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On the Groundwater of Nishinomiya District, Kinki, Japan —with Special Reference to the Characteristics of Permeability of the Aquifer and Chemical Composition of the Miyamizu—

By

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—with 10 Text figures and 2 Tables—

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ABSTRACT

The geological structure and constituents of aquifer and chemical composition of the groundwater of Nishinomiya city, Kinki, Japan were investigated. The Miyamizu, a brewing water of the city has long been known as a most suitable water for brewing purpose of japanese Sake. The district is composed of Alluvial sediments and the aquifer of the district is restricted to the Alluvial sediments which can be divided into several zones according to its permeability. The Miyamizu aquifer corresponds to the first aquifer(higher than 5×10^{-2} cm/sec) and with increasing the depth, permeability decreases gradually. The basement of the sediments is consisted of the aquiclude with permeability smaller than 5×10^{-4} cm/sec.

Based on the analysis of the groundwater levels, it is clarified that the groundwater flowing into the Miyamizu aquifer comes from several underflows of the old rivers, and each old river has its own chemical characteristics. Chemical composition of the Miyamizu is characterized by high contents of phosphorous, potassium and calcium and very low content of iron. Variation of the chemical composition of the Miyamizu for long years, seasonal and monthly variations are clarified. Concerning the formation process of the chemical characteristic of the Miyamizu, it is concluded that the present composition is formed under the great influence of Paleo-environment of about 1,000 years ago, i.e., so-called the Jōmon transgression, especially in relation to the development of shallow sea.

CONTENTS

I. INTRODUCTION

A part of the groundwater in the southern district of Nishinomiya city is well known as Miyamizu, and is very famous as high quality water for brewing of japanese Sake. Both Miyamizu and Ki-ippon of Nada are famous. Improvement of Nishinomiya port took place in the late 1900's to early 1910's. Since the brewing wells were close to the port, they were suffered brineing and the brewing wells were transfered to the northeast region (see, Fig. 3). The great increase of pumping discharge after the Word War I caused the exhaustion of the Miyamizu, and the first Preservation and Research Committee of Miyamizu was organized. As the early results obtained by investigation of the Committee, the following contributions were reported; Ogawa and Ueji (1926) on the outline of geology of Northern district of Nada, Ogawa (1926) on geology and groundwater, Matsubara and Sakurada (1926) on the chemical composition of underground water of the district. Subsequently, Matsubara (1926, 1927) studied the groundwater of the Nishinomiya district and Ueji (1927, 1936, 1937) and Huzita et al. (1959) investigated the geology of the same district. After that, demand of the brewery water gradually decreased and the Committee ceased to operate. In the meantime, salt content of the Miyamizu increased abruptly after the high tide caused by the Muroto typhoon on 1934, and new wells were drug in a more northern area of the district. From 1930 to 1945, a small amount of the groundwater was used and no brine problem was occurred. As the demand of water increased after the World

War II, the second Preservation and Research Committee of Miyamizu was reorganized. In 1953, the Research Committee for groundwater in Nada district was organized in relation to the reclamation of the east sea beach of Kobe city. The author became the professional hydraulic consultant of this Committee. Since that time, the development of Nishinomiya city and the surrounding district, new civil engineering works had been executed and the groundwater was researched at each site to assess the state of the water. The pumping discharge area of the Miyamizu has gradually transfered from the sea shore to the north district, and nowadays it is in an area about 500 m long in the south-north direction and 300 m in east-west direction (see, Fig. 3). For about 35 years, the author has studied on the Miyamizu from hydraulic and geological point of view as well as on the seasonal and temporal variation of the chemical characteristics. In this paper, based on the numerous data collected by the author during past 35 years, the characteristics of the Miyamizu will be clarified, and furthermore, the origin and/or genesis will also be discussed.

Acknowledgments

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II. EXAMINATION OF PERMEABILITY OF THE AQUIFER

The geology around the Miyamizu area, southern part of the Nishinomiya district is composed of the Itami gravel bed of upper Pleistocene age and Alluvium sediments. The author has already reported the outline of the constituents, thickness and distribution of the Itami gravel bed and the Alluvial sediments (Sumikawa, 1961). The Itami gravel bed is composed mainly of gravels of granite, shale and sandstone of Paleozoic and volcanics such as liparite. The gravels are generally rounded with diameter of 3 to 10 cm. Thin clay and/or silt bed is intercalated. When regarding the Alluvial sediments as an aquiferous beds, permeability is the most important factor. Therefore, the Alluvial sediments were classified based on the permeability (k value) in this paper. Measurements of the k value were performed using pumpimg and impregating methods. In addition, permeability was also measured in the laboratory on carefully collected samples, so as to get precise results. The measurement was conducted about 20 cm intervals, considering the heterogeneity of the Alluvial sediment. All k values described in this paper are average value of several measurements. In the following, the outline of permeability of the Alluvial sediment will be first described, then, the Miyamizu aquifer will be examined in detail.

A. Zonal Arrangement of the Aquifer

As an representative example of the area, a E-W cross section along National Road No. 2 in Nishinomiya city, is shown in Fig. 1. This is a typical example of the zonal arrangement of the Alluvial sediments based on the k value. The Miyamizu area situates about 0.6 km south of the Rokutanji river located at the center in Fig. 1. As is seen in the figure, k value decreases gradually from the upper to the lower inspite of the heterogeneity of the constituents and non continuous property. In some cases, the ground surface is covered with a thin clayey soil. However, the upper sediment is, in general, high quality aquifer with k value higher than 5×10^{-2} cm/sec throughout the whole section. The Alluvial sediments are composed of medium and coarse grained sand with some light yellow brown colored gravels and are developed from the surface to 2 or 3 m depth. Although dark blue grey colored fine sediment rich in organic materials and seashells are intercalated in some parts, the most of the sediment is composed of sandy gravel. In this paper, this sandy gravel bed is called the first aquifer. What is remakable in Fig. 1 is that the k value gradually increases with depth. This fact seems to occur because the diameter of the sands is homogenized by sorting and fine grains are discharged from the sediments during the transportation of the sediment. Since the first aquifer is the source supply of the Miyamizu, detailed structure of the aquifer in the Miyamizu area will be examined in the following section. Sediments with the k values of 10^{-3} to 10^{-4} cm/sec are developed under the first aquifer. The layer is composed of fine sands with dark grey colored blue silts characterized by intercalation of thin layers of iron hydroxides. As is seen in Fig. 1, the thickness of the layer varies from place to place. In addition, the layer characteristically contains organic materials and in some parts shallow seashells. The intermediate sediment with k value of about 10^{-2} cm/sec is composed of sandy gravels but the continuation of the sediment is relatively poor. The lowest part of the layer is rich in clay and black humic soil, and finally unconformably overlies the Itami gravel bed. This lowest layer plays a role of aquicludes for the first aquifer.

The average thickness of the Alluvial sediments including the first aquifer is about 15 m in this cross section and approximately 18m in the Miyamizu area. Under the Alluvial sediments, i.e., beneath the unconformity, high permeable gravel bed is developed throughout the district. The thickness of the gravel bed varies in the range from a few to about 8 m. The k value of this

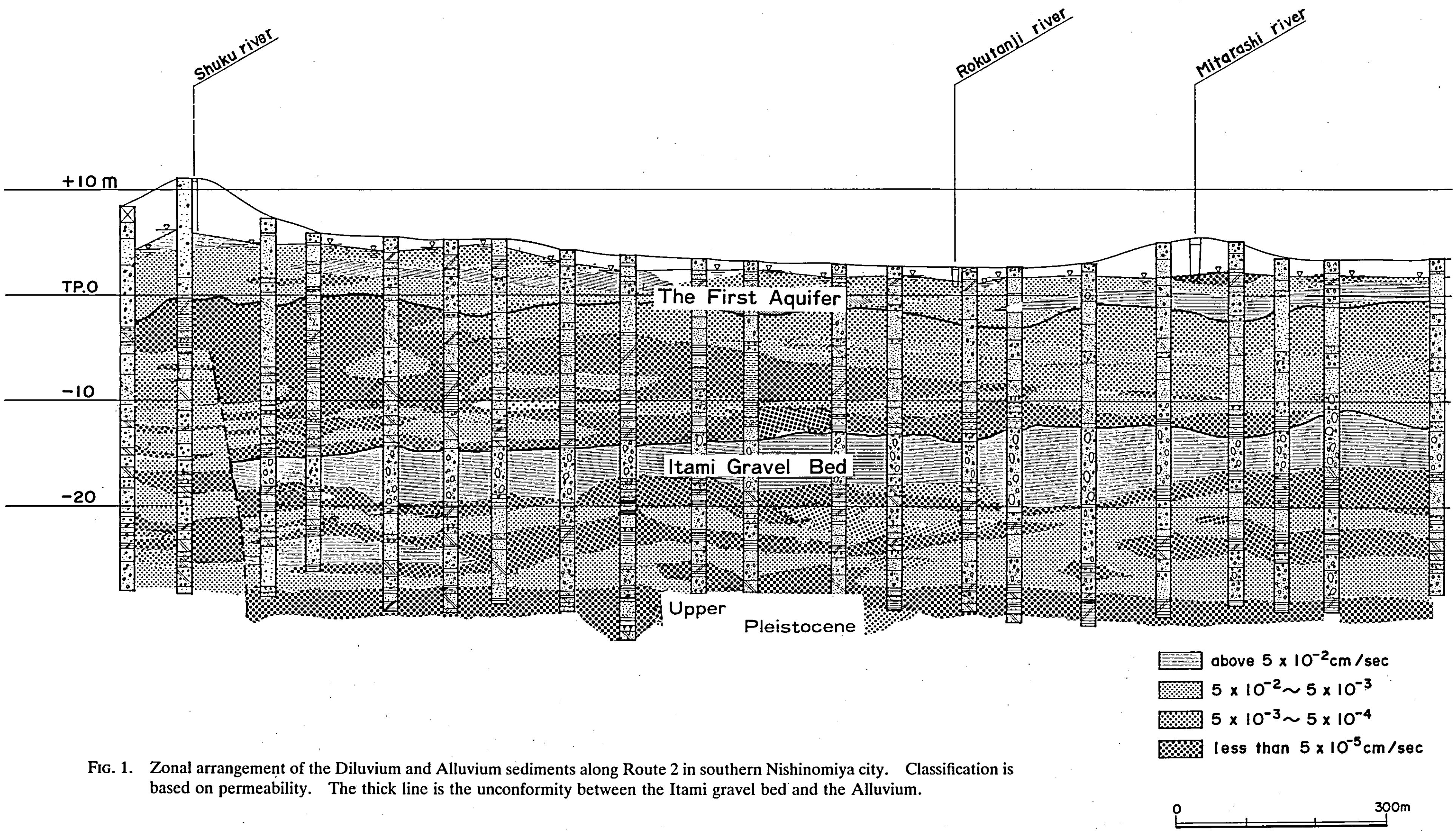

FIG. 1. Zonal arrangement of the Diluvium and Alluvium sediments along Route 2 in southern Nishinomiya city. Classification is based on permeability. The thick line is the unconformity between the Itami gravel bed and the Alluvium.

bed is higher than 10^{-2} cm/sec., and this bed corresponds to the second aquifer with respect to the k value, and stratigraphically belong to the Itami gravel bed of the upper most Pleistocene. The main constituents are gravel of granitic rocks, liparite and Paleozoic rocks with diameter of 3 to 15 cm and, in some parts, fine sands are intercalated. The k value varies from place to place in the range above 10^{-2} cm/sec. This gravel bed suddenly disappears near the Shuku river (left end part in Fig. 1) where probably exists a small fault which may continue to the "Itami fault" described by Fuzita (1967).

B. Miyamizu Aquifer (The First Aquifer)

As a typical example illustrating the structure of the aquifer in the Miyamizu area, a cross section along National Road No. 43 is shown in Fig. 2. Sediments shown in the figure is restricted mainly to the first aquifer mentioned above. The k value of the first aquifer is higher than 5×10^{-3} cm/sec. It is noted that the lowest part of the aquifer is composed of clay-rich layer with low permeability. As observed in the figure, k value in the first aquifer is very complicated, and in some cases it varies only within a several tens cm in both horizontal and vertical directions. In the NS profile perpendicular to the A_1-A_2 direction of Fig. 2, the k value shows more complicated variation which will be mentioned in the next section. The reason of this complex variation is caused by the fact that the three dimensional distribution range of the sediments is very small. Such detailed structure could be revealed by the testing method using waterless boring, i.e., without using bentonite during the boring process. That is, mixing of mud in the specimen obscure the true k value. Successive sampling has also helped to establish the the detailed structure. Thus, the results as shown in Fig. 2 are obtained.

The maximum k value in the aquifer reaches 3×10^{-1} cm/sec, and the minimum is 2×10^{-3} cm/sec. Concerning the sandy gravel with diameter less than 2mm, high permeability of the layer is the result of sorting. Well sorted and equi-granular sediment improves the k value. In other words, k value is high when the sediment does not contain excessively fine grains. In all bored columnar sections, the sandy gravel layer of the first aquifer contains rarely large grains about 5 cm, but in general, the layer is composed of well sorted sand with high k

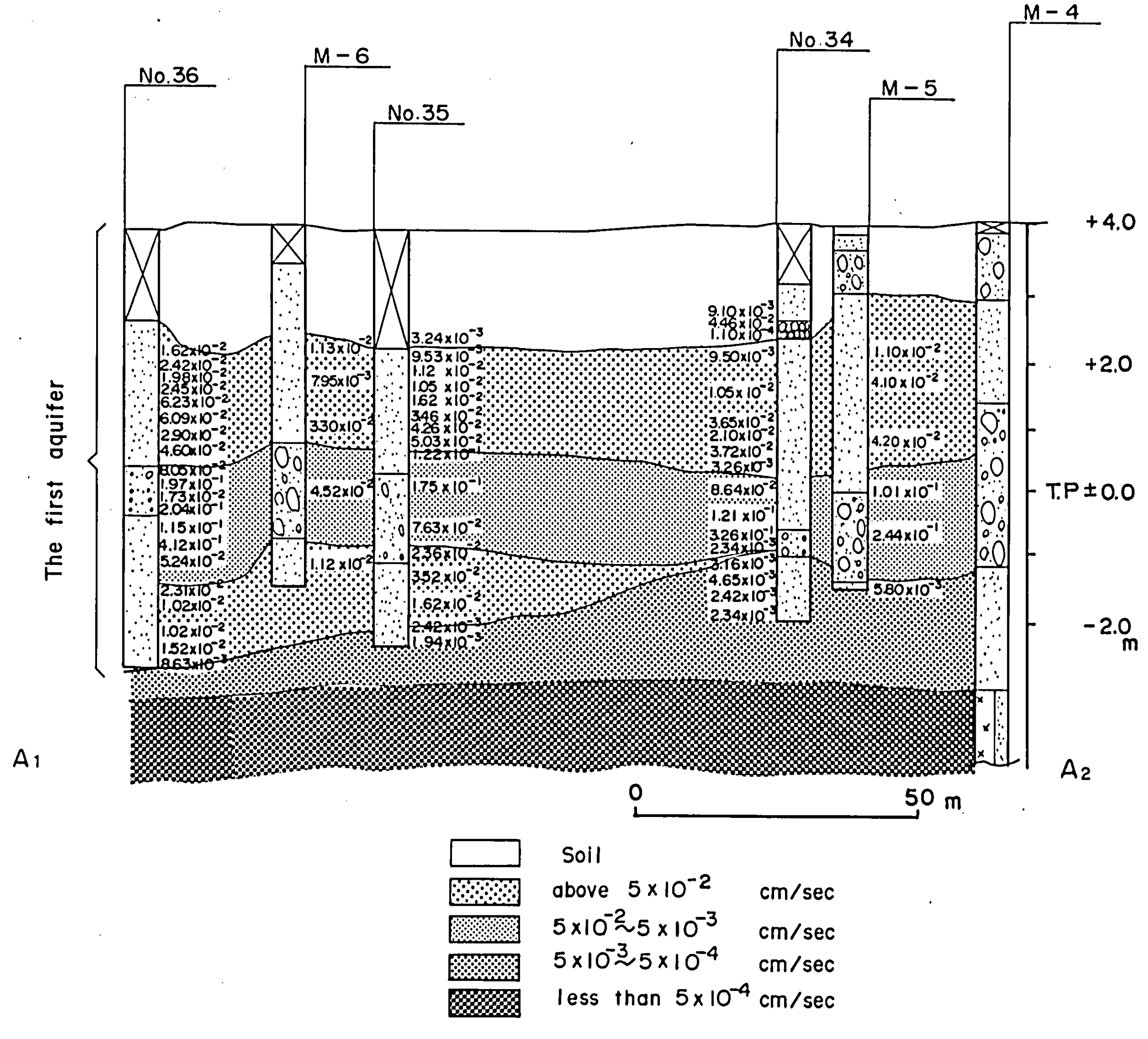

FIG. 2. Detailed classification of the first aquifer (Miyamizu aquifer) based on permeability. The profile line of A_1-A_2 is shown in Fig. 8.

value. The size of gravels in the columnar section of No. 34 is relatively small compared with that of M-6 and No. 35. This also support the small extension of the respective sediment. However, in the cross section as a whole, aquifer with high k value of 10^{-1} cm/sec continues throughout the district. The fact that the sandy and gravel beds are cut into pieces is a characteristic feature of sediments in the Alluvial fan. All wells for brewing purposes in the Miyamizu area are drug into this sandy gravel layer. Just beneath the sandy gravel layer, a thin bed with k value far lower than the other is developed as is shown in Fig. 2. In general, the aquiclude contains thin limonite layer and is composed of mainly fine sand. In some cases, the fine sandy layer contains shallow seashells. Attentions have been payed that the wells for brewery use do not reach the limonite layer developed on the upper most part of the aquiclude. This is because closely related to water quality, and will be described later. The impermeable layer distributed at the lowest portion of the figure with k value lower than 5×10^{-4} cm/sec is fine sand accompanied with silt of dark grey color which plays as aquiclude supporting the Miyamizu. Although the layer is consisted of partly sandy sediments, as a whole, the layer is relatively impermeable. The groundwater level on this district does not descend below this layer.

III. Groundwater Tables

As mentioned in the previous chapter, the Alluvial sediments have brought by the Shuku river originated in the Rokko mountains and by the Muko river originated in the northern mountains. The thickness of these sediments are approximately 20 m and 30 m in the areas close to Nishinomiya port and at the Muko river estuary, respectively. This Alluvial sediment has mostly developed as a delta. The upper sandy gravel layer of the Alluvial sediment which is also the foreset bed of this delta, corresponds to the Miyamizu aquifer mentioned in the previous chapter. In this chapter, real state of the groundwater in these sediments is intended to clarify.

The groundwater level of the southern part of Nishinomiya city at the winter time of 1961 is represented by contour lines in Fig. 3. The present Miyamizu area is also shown in the figure. In addition to the present rivers, the underflow of old river also have an great influence on the groundwater level. Therefore, the wa-

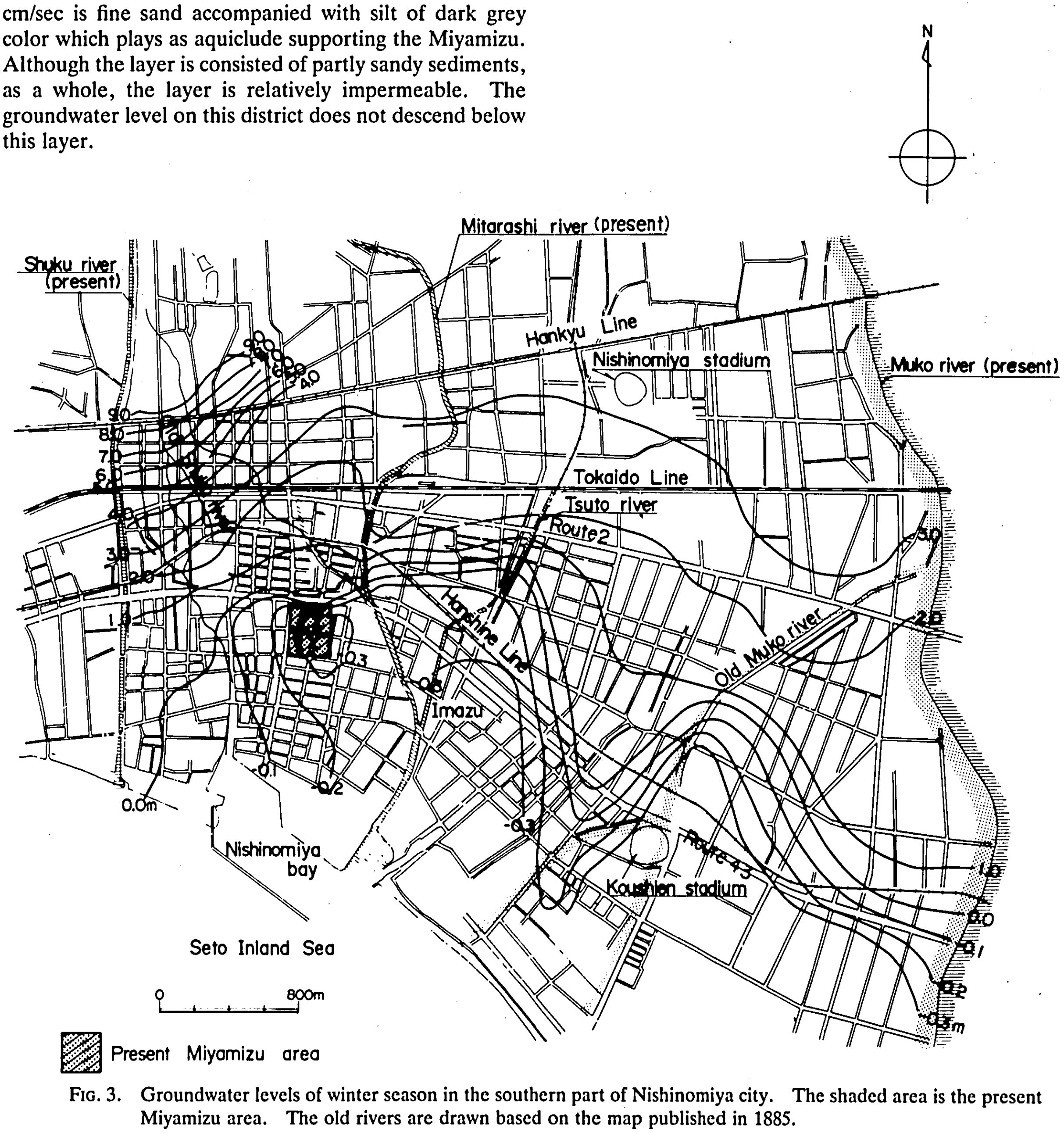

Fig. 3. Groundwater levels of winter season in the southern part of Nishinomiya city. The shaded area is the present Miyamizu area. The old rivers are drawn based on the map published in 1885.

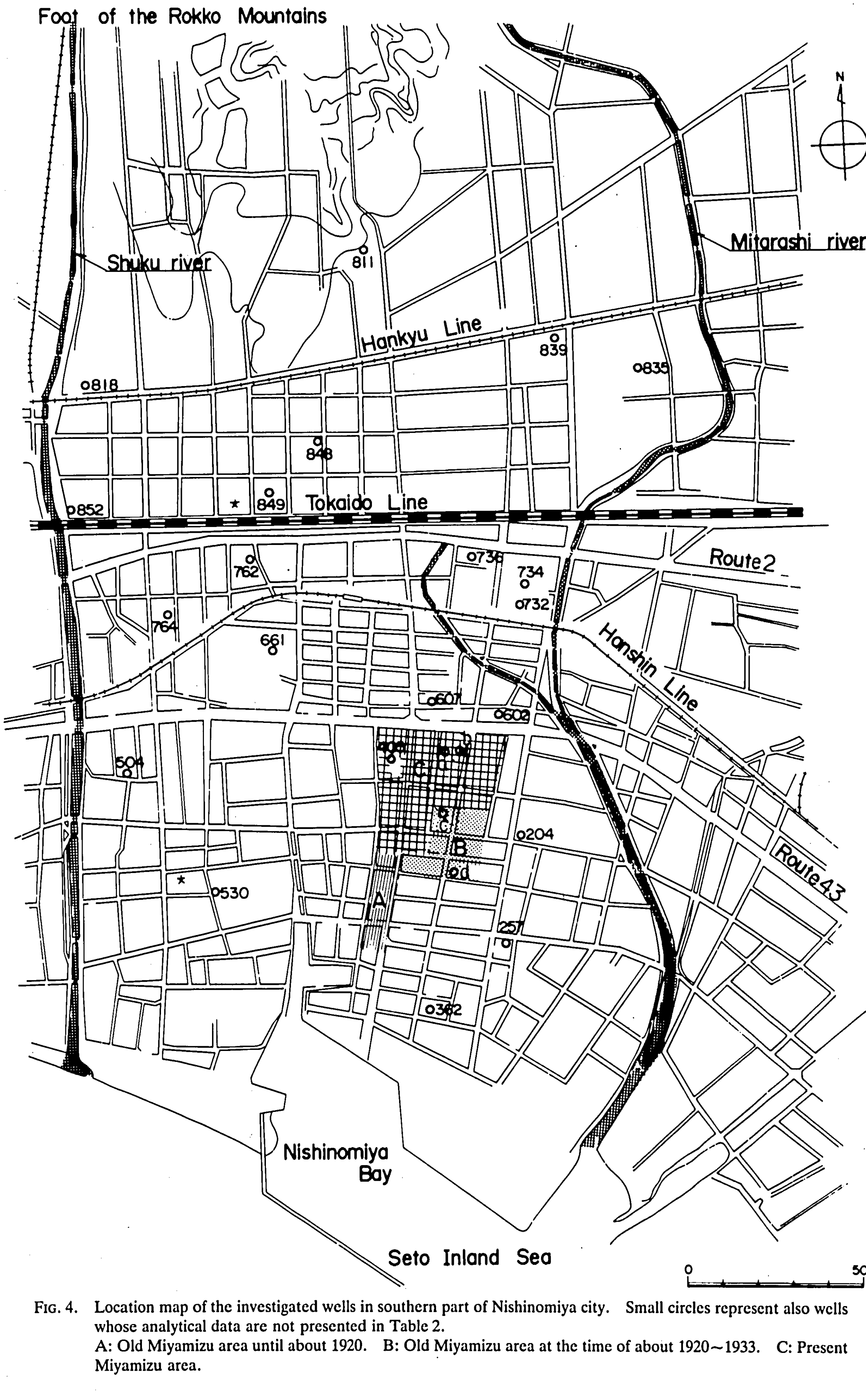

FIG. 4. Location map of the investigated wells in southern part of Nishinomiya city. Small circles represent also wells whose analytical data are not presented in Table 2.
A: Old Miyamizu area until about 1920. B: Old Miyamizu area at the time of about 1920~1933. C: Present Miyamizu area.

ter course of old rivers obtained from a map published in 1885 are also shown in the figure. Contour lines are recorded for every 10 cm below the 0 m level, because the water level in the Miyamizu area is close to the level. The precise cross section of the Miyamizu aquifer described in the previous is located on an east-west line at the north end of the Miyamizu area shown in Fig. 3. As is seen in this figure, two large underflow drainages are noted in this district. One is the present Muko river and the other is old Shuku river drainages, respectively. The former drainage originated in the north-west end of the figure. The triangular area of which the two edges are the present current of the Shuku river and the line between the upstream Shuku and Imazu, is most probably considered as the old Shuku river fan. The center of the present Miyamizu area (shaded area in Fig. 3) is located near the center of this triangle. The old Shuku river drainage is assumed to flow from the north-west end of the figure down to south-east direction cutting almost perpendicular to the contour lines of groundwater level. The main source of the present groundwater of the Miyamizu area is derived from this underflow. Together with the central Tsuto river and underflow water of the Muko river drainage coming from the north, the artificially constructed Mitarashi river play also role of supplying groundwater to the Miyamizu area. For the whole area of the southern Nishinomiya district including the Miyamizu area, both the Muko and Shuku river drainages are important as underflow water. Thus, groundwater in the Miyamizu area mainly comes from the Shuku and Mitarashi rivers originating in the Rokko mountains composed mainly of granitic rocks. Interesting facts are noted when comparing the hydraulic gradients of the both drainages. In the area between the Hankyu and Tokaido lines, the western hydraulic gradient of the Shuku river is about 1/150 to 1/200 and that of the Muko river from the east is about 1/400 to 1/600, respectively. Between the Tokaido line and National Road No. 43, the former is approximately 1/300 and the latter is 1/500 to 1/600, respectively. In both cases, the existence of groundwater diversion should be considered. The upstream of the Shuku river drainages is supplied by river diversion as shown in Fig. 3. Considering the distribution density of the contour lines, small temporary storage of Shuku and Mitarashi river drainage are reasonably expected. This temporary storage has an important influence on the chemical properties of the Miyamizu. The groundwater level in winter time, i.e., dry season, is shown in Fig. 3. In summer, the pluvial season, the groundwater level rises not only because the rainy season but also the decrease of the pumping discharge in the Miyamizu area. Thus, the groundwater level of the Miyamizu area rises about 60 cm in summer. As a result of this, underflow water flows towards the east, in a south-eastery direction corresponding to the general flow direction of drainage of the Shuku river groundwater. The coastal groundwater is, as mentioned in the following chapter, controlled largely by the tide level. The main reason why the Miyamizu area have moved gradually to the north (Fig. 4) is the effects of the brine content in the groundwater. The difference between monthly average tide levels for winter and summer is about 25 to 45 cm, although some annual variation does exist (see, Fig. 7 in the later chapter). The contour line of water above 3 m from sea level, only a small summer/winter variation is recognized.

IV. Chemical Characteristics of the Miyamizu

A. Chemical Composition

As was described in the above chapter, the groundwater in this area is mainly contained in the first aquifer (Miyamizu aquifer) developed within 5 m below the ground surface. The water for the brewery in the Miyamizu area is pumped from this aquifer and this water is commonly called Miyamizu. Because of the usefulness for brewery purpose, many analysis data on the chemical properties of this water have been reported (Kano, 1953; Sumikawa, 1957; Iwai and Sumikawa, 1964; Kusaka, 1980). Although there exist some annual, seasonal and monthly variations, these analysis data show definitive characteristic chemical composition of the Miyamizu compared with groundwater of other districts. The average chemical composition of the Miyamizu is shown in Table 1 in comparision with other brewing water in Japan. As observed in the Table, the Miyamizu is characterized by 1) high phosphorous content, 2) high potassium content, 3) very low iron content and 4) relatively large amount of ignition loss. Among these characteristics, high phosphorous and potassium (including sodium) content promote fermentation at the brewery, and the low iron content is useful for making the flavour of "sake" refreshing. In the following, chemical properties of the Miyamizu posessing the above noted characteristics are more precisely examined. As has been mentioned, annual variation of chemical composition of the Miyamizu is, in general, very small. Representtative analytical results of the groundwater taken from 25 wells in the Nishinomiya district at the time of summer of 1985 and winter of 1986 are shown in Table 2. The both values represent clear difference in chemical omposition between the pluvial and dry seasons. In Table 2, the resistivity, the value largely depends on the cation concentration is also shown. The locations of these

Table. 1. Chemical characteristic of "Miyamizu" brewing water. The data are taken from Kano (1953).
* Average value of 11 brewing water in Miyamizu area.
** Average value of 65 brewing water in Japan without those of the Miyamizu.

Element		Miyamizu *	Brewing wate in Japan **
pH.		6.98	6.71
ig. loss		301.4	255.9
Si	ppm	11.5	10.5
Fe	〃	0.0023	0.006
Al	〃	0.262	0.295
Ca	〃	37.2	27.1
Mg	〃	5.61	6.97
Mn	〃	0.04	0.05
K	〃	19.7	11.9
Na	〃	32.1	32.1
P	〃	2.28	0.19

TABLE. 2. SELECTED CHEMICAL COMPOSITION OF THE GROUNDWATER IN NISHINOMIYA CITY.
*1 LOCATION OF WELLS ARE SHOWN IN FIG. 4.
*2 ANALYSED DATA: S85: JULY 4, 1985, W86: FEBRUARY 4, 1986.
*3 THE VALUE IS AMOUNT OF 1/50 N. H_2SO_4 CONSUMED TO OBTAIN THE pH VALUE OF 4.5 WHICH IS EQUIVALENT TO TOTAL AMOUNT OF HCO_3^-.

No.	Date	Temp	Resistivity	Total alkali	Cl	PO_4	Na	K	Mg hardness	Ca hardness
※1	※2	℃	Ω・cm at20℃	$CaCO_3$※3 ppm	ppm	ppm	ppm	ppm	CaOmg/100ml	CaOmg/100ml
a	S 85	18.8	1930	126	47	5.9	36.0	12.1	1.6	7.6
	W 86	16.5	2460	85	40	6.1	33.0	11.0	0.9	6.3
b	S 85	19.0	2320	92	28	4.8	17.5	11.4	0.7	5.4
	W 86	16.0	2460	128	35	4.1	26.0	12.0	0.7	9.7
c	S 85	18.2	2600	102	41	3.7	32.5	8.0	1.8	5.5
	W 86	16.8	2710	88	34	4.0	26.0	7.8	0.6	6.6
d	S 85	18.5	2290	92	44	3.6	35.0	11.4	1.1	6.3
	W 86	16.0	1970	100	62	3.9	51.5	12.8	2.6	5.8
204	S 85	20.0	3540	62	28	3.0	19.5	7.0	0.5	5.0
	W 86	13.5	2790	88	34	3.7	24.0	7.5	2.8	5.8
257	S 85	18.5	4580	42	25	4.4	21.5	6.5	1.7	2.0
	W 86	14.0	2950	76	35	2.0	30.5	9.3	2.0	4.4
362	S 85	19.0	3120	72	37	3.2	25.0	10.3	2.4	3.0
	W 86	14.5	1570	110	92	3.0	65.5	14.0	2.1	7.6
405	S 85	18.0	2550	76	42	3.4	21.5	11.0	0.7	6.2
	W 86	13.5	2260	88	41	4.0	30.5	10.8	0.8	6.9
504	S 85	20.0	3330	75	33	2.0	18.0	5.7	0.8	4.6
	W 86	12.0	2990	90	38	1.1	32.0	5.8	0.9	5.0
530	S 85	20.0	2810	100	41	1.1	20.0	6.5	1.3	5.4
	W 86	9.5	2810	108	28	2.0	25.0	6.6	1.1	6.3
602	S 85	17.0	2700	90	32	2.3	25.5	10.3	1.1	5.5
	W 86	13.5	2160	102	35	2.5	30.5	9.6	1.3	8.1
607	S 85	17.5	3020	52	36	4.8	25.5	6.2	1.2	3.9
	W 86	15.5	2440	76	47	5.2	37.5	7.2	0.9	6.1
661	S 85	18.5	3850	96	13	3.6	10.0	3.5	1.3	5.4
	W 86	11.0	2430	54	53	0.8	25.0	5.4	1.8	6.4
732	S 85	21.5	3740	96	11	4.9	11.0	11.6	1.0	4.4
	W 86	14.5	3180	88	32	3.0	27.5	10.0	0.8	4.3
734	S 85	20.0	6030	58	9	0.5	6.0	2.9	0.2	3.3
	W 86	12.0	2720	96	42	0.6	26.0	9.0	0.4	6.7
736	S 85	18.5	1840	92	71	0.4	34.5	7.9	1.1	7.9
	W 86	14.0	2600	98	33	0.3	30.5	6.1	1.6	6.1
762	S 85	19.5	2700	66	32	0.6	23.5	7.0	1.3	5.3
	W 86	11.5	2420	76	35	0.3	28.5	7.5	1.1	7.1
764	S 85	20.0	2550	88	31	0.8	20.0	5.6	1.3	6.5
	W 86	10.0	1790	84	40	0.3	29.5	6.9	1.9	6.7
811	S 85	18.0	3540	22	36	0.4	30.0	3.0	1.9	2.1
	W 86	15.5	3520	26	34	0.3	34.5	3.4	1.6	2.8
818	S 85	22.5	3540	92	21	0.8	13.0	4.7	1.0	5.1
	W 86	11.0	3870	88	19	0.7	16.0	4.4	1.1	5.0
835	S 85	22.5	8810	32	12	2.6	4.5	3.0	0.8	1.8
	W 86	9.5	3170	60	39	3.0	32.0	11.2	0.7	4.5
839	S 85	19.5	3740	86	18	3.5	14.0	7.0	0.7	4.2
	W 86	11.0	2730	120	38	3.5	28.5	7.2	1.6	6.2
848	S 85	20.0	5200	28	14	4.0	12.5	6.5	0.2	2.5
	W 86	11.5	3270	42	32	3.3	22.0	7.5	1.1	4.4
849	S 85	18.0	2500	84	46	0.5	35.0	7.0	0.9	4.8
	W 86	11.0	2370	86	44	0.4	49.0	6.3	0.3	6.4
852	S 85	21.5	4200	58	21	0.9	18.5	5.9	0.7	3.2
	W 86	10.5	3270	66	39	1.2	34.5	5.0	0.9	4.2

wells are shown in Fig. 4. Among these, Nos. a, b and c are from the Miyamizu area and the others are selected to surround the Miyamizu area in order to establish the characteristics of the Miyamizu. The temperature difference between summer and winter is usually less than 7°C. This is within the range of variation of typical surface groundwater. In the second aquifer (Itami gravel bed) under the Miyamizu aquifer, the temperature variation is less than 2°C (Sumikawa, 1960). Although the data concerning the water temperature in the deep zone of the Miyamizu area is not described in this paper, their variation in the depth of about 5 m (corresponding to about TP. −1 m) follows the air temperature variation with one month delay in the Miyamizu area. The lowest temperature in the figure is recorded from late February to early March. Water pumping for the brewery takes place from eary November to the middle of March of the next year. During this period, the water temperature is held constant at about 15°C. The pH value is held throughout the year of about 7.0. In the Miyamizu area,

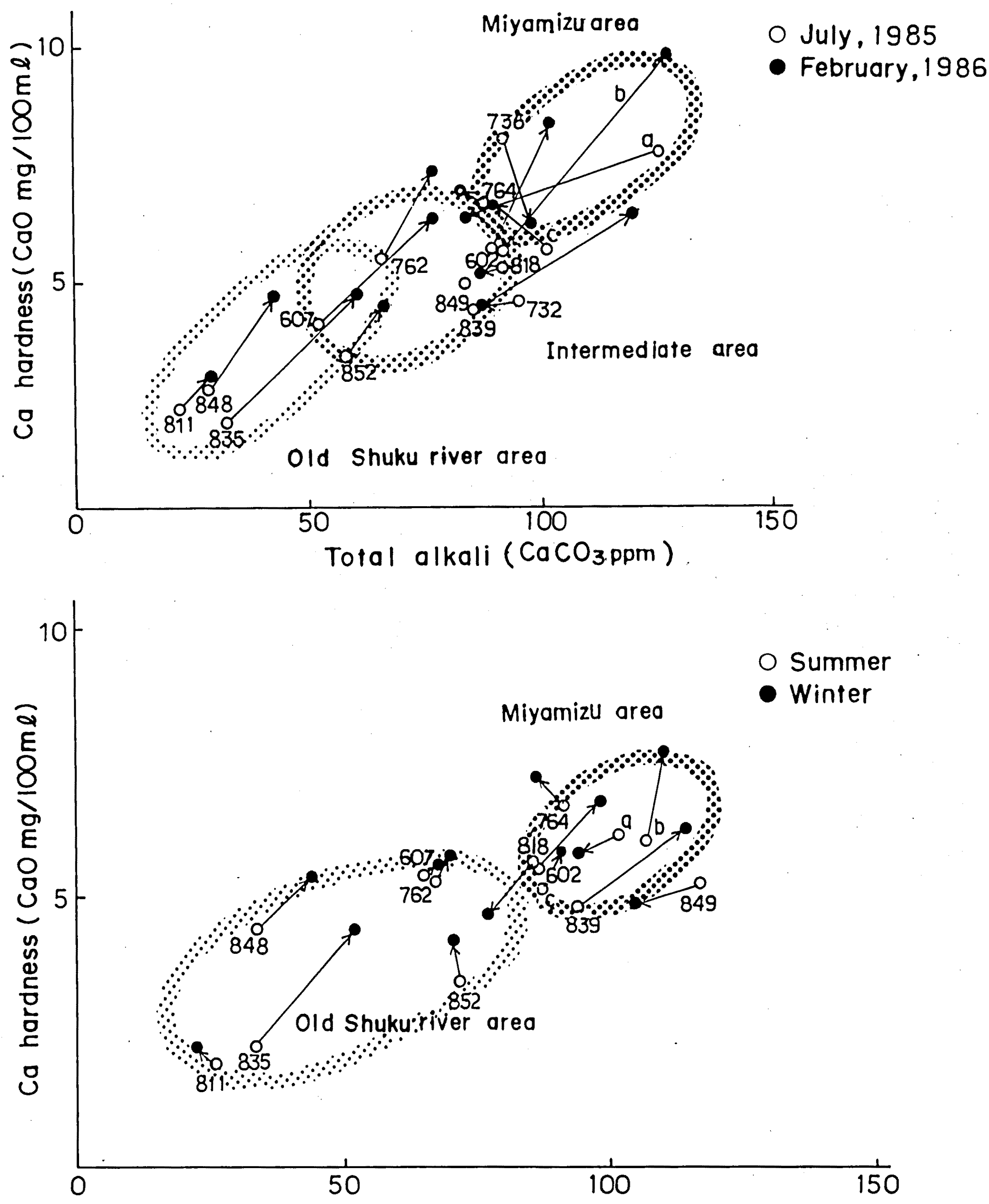

FIG. 5. Relatios between Ca hardness and total alkali. The arrows show the variation direction from summer to winter. Note that the values of each area is restricted to certain region.
(a) Use the values of summer, 1985 and winter, 1986 listed in Table 2.
(b) Use the average values from 1975 to 1986.

chlorine content is within the range of 30 to 50 ppm. However, a value exceeding 100 ppm is frequently observed in the wells close to the sea shore. Contents of the other elements keep almost constant throughout the year in the Miyamizu area. The variation of the chlorine content will be further examined later. Total hardness (total amount of Ca and Mg hardness in Table. 2) of the Miyamizu area is in the range of 6 to 9 (CaOmg/100 m ℓ) keeping almost constant with average value of 8.0. About 84% of this hardness is derived from calcium content. As is observed in Table 2, total hardness outside of the Miyamizu area is very low except that of the wells close to sea shore. Potassium, PO_4, iron and total alkali content are 10, above 4, less than 0.01 ppm, respectively, and all of these contents are comparatively stable. High contents of potassium, phosphorous and total alkali vary consider-

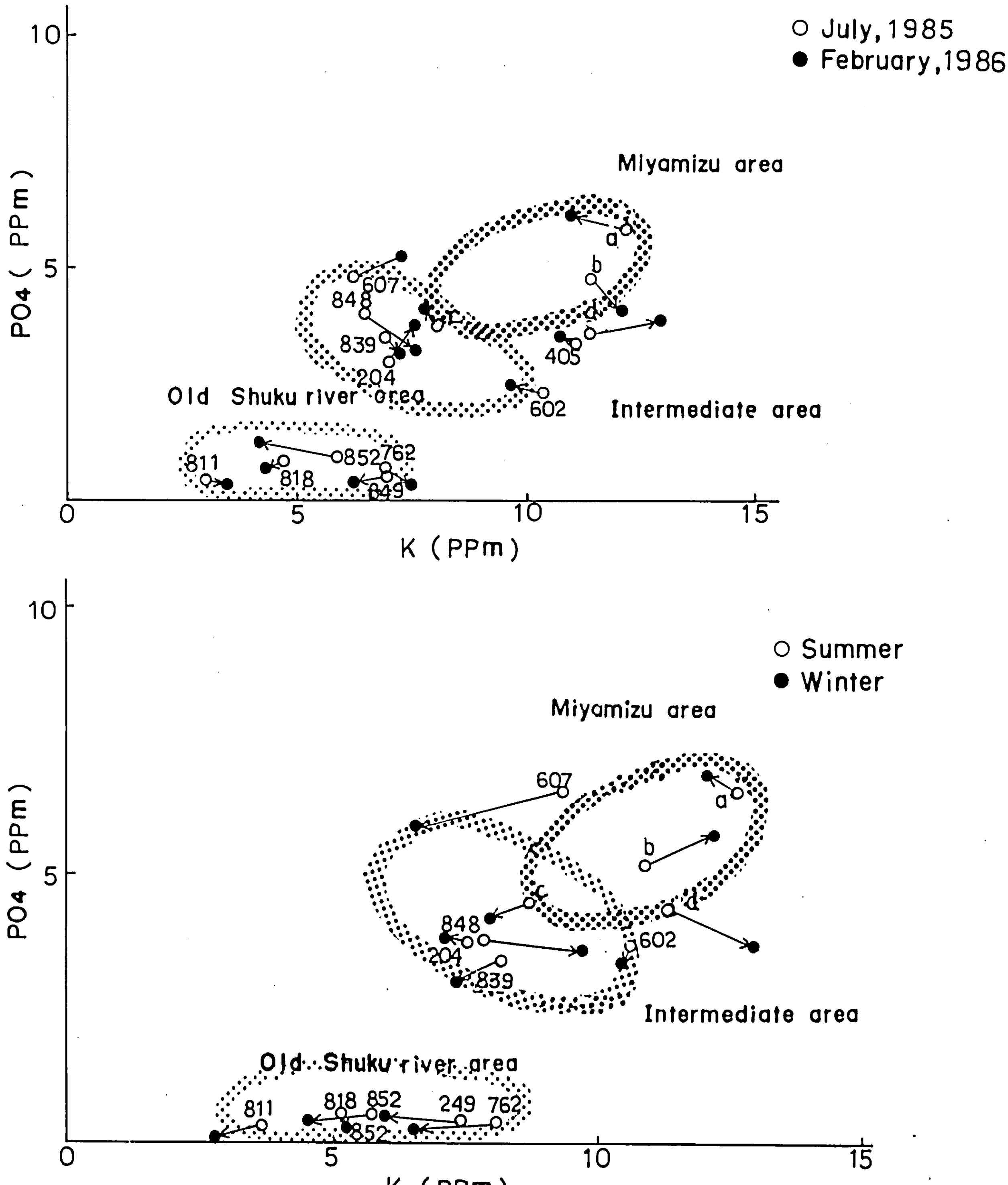

FIG. 6. Relations between phosphorus and potassium contents. The arrows show the variation direction from summer to winter. The variation range of each area is restricted to certain region.
(a) Values of summer 1985 and winter, 1986 listed in Table 2.
(b) Average values from 1975 to 1986.

ably from place to place. It is especially remarkable that phoshorous content is very high in the Miyamizu area and its downstream area. Moreover, in the area between Hankyu and Tokaido lines, northeast of the Miyamizu area, high phosphorous content close to that of the Miyamizu area is recognized. This fact plays an important role on the genesis of the chemical characteristics of the Miyamizu, and will be discussed in the next chapter. The iron content is characterized by its exceptional low value in the Miyamizu area. A distinct difference is found in chlorine content between summer and winter. The content is high in summer and low in winter. Conversely, total hardness is low in summer and high in winter. This phenomenon is frequently observed in wells close to the coast. This is considered to be caused under the influence of sea water together with the groundwater level variation. On this subject, further details will be mentioned in the next section.

Restricted to the Miyamizu area, variation of the alkali content during summer is remarkable whereas that of in winter is almost constant with the value of approximately 120 ($CaCO_3$mg/ℓ). Noteworthy is that total alkali content gradually decreases from that of the Miyamizu area in northery direction, i.e., toward the Rokko mountain regardless of the season, winter or summer. Thus the lowest value is found at points No. 811 and No. 848, both are close to the north end of Fig. 4, with alkali content of about 50. This tendency is also recognized concerning the total hardness. These facts clearly shows that groundwater from mountains changes its chemical composition during passing through the sediments of the old Shuku river as groundwater. This fact is intimately related to the fact that the Alluvial sediments of the area through which the groundwater passes includes carbonates such as shell.

The difference of the chemical composition between the summer (pluvial season) and that of winter (dry season) is also shown as functions of the correlation of two elements. The correlation between Ca hardness and total alkali is shown in Figs. 5(a) and (b). Fig. 5(a) is obtained based on the values of the summer in 1985 and winter in 1986 listed in Table 2, and (b) is based on the mean value of summer and winter during 1975 to 1986. The normal difference between summer and winter can be seen in Fig. 5(b). As observed in Figs. 5(a) and (b), both Ca hardness and total alkali contents are relatively low in summer with high groundwater level and increase towards winter, i.e., dry season.

The No. 811 well is located at the foot of the Rokko mountain and Nos. 848, 835, 852, 762 and 607 are those along the Shuku river from the upper to the lower reaches in the order. As is seen in Fig. 5, Ca hardness and amount of total alkali increase successively and reach a maximum in the Miyamizu area. As observed in this example, chemical composition of the Miyamizu gradually changes during the flowing process as groundwater from the upper to the lower reaches.

Figs. 6(a) and (b) show the correlation between PO_4 and potassium contents. (a) and (b) are drawn respectively based on the data described in Table 2. As observed in Fig. 6, there is no distinct difference between summer and winter. What is remarkable in the figure is that each area has different distribution range. The data concentrated at the lower left portion of the figure are from the northwest part of upper reaches of the old Shuku river drainage system, where low contents of PO_4 and potassium are observed. At the upper portion of the figure, with high PO_4 content, the wells are situated comparatively upstream of the Mitarashi river drainage corresponding to the northeast part of the Miyamizu area. The Miyamizu area is located at the place where both PO_4 and potassium contents are high. The fact is very interesting when the genesis of the Miyamizu is considered, and will be discussed in the next chapter.

B. Behaviour of Chlorine Ion

As mentioned above, annual and seasonal variation of chemical properties of Miyamizu is relatively small. But several short term anomalies in the chemical composition are noted particularly at the time of typhoon or an unusually dry season. Additionally, large scale constructions associated with modern day urbanization may cause an anormaly. Since the Miyamizu area is close to the sea shore and the sediments is highly permeable, an anormaly in the chlorine concentration has occurred several times in the past. In Fig. 7, the time course of tide level, ground surface water and chlorine concentra-

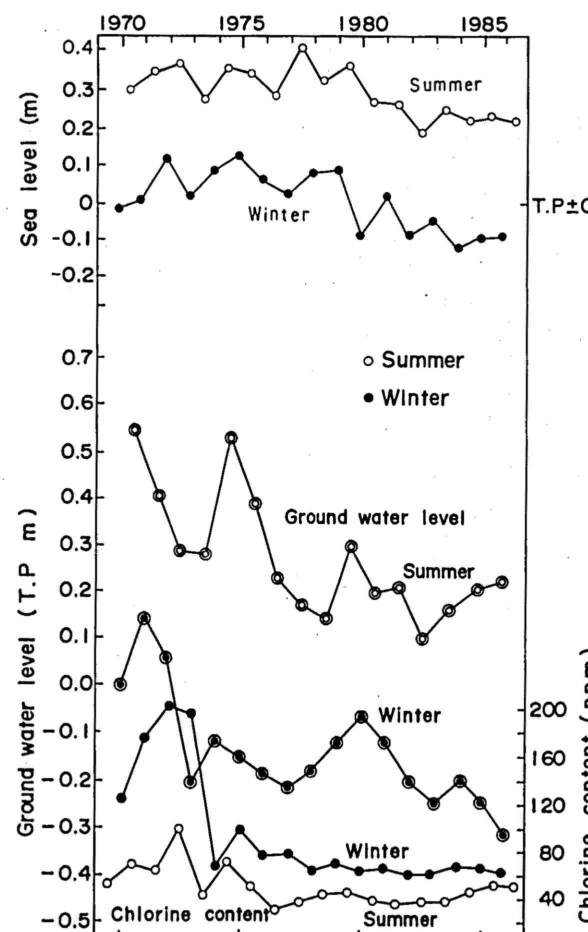

FIG. 7. Variation of groundwater level together with chlorine content and sea level during the past 16 years. Groundwater level and chlorine content are those of No. d well. Sea level is that of Nishinomiya Bay compared with that of Japanese mean sea level (TP=0 m) in Tokyo Bay.

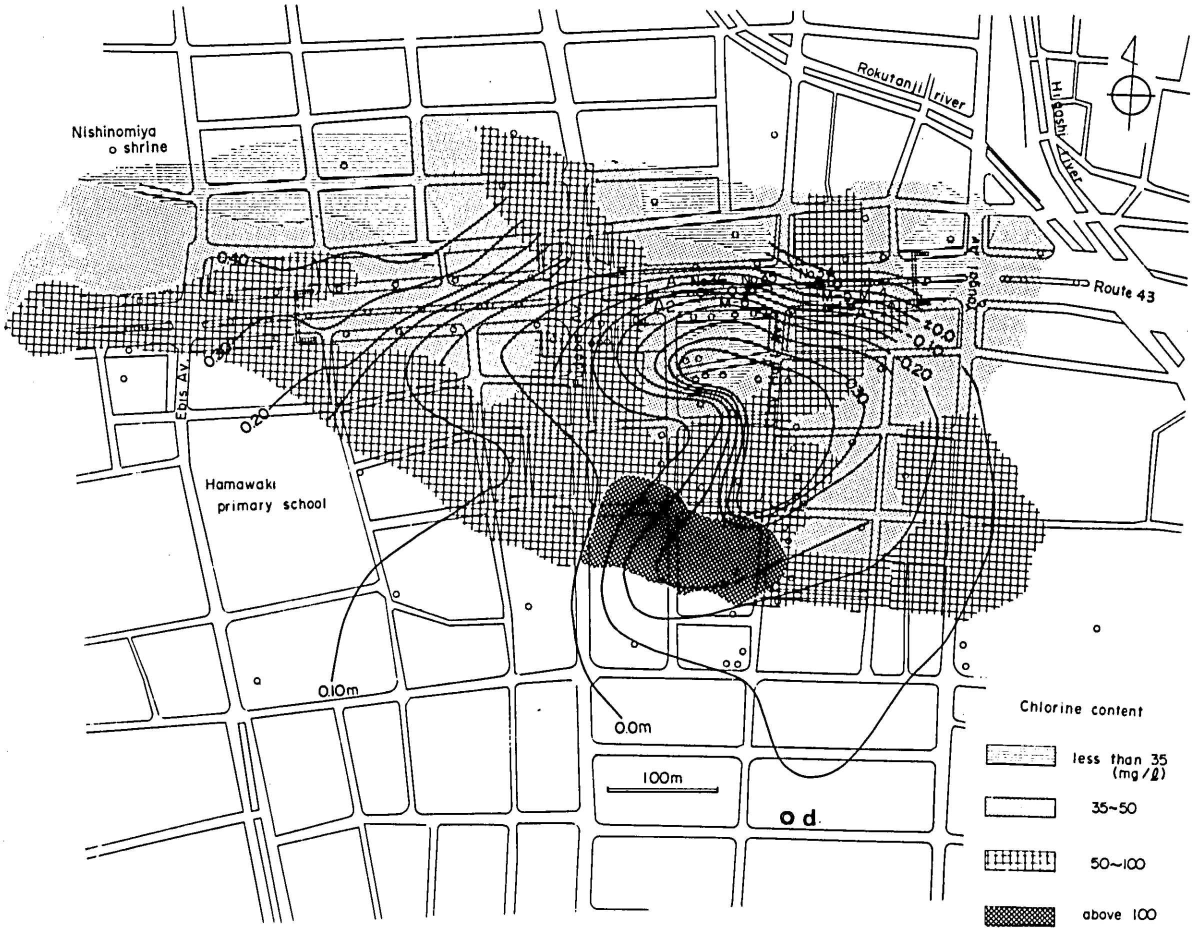

FIG. 8. Distribution of chlorine content measured on February 8, 1968 together with groundwater level of the same day. The arrwos indicate the flowing direction of the underground water.

tion was measured from 1970 to 1986 at No. d well located 100 m south of the Miyamizu area (in the area of B in Fig. 4.). As clarified in the figure, chlorine concentration is apparently increased when water level is reduced. The complicated variation of the chlorine content depends not only on the temporary artificial cause but also on natural tide level variations.

Fig. 8 shows distribution of chlorine content in 1968 in the vicinity of the Miyamizu area. As was described in the previous, high chlorine concentration was recognized at No. b well on the same day. The high chlorine concentration in the Miyamizu area presumed from Fig. 7 suggests the infulence from the area of No. d well. However, chlorine concentration decreases gradually and becomes comparatively stable since 1974 (Fig. 7). At the same time, tide level is also reduced. In recent years, almost no chlorization in the Miyamizu area has been observed owing to the effort to preserve the quality of the Miyamizu.

V. GENESIS OF THE MIYAMIZU

As has been mentioned in the previous, groundwater in the Miyamizu area of Nishinomiya district is suitable for brewing. According to the old records, this water has been used for brewing in this district since 1840 (Taoka, 1957). This is because mainly the suitable chemical composition of the Miyamizu. In this chapter, the origin of the characteristic chemical properties will be discussed in relation to the aquifer structure. There have been no studies on the genesis of Miyamizu, especially from the view point of the total chemical composition. Regarding the structure of Alluvial sediment in this district, Ogawa and Ueji (1926) made an assumption of the sediments structure of the Miyamizu area based on a survey in the northern district of Nishinomiya city. Matsubara and Sakurada (1926) and Matsubara (1926, 1927, 1957) have clarified the chemical composition of the water. The author first drilled boring in the Miyamizu area and since that time, the detailed underground structure has gradually become clear. Sumikawa (1957) and Matsubara (1957) explained the low iron content in Miyamizu, as a result of filtration by the Alluvial sediments. But there has not been any study that explained the high contents of phosphorous, calcium and potassium in the Miyamizu without any contradiction. Not only for these elements, what must first be considered when discussing groundwater quality is geological characteristics of the aquifer and the environmental geology along the flowing course of water (Parks, 1967; Förstner und Müller, 1973; Chambrell et al., 1980). Therefore, the characteristics of the Miyamizu aquifer will first be discussed.

As mentioned in chapter 2, characteristics of the Miyamizu aquifer is the development of the sandy gravel sediment with brownish color gravel of mainly granitic rocks. This kind of sediment is distributed not only in the Nishinomiya district but also in the brewery area named Nada Gogou (five villages of Nada including eastern Kobe city), adjacent to the Nishinomiya area. The permeability of the sandy gravel is higher than 5×10^{-2} cm/sec and is regarded as high quality aquifer. In general, the sediment is lens shaped and perimeter of each lens gradually changed into a grayish blue sand fertilized with organic materials. The wells for brewing are drilled in the lens shaped sandy gravel layer and not to the lower gray to blue sediments rich in clay. The light

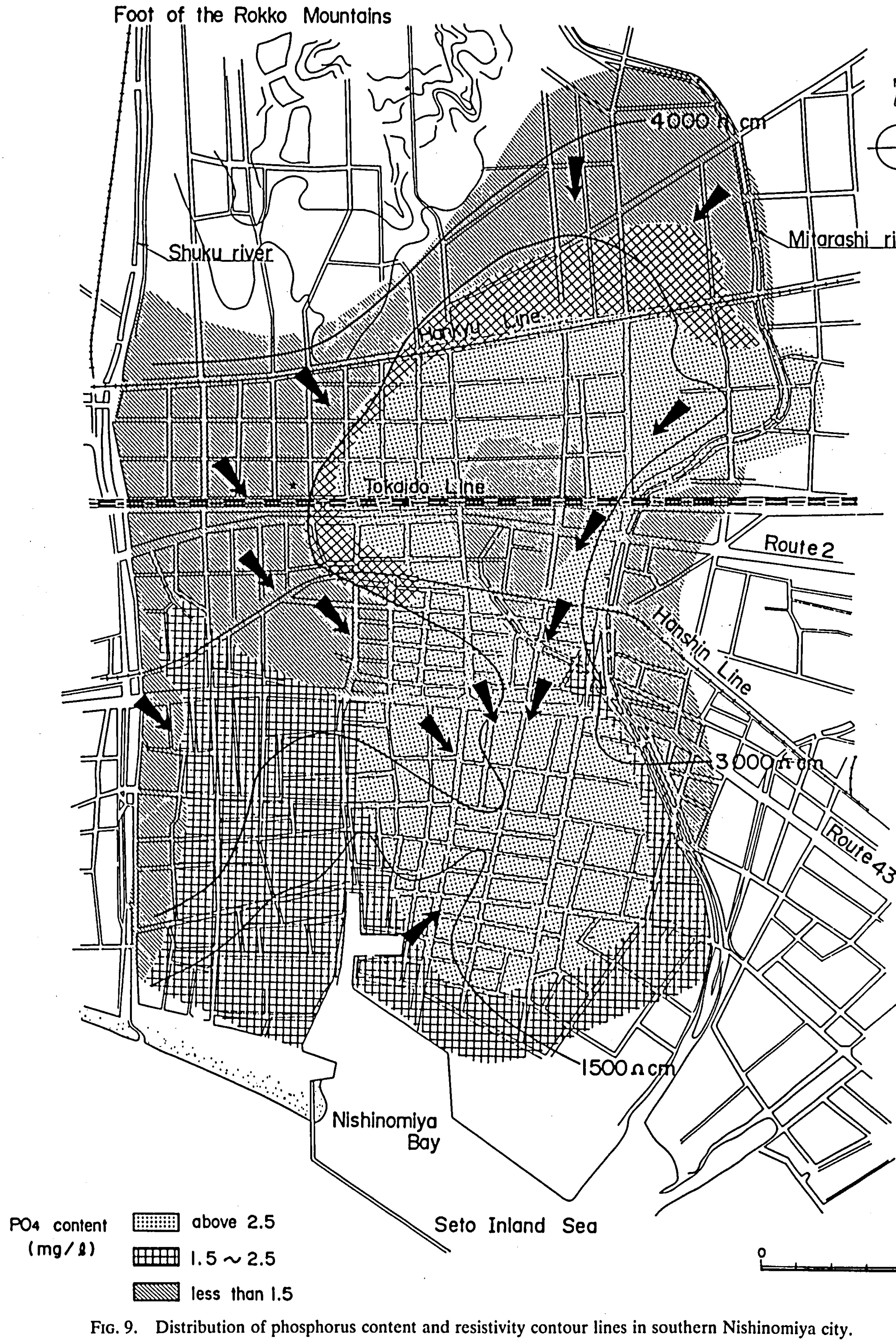

FIG. 9. Distribution of phosphorus content and resistivity contour lines in southern Nishinomiya city.

yellow brown color of the gravel is due to iron hydro-oxyde, and this explains the low iron content in the groundwater from this layer. In all the brewing areas around Nishinomiya city, potassium content is as high as in the Miyamizu area. This fact can be understood because that all rivers and underflows in this district are originated from the Rokko mountains composed of mostly granitic rocks. Among the drainage of Nada Gogou including the Miyamizu area, only the Shuku river passed through the area of the small body of orthopyroxene andesite (Mt. Kabutoyama) in addition to the granitic rocks in its upstream system (Huzita, 1959). But the existence of this small volcanic rock cannot cause the difference between the composition of the Miyamizu and that of the groundwater in the adjacent areas. However, Matsubara and Hirotsu (1957) detected very few amount of boron and vanadium in the Miyamizu brewing water in ppb order and concluded that boron came from the small volcanic body (Mt. Kabutoyama) because of the similarity of composition of minor elements between those of the Miyamizu and the mineral springs in and around the volcanic body. These elements such as boron and vanadium are characteristically rich in the Miyamizu compared with those of neighborhood district. Based on the relative amount of minor elements and also on the ratio of vanadium against phosphorous, Kusaka et al. (1980) concluded that phosphorous, which is characteristically rich in the Miyamizu, was derived from organic materials such as planktons and seaweeds contained in the sediments.

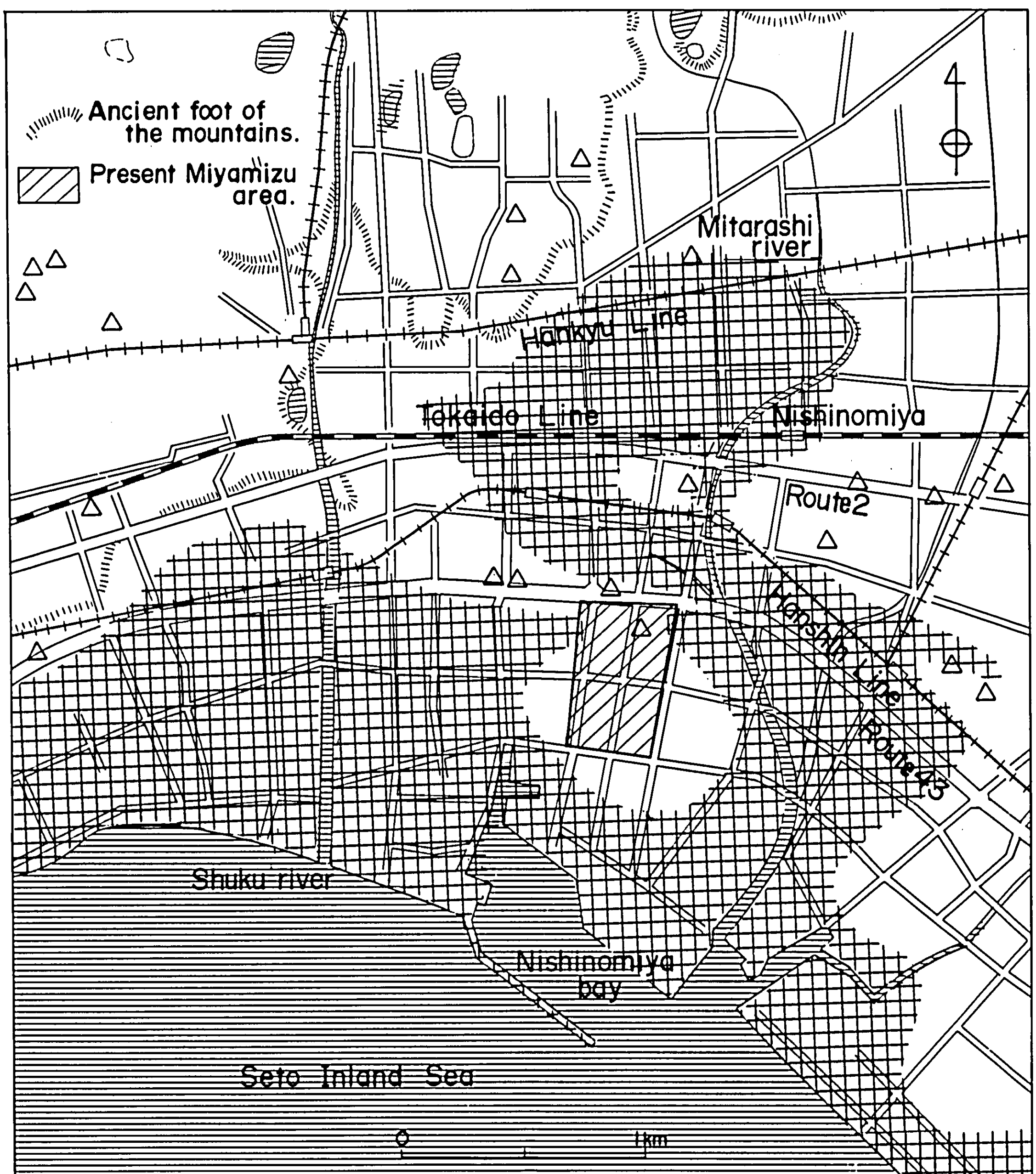

FIG. 10. Ancient geographical map of about 1,000 years ago around Nishinomiya city constructed based on archaeological evidences(Modified from Taoka, 1959). Triangle represents archaeological evidences such as shell mound and ancient tomb. Note that the paleo-bay well corresponds to the high phosphorous area shown in Fig. 9.

On the sandy gravel layer in the Miyamizu aquifer, Matsubara (1957) insisted that this layer is originated from large floodplain sediments of the old Shuku river, and the Miyamizu area is located in the center of this floodplain. This fact coincides with the direction of the underflow of the old Shuku river from northwest to southeast (Fig. 3) established in this paper. Furthermore, the underflow of the old Mitarashi river from northeast to southwest is also provides groundwater flowing into the Miyamizu area.

The resistivity contour line in Nishinomiya district and phosphorous content devided into three grades of the southern part of the Nishinomiya city are shown in Fig. 9. The resistivity shows a distribution tendency similar to the groundwater level contour lines shown in Fig. 3, and this fact clearly indicates the flow direction of the old Shuku and Mitarashi rivers (the arrows in Fig. 9). The distribution pattern of the resistivity contours shown in Fig. 9 also indicates the flowing direction of the groundwater along the old rivers.

It should be noteworthy that distribution pattern of phosphorous content suggests certain sea shore. The assumed old sea shore line about 1,000 years ago of this district is established based on the archeological evidences such as Yayoi pottery, shell mound and ancient tomb (Fig. 10). The distribution pattern of the old sea shore line well comparable with that of high phosphorous content area (Fig. 9) as well as with that of the water level contour line in Fig. 3. The present Miyamizu area (slashed part in Fig. 10) exactly situates in the sand bar. Therefore, the sediments are came from the ends along the flow direction of the old Shuku river. High phosphorous content distribution coincides quite well with the basin at that time. The location, corresponding to the old day basin, is assumed to store sea water as connate water (as a sort of fossil water) during period of the Jōmon transgression and the sediments contain a lot of shallow shells. In fact, many shells of the shallow sea type such as Dosinia sp are found in this area (Ogawa and Ueji, 1926; Huzita and Maeda, 1985). The comparatively high calcium content of the Miyamizu can be explained by this fact. For phosphorous distribution (Fig. 9), phosphorous content is relatively small along the old Shuku river whereas high in the northern part of the Miyamizu area. This distribution pattern well coincides with basin distribution at that time. Thus, it is reasonably suggested that phosohorous is derived from sea weeds and planctons rich in phosphorous.

As this district thereafter gradually became land as deposition of sediments from the rivers proceede accompanying with the uplift movements, and the basin became gradually marsh. Finally, the old basin was sunk under the ground accompanying the deposition of the clayey soil on the top as was shown in Fig. 1, and the sea water in the basin became connate water. The clayey soil layer prevents the contamination by the groundwater polluted by urbanization.

Consequently, the chemical characteristic of the Miyamizu, a famous brewing water, with high phosphorous and calcium contents originated from the connate water and the marine sediments of the old sea, and the high potassium content is assumed to have originated from the granitic rocks of the Rokko mountains like in the groundwater of the adjacent district. Low iron content is also important. This characteristics is caused by iron precipitation as hydro-oxide under the oxygen rich condition. This can be explained by the fact that the sediments of the Miyamizu area is composed of floodplain sediments of the old Shuku river and during the deposition process, oxygen supply is considerable. The existence of high permeablility aquifer with the aquiclude below have contributed formation of the most suitable groundwater for brewery.

VI. Summary

The groundwater in the Nishinomiya district has long been known as suitable for brewing because of its chemical characteristics. Concerning the characteristics of the aquifer and chemical composition of the groundwater, the following results were obtained.

1. The Alluvial sediments, the main aquifer of the groundwater in this area is classified based on permeability. The first aquifer corresponds to the Miyamizu aquifer, where the k values are higher than 5×10^{-2} cm/sec.

2. Permeability of the aquiclude layer developed below the Miyamizu aquifer is lower than 5×10^{-4} cm/sec and the existence of the layer stabilize quantity of the the Miyamizu.

3. The flow direction of the old rivers and the related underflow were determined by means of analysis of the groundwater level contour line in this area. Groundwater flowing into the Miyamizu aquifer comes from the underflow of the old Shuku river and Mitarashi river drainage systems, and in part from the Muko river.

4. The groundwater in this district, especially that of the Miyamizu area is fertilized with phosphorous, potassium and calcium and has very low iron content. The annual variation of the chemical composition is relatively small, and the difference between summer (pluvial season) and winter (dry season) is explained as functions of correletion between the elements.

5. The chemical composition of the groundwater in Nishinomiya district are different from place to place. The variation of calcium, potassium and phosphorous content have relationship with the direction of underflow of the old rivers.

6. Temporary variation in chlorine content is noted. The reason of this variation is related to tide level, pumping discharge, precipitations and other factors. Almost no chloritization in the Nishinomiya area has been recognized in recent years.

7. In comparing the ancient geographical map established on archeological evidences, the Miyamizu area is proved to be a sandbar with the sediments composed of old floodplain since the Jōmon transgression period. The existence of old basin explain the high contents of phosphorous and calcium content in the Miyamizu.

References

Chambrell, R. R., Rhaid, R. A. and Patrick, W. H. Jr. (1980): Chemical availability of Hg, Pb and Zn in Mobile bay sediment suspensions as attested by pH and oxidation-reduction conditions. Environ. Soc. Tech., 14, 431–436.

FÖRSTNER, U and MÜLLER, G. (1983): Heavy metal environmental pollution. Geofor., 14, 53-61.
———, ———, (1974): Schwermetalle in Flüssen und Seen. Springer-Verlag, Berlin, Heidelberg.
HUZITA, K. (1959): Geology of Nishinomiya city (in Japanese). in History of Nishinomiya city (Ed. S. Uozumi), 1, 174-310.
———, (1967): Geology of Nishinomiya city (in Japanese). in History of Nishinomiya city (Ed. M. Mutō & T. Arisaka), 7, 618-630.
———, and MAEDA, Y. (1985): Geology of the Osaka-Seinambu district. Quadrange Series, scale 1:50,000, Geol. Surv. Japan. 97.
IWAI, S. and SUMIKAWA, K. (1964): On preservation of the Miyamizu (in Japanese). Jour. Water. Wast., 6, 95-103.
KANO, S. (1953): Studies on brewing water (in Japanese). Jour. Agric. Chem. Soc. Jap., 27, 881-885.
KUSAKA, Y., TUJI, H., FUJIMOTO, Y., ISIDA, K., MAMURO, T., MATSUNAMI, T.,MIZOHATA, A. and HIRUI, S. (1980): On the groundwater in Mikage, Uosaki and Nishinomiya district (in Japanese). Rept. Nada. Brew. Soc., No. 43, 74-90.
MATSUBARA, A. and SAKURADA, Y. (1926): Report on the Miyamizu (I) (in Japanese). Rept. Soc. Miyamizu Presv. Published by Nishinomiya Tax Office.
———, (1926): On the groundwater of Nishinomiya and its Environs. Proc. 3rd Pan-Pacif. Sci. Cong. Tokyo, 817-837.
———, (1927): Chemical studies on the groundwater in the vicinity of Nishinomiya city (in Japanese). Jour. Geol. Soc. Jap., 34, 408.
———, and SAKURADA, Y. (1928): Brewing groundwater in Nishinomiya city (in Japanese). Mag. Brew. Soc. Jap., 5, 878-895.
———, and HIROTSU, T. (1957): Trace elements in Miyamizu (in Japanese). Jour. Brew. Soc. Jap., 52, 34-37.
———, (1957): On the cleaning mechanism of Miyamizu (in Japanese). Jour. Ferm. Tech. Soc. Jap., 52, 34-37.
MUSKAT, M. (1937): The flow of homogeneous fluids through porous media. McGraw Hill, 462-466, 453-459.
OGAWA, T. and UEJI, T.(1926): Geological report of the Nishinomiya distict (in Japanese). Presv. Comm. Miyamizu, Nishinomiya Tax Office, 1-24.
———, (1926): Report on well drillings in Nishinomiya city (in Japanese). Presv. Comm. Miyamizu, Nishinomiya, 1-14.
PARKS, G. A. (1960): Equilibrium concepts in natural water system. Advances in chemistry series, Amer. Chem. Soc.
POLUBARINOVA, K. (1952): Theory of groundwater movement (in Russian; English taransl. by R. J. M. De Wiest, Princeton Univ. Press.
SUMIKAWA, K. (1957): Report on well drilling in Miyamizu area (in Japanese). Miyamizu Presv. Comm., 1-26.
———, and TAKAI, Y. (1960): Groundwater level, chlorine content and hardness of Miyamizu, a brewing water from 1957 to 1959 (in Japanese). Miyamizu Presv. Comm., 1-29.
———, (1960): Hydraulical studies on the alluvium sediments in Nada district, Hyogo, Pref. (in Japanese). Jour. Geol. Soc. Jap., 66, 488.
———, (1961): Preliminary report on hydraulic-geological study of the Nada district,Hyogo Pref. (in Japanese). Geol. Rept. Hiroshima Univ., No. 11, 1-14.
TAOKA, K. (1959): On Miyamizu (in Japanese). in History of Nishinomiya city (Ed. S. Uozumi), 1, 69-109.
UEJI, T. (1927): Diluvium and its fossils in Kōroen, Nishinomiya city (in Japanese). Earth (Chikyuu), 6, 61-62.
———, (1936): Cenozoic low land developed in the southern foot of the Rokko mountain (in Japanese). Earth (Chikyuu), 25, 51-64.
———, (1937): Geological structure of the Rokko mountains (in Japanese). Jour. Geol. Soc. Jap., 48, 584.

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