Hydrogeology of the Shigenobu-gawa Alluvial Fan, Ehime Pref., Shikoku, Japan

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Abstract

Approximately 600,000 people inhabit the Dogo-plain in western Shikoku where the mean annual precipitation is approximately 1,300 mm, occurring primarily in June and July. Since the R. Shigenobu-gawa and its tributaries are fast flowing streams with long stream lost, "Segire" sections, the amount surface waters abstracted from the rivers are relatively low. Consequently, groundwater abstraction for portable water, and water for industrial and agricultural use is extensive.

The tectonic basin upstream of the Dogo Plain at the confluence of the R. Shigenobu-gawa and R. Tobe-gawa is approximately 600 m or more with gravel beds and debris flow deposits, which have a high potential for abundant groundwater in their numerous voids. The permeability coefficient of gravel beds and debris flow deposits was 10^{-3} to 10^{-2} m/sec, apparently decreasing further with depth. In order to better analyze the hydrologic cycle and potential utilization of this groundwater basin it is thus necessary to clarify the spatial scale and characteristics of this buried tectonic basin.

KEYWORDS : Dogo-plain, Buried Tectonic Basin, Hydrogeologic Structure, Stream Lost "Segire" sections

1. Introduction

The westward-flowing R. Shigenobu-gawa drains catchments in the Setouchi climatic region. The mean annual temperature and annual precipitation is 16°C and approximately 1,300 mm in Matsuyama, respectively, with most of the rainfall falling from June to July.

The floodplain of the R. Shigenobu-gawa, also called Dogo-plain, is primarily used for rice cultivation. With a length of only 36 km, the R. Shigenobu-gawa is relatively short for one of the major rivers draining 204 km^2 catchments areas in western Shikoku. The steep stream gradient also means that the river regime is unstable, even when it reaches the floodplain. Many subjects such as stream lost occurred, are held in utilization of surface water.

At present, the Dogo-plain supports approximately 600,000 inhabitants. Taken together, the requirements for potable water and industrial use by the urban centers in the catchments account for a daily use of approximately 170,000 m^3. This dependence on groundwater resources, which has increased on an annual basis, will have marked impacts on the use of groundwater for drinking, and industrial and agriculture. This study was conducted with the aim of examining measures that can be adopted to improve the groundwater environment.

Specifically, aspects associated with the future utilization of river water and groundwater is clarified relative to subsistence flow and groundwater conditions in the downstream region of the R. Shigenobu-gawa. Predicted patterns of water-utilization will also be investigated for a variety of climatic conditions.

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Fig.1 Satellite image showing the geomorphology of the Dogo-plain (I.T.P.A Japan, 1995)

2. Geomorphology

The occurrence of differing geomorphologic elements near the R. Tobe-gawa has meant that the region of the Dogo-plain is called the Shigenobu lowland while the region downstream is referred to as the Coastal lowland (Fig. 2).

The alluvial fans formed by the R. Shigenobu-gawa, R. Ishide-gawa and R. Ono-gawa as they enter the floodplain are referred to as the Shigenobu-gawa alluvial fan, the Ono-gawa alluvial fan, and the Ishide-gawa alluvial fan, respectively; a large alluvial fan of packed scale does not exist.

The length of the Shigenobu lowland area extends 8 km from near the R. Omote-gawa to near the R. Tobe-gawa, and approximately 4 km from the north to the south. The stream gradient is 7/1,000 - 8/1,000, and the river has terraced plains on the mountainside and a floodplain further downstream, with both banks of the river are used for rice cultivation. There are long river sections in the Shigenobu lowlands where period of underground flow is also long. In spring, water ponds are form on the right riverbank.

In the area of coastal lowland downstream of the R. Tobe-gawa, the surface water returns to the R. Shigenobu-gawa. The R. Shigenobu-gawa then flows northwest and enters the Iyo Sea approximately 8 km later. The stream gradient immediately downstream of the R. Tobe-gawa is approximately 5/1,000, becoming 2/1,000-3/1,000 further downstream. There are no meanders in the stream and the riverbed is covered with gravel. The elevation of both riverbanks decreases as the river approaches the sea, with the last 1-km section of the river estuary forming a tidal river and a low-water channel of marsh.

The Shigenobu-gawa alluvial fan spreads from its junction with the R. Omote-gawa and the area is used primarily for rice agriculture. This alluvial fan has a length of 4.5 km and a central angle of 80°, and the stream gradient in the area is as steep as 17/1,000. In the river of the alluvial fan, the water flows underground except during the wet season. The mountains near the outlet are characterized as having marked relief, and terraced plains with relative heights measuring approximately 20-50m are sticking to the skirt. The geomorphologic features of the alluvial fan become less apparent downstream of the R. Omote-gawa and it is accompanied with a mountain by

the terrace surface, the river valley is accompanied on the riverside by the river plain, and both banks are used for rice agriculture.

The R. Ishide-gawa joins the R. Shigenobu-gawa 4 km from the estuary. The Ishide-gawa alluvial fan is formed at the outlet of the R.Ishide-gawa in an area that has undergone extensive urbanization in recent years.

The Ono-gawa alluvial fan is smaller and spreads out at the right-bank mountains skirt of the Shigenobu lowland.

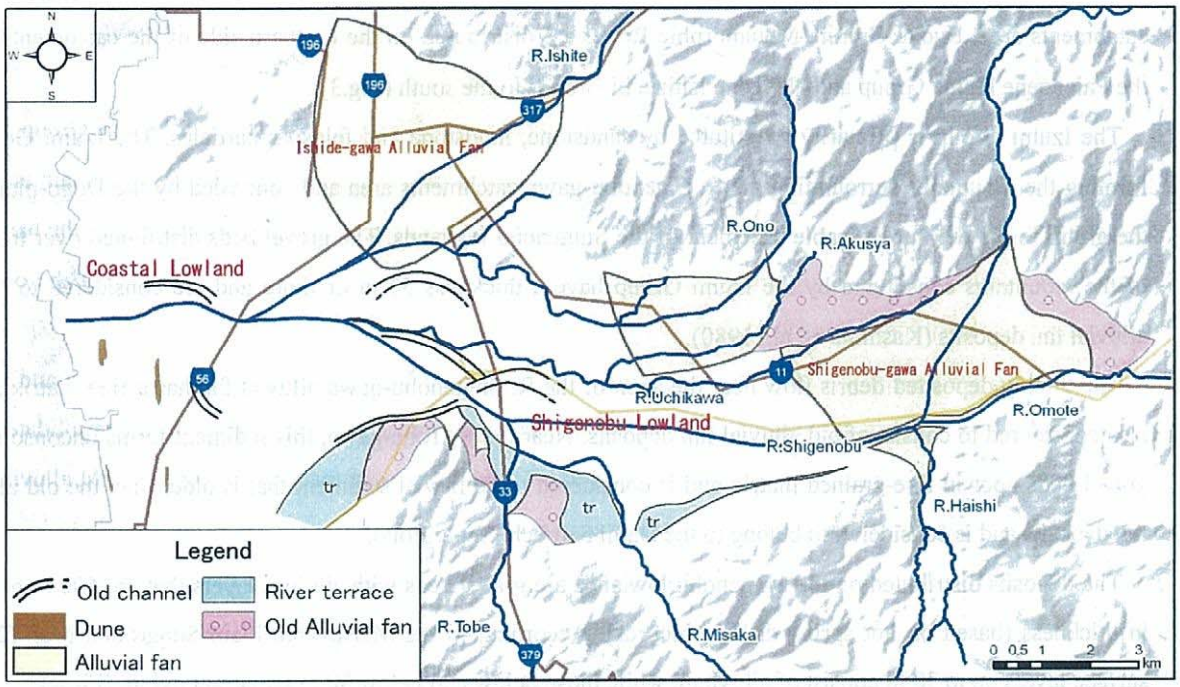

Fig.2 Topographical classification of the study area showing the different alluvial fans

3. Land-Use Changes and Water-utilization Environment

In this area, conversion of the lowlands and alluvial fans for rice cultivation has progressed with development of irrigation networks in the 20th century. The area under rice cultivation has increased at least 60% and a stable supply of irrigation water is necessary. Although Japan generally not considered to be a rainfall scarce area, the Dogo-plain has comparatively little rain and most of the rain falls from June to July; consequently, securing a constant supply of water from the rivers in the area for irrigation is difficult.

In addition, the relatively marked increase in the extent of urbanization within the catchments has meant that municipal and industrial water demand is also increasing.

Even if water reaches the floodplain, the steep gradient of the R. Shigenobu-gawa combined with the characteristics of the catchments mean that the river regime is not constant. Many subjects such as stream loss occurred, are held in utilization of surface water. Consequently, the dependence on groundwater increases every year, and groundwater drawdown is a serious concern given the need to supply water for domestic, industrial and agricultural use.

The springs that flow inland on the right riverbank of the R. Shigenobu-gawa have consequently became valuable water sources, numerous springs have been converted to artificial wells as the groundwater level has decreased.

4. Hydrogeology

4.1 Stratigraphy

The Cretaceous Izumi Group is widely distributed and forms the basement of much of the R. Sigenobu-gawa catchments area. Ryoke Granite-Metamorphic Rocks are distributed on the northern side of the catchments, with the Paleogene Kuma Group and Neogene Ishizuchi Groups to the south (Fig.3).

The Izumi Group is primarily constituted by sandstone, mudstone and feldspar particles. The Izumi Group is forming the mountains surrounding the R. Sigenobu-gawa catchments area and concealed by the Dogo-plain and the group forms the impermeable basement of the Shigenobu lowlands. The gravel beds distributed over the base of the mountains constituted by the Izumi Group have a thickness 50 m or more and are considered to be old alluvial fan deposits (Kashima et. al., 1980).

The thickly deposited debris flow near the apex of the R. Shigenobu-gawa alluvial fan has a fine matrix and is also considered to consist of old alluvial fan deposits. Near the R. Tobe-gawa, this sediment forms unconsolidated gravel beds poor in fine-grained matrix and is considered to be fluvial sediment that is older than the old alluvial fan deposits and is considered to belong to the Daini Setouchi Supergroup.

The deposits distributed on the Shigenobu lowlands are gravel beds with silt lens layers that are 600 m or more in thickness (based on hot spring drilling records). According to the Matsuyama Plain Subground Map (2003), surface layers up to 30 m consist of alluvium, while those below and below 30 m are pre-alluvium (Fig.4).

The alluvium consists of sandstone gravels from Izumi-Group with volcanic rock pebbles and granite pebbles. The surface layers are subrounded-rounded gravel with a poor matrix but rich in voids, particularly near the present-former riverbed. The discontinuous silt lenses concealed 20-30 m underground form the lowermost layer of the alluvium (Table 1, Fig.4).

The pre-alluvium gravel beds are poorly characterized, but it is likely that they are correlated with the old alluvial fan deposits.

Table 1 Hydrogeologic correlation table of the Dogo-plain

Geologic time			Formation	Stratigraphic Facies			Aquifer	Depth
				Coastal Lowland	Shigenobu Lowland	Shigenobu-gawa Alluvial Fan and Others		
Cenozoic	Quaternary	Holocene	Alluvium	Sand bed (intercalated silt layer)	Rounded-gravel bed with many voids (2.0×10^{-3} to 4.1×10^{-2} m/sec)	Fluvial Sediment (river bed)	Shallow	20–30m
				Gravel bed (intercalated silt layer)	Silt layer (lens-like thin layer)			
		Pleistocene	Old Alluvial Fan	Debris flow deposit (Fluvial sediment, Floodplain deposit)			Deep	
				(1.0×10^{-5}m/sec –)	(1.0×10^{-4}m/sec –)			
	Neogene	Pliocene	Second-Setouchi Group	Fluvial sediment (poor in the fine-grained matrix)	–			600m
			(Ishizuchi Group)	–			–	
	Paleogene	Eocene	(Kuma Group)	–				
Mesozoic/Cretaceous			Izumi Group	Sandstones and Mudstone			Impermeable Basement	

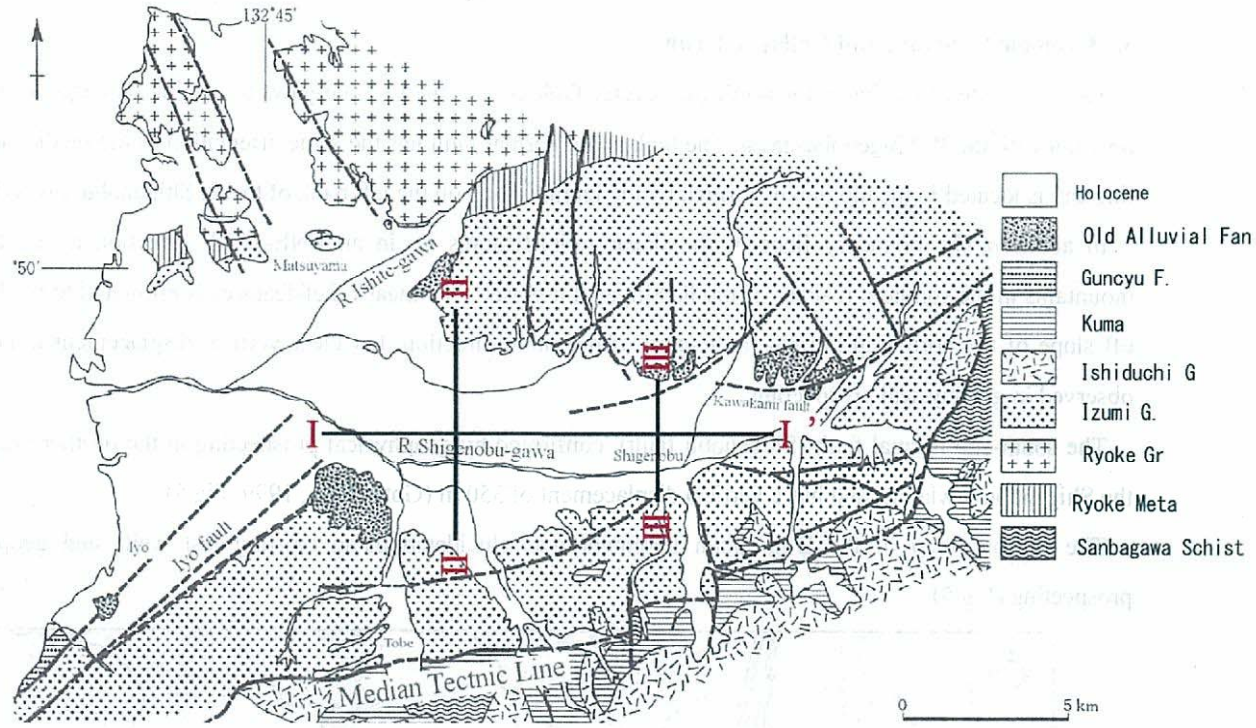

Fig.3 Geological map of the Dogo-plain (from Kajima et. al., 1980)

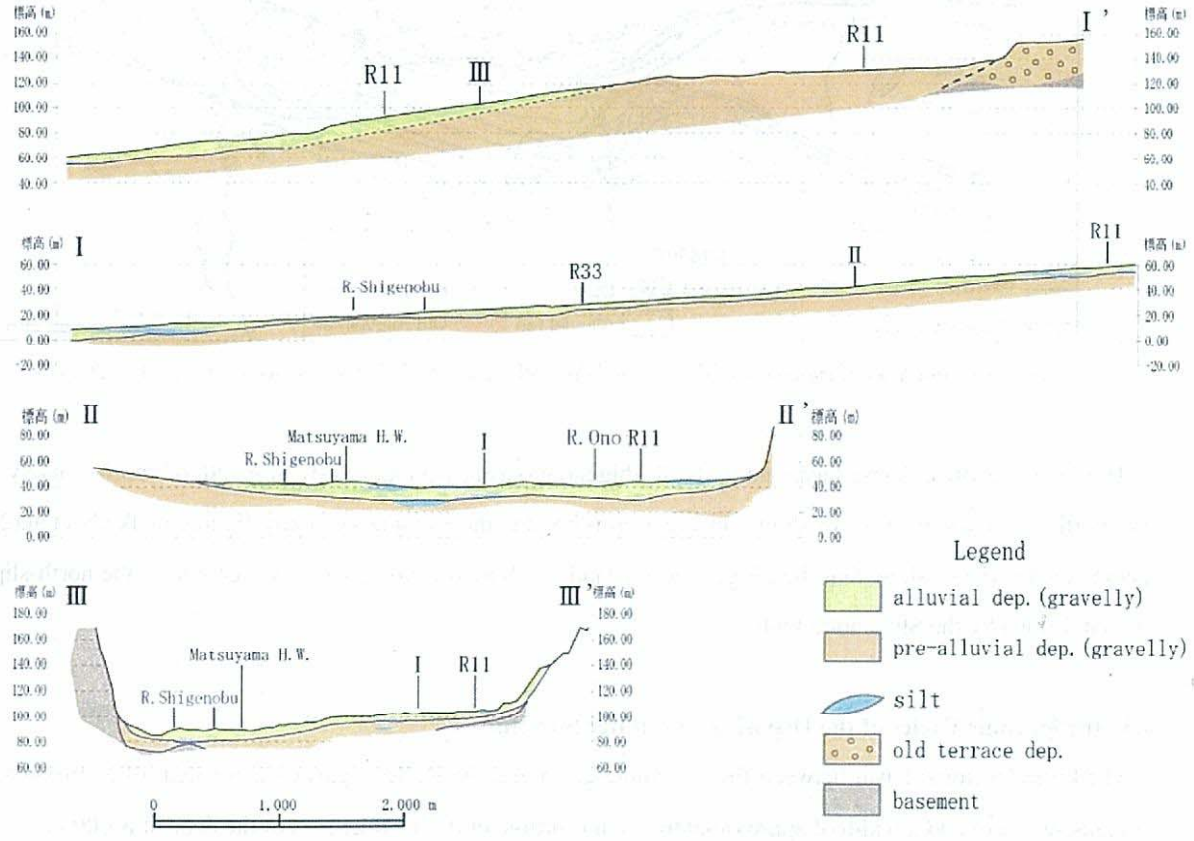

Fig.4 Geological section (with geotechnical map of the Matsuyama Plain, 2003)

4.2 Geologic Structure and Collapse Basin

The median tectonic line of the north slip reverse fault crosses the R. Tobe-gawa at a point 6 km upstream of the junction with the R. Shigenobu-gawa. The high angle normal fault has the same orientation as the median tectonic line and is located in the mountains formed by the Izumi Group on the left bank of the R. Shigenobu-gawa (Fig.3).

In addition, the boundary lines of the linear relief-features lie in an ENE-WSW direction at the base of mountains in the southern reaches of the R. Shigenobu-gawa. The linear relief-features is estimated to be the back off slope of the north-slip normal fault scarp of the same direction, but clear vertical displacement is not been observed in geophysical prospecting.

The south-slip normal fault (Shigenobu fault), confirmed by geophysical prospecting in the northern region of the Shigenobu lowlands, and has a vertical displacement of 350 m (Goto et. al., 1999, Fig.5).

The contour map of the Dogo-plain basement was elucidated using existing test wells and geophysical prospecting (Fig.5).

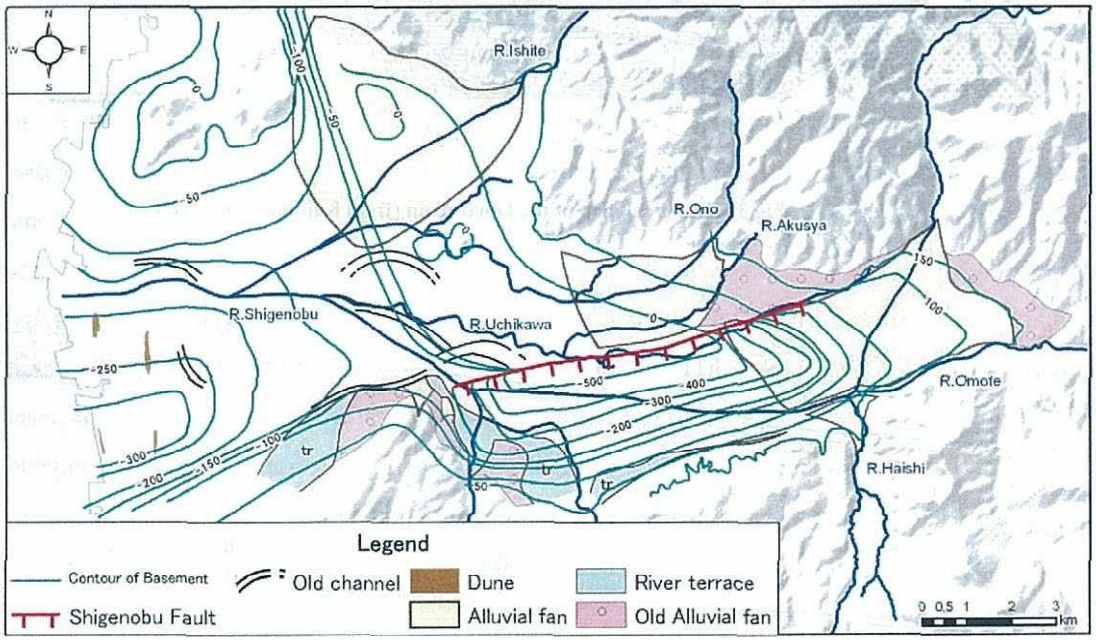

Fig.5 Contour Map of Basement of the Dogo-plain (with Ikeda et. al., 2003 and Geotechnical Map, 2003)

The long, narrow collapse basin along the R.Shigenobu-gawa, with an east-west length of approximately 8 km and north-south width of 3 km shown in Fig.5 corroborates the Bouguer-anomaly figures of Ikeda et.al.(2003). These characteristics show that the Shigenobu lowland is a buried tectonic basin, which buried the north-slip half graben formed by the Shigenobu fault.

4.3 Stratigraphic Facies of the Deposit and Aquifer Structure

The buried tectonic basin between the R. Omote-gawa and the R. Tobe-gawa has a length of approximately 8 km (east-west) of and a width of approximately 4 km (north-south). The thickness of the deposit is 600 m.

In the development of this tectonic basin, it is considered that the fluvial deposit was formed by the debris flow

deposit, which was formed by the fluvial or the floodplain deposits. The surface alluvium is primarily composed of rounded-gravel with numerous voids, intercalated with thin lens-like silt layers (Fig.4).

In the alluvial fans of the R. Shigenobu-gawa and the R. Ono-gawa, debris flow deposits were mainly composed of deposits as well as surface layers and fluvial sediments are inserted along former riverbeds.

The aquifer is divided into two types of aquifers, the shallow aquifer is in the surface gravel bed with many voids and the deep aquifer is in the debris flow deposit.

In the area of coastal lowland, the area extending downstream from the R. Tobe-gawa, the thickness of the gravel bed decreases toward the seashore. The surface alluvium near the confluence of the R. Shigenobu-gawa is primarily composed of gravel beds with numerous intercalated silt layers. However, 4 km downstream in the R. Shigenobu-gawa in the coastal lowland, the surface alluvium is mainly composed of sand beds with silt layers. The characteristics of the shallow aquifer differ between the Shigenobu and the Coastal lowland areas, with the distribution of wells in the coastal lowland becoming increasingly sparse.

4.4 Permeability

Permeability tests were restricted to Matsuyama City (Fig.6). Due to administrative constraints, most of the tests were carried out in shallow wells in the alluvium layer near R. Uchi-kawa. The test results revealed that the permeability coefficient in the area surveyed ranged between 2.0×10^{-3} to 4.1×10^{-2} m/sec. Given that the gravel transported by the larger R.Shigenobu-gawa is likely to consist of lager particles, the permeability of the R.Shigenobu-gawa is likely to be greater than that observed for the R.Uchi-kawa.

On the other hand, comparisons of pre-alluvium from the Shigenobu lowland, which is buried tectonic basin, and coastal lowland areas revealed that the areas had permeability of 10^{-5} m/sec and 10^{-4} m/sec, respectively. Because the debris flow deposits with many voids is mainly in pre-alluvium on the Shigenobu lowland.

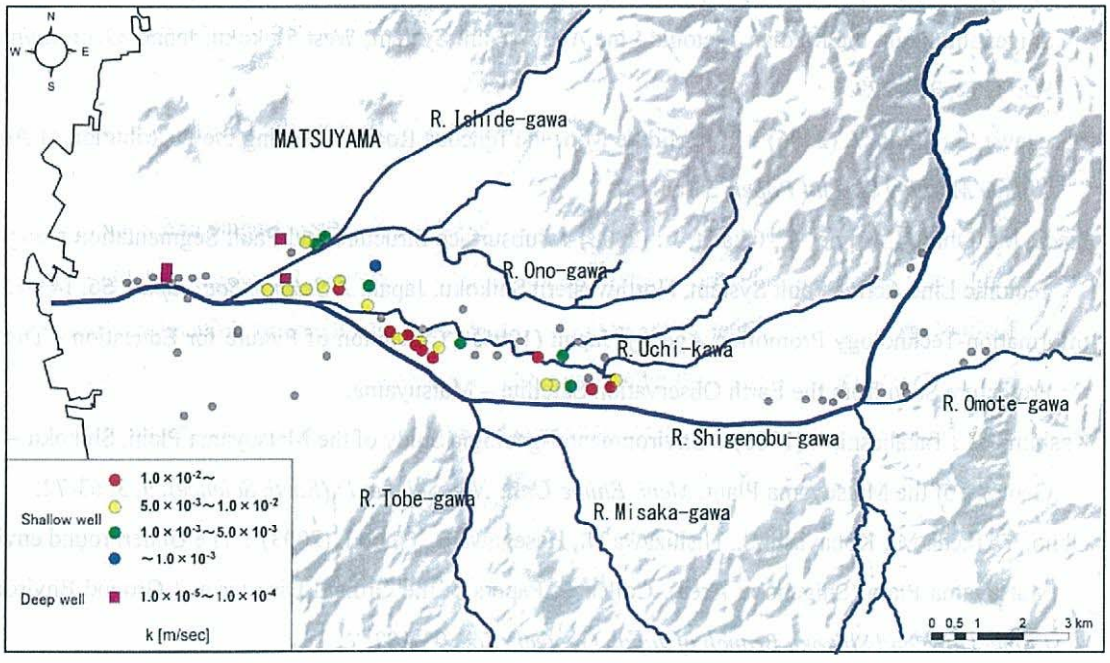

Fig.6 Location of Pumping-test Wells and there permeability

5. Conclusions

(1) The Dogo-plain is divided into the Shigenobu lowland, which is upstream of the confluence the R.Tobe-gawa, and the coastal lowland, located downstream of the confluence.

(2) The Shigenobu lowland is a buried tectonic basin with deposits consisting of debris flow deposits originating from the surrounding mountains. The thickness of the deposit is at least 600 m.

(3) Small-scale alluvial fans, such as the Shigenobu-gawa alluvial fan and Ono-gawa alluvial fan are still evident.

(4) The gravel bed that covers the surface of the Shigenobu lowland is characterized as having numerous voids resulting from repeated deposition of eroded debris flow deposits, and formed different aquifer in lower debris flow deposit.

(5) In the coastal lowland, the surface alluvium near a river confluence is mainly composed of a gravel bed with aquifer. Downstream of the coastal lowland, the surface alluvium is composed mainly of sand beds which have a lower permeability than gravel beds.

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References

Ehime Construction Research Institute (2003) : Geotechnical Map of the Matsuyama Plain, 2003.

Goto, H., Nakata, T., Okumura, K., Ikeuchi, A., Kuramura, Y., Takada, K. (1999) : Holocene Faulting of the Shigenobu Fault, the Median Tectonic Line Active Fault System, West Shikoku, Japan. *Geography Rev. Japan Ser. A*, 72, 267-279.

Hasegawa, S., Ohno Y. (2006) : The Middle Miocene Igneous Rocks Affecting the Distribution of Active Faults. *Chikyu Monthly Special Paper*, 54, 50-58.

Ikeda, M., Ohno, I., Ohno, Y., Okada, A. (2003) : Subsurface Structure and Fault Segmentation along the Median Tectonic Line Active Fault System, Northwestern Shikoku, Japan. *J. Seismo. Soc. Japan*, 56, 141-155.

Information-Technology Promotion Agency, Japan (1995) : Collection of Picture for Education - The Seat of the Prefecture Seen from the Earth Observation Satellite – Matsuyama.

Kashima, N., Takahashi, J. (1980) : Environmental-geologic Study of the Matsuyama Plain, Shikoku – 1. Regional Geology of the Matsuyama Plain. *Mem. Ehime Univ. Nat. Sci. Ser.D (Earth Science)*, 9, 3, 63-72.

Ohno, Y., Ikeda M., Kobayashi S., Nishizawa N., Hasegawa S., Ohno I. (2003) : The Underground environment of Matsuyama Plain (Shigenobu Area), Collected Papers of the Ground Disaster and Ground Environ. Problem. *Ehime Univ. and Shikoku Branch of Japan Geotech. Soc.* 93-102.