# Electrical Conductivity Structures around Seismically Locked Regions

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## 1. Introduction

Existence of fluid on seismogenic zones has a key role on great earthquakes because high pore pressure in a fault zone allows sliding at low shear stress [e.g., *Blanpied et al.*, 1992]. In fact, *Fujie et al.* [2002] found in the Japan Trench region that large amplitude reflected waves generated at the subducting plate boundary were observed at low seismicity region and vice versa. The heterogeneous distribution of reflectors may be attributed to heterogeneous fluid distribution on the plate boundary, and may indicate the role of fluid on the earthquake occurrences. However, other factors can explain such reflectors, so that independent geophysical surveys sensitive to fluid are required for further discussion. Electromagnetic surveys have revealed fluid distribution in seismogenic zones [e.g., *Unsworth et al.*, 2000] because enhanced electrical conductivity at subsolidus temperatures is principally controlled by the presence of water. In this study, I review two conductivity structures across seismically locked regions, conclude a hypothesis of relation between the locked regions and fluid, and introduce a future electromagnetic survey in the Tokai seismogenic zone.

## 2. Nankai Trough

The 1944 Tonankai earthquake (M 7.9) in the Nankai Trough, off the Kii peninsula, southwest Japan is one of the typical megathrust earthquakes recurred along subduction zones. The source region with high velocity rupture was located just below the Kumano basin, and had a large slipped area with a length scale of 100 km [*Kikuchi et al.*, 2003], where recent seismicity is quite low [*Obana et al.*, 2003]. These observed features suggest that the plate boundary between the subducting Philippine Sea plate and the Japan arc is currently locked below the Kumano basin, and most of the locked zone will be ruptured rapidly with a single large earthquake. Therefore, the Kumano basin is one of the best fields to elucidate characters and mechanisms of a large thrust earthquake on the subducting plate.

Land and marine magnetotelluric surveys in the Kii peninsula, the Kumano basin and the Nankai Trough were carried out in 2002-2004. On the basis of the marine data, *Goto et al.* [2003] estimated an electrical conductivity model below the seafloor, in which the Philippine Sea plate has a conductive oceanic crust before subduction (Fig. 1). As the plate goes down the Kumano basin, the conductivity becomes low at the depth of 10 km below the seafloor, which approximately coincides with the up-dip limit of the Nankai mega-earthquake zone. Meanwhile, *Kasaya et al.* [2005] tried a joint modeling by using land and marine data, and their preliminary model shows that the Philippine Sea plate becomes more conductive (with 0.1 S/m) again below the depth of 30 km, around the down-dip limit of the earthquake zone.

## 3. Atotsugawa Fault

Seismicity along the Atotsugawa Fault, located in central Japan, shows a clear heterogeneity. The central segment of the fault with low-seismicity is recognized as a seismic gap, although a lot of micro-earthquakes occur along this fault [*Ito and Wada*, 1999]. The electrical conductivity structure investigated across the central segment of the Atotsugawa Fault [*Goto et al.*, 2005] indicates a shallow, high conductivity zone along the fault to a depth less than 1 km (Fig. 2). The model shows an underlying low conductive crust at the depth of about 5 km below the fault trace. Comparing the conductivity models across the Atotsugawa and other large strike slip faults such as the San Andreas Fault, *Goto et al.* [2005] conclude that the low conductive crust is a common feature of a locked fault segment. *Goto et al.* [2005] also reported a conductive lower crust below the fault trace, where micro-earthquake activity is relatively high.

## 4. Discussion

In the two cases, the shallow structures of the seismically locked zones have relatively high conductivity, explained by existence of fluid. In the Nankai Trough, the shallow conductive zone on the Philippine Sea plate can be interpreted as the fluid-rich oceanic crust because the temperature is too low. Although conductive clay mineral may a candidate to make the conductive zone, the thickness of the shallow conductive zone is too thick and whole of them cannot be explained by clay mineral only. Meanwhile, the high conductivity zone along the Atotsugawa Fault is possibly due to fluid in the fracture zone [*Goto et al.*, 2005].

High conductive zones beneath the seismically locked zones are also commonly obtained at both the Nankai and the Atotsugawa regions. The conductive Philippine Sea plate below the depth of 30 km is considered to relate to the dehydrated fluid from the subducting plate itself [*Kasaya et al.*, 2005]. Again, fluid in the lower crust is inferred as a preferable cause of the conductive zone below the seismically locked zone along the Atotsugawa Fault [*Goto et al.*, 2005].

In the two examples, the seismically locked zones are commonly characterized as low conductivity. As the high conductive zones due to high-fluid content exist upon the up-dip limit and beneath the down-dip limit of the seismically locked zone, I conclude that the fluid content in the seismically locked zones are possibly lower than the surrounding zones along the plate boundary and the fault. This conclusion is consistent with theoretical and experimental results in which high-fluid content can make a fault slide easily and low-fluid content prevents a fault slip at low stress condition. Note that not only the fault plane, but also the surrounding zone along the fault show low conductivity.

## 5. Future Survey

Although electromagnetic surveys can show less fluid condition around seismically locked zones, there is no information how fluid can act on occurrence of great earthquakes: for example, whether highly-pressurized deep fluid moves into seismically locked zones and reduces strength of locked zones, or not. One of the best ways to test such hypothesis is electromagnetic monitoring around seismically locked zones. Here, I suggest a future observation plan on the Tokai region, Japan (Fig. 3), where a locked plate boundary on the subducting Philippine Sea plate is clearly recognized [*Sagiya*, 1999]. In addition, a slow slip on the plate boundary is recently found by GPS observation [*Ohta et al*., 2004; Fig. 3]. Such a slip makes a stress concentration near the boundary between the locked and slipping zones, so that the boundary region has a potential of an initial rupture of the next Tokai earthquake. The Toyohashi cables, installed and maintained by KDDI, are located on both the locked and slipping zones of the Tokai region (Fig.3). This cable is a best facility for monitoring physical properties of the plate boundary if it can be available for scientific purpose.

On the basis of numerical calculations, I demonstrate a possibility to detect conductivity variation (indication of fluid migration) on the plate boundary by using the Toyohashi cables, artificial transmitter and ocean-bottom receivers of electric field (Fig. 4). Conductivity of the crust, seawater and a high conductive zone on the plate boundary is assumed as in Figure 4. The Toyohashi W-cable is used as a dipole source with two electrodes located at 0km (coast line) and 60 km (off shore), respectively. The shape of source current is rectangle with amplitude of 1 A. Eleven ocean-bottom receivers, located along the source dipole and connected to the Toyohashi E-cable, consist of a dipole cable with length of 1 km. Hundred received electric waves are stacked at each receiver, and transformed to apparent resistivity by using the dipole-dipole DC resistivity sounding method. As I adopted the DC resistivity sounding, the source wave should have enough long periods. The skin depth at the period of 1000 sec on the uniform earth with conductivity of 0.01 S/m is about 160 km, so that such a long period can allow us to apply DC resistivity sounding. In this case, about one-day observation is necessary for 100 stacking. Error of the received electric field is assumed as 1 micro-Volt normally observed on the seafloor electric field observation.

As shown in Figure 4, apparent resistivity values with the high conductive zone on the plate boundary is distinguished from ones without the high conductive zone. The apparent resistivity can be obtained daily, so that the submarine cables are useful tools for monitoring fluid in the crust. One problem using long cables for monitoring is low spatial resolution. Before the monitoring, I suggest a conventional electromagnetic survey with ocean-bottom electromagntometers (OBEMs) such as reported in *Goto et al*. [2003]. A combination of OBEM surveys and electromagnetic monitoring ith long cables allow us to detect locations of anomalous conductivity variation related to fluid migration below the seafloor.

## 6. Conclusion

I reviewed the two conductivity structures around the seismically locked regions. Both seismically locked regions correspond to the low conductive zones, interpreted as relatively low fluid content. The electromagnetic surveys reveal a possible relationship between fluid content and a seismically locked zone with potential of great earthquakes: less fluid condition around subducting plate and fault zone is related to mega-earthquakes. For more discussion on the role of fluid to earthquake occurrence, electromagnetic monitoring is necessary. I suggest a future observation plan off Toyohashi, where both slow-slipping and locked zones are obvious in and around the Tokai seismogenic zone, by using long submarine cables.

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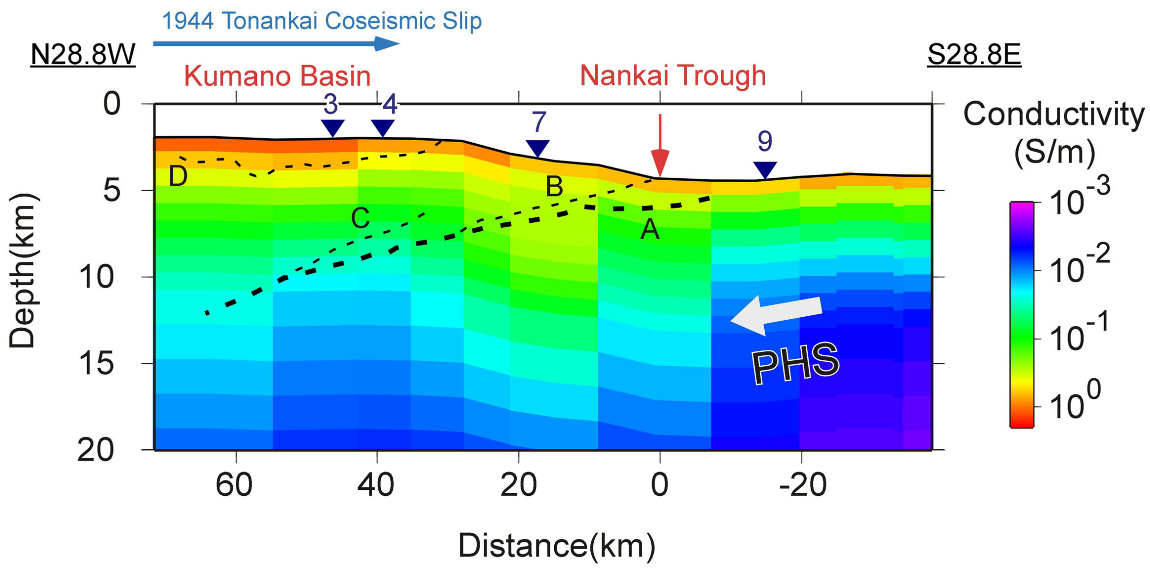


**Figure 1**. Electrical conductivity structure across the Nankai Trough and Kumano Basin [*Goto et al*., 2003]. The seaward distribution of the 1944 Tonankai coseismic slip by *Kikuchi et al*. [2003] is projected as a blue line. Triangles indicate locations of the OBEM used for the modeling. Seismic reflectors by *Park et al*. [2002] are shown as broken lines (A: top of the oceanic crust, B: decollement, C: splay fault, and D: basement of the forearc Kumano basin). PHS: Philippine Sea Plate.

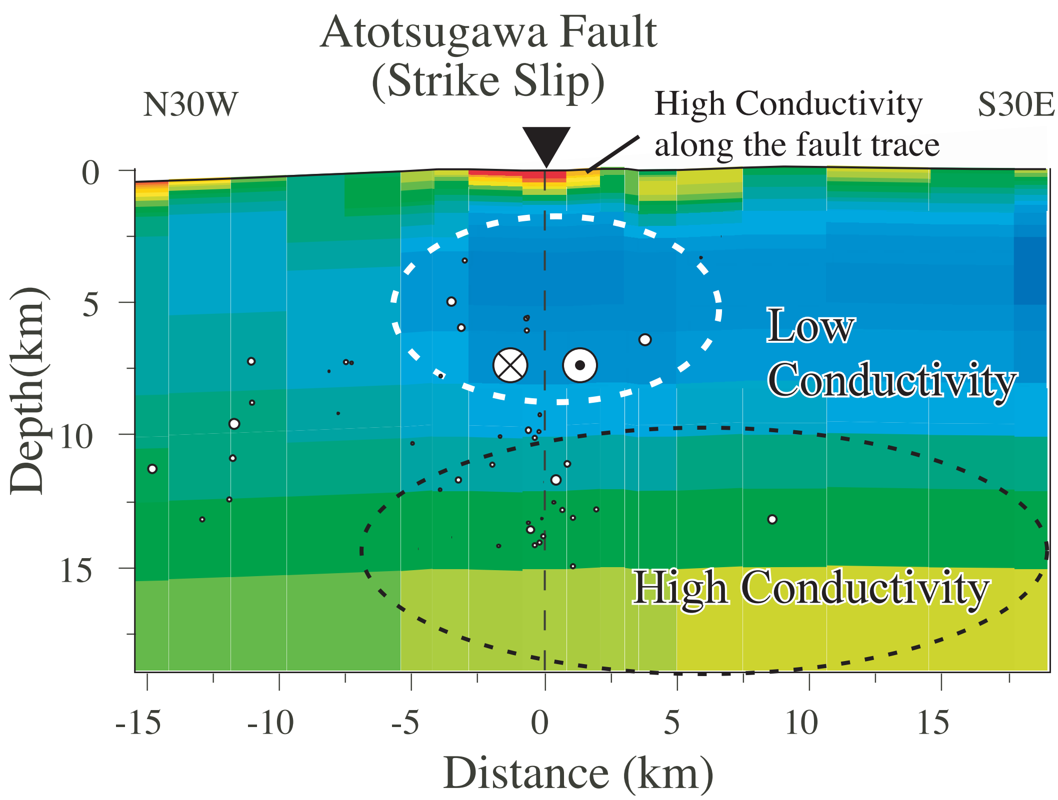


**Figure 2**. Electrical conductivity structure across the central segment of the Atotsugawa fault, interpreted as the seismically locked zone [*Goto et al*., 2005]. The location of the Atotsugawa Fault is indicated by a broken line. Hypocenters based on *Ito and Wada* [1999], occurred in a horizontal width of 15 km along this profile, are plotted by circles.

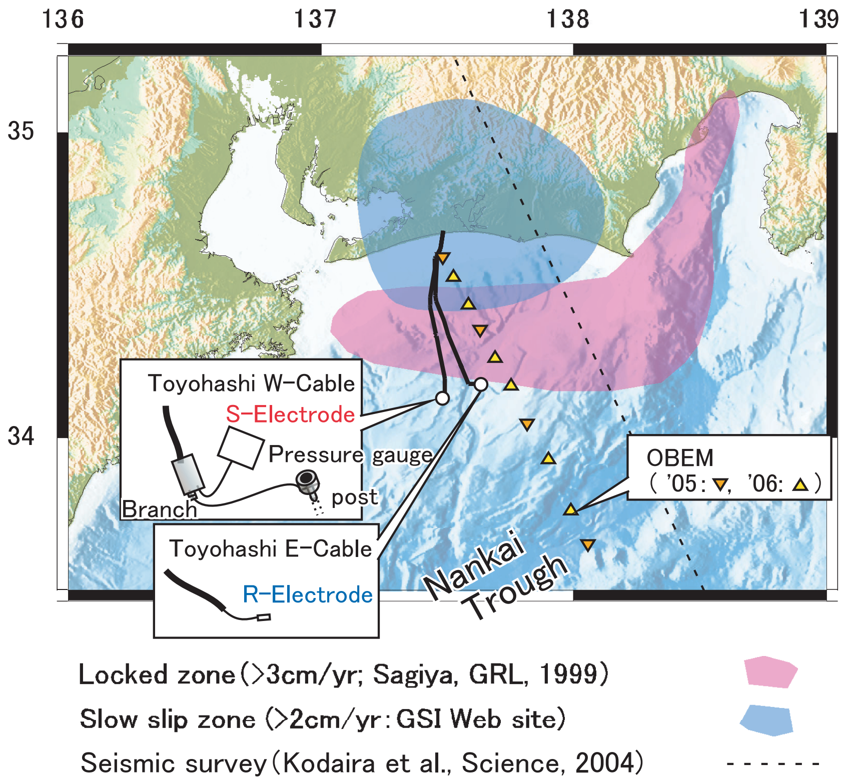


**Figure 3**. Location of the Toyohashi E and W Cables. Triangles indicate a proposed location of the OBEM deployments. A broken line is a seismic refraction profile [*Kodaira et al*., 2000]. Blue and red regions indicates slow-slipping and locked plate boundary, respectively.

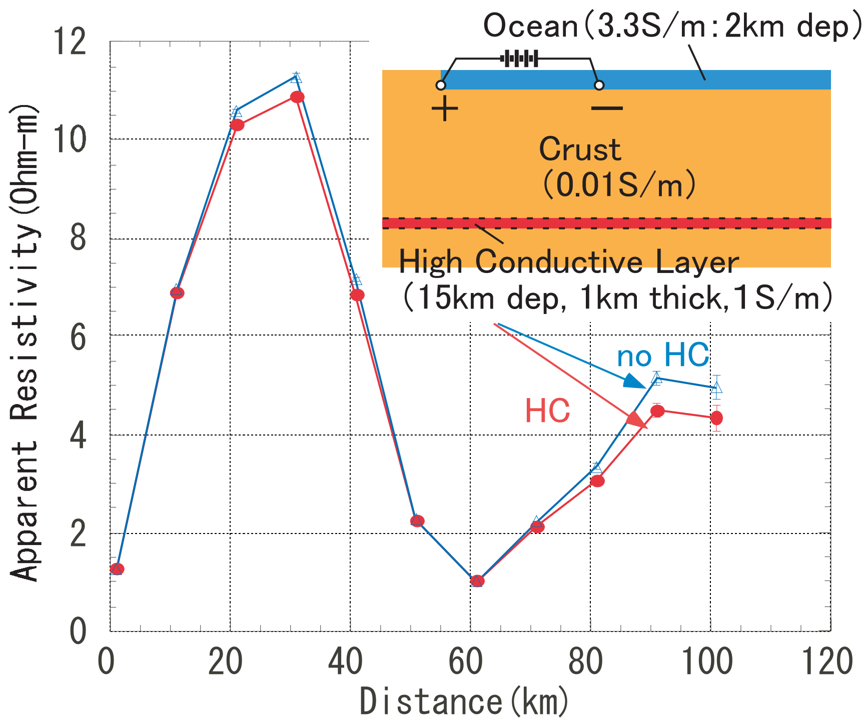


**Figure 4**. Numerical calculation of DC resistivity sounding by using the Toyohashi Cables. See details in the main text. The top-right figure indicates a model used in the calculation.