Case History No. 9.7. Niigata, Japan, by Soki Yamamoto, Rissho University, Tokyo, Japan

9.7.1 TOPOGRAPHY AND GEOLOGY

Niigata Plain is the largest coastal plain along the Japan seacoast. It is bounded on the east by mountains, on the south and west by hills and on the north by the Japan Sea, with coastal sand dunes. Through the center of this plain the R. Shinano, the R. Agano and their branches flow down from south to north into the Japan Sea. Along these rivers, especially on down reaches, there are many back marshes, swamps, and lakes (Figure 9.7.1.).

This area is a typical synclinal basin with deposits of Cenozoic age underlain by a basement complex (Figure 9.7.2.). The subsurface geology of this area consists of Holocene, Pleistocene and Neocene deposits. The stratigraphic correlation is as shown in Table 9.7.1.

9.7.2 HYDROLOGY

It had been well known that there was abundant methane gas in this area. The major gas reservoirs in the Niigata gas field belong to the Uonuma Group of Pleistocene age which is characterized by the alternation of clay, sand and gravel beds. Gas reservoirs, i.e., confined aquifers consisting of sand and gravel, are filled with brackish to saline water.

Large quantities of saline ground water containing dissolved gas are pumped up from wells as much as 1000 metres deep, tapping relatively unconsolidated segments of the G_1, G_2,....G_7 layers of Cenozoic age (Figure 9.7.3.). Shallow aquifer G_1 is exploited for domestic use, but the others are exploited for industrial uses (Figures 9.7.4. and 9.7.5.). About 200 million cubic metres of methane was produced in 1958, 60 per cent of the methane gas production in Japan.

The producing wells increased rapidly to 1959 near the mouth of the R. Shinano along the coast of the Japan Sea. With increase of the amount of ground-water withdrawal from gas wells, the rapid lowering of the groundwater level was recognized. The permeability of the gas reservoirs varies from 50 to 200 millidarcys.

9.7.3 SUBSIDENCE

Although no attention had been paid, about 1930 the land subsidence in Niigata was indicated by geologists as "Pseudo-sinking" of sea coast. Subsidence of the Niigata area, especially the harbor district, became noticeable by 1955 (Figure 9.7.6.). Most of the harbor area which initially was only 1-2 m above mean sea level had been damaged by inundation from the sea.

The results of first-order leveling over this area were reexamined and extraordinary subsidence was recognized. Another area of surface subsidence had occurred in the inland part of the Niigata Plain, in the southern part of Niigata city. In 1959, the center of the subsidence was located near Shirone town, and the subsidence rate was about 14 cm in ten months. Based on the data of compaction meters, it was concluded that the compaction was located in the zone shallower than 120 m depth, which is correlated with the Holocene and younger Pleistocene deposits. As shown in Figure 9.7.7, about 10,000 wells producing natural gas for domestic use are located in this area. The amount of the ground-water withdrawal from these wells in 1960 was estimated to be approximately 60,000 m^3/day.

First-order level surveys have been made in Niigata and its vicinity by the Japan Geographical Survey Institute in 1898, 1930, 1951, 1955 and 1957, and leveling has been conducted at 6-month intervals since 1957. (See Figure 2.2.) The subsidence of 20 cm at the harbor mouth in 6 months indicates an annual rate of 40 cm. By 1959, the annual rate had increased to 54 cm a year.

Long-term graphs of elevation change for five bench marks which are representative of the subsidence trend are shown in Figure 9.7.8. They show a slow subsidence of about one half a centimetre per year from 1898 to 1952 and a rapid acceleration since 1955. The cause of the slow

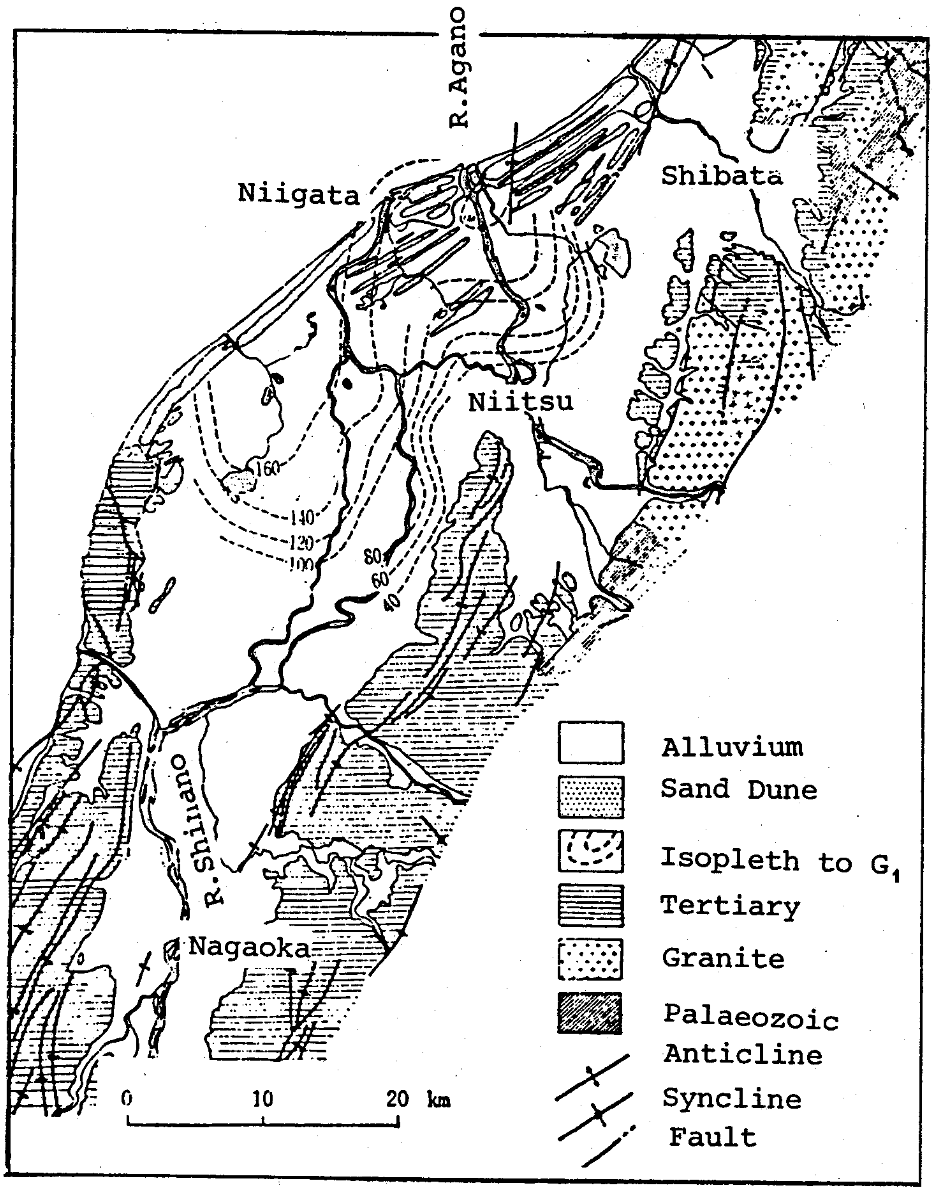

Figure 9.7.1 Physiographic map of Niigata area.

subsidence prior to 1952 has not been explained. Natural gas production, shown in Figures 9.7.4 and 9.7.5, began about 1947 and increased rapidly in the fifties. The volume of gas-bearing water pumped reportedly has been about equal to the volume of gas recovered. Because of the coincidence in time and place of the increase in rate of subsidence and of fluid withdrawal, we concluded that the cause of the accelerated subsidence is the withdrawal of the water and gas. This withdrawal has decreased the fluid pressure in the gas-bearing zones and has caused the compaction of sediments.

The rate and distribution of compaction in depth is being observed by means of 12 novel compaction recording wells, installed in 1958-1959, and ranging in depth from 20 to 1190 m. When the results obtained from these observation wells were analyzed, they showed a remarkable contraction of the layer from 380 to 610 m depth. The subsiding area of Niigata districts is about 430 km^2.

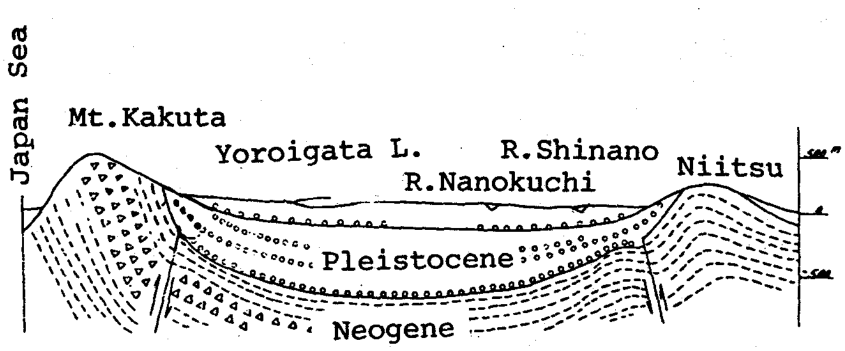

Figure 9.7.2 Diagrammatic cross section of Niigata.

9.7.4 PARAMETERS

M_V	1×10^{-2}	-	5×10^{-2}	CM^2/kg
C_V	1×10^{-1}	-	1×10^{0}	$CM^2/min.$

9.7.5 LEGAL ASPECTS AND COUNTERMEASURES

Since 1960, control of ground-water withdrawal has been undertaken by putting area "A" completely under the ban of gas production (Figure 9.7.9). They also established area "B," where extraction of gas from shallower reservoirs than G_6 is prohibited, and "C," where gas production is permitted within the limit of the past production record. Over all this area, new drilling is prohibited.

Besides legal restrictions, hydrogeologists had carried on experiments of water injection into gas reservoirs since 1966 or so. The injectivity index is usually less than a quarter of the productivity index. After 1965, the gas company started to inject saline water into four reservoirs (G_{4-1}, G_5, G_{5-1}, G_6). The change of ground-water level and compaction of these layers has been observed in this area (Figures 9.7.10, 9.7.11, 9.7.12, and 9.7.13). Since 1973, all the pumped water, about 110,000 cubic metres per day, after gas separation, has been injected into the gas reservoirs through injection wells, with no surface drainage.

The total estimated cost of countermeasures over the whole Niigata area is difficult to estimate but the direct cost is estimated as $12 million for the period 1957 to 1974.

9.7.6 SELECTED REFERENCES

AOKI, S. 1977. Land subsidence in Niigata. IAHS Pub. No. 121, p. 629-634.

HOKURIKU AGRICULTURAL BUREAU. 1965. Land subsidence of agricultural land in Niigata, pp. 1-485.

ISHIWADA, Y. 1969. Experiments on water injection in the Niigata gas field. IASH Pub. No. 88, pp. 629-634.

Table 9.7.1 Geological correlation and gas reservoir.

Age	Division	Lithology	Thickness
HOLOCENE	I	Silt & clay alternation	120 - 160 m
	II	Silty clay	
	III	Silt, clay and sand	
	IV	Peat, clay & sand alternation	
	V	Clay-silt, Gravel, sand and silt G_1	
PLEISTOCENE (Uonuma - Kanbara)	upper	G_2 Sand & gravel G_3	
	middle	G_4 Mudstone,Conglomerate and sandstone	
	lower	G_{4-1} Mudstone G_5 sandstone & conglomerate	310 - 660 m
NEOGENE	Haizume	G_{5-1} Conglomerate G_{5-2} Conglomerate G_6 Conglomerate	500 - 700 m
	Nishiyama	G_7 Sandstone G_8 Sand & gravel	

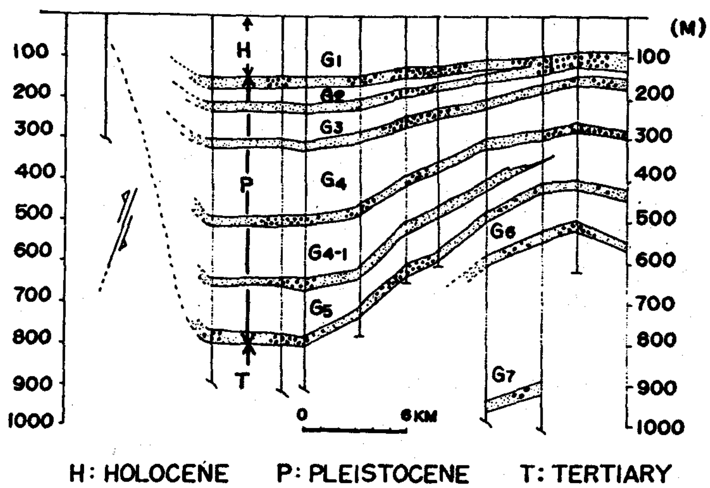

Figure 9.7.3 Geologic profile.

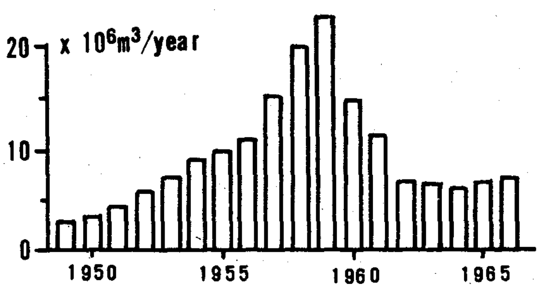

Figure 9.7.4 Annual amount of withdrawal of gas water for industrial use.

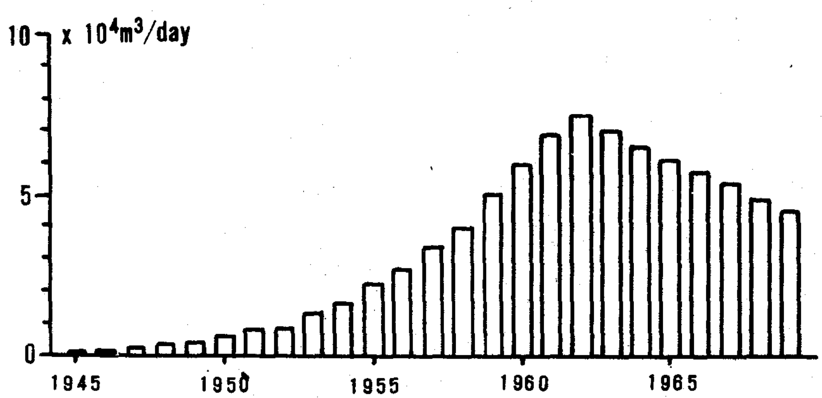

Figure 9.7.5 Daily amount of withdrawal of gas water for domestic use.

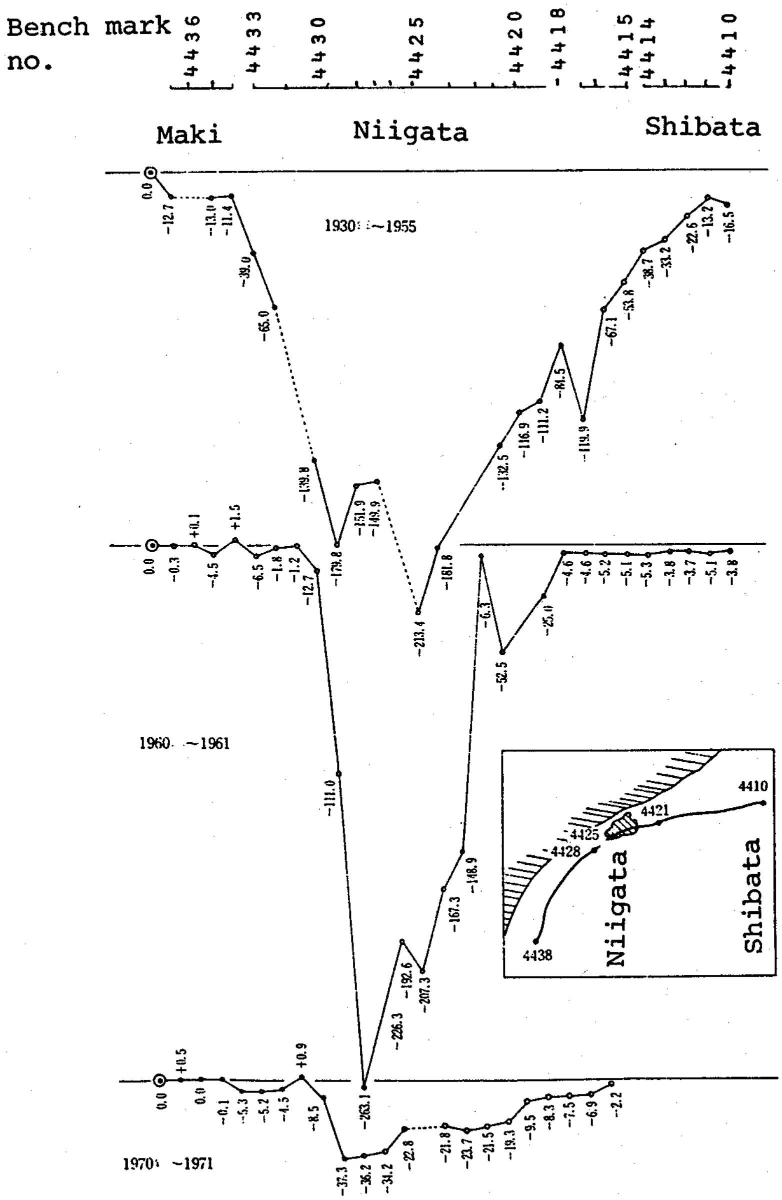

Figure 9.7.6 Subsidence of bench marks on selected points in Niigata and vicinity, in millimetres.

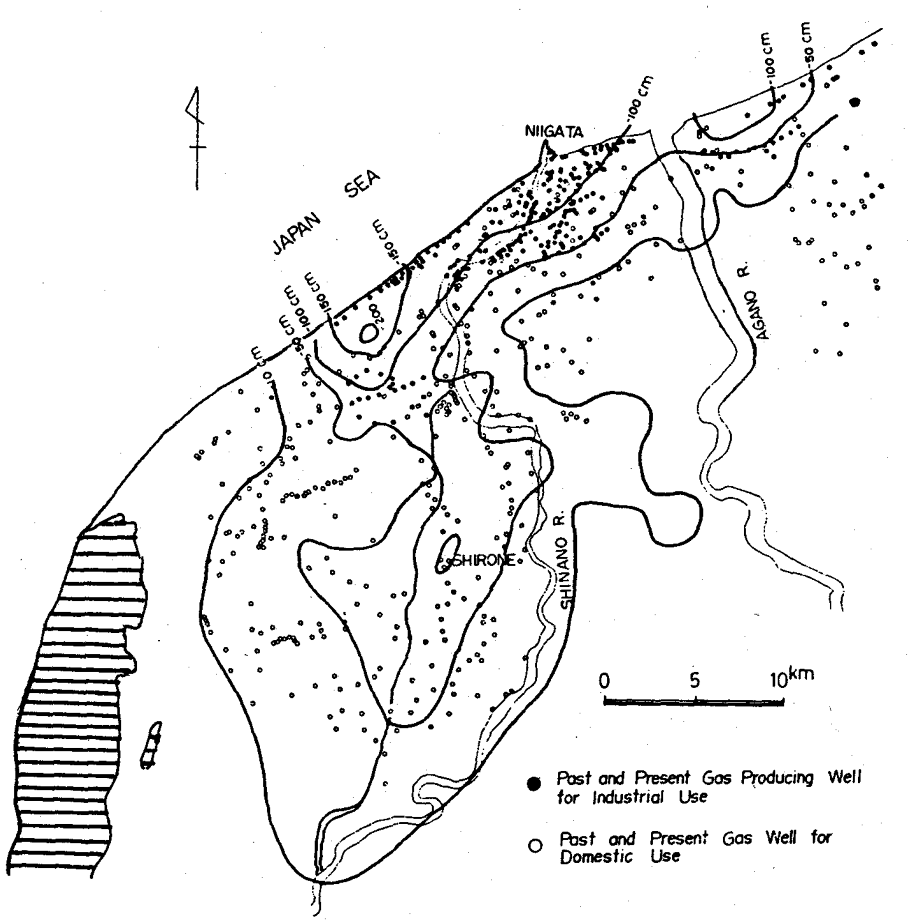

Figure 9.7.7 Distribution of gas wells and total amount of land subsidence during the period 1959-74.

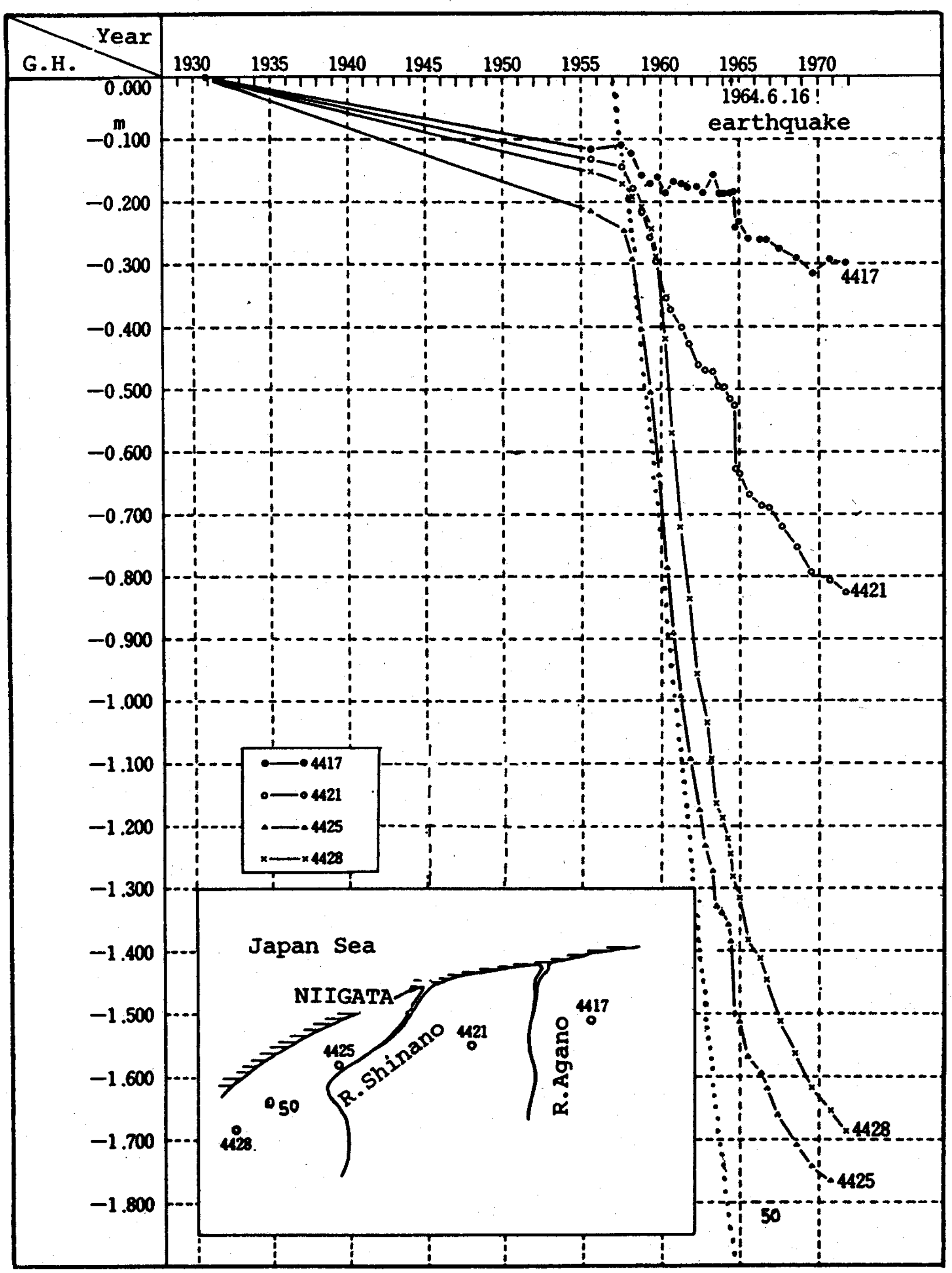

Figure 9.7.8 Change of ground height in Niigata (m).

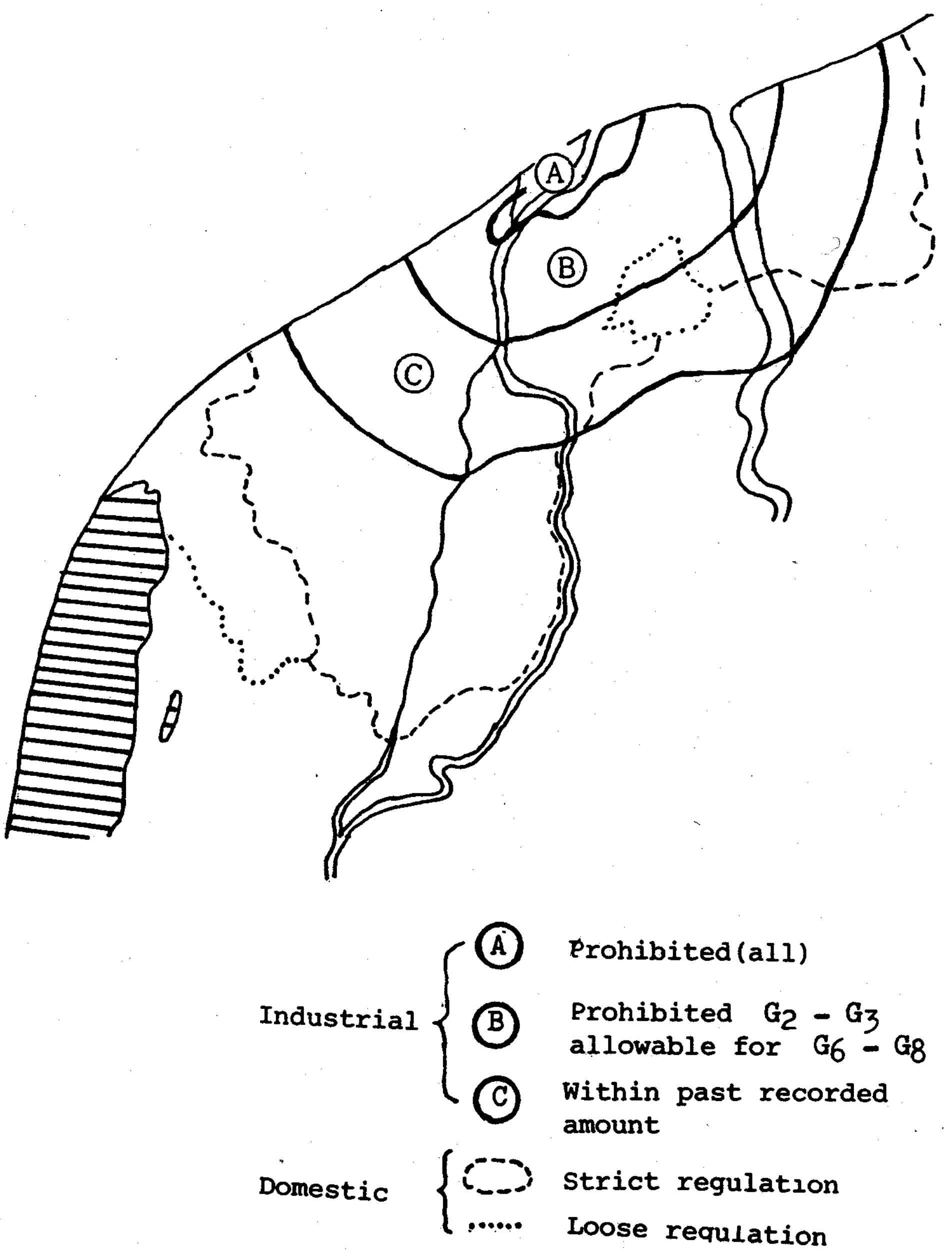

Figure 9.7.9 Regulation by law in Niigata area.

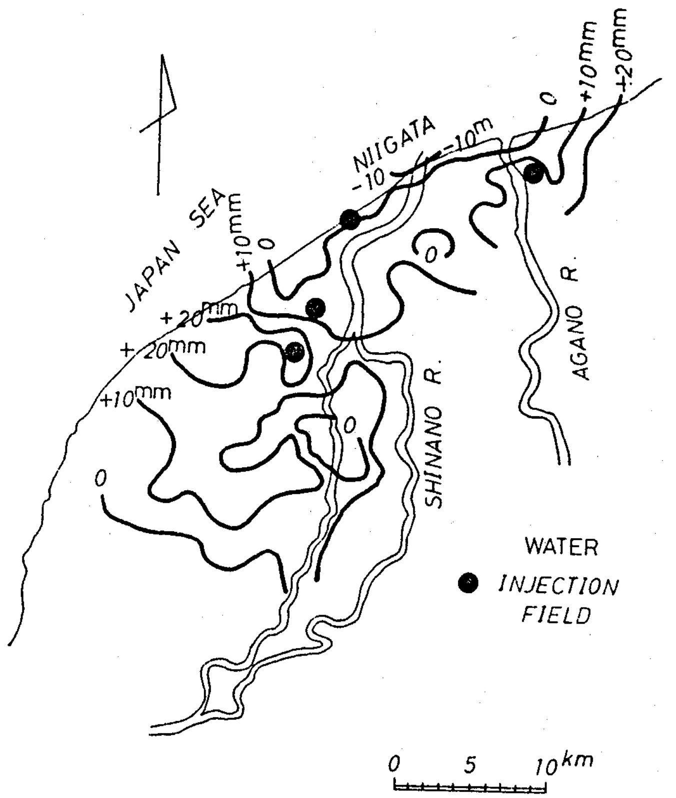

Figure 9.7.10 Land subsidence during 1973-74.

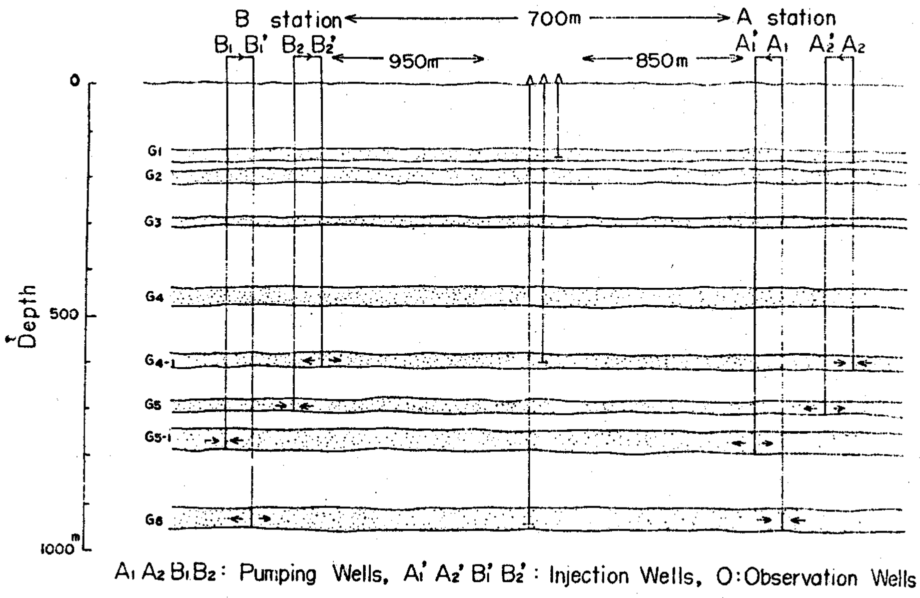

Figure 9.7.11 Profile of water injection experimental station (at Kurosaki).

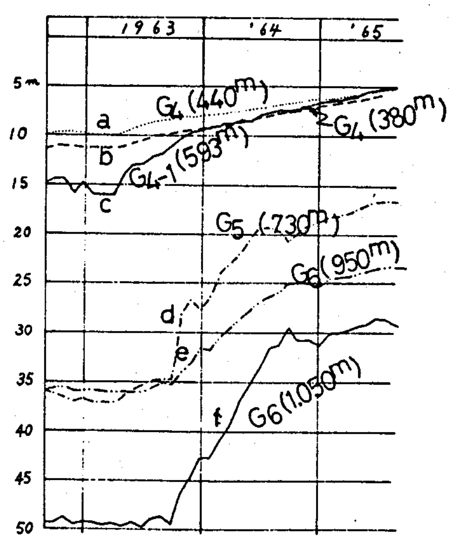

Figure 9.7.12 Change in ground-water levels at observation wells (Kurosaki).

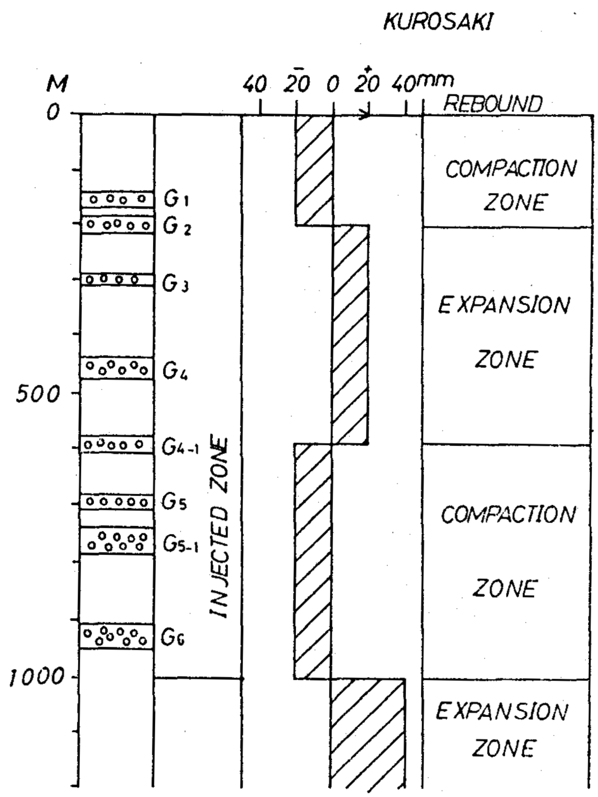

Figure 9.7.13 Columnar section showing the position of expansion and compaction layers at Kurosaki.