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CHARACTERISTICS OF QUATERNARY SEDIMENTARY FACIES IN RELATION TO WATER BEARING CAPACITY OF AQUIFERS AND AQUICLUDES IN RED RIVER DELTA, VIETNAM

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Abstract

There are 5 Quaternary sedimentary sequences in Red River Delta, Vietnam. The forming of each sequence related to transgression and regression phases. For the sequences what formed in transgression period composed mainly of fine grained size leading to the water bearing capacity is very low and play a role as aquicludes. Besides, in these fine grain size layers, the contents of arsenic and iron are high, especially in dark clay, silty clay rich in organic material of swamp facies and brown, drark brown clay of flood facies so that they are stated as source of arsenic contamination in groundwater. And for the sequences formed in regression period what composed mainly of gravel, cobbles, pebbles, coarse sand of fluvial, river channel facies are good aquifers. These aquifers are main supply sources for human activities in Red River Delta.

***Keywords**: aquiclude, aquifer, Red River Delta, sedimentary facies*

I. INTRODUCTION

Like many cities and provinces of Vietnam, the provinces in the Red River delta receive water supply from the groundwater in Quaternary sediments. The characteristics, potential and variation trend of this water resource depends much on the distribution of sedimentary facies in the stratigraphic column. The depositional environment and material composition express different paleogeographic environments such as marine, continental environment or transitional environment. In Red River delta area, the facial association rule is examined in three spatial directions: vertical, perpendicular and parallel with the present coastline.

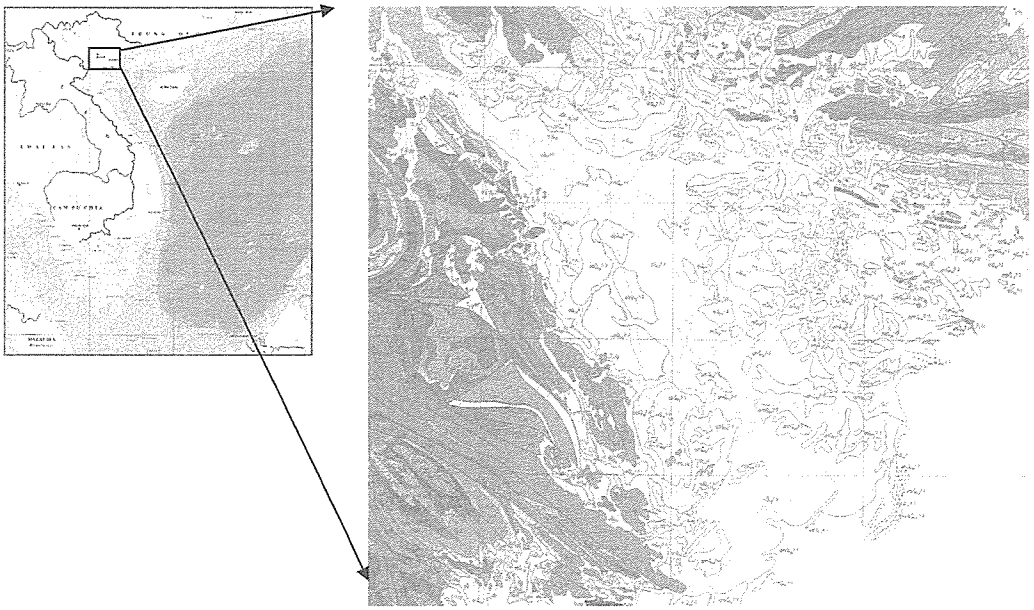

Fig 1. Geological sketch of Red River Delta and study location

II. CHARACTERISTICS OF QUATERNARY SEDIMENTARY SEQUENCES

In Quaternary, the Red River Delta experienced glaciation stages: Gunz, Mindel, Riss, Wurm 1, Wurm and transgression phases which corresponding with them. These stages have left behind 5 sedimentary sequences corresponding with 5 sedimentary cycles in Quaternary each began. The coarse grain size sediments were formed in regressions phase and fine ones sediments were formed in transgression phases. Corresponding with them, the Quaternary sediments in Red River Delta are identified by following sedimentary sequences:

- The first sequence that formed in Early Pleistocene and corresponded with Le Chi formation. The sediments of this sequence are composed mainly of cobbles, pebbles, and coarse sand of river channel environment in the lower part and medium sand, silt and clay of flood plain in the upper part.

- The second sequence that corresponds with the second depositional cycle, formed in Middle to lowermost late Pleistocene. This sequence corresponds with Hanoi formation and consisting of cobbles, pebbles, gravel of proluvial and mountainous riverbed facies.

- The third sequence corresponds with the third depositional cycle and formed in uppermost of Late Pleistocene. It corresponds with Vinh Phuc formation which contain coarse to medium grained sand of plain river bed facies and changing upwards into finer sediments consisting mainly silty clay mixed with fine sand of flood plain facies and clay of lagoonal facies.

- The fourth sequence was formed in Lowermost of Late Pleistocen to Early - Middle Holocene, corresponding with the fourth depositional cycle of Hai Hung formation, composed of greenish gray clay and peat of lagoon and coastal swamp facies.

- The fifth sequence was formed in late Holocene and composed of sand, silt and clay of deltaic facies, corresponding with the fifth depositional cycle of Thai Binh formation.

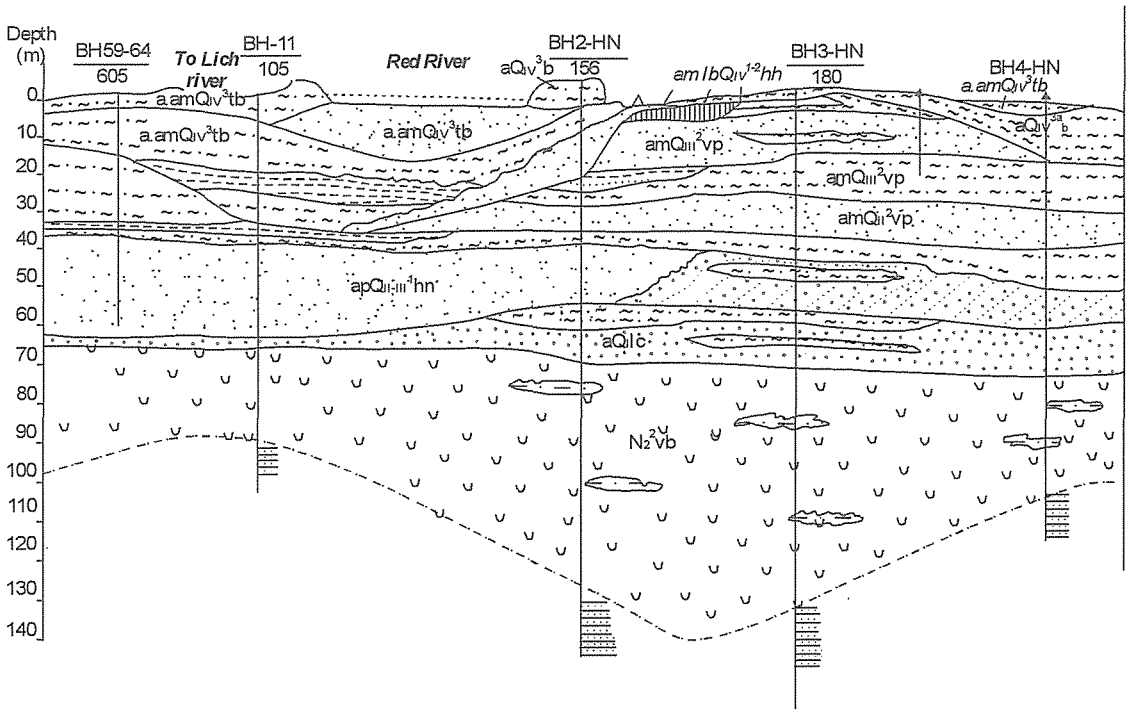

Fig 2. Quaternary sedimentary facial cross section in the Red River Delta (Tran Nghi, 1991)

In spatial distribution, the sediments of the first and the second sequences are rather widespread in the plain. The third sequence has a continuous change of facies from sand, silt and clay of alluvial faces to clayey silt mixed with sand of deltaic facies and silty clay of lagoonal facies in the central part passing into silty clay of flood plain, oxbow, coastal swamp and peat facies in the direction from the plain to the modern coastline.

The fourth sequence consits of swamp clay, lagoonal clay and peat. In the direction towards the center of the plain, each of these sequences appears more and more particular facies that forming a quite complete facies association. Thus, in the evolution process of the Quaternary sediments in Red River Delta there there is clear change of sedimentary facies associations and corresponding with it is the change in lithological composition and sedimentation parameters such as: Md, Ro, So, Me... permeability and paleogeographic environments in each period, which represent the water bearing properties as well as the quality of the groundwater in the region. Therefore, the important aquifers with good quality corresponds with the coarse grained sediment layers of alluvial and proluvial facies (formed in the first stage of each cycle), while the aquacludes are fine sediments of deltaic, coastal swamp and marine facies (formed in the final stage of each cycle). Based on this point of view, the Quaternary sediments in Red River Delta can be divided into the following hydrogeological units: Holocene aquifer (Qh); Pleistocene aquifer (Qp), Pleistocene – Holocene aquiclude, Middle – Late Pleistocene aquiclude.

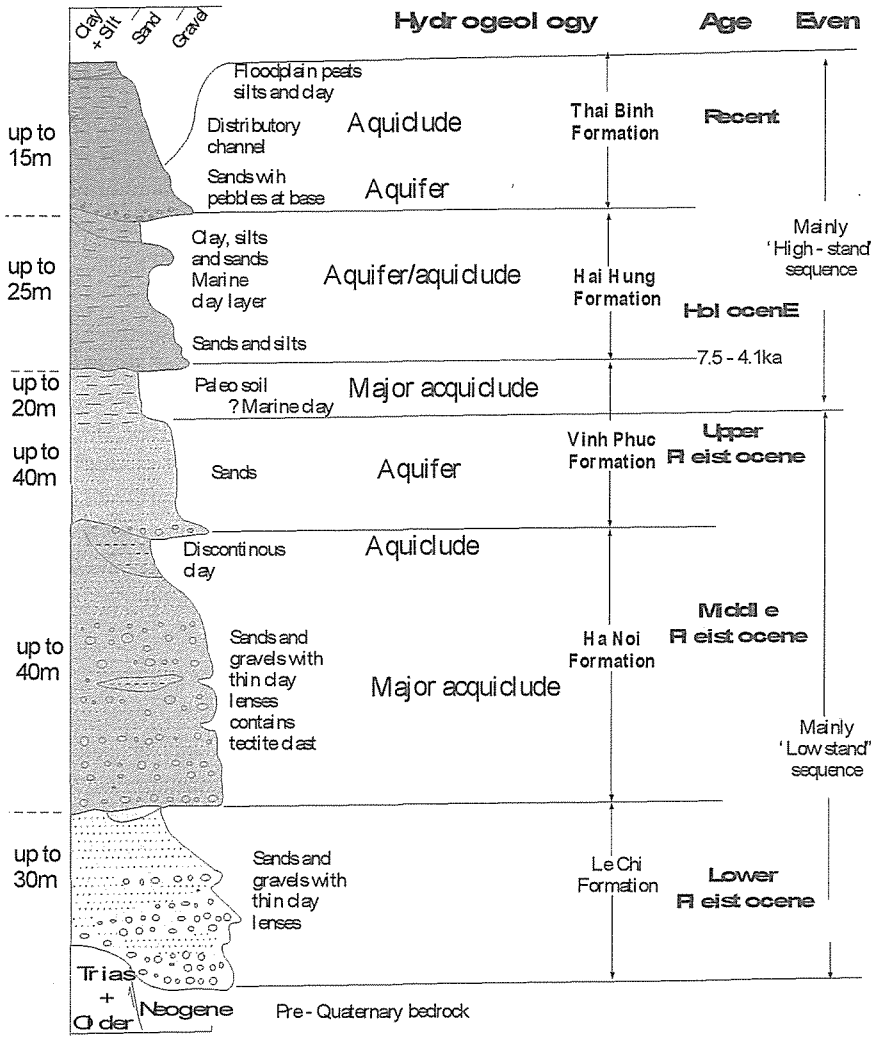

Fig 3. Aquifers and aquicludes in Quaternary Stratigraphic Column of the Red River Delta (Tran Nghi, 1995)

III. FACIAL CHARACTERISTICS AND WATER BEARING PROPERTIES OF THE AQUIFERS AND AQUICLUDES IN RED RIVER DELTA

1. Holocene aquifer (Qh)

The Holocene aquifer is distributed at a shallow depth where the water fluctuates in a wide range from 2 – 4m up to 36m, with thickness increasing towards the center of plain. It is composed of sand, silt, clay of alluvial facies of Thai Binh formation (Fig 4) in the upper part and lens of sand, silt, clay of Hai Hung formation in the lower part which are low water bearing capacity layers. The particle size distribution is: gravel 2%, sand 30-85%, silt – clay 15-70%. The sediment indicators are: Md=0.02-0.11mm, So=1.21-2.85, $pH_{sediments}$=5.5-8.2, $Eh_{sediments}$=-5->-10mV. In this layer, the specific capacity of wells is very low and changing from 2 to 3l/sm.

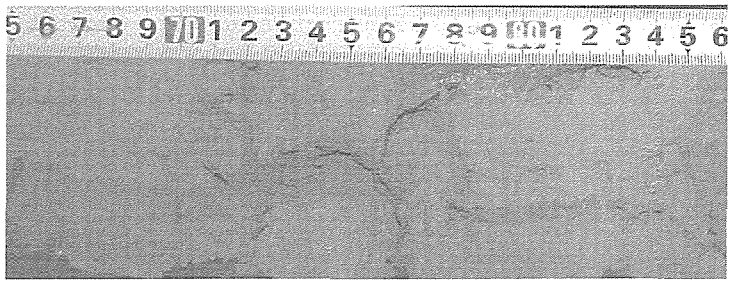

Fig 4. Laminated fine sand interclated with silt of alluvial facies of Holocene aquifer in VP2 borehole, Hanoi area (6.9-7.2 m deep) (Tran Nghi, 2006)

Especially, the groundwater regime is affected directly by river and rain water percolating though the overlying Thai Binh formation. The flunctuation amplitude of the water level decreases with the distance from the river. Therefore, this aquifer is mainly recharged by the rain water and surface water, especially in some big rivers in Red River system. The groundwater is discharged mainly through the evaporation process and percolation to the Pleistocene aquifer. Water quality of this layer is fresh, soft to slightly hard with total dissolved solid (TDS) content <1mg/l and bicarbonate calcium, bicarbonat sodium calcium type. According to the results of chemical analysis, the groundwater in the Holocne aquifer has a rNa/rCl ratio of 1.56, a hardness of 2-9, a pH of 7.5, a TDS content changing from 1.2 to 11.7g/l, inparticular its iron content reaches 1.24 to 33.5mg/l.

2. Pleistocene aquifer (Qp)

The Pleistocene aquifer is widely distributed in the Red River Delta and is overlain by the younger sedimentary layer which is the Pleistocene - Holocene aquiclude. The sediments of this layer consist of 3 formations: Le Chi formation, Ha Noi formation (Fig 7) and Vinh Phuc formation (Fig 5, 6). These sediments are intercalated by fine sediments of clayey mud of lagoon environment of Le Chi formation, the tidal flat silty sand and lagoonal clay and lenses of lacustrine clay of Hanoi formation, the laterized lagoonal clay of Vinh Phuc formation, the alternating greenish gray clay and peat bearing swamp clayey mud of Hanoi formation which serve as an aquiclude and aquitard. The particle size distribution is as follows: cobbles, pebbles, gravel 2.5%, sand 56.7%, silt - clay 40.8%. The sediment indicators are Md = 0.25, So = 3.2, pHsediments = 6.7. The specific capacity of boreholes drilled into this aquifer is higher than the Holocene aquifer (in the sediment layer of Vinh Phuc formation: 2-91/ms, and Ha Noi and Le Chi formations 26-511/ms). The groundwater in this aquifer is fresh (TDS<l g/l), of bicarbonate calcium, bicarbonate sodium - calcium type, with rNa/rCl ratio = 0.98-5.6, pHwater= 1-8.1, TDS = 0.1- 0.5g/l and iron content very high (2-25mg/l). However the iron content in this aquifer is lower than in the Holocene aquifer.

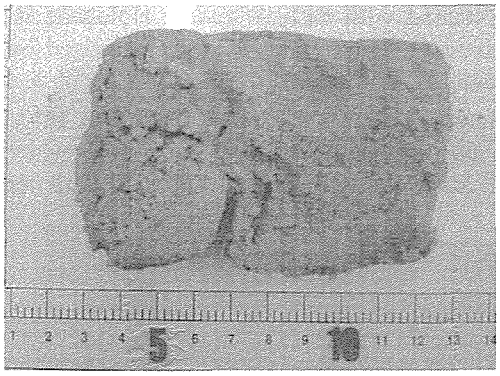

Fig 5. Late Pleistocene coarse grained sand of river channel facies in VP2 borehole, Hanoi area (28-28.3m deep) (Tran Nghi, 2006)

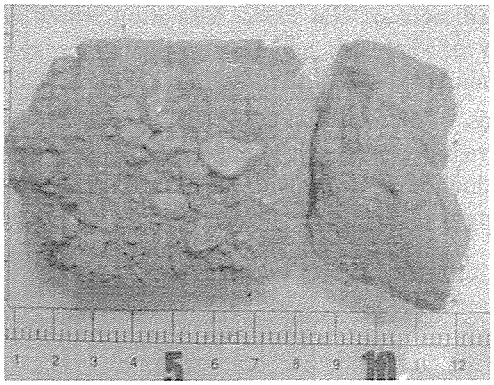

Fig 6. Late Pleistocene coarse grained sand, gravel of river channel facies in VP2 borehole, Hanoi area(39.2-41.2m deep) (Tran Nghi, 2006)

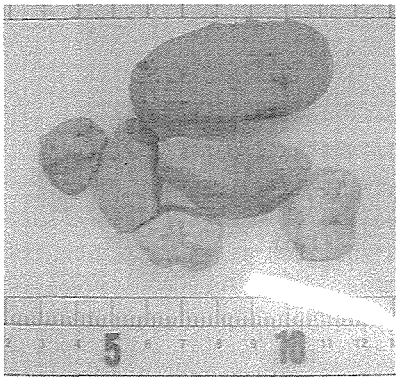

Fig 7. Early Pleistocene pebble, cobble of fluvial facies in VP2 borehole, Hanoi area (55-57m deep) (Tran Nghi, 2006)

3. Uppermost of late Pleistocene – Holocene aquiclude

The Holocene and Pleistocene aquifers are separated by the Pleistocene Holocene aquiclude. The Pleistocene - Holocene aquiclude is composed mainly of greenish gray fine clayey sand of lagoonal and coastal swamp facies of Hai Hung formation in the upper sequence and the fine sediments of deltaic and marine facies of Vinh Phuc formation in the lower sequence.

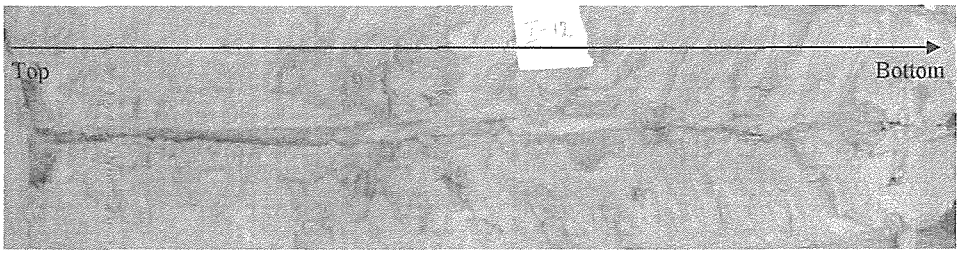

Fig 8. Silty clay, clay spotted weathering of marine sediment in VP1 borehole, Hanoi area (13 – 13.74m deep) (Tran Nghi, 2006)

The sediment of Vinh Phuc formation which corresponding with Late Pleistocene sediment was weathered (Fig 7) that created reddish brown to orange. The Fe^{2+}/Fe^{3+} = 0.1-0.05, TOC is changing from 0.23 – 0.26(μg/g) in deltaic sediments and Fe^{2+}/Fe^{3+} = 1.7; TOC=0.54 in marine sediments [Mai Trong Nhuan, 2003]. The rNa/rCl ratio of this layer is 0.66, pHwater 1-8 and the water hardness is 1.5 to 1.6mg/l.

The sediment of Hai Hung formation which corresponding with early – middle Holocene is composed mainly of silty clay and fine sand mixed clay of deltaic facies. This layer is characterized by oxidation environment that indicated by low value of TOC and ratio of Fe^{2+}/Fe^{3+}.

Besides, silty clay and clay rich in orgranic material of swamp facies that formed in early Flandrian transgression (10.000 to 6.000 year BP) (Fig 9) are in high values of TOC and Fe2+/Fe3+, which indicated for reduction environment. Moreover, content of total arsenic in sediment of this facies are very high (6-33.0um/g) (Tran Nghi, 2004).

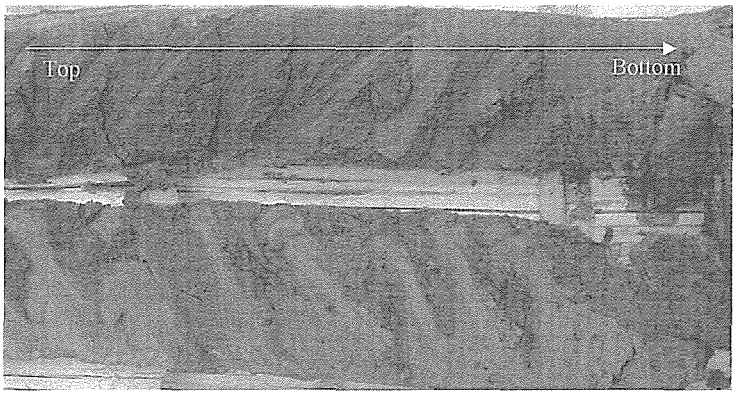

Fig 9. Clay, silty clay rich in organic material of swamp facies in VP2 borehole, Ha Noi area (0.95-1.0m deep) (Tran Nghi, 2006)

Regression phase happened after Flandrian transgression that formed sandy silt clay and silty clay of deltaic and dark brown clay of river flood facies. The sediments what took in dark brown clay of river flood in Phap Van borehole have content of arsenic reach to 2 - 12um/g (Mai Trong Nhuan, 2003).

The combination of them created as thick sedimentary layer playing a role of relatively thick aquiclude that separating the overlying Holocene aquifer above and the Pleistocene aquifer below. The thickness of the Pleistocene - Holocene aquiclude varies from 6 to 11.5m. However, due to the action of old river systems, in some places there is no trace of the fine grain sediments, but there remain only the coarse grained sediments of river bed facies which are of high storage and water bearing capacity. These are "hydrogeological windows" (Fig 10). The hydrogeological windows are areas where the groundwater in the Holocene aquifer is interconnected with the Pleistocene aquifer.

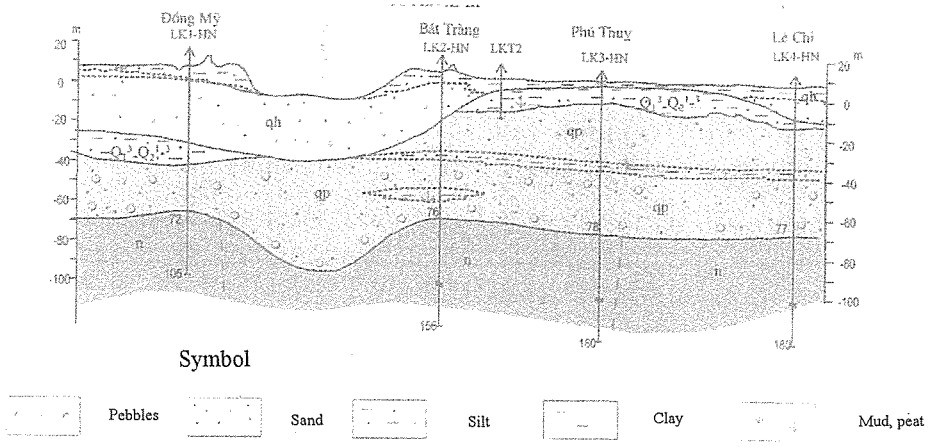

Fig 10. Hydrogeological window between Pleistocen aquifer and Holocene aquifer in Hanoi area (Nguyen Van Dan, 2004)

4. Middle – Lowermost of Late Pleistocene aquiclude

The upper part of the Ha Noi formation with green gray to dark gray clay and silt of lagoon facies, lens of lacustrine clay formed during the Middle - Late Pleistocene transgression is called Middle - Late Pleistocene aquiclude. However as it is eroded during the regression phase and its distribution area is small and is associated with silty sand of tidal flat facies and alluvial cobbles, pebbles, this aquiclude is of and much smaller extent than the Pleistocene - Holocene aquiclude above. Also for this reason usually it is neglected and attributed to the local aquiclude in the Pleistocene aquifer. The specific capacity of the boreholes drilled to this aquiclude is 0.0 l/sm. The particle size distribution is: Sand = 46%, silt - clay = 60%, the sediment indicators are Md = 0.15mm, So = 4.5, $Eh_{sediments}$ = 50mV, pHsediments = 7.5. The rNa/rCl ratio of the groundwater is 0.8, pHwater= 7.5. The iron content in the water is relatively high >10mg/l.

IV. RESULT AND DISCUSSION

The relationship between sedimentary facies and aquifers, aquicludes is very strong. The first and the second sedimentary sequences are composed mainly of coarse-grained sand, cobbles and pebbles of mountainous river facies in the lower part that is a good potential and quality layer. Besides, the upper part of each layer was covered mainly by silty clay; clayish silt mixed fine sand of flood and deltaic facies is a bad aquiclude. The Pleistocen – Holocene aquiclude, which contained mainly of fine grained size such as clay, silt, silty clay, clayey silt and rich in organic material is good regional aquiclude. These sediments are mainly formed in reduction environment ($Fe^{2+}/Fe^{3+}>1$ and TOC are high) and have high content of total arsenic. Besides, the upper part of Holocene aquiclude appeared brown and dark brown clay of flood facies what are in high content of arsenic. Arsenic absorbed by iron hydroxide while iron hydroxide absorbing by clay mineral. Therefore, this layer was considered as a main source of arsenic contamination in groundwater.

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