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Assessment on Potential Area for Aquifer Thermal Energy Storage (ATES) in Osaka Plain

Muneki Mitamura[a]*

[a]*Geosciences, Graduate School of Science, Osama City University, 3-3-138 Sugimoto, Sumiyoshi, Osaka 558-8585, JAPAN*
[b]*Second affiliation, Address, City and Postcode, Country*

Abstract

Aquifer Thermal Energy Storage (***ATES***) is one of the available resources for energy conservation in urbanized area. After the 2011 Tohoku Region Pacific Coast Earthquake (Mw=9.0), all nuclear power stations in Japan are constrained to be reviewed on geological condition of site location and safety inspection of structures. For this reason, the electric power supply is reduced, and electric power companies reuse aging generating plants with fossil fuel. ATES is now draw attention as one of the peak cut measures on electricity demands. It is necessary the condition for Aquifer structure to be simple and stable, and for groundwater flow to be stagnant condition for ATES. The distribution of well-permeability aquifer intercalated between thick aquicludes is also important. In the Osaka Plain, groundwater pumping for industrial use had been active until the 1960s when groundwater regulation for the countermeasure on ground subsidence has been started. The effects by the regulation, the groundwater flow from 100 meter to 200 meter level below ground surface is in stagnant condition. The aquicludes in these levels consist of over-consolidated clays. For the ATES taking groundwater in and out to the aquifer, these levels are the suitable horizon with low risks. From these points of view, we tried to review the suitable area for ATES in the Osaka Plain, southwest, Japan. This paper reports the target aquifer and its distribution and the potential area of Osaka City area for ATES.

Keywords: Quaternary; Pleistocene; Osaka Plain; Aquifer Thermal Energy Storage (ATES)

1. Introduction

Aquifer Thermal Energy Storage (ATES) is an open-loop geothermal technology. It relies on seasonal storage of cold and/or warm groundwater in an aquifer. Of course, to minimize thermal mixing within the aquifer, the supply and injection wells have to be spaced an appropriate distance apart. There are essential requirements to the aquifer for the successful application of ATES:

1. A suitable aquifer with low groundwater flow velocities;
2. High permeability of aquifer for high efficiency groundwater production.

At the assessment on the potential area for ATES, aquifer properties, such as thickness, permeability, geological structure, and the pumping situation of the surrounding area are required.

In the Osaka sedimentary basin, central Japan, thick Quaternary formation is widely distributed. These strata involve rich groundwater. Groundwater in these aquifers has been pumped up and used for mainly industrial

* Corresponding author. Tel.: +81-6-6605-2592; fax: +81-6-6605-2522.
E-mail address: mitamura@sci.osaka-cu.ac.jp.

water. In this study, we try to review the suitable aquifers and potential areas with above essential requirements for ATES in the Osaka Plain (Fig. 1).

2. Subsurface Geology and Aquifer Division in Osaka Plain

The Osaka Plain and the surrounding hilly areas consists of the Quaternary formation (Fig. 2, 3; Itihara 1993), such as The Osaka Group (Plio-Pleistocene), terrace deposits (Middle-Upper Pleistocene), and Namba Formation (Upper Pleistocene - Holocene). Total thickness at the main part of the Osaka Plain is about 1500 meters. The upper half part of the Quaternary formation consists of alternation marine clay beds and sand/gravel named as Tanaka Formation (Yoshikawa and Mitamura, 1999). More than 10 thick marine clay beds are intercalated in the Quaternary formation, and these beds are regarded as aquicludes. The upper most confined aquifer named as DG 1 is located between the Namba Formation and Ma12 Bed (Upper Pleistocene marine clay bed). Pleistocene sand and gravel layers as subordinate confined aquifers named as DG 2, DG 3are also intercalated among the Ma12, Ma11, and Ma10 (Fig 3; KG-NET and Kansai Geo-informatics Research Committee, 2007).

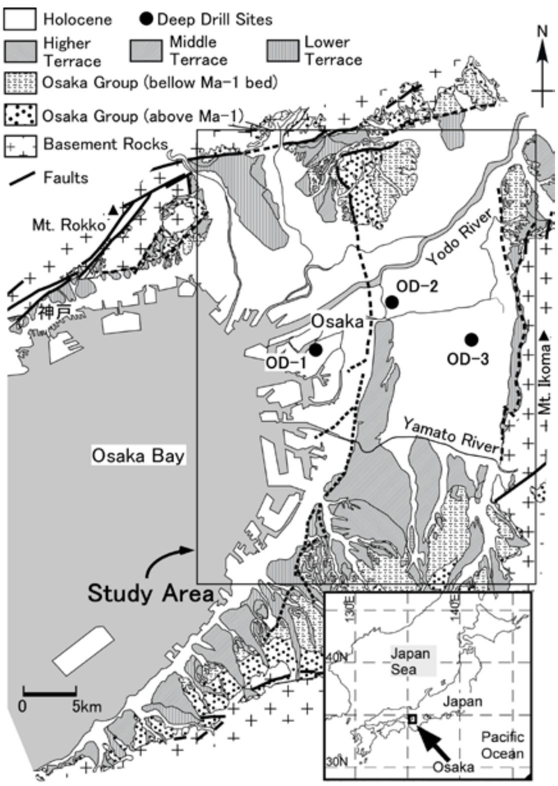

Fig. 1. Quaternary Geologic map of Osaka and the location of study area

Pleistocene marine clay beds are over-consolidated clays which are lightly affected to consolidation settlement due to the decent of ground water level. In the main part of the Osaka Plain, DG 2and DG 3 are generally intercalated between 50 to 100 meters deep. In Osaka and Higashiosaka City where land subsidence occurred due to the over pumping of groundwater. Because laws on groundwater pumping regulation have been enacted, the groundwater of DG 2and DG 3 in these areas, now, is in stable condition. Therefore, these aquifers are the suitable horizon for ATES.

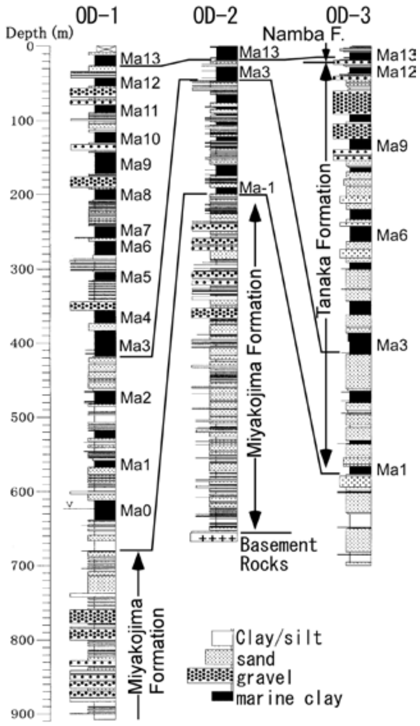

Fig. 2. Deep drill logs in Osaka Plain
The site location is shown in Fig.1.
(after Yoshikawa and Mitamura, 1999)

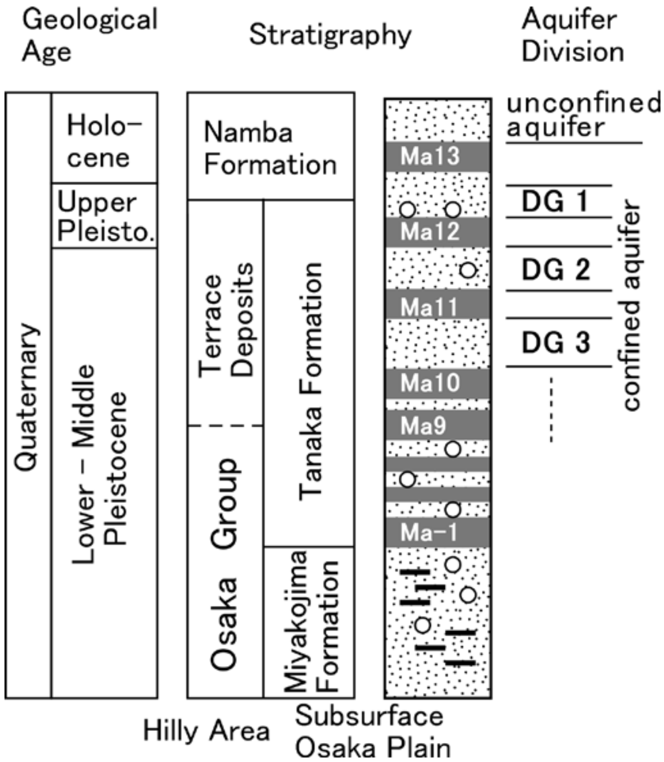

Fig. 3. Outline of Quaternary stratigraphy in Osaka Plain and aquifer division (after KG-NET and Kansai Geo-informatics Research Committee, 2007)

3. Distribution of DG 2 and DG3 Horizons

For the making of the distribution maps, we use the drilling database in Osaka and the surrounding areas. KG-NET and Kansai Geo-informatics Research committee (2007) has compiled many drill logs more than 3000 sites in these areas, and represented standard geological cross-sections and depth distribution maps of main marker horizons, such as thick marine clay beds, in/across the Osaka Plain. In the hilly areas, detail geological maps are already published (Itihara 1993). More than 10 deep drillings from 1960s and 1990s brought the standard stratigraphy of Quaternary formation in the subsurface of the Osaka Plain (Yoshikawa and Mitamura, 1999). Seismic profiles by reflection surveys in the Osaka Plain are also available for tracing marine clay horizons. We compiled distribution maps on the base and top surface of Ma12, Ma11, and Ma10 marine clay beds (Fig 4a to 4d). Isopach maps on DG 2 and DG 3 are made by the difference of the base and top surface horizons (Fig. 5a, 5b).

DG 2 is intercalated between the base of Ma12 bed and the top of Ma11 bed. The base horizon of Ma12 bed as the top surface of DG 2 is distributed from -40 to -60 meters level in the western part of Osaka, and from -30 to -40 meters level in eastern part of Osaka (Fig. 4a). The top horizon of Ma11 bed as the base of DG 2 is widely distributed in both parts of Osaka ranging from -30 meter to -70 meter level (Fig. 4b). In the western part of Osaka, DG 2 appears in horizontal distribution. On the other hand, this aquifer in the eastern part is gently dipping eastward. The DG 2 aquifer also keeps stable thickness of 15 meters in the western part. In the eastern part, thickness of this aquifer gradually increases to eastward (Fig 5a).

DG 3 is intercalated between the base of Ma11 bed and the top of Ma10 bed. The base horizon of Ma11 bed as the top surface of DG 3 is distributed from -50 to -100 meters level in the western part of Osaka, and from -40 to -70 meters level in eastern part of Osaka (Fig. 4c). The top horizon of Ma10 bed as the base of DG 3 is widely distributed in both parts of Osaka ranging from -40 to -130 meter level (Fig. 4d). DG 3 has also similar structure with DG 2 aquifer. Thickness of DG 3 is ranging from 20 to 30 meter (Fig 5b) .

Distribution maps on the main marker horizons of Quaternary formation such as Ma-1, Ma3, Ma6, Ma9, and Ma12, in the Osaka Plain have been already compiled with geologic data by Mitamura (2004). This study added the distribution maps on Ma10, Ma11 horizons. Fig 6 shows the geological structure map (dip distribution map) between -80 and 120 meters level in the study area. This geological structure map is made by the terrain slope method (Moore et al., 1993) with these horizons distribution. The Uemachi Fault is running from south to north in the central part of the Osaka Plain. The Quaternary formation is dominantly deformed along this fault. Therefore, the east side of the Uemachi fault is relatively uplifted to the western area. The dip of the Quaternary

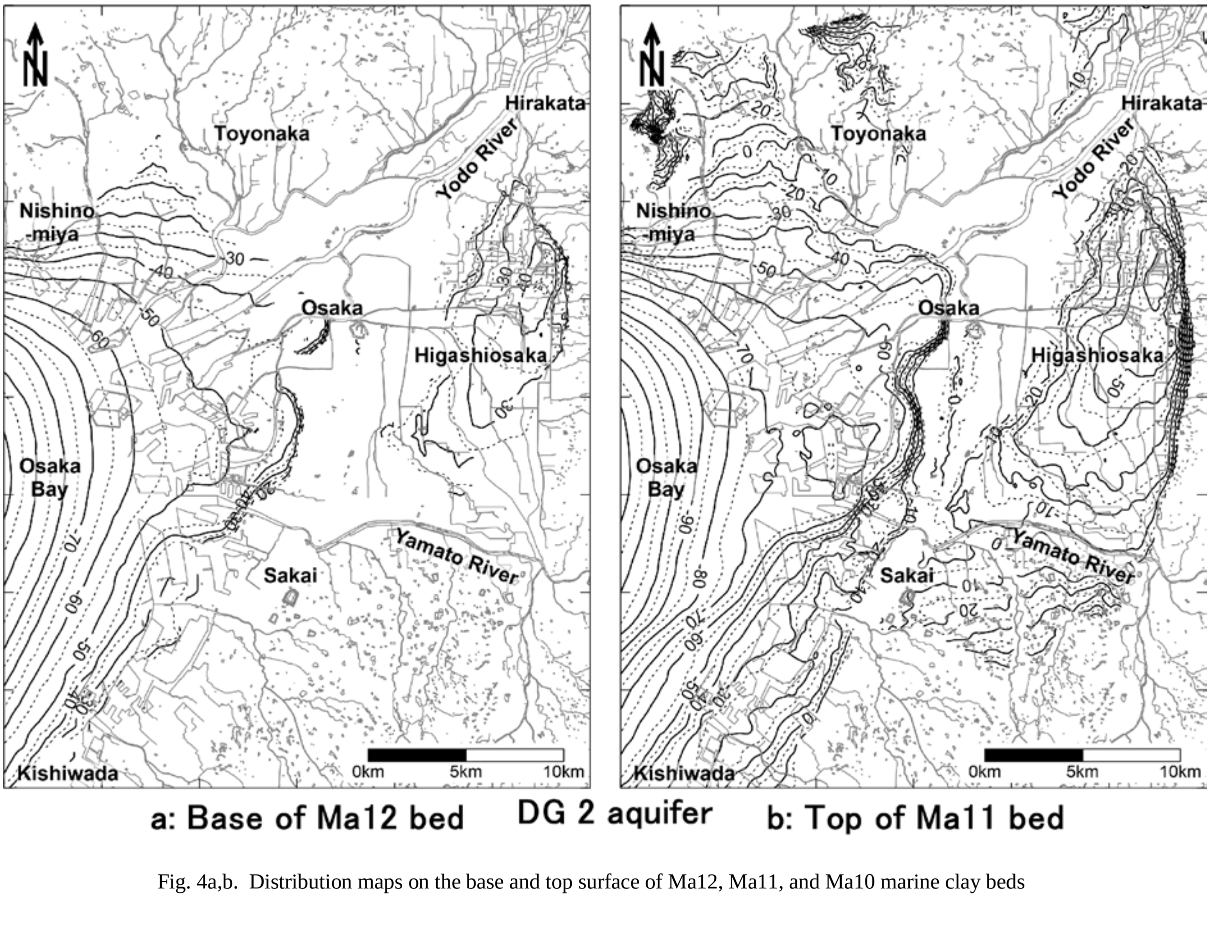

Fig. 4a,b. Distribution maps on the base and top surface of Ma12, Ma11, and Ma10 marine clay beds

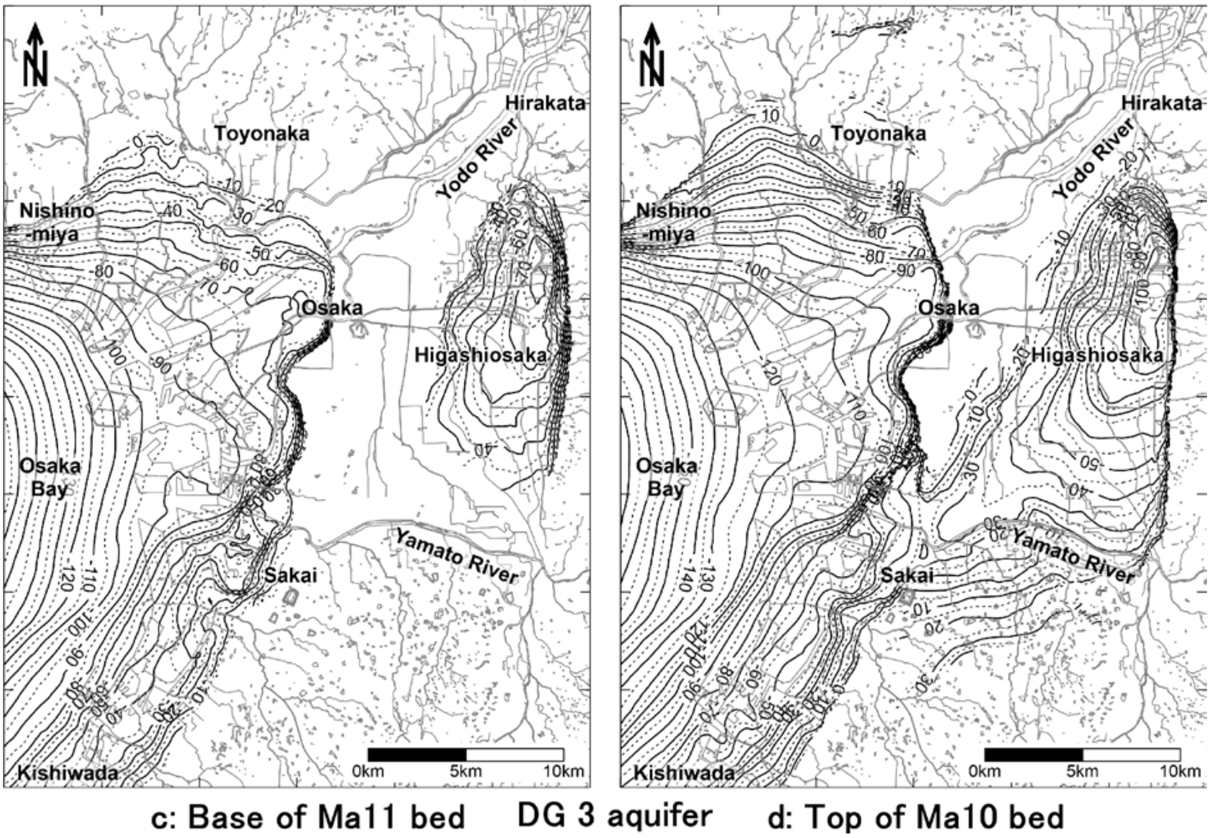

Fig. 4a,b. Distribution maps on the base and top surface of Ma12, Ma11, and Ma10 marine clay beds

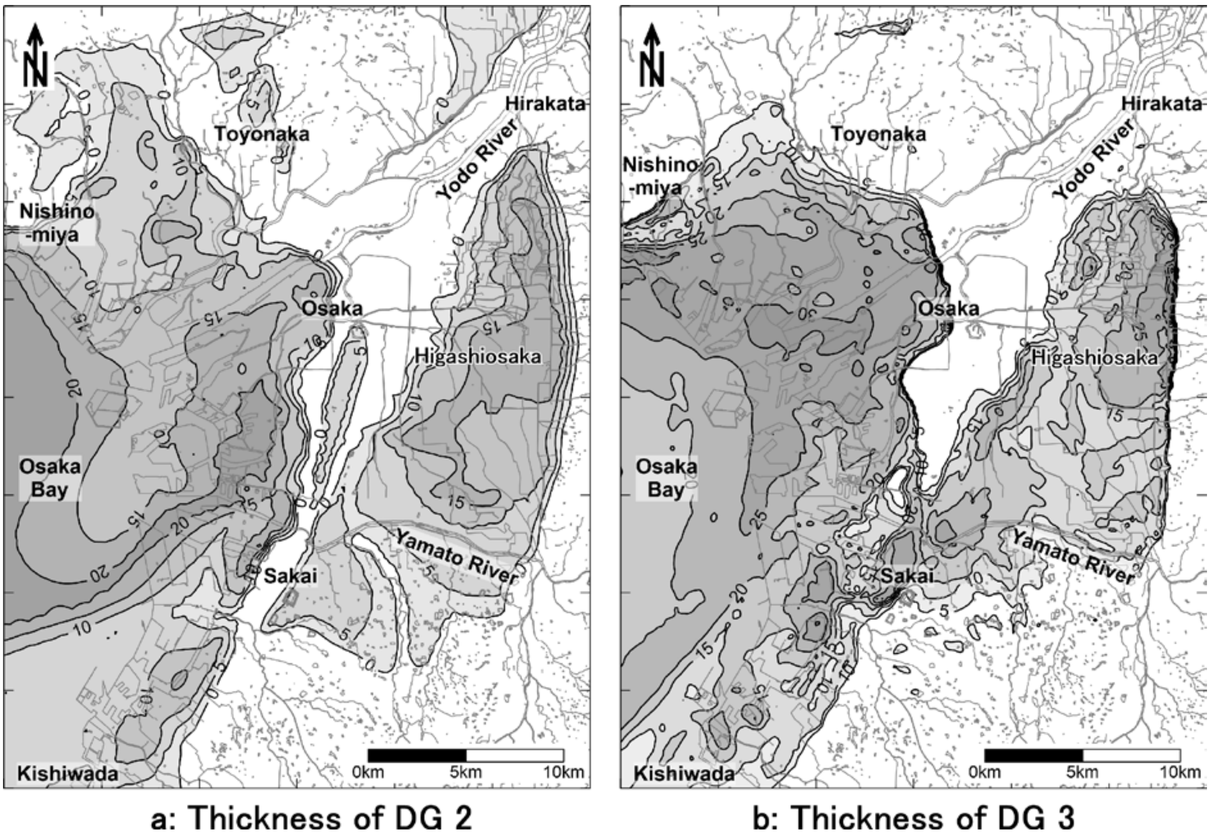

Fig. 5 Isopach map of DG 2 and DG 3 aquifers
Numbers of contour are shown in meters.

layer is more than 5 degrees along the Uemachi Uplifted zone in the central part of the Osaka. While, the dip of Quaternary layer in the western part is less than 1 degree. In the eastern part, Quaternary layer gently dips eastward with from 1 to 2 degrees. DG 2 and DG 3 aquifers also are not distributed along this uplifted zone.

4. Permeability of DG 2 and DG3 Horizons

Land and Water Bureau, National Land Survey Division, Ministry of Land, Infrastructure, Transport and Tourism, Japan has carried out the basic survey on water resources (groundwater survey) which has collected deep tube well document of all over Japan since 1952. These well documents are gathered together into a public domain database on the web site (National Land Agency of Japan, 1975). Specific capacity (Sc) is the pumping rate at unit drawdown level (1 m), and is an index almost equivalent to transmissivity. Permeability coefficient can be derived from dividing transmissivity (T) with aquifer thickness. We pick up the corresponding permeability coefficients (K) on DG 2 and DG 3 with the range of horizon level of each distribution map. The result of retrieval is shown in Fig 7a and 7b. The retrieval sites on DG 2 are 5 sites, and the permeability coefficient of DG 2 ranges from $5.0*10^{-3}$ to $5.0*10^{-2}$ cm/sec. DG 3 Aquifer has the permeability coefficient around $5.0*10^{-3}$ cm/sec.

Fig. 6. Geological structure map (dip distribution map) between -80 and 120 meters level in the study area (dip are shown in degree)

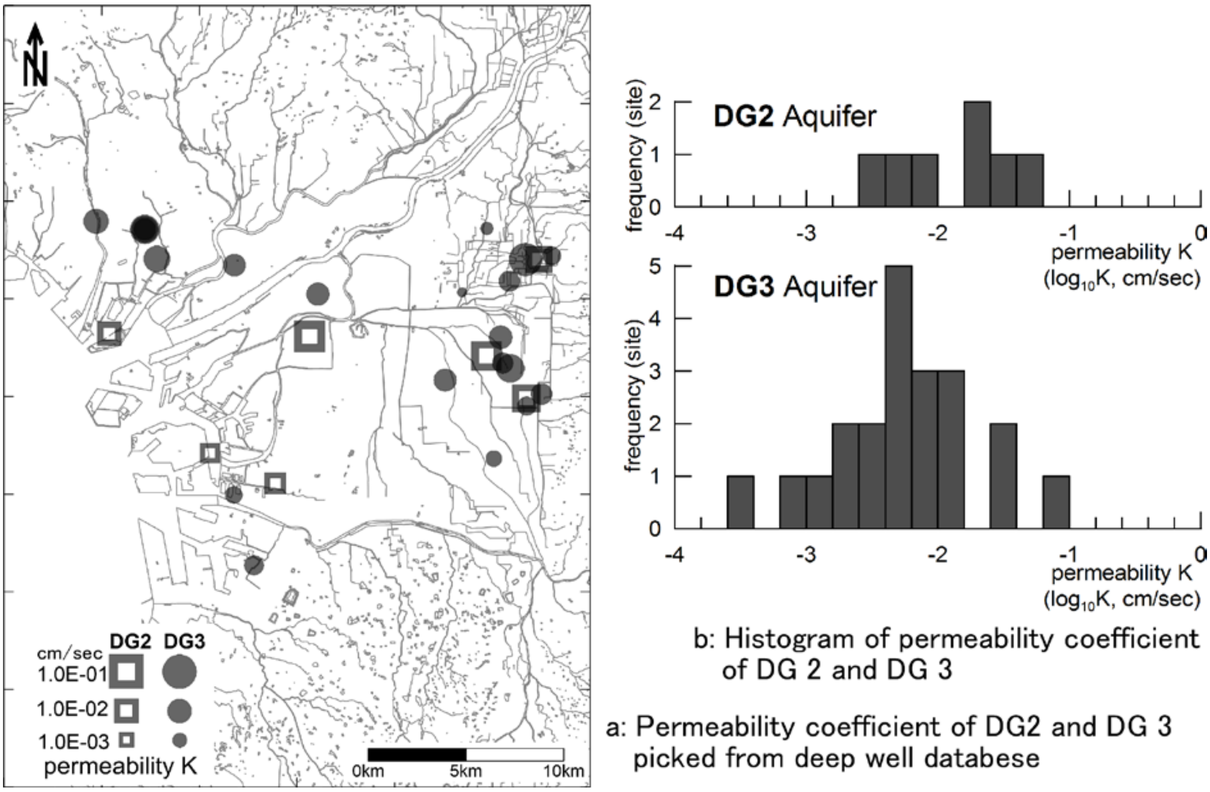

Fig. 7 Distribution and histogram of permeability coefficient of DG2 and DG3

5. Potential area for ATES

As mentioned above, DG 2 and DG 3 aquifers are intercalated between Pleistocene thick over-consolidated marine clays. Because the groundwater pumping is regulated by low for the countermeasure for land subsidence, the concerned artificial flux of confined groundwater is low. As the retrieval result on the permeability with the deep well database, these aquifers have well permeability for ATES. The geological structure of these aquifers in the western part of Osaka City is stable horizontal situation. Therefore, the western part is the best potential area for ATES. These aquifers dips gently eastward with from 1 to 2 degree, and stable geological structure area is distributed in the eastern part. So, this part is also evaluated as the second potential area for ATES. DG 3 has larger potential area in both parts than DG 2 (Fig. 8).

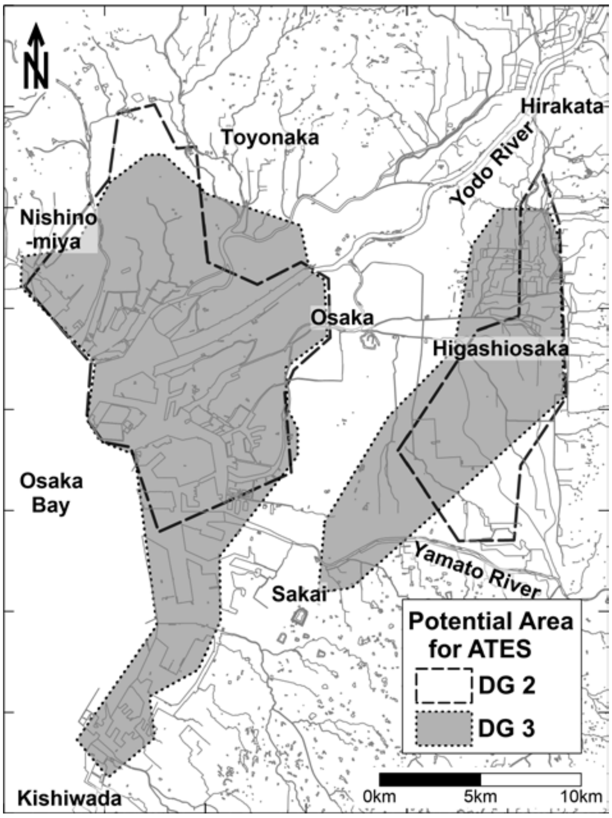

Fig. 8. Potential area on DG2 and DG 3 for ATES

6. Conclusion

The suitable aquifer and the potential area in the Osaka Plain have been reviewed with drilling database, deep well database, geological maps, and seismic profiles. As the results of the assessment on the essential requirements to the aquifer for the successful application of ATES, two Pleistocene aquifers and two potential areas are picked up as follows:

1) DG 2 aquifer intercalated between Ma12 and Ma11 beds, has well permeability of 10^{-2} cm/sec order, 15 meters thick. DG 3 aquifer intercalated between Ma11 and Ma10 beds, has well permeability of $5*10^{-3}$ cm/sec order, 25 meters thick. These aquifers are available for storage horizon for ATES.

2) The two potential area of the surrounding Osaka City are picked up. The western part of Osaka City is the best potential area. The second potential area is Higashiosaka City and its surroundings.

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