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Active Faults along Japan Trench and Source Faults of Large Earthquakes

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ABSTRACT: Active faults observed on seafloor along Japan Trench are resultants of repeated large earthquakes. We discuss on relation between large earthquakes and their source faults based on a detailed active fault map along Japan Trench. Judging from location and continuation of active fault, we presume that one of the extensive thrust faults extends from off-Sanriku to off-Ibaraki for over 400km, is directly related to the source fault of the 2011 off the Pacific coast of Tohoku Earthquake.

Key Words: Great East Japan earthquake, Japan Trench, submarine active fault

INTRODUCTION

Active faults on land are regarded as large earthquake source faults, and are highly considered in the long-term earthquake prediction in Japan. However, importance of submarine active faults along the plate boundaries around Japan has been overlooked or under-estimated mainly due to lack of interest among marine geologist as well as seismologists. They seem to believe that large earthquakes along the plate boundaries occur on the deep-sheeted fault plane, and are not necessarily related to sea-floor faulting along the plate boundaries such as Japan Trench (Fig.1).

We depict distribution and geometry of active faults identified by tectonic geomorphology method similar to a method we used in stereo-pair air-photo interpretation for inland active faults by interpretation of stereo-pair set as well as anaglyph images, and discuss on relation between tectonic seafloor features and earthquake source faults.

SUBMARINE ACTIVE FAULTS ALONG THE JAPAN TRENCH

Identification of active faults

Japan Coast Guard and JAMSTEC have conducted narrow multi-beam bathymetric survey since 1985, and accumulated dense raw data, but these data were not been used for detailed analysis on submarine topography until we process for this study. We made detailed submarine topographic images based on 150m grid DEM processed from the raw data. Then we have made stereo-pair topographic images as well as anaglyph images for stereo imaging of the heart using 3D red cyan glasses prepared by Simple DEM Viewer®, and two images each given different shadow direction were combined on Photoshop® in order to make clear images for interpretation of topography. The 250m topographic

DEM in and around Japan (Kishimoto 2000) and SRTM3 data are also used to fill the data uncovered by narrow multi-beam bathymetric survey.

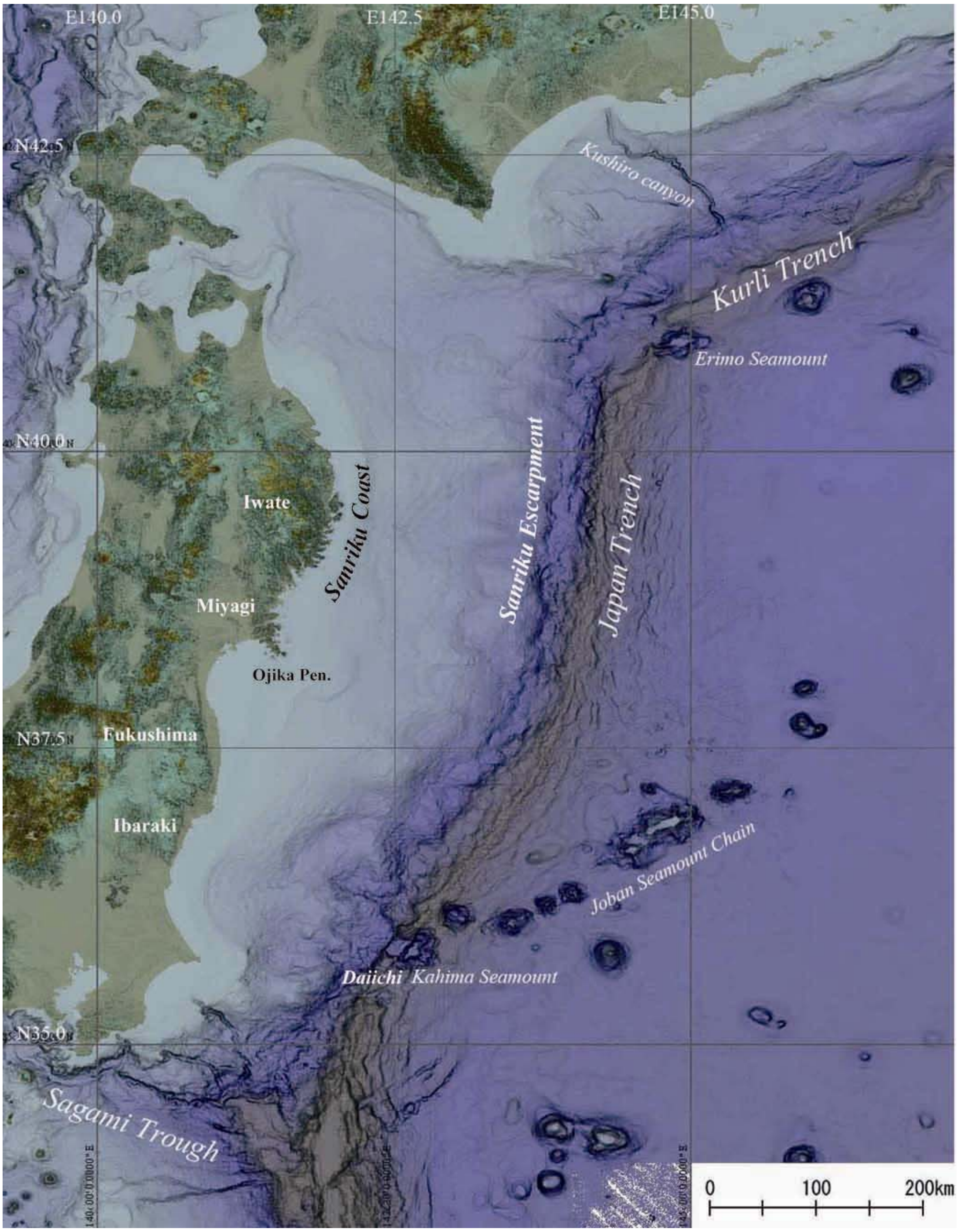

Fig. 1 Index map of study area around Japan Trench

Effectiveness of an anaglyph image in interpretation of seafloor topography cannot compare with a shaded-relief image (Fig. 2). 3D image viewed through red cyan glasses enables us to find submarine active faults very easily, if we have certain knowledge of tectonic geomorphology. Numerous normal faults dislocating a subsiding seamount in Fig. 1 can be detected by shaded-relief image, but not the sides upraised along the faults.

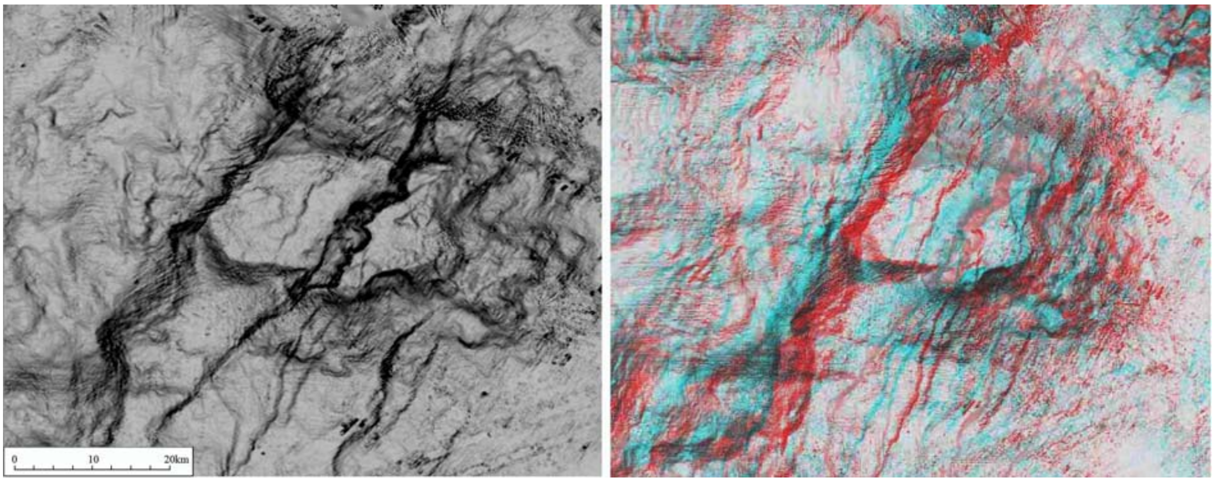

Fig 2. Comparison of shaded-relief image and anaglyph around Daiichi-Kashima Seamount
3D red cyan glasses are necessary to view the anaglyph image (right) correctly

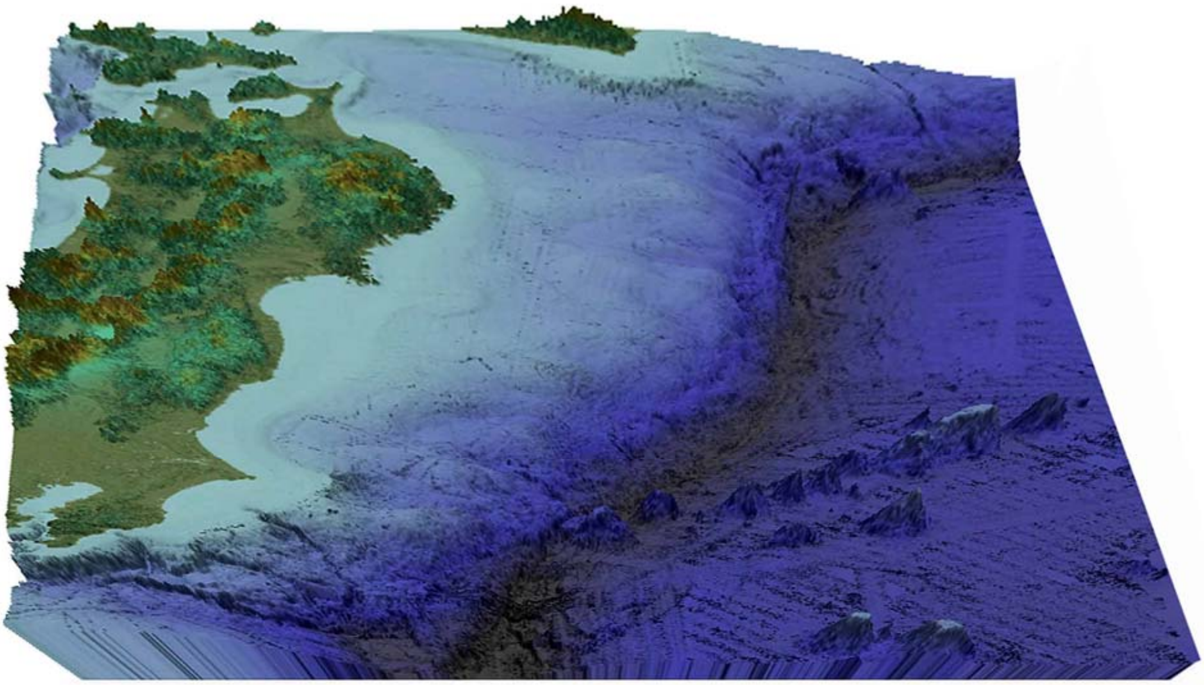

Fig. 3 Three dimentional image of study area
Extesive trench slope about 4000-5000m high along Japan Trench in the north is called Sanriku Escarpment. The escarpment is concvex in cross section.

The area we discuss in this papaer is between Erimo Seamount to the north and Daiichi Kashima Seamount to the south. As shown in fig. 3, relief along Japan Trench is much bigger than that on land, and is composed of four major topographic units; wide undulated shelf slope dipping east about 2% up to 3000m deep, continuous gigantic trench slope about 4000m high, trench floor between 7000 - 8000m deep, and warped outer rise to the east. The eastern part of the shelf slope is widely occupied with several elongated bulges with flexure scarps along their eastern margins. The trench slope is of steep escarpments, a part of which is called Sanriku Escarpment with relative height over 3000m.

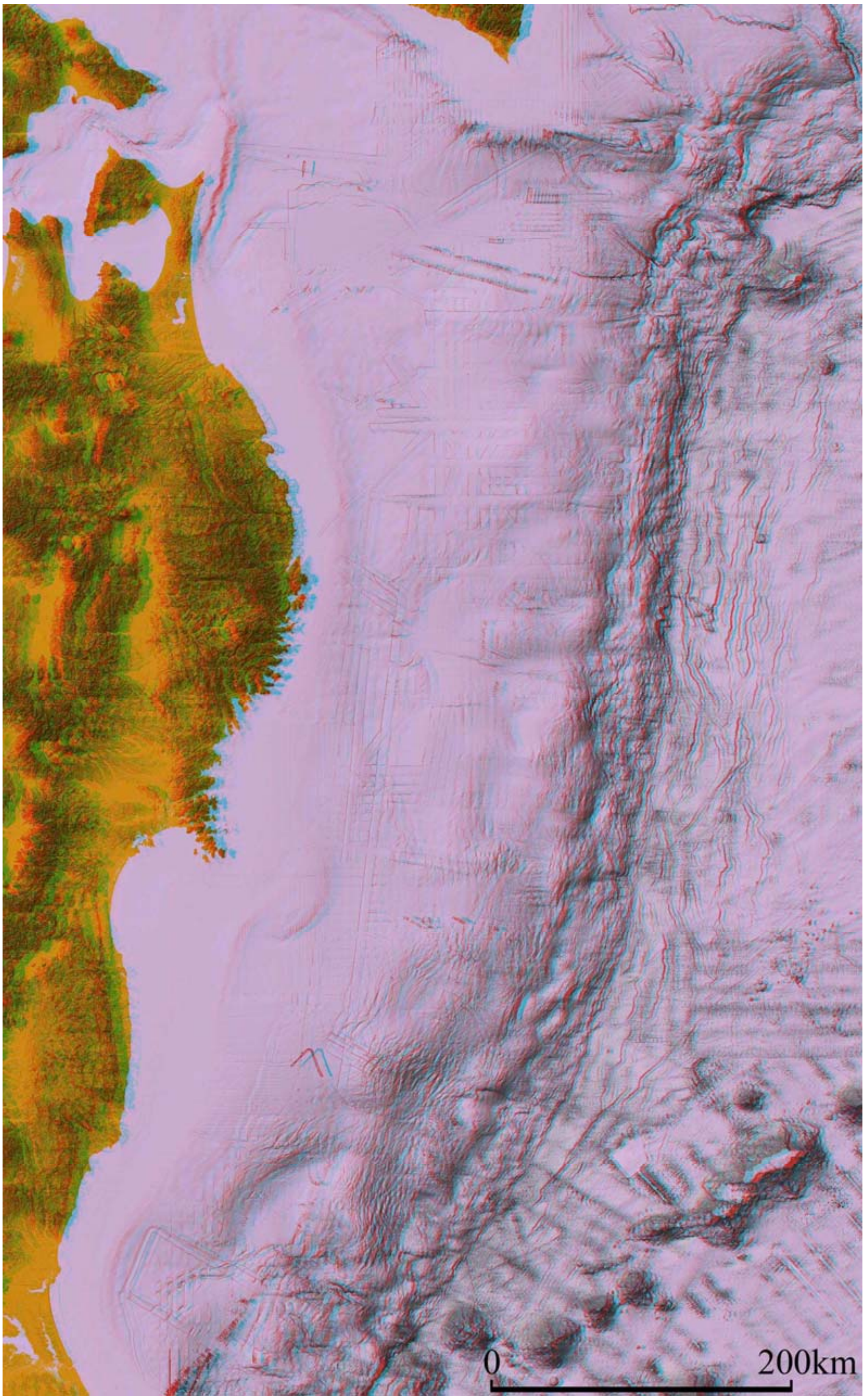

Fig. 4 An anaglyph image of Japan Trench
3D red cyan glasses are necessary to view the image correctly

Geometry of submarine active faults

Fig. 4 is an anaglyph image of Japan Trench with island parts of Northeast Japan. Notice that vertical exaggeration of the figure is about 5 -10 times depending on distance from the figure to eyes. In the anaglyph image, we can easily observe seafloor relief throughout wide area, and it is no so difficult for most of us to see minor relief, and find faults that dislocate seafloor. Escarpments or flexure slopes were formed by reverse faulting, whether individual fault reaches seafloor or terminates in depth. Slope tectonically formed are convex in their cross sections, and are associated with tectonic bulge to their west. Active faults along Japan Trench have been first mapped by Research Group for Active Faults of Japan (1991), but the faults were identified by the rather small-scale bathymetric maps seismic reflection records available at that time, the fault traces are intermittent and their location and extents are not always accurate. Active faults in the study area are grouped into the following three fault zones. They are from east to west, (1) normal faults on Outer Rise, (2) extensive thrust faults on the trench slop, and (3) lineaments on the shelf slope (Fig. 5).

Normal faults on Outer Rise

Normal faults on Outer Rise between Erimo Seamount and Daiichi Kashima Seamount extend in N-S direction. They are not straight but sinuous, and extend parallel each other, and are rather evenly spaced about 5km apart, and form a basin and range type horst and graben topography. These fault scarps are lower in the east and higher in the west, and fault scarps are relatively over 300m high near the trench axis. They are mostly around 50km long. Some of the faults extending NE-SW to the northeast of Joban Seamount Chain become around 100km long. One of the aftershocks of the 311 Earthquake probably took place along one of the NNE-SSW normal faults on the outer rise to the north of Joban Seamount Chain off Fukushima.

Extensive thrust faults on the trench slop

The most extensive thrust fault on the trench slop extends from Sanriku-Oki to Ibaraki-Oki for about 400km. This fault is associated with fault escarpments about 1500m and tectonic bulges to the west along its northern and southern section parts, while in the area southeast of Ojika peninsula where the fault branches northward as well as southward, younger low fault scarps, yet, higher than 100m, extend on landslide mass derived from the major escarpment, suggesting that repeated faulting has been taking place along the fault trace.

At Sanriku-Oki close to the trench axis, a 200km-long active thrust fault is identified by a steep straight escarpment extending N-S between the above-mentioned extensive fault and Japan Trench. This escarpment is associated with a 50km-long N-S trending sharp break in the north and several huge landslides in the south suggesting that this fault has been growing this escarpment very rapidly. Distribution of thrust faults along and around the Japan trench is rather simple compared with that of the Nankai trough or/and the southwestern part of the Kuril trench.

On the eastern part of the shelf slope to the west of the extensive thrust fault, several elongated bulges are fringed along their eastern margins by flexure scarps, They are presumably formed by subsurface reverse faulting on west-dipping fault planes.

Lineaments on the shelf slope

N-S trending lineaments are densely distributed in the eastern part of the shelf slope. They are mainly concentrated on tectonic bulges, especially on their flexure scarps where seafloor have been expanded due to bending on the hanging walls of subsurface thrust faults.

On the other hand, we could not find any extensive normal faults on the shelf slop, except for the one off Fukushima. Some of the large tectonic bulges are associated with eroded anticlinal ridges that are comonly observed along the active faults in Nakai Trough region. Erosion of the anticlines may be due to strong shaking by faulting around the bulges.

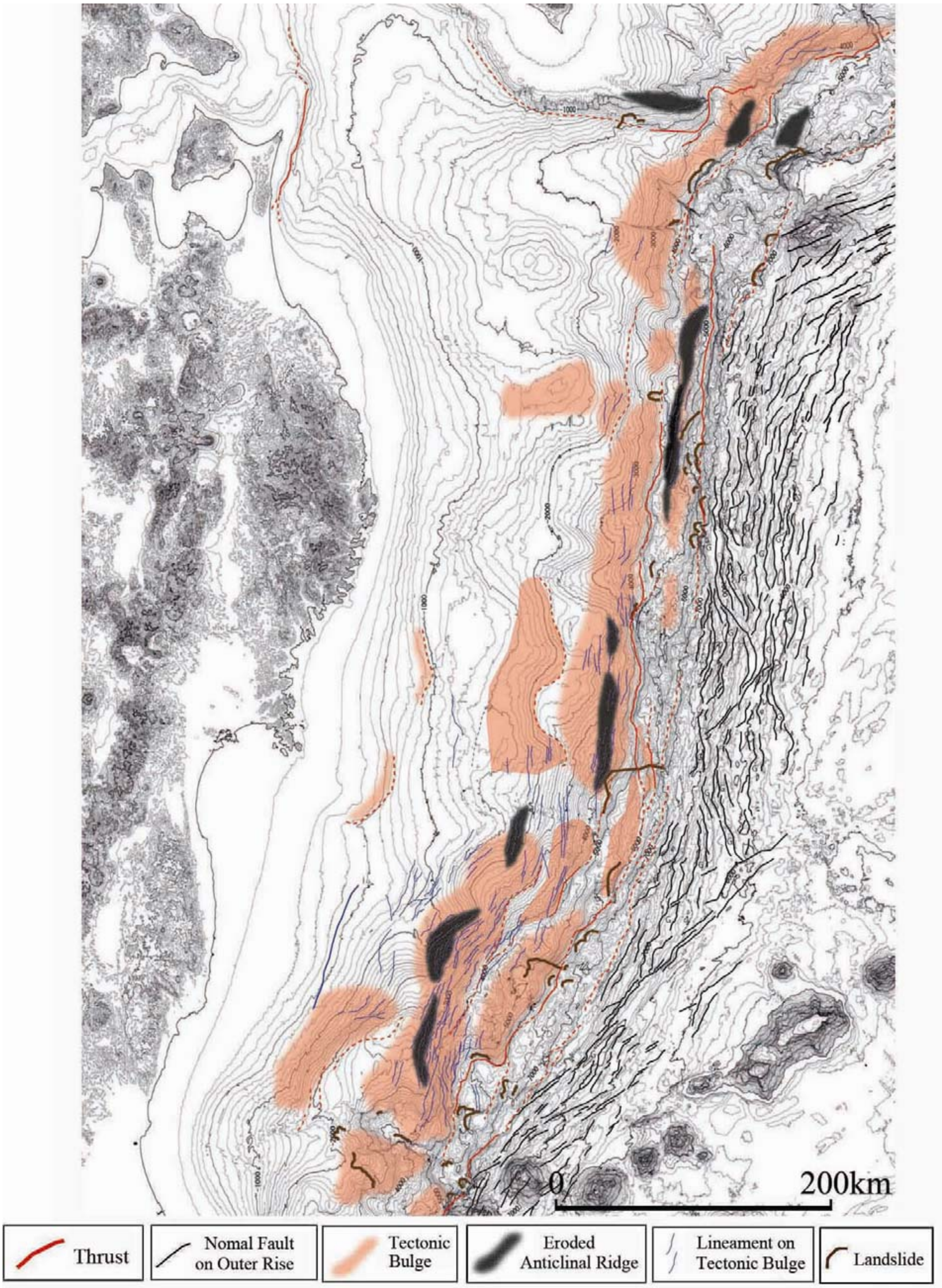

Fig. 5　Tectonic map along Japan Trench.　　Contour inteval is 100m

Active fault and source fault of the 11 March 2011Tohoku-Oki earthquake earthquake

The 11 March 2011tohoku-Oki earthquake earthquake (*Mw9.0*) generated large tsunami with massive pulsating pattern of waves (Maeda et al. 2011). The earthquake source fault that generated the earthquake, is beleived to have caused near-surface fault rupture reaching Japan Trench. Large displacement ~50m eastward and ~7 to ~10m upward was estimated between 2004 and 2011 from comparison of data obtained by multibeam bathymetric surveys across the trench (Fjiwara et al. 2011).

Satake et al. (2011) explained the large tsunami height by similutaneous faulting on two different fault planes, one on subducting plate boudary and the other near the trench axis. Since most of workers believed that the earthquake was caused by the fault ruptured up to the trench axis, exsitence of submarine active fault is rather overlooked so far,although the 400km long active fault trace coincidentally locates close to the trench in the area where Maeda et al.(2011) estimated large displacement.

We simulated pattern of seafloor deformation associated with the earthquake using a simple dislocation model for a single fault plane with uniform slip that dips 14 degree in depth and 33.6 degree beneth the tectonic bulge related to the extensive active fault (Fig. 6). A result shows that an area of large uplift agrees more or less with area of tectonic bulge with width of about 20km.

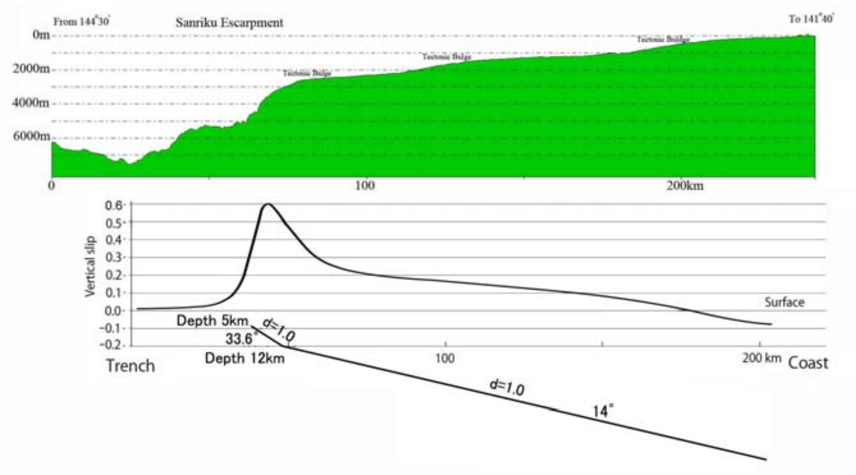

Fig. 6 A simulation of sefloor deformation by simple dislocation modele.
Topographic profile abobe follows along N39 degree.

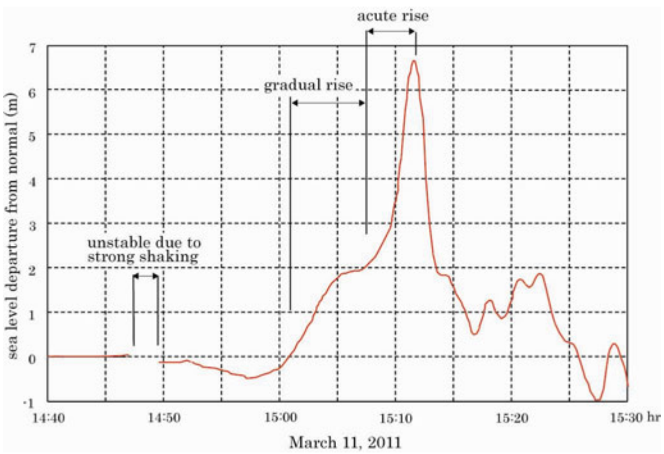

Fig. 7 Tsunami first wave recorded by GPS wave gage off Kamaishi
(Modified after Port and Airport Research Institute, 2001)

Fig. 7 is the record of tsunami first wave obtained by the GPS wave gage set on about 200m deep seafloor off Kamaishi on southern Sanriku Coast (Port and Airport Research Institute, 2011). The record suggests that after gradual sea-level rise of 2m during 6 minutes, acute sea-level rise of 4m took place within 4 minutes, and then sea-level abruptly dropped by 4m within 2 minutes. The length of pulsating tsunami wave is estimated about 17km from tsunami propagation velocity at 200m deep sea and total duration of pulsating pattern of tsunami, i.e. 7 minutes. This pattern resembles the extent of seafloor deformation we calculated above. Therefore, we believe that the thrust fault that extends from off-Sanriku to off-Ibaraki for over 400km is closely related to the source fault of the 2011 off the Pacific coast of Tohoku Earthquake.

Active fault and historical earthquake

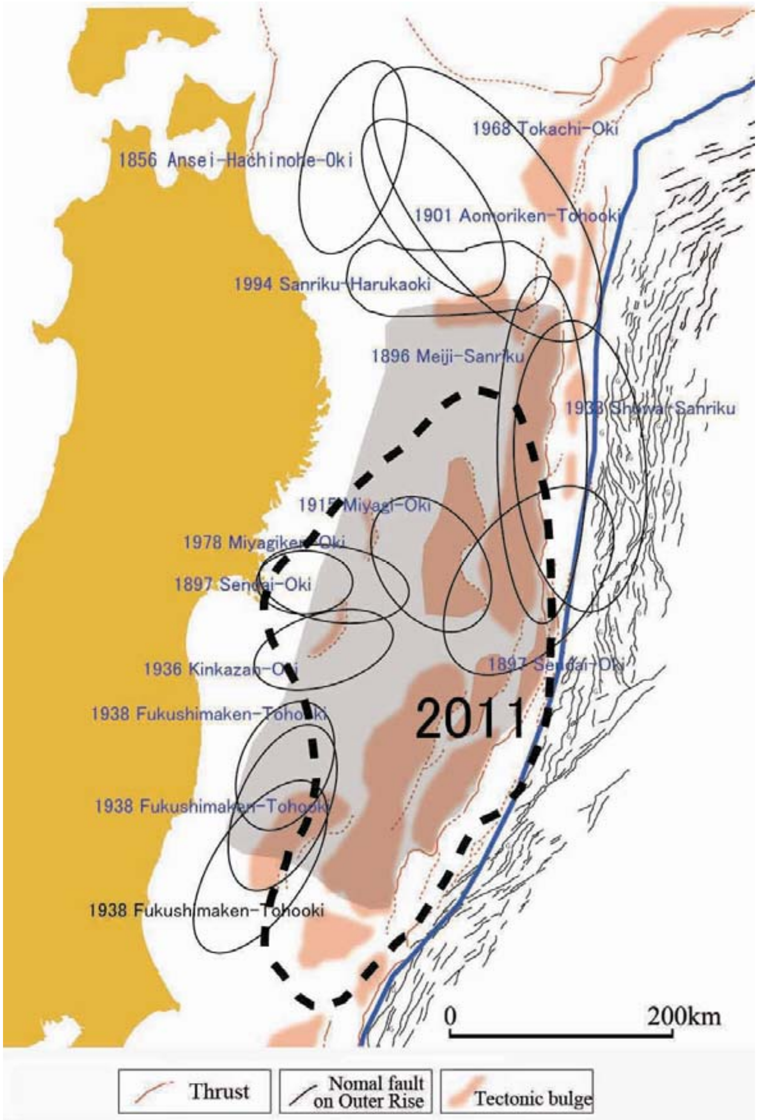

Fig. 8 Distribution of tectonic geomorphology

Hypocentral region of historical earthquakes after Earthquake Research Committee (1999) Solid line oval: hypocentral region of historical earthquakes, Broken line oval: source fault of the 2011 earthquake(after Earthquake Research Committee, 2011), Shaded area:seismic

source fault of the 2011 earthquake proposed by this study, Solid blue line:trench axis.
We compare location of hypocentral regions of historical earthquakes (Earthquake Research Committee, 1999) and tectonic landoform and distribution of submarine active faults and tectonic bulges (Fig. 8). It is noteworthy to mention that some of the hypocentral regions are located on tectonic bulges. This suggests that location and extent of seismic source faults in depth will be detected from distribution of tectonic bulges. In this context, one of the M8 earthquake source faults is possibly located under a large tectonic bulge with flexure scarp extending N-S for 200km off Fukushima and Ibarak.

The source fault for Meiji Sanriku earthquake (M8.2 - 8.5) may be related to a 200km-long active fault along the trench off Sanriku. Numerous normal faults are distributed on the outer-rise slope and they are generally short, and may cause M7 class earthquakes. The 1933 Sanriku earthquake (M8.1-Mw8.4) is believed as one of the outer-rise earthquakes, but it is hard for us to indentify certain around normal fault that matches to the extent of a M8 class earthquake.

CONCLUSIONS

Based on tectonic geomorphology, we claim that the submarine active faults are closely related to earthquake source faults, and it is important to consider active faults as direct evidence of repeated large earthquakes along Japan Trench.

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