Heterogeneity in the lower crust and the process by which intraplate earthquakes are generated

Yoshihisa Iio

Disaster Prevention Research Institute, Kyoto University

The generating process of the 1984 Western Nagano Prefecture, Japan Earthquake is estimated as follows. Aseismic quasi-static slips occurred on the S-wave reflector. The slips produced a dilatational stress field near the mainshock fault and the dilatational stress decreases the normal stress and increases the shear stress on the fault. Then, slips began to be generated on the fault plane just above the S-wave reflector. It is thought that aseismic slips generate both the strength reduction and stress concentration on the mainshock fault.

1. INTRODUCTION

At present, the process by which intraplate earthquakes are generated is not well known. How do stress concentration and strength reduction occur on those faults? What determines a recurrence interval of intraplate earthquakes that is generally much longer than that of interplate earthquakes.

An excellent opportunity for the investigation of the generating process of intraplate earthquakes was offered by the 1984 Western Nagano Prefecture, Japan Earthquake, Ms6.8 (from now on, we abbreviate it as WNPE), which occurred in the central part of the Japanese Island. It is inferred from an inversion analysis that the maximum slip occurred at a depth of about 2 km. Very shallow aftershocks were observed at a surface station and the minimum S-P time is 0.055 s. Since the focal region is very shallow, various kinds of data of high quality have been obtained by various observations in the Western Nagano Prefecture region. A precise location of aftershocks, 3D velocity tomography, slip distribution, a determination of the S-wave reflection points, strong ground motions inferred from displaced (thrown out) boulders, stress distribution around the focal region and etc. were reported.

The most unique dataset is the distribution of the displaced (thrown out) boulders above the earthquake fault. Those indicate that WNPE has a normal fault component, which is also estimated by the inversion analysis of rupture process. This fact is consistent with the stress distribution derived from core samples which were obtained from four boreholes of a length of about 1 km drilled by NEDO (New Energy Developing Organization).

This paper precisely analyzed these data in order to investigate the process by which this intraplate earthquake was generated.

2. DATA

(1) Aftershock distribution

Figure 1 shows an aftershock distribution of the WNPE obtained from a dense seismic network with about 57 stations of the Joint Seismological Research in Western Nagano Prefecture region in 1985. It is seen in this figure that very shallow events occur up to a depth of a few hundreds of meters from the surface. Further, the lower limit of seismicity varies horizontally.
Rupture process of the main shock

The rupture process of WNPE is inferred from a simultaneous inversion of displacements of the second order trilatелation points mainly around the eastern part of the aftershock area and JMA strong motion seismograms. As shown in Figure 2, the right lateral strike slip components are predominant, but small dip slip components are also estimated. The assumed fault plane is dipping to the north (NNW) by a dip angle of 70 degrees. Thus, the southern side up motion means that WNPE has a normal fault component. This fact is consistent with the focal mechanism derived from P-wave first motions shown in Figure 1, which displays a small normal fault component. The upper and lower margin of the fault is 500m and 10km, respectively. The maximum slip occurs close to the upper margin of the fault, at the depth of about 2 km.

Around the eastern part of the aftershock area, it is found that numerous boulders were displaced (thrown out) from their sockets. Figure 3 shows the distribution of the displaced boulders. It seems that the region where the boulders are displaced is located close to the portion of large slips (> 0.6 m). Furthermore, the region where displaced boulders are found is seen only in the south of the fault.

This may be explained by the surface displacement due to the fault slip. Large surface displacements of south side up are estimated near the large slip area in the south of the fault. Since upward ground motions make boulders to fly farther than downward ones, it is thought that boulders are displaced there.

Stress estimate from boring core samples

The stress distribution around the earthquake fault is estimated from core samples which were obtained from four boreholes of a length of about 1 km drilled by NEDO. It is noted that the boreholes were drilled two or three years after the occurrence of WNPE.

The stress estimates were performed by the deformation rate analysis developed by Yamamoto et al. (1990), which is one of the methods of stress estimate using core samples. It is confirmed that the vertical stress increases proportional to depth. This is thought to justify the method of the stress estimate from core samples.

Figure 4 displays the magnitudes of the maximum and minimum horizontal stress reduced to a depth of 1km (from the earth surface), the uppermost part of the seismogenic region of the Western Nagano Prefecture region. It is assumed that the directions of each stress intersect the fault.
strike at an angle of 40 degree referring to the result of a stress inversion\(^3\), since the direction of the cores are not determined. It is found that the magnitudes of the maximum compressional stresses are almost equal, while those of the minimum compressional stress decrease with decreasing distance from the fault. The magnitude of the minimum compressional stress closest to the fault is much smaller than that of the vertical stress and is very unusual in the central Japan, while that farest from the fault is almost equal to that of the vertical stress. These data suggest that the dilatational stress in the NNE-SSW direction acts near the fault.

These stress values are obtained at a depth of only 1km. However, the depth is within the uppermost part of the seismogenic region, as shown in Figure 1. Thus, it is thought that these stresses are possibly related to the generating process of WNPE. The stress distribution is consistent with focal mechanisms of aftershocks. It was found that reverse faults are typical while strike slips are predominant only close to the mainshock fault\(^9\). Furthermore, it is consistent with the normal fault component of the mainshock slip, since the magnitude of the vertical stress is much larger than that of the minimum compressional stress near the fault. However, it should be noted that the estimated stresses are affected by the coseismic slips. Since it is difficult to estimate to what degree the stresses are affected (it depends on the fault strength), the effect is not considered here.

3. GENERATING PROCESS OF WNPE

We will infer the generating process of WNPE from the data presented above. Another important observation is distributions of S-wave reflection points shown in Figure 3\(^6\). S-wave reflection points are thought to reflect fluid-filled pores or cracks and are frequently found in volcanic regions. The important point of this figure is that the reflection points are distributed widely in the north of the mainshock fault plane while those are scarcely found in the south of its lower margin. When the reflection points are assumed to constitute one plane (S-wave reflector), it is thought that the plane acts like a fault plane and slips occur on the plane, since the friction on the plane probably very small, due to high pore pressures. Further, it is thought that the slips occur quasi-statically, since the plane is located below the seismogenic region. Here, the

Figure 3 S-wave reflection points derived from a dense seismic network\(^6\) and the distribution of thrown-out boulders\(^5\). The estimated fault plane is shown by rectangles\(^1\). Reverse triangles are temporary stations.

Figure 4 Stress distribution around the earthquake fault is derived from core samples\(^8\).

Figure 5 Stress distribution above the S-wave reflector.
plane is regarded as an aseismic detachment fault.

As shown in Figure 5, the azimuth of the S-wave reflector is almost the same as the direction of maximum compressional stress and earthquakes immediately above the plane are characterized by reverse faults. Then, the S-wave reflector acts like a pure reverse fault and the dilatational stress in the NNE-SSW direction is produced around the southern edge of the S-wave reflector, namely near the mainshock fault plane, in particular, at the lower margin of the mainshock fault. It is thought that this dilatational stress can be the origin of the normal fault component of the mainshock slip and strike slip aftershocks near the mainshock fault.

The generating process of WNPE is shown in Figure 6. Aseismic quasi-static slips occurred on the S-wave reflector (detachment). The slips produced a dilatational stress field near the mainshock fault. The dilatational stress decreases the normal stress and increases the shear stress on the fault. Then, slips began to be generated on the fault plane just above the S-wave reflector.

4. Conclusion and remained problems

The generating process of the 1984 Western Nagano Prefecture, Japan Earthquake is estimated as follows. Aseismic quasi-static slips occurred on the S-wave reflector. The slips produced a dilatational stress field near the mainshock fault and the dilatational stress decreases the normal stress and increases the shear stress on the fault. Then, slips began to be generated on the fault plane just above the S-wave reflector. It is thought that aseismic slips generate both strength reduction and stress concentration on the mainshock fault.

The dilatational stress generated by the aseismic slip is thought to be large at the edge of the S-wave reflector (the lower margin of the mainshock fault), while the estimated stresses and the normal fault component of the mainshock slip are estimated around the upper margin of the mainshock fault, far from the S-wave reflector. Consequently, it may be necessary the mechanism that concentrates stresses at shallower parts. As seen in the lower panel of Figure 1, the bottom of the seismogenic region varies in space, about 9 km at the western part to about 5 km in the eastern part. Probably, there exists an aseismic part even on the mainshock fault and a slow slip there also can generate stress concentration and strength reduction in shallower parts.

ACKNOWLEDGMENT: This work is partly supported by JSPS.KAKENHI (19204043), Japan.

REFERENCES


