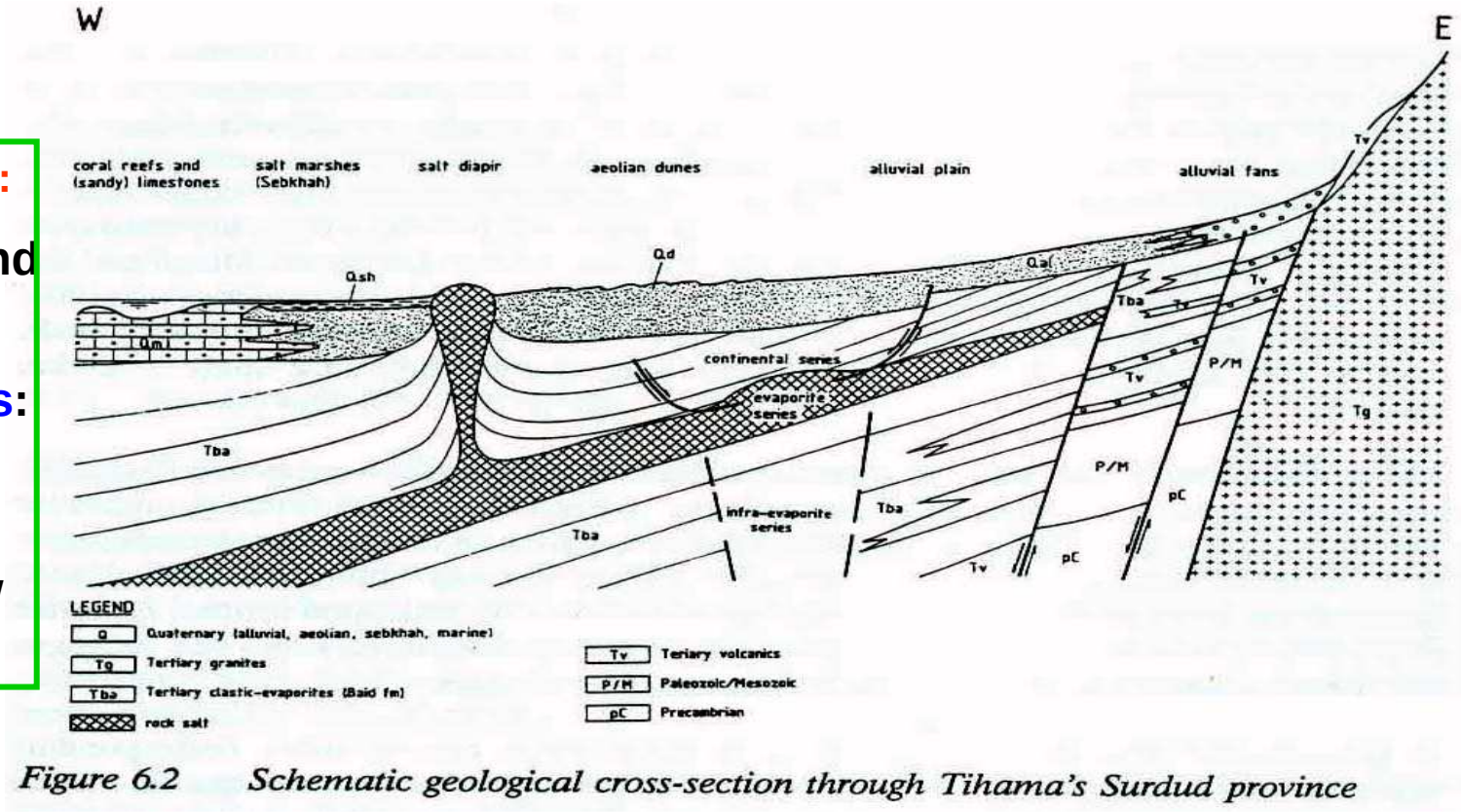
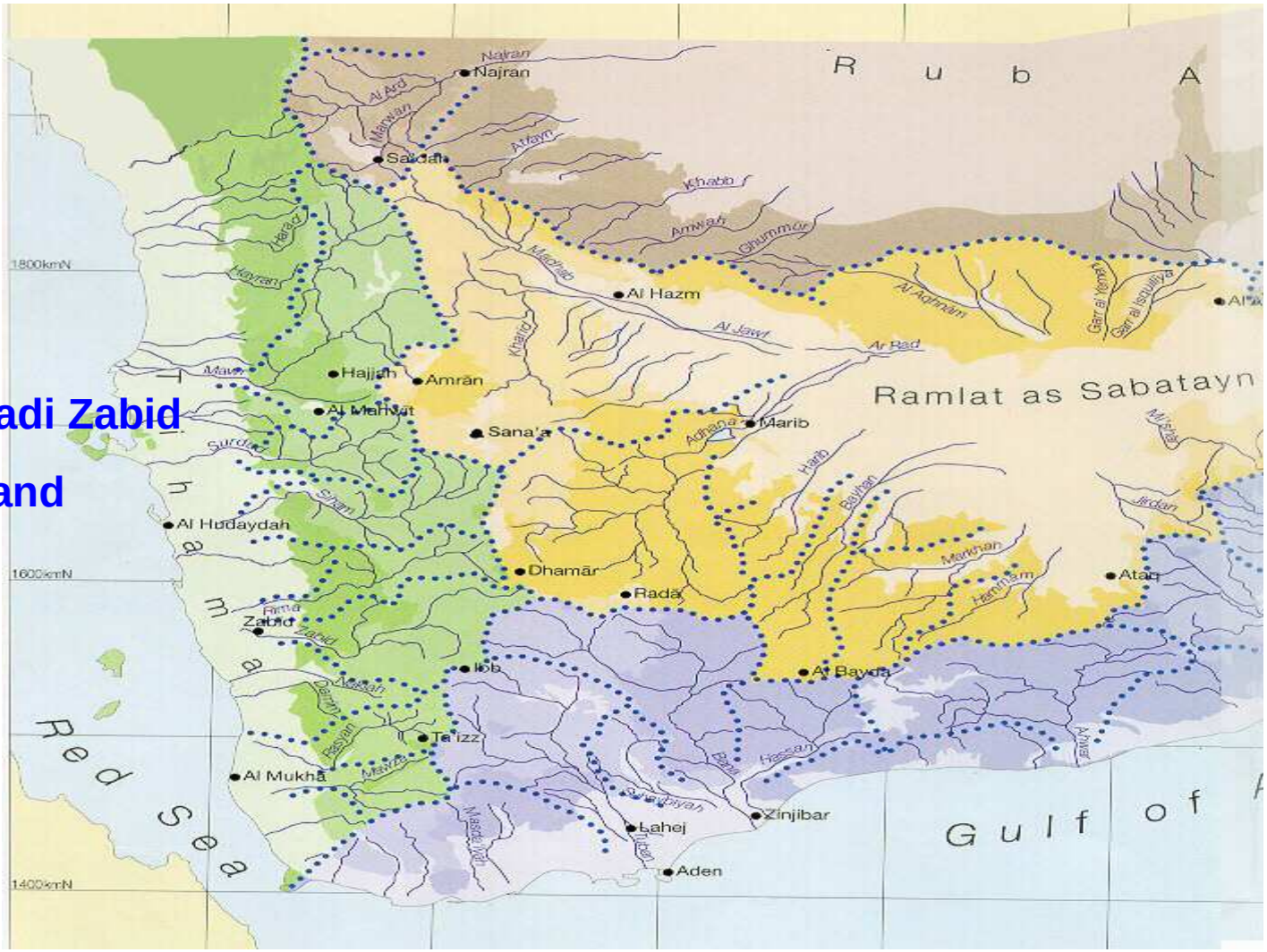


Figure 6.2 Schematic geological cross-section through Tihama's Surdud province

The Tihama Quaternary aquifer system is not a single, laterally homogenous aquifer.

Recent studies on Tihama Quaternary aquifers system subdivided the Tihama aquifer into separate groundwater provinces as follows:

1. **Wadi Harad**
2. **Wadi Hayran**
3. **Wadi Mawr**
4. **Wadi Surdud**
5. **Wadi Siham**
6. **Wadi Rima/ Wadi Zabid**
7. **Wadi Rasyan and**
8. **Wadi Mawza**

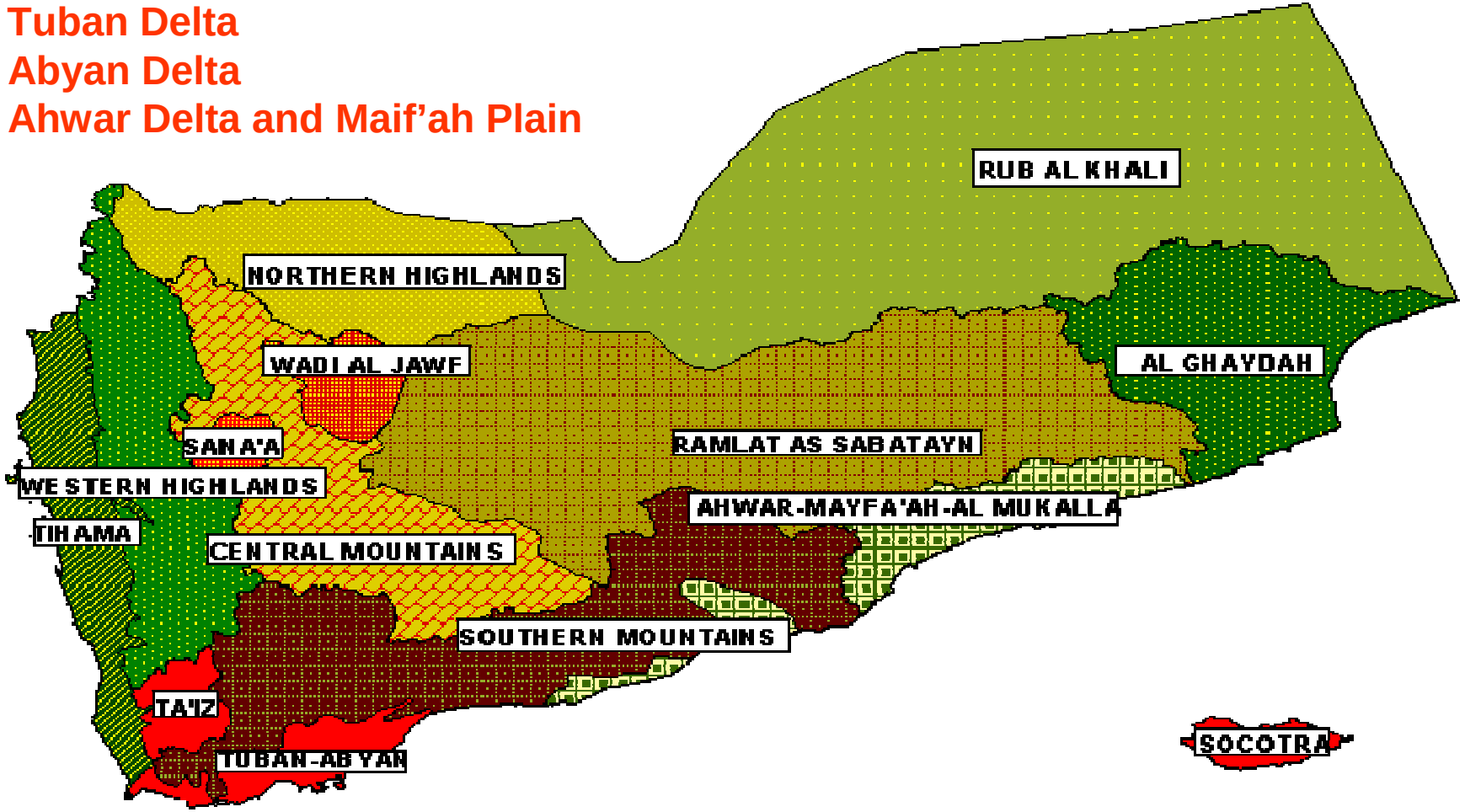


B. The Quaternary Aquifer of the Southern Coastal Plains:

- The southern coastal plains are located in the Gulf of Aden rift.
- They show similarity to the Tihama, but the thickness is less.

- A number of independent flow domains from west to east are:

1. Tuban Delta
2. Abyan Delta
3. Ahwar Delta and Maif'ah Plain



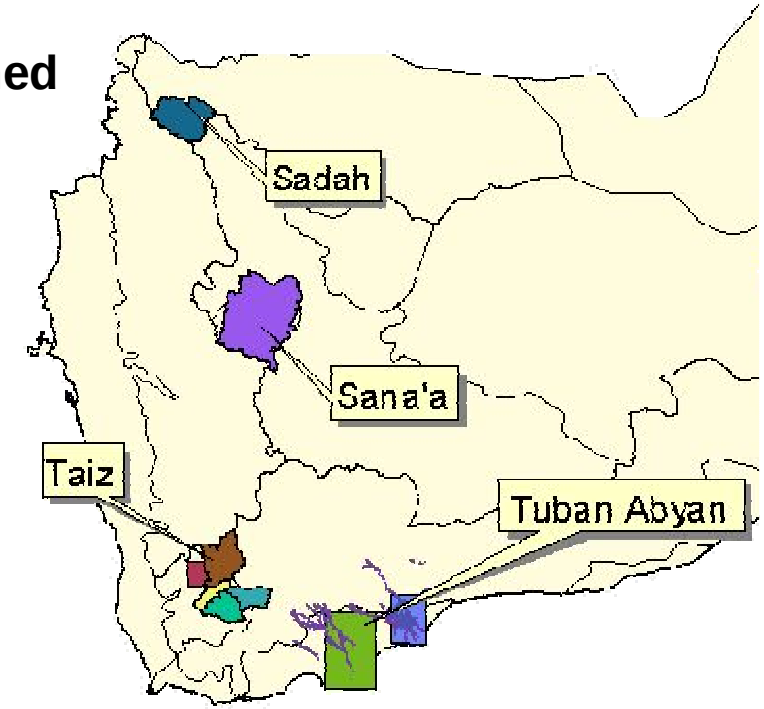
1. The Aquifer system of Tuban Delta:

- **The thickness may increase from 30 m to some 120-170 m,**
- **No highly transmissive zones are observed at depths below 90 m.**

- **Aquifer depths increase in the lower Delta, at least to 200 m**

- **The aquifer type change from Unconfined to semi confined conditions near the coast.**

- **Groundwater is known to be brackish in the coastal fringes.**



2. The Aquifer system of Abyan Delta:

- **Two major wadis dissect and recharge Abyan Delta:**

  Wadi Bana and Wadi Hassan

- **The maximum thickness:**

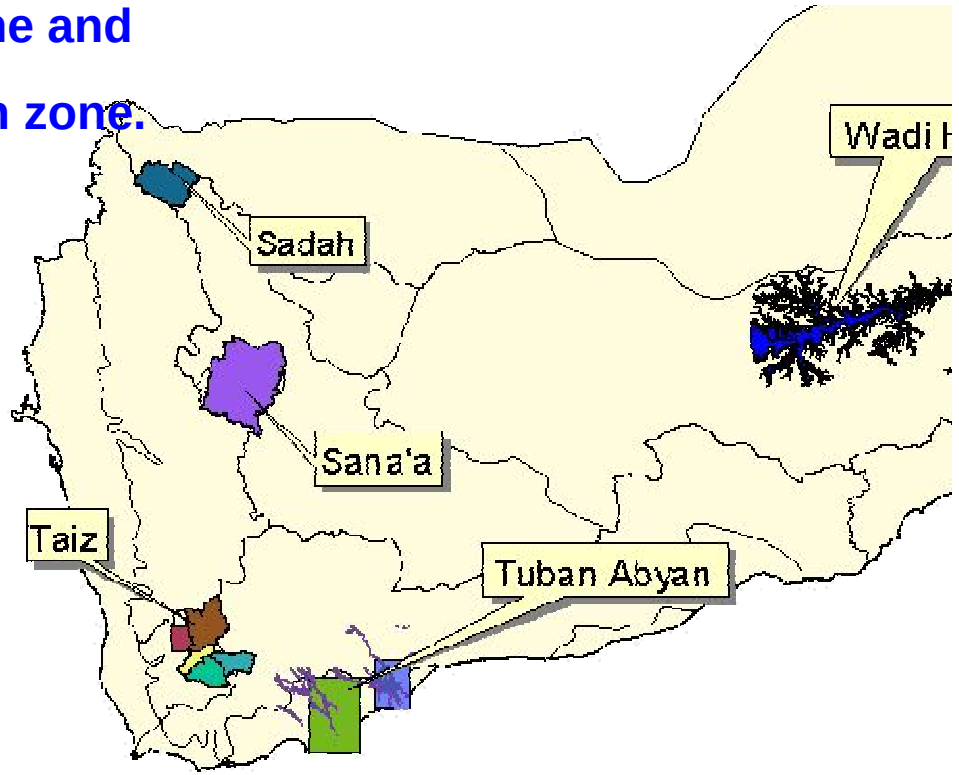
  100 m in southern zone,

  some 50-60 m in the central zone and

  more than 100 m in the northern zone.

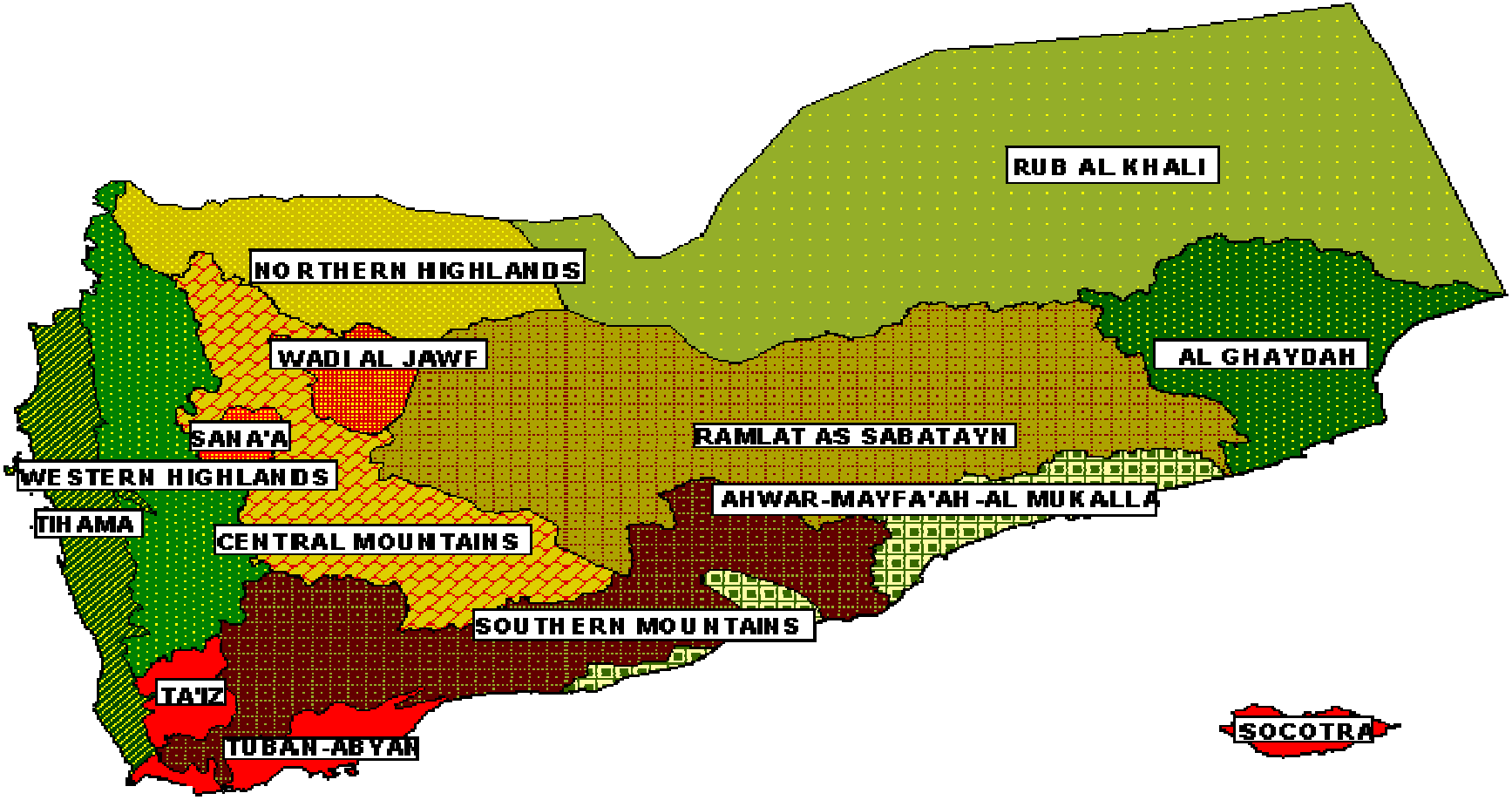
- **Transmissivities vary:**

  from 300 to 10000 m^2/day.



3. The Quaternary Delta of Wadi Ahwar:

- It is smaller than the Tuban and Abyan Deltas
- It is made up of Quaternary alluvial and marine deposits
- Maximum thickness: 50 m
- Depth of water: vary from 2 m near the sea to some 20 m further inland (1995).

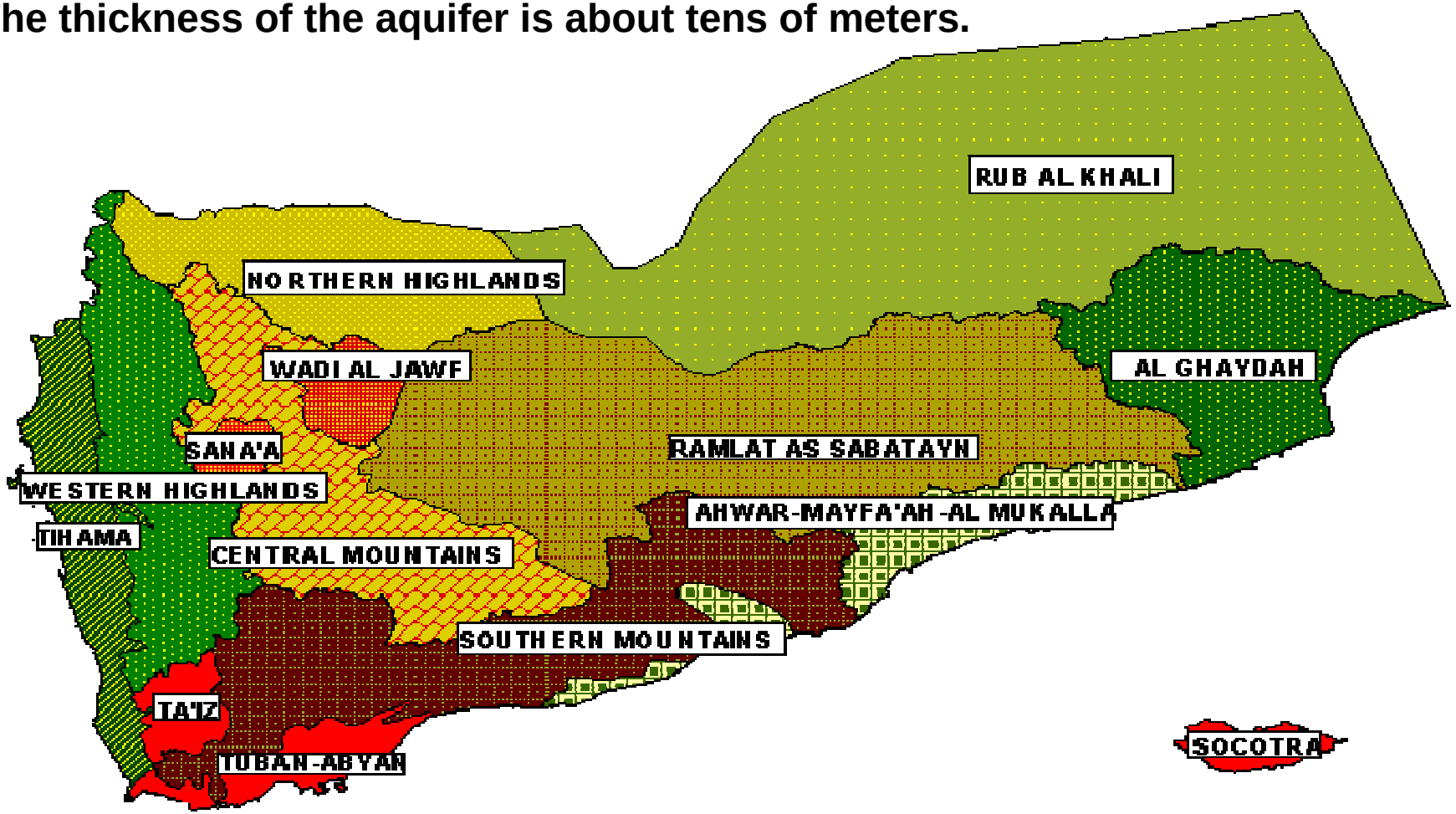


4. The Quaternary aquifer of Wadi Maifa’ah:

- **It opens to a vast plain which slopes gently down towards the sea from an absolute height of 700 m.**

-**The aquifer consists of Quaternary series of gravel-pebble material, unsorted sands and loams.**

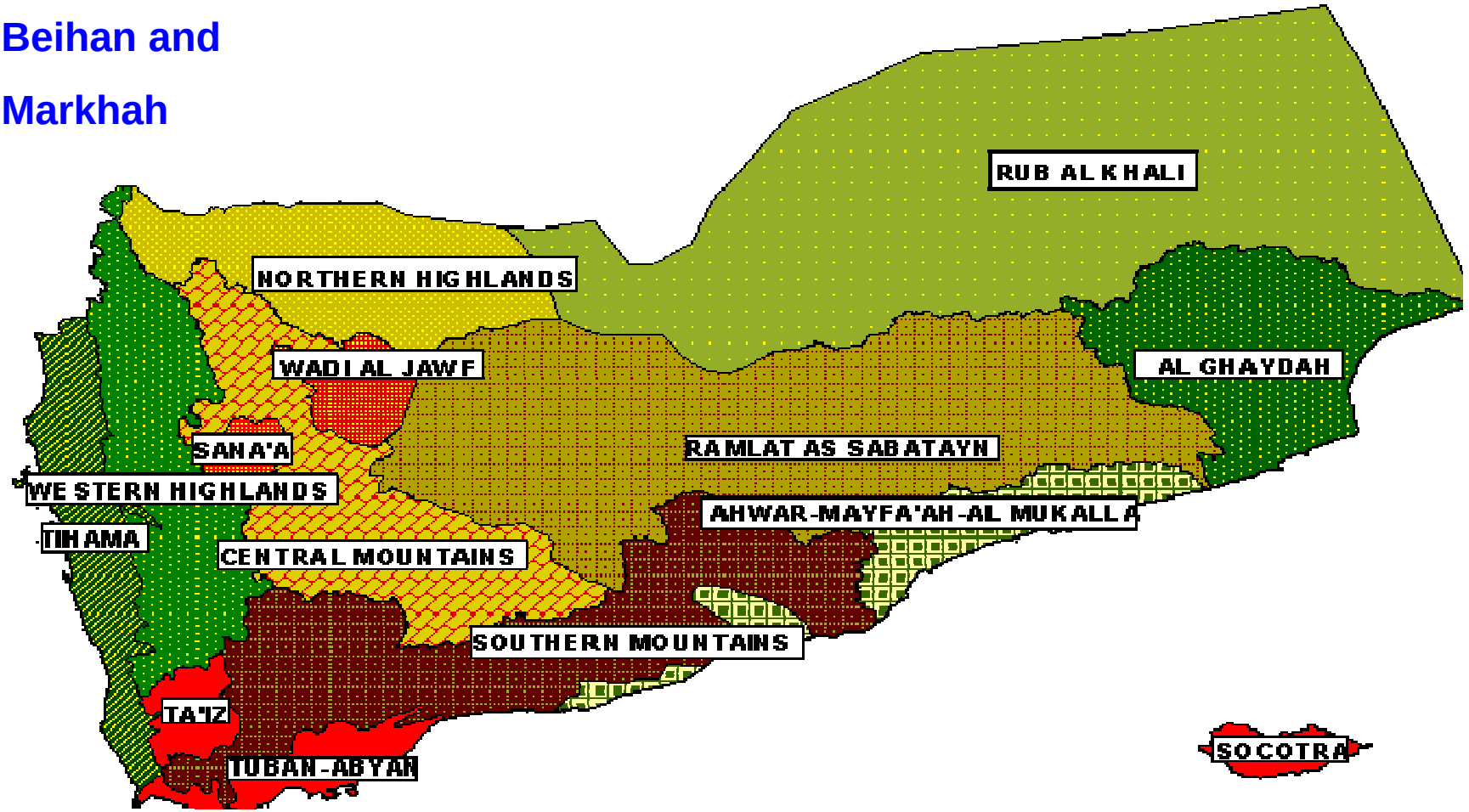
- The thickness of the aquifer is about tens of meters.



C. Quaternary aquifers at western and southern margins of the Ramlat-as-sabatayn:

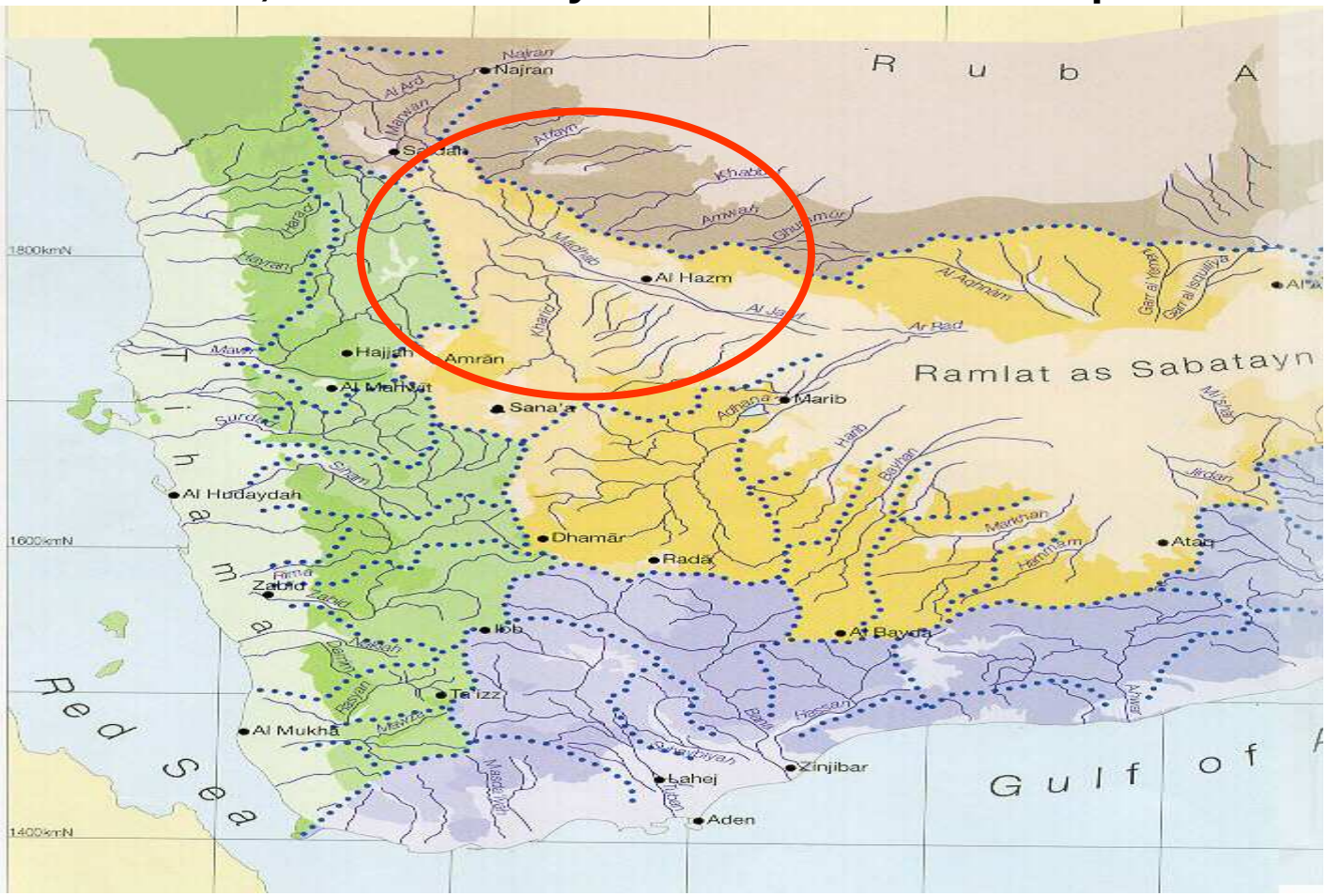
The largest wadi systems running from the Yemen mountain massif towards the Ramlat-as-sabatayn are:

1. **Wadi Al-Jawf**
2. **Wadi Adhana**
3. **Wadi Beihan and**
4. **Wadi Markhah**



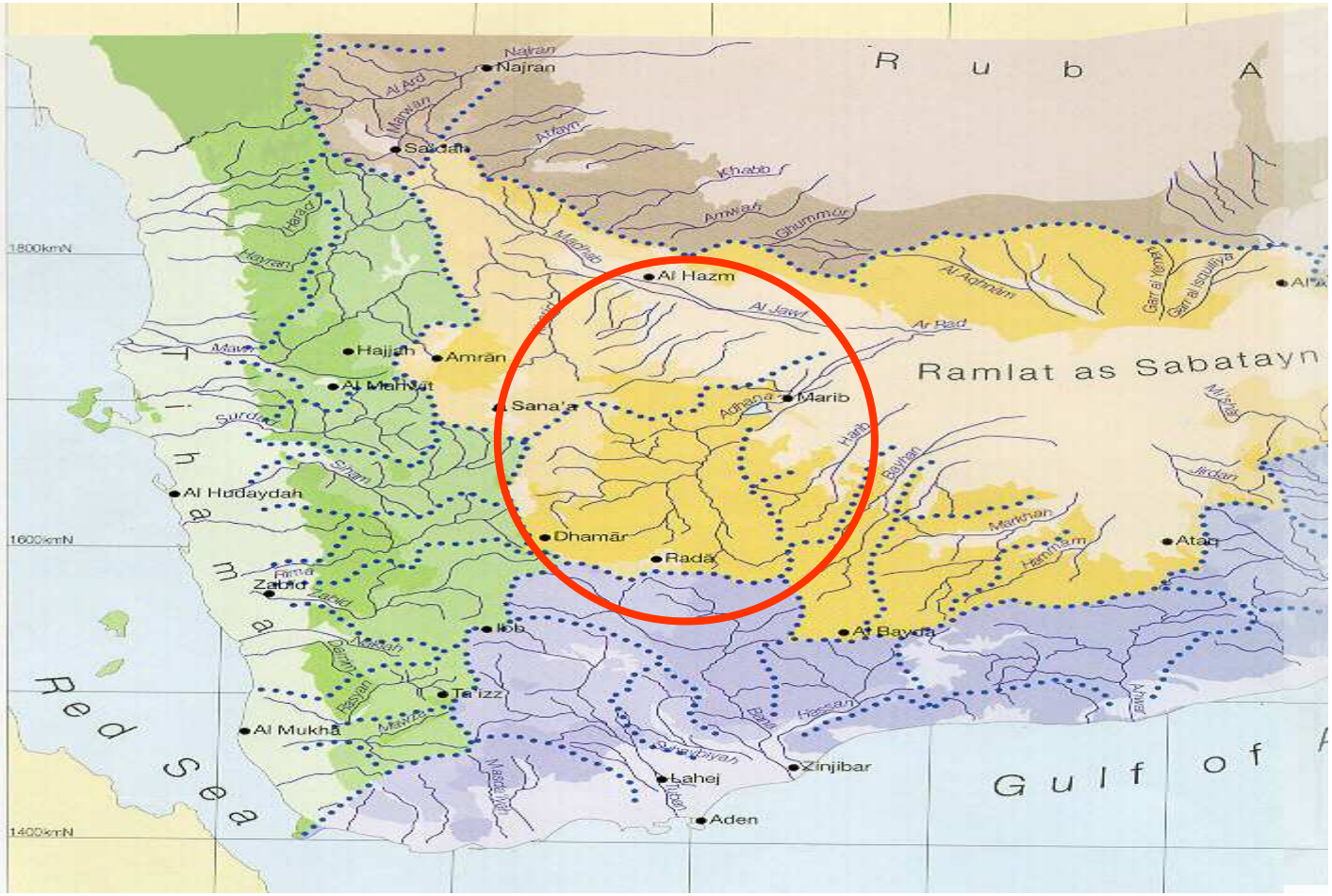
1. Wadi Al-Jawf Quaternary Alluvial Aquifer:

- It consists of Quaternary alluvial and eolian deposits,
- It has a limited thickness of 50 – 70 m in the western part, but only 10 – 20 m in the Al-Hazm area.
- It has relativly poor water quality (EC more than 2000 micromho/cm).
- At the western zone, it underlain by Amran limestone Group.



2. Wadi Adhana Quaternary Alluvial Aquifer:

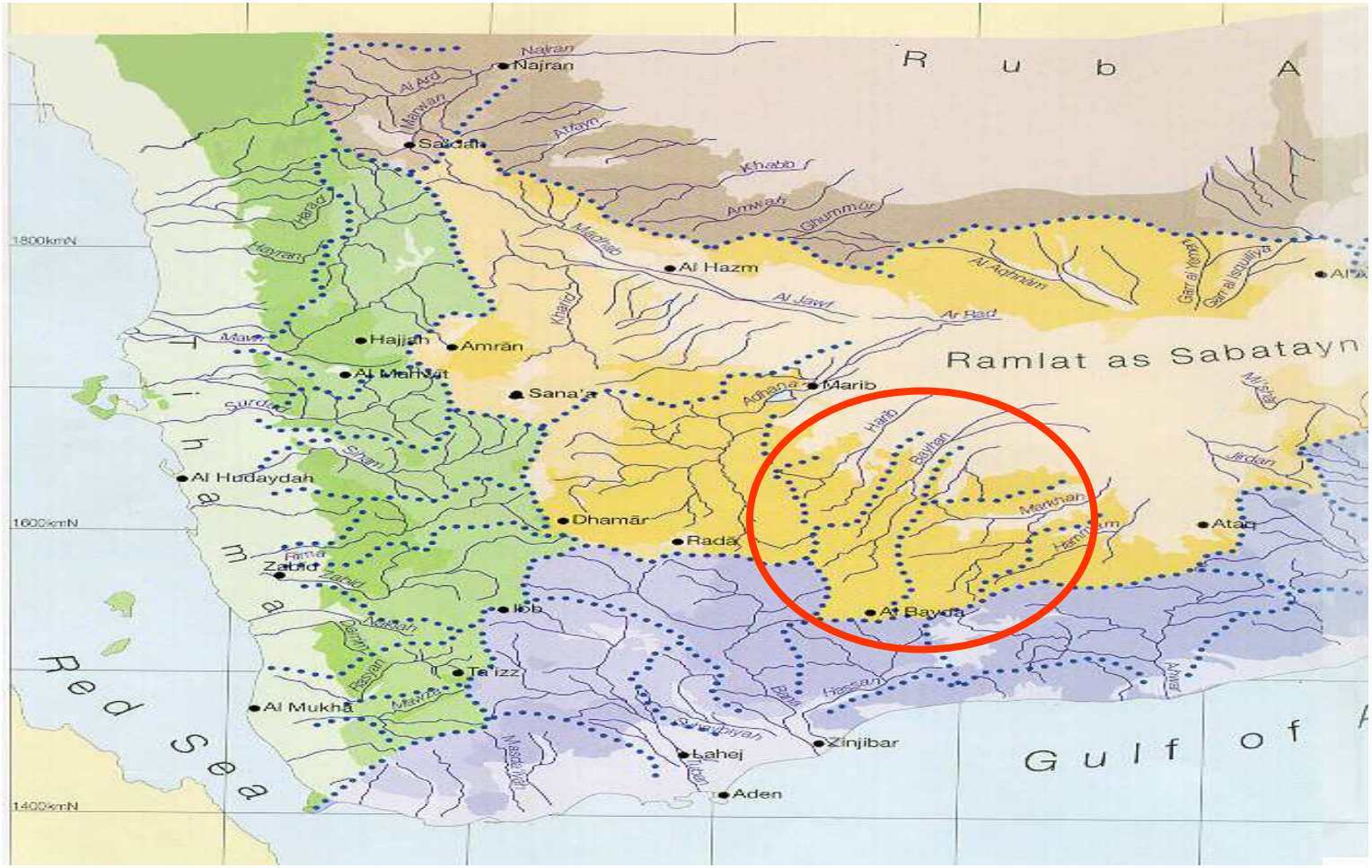
- **It covers marib plain and having a thickness of 50-70 m.**
- **It has a high transmissivity**
- **The main groundwater flow coincides with that of wadi, which is north-east.**
- **The recharge process has been altered by the construction of dam in the Wadi Adhana in 1986.**



3. Wadi Markhah and Wadi Beihan Quaternary Alluvial Aquifer:

• These Quaternary aquifers shows similarities with other systems, but the groundwater systems are less productive due to:

1. Smaller catchment
2. Dry climatic conditions



D. Quaternary Alluvial Aquifer of Wadi Hadramawt:

Wadi Hadramawt is located in a canyon cut into the carbonate rocks of the Hadramawt Group.

- **The vertical sides of the canyon rise to some 300 m above the top of the Quaternary deposits.**
- **The aquifer has approx. 90 km long, from 1.5 to 20 km wide and locally more than 100 m thick.**
- **It has high transmissivities and good sources of recharge**
- **Various large tributaries quickly brings floods from around 22500 km^2 of limestone plateaus to Wadi Hadramawt canyon**

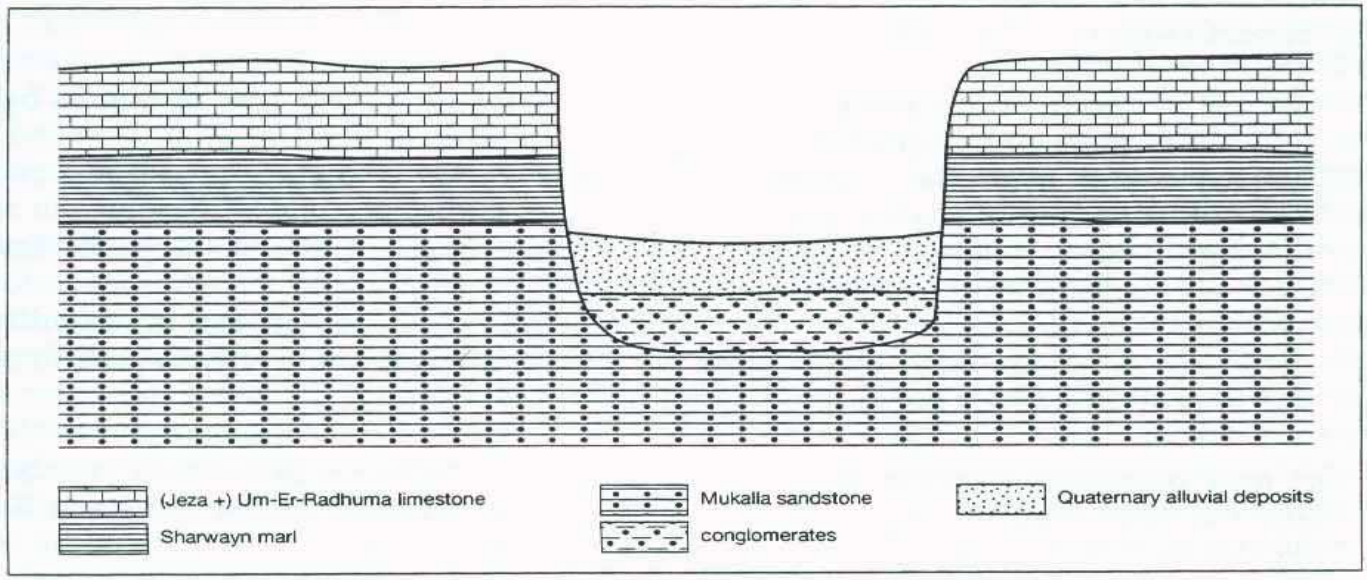


Figure 6.4 Schematic geological cross-section through Wadi Hadramawt

2. Groundwater basins of the Highland Plains:

The most important highland groundwater basin are from north to south:

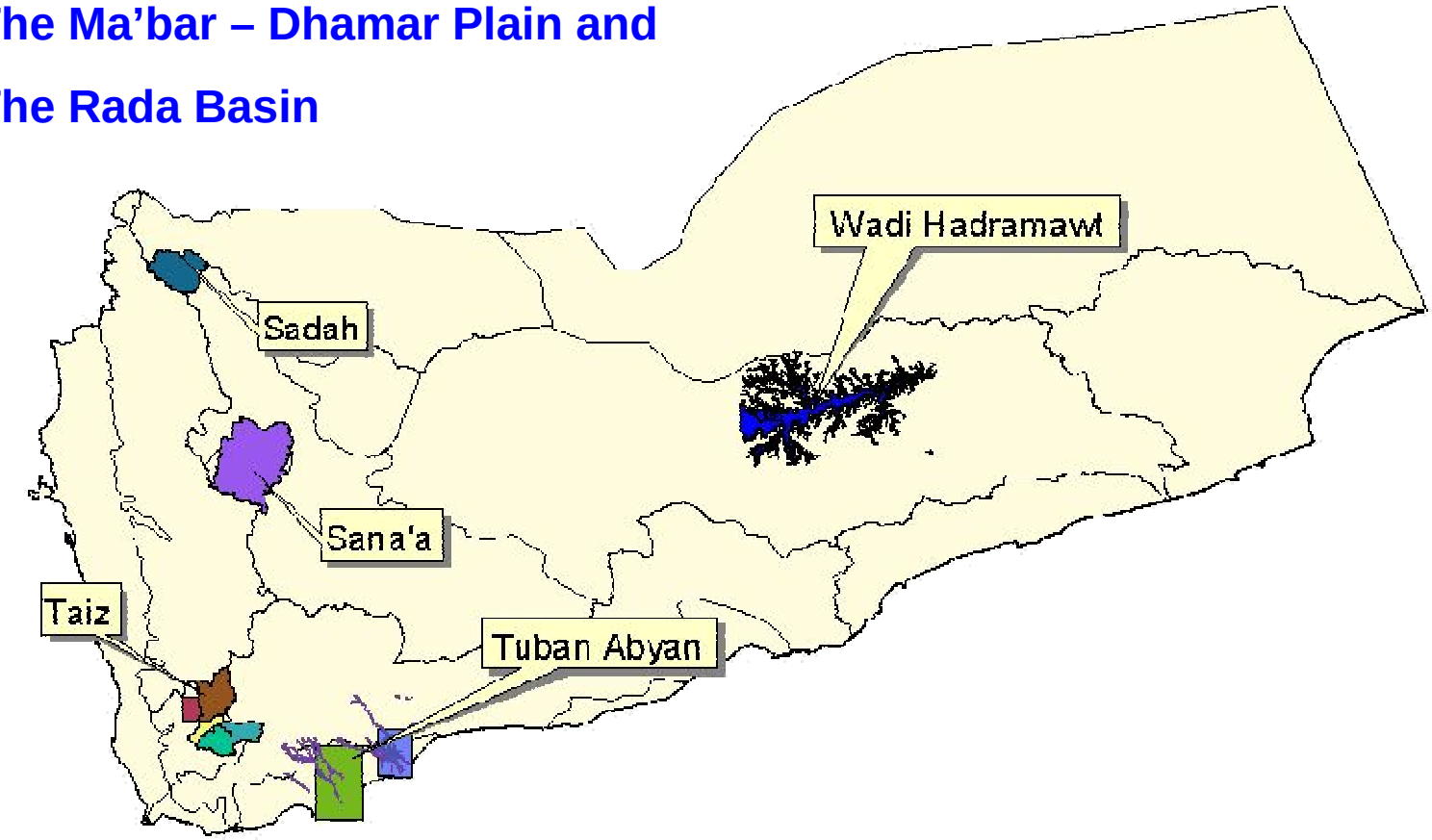
A. The Sadah Basin

B. The Amran Basin

C. The Sana'a Basin

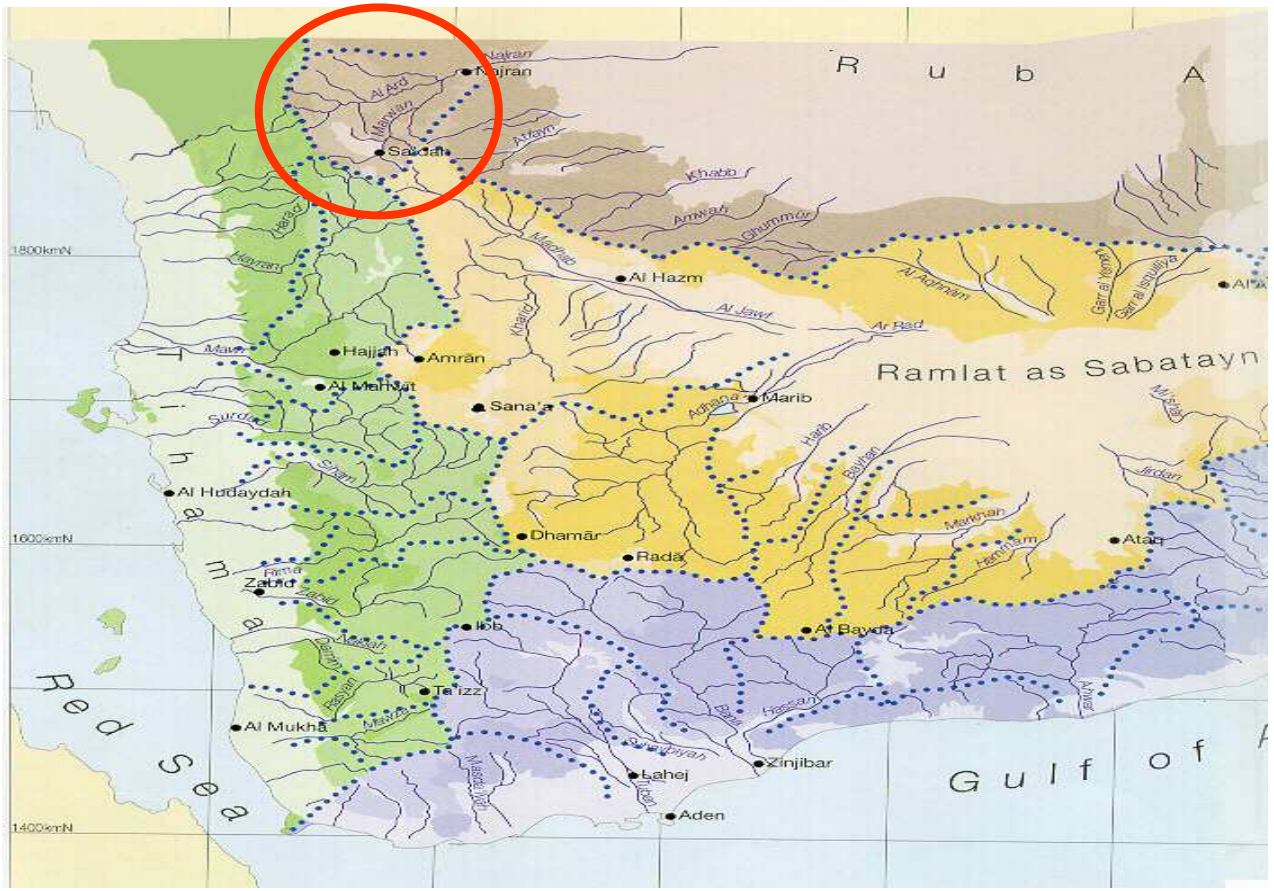
D. The Ma'bar – Dhamar Plain and

E. The Rada Basin



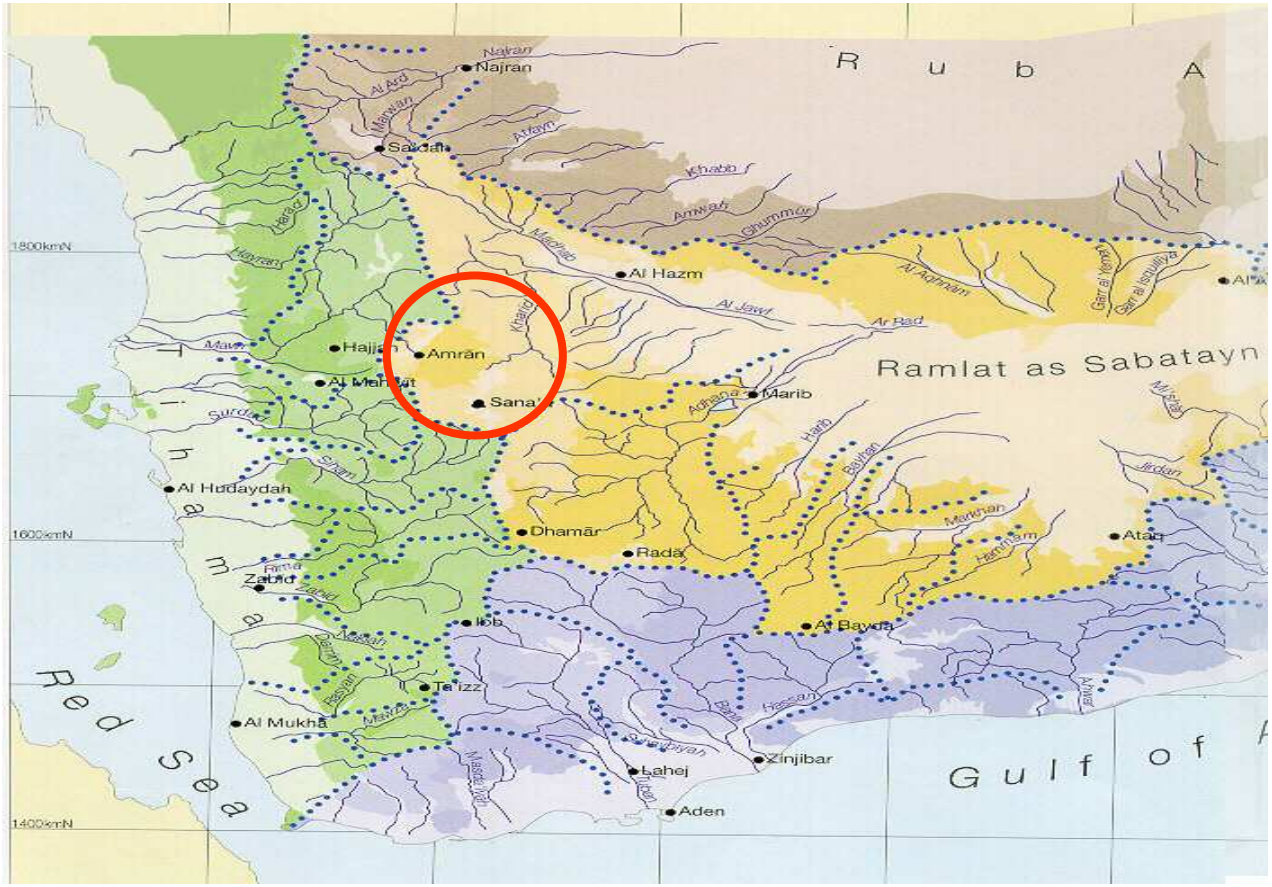
A. The Sadah Basin

- **It is defined by the Sadah graben, a strongly down faulted block.**
- **Wajid Sandstones occur under a 30-60 m thick cover of unconsolidated Quaternary deposits.**
- **It has a thickness between 300 – 600 m.**
- **The Wajid sandstone has low porosity and hydraulic conductivities**



B. The Amran Basin

- **It is filled with Quaternary alluvial deposits with intercalations of Quaternary basalts .**
- **Transmisivities of the aquifer range from 75 to 860 m^2/day.**
- **Groundwater pumping in the Amran basin is intensive.**
- **The Wajid sandstone has low porosity and hydraulic conductivities**



C. The Sana'a Basin

- It characterized by a complex groundwater system.
- Several major studies carried out during the last 20 years including:

1. Italconsult, 1972
2. Mosgiprovodkhoz, 1986;
3. SAWAS Project, ……..
3. Bloemendaal et al, 1994
4. TS-HWC, 1992
5. WEC, 2002

But still imperfectly known.

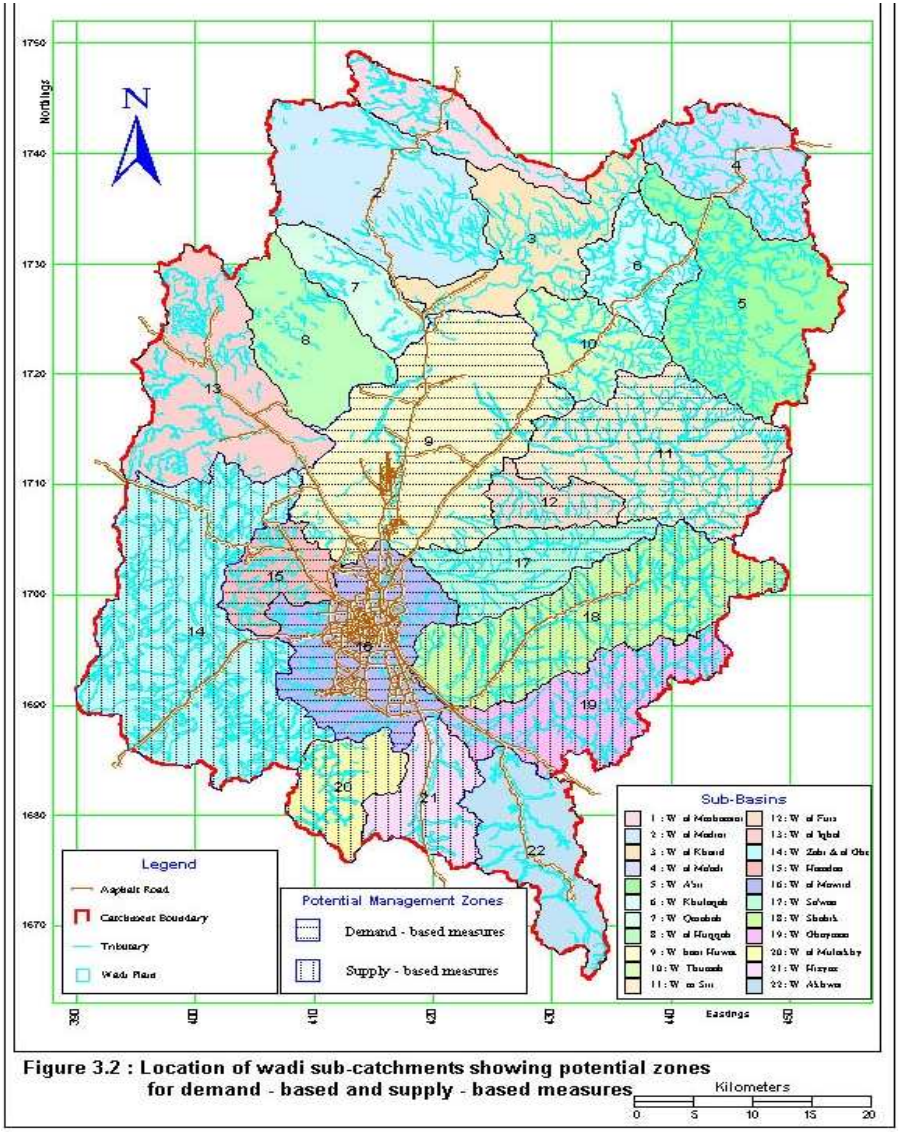


Figure 3.2 : Location of wadi sub-catchments showing potential zones for demand - based and supply - based measures

The following Fig. gives an impression of the geology of Sana'a Basin

The most important groundwater aquifers in Sana'a Basin are:

- ***Quaternary alluvial aquifer***
- ***Tertiary Yemen Volcanic***
- ***Tawilah Sandstones and***
- ***perhaps Kohlan sandstones***

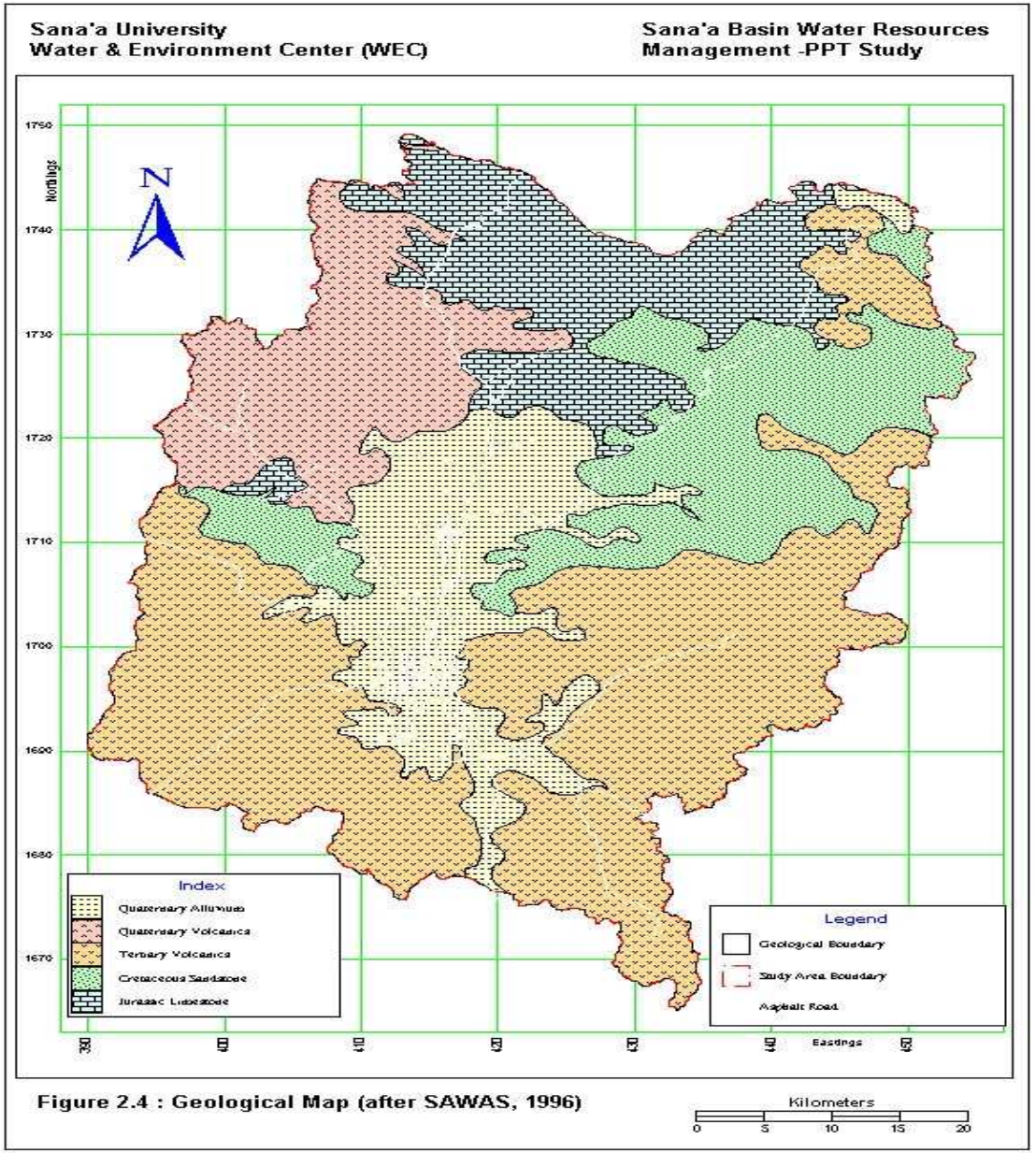


Figure 2.4 : Geological Map (after SAWAS, 1996)

1. Quaternary alluvial aquifer:

- **Alluvial deposits used to be an important source in groundwater in the past.**

- **Serious declines of groundwater tables have reduced their role.**

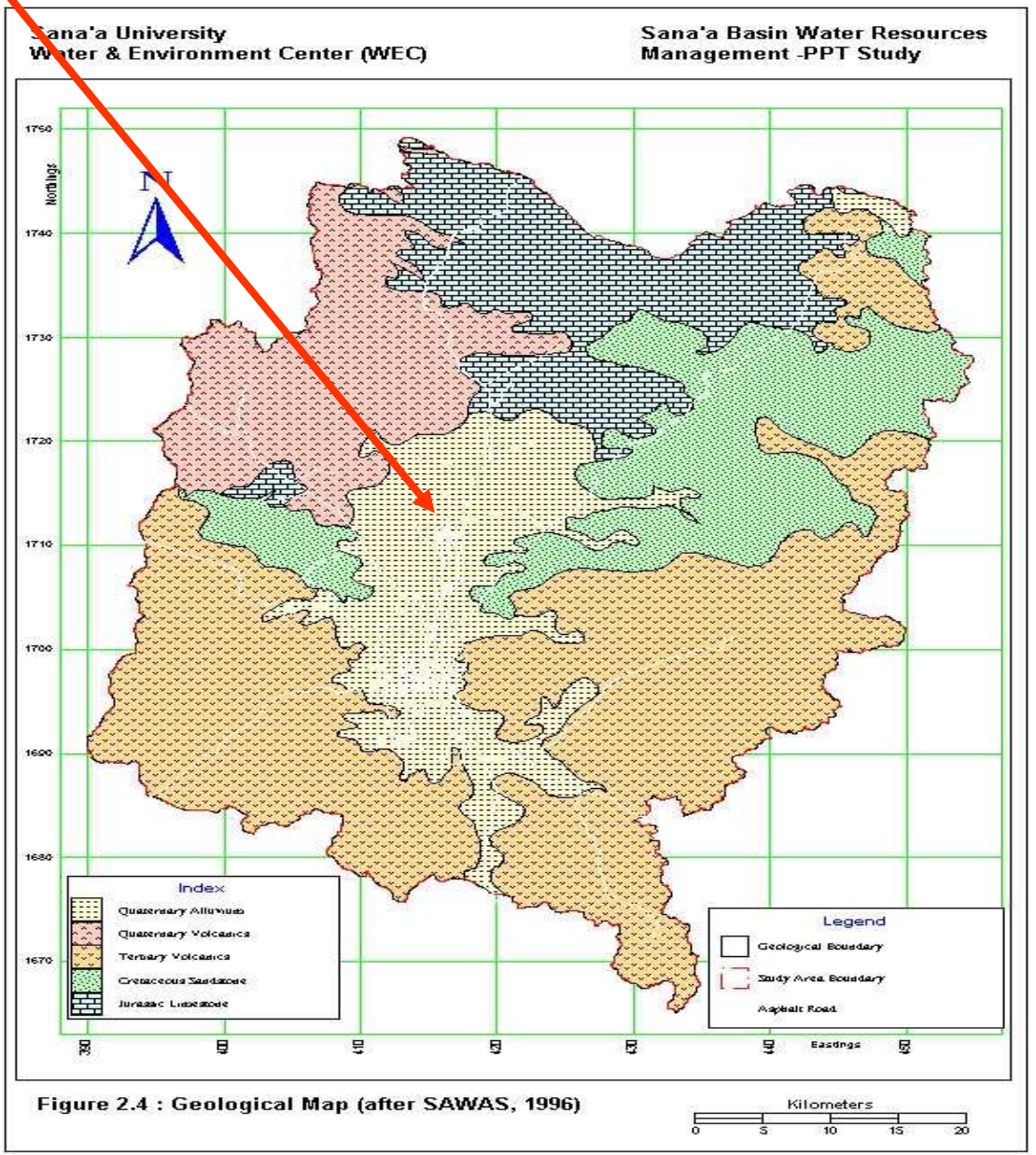


Figure 2.4 : Geological Map (after SAWAS, 1996)

2. Tawilah Sandstones:

- The Tawilah sandstones have become the most important aquifer since they were explored in the early 1970s.
- The sandstones are absent in the northern part of the Sana'a basin, probably partly due to erosion.
- south of Sana'a the Tawilah sandstones dip under a complex of Tertiary volcanic rocks and alluvial sediments.
- Productive wells have been drilled in the Tawilah Sandstone in the southern zones of the urban area
- Further south, the volcanic/alluvial complex is the only significant aquifer known.
- Recent studies indicate that:
    - More than 13000 well were drilled in Sana'a basin,
    - Abstraction exceeds recharge by 400%.

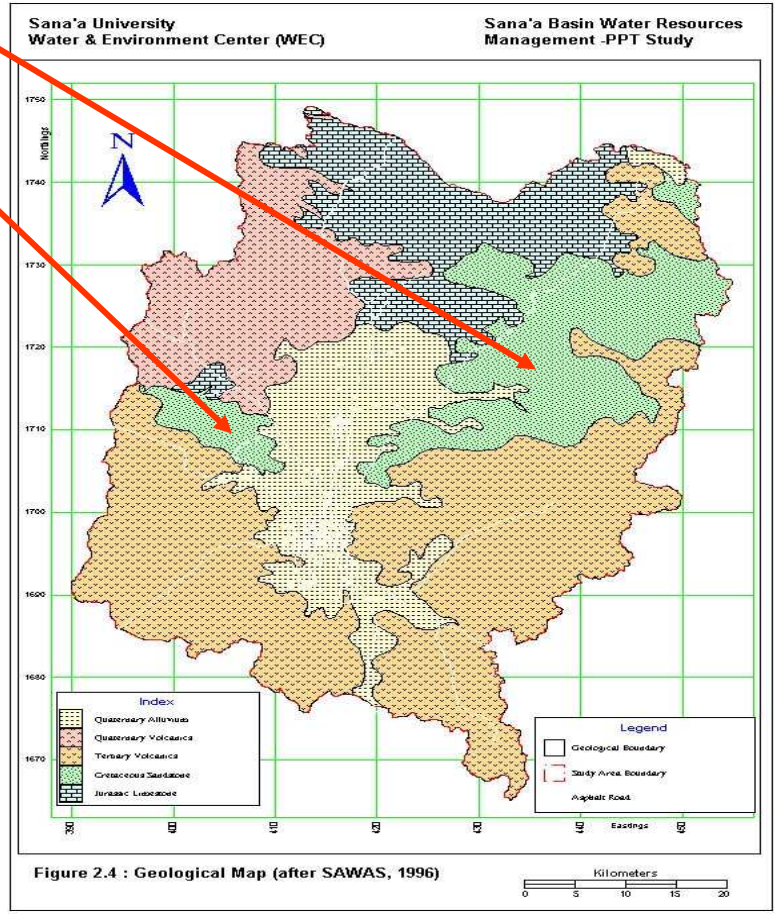


Figure 2.4 : Geological Map (after SAWAS, 1996)

D. The Ma’bar – Dhamar – Kitab Plains

- They consist of a number of larger and smaller plains.
- Some of them such as Qa Jahran are filled to great depths (more than 100 m) with alluvial deposits, which constitute the main aquifer system.
- In these plains, due to tectonic features, the volcanic rocks form a highly productive and permeable aquifer.

E. The Rada Basin

- The Fractured Tawilah sandstones represent the main aquifer in Rada Basin.
- The Quaternary alluvial deposits in Rada Basin forms a locally shallow aquifer.
- The volcanic rocks forms a less important groundwater systems.
- All these groundwater system are interconnected.
- Groundwater is intensively abstracted in Rada Basin leading to significant declines of the groundwater levels.

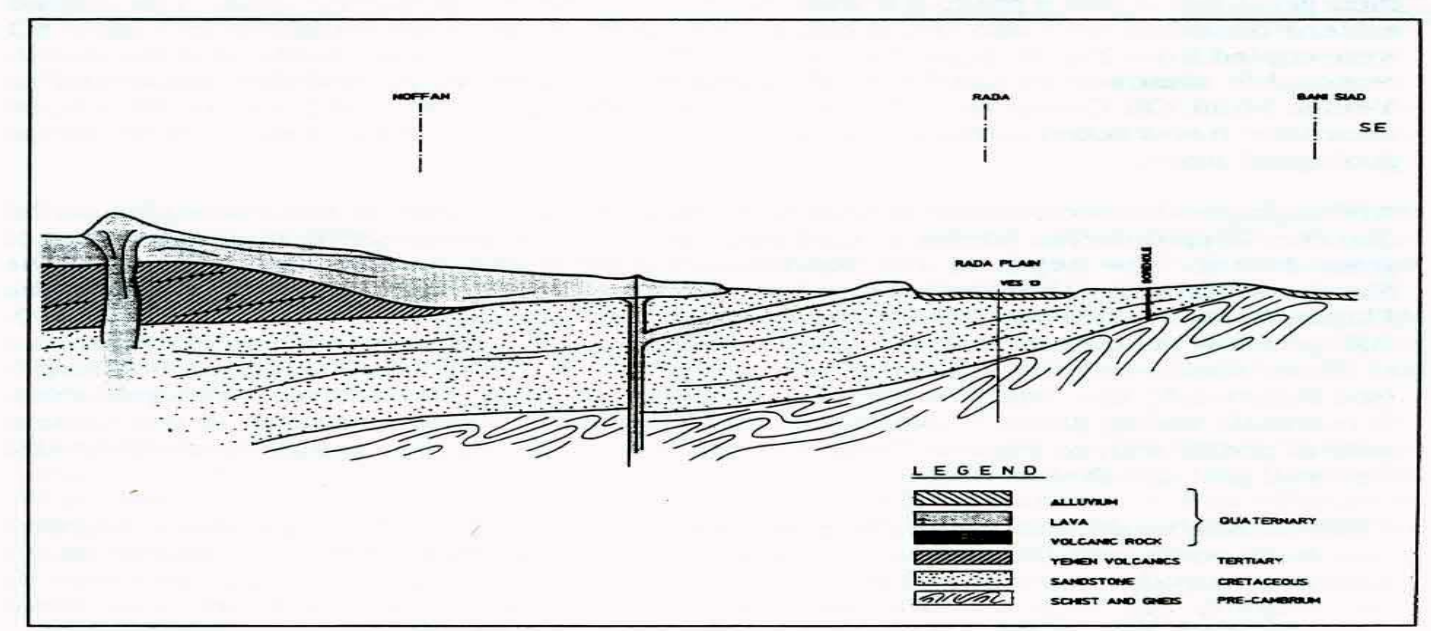


Figure 6.7 NW-SE cross-section through the Rada area (ILACO, 1990a)

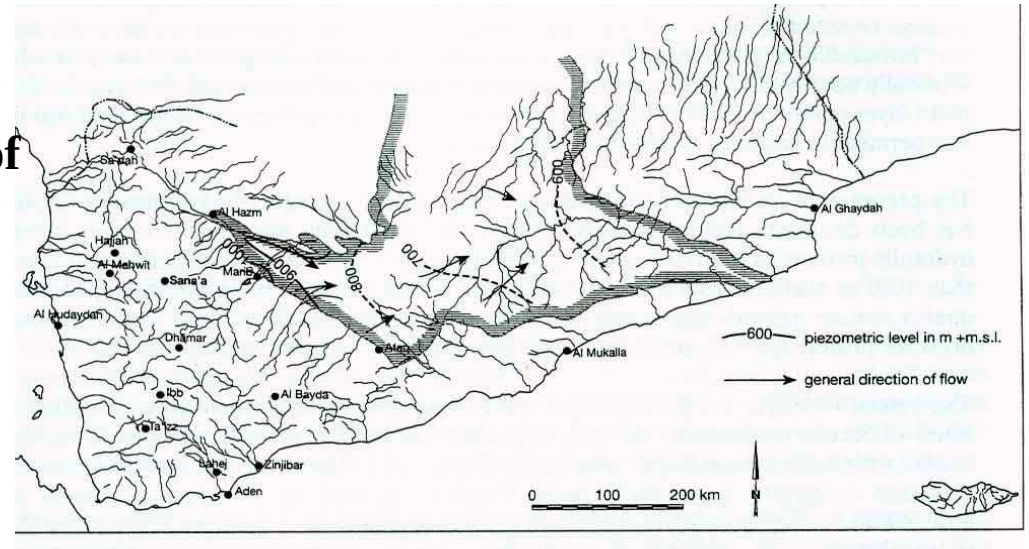
The Regional Mukalla Sandstone Aquifer

- **Location:** East of the Arabian Shield

  North of Al-Ghaydah Basin and Gulf of Aden rift zone

- It forms a continuous regional aquifer of large lateral extent

- It constitute the largest groundwater system in Yemen.



- It is equivalent to Tawilah group that presents in the West

- **Lithology:** Sandstone

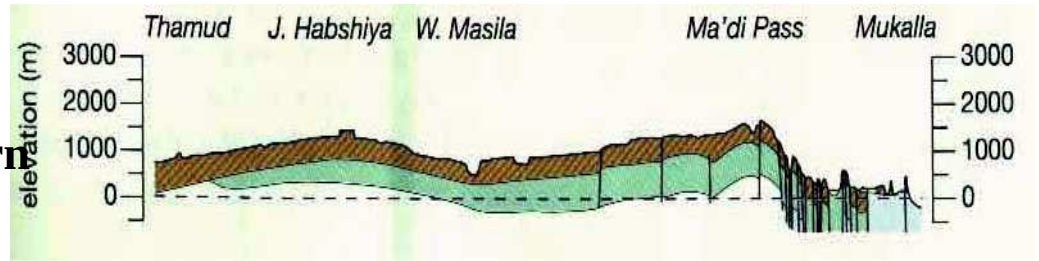
- **Thickness:** 300-400 m, Max.thickness(1000 m) in Shabwa area.

- In the western part (Ramlat-as-Sabatayn) it rests upon Jurassic sediments, containing saline groundwater.

- I has higher porosity (up to 25 %)

- I has high transmissivites (3000 to 3500 m^2/day).

- It recharged from Wadis in the Western and Central parts



Other Regionally Extensive Aquifers:

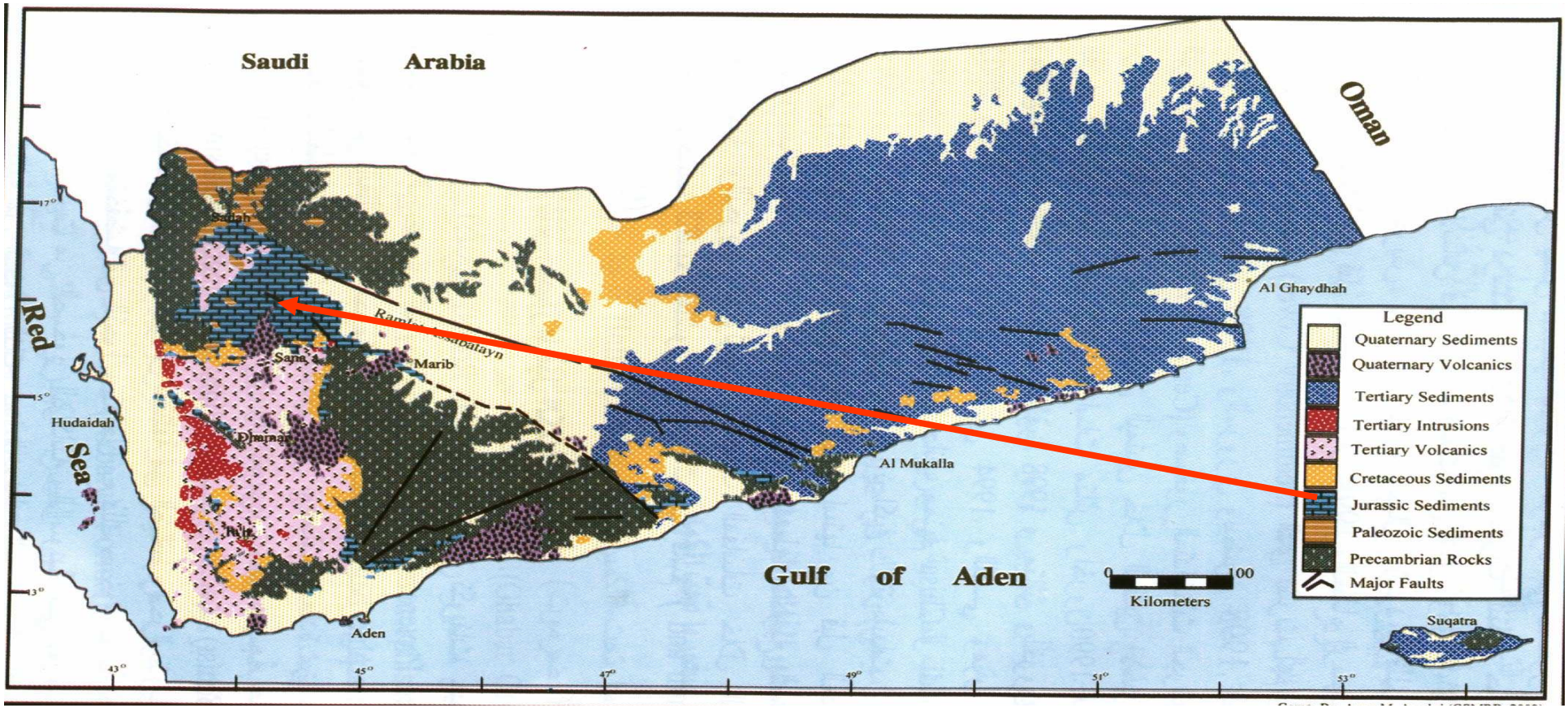
1. Amran Limestone Aquifer

2. Yemen Volcanics Aquifer

3. Um-Er-Radhumma Aquifer

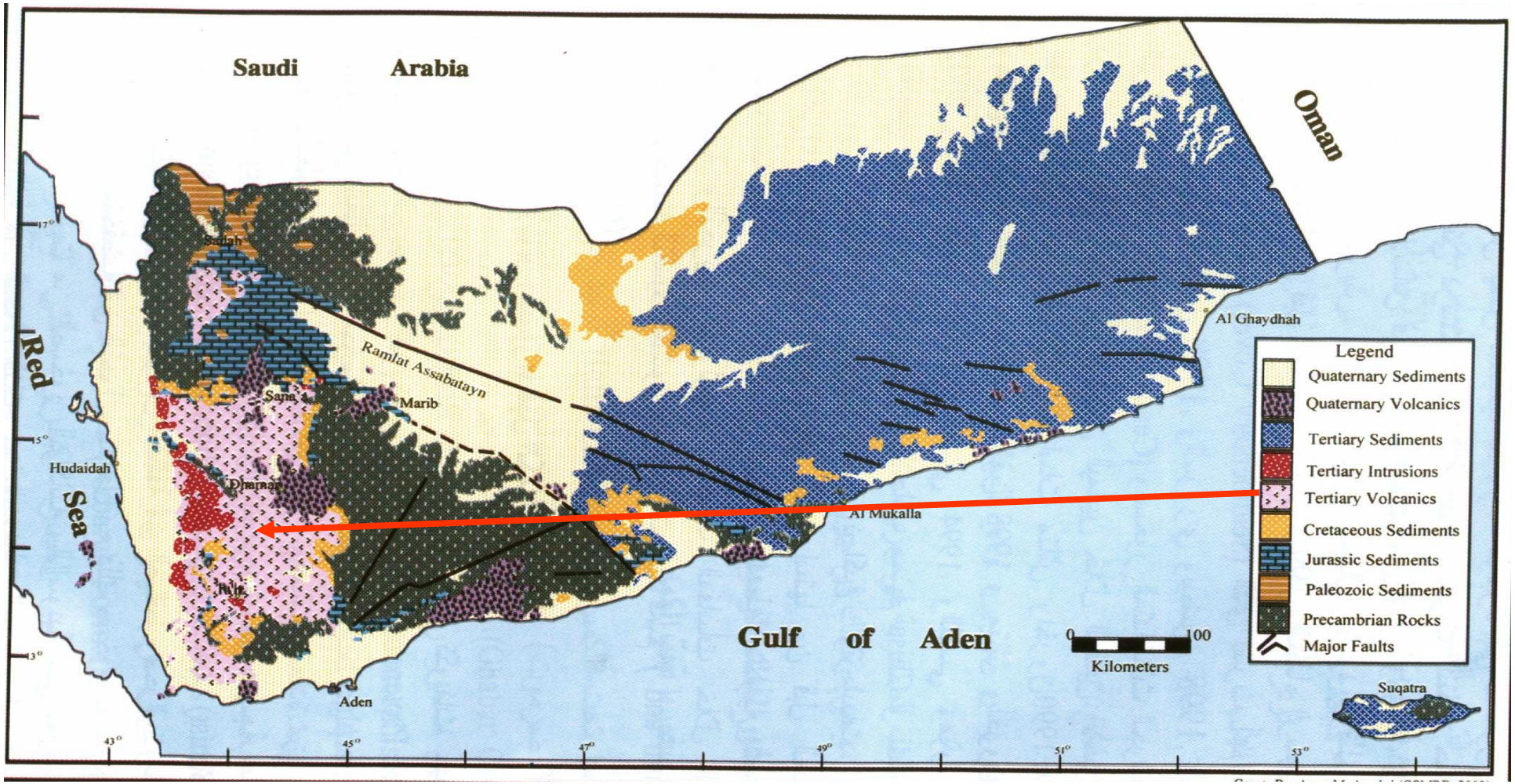
1. Amran Limestone Aquifer

- It forms an extensive and thick outcrop between Sana'a and Sadah.
- In this aquifer groundwater predominantly flows through fissures
- The hydraulic properties of this aquifer are generally not favorable for groundwater development
- The productive wells are observed locally especially near the Wadis.



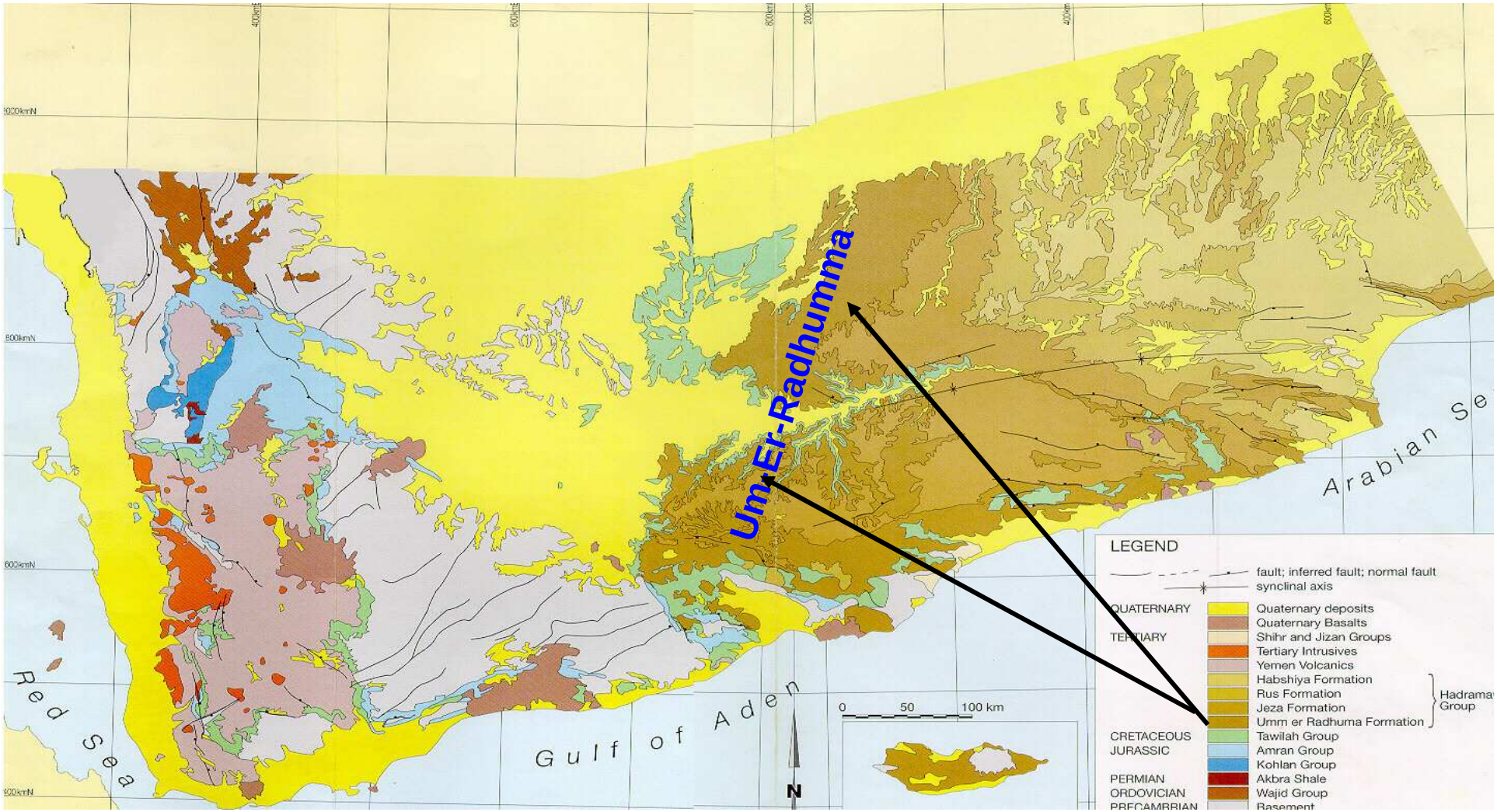
2. Yemen Volcanic Aquifer

- It present predominantly south of Sana'a and between Hajjah and Sadah.
- It forms a poor, fissured regional aquifer system except in the Central Higher Plains Area where it forms favorable zone due to the tectonic activity



3. Um-Er-Radhumma Aquifer

- It forms outcrops in the eastern part of Yemen especially Hadramout and Ramalt –as- Sabatayn.
- In this aquifer groundwater predominantly flows through fissures

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