BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
UNIVERSITY OF TOKYO
Vol. 69 (1994) pp. 19–38

A Destructive Shallow Small Earthquake – The 1992 Tsunan Earthquake of M4.5 in Southern Niigata Prefecture, Central Japan –

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(Received December 28, 1993)

Abstract

A small earthquake of M4.5 severely attacked Tsunan Town, Niigata Prefecture on December 27, 1992. Unexpectedly destructive damage to school buildings and gymnasiums was mainly attributed to an extremely shallow focal depth of 2–3 km within the Tertiary layer, which is as thick as 5–6km. The accuracy of the depth determination is estimated to be within 1 km. A high Vp/Vs ratio of 2.0 measured locally also supports the shallow focal depths. We have no seismometric reports of a shallow earthquake with magnitude greater than 4 whose fractured region is entirely within the Tertiary layer other than this paper.

The epicentral region is tectonically complicated, where the Shinano River Seismic Zone and the Naoetsu-Choshi Line deduced from Bouguer gravity anomalies cross each other. Probably due to this complexity, the earthquake generating stress of the mainshock indicates NNW-SSE compression, while the major aftershocks are generated by WNW-ESE compressional stresses which are in harmony with the surrounding stress field.

This earthquake is followed by a comparatively small number of aftershocks, and preceded by microearthquake activity about 3 months before and during the 12 hours before the mainshock. The aftershock region is separated into three spots, one of which was the source region of the precursory activity 3 months before.

Introduction

Small earthquakes with magnitude less than 5 have caused no severe damage in modern Japan. However, the Tsunan earthquake that occurred on December 27, 1992, at 11:17 JST, was an extraordinary destructive event in spite of its small magnitude of 4.5. The epicenter is located near the border between Niigata and Nagano Prefectures; its aftershock area is mostly in Tsunan Town, Niigata Prefecture (Figs. 1 and 2). The severely damaged area is confined to the area of 1km^2 covering Sakasamaki, Miyanohara, Kameoka and Hakura villages in Tsunan Town (Fig. 2). The main damage was as follows:
(1) Kamigo Junior High School in Sakasamaki: Part of the gymnasium ceiling collapsed onto the floor. Window frames were dislocated and window glass was broken in many places of the two-story reinforced concrete buildings and the gymnasium.
(2) Kamigo Elementary School in Sakasamaki: Windows and walls of the three storied mortared frame building and the gymnasium were broken in many places.

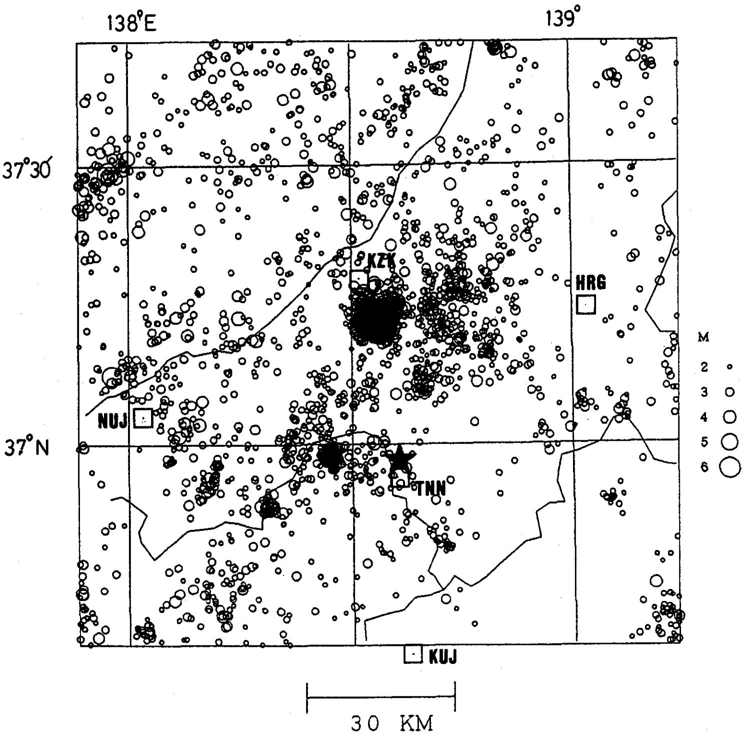

Fig. 1. Epicentral map of microearthquakes and the source region of the Tsunan earthquake (star). Hypocentral data are mostly from the original catalogue provided by Shin'etsu Observatory, Earthquake Research Institute, with some corrections for the earthquake group around northeastern Nagano Prefecture. The period: from January, 1978 to March, 1993; depth ≤30km, M≥1.5. Open rectangles are permanent stations used for hypocentral determination.

(3) Houses and shops in the Sakasamaki, Miyanohara, Kameoka and Hakura regions: The number of houses which suffered broken window glass, cracked walls, and slight strain in frames totaled 137. Damage extended to hydrants and pipe lines for water supply. Electric power supply was suspended for an hour since shortly after the mainshock (10s after the immediate foreshock at seismic station TTN of Shin'etsu Seismological Observatory, Earthquake Research Institute, University of Tokyo).

There appeared a number of small open cracks in the asphalt road, Route 117, and side lanes in and around Sakasamaki. YAMASHINA (1993) reported detailed field observations of the above cracks and road deformation. There was no loss of lives and no severely injured persons. It was quite fortunate that the earthquake struck the schools during winter vacation.

The purpose of this paper is to estimate the precise location of the source region of this earthquake by using data from routine and temporal observations, and to discuss its tectonic implications.

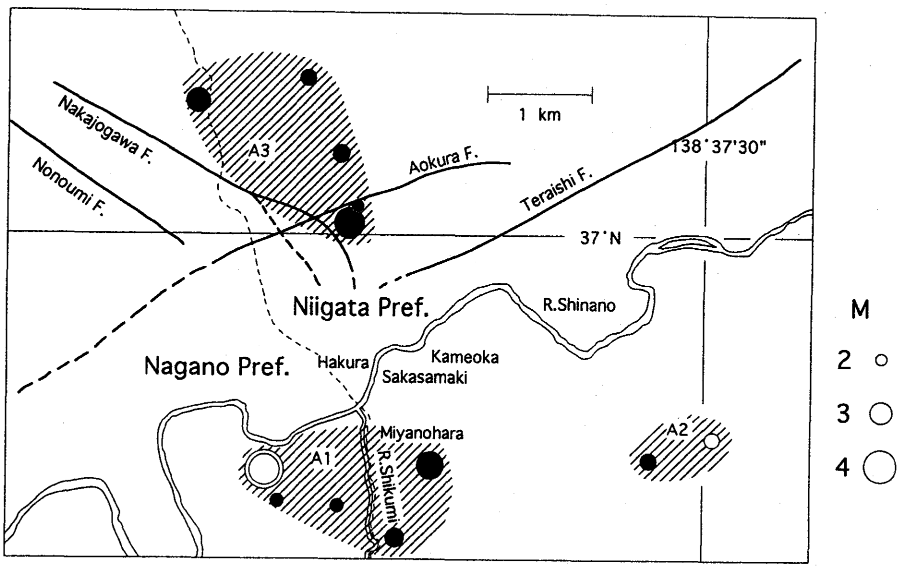

Fig. 2. Local map of the source region. Double circle indicates the mainshock epicenter (exactly the location of the immediate foreshock which occurred 4 seconds prior to the mainshock and is estimated to have occurred in nearly the same place). Solid circles represent aftershocks. An open circle denotes the precursory shock on September 19, 1992, which was the unique located precursory event. The shaded zones A1, A2 and A3 are source regions of aftershocks. Active faults are after OKI *et al.* (RESEARCH INSTITUTE for HAZARDS in SNOWY AREAS, NIIGATA UNIVERSITY, 1994). The Miyanohara fault described in the map by the Research Group for Active Faults (1991) is omitted here because one of the authors could not recognize it in his field research.

Temporal Observations and Hypocentral Determination

The Research Institute for Hazards in Snowy Areas, Niigata University, carried out seismic observations at four sites in the vicinity of the damaged area after the destructive earthquake. The Shin'etsu Seismological Observatory, Earthquake Research Institute, University of Tokyo, has been operating a telemetered high sensitivity seismic network in the region. Stations used in this paper are listed in Table 1. The locations of stationary stations are shown in Fig. 1 and those of local stations in Fig. 4.

The first six stations were used for the tentative determination of aftershock hypocenters. Six events were registered at all the nearby stations. As most of the seismograms of these events are saturated in amplitude, we could not read the S phases. Therefore, we calculated hypocenters using solely P times. The O-C residuals of P times almost vanish except for the relatively distant stations, KZK, HRG, NUJ and KUJ, of which residuals were used for the station corrections listed in Table 1. The station correction terms were effectively applied to determining hypocenters of the mainshock and shocks without data from temporary observations.

P velocity structure used for hypocenter determination is shown in Fig. 3, based on the model inferred from the explosion seismological experiment by IKAMI *et al.* (1986). The hypocentral determination is based on a Baysian estimation method by HIRATA and

Table 1. Seismic stations used. The temporal stations TRI and OID are located in Tsunan Town, Niigata Prefecture; SKM and SOJ in Sakae Village, Nagano Prefecture. The station correction terms are applied to the final hypocentral determination.

Code	Location	Longitude (°E)	Latitude (°N)	Altitude (m)	Observation Period	Station Correction (sec)
TRI	Teraishi, Tsunan	138.5944	36.9956	290	Jan. 5 – Feb. 28, 1993	
OID	Oidaira, Tsunan	138.6079	36.9916	295	Jan. 13 – Feb. 2, 1993	
SKM	Shikumi, Sakae	138.5872	36.9749	310	Jan. 5 – Apr. 5, 1993	
SOJ	Shiojiri, Sakae	138.5748	36.9834	259	Jan. 25 – Mar. 7, 1993	
TNN	Deura, Tsunan	138.5947	36.9423	430	Oct. 12, 1987 –	
KZK	Kashiwazaki	138.5157	37.2951	220	Nov. 1, 1988 –	–0.17
HRG	Hirokami	139.0361	37.2369	210	Jun. 2, 1981 –	0.64
NUJ	Nou	138.0308	37.0478	240	Jun. 2, 1981 –	–0.28
KUJ	Kuni	138.6353	36.5714	760	Jun. 1, 1981 –	0.86

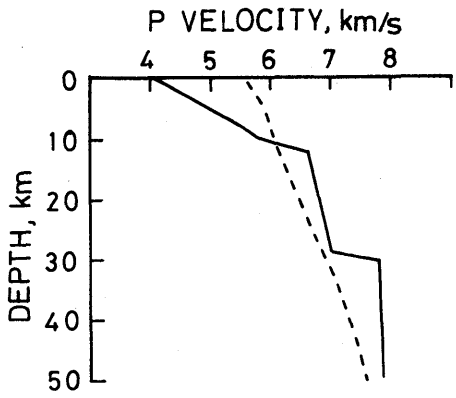

Fig. 3. P velocity structure models used for obtaining hypocentral data (solid line) and focal mechanism solutions (broken line).

MATSU'URA (1987). The final determination was conducted by selecting six stations at most and not less than four among those listed in Table 1, so that they cover the source region as closely as possible. The absolute average O-C values are within 0.2s for each event. The hypocentral parameters calculated are listed in Table 2.

The distribution of the mainshock, aftershocks and a precursory shock is shown in Fig. 2 and Fig. 4. The accuracy of the hypocentral coordinates for individual events is within 1km as derived by a hypocentral error simulation (Fig. 5).

The shallow focal depths were also confirmed using other independent data. Figure 6 provides us with Vp/Vs ratios by fitting P and S arrival times for locally detected small aftershocks, which were difficult to precisely locate because of insufficient coverage of stations. The average value 2.0 gives the Omori coefficient k of 3.1–4.7 km/s for the P velocity 3.1–4.7km/s. These values of Vp/Vs and k are quite different from those for ordinary crustal earthquakes (e.g., TSUKUDA, 1976), but are consistent with very shallow

Table 2. List of hypocenters located in this study. Seismic regions A1, A2 and A3 are shown in Fig. 2. The parenthesized values are rough estimates.

Y	MD	HM	S (JST)	Longitude (°E)	Latitude (°N)	Depth (km)	M	M_{JMA}	Region
1992	919	1859	42.43	138.6261	36.9831	2.4	2.5		A2
1992	1227	1117	5.13	138.5789	36.9804	2.2	(2.5–3.0)		A1
1992	1227	1117	9.13	(138.5789	36.9804	2.2)	4.6	4.5	A1
1992	1227	1238	3.06	138.5966	36.9808	1.2	3.6		A1
1992	1230	1011	17.28	138.6195	36.9814	1.3	2.6		A2
1993	1 5	044	38.82	138.5929	36.9748	3.3	2.8		A1
1993	117	1141	19.70	138.5866	36.9775	1.5	2.4		A1
1993	117	1144	37.14	138.5803	36.9779	2.5	2.3		A1
1993	122	6 4	56.76	138.5868	37.0068	2.2	2.7		A3
1993	122	817	25.19	138.5886	37.0024	2.4	2.2		A3
1993	123	1614	43.14	138.5718	37.0111	0.2	3.2		A3
1993	123	1621	39.94	138.5833	37.0130	0.0	2.6		A3
1993	123	1836	36.31	138.5877	37.0009	3.2	3.9		A3

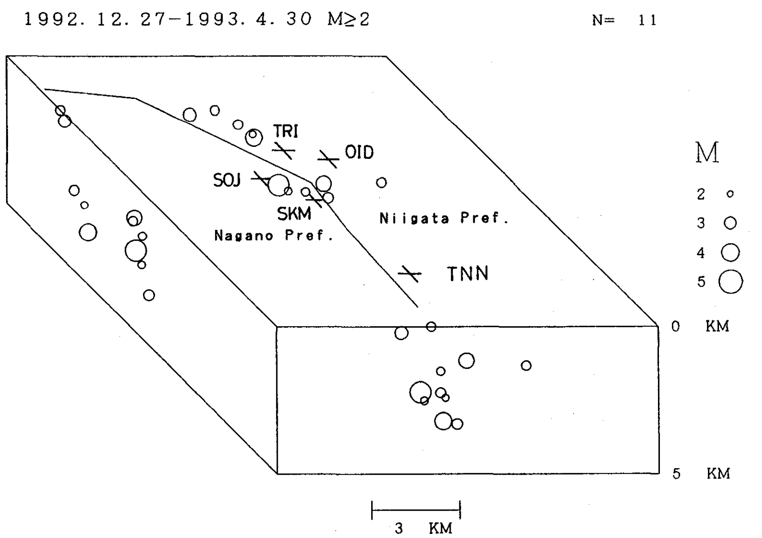

Fig. 4. Aftershock distribution. The largest event is the mainshock. Crosses indicate local seismic stations listed in Table 1.

hypocenters like those in this study.

Let us reexamine the previously determined hypocentral data. The records at TNN of the located shocks are mostly saturated in amplitude so that we cannot read the S phases. We assume the S-P time to be the same for smaller shocks which took place immediately before and after the mainshock. Then, we calculated k by dividing the hypocentral distance by the S-P time. Thus, estimated values of k are in the range from 3.0 to 4.0 km/

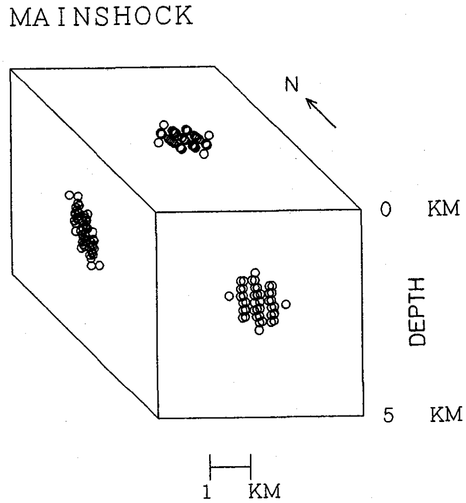

Fig. 5. Simulation of hypocenter determination showing the extent of the errors in hypocentral coordinates due to reading errors. Assigned arrival time errors are ±0.1 s in P times. This value was added to the arrival time data at the stations selected by a random sampling method. The reference event is the mainshock and/or the immediate foreshock.

s against hypocentral distances ranging from 4.4 to 8.0 km, which are consistent with those derived by the local small events. If the Omori coefficient took an ordinary value of about 8.0km/s, the foci would have been as deep as about 10km, because the epicenters are well constrained within several kilometers to account for the P arrival times at all surrounding stations. The shallow focus aftershocks are also confirmed by the S-P time distributions at the local stations.

P arrival times of the mainshock are difficult to read due to the seismic disturbance from the immediate foreshock. However, careful reading by paying attention to the spectral change of waveforms leads to almost the same difference of arrival times of 4.0±0.1s between the two shocks at more than 5 stations; polarities of the onset motions are also the same as each other. Based on the estimate of hypocentral error shown in Fig. 5, the two shocks are concluded to have taken place closely within 1km at most and to be classified as A1 events (Fig. 2).

The shallow depth earthquake well explains the destructive damage just above the source region. The detailed intensity distribution for ground motion was studied by one of the authors and others (RESEARCH INSTITUTE for HAZARDS in SNOWY AREAS, NIIGATA UNIVERSITY, 1994). The distribution shows that the center of the strong motion is located close to the eastern end of region A1. The rupture of the mainshock initiated at around the hypocenter of the immediate foreshock at the western end of A1 and probably stopped at the eastern end of it. If this was in fact the case, the strongest ground motion would be due to the abrupt termination of the rupture together with effects of the local topographical and

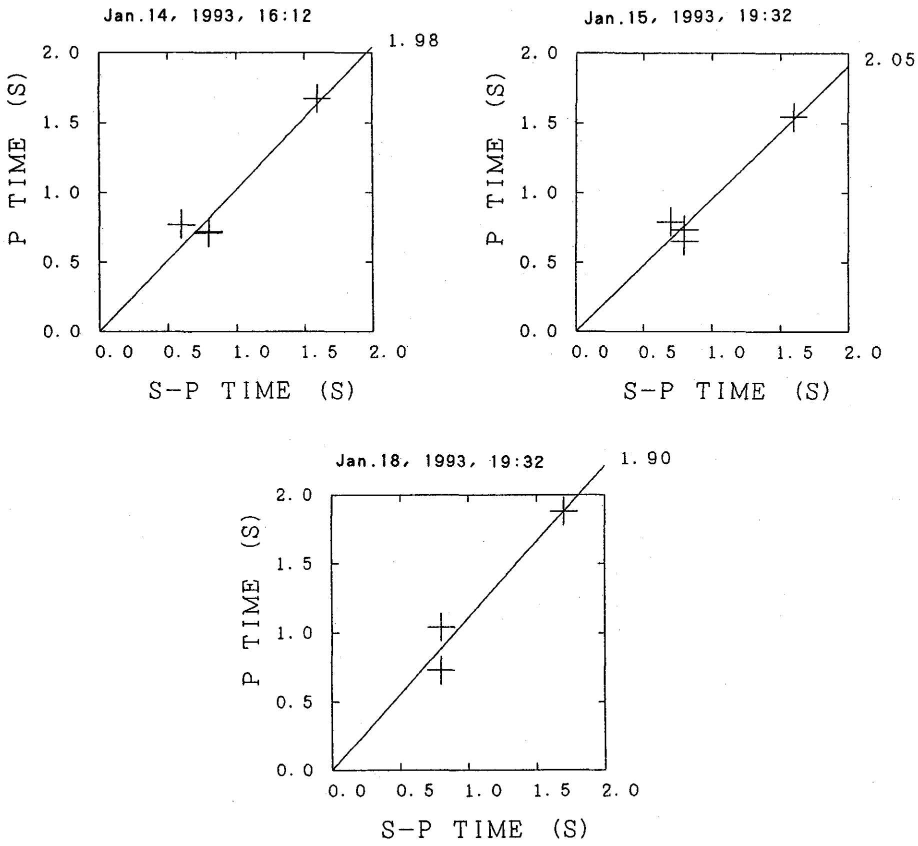

Fig. 6. Wadati diagrams for data from nearby stations.

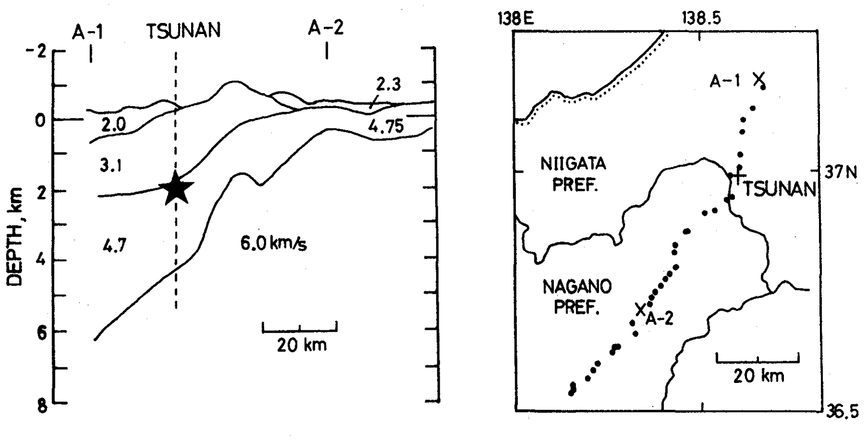

Fig. 7. Crustal structure after IKAMI *et al.* (1986) (left). The star indicates the depth of the source region of the Tsunan earthquake. In the right figure, A-1 and A-2 (crosses) are shot points and small solid circles indicate observation points in the explosion seismological experiment.

geological conditions on the incidence of seismic waves.

The explosion seismic study by IKAMI *et al.* (1986) revealed the upper crustal structure just beneath the source region. Figure 7 is the northeastern half of the profile section and shows that the 2km thick uppermost layer has a P velocity of 3.1km/s, and the second layer with 4.7km/s reaches the depth of 5–6km over the granitic layer with P velocity of 6km/s. From this figure, we conclude that the focal depths shown in Fig. 4 are entirely within the superficial layers. Those layers are probably made of Tertiary marine sediments including the Plio-Pleistocene Uonuma group which are exposed in the Uonuma District including Tsunan and are estimated to attain 2500m in total thickness (KAZAOKA *et al.*, 1986). The Tsunan earthquake fractured the body of rocks in this Tertiary layer.

Implication for the Tertiary Layer Event

A closely observed shallow earthquake swarm with the maximum magnitude 3.6, clustered at a depth of 2–4km, in the vicinity of Lake Tazawa, northern Honshu, Japan has been reported (TOHOKU UNIV., 1988). However, we have no seismological data available to confirm whether the clustering foci are confined in the Tertiary layer or not. The present paper may be the first report of an earthquake fracture of magnitude more than 4 that took place within the Tertiary layer, a medium with relatively weak fracturing strength.

In central Niigata Prefecture, around Nagaoka City (see Fig. 16), there have been remarkable earthquakes of presumably shallow origin. The 1927 Sekihara earthquake of M5.3 resulted in a local upheaval of ground up to 1 cm as found by leveling (IMAMURA, 1928). The coseismic leveling change had a similar spatial pattern as that of a pre-seismic stage during 33 years, suggesting that the Sekihara earthquake was generated by the tectonic folding process. On the other hand, the coseismic leveling change of the 1961 Nagaoka earthquake of M5.1 amounted to 4cm in uplift and 2cm in subsidence. Although the pre-seismic change during about 10 years showed relative subsidence up to 3cm at around the uplifted leveling point at the time of the earthquake, the source region had been close to an uplifted zone for a long period of more than 30 years.

The zones from Akita to Niigata Prefectures along the Japan Sea coast and the Fossa Magna in central Japan are regions of active folding known as the Mizuho-Fossa Magna Folded Zone (OTUKA, 1937). In central Niigata Prefecture along the Shinano River, active folding with a small wavelength of up to several kilometers has been recognized by geomorphological studies on deformed terrace plains (OTA, 1969), and by geodetic studies of leveling (MIZOUE *et al.*, 1980). Seismometric study of the Tsunan earthquake and the studies on coseismic level changes prove empirically that this active folded region with a small scale basin and range system, in central to southern Niigata Prefecture including Tsunan Town, is generating very shallow destructive earthquakes. This paper presents the most reliable evidence for it.

It is quite interesting to study the stress regime in the layered crust in terms of the rheological properties of rocks. The thickness of the Neogene sediments may be different from place to place corresponding to depressions and upheavals of the undulated basement layer. According to OTA (1969), the wavelength of the surface folding in the region of the Shinano River is on the order of several kilometers. This small scale folding suggests the existence of high horizontal compression at shallow depths, which is the origin of the generating stress of shallow earthquakes. However, the superficial layers cannot be a main transmitter of the crustal stress in the regime of plate tectonics. We ascribe the origin of the above compressive stress to the basement layers. The wavelength for folding of the basement should be longer than that in the superficial layers, and may be at least the order of the thickness of the upper crust. The authors suppose that the Tsunan region is situated at the depression of the basement and the thick sediments are laterally compressed by the wall-like uplifted basement layer on both sides. Then, the high stresses are maintained within the Tertiary layer. To confirm the above speculation, we have to study the detailed structure of the upper crust and wait for additional seismic events.

Aftershock Activity

Aftershocks are plotted in Figs. 2 and 4. The source region is divided into three subregions, A1, A2 and A3. They have linear dimensions of 1–2km and are spaced at intervals of 3–4km from center to center. Very small aftershocks are registered only at nearby stations and cannot be located. Figure 8 shows the S-P distributions of aftershocks. The peak frequency at around 1.5s in S-P time at the TNN station corresponds to the cluster of shocks in A1, the peak in 2.0s to that in A3. The 1.3s peak may be related to A2, as in the precursory activity of about 3 months before.

Figure 9 shows the temporal change of frequencies of aftershock occurrence. The number of shocks is extremely small, which is observed in the seismogram record for a period of one hour started about two hours after the mainshock (Fig. 10). We have had 20

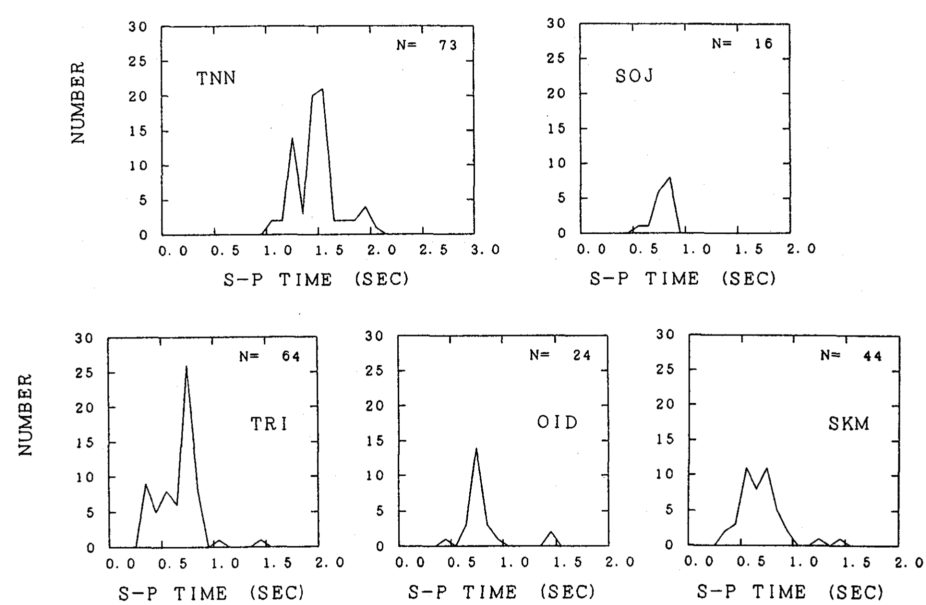

Fig. 8. S-P time distribution for aftershocks.

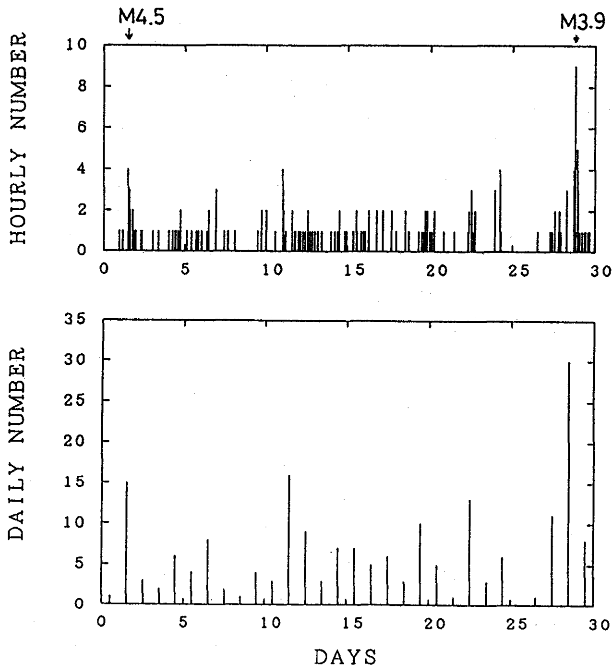

Fig. 9. Temporal change of number of shocks (foreshocks, mainshock and aftershocks).

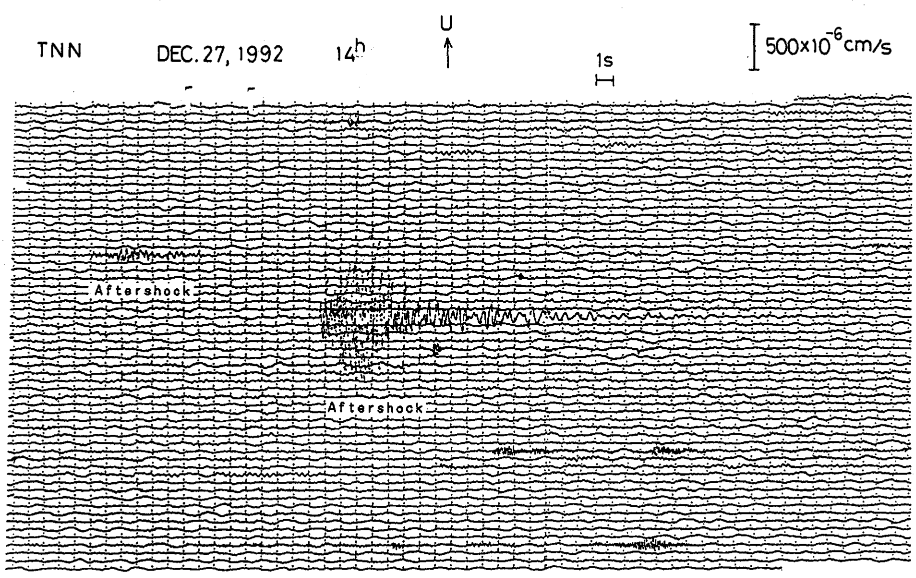

Fig. 10. Seismogram record from the TNN station showing aftershock waveforms.

shocks with magnitude ranging from 4.3 to 4.7 in the Shin'etsu region (Nagano and Niigata Prefectures) of about 10000km^2 during the 15 years since 1978. By surveying the hypocentral catalog of the Shin'etsu Seismological Observatory, 10 events or 50% have had small number of aftershocks, less than 10 during 30 days after the mainshock. The Tsunan event is one of them.

The aftershock occurrence may be dependent on the local properties of the crust around the source region. It is quite interesting to compare events of nearly identical magnitude which occurred close to each other. There is a good and unique example: the September 14, 1987 Iiyama-Nozawa Onsen earthquake of M4.6 at a depth of 8km. This event took place only 10km west of the epicenter of the Tsunan earthquake with a large number of aftershocks. The maximum hourly frequency of aftershocks was 140 in contrast to only 4 events per hour for the Tsunan earthquake. This appears to have been caused by heterogeneity of the crust. Whether the small number of aftershocks in the Tsunan event is related to the Tertiary source region or not is left for future studies.

Foreshock Activity

The TNN station, about 4km south of the mainshock epicenter, recorded ultra-microearthquakes just before the mainshock (Fig. 11). The first foreshock with magnitude 0 was registered at 22:53, December 26, about 12 hours before the mainshock. The second event with magnitude 0 occurred at 03:54, December 27, about 7 hours before. The above events are identified by the S-P times and waveforms which are similar to the aftershocks belonging to the cluster A1. The third one preceded the mainshock by only 4 seconds. Its magnitude is estimated at 2.5–3.0 based on the attenuation rates with distance for the initial part of the seismic waves recorded at distant stations.

In addition to the above mentioned foreshocks in a narrow sense, precursory microearthquake activity was detected about three months before the Tsunan event during the period from September 19 to October 5, 1992. The S-P times at TNN ranged from 1.0s to 1.6 s with a peak at 1.3–1.4s. The S-P time distribution is given in Fig. 12. The biggest shock of M2.5 in this activity, which occurred on September 19, 1992 (see Table 2), was

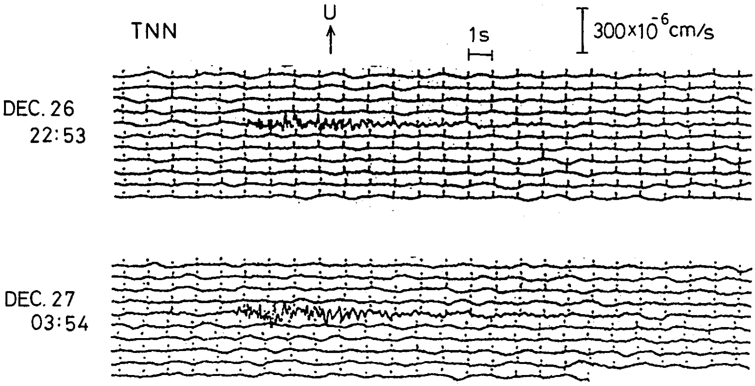

Fig. 11. Waveforms of foreshocks on December 26 and 27, 1992.

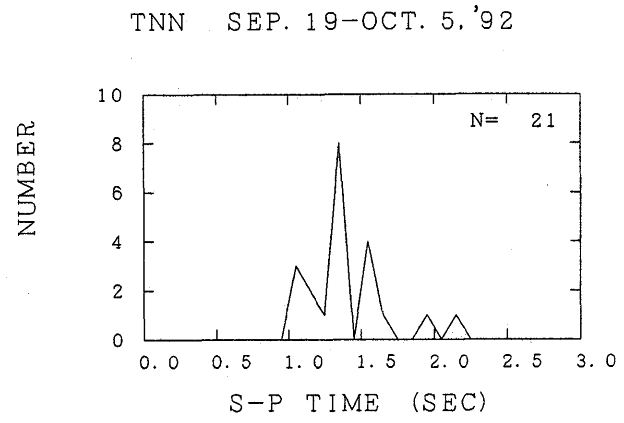

Fig. 12. S-P time distribution for the precursory microearthquakes from September, 1992.

located in region A2 in Fig. 2. This spot was activated again by aftershock activity as suggested by the S-P time distribution at TNN with a peak at 1.2–1.3s; one event (December 30, M2.6) was located as shown by the solid circle in Fig. 2.

Tectonic Implications

The tectonic setting around the epicentral area of the Tsunan earthquake is fairly complicated, as described below. It is difficult to deduce here the generating mechanism of the seismic activity in connection with tectonics. All we can do here is to collect data which might reveal the seismotectonic mechanism of earthquakes in this region such as the shallow Tsunan earthquake.

Focal mechanism solutions for the mainshock and major aftershocks are shown in Fig. 13. In calculating travel times and angles of emergence, we used a smoothed velocity structure (Fig. 3), which is generally effective over a wide range of epicentral distances. The immediate foreshock of M2.5–3.0, which is estimated to be at A1 in Fig. 2, has the same polarities in the initial onset as the mainshock at more than 5 stations. The size of the mainshock is 1–2km in linear dimension for an earthquake of around M4.5 (e.g. NISHIGAMI and TSUKUDA, 1984). The immediate foreshock occurred within this distance, as inferred from the simulation (Fig. 5). It is probable that the fault plane initially generated by the foreshock extended on the same plane generating the mainshock fault. The maximum compressional axis of the mainshock strikes N30°W.

On the other hand, pressure axes of the surrounding regions, the Shin'etsu District, for major earthquakes in the last 10 years are in the WNW-ESE or E-W direction (Fig. 14). Strike directions of compression around Kashiwazaki and Iiyama are in the range from N45°W to N80°W. Previous studies of focal mechanism solutions (e.g., MIKUMO and ISHIKAWA, 1978) and the geologic method of dikes developed by NAKAMURA (1977) also show NW-SE or E-W trending compression across the Shin'etsu tectonic region since the Pliocene (TAKEUCHI, 1978). The above compressional direction has been stable for a long

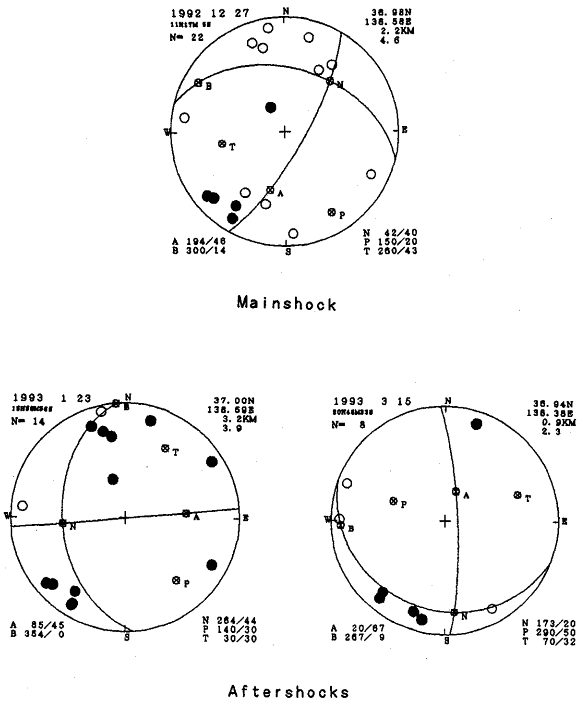

Fig. 13. Focal mechanism solutions for major shocks. Equal area projection on the lower hemisphere. Open and solid circles represent dilatation and compression at stations, respectively.

geologic time. In particular, Pliocene dikes at Mt. Yoneyama (see Fig. 16), south of Kashiwazaki and 35km north of the Tsunan earthquake epicenter, have an average strike of N75°W (TAKEUCHI, 1978).

The pressure axis of the Tsunan earthquake is clockwise rotated about 40° against the stable general trend of the surrounding regions. In contrast, major aftershocks show compressional axes conforming to the general trend. In the northern Shin'etsu region, a temporal change of the pressure axis was reported (EARTHQUAKE RESEARCH INSTITUTE, 1989). This is not probable in our case, because the focal mechanisms are not consistent for the mainshock and aftershocks. The differences of earthquake generating stresses between the mainshock and aftershocks may be due to the structural complexity of the medium at the source indicated by the tectonic setting there as described below.

The source region is roughly located in the so-called Shinano River Seismic Zone from Niigata to Nagano. Figure 15 shows the presence of the zone of high microseismicity in the last 15 years. The seismic zone is active partly in such areas as around Nagano and the section between Kashiwazaki to Iiyama. The Tsunan event took place at the southeastern edge of the latter seismic section.

Figure 16 shows the topography and distribution of active faults in Shin'etsu District. A basin and range system striking in the N-S or NNE-SSW direction around Nagano is

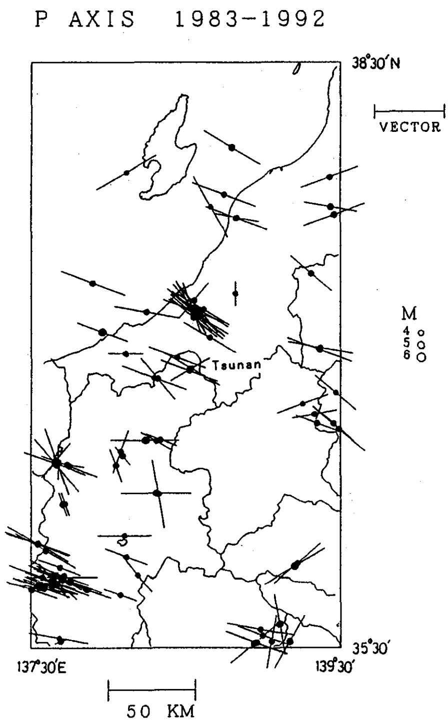

Fig. 14. Axes of maximum compressive stress projected on the horizontal plane, which are derived from focal mechanisms of shocks with magnitude greater than 4 in the Shin'etsu District. The total length of the vectors is shown on the right hand side.

terminated at around the Iiyama-Tsunan region. The active folded zone along the Shinano River with a small scale basin and range system striking in the NNE-SSW direction which is parallel to the Shibata-Koide Tectonic Line (GEOLOGICAL SURVEY, 1979) is also terminated at around the Tsunan region. Furthermore, the topographic contours are laterally bent in this region. Along the curved mountain range are active faults. The Tsunan earthquake took place in this region of active faults.

On the other hand, the underground tectonic structures can be studied in terms of the gravity Bouguer anomalies shown in Fig. 17. The source region is located in the vicinity of the Naoetsu-Choshi Line proposed by KONO (1988), across which high and low anomaly contours are laterally distorted. The lateral distortion of steep horizontal gradient zones or zones of high density of contours of gravity anomalies take place at the line (KONO and FURUSE, 1989).

The seismic active zones shown in Fig. 15 may be related to the above gravity anomalies. For example, the Naoetsu-Iiyama seismic zone is very close to and parallel to the Naoetsu-Choshi Line. The southeast extension of the Ogi-Kashiwazaki seismic zone, which is also parallel to the Naoetsu-Choshi Line, perpendicularly crosses the steep

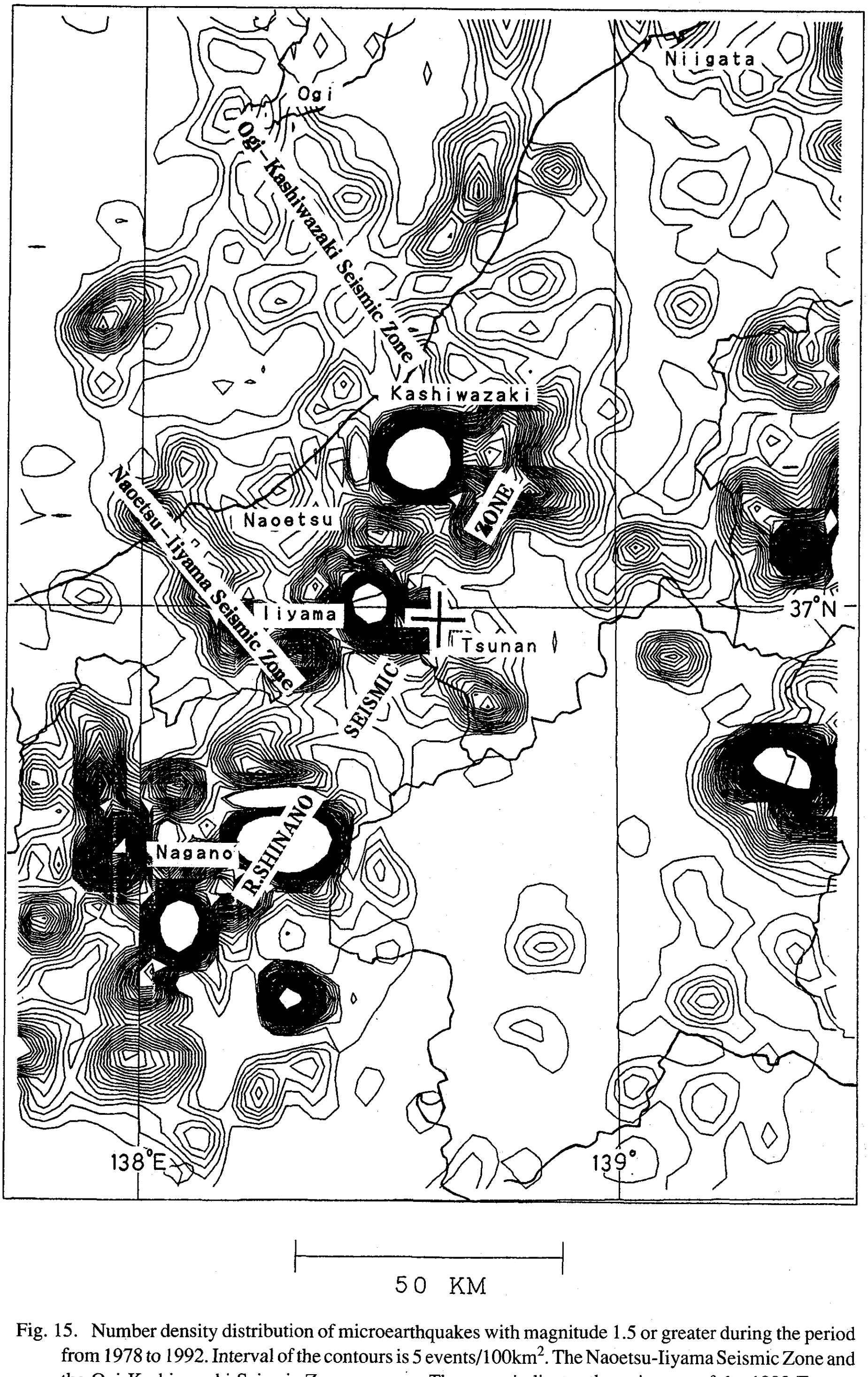

Fig. 15. Number density distribution of microearthquakes with magnitude 1.5 or greater during the period from 1978 to 1992. Interval of the contours is 5 events/100km^2. The Naoetsu-Iiyama Seismic Zone and the Ogi-Kashiwazaki Seismic Zone are seen. The cross indicates the epicenter of the 1992 Tsunan earthquake.

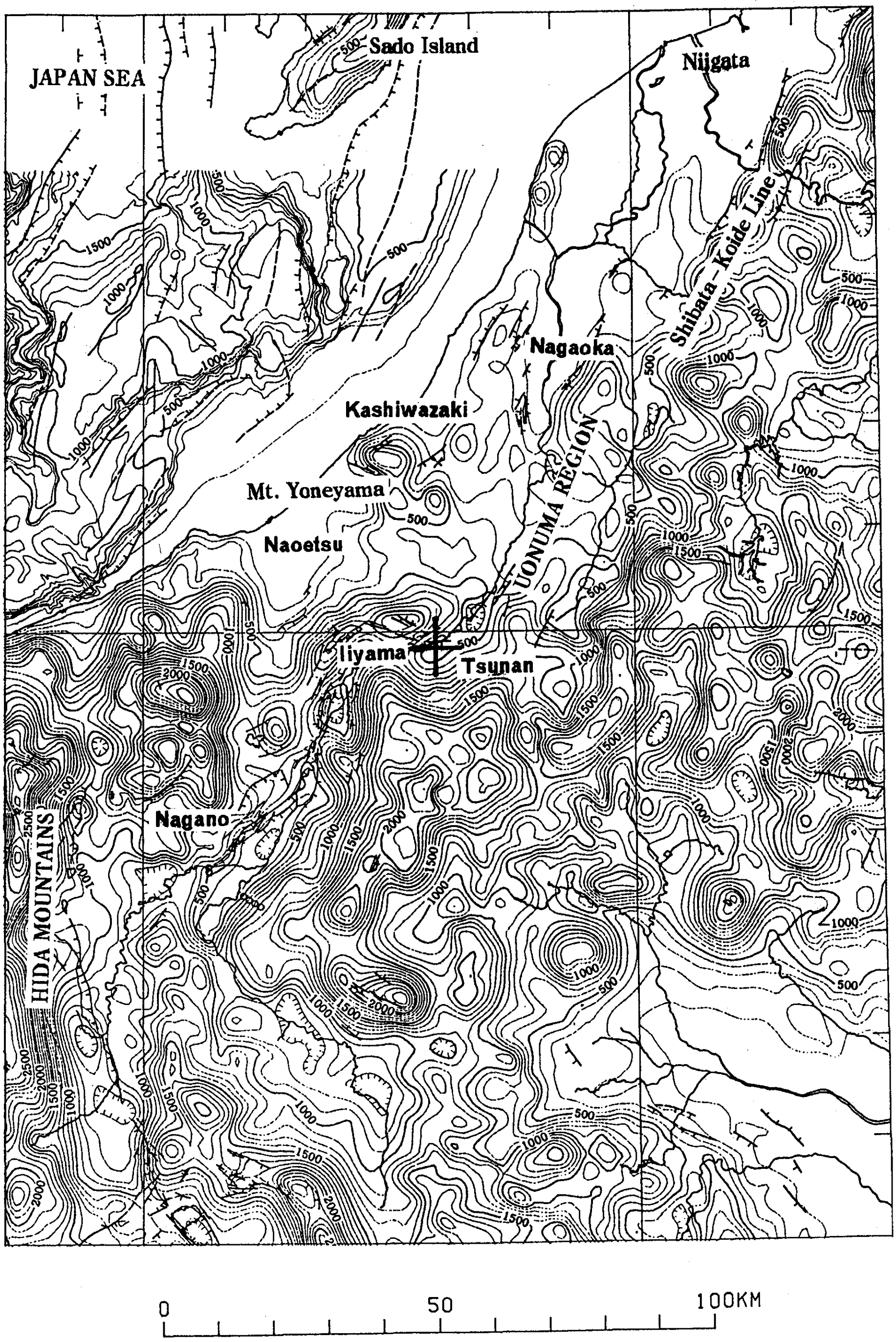

Fig. 16. Map of topography and active faults. Summit level contours are given at 100m intervals. The fluff attached to the active fault indicates the downthrown side. This map was originally produced by the Association for the Developmet of Earthquake Prediction (1989). The cross indicates the epicenter of the 1992 Tsunan earthquake.

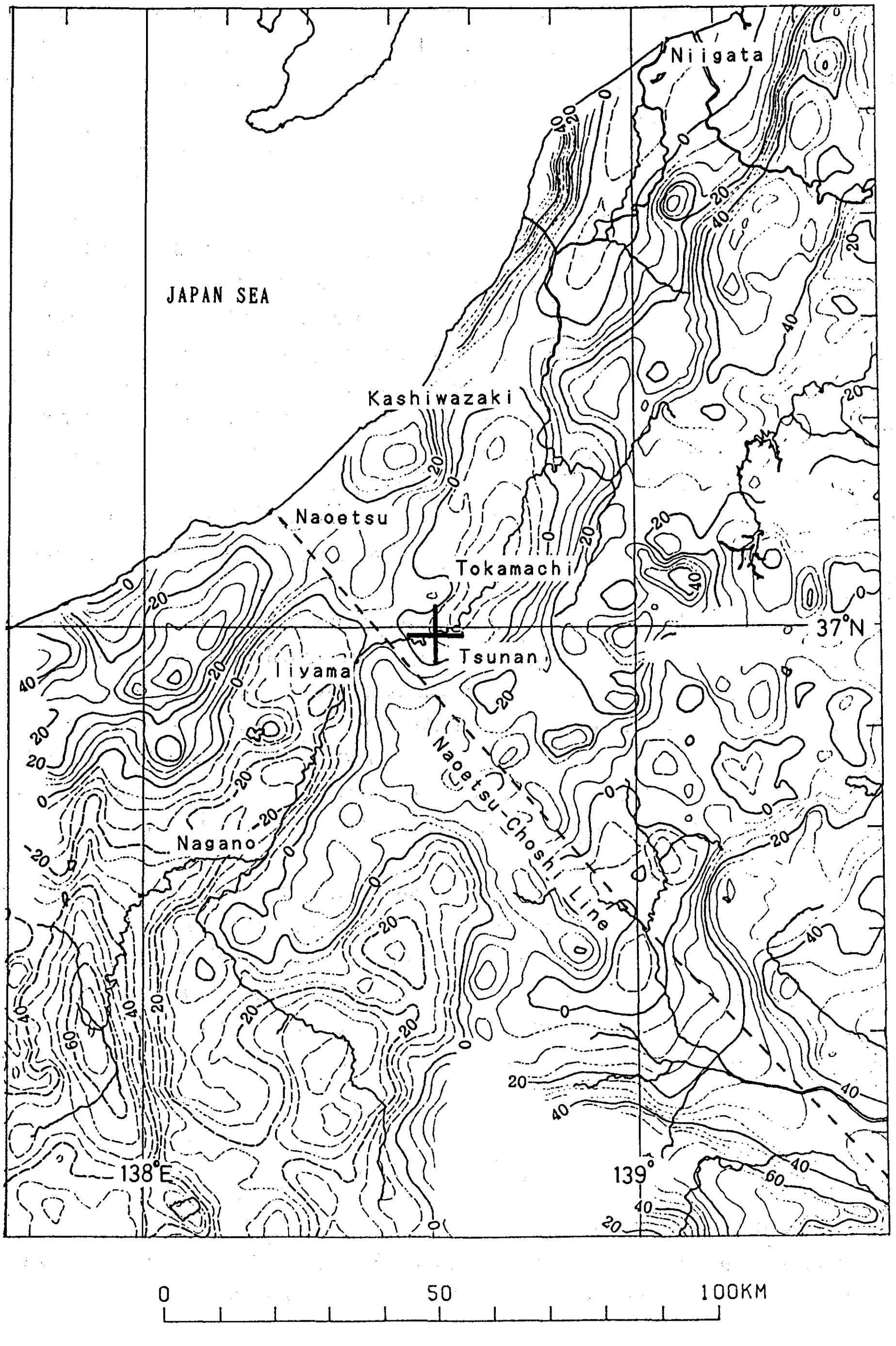

Fig. 17. Bouguer anomaly distribution. Data are reproduced from NEDO (1988). Contours are given in mgal. Dotted lines indicate minus values. This map was originally produced by the Association for the Development of Earthquake Prediction (1989). The cross indicates the epicenter of the 1992 Tsunan earthquake.

horizontal gradient zone, which is dislocated at the crossing region. The seismicity between the above two seismic zones has been particularly active since the 1990 Kashiwazaki-Takayanagi earthquake of M5.4 (TSUKUDA *et al.*, 1992) and the Tsunan earthquake of M4.5 followed it.

Conclusions

Precise hypocenters for the December 27, 1992 Tsunan earthquake sequence were determined by data from routine and temporal observations. The locations of some events including the mainshock were determined by using data from the permanent stations correcting the P arrival times. The station correction terms are estimated in reference to the hypocentral parameters derived by the data from temporary stations. The accuracy of the hypocenters is within 1km as inferred from a simulation. From the Wadati diagrams the local Vp/Vs ratio is estimated to be 2.0 on average, which gives an Omori coefficient of 3.1–4.7km/s. These values are consistent with the shallow focal depths.

Unexpectedly large damage by the small earthquake of M4.5 is ascribed to an extremely shallow focal depth of 2–3km within the Tertiary layer overlying the granitic layer.

The epicenter is located in the region of active faults and of active folding along the Shinano River, and in the low seismic section along the so-called Shinano River Seismic Zone. The Naoetsu-Choshi Line in gravity anomalies crosses the seismic zone at around the source region. The focal mechanism solution of the mainshock shows compression in the N30°W direction, which is 40° clockwise rotated against the general trend of this region. The major aftershocks have ordinary pressure axes for focal mechanisms. The irregular focal mechanisms may be related to the complexity of the tectonic situation mentioned above.

This earthquake was characterized by a small number of aftershocks. The aftershock regions are separated into three small areas with linear dimensions of 1–2km separated by 3–4km from center to center. At least one of them was a source region of precursory microseismic activity about 3 months before the M4.5 event. A nearby stationary high sensitivity seismic station registered three small foreshocks, which started 12 hours before the mainshock and took place in the immediate vicinity of the mainshock hypocenter.

Acknowledgments

The authors are indebted to Mr. Koji Suzuki for developing temporal seismic observations; and Mrs. Kaname Sakai, Masaru Kobayashi, Shin'ichi Hashimoto and Toshio Haneda for processing data from stationary observations.

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破壊的浅発小地震
－新潟県南部津南の地震（1992年12月27日，M4.5）－

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新潟県南部の長野県境に近い中魚沼郡津南町にて，1992年12月27日11時17分，M4.5の地震が発生した．小さい地震の割に中学校や小学校の建物などに大きな被害を及ぼした．被害地域は逆巻地区を中心に1 km^2 の範囲に限られている．強い震動の原因は，震源の深さが2～3 km と非常に浅い直下地震であったためである．地震発生域は花崗岩層の上の第三紀層内である．精密な震源は新潟大学積雪災害研究センターによる余震の臨時観測と東大地震研究所のテレメータ観測網のデータを組み合わせ，媒質の不均質性を補正して得られた．震源地はいわゆる信濃川地震帯にあり，その比較的活動が低い部分に位置する．ここは，重力ブーゲ異常の急変帯の屈曲や不連続する地点を結んだ直江津－銚子線が地震活動線に交差する地域でもある．発震機構は周囲のこれまでの地震の主圧力軸が東西から北西－南東の方向を示すのに対し，北西－南東から南北方向である．この地震は余震の回数が少ないものの一つであった．余震の震源域はそれぞれ3～4 km 離れて3つに分かれ，付近の活断層を挟んで分布する．その一つは3カ月前に前駆的な微小地震が発生した場所である．最寄りの定常観測点は本震の近傍で12時間前，3時間前，および4秒前に発生した前震を捉えた．