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1995 Northern Niigata Earthquake of M6.0 and a Buried Fault Imaged by Distribution of Seismic Intensity

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(Abstract)

A destructive earthquake of M6.0 on the Richter scale occurred at 18km east away from Niigata city in flat paddy field of the Niigata plain. The epicenter was so shallow at 10km deep that 55 houses were completely collapsed and 165 houses were half collapsed, but no one died. The distribution of seismic intensity was analyzed by the rotatory moment calculated from overturned rectangular gravestones. The vertical acceleration at the epicenter was encountered as fairly larger than the acceleration of gravity. The seismic intensity 6 on the scale of the Japan Meteorological Agency (JMA) covered an area of 5.2×1km trending NNE-SSW, which may indicate the distribution of the buried ruptured fault beneath the plain. This destructive earthquake actually came true at the eastern margin of the seismic gap, which might be a precursor of a strong destructive earthquake, soon, as predicted by Mogi(1988), Ishikawa (1990, 1994) and Ohtake (1994). Special attention for the impending earthquake disaster should be required in the Niigata area, soon.

Key words : Northern Niigata earthquake, shallow earthquake, overturned gravestone, buried ruptured fault, seismic gap.

Introduction

The 1995 Northern Niigata earthquake occurred at the eastern margin of the Niigata seismic gap, which has been pointed out by Mogi (1988), Ishikawa (1990, 1994) and Ohtake (1994). It should be noted that a long termed prediction based on seismic gap actually comes true at the eastern margin of the predicted area.

1. Earthquake and Damage

At 12:49, April 1 of 1995, a magnitude 6.0 earthquake occurred at Sasakami village, Northern Kanbara district, Niigata Prefecture, 18 km east away from populated Niigata city. At the beginning, it was reported that the epicenter located at Japan sea floor a few kilometers off the mouth of Kaji river with 17km deep. Shortly after it was corrected that the epicenter was inland at the Kamitakada hamlet, Sasakami village between the Suibara station and the

Toyoura station of the JR Uetsu line. According to the Fire Protection Section of Niigata Prefectural Government, 6 persons were heavily injured, 62 persons were wounded, but no one died. The Kogetsukaku Guest House of the Ichishima landlord, a cultural heritage of the Niigata Prefecture was completely collapsed (Photo 1). In total, 55 houses were completely collapsed, 165 houses were half collapsed, 783 houses were partially destroyed. About $930 millions of total loss was estimated. The main shock was felt not only in the Niigata Prefecture, but also in its surrounding prefectures as shown in Fig.1. Building failures are analyzed by Isoda (1995) and disasters of irrigation facilites are examined by Misawa *et al.*(1995).

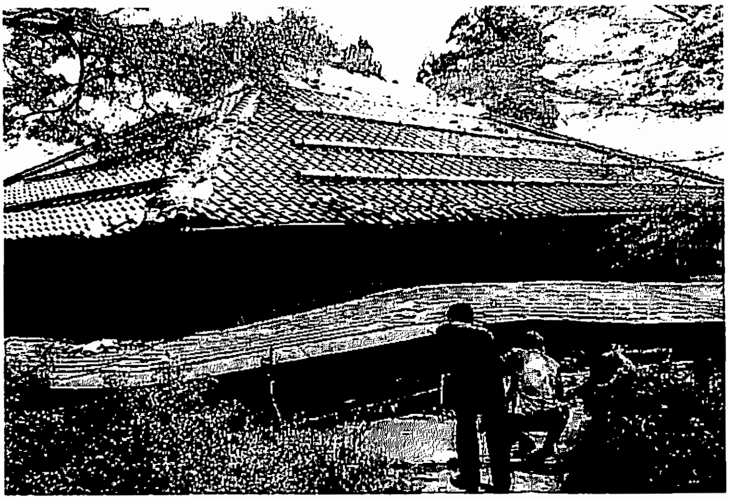

Photo 1 Pancake collapsed Kogetsukaku guest house, Ichisima landlord, a cultural heritage of Niigata Prefecture,Tenno, Toyoura Town.

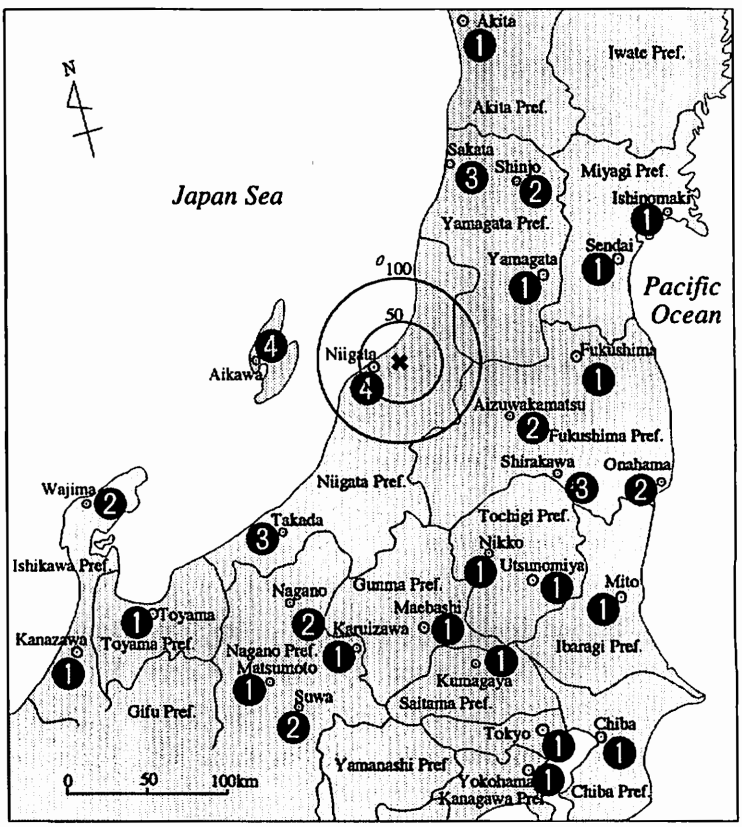

Fig.1 The distribution of seismic intensities of the Northern Niigata earthquake (after Japan Meteorological Agency, 1995).

2. Distribution of Seismic Intensity Calculated by Overturn of Gravestones

Because there is no seismogram of JMA in the epicentral area, the intensity 4 of JMA scale was primarily applied to the epicentral area (Fig.1). It was reported by brief examination that only several old houses were destroyed, but most of the houses were assumed to be not seriously destructed. For this reason, the intensity 5 was officially revised. However, at the epicentral area, in addition to several houses completely collapsed, strong vertical earthquake motion greater than the terrestrial gravity acceleration was estimated at the Kumano Shrine. Many gravestones and the stone gateways of shrines were overturned there. Thus, the intensity 6 would be properly confirmed. Authors have carried out the investigation of earthquake intensity distribution based on gravestones overturned.

In Japan, most of gravestones are rectangular type, which is convenient to estimate the horizontal acceleration of earthquake based on the moment of overturned gravestone. The horizontal acceleration of earthquake motion can be calculated by the following formula: $\alpha = k \cdot g$, where α is a maximum horizontal acceleration, k is the factor of overturn, calculated by the ratio of width to height of overturned gravestone and g is the acceleration of the terrestrial gravity . The critical boundary line between the plots of overturned gravestones and of stably standing gravestones in the height-width diagram provides k value for the calculation of the maximum horizontal acceleration of earthquake (Fig.2). The list of maximum horizontal accelerations is given in Table 1 and the areal distribution is shown in Fig 3.

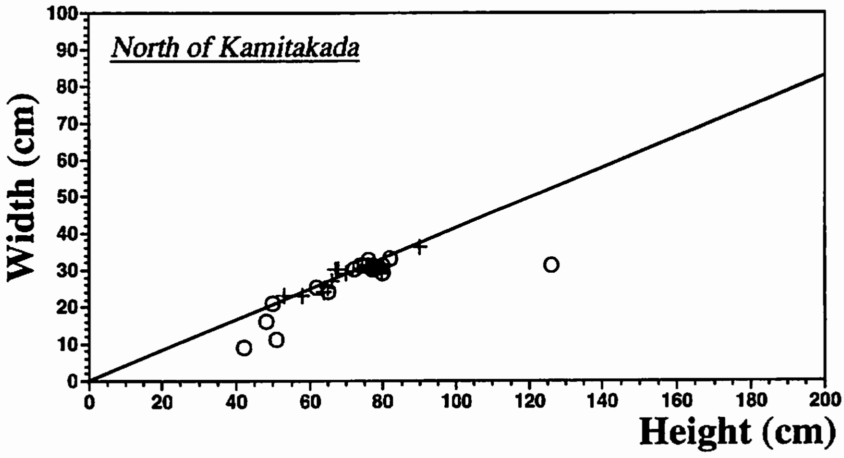

Fig.2 Height-width diagram for the calculation of horizental acceleration of earthquake from stable gravestones (+) and overturned gravestones (○). The inclination of boundary line provides k value for maximum earthquake acceleration (North of Kamitakada grave yard).

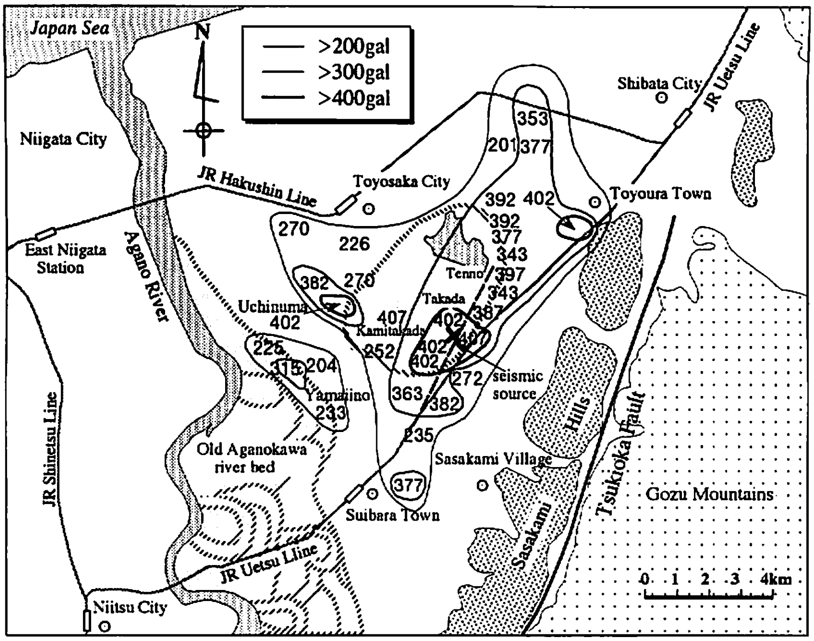

Fig.3 The distribution of horizontal accelerations estimated by the overturned gravestones.

Table 1 The rate of overturned gravestones in the epicentral area.

Administrative district	Location of graveyard	Total number of gravestones	Number of the overturned gravestones	Rate of the overturned gravestone (%)	Acceleration (gal)
Sasakami Village	Kamitakada	27	22	81.5	407
	North of Kamitakada	45	30	66.7	402
	Takada	20	6	30.0	402
	Enoki	30	9	30.0	402
	Fujiya	28	8	28.6	407
	Iiyamashin	16	2	12.5	387
	Nakanotori	40	2	5.0	343
	Funai	80	10	12.5	363
	Shimada	20	3	15.0	382
	Enokifunato	28	1	3.8	272
Toyoura Town	Tenno	138	15	10.9	397
	Yoshiura	170	63	37.1	402
	Todoroki	80	8	10.0	377
	South of Todoroki	11	2	18.2	343
	Norimawashi	51	16	31.4	392
	North of Norimawashi	97	8	8.2	392
Shibata City	Iijima	120	20	16.7	377
	Norikiyo	200	32	16.0	353
	Otashinden	300	2	0.7	201
Suibara Town	Chihara	17	3	17.6	235
	Hinodecho	270	10	3.7	377
Toyosaka City	Uchinuma	75	12	16.0	402
	Uraki	70	7	10.0	382
	Nagato	86	10	11.6	382
	Yamaiino	400	6	1.5	315
	Nagatoro	250	2	0.8	225
	Kamihorida	6	0	0.0	204
	Shimodochigame	82	3	3.7	270
	Kamidochikame	61	3	4.9	226
	Washizu	40	5	12.5	252
Kyogase Village	Komabayashi	260	2	0.8	233

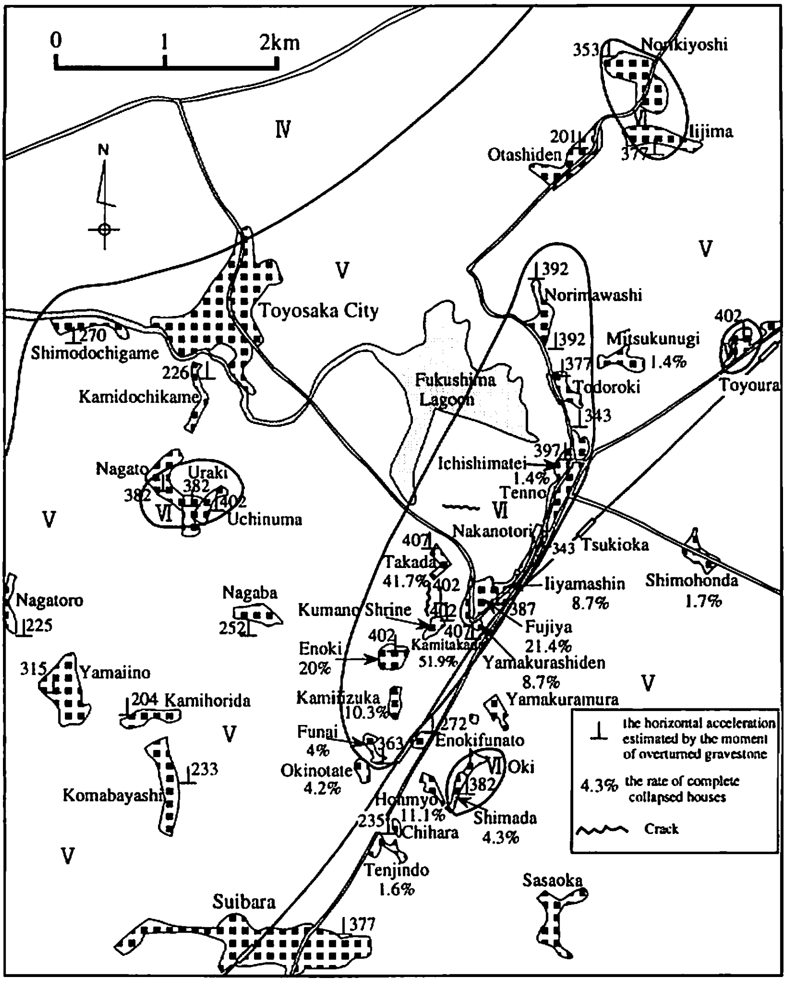

Fig.4 The distribution of seismic intensities overlapped with the rates of completely collapsed houses and horizontal accelerations.

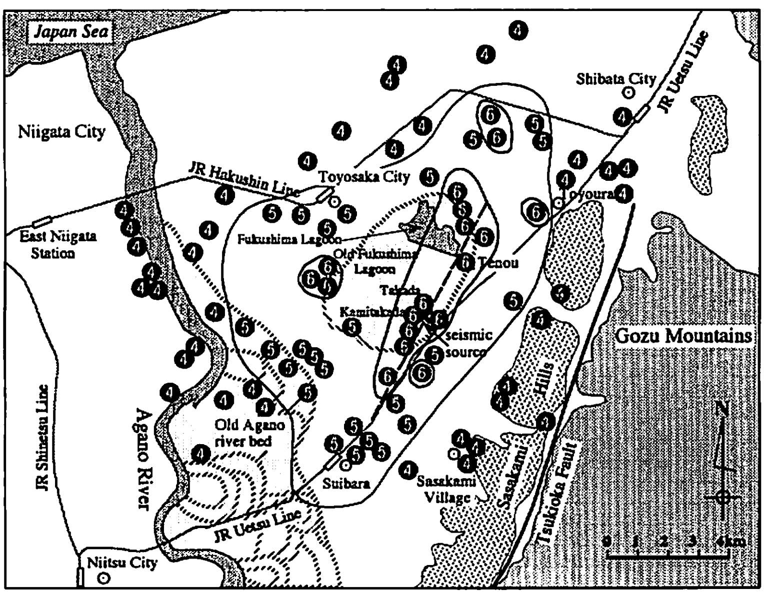

Fig.5 The distribution of seismic intensities estimated by the moment of the overturned gravestones.

3. Distribution of Completely Collapsed Houses

According to the seismic intensity scale of JMA, the seismic intensity 6 is defined by the area having less than 30% of houses completely collapsed associated with landslides and cracks in ground. In this paper, the area of seismic intensity 6 is defined the area of the horizontal acceleration greater than 300 gal. The distribution of seismic intensity is shown in Fig.4 overlapped with ratios the completely collapsed houses and horizontal acceleration. At the epicentral area, the completely collapsed rates of Kamitakada and of Takada are 52% and 42%, respectively (Table 2). Although the rate of overtured gravestone is low at the Tenno, considering the completely collapse of the Kogetsukaku Guest House, together with serious collapse of a warehouse and tea houses in the Ichishima landlord, the seismic intensity 6 can be applied to this area. Several additional areas of intensity 6 distributed like as isolated islands such as Shimada, Yoshiura, Iijima and Uchinuma. The area of seismic intensity 6 is thus defined as the area of the horizontal acceleration above 300 gal with houses completely and half collapsed. This classification is adequately coincided with the definition of intensity 6 of JMA seismic intensity scale (250-400 gal).

Table 2 The rates of the collapsed houses in the epicentral area.

Administrative district	Name of Village	Total number of houses	Number of the complete collapsed houses	Rate of the complete collapsed houses (%)	Number of the half collapsed houses	Number of the complete and half collapsed houses	Rate of the complete and half collapsed houses (%)
Sasakami Village	Takada	36	15	41.7	10	25	72
	Kamitakada	27	14	51.9	10	24	89
	Enoki	25	5	20.0	8	13	52
	Kamiiizuka	39	4	10.3	2	6	15
	Fujiya	28	6	21.4	17	23	82
	Iiyamashin	42	1	2.4	6	7	17
	Nakanotori	171	0	0.0	0	0	0
	Yamakurashinden	23	2	8.7	4	6	26
	Funai	25	1	4.0	19	20	80
	Okinotate	24	1	4.2	8	9	38
	Honmyo	18	2	11.1	4	6	33
	Shimada	23	1	4.3	1	2	9
	Oki	28	0	0.0	2	2	7
	Enokifunato	50	0	0.0	0	0	0
	Minamiokiyama	4	0	0.0	0	0	0
	Kamitakada(Kamuyama)	16	0	0.0	0	0	0
	Yamakuramura	51	0	0.0	0	0	0
Toyoura Town	Tenno	146	2	1.4	3	5	3
	Norimawashi	69	0	0.0	0	0	0
	Mitsukunugi	71	0	0.0	3	3	4
	Shimohonda	58	1	1.7	2	3	5
	Fukushima	43	0	0.0	3	3	7
	Kamihonda	113	0	0.0	0	0	0
	Yoshiura	41	0	0.0	0	0	0
	Hachiman	22	0	0.0	0	0	0
Toyosaka City	Uchinumaoki	34	0	0.0	2	2	6
	Uchinuma	129	0	0.0	5	5	4
	Nagaba	127	0	0.0	10	10	8
	Uraki	105	0	0.0	4	4	4
	Nagato	37	0	0.0	0	0	0
	Ozuki	112	0	0.0	0	0	0
Suibara Town	Tenjindo	61	1	1.6	23	24	39
	Chihara	26	0	0.0	13	13	50
	Okitori	33	0	0.0	10	10	30
	Hinodecho	53	0	0.0	2	2	4
	Total	1910	56	2.9	171	227	12

The area of intensity 6 extending 5.2 × 1 km embracing the zone of completely collapsed houses trends to NNE-SSW direction. This revised length of the fault 5.2 km long is 1.7 km longer than that described in our previous article, in which the 3.5 × 1 km area was confirmed (Ōki *et al*, 1995). The lower limit of intensity 5 is defined by 200 gal (the definition of JMA is 80-250 gal). This boundary limit coincides with the boundary of gravestones began to overturn. The areal extent of intensity 6 and 5 is about 10 × 5 km. At the upper limit of the intensity 4 the gravestones of ordinary shape were not overturned except for tall gravestones. Many of stone lanterns and gateways of shrines were overturned at the area close to the boundary of the intensity 5. The axial direction of the areas of intensity 6 and 5 is located by 5 km far west from the Tsukioka active fault. The location of the long axis of intensity 6 is an image of earthquake fault that generated this destructive earthquake. It is named as buried active fault of the Fukushima lagoon eastern margin.

There is a empirical formula between the magnitude of inland earthquakes of Japan and the length of earthquake fault (Matsuda, 1975)

$$\log L\ (\mathrm{km}) = 0.6M - 2.9$$

M6.0 earthquake will generate 5km long earthquake fault. The actual intensity 6 area extending by 5.2 km long shows proper correlation with Matsuda's formula. The isolated areas of the intensity 6 and the westerly expanding of the intensity 5 area including the Fukushima lagoon may be formed with soft sediments filling the meandering stream of the old Aganokawa river and the lowlands of marshes behined the Niigata seashore sand dunes.

The regional distribution of the seismic intensity is surveyed by an enquête method by Shiono (1995).

4. Vertical Earthquake Motion

A vertical earthquake motion greater than the terrestrial gravity acceleration was inferred from the Kumano shrine located at the epicentral area of Kamitakada hamlet. The couple of the main pillars with a tenon of 3cm long each placed into a mortise of the stone foundation had been transferred by 30cm west away without any streak of wooden powder on the surface of the stone foundation (Photo 2). The evidence of no scratched streaks on the surface of the stone foundation except one example surely indicates that a vertical power grater than the terrestrial gravity had been applied to the shrine by the main shock. The area of 300 × 200m surrounding the Kumano shrine was subjected to the strong vertical motion and thus resulted with 52% of the houses completely collapsed.

A new residence of Mr. Ikarashi, a two-story Japanese style was a wooden house built in 1990 at 30 m north of the Kumano shrine. The house was not suffered any destruction just viewed from looking of outside, but the damage of inside was extremely serious. For example, a main pillar was sharply sheared (Photo 3) probably by strong vertical acceleration. The deformation and destruction of walls and the frames in E-W direction perpendicular to the

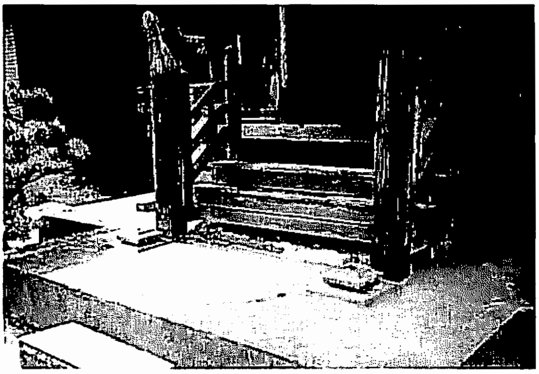

Photo 2 Kumano shrine, Kamitakada, Sasakami Village thrown by 30 cm west. The couple of the main pillars transferred without wooden powder streak on the surface of the stone foundations suggesting strong vertical acceleration than terrestrial gravity occurred.

Photo 3 A wood pillar sharply sheared by vertical shock, Kamitakada, Sasakami Village.

fault plain were more intense than N-S direction. It is noted that the wooden houses built by the "two by four" method of wall structure since 1974 were not destroyed even at the epicenter area. The Kogetsukaku guest house of the Ichishima landlord built in 1897 was collapsed by the main shock in pancake collapse. At that moment, a couple of husband and wife just visiting this guest house was placed under the ruins of the Kogetsukaku guest house. The husband fortunately escaped by himself, but his wife was caught by the pancake collapsed. After 50 minutes, she was safely rescued by the firemen. As seen in Photo 1, the guest house was covered with heavy tiled roof of 100 years old and constructed on a soft ground of the Fukushima lagoon. Thus, they said that it was easily collapsed by the earthquake no matter the intensity of the shock small. There is a tea-house close to the guest house settled on stone foundations. The tea-house was displaced by 10 cm to west without any streak of wooden powder on the stone surface like the case of the Kumano shrine and suggests that strong vertical motion larger than the terrestrial gravity hit the tea-house of the Ichishima residence.

5. Crack in the Paddy Field of Kamitakada to Takada Area

A 620m long straight crack with N20°E direction developed in the paddy field from Kamitakada to Takada of the epicentral area. There is a 1 m deep irrigation canal by 2 m west from the crack. The direction of the crack is parallel with the canal. By strong quake, the soil of paddy field slid by several centimeters toward the canal and fractures of 10cm wide at maximum opened (Photo 4). There were a lot of small scale cracks appeared in the firm yard around the Kamitakada hamlet, too.

A N80°E trending crack 40 m long with maximum opening of 10 cm was appeared in the river bed of the Odori river 1.5 km far from the Kumano shrine, the southern margin of the

Fukushima lagoon.

In spite of strong motion, serious liquefaction could not observed. Aoki *et al.*(1995) reported that small scale liquefaction occurred at several places of soft ground in the surrounding of the Fukushima lagoon.

Photo 4 Straight crack 620m long appeared in the paddy field of the epicentral area, Kamitakada, Sasakami Village.

6. Seismic Activity

From December 1994, there was a series of felt earthquakes occurred in Shibata city and its vicinity (Kawauchi *et al.* 1995). In order to monitor the seismic activity in this region, we have installed a vertical component seismometer at the Tokushoji temple in the Sasakami village on March 27, 1995. On April 1, 1995, the main shock of M 6.0 occurred at 12:49, however, the electric power had stopped for several minutes, our seismometer at the epicenter could not record the main shock. The epicentral area of the northern Niigata plain is almost boundary between the thick pile of Neogene sediments and the older complex of granite and metamorphic rocks forming the basement of the Neogene. Simple layer structure of seismic wave velocities can not apply for the epicenter calculation. We obtained the origin time of each shock by the Wadachi's graphic method and calculated the Omori parameter. Fig.6 is the spatial variation of the Omori parameters showing big difference between the Niigata plain and the Echigo mountain. It is noted that the Omori parameter is considerably small in the Niigata plain.

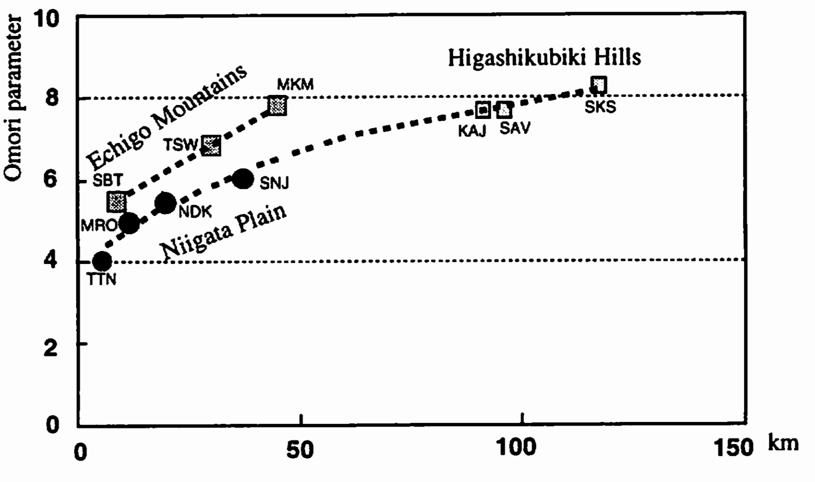

Fig.6 Spatial variation of the Omori parameter vs. epicentral distance diagram. Abbreviations are seismogram stations.

The distribution of epicenters including the main shock has been analyzed as shown in Fig.7 by the seismic records of the Niigata University together with those by Niigata Prefectural government. The focal mechanism analyzed by the Tohoku University (1995) is that E-W maximum compressive stress ruptured a reverse fault with NNE-SSW or NW-SE strike. It is not yet decided whether the earthquake fault plane dips to west or east. The direction of the seismic intensity 6 is different from the strike of earthquake fault analyzed by the Tohoku University. Sakai *et al.* (1995) reviled the distribution of the epicenters with careful attention to depth of the foci. They have pointed that the Northern Niigata Earthquake is regarded as very shallow seismic activity, which takes place at the basal part of the Neogene sediments highly deformed by E-W compressional stress. The daily number of earthquakes observed at our seismogram station at Tokushoji is shown in Fig. 8. The aftershock activity lasted 40 days after the main shock.

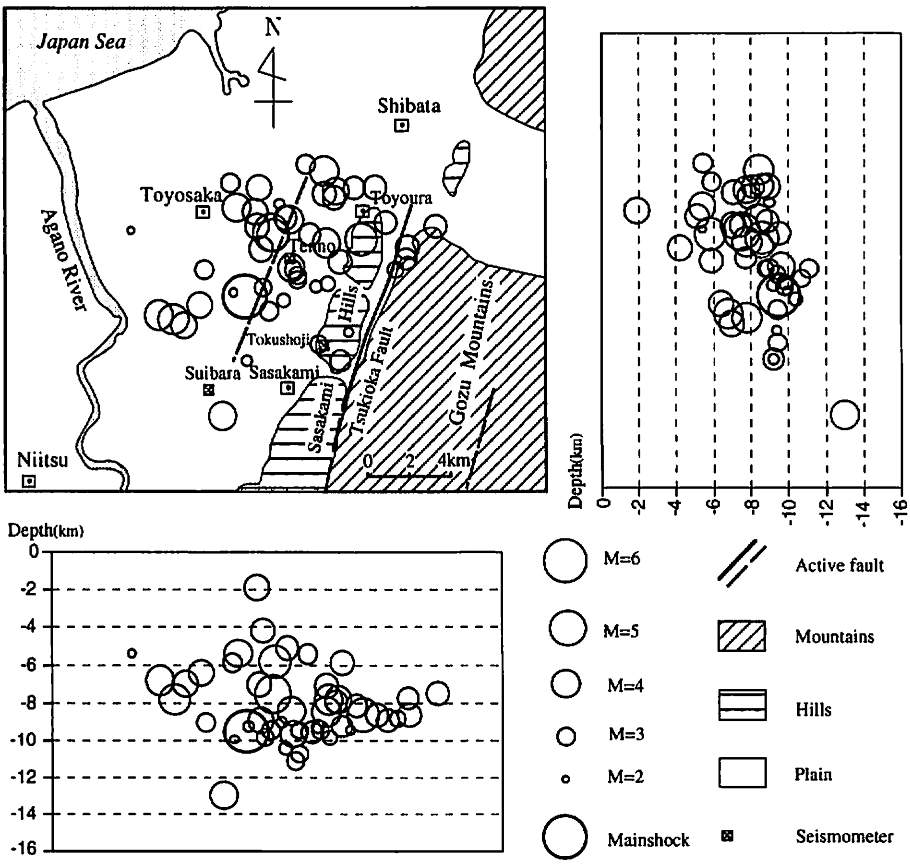

Fig.7 The distribution of epicenters of the Northen Niigta earthquake and its aftershocks.

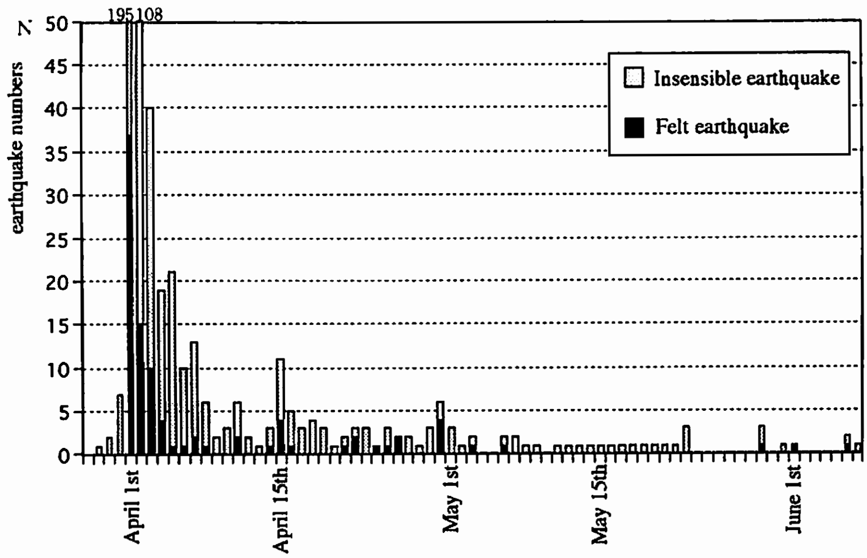

Fig.8 Temporal variation of the daily number of earthquakes recorded at the Tokushoji temple.

7. Shibata-Koide Tectonic Line

The Shibata-Koide tectonic line trending NNE-SSW from Murakami through Shibata, Gosen and Tochio to Koide making the western border of the Echigo Range. On the west side of the line, Tertiary and Quaternary sediments are accumulated as thick pile of several thousand meters. On the east side Mesozoic granites and metamorphic rocks of the Ashio belt which form the back bone terrain of the Honshu Island are widely exposed.

The geologic structure of the northern Niigata district is summarized by Kobayashi (1995) based on the deep drilling information obatined by the petrolum explorations.

In the study area this tectonic line is the boundary between the Gozu mountains on the east and the Sasakami hills on the west and manifests a fault valley basin named as the Murasugi lowland. The fault escarpments facing east developed in the east margin of the Sasakami hills is named as Tsukioka fault. However, the precise location of the fault plain is not yet known, because the fault escarpments are covered by thick talus. Most of the rivers originated from the Gozu mountains are left lateral offset associeted with the development of the Murasugi lowland. No remarkable movement is recognized in the Tsukioka fault by this earthquake and the fault rupture did not appear on the surface. The focal mechanism proposed by the Tohoku University is that main shock was caused by E-W compressional stress with the development of reverse faults. In this model, the nodal plane subparallel to the Tsukioka fault dips to the west, at this moment, however, it is difficult to find harmonic solution between the geomorphological features of left lateral offset of the Tsukioka fault and the focal mechanism.

8. Geopressured Hydrothermal Water and Precursor Anomalies of Earthquake

The Sasakami area is 13km NE far from the Niitsu oil field, which was exploited from the Meiji era (1870) to the early days of Showa (1945). Even now every family utilizes natural gas collected from wells of 100-200 m deep. There are thermal and mineral water springs such as Tsukioka, Deyu, Imaita, Murasugi and Houshu distributed along the Tsukioka fault. Sakihana and Mikawa hot springs issue from granite of the Gozu mountains. Ōki *et al.* (1992) and Watanabe (1995) pointed out that a geopressured hydrothermal system exists widely in the Northern Fossa Magna region at several kilometers deep closely associated with petroleum and natural gas. It is likely that destructive earthquakes were triggered by the activity of high geopressured hydrothermal system. For example, enormous outflow of warm bicarbonate saline water was recognized closely associated with the 1965 Matsushiro earthquake swarm and Nakamura (1989) described this voluminous water discharge as "water eruption", which might be a presentation of the geopressured hydrothermal activity. In the 1992 Tsunan earthquake of M4.5 accompanied an obvious anomaly of warm water from a well 1300m deep decreased considreably 3 days before the main earthquake (Ōki *et al.* 1994). Many notable anomalies of groundwater and hot springs related to the 1995 Northern Niigata earthquake were described by Kawakami (1995). The water head of warm water in a well 200m deep, Deyu Hot Springs rose by ca. 1 m up during three days before the main shock. Thermal water discharge of Tsukioka and Deyu spas also increased and water discharges from deep irrigation well 150 to 200 m deep in Honda near Tsukioka were doubly increased.

9. 1828 Sanjo Earthquake

The 1828 Sanjo earthquake of M6.9 hit the Echigo plain and the area of the intensity 6 was about 40×20km (Fig.9). The serious disasters were that 1443 persons killed, 9808 houses completely collapsed and 1204 houses burnt. The intense liquefaction induced, the eruption of mud and blue turbidity sand were erupted from cracks opened in the ground. It was reported that bases of houses were subsided in the area of the intensity 6 to varying degrees. Based on the Matsuda empirical formula (1975), the earthquake fault was estimated 17km long. Before 168 years ago, the densities of villages and the population were smaller compared with the present, so the above-mentioned damages might indicate the earthquake motion was so strong like the 1995 Hanshin-Awaji Earthquake Disaster. The depth of the 1828 Sanjo Earthquake was shallow (around 10 km deep). The impending earthquake in the seismic gap of the Niigata plain would be the same in scale with the 1828 Sanjo earthquake. Carefull reexamination of earthquake disaster will be needed for the prepavation of our counterplan to the impending Niigata earthquake.

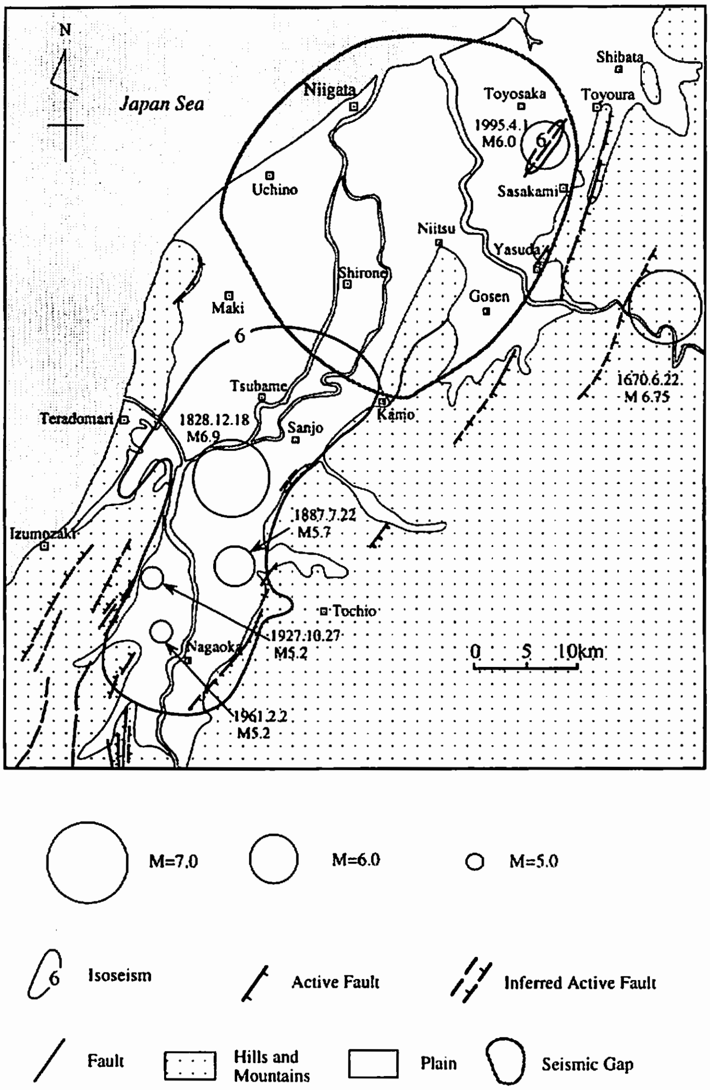

Fig.9 The area of seismic intensity 6 of the 1828 Sanjo earthquake (modified after Usami, 1987) and the seismic gap of the Niigata plane.

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