# Introduction to EPS special section for the M7.1 and M6.4 earthquakes in northeastern Japan

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## 1. Introduction

In 2003 two destructive earthquakes struck the northern part of Miyagi prefecture and its surrounding areas; one is an intraslab earthquake with M7.1 that occurred on May 26 beneath the northern coast of the prefecture and the other is a shallow inland earthquake with M6.4 that occurred on July 26 in the northern part of the prefecture. After their occurrences, investigations on these two events have been intensively made by many researchers, covering a wide range of topics and scales. The present special section of Earth, Planets and Space contains nine papers out of such intensified investigations which must contribute to deepen our understanding of earthquake process. They are aftershock distribution and focal mechanism studies by precise hypocenter locations (Okada and Hasegawa, 2003; Okada *et al.*, 2003b; Umino *et al.*, 2003), source process studies by seismic waveform inversions (Okada and Hasegawa, 2003; Hikima and Koketsu, 2004), fault model studies by inversions of geodetic data (Nishimura *et al.*, 2003; Miura *et al.*, 2004; Yarai *et al.*, 2004), and seismic dynamo effect studies associated with the two events (Ujihara *et al.*, 2004; Honkura *et al.*, 2004).

Remarkable seismic activity on the plate boundary off Miyagi prefecture had started about seven months before the May 26 event. Locations of these activities and the above two earthquakes suggest that they are closely related to the present stage of the interplate coupling east off northeastern Japan. The purpose of the present overview is to briefly discuss tectonic implications of the occurrences of the two earthquakes based on the results of the studies presented in this special section and other recent studies.

## 2. Asperity on the Plate Boundary off Miyagi Prefecture

Recent studies based on seismic data and GPS data have revealed that the asperity model (Lay and Kanamori, 1981; Lay *et al.*, 1982) is applicable to the process of seismic and aseismic slips occurring on the plate boundary east off northeastern Japan (e.g., Igarashi *et al.*, 2003; Matsuzawa *et al.*, 2002; Nagai *et al.*, 2001; Nishimura *et al.*, 2000; Okada *et al.*, 2003a; Suwa *et al.*, 2003; Uchida *et al.*, 2003; Yamanaka and Kikuchi, 2003). The plate boundary in this region is divided into areas where frictional coupling is strong and stick-slip dominates (asperities), and intervening areas where frictional coupling is weak and stable sliding dominates (stably sliding areas). Small and large asperities are scattered on the plate boundary, surrounded by stably sliding areas. Location of each asperity is unchangeable and are inherent feature of that location of the plate boundary. Asperities are strongly locked in interseismic periods, and rupture repeatedly at the time of earthquakes. Large asperities rupture as large earthquakes at long time intervals, while small asperities as small earthquakes at short time intervals. Sometimes earthquakes may rupture one or more adjacent asperities, resulting in larger magnitude events.

Locations of large asperities on the plate boundary can be estimated as large slip areas at the time of their ruptures by seismic waveform inversions. Inversions of strong motion seismograms of large earthquakes for the last 70 years by Yamanaka and Kikuchi (2003) revealed the distribution of large asperities on the plate boundary east off northeastern Japan. Some of the large asperities estimated by them have been ruptured recently by the large Sanriku-oki earthquakes of 1989 M7.1, 1991 M6.9 and 1994 M7.5, while other large asperities are left as unruptured patches on the plate boundary. Major ones out of such unruptured asperities are located at the areas off Miyagi prefecture, east off Aomori prefecture and off Tokachi. The asperity off Miyagi prefecture was ruptured previously by the 1978 M7.4 Miyagi-oki earthquake, and the asperity off Tokachi by the 1952 M8.2 Tokachi-oki earthquake. The asperity east off Aomori prefecture is one of two major asperities which were ruptured by the 1968 M7.9 Tokachi-oki earthquake. The other asperity in the south was ruptured again recently by the 1994 M7.5 Sanriku-oki earthquake (Nagai *et al.*, 2001). Back slip distribution on the plate boundary east off northeastern Japan as estimated from GPS data for the last 5 years (Suwa *et al.*, 2003) shows that these major unruptured asperities are located in areas of large back slip amounts. This indicates that strong interplate coupling at present on these unruptured asperities causes the observed large back slip amounts for those areas.

## 3. May 26, 2003 M7.1 Earthquake

An intraslab earthquake with M7.1 occurred on 26 May 2003 at 68 km depth beneath the coast of northern Miyagi prefecture, which caused slight damage to Miyagi and Iwate prefectures, with two dwellings completely destroyed. This

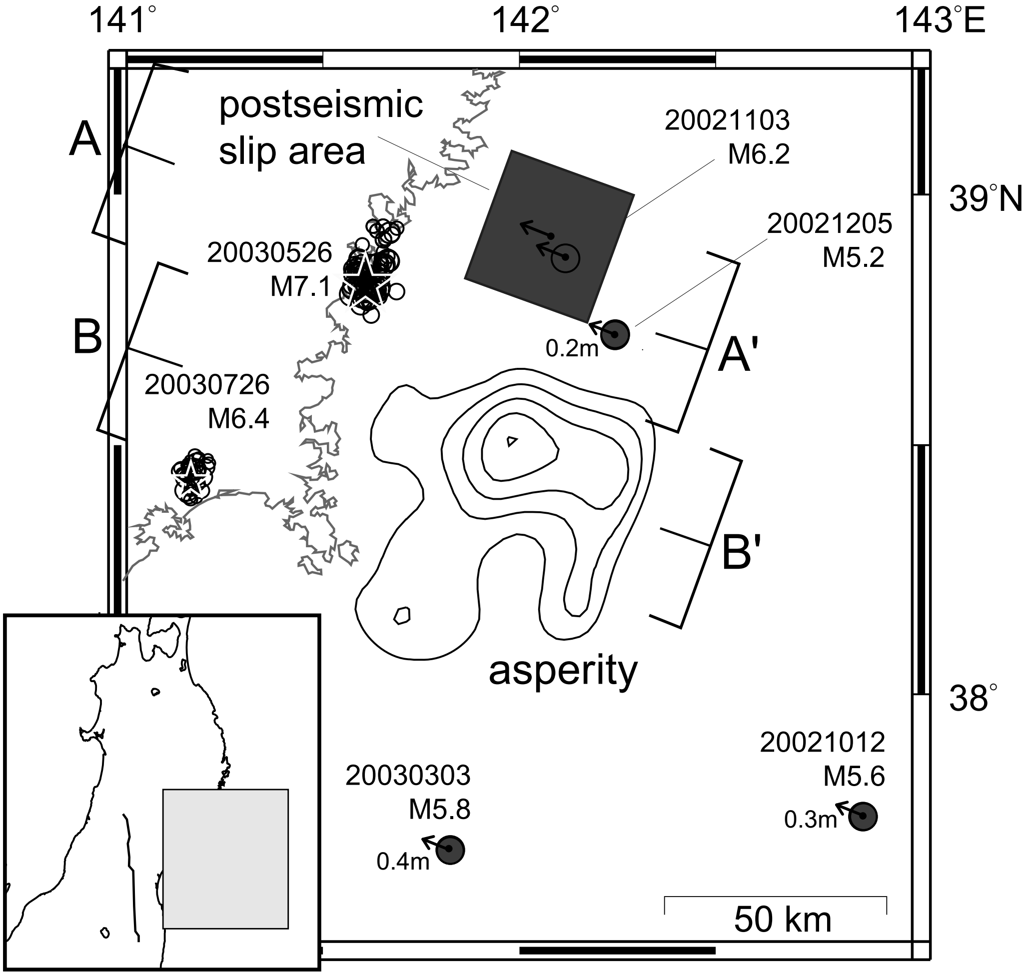


Fig. 1. Asperity east off Miyagi prefecture and recent seismic activity. The asperity which caused the 1978 M 7.4 Miyagi-oki earthquake (Yamanaka and Kikuchi, 2003) is shown by contours. Epicenters of the main shocks and aftershocks of the May 26 2003 M 7.1 event and the July 26 2003 M 6.4 event are shown by asterisks and circles, respectively. Epicenters of earthquakes with M 5 or larger that occurred on the plate boundary in 2002 and 2003 are also shown by open circles. Postseismic slip area associated with the 2002 M 6.1 earthquake (Miura *et al.*, 2003) is shown by a rectangle. Numeral attached to the arrow shows estimated slip amount of each event.

event occurred on the upper seismic plane of the double-planed deep seismic zone, which is clearly seen in the subducted Pacific plate beneath northeastern Japan (Hasegawa *et al.*, 1978). Focal mechanism of this event is down-dip compression, which is typical for the upper plane of the double seismic zone.

Epicenters of the 26 May M7.1 event and its aftershocks are shown in Fig. 1. The asperity off Miyagi prefecture and recent interplate events with magnitudes larger than 5 are also shown in the figure. The M7.1 event occurred in an area surrounding the asperity. Vertical cross section of earthquakes along line A-A′ in Fig. 1 is shown in Fig. 2(a). The hypocenter distribution and main shock focal mechanism delineate the fault plane of this event, which is steeply dipping to the WNW (Okada and Hasegawa, 2003; Ito *et al.*, 2004a).

Spatial extent of the rupture area of this event, as estimated from waveform inversions (Okada and Hasegawa, 2003; Ito *et al.*, 2004a) is about 20 km × 16 km, which is almost consistent with that of the aftershock area. Aftershock activity tends to concentrate in areas with small slip amounts and not in areas with large slip amounts (asperities), as can be seen in many shallow large earthquakes (Okada and Hasegawa, 2003; Ito *et al.*, 2004a). The estimated spatial extent of the steeply dipping fault plane indicates that the rupture of this event was not confined to the subducted oceanic crust but extended to the slab mantle. A small difference between the dip angle of the aftershock distributions above and below the mainshock hypocenter suggests that the rupture initiated near the Moho of the slab and then propagated into both the crust and the mantle of the slab (Okada and Hasegawa, 2003).

Seismic activity on the plate boundary surrounding the asperity off Miyagi prefecture had increased since October 2002, about seven months before the 26 May M7.1 event. As shown in Fig. 1, on 12 October 2002, an M5.6 event occurred ∼70 km to the southeast of the asperity. About one month later, on November 3, an M6.1 event occurred ∼30 km to the north of the asperity. A remarkable postseismic slip associated with this M6.1 event was detected by GPS observations (Geographical Survey Institute, 2003; Miura *et al.*, 2003). It lasted for one or two months. Postseismic slip area estimated by Miura *et al.* (2003) is shown by a rectangle in Fig. 1 and by a thick line in Fig. 2(a). On December 5, about one month after the M6.1 event, another interplate earthquake with M5.2 occurred near the southeastern edge of

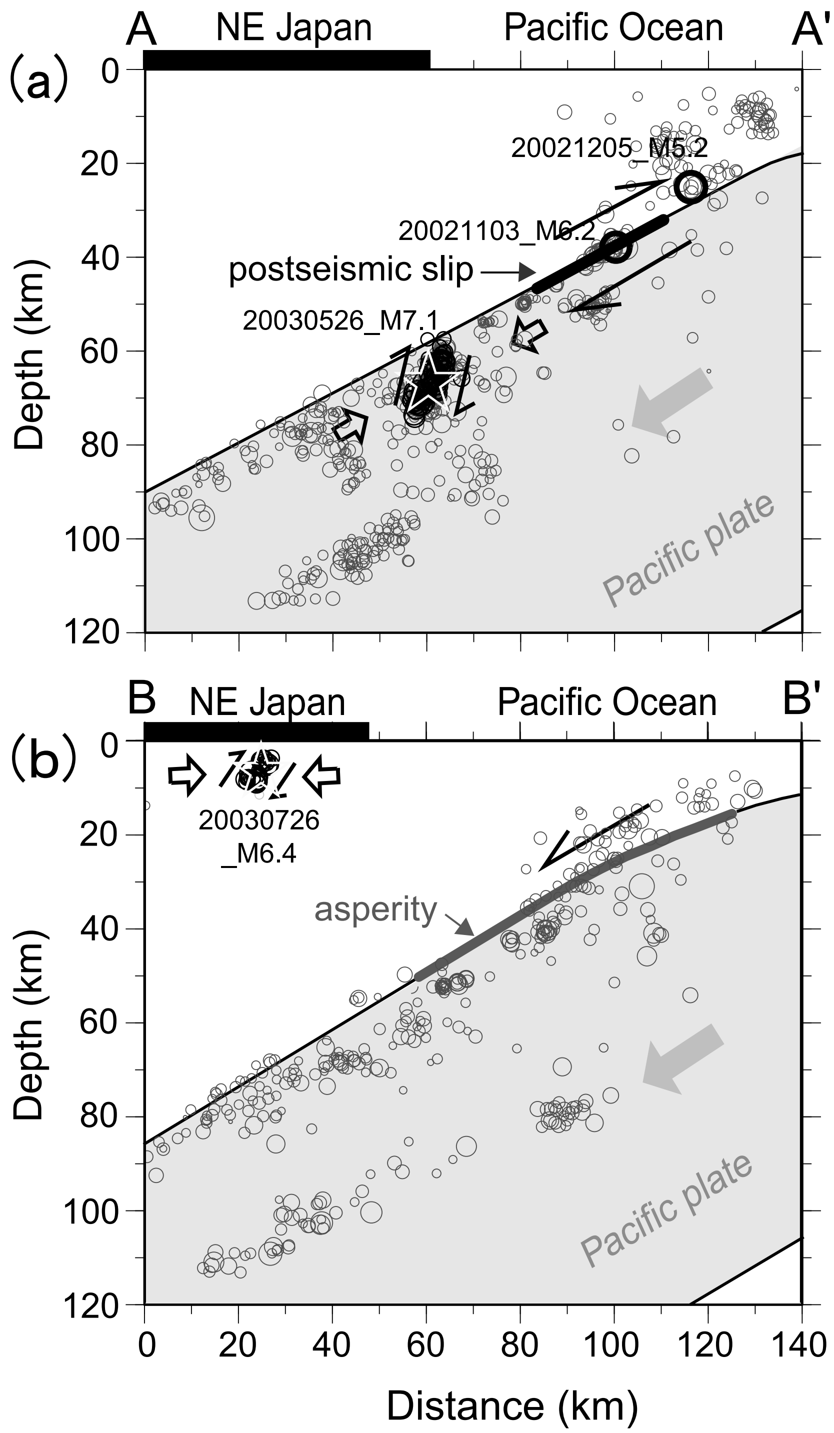


Fig. 2. Vertical cross sections along lines AA′ and BB′ in Fig. 1. Hypocenters of the mainshock and aftershocks of the May 26 M 7.1 event is shown by an asterisk and circles, respectively, in Fig. 2(a). Those of the July 26 M 6.4 event is shown by an asterisk and circles in Fig. 2(b). Circles show earthquakes located by the seismic network of Tohoku University. The postseismic slip area is shown by a thick line in Fig. 2(a), and the asperity is shown by a thick line in Fig. 2(b).

the postseismic slip area, just to the north of the asperity off Miyagi prefecture. On March 3, 2003, an M5.8 earthquake occurred ∼50 km to the south of the asperity. Then the 26 May M7.1 event occurred not on the plate boundary, but within the subducted slab. The focal area of the M7.1 event is located right below the plate boundary on the deeper extension of the postseismic slip area of the 03 November M6.1 event as shown in Fig. 1 and Fig. 2(a). This suggests that the 03 November M6.1 event and its postseismic slip on the plate boundary affected the occurrence of the 26 May M7.1 event within the subducting plate.

## 4. July 26, 2003 M6.4 Earthquake

A shallow inland earthquake with M6.4 occurred again in the northern part of Miyagi prefecture on July 26, 2003, two months after the M7.1 intraslab event. The mainshock was preceded by a distinct foreshock with M5.6, and the largest aftershock with M5.5 occurred about ten hours after the mainshock. This shallow reverse-fault type earthquake sequence caused severe damage to the area right above its focal area, with 1273 dwellings completely destroyed.

Aftershock distribution and focal mechanism studies based on temporary seismic observation data just above the focal area and permanent station data in the surrounding areas delineate the fault plane of this earthquake sequence. Estimated fault plane strikes NS in the north and NE-SW in the south. Its northern portion dips to the west at an angle of $\sim 50°$, and its southern portion to the northwest at an angle of $\sim 45°$in the depth range of 2 km to 12 km (Okada *et al.*, 2003b; Umino *et al.*, 2003). The rupture area of this earthquake sequence estimated by waveform inversions extends in an area of about 15 km $\times$ 12 km (Hikima and Koketsu, 2004; Ito *et al.*, 2004b; Yagi *et al.*, 2003). Crustal deformation data observed just above the focal area and its surroundings enabled to accurately estimate slip distribution along the curved fault plane of this earthquake sequence (Nishimura *et al.*, 2003; Miura *et al.*, 2004; Yarai *et al.*, 2004), which is approximately consistent with that estimated from waveform inversions using strong-motion records and/or teleseismic broad-band records (Hikima and Koketsu, 2004; Ito *et al.*, 2004b; Yagi *et al.*, 2003).

The focal area of the July 26 M6.4 earthquake sequence is located just to the west of the asperity off Miyagi prefecture as shown in Fig. 1. Nearly 100% interplate coupling at this asperity causes compressional stress within the seismogenic upper crust of the overlying continental plate in the direction of the plate conversion, i.e. EW direction. This EW compressional stress within the seismogenic upper crust reaches its maximum near the focal area of this earthquake sequence based on the back slip model by Suwa *et al.* (2003). This observation suggests that the strong interplate coupling at the asperity off Miyagi prefecture for the interseismic periods including the present one had contributed to build up the stress and to attain the level of the final rupture on the fault plane of this earthquake sequence.

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