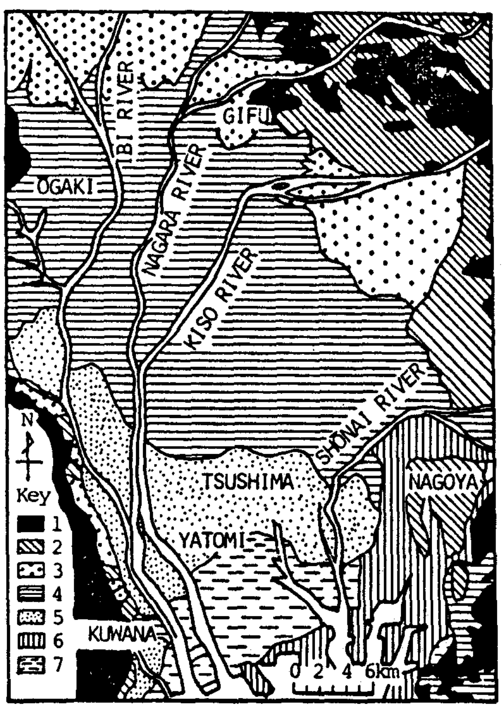
Case History No. 9.6. Nobi Plain, Japan, by Soki Yamamoto, Rissho University, Tokyo, Japan

9.6.1 TOPOGRAPHY AND GEOLOGY OF NOBI PLAIN

The Nobi Plain underlain by young sediments is situated in the central part of Japan and is about 1800 km^2 in area. This plain faces Ise Bay, where the Ibi, Nagara, Kiso, and Shonai rivers discharge, and is composed of alluvial fans, flood plains, deltaic plains, terraces, reclaimed lands, and filled-up ground (Figure 9.6.1).

The west-east profile of the southern part of this area is illustrated in Figure 9.6.2. The basement block in the Nobi Plain area bounded by the Yoro fault has tilted and is covered with sediments dipping westward. The depth of strata is about 2,000 m to the basement rocks.

The subsurface stratigraphy of these sediments in the plain has been explored on the basis of borehole material obtained from several thousands of water wells and test borings. The



1. Mountain and Hill 2. Terrace
3. Alluvial Fan and Cone
4. Flood Plain 5. Deltaic Plain
6. Filled-up Ground
7. Reclaimed Land

Figure 9.6.1 Topographic features of the Nobi Plain.

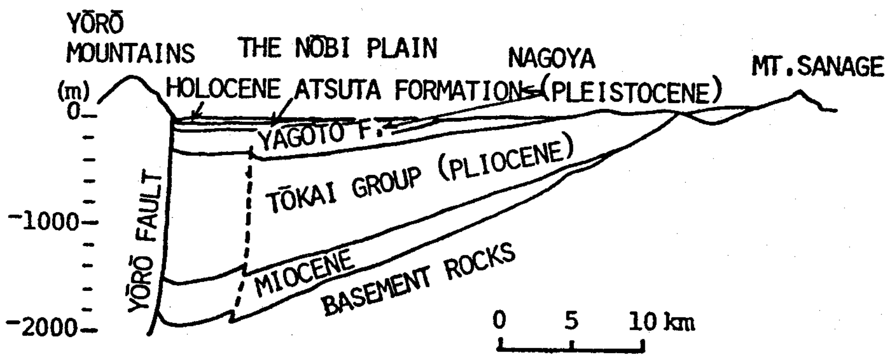


Figure 9.6.2 West-east profile of the Nobi plain.

Table 9.6.1 The Subsurface Stratigraphy in the Nobi Plain

		(Thickness)
HOLOCENE	NANYO FORMATION (H) (loose upper sand bed and very soft marine clay bed)	10-60 m
PLEISTOCENE	NOBI FORMATION (N) (alternation of sand and silt bed)	10-20 m
	DAICHI GRAVEL BED (G1)	10-30 m
	ATSUTA FORMATION (D3) (upper sand and clay beds and unconsolidated lower marine clay bed)	10-100 m
	DAINI GRAVEL BED (G2)	5-30 m
	AMA FORMATION GROUP (alternations of semiconsolidated sand, clay and gravel beds)	30-100 m
	PRE-AMA FORMATION GROUPS (alternations of semiconsolidated sand, clay and gravel beds)	30-70 m
PLIOCENE	TOKAI GROUP (alternations of semiconsolidated clay, sand and gravel beds)	200-1000 m
	M I O C E N E S E R I E S	
P R E - T E R T I A R Y B A S E M E N T R O C K S		

geological succession of these sediments is shown in Table 9.6.1, and a geologic cross section in Figure 9.6.3.

The middle Pleistocene and younger sediments are composed of an alternation of clay, sand and gravel beds. Changes in sedimentary environments and climatic fluctuations of these sediments have been studied by means of microfossil analyses of numerous core samples (Nobi Plain Quaternary Research Group, 1976).

Semiconsolidated fresh-water lacustrine clay beds and fluvial sand and gravel beds are interbedded in the lower horizon of the Pleistocene sediments, the so-called Pre-Ama Formation Groups. The Ama Formation Group and the younger sediments are composed of alternations of fluvial sand or gravel beds and unconsolidated marine clay beds, deposited under inner bay conditions. Each of these marine clay beds shows a sedimentary cycle from transgressive to regressive phase, and represents a relatively warm period, interglacial epoch or interstadial. In colder periods, the gravel beds have been deposited as either terrace or river-bed gravels

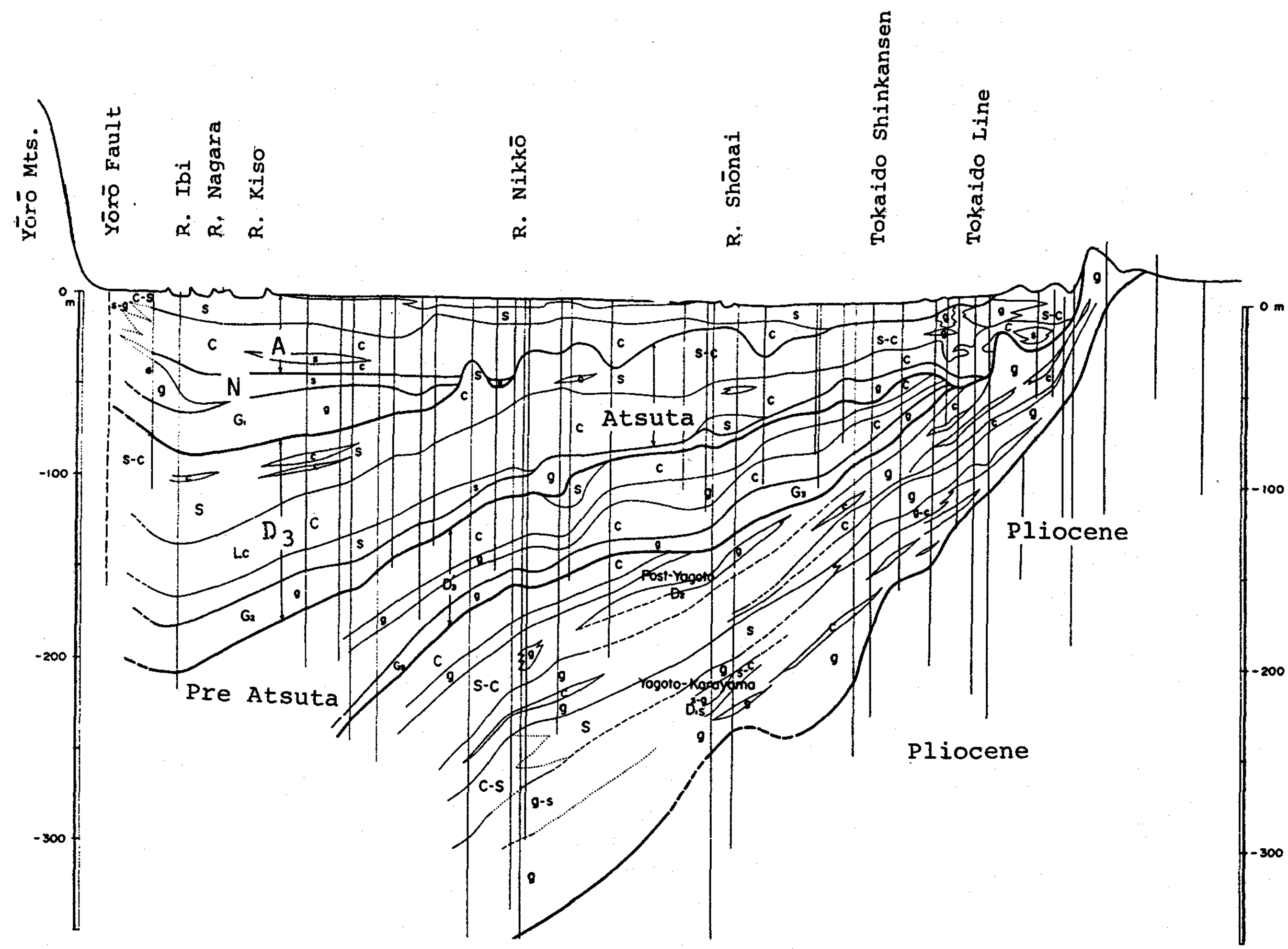


Figure 9.6.3 Geologic cross sectiopn of Nobi Plain.

in the valleys formed during the period of low sea level falling. The river-bed gravel deposited in the bottom of the valleys during a maximum stage of sea level falling reaches 20 m or more in thickness. The terrace gravel beds are generally thinner than the valley bottom gravel beds. These two types of gravel beds are distributed under almost the whole area of the Nobi Plain. Buried topography such as hills, terrace, and valleys formed in the process of sea-level lowering is depicted in the base contour map of these gravel beds. The buried topography and types of gravel beds affect ground-water yield in this plain. The marine clay beds overlying the gravel beds have attained more than 30 m in thickness in the valleys, and spread far and wide under the plain area except for the alluvial fan area, where the clay beds thin out and grade into sand or gravel beds (Figure 9.6.3).

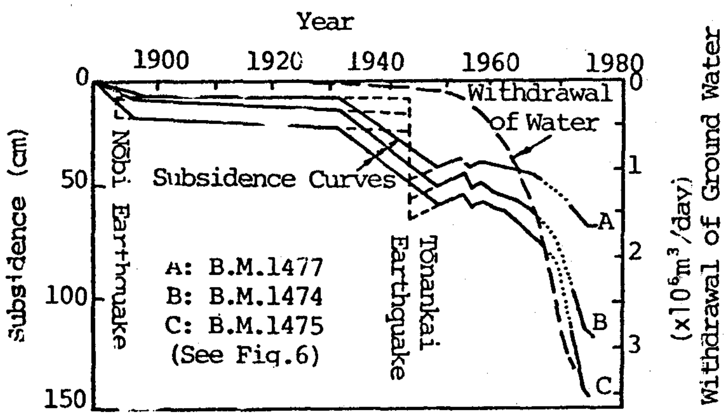


Figure 9.6.4 Subsidence of bench marks and withdrawal of ground water in the Nobi Plain.

Table 9.6.2 Withdrawal of ground water in the Nobi Plain.

Year	m^3/day
1925	1638
1945	129088
1950	154040
1955	360301
1960	849338
1965	1552764
1970	3002128
1973	3514195

9.6.2 HYDROLOGY

In the alluvial fan area, precipitation and surface water percolate downward through these permeable sand and gravel beds, and recharge ground water in the Nobi Plain. A superficial sand bed, the upper member of the Nanyo Formation, as much as 15 m thick, contains unconfined ground water which is recharged directly from precipitation and infiltration of irrigated water. The gravel beds, Gl, G2, and others interbedded in clay beds, are artesian aquifers and supply a large quantity of ground water. Before the pumping was largely developed, many flowing wells tapped these gravel beds in most of the Nobi Plain.

The increasing withdrawal of ground water in the Nobi Plain is shown in Tables 9.6.2 and 9.6.3. The use for industry amounts to 60 per cent of the total.

Recent annual withdrawals of ground water in the Nobi Plain equal 32 per cent of the annual rainfall on this plain. This volume is much larger than the natural recharge of ground water.

In the 1920’s, the piezometric levels of confined aquifers were above the ground surface in most of this plain. In the 1940’s, flowing wells were still observed in Ogaki, Kanie, and Kasugai districts. But since then, the piezometric levels have declined due to the increase in the number of artesian wells.

Table 9.6.3 Use of ground water for each purpose in the Nobi Plain (1973).

Item	Total	Industry	Buildings	Water Supply	Agriculture
Withdrawal of Ground Water (m^3/day)	3,802,293	2,290,015	343,025	477,028	692,225
Percentage	100	60	9	13	18

9.6.3 LAND SUBSIDENCE

The records of three bench marks depicted in Figure 9.6.4 show the evolution of land subsidence in this area. During the period from 1950 to 1973, the subsidence increased exponentially and some areas subsided more than 20 cm in 1973.

Figure 9.6.5 shows a comparison between the areas subsiding more than 2 cm/yr from Feb., 1961 to February, 1962, and from November, 1972 to November, 1973. This figure illustrates how the subsiding area in this plain enlarged from 1961 to 1973.

The subsidence of this plain during about 15 years from February, 1961 to November, 1975 is shown in Figure 9.6.6. The southern part of Nagashima facing the Ise Bay settled 147 cm during these 15 years. The total subsiding area is 1140 km^2 (Environment Agency, Japan, 1976). By 1973, 363 km^2 had become lower than the mean high-sea level (1.1 m higher than the mean sea level), 248 km^2 lower than the mean sea level, and 37 km^2 lower than the mean low-sea level (1. 4 m lower than the mean sea level). The area below mean sea level enlarged from 186 km^2 in 1961 to 248 km^2 in 1973.

Regulations for withdrawal of ground water in the Nobi Plain are as follows:

1. The Industrial Water Law (established in 1956)
   The areas designated by the Industrial Water Law are supplied with industrial water from surface sources instead of restriction on pumping of ground water. The regulations for these areas are shown in Table 9.6.4.

2. Regulations by Ordinance of Aichi Prefecture
   Aichi Regulation Zone I (enforced on 30 September 1974)
   This regulation zone was decided considering the rate of subsidence greater than 5 cm/year in 1972 and/or 1973. In this zone, a newly bored well must meet the following conditions;
   a. The depth of strainer should not be greater than 10 m.
   b. The inside area of discharge pipe should be less than 19 cm^2.
   c. The power of motor should be less than 2.2 kw.
   d. Total discharge should be less than 350 m^3/day.
   Concerning the wells that existed before the regulation, flow meters were installed in them and the discharge records are reported to the Prefectural office every year. Since the lst of January, 1976, the withdrawal of ground water from existing wells was restricted within 80 per cent of the discharge in the past (Figure 9.6.7).
   Aichi Regulation Zones II and III (enforced on 1 April 1976)
   The regulations for newly bored wells and existing wells are the same as those for Zone I, except that for the existing wells in Zone II, the withdrawal from the lst of April, 1977 is going to be restricted within 80 per cent of the discharge in the past, and for the existing wells in Zone III, the withdrawal in future is going to be restricted within the discharge in the past.

3. Regulations by Ordinance of Mie Prefecture (enforced on 1 April 1975)
   The regulations for newly bored wells and existing wells are the same as those explained for Aichi Regulation Zones II and III, where Mie

Table 9.6.4 Regulations for the Areas Designated by the Industrial Water Law

Area	Zone (See Fig. 9.6.7)	Allowed Depth of Strainer	Inside Area of Discharge Pipe
Southern	N_1	deeper than 80 m	less than 46 cm^2
Industrial Area of		deeper than 300 m	greater than 46 cm^2
Nagoya	N_2	deeper than 90 m	less than 46 cm^2
designated in 1960		deeper than 180 m	greater than 46 cm^2
Industrial		deeper than 100 m	less than 21 cm^2
Area of	Y_1	deeper than 230 m	from 21 cm^2 to 46 cm^2
Yokkaichi designated			
in 1957	Y_2	deeper than 50 m	less than 21 cm^2
and 1963		deeper than 150 m	from 21 cm^2 to 46 cm^2

Table 9.6.5 Dealing with existing wells in the case where the strainers are deeper than 10 m in Nagoya

Zone	Wells for Buildings	Wells for Industry
I	Changed to use city water since 16 Nov. 1975	Change to the industrial water supply as soon as possible
II	Changed to use city water since 16 Nov. 1976	
III	Increasing withdrawal is forbidden	

Regulation Zones I and II correspond to Aichi Regulation Zones II and III, respectively.

4. Regulation by Ordinance of Nagoya City (enforced on 16 November 1974) According to the ordinance of Nagoya City, a new well can be allowed only in the case where the strainer is not deeper than 10 m and the inside area of discharge pipe is less than 19 cm^2. Existing deep wells are being treated as shown in Table 9.6.5. The regulation zones of Nagoya City are overlapped by the regulation zones of Aichi Prefecture. Therefore, the withdrawal of ground water in Nagoya is controlled by ordinances of Nagoya City and Aichi Prefecture.

Figure 9.6.8 shows the subsidence of Nagashima during the recent ten years and piezometric levels of the lst confined aquifer (G_1) and the 2nd confined aquifer (G_2) measured at Matsunaka observation well during the recent five years. The confined aquifers G_1 and G_2 are located at depths between 40 m to 60 m and 100 m to 115 m respectively at the observation site. Concerning the piezometric levels, seasonal changes are superposed on total trends of ground water levels. The seasonal drops of piezometric levels are caused by the increase of pumpage for cooling and

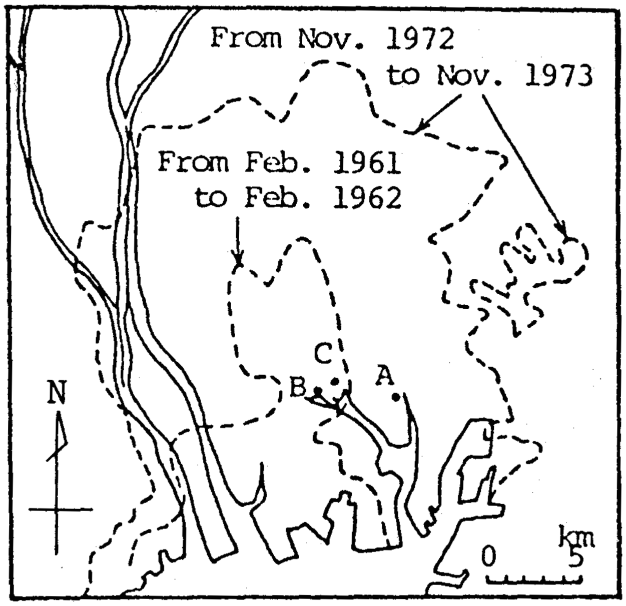


Figure 9.6.5 Enlargement of the area subsiding more than 2 cm/yr.

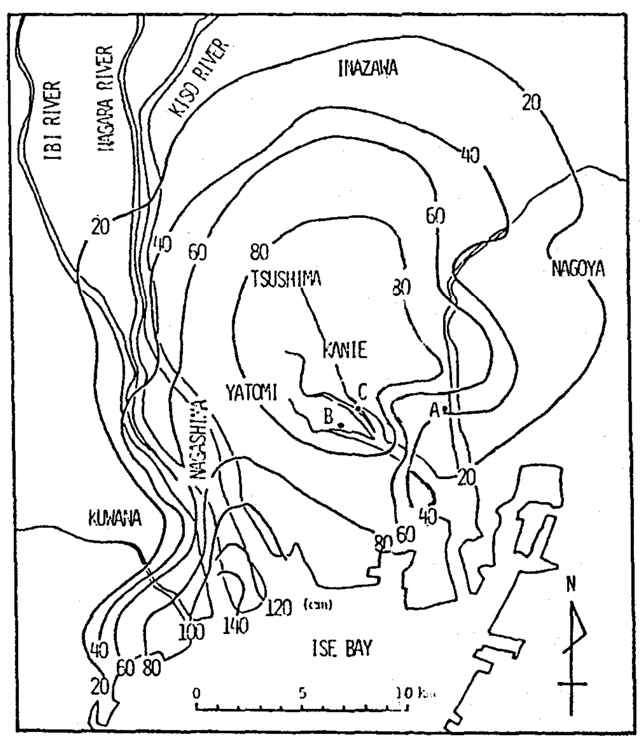


Figure 9.6.6 Subsidence for 15 years from February 1961 to November 1975 in the Nobi Plain.

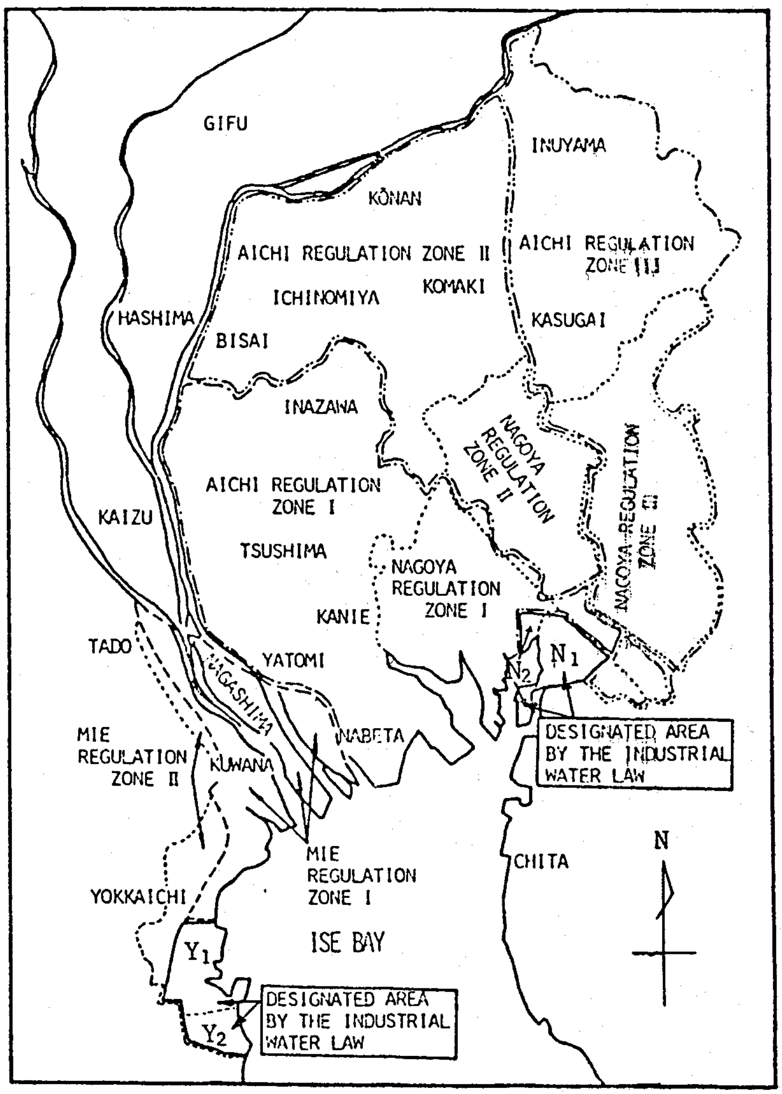


Figure 9.6.7 Restriction of withdrawal of ground water in the Nobi Plain.

irrigation in summer. The piezometric level of the deeper confined aquifer is lower than the one of the shallower confined aquifer, because ground water of better quality is pumped up in plenty from the deep aquifer.

The piezometric levels of aquifers show, recovering trends since 1974. Reflecting this favorable turn in the ground water situation, the subsiding area became smaller and the rate of subsidence decreased.

Moreover, several rebounding areas appeared around the area having reduced subsidence. (See Figure 9.6.9.)

9.6.4 PARAMETERS

The compression index C_c varies vertically and horizontally in clay layers and the values are closely related to the sedimentary facies. The value is the largest in the middle horizon of finer materials. Lateral distribution of the mean C_c value calculated by averaging vertical

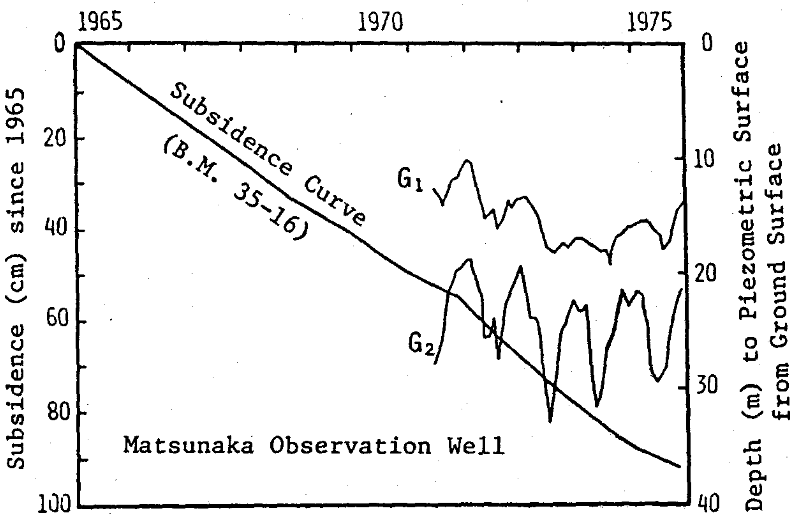


Figure 9.6.8 Subsidence and ground water conditions at Nagashima during recent years.

variations reflects the sedimentary environment of the clay bed. It varies from 0.3 to 0.8 from the margin of this plain to the central area. There is a good correlation between e_o and C_c which can be expressed as follows:

$$C_c = 0.5 (e_o - 0.5)$$

where e_o is the natural void ratio of clay.

9.6.5 SELECTED REFERENCES

IIDA, K., SAZANAMI, T., KUWAHARA, T., and K. UESHITA. 1977. Subsidence of the Nobi Plain, IAHS Pub. No. 121, p. 47-54.

KUWAHARA, T., UESHITA, K., and K. IIDA. 1977. Analysis of land subsidence in the Nobi Plain, IAHS Pub. No. 121, p. 55-64.

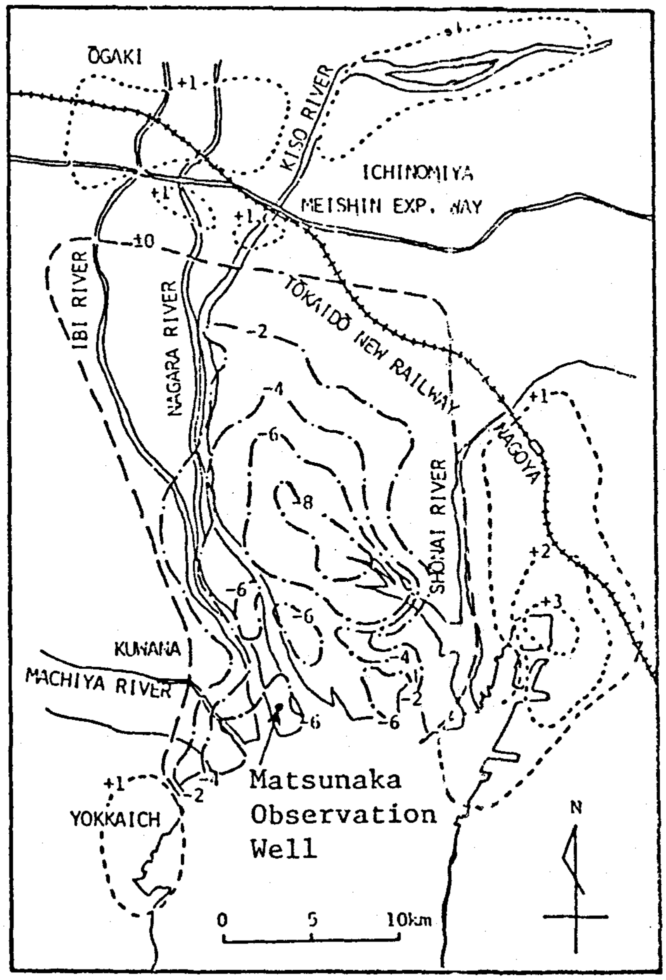


Figure 9.6.9 Subsidence and rebound of the Nobi Plain from November 1974 to November 1975 (unit: cm/yr).