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REGIONAL CHARACTERISTICS OF FAULT PARAMETERS FOR SUBDUCTION INTER-PLATE EARTHQUAKES

S. Ogawa(1), D. Ju(2), K. Dan(3), K. Irie(4), and H. Torita(5)

(1) *General Manager, Research Department, Ohsaki Research Institute, Inc., ogawa@ohsaki.co.jp*
(2) *Chief Researcher, Research Department, Ohsaki Research Institute, Inc., judianshu@ohsaki.co.jp*
(3) *Research Fellow, Ohsaki Research Institute, Inc., dan@ohsaki.co.jp*
(4) *Principal Researcher, Ohsaki Research Institute, Inc., k.irie@ohsaki.co.jp*
(5) *Deputy Director, Ohsaki Research Institute, Inc., torita@ohsaki.co.jp*

Abstract

In predicting strong motions from the subduction inter-plate earthquakes, the assessment procedure proposed by the Headquarters for Earthquake Research Promotion (2005)[1], called Recipe, is widely used in Japan. This procedure was proposed based on the findings mainly from the 1978 Miyagiken-oki earthquake and the 2003 Tokachi-oki earthquake. These earthquakes are categorized into the first stage as the scaling relations in the three-stage scaling model, which is established for crustal earthquakes. In order to predict strong motions of subduction inter-plate mega-earthquakes, such as the 2011 off the Pacific coast of Touhoku earthquake which is categorized into the second stage, we should solicit the findings on the source parameters and strong motion characteristics of the past mega-earthquakes all over the world, and reflect them in the prediction.

In this study, we collected 184 literatures on the subduction inter-plate mega-earthquakes, which were assigned to 26 regions of the plate boundaries categorized by the utility's analysis report (2015) [2] submitted to the Japan Nuclear Regulation Authority, to obtain their fault length (L), fault width (W), fault area (S), seismic moment (M_0), and short-period level (A), and compare them with the past scaling laws, i.e. 1) W-L relation, 2) S-M_0 relation, and 3) A-M_0 relation.

The W-L relations of the Japan's eathquakes and the outside Japan's are not different where L is larger than 300km, and their average is consistent with the empirical relation of Watanabe *et al.* (2002)[3], in which the saturated fault width is considered to be 150km. The fault width of the second stage depends on the regions, and it is larger than 150km in Sumatra, Alaska, and Central Chile, and smaller in Cascadia and Aleutians.

Regarding the S-M_0 relations, the fault areas of the outside Japan's earthquakes are larger than those of the Japan's for the large M_0 range (i.e. $M_0 \geqq 5.0\times10^{19}$ N・m: Mw ≧ 8.4), and the average of all the earthquakes is consistent with the empirical relation of Tajima *et al.* (2013)[4] for the second stage. The fault areas of Sumatra, Alaska, and Aleutians are larger than those by the empirical relation.

Regarding the A-M_0 relations of the Japan's eathquakes and the outside Japan's, their short-period levels are scatered between the range of 0.5 to 2.0 times of the empirical relation of Dan *et al.* (2001)[5] for crustal earthquakes. Focusing on the regional difference, the short-perid level of the Pacific Plate in Japan is larger than that in the other regions, i.e. Philippine Sea Plate in Japan, Central America, and Central Chile.

As the reult, the collected data indicate that the second stage as the scaling relations should be applied to the subduction inter-plate mega-earthquakes, analogiously to crustal earthquakes.

Keywords: subduction inter-plate earthquakes, regional characteristics, recipe for strong motion prediction

1. Introduction

The new regulatory standards of the Japan Nuclear Regulation Authority (2013)[6] require that the seismic source region is to be set by taking into account the similarity of the past huge earthquakes, not only in Japan but also outside Japan, in terms of their generation mechanisms and tectonic backgrounds. For the subduction inter-plate earthquakes, especially for large ones which periodically occur every few decades, the location and magnitude of the scenario earthquake can be predicted based on the findings obtained from the researches of past earthquakes. In order to accumulate the seismic source characteristics of subduction inter-plate mega-earthquakes which occur every few hundred years, like the 2011 off the Pacific coast of Touhoku earthquake, it is even more important to research the observation records of the past mega-earthquakes all over the world to predict the ground motions of the scenario earthquakes.

In predicting strong ground motions from the subduction inter-plate earthquakes, the assessment procedure proposed by the Headquarters for Earthquake Research Promotion (2005)[1], called Recipe, is widely used in Japan. This procedure was proposed based on the findings mainly from the 1978 Miyagiken-oki earthquake and the 2003 Tokachi-oki earthquake. These earthquakes are categorized into the first stage as the scaling relations in the three-stage scaling model, which is established for crustal earthquakes. In order to predict strong motions of subduction inter-plate mega-earthquakes, such as the 2011 off the Pacific coast of Touhoku earthquake which is categorized into the second stage, we should solicit the findings on the source parameters and strong motion characteristics of the past mega-earthquakes all over the world, as mentioned above, and reflect them in the prediction.

In this study, we collected past literatures on the subduction inter-plate mega-earthquakes to obtain their fault length (L), fault width (W), fault area (S), seismic moment (M_0), and short-period level (A), and compare them with the past scaling laws, i.e. 1) W-L relation, 2) S-M_0 relation, and 3) A-M_0 relation, focusing on their regional differences and confirming whether the second stage as the scaling relations can be applied to the subduction inter-plate mega-earthquakes, analogiously to crustal earthquakes.

2. Survey of Fault Parameters

We collected 184 literatures on the subduction inter-plate mega-earthquakes, and surveyed the following fault parameters: 1) categorized region, 2) earthquake name and date of occurrence, 3) longitude and latitude of the epicenter, 4) moment magnitude, 5) seismic moment, 6) fault length, 7) fault width, 8) fault area, 9) average stress drop, 10) short-period level, 11) stress drop and area of asperity, 12) corner frequency, and 13) shear wave velocity.

The subduction plate boundaries were categorized into 26 regions based on the utility's analysis report (2015)[2] submitted to the Japan Nuclear Regulation Authority as follows: 1) Sumatra, 2) Java, 3) Banda Sea, 4) New Zealand, 5) Kermadec, 6) Tonga, 7) Vanuatu, 8) Solomon Islands, 9) Philippine, 10) Marianas, 11) Izu Bonin, 12) North East Japan (Pacific plate), 13) Kuriles, 14) Kamchatka, 15) Aleutians, 16) Alaska, 17) Cascadia, 18) Central America, 19) Caribbean, 20) Colombia, 21) Peru, 22) Central Chile, 23) South Chile, 24) Scotia, 25) Ryukyus, and 26) South West Japan (Philippine Sea plate). Fig. 1 shows the categorized regions and the epicenters of the compiled earthquakes from the collected literatures outside Japan, while Fig. 2 shows the epicenters of those in Japan.

3. Survey Results

3.1 Fault width (W) and fault length (L) relations

Fig. 3 shows the relations of the fault width (W) and fault length (L) for all the subduction inter-plate earthquakes compiled here, both inside Japan (white circles) and outside Japan (black circles). The red lines

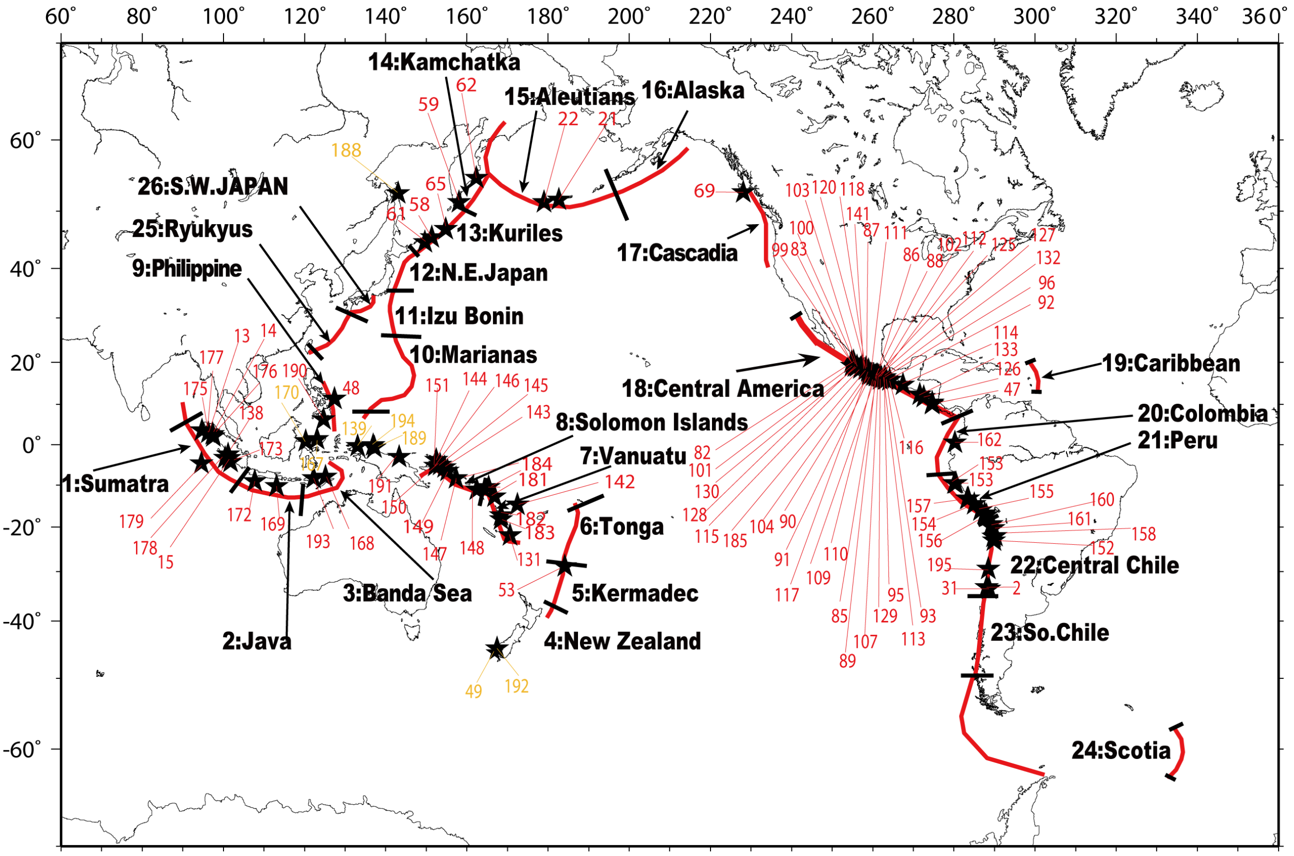

Fig. 1 – Categorized regions of subduction plate boundaries and the epicenters of the compiled earthquakes outside Japan

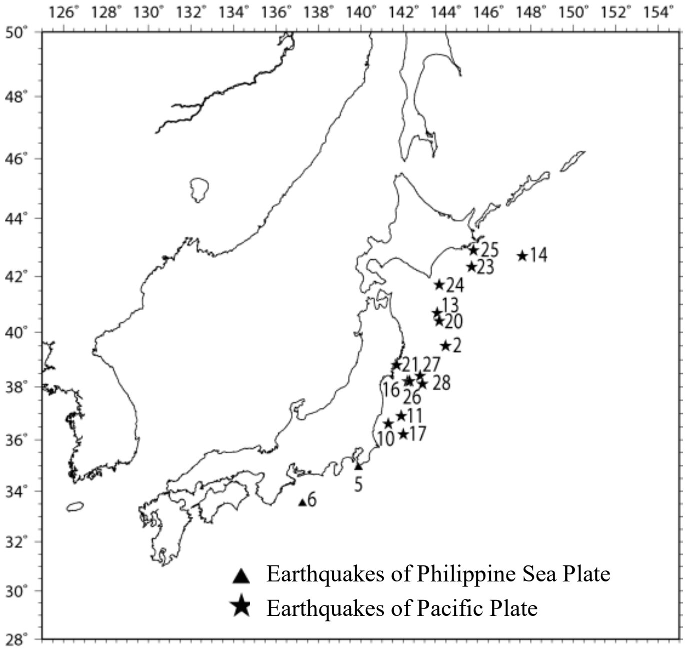

Fig. 2 – Epicenters of the compiled earthquakes in Japan

show the empirical relation of Watanabe *et al.* (2002)[3], in which the saturated fault width is assumed to be 150km. Figs. 4 to 21 show the *W-L* relations for individual regions. Where *L* is larger than 300km, the *W-L* relations of the Japan's earthquakes and the outside Japan's earthquakes are not different, and their average is consistent with the empirical relation of Watanabe *et al.* (2002)[3]. The fault width of the second stage depends on the regions, and it is larger than 150km in Sumatra, Alaska, and Central Chile, and smaller in Cascadia and Aleutians.

3.2 Fault area (S) and seismic moment (M_0) relations

Fig. 22 shows the relations of the fault area (S) and seismic moment (M_0) for all the subduction inter-plate earthquakes compiled here, both inside Japan (white circles) and outside Japan (black circles), in which three empirical relations are also shown, as follows:

$$S[\mathrm{km}^2] = 1.48\times10^{-10}\times(M_0[\mathrm{N\cdot m}])^{2/3} \quad (1.4\times10^{17}\ \mathrm{N\cdot m}\leqq M_0\leqq 5.0\times10^{19}\ \mathrm{N\cdot m}), \tag{1}$$

$$S[\mathrm{km}^2] = 5.82\times10^{-7}\times(M_0[\mathrm{N\cdot m}])^{1/2} \quad (5.0\times10^{19}\ \mathrm{N\cdot m}\leqq M_0\leqq 5.6\times10^{20}\ \mathrm{N\cdot m}), \tag{2}$$

$$S[\mathrm{km}^2] = 8.58\times10^{-11}\times(M_0[\mathrm{N\cdot m}])^{2/3}. \tag{3}$$

Eq. (1) is the S-M_0 relation by Murotani *et al.* (2008)[7] (black line). Eq. (2) is that by Tajima *et al.* (2013)[4] (red line), applied to the second stage where the fault width is saturated. Eq. (3) is that by Utsu (2001)[8] (blue broken line) which is adopted in the Recipe by the Headquarters for Earthquake Research Promotion (2005)[1]. Figs. 23 to 40 show the S-M_0 relations for individual regions. For the large M_0 regions, i.e. $M\mathrm{w}\geqq$ about 8.4, the ratios of the compiled fault areas to those by Eq. (2) are calculated assuming $S\propto M_0^{1/2}$ and their geometric means are shown in Table 1. The fault areas of the outside Japan's earthquakes are larger than those of the Japan's, and the average fault area of all the earthquakes is consistent with the empirical relation of Tajima *et al.* (2013)[4], applied to the second stage. The fault areas of Sumatra, Alaska, and Aleutians are larger than those by the empirical relation, and those of Philippine Sea Plate in Japan and Cascadia are smaller.

3.3 Short-period level (A) and seismic moment (M_0) relations

Fig. 41 shows the relations of short-period level (A) and seismic moment (M_0) for all the subduction inter-plate earthquakes compiled here, both inside Japan (white circles) and outside Japan (black circles), in which the empirical relation of Dan *et al.* (2001)[5] for crustal earthquakes is also shown (black solid line) as follows, which is adopted by the Recipe:

$$A[\mathrm{N\cdot m/s^2}] = 2.46\times10^{10}\times(M_0[\mathrm{N\cdot m}]\times10^{7})^{1/3} \quad (3.5\times10^{17}\ \mathrm{N\cdot m}\leqq M_0\leqq 7.5\times10^{19}\ \mathrm{N\cdot m}). \tag{4}$$

The black broken lines in Fig. 41 are 0.5 and 2.0 times of the empirical relation, and the gray broken lines are their extrapolations. Figs. 42 to 45 show the A-M_0 relations for individual regions. The ratios of the compiled short-period levels to those by Eq. (4) are calculated assuming $A\propto M_0^{1/3}$ and their geometric means are shown in Table 2. The A-M_0 relations of the Japan's earthquakes are larger than those of the outside Japan's, and their short-period levels are scattered between the range of 0.5 to 2.0 times of the empirical relation. Focusing on the reginal difference, the short-perid levels of the earthquakes on the Pacific Plate in Japan are larger than those in the other regions, i.e. Philippine Sea Plate in Japan, Central America, and Central Chile.

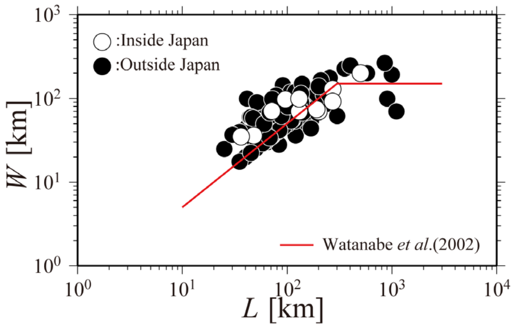

Fig.3 – *W-L* relations of all earthquakes compiled

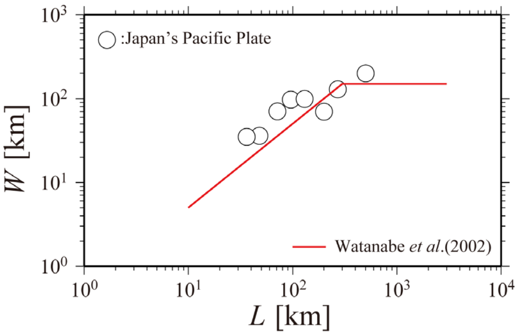

Fig.4 – *W-L* relations of earthquakes in Japan's Pacific Plate

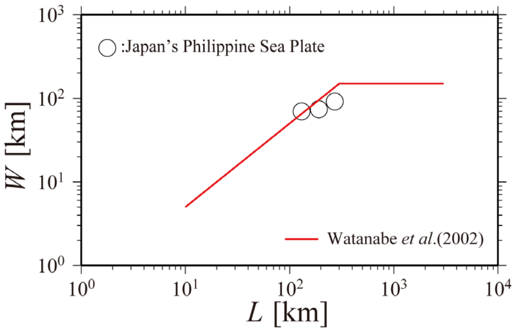

Fig.5 – *W-L* relations of earthquakes in Japan's Philippine Sea Plate

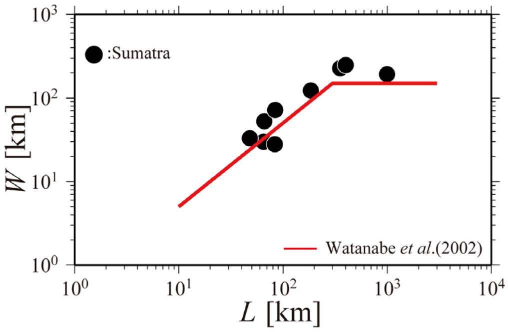

Fig.6 – *W-L* relations of earthquakes in Sumatra

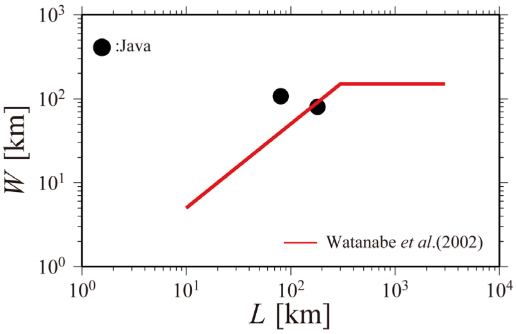

Fig.7 – *W-L* relations of earthquakes in Java

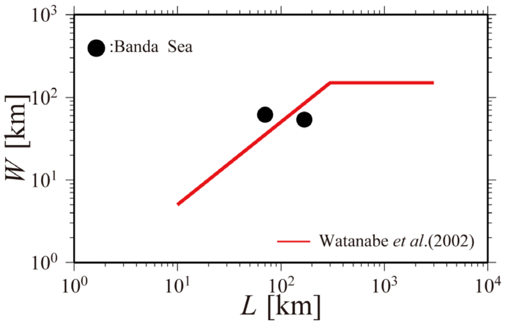

Fig.8 – *W-L* relations of earthquakes in Banda Sea

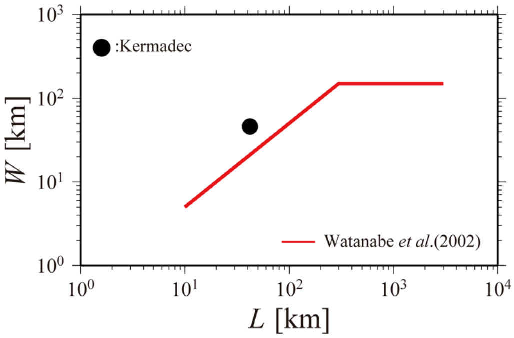

Fig.9 – *W-L* relations of earthquake in Kermadec

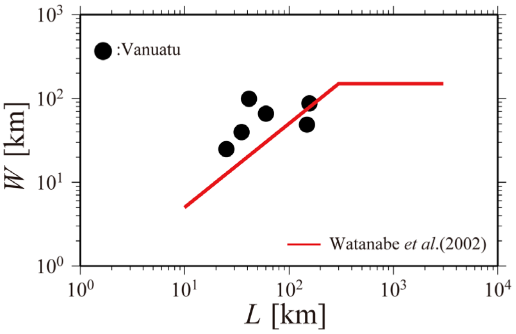

Fig.10 – *W-L* relations of earthquakes in Vanuatu

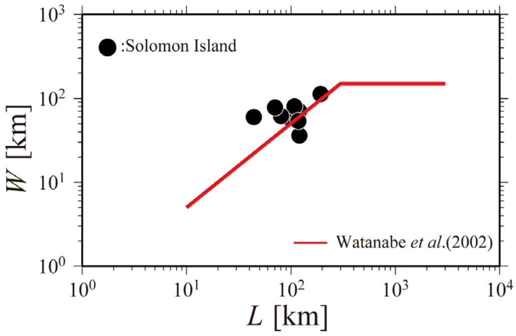

Fig.11 – *W-L* relations of earthquakes in Solomon Island

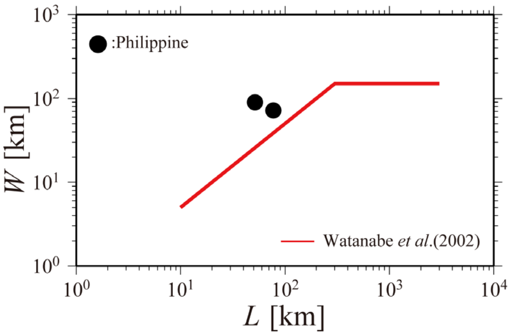

Fig.12 – *W-L* relations of earthquakes in Philippine

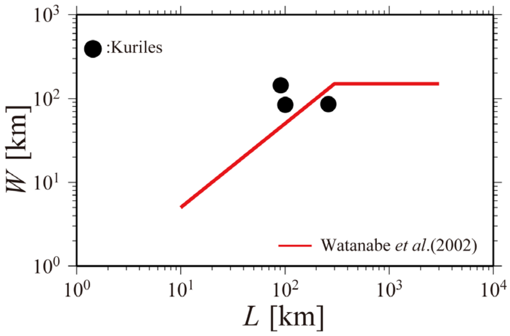

Fig.13 – *W-L* relations of earthquakes in Kuriles

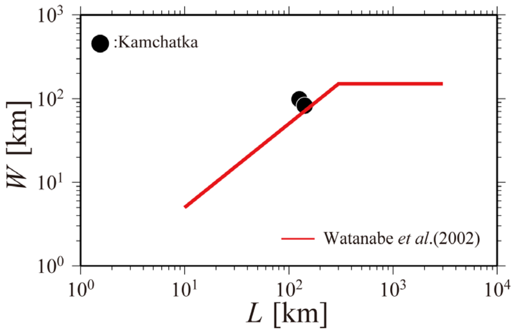

Fig.14 – *W-L* relations of earthquakes in Kamchatka

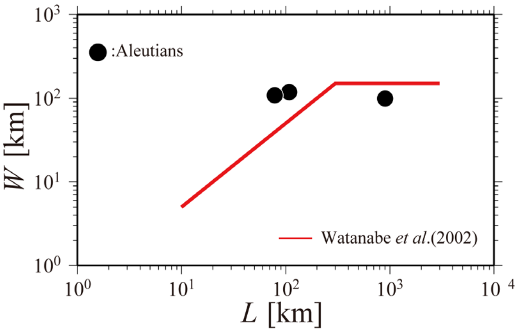

Fig.15 – *W-L* relations of earthquakes in Aleutians

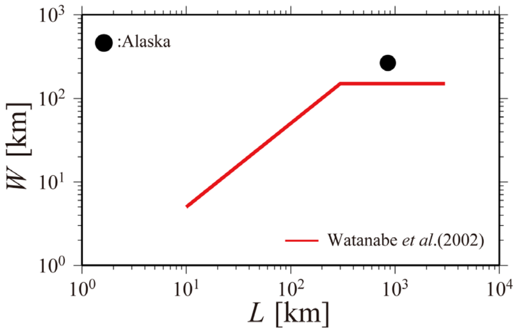

Fig.16 – *W-L* relations of earthquake in Alaska

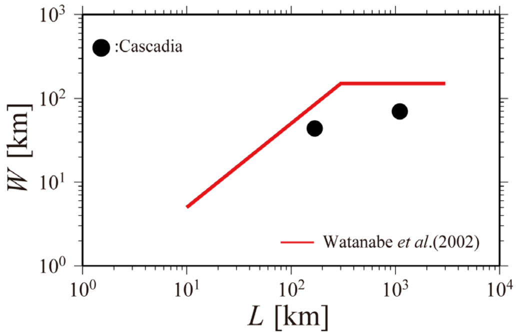

Fig.17 – *W-L* relations of earthquakes in Cascadia

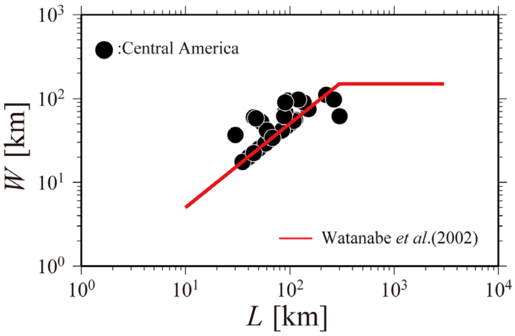

Fig.18 – *W-L* relations of earthquakes in Central America

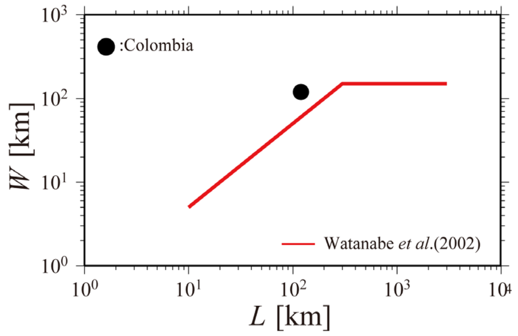

Fig.19 – *W-L* relations of earthquake in Colombia

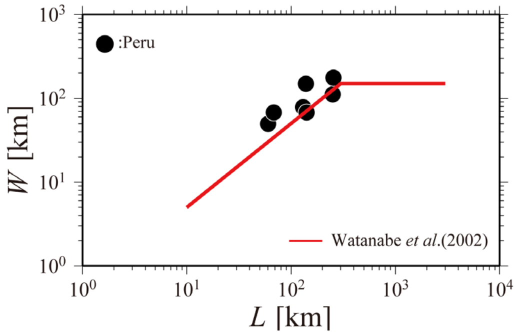

Fig.20 – *W-L* relations of earthquakes in Peru

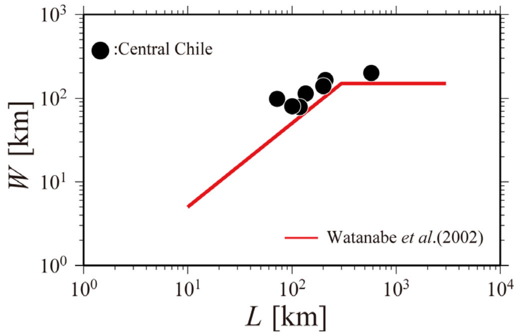

Fig.21 – *W-L* relations of earthquakes in Central Chile

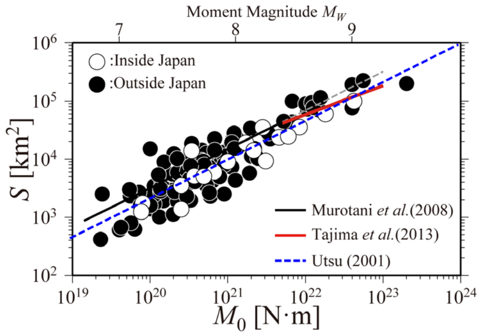

Fig.22 – *S-M*$_0$ relations of all earthquakes compiled

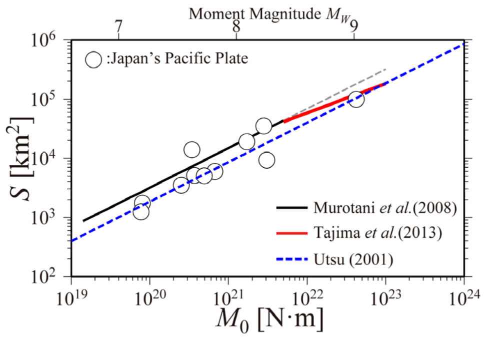

Fig.23 – *S-M*$_0$ relations of earthquakes in Japan's Pacific Plate

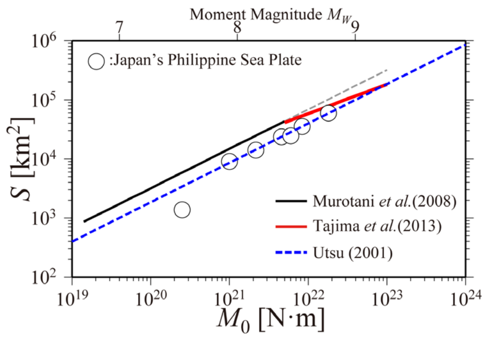

Fig.24 – *S-M*$_0$ relations of earthquakes in Japan's Philippine Sea Plate

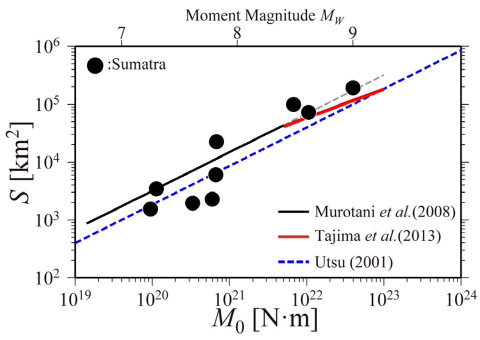

Fig.25 – *S-M*$_0$ relations of earthquakes in Sumatra

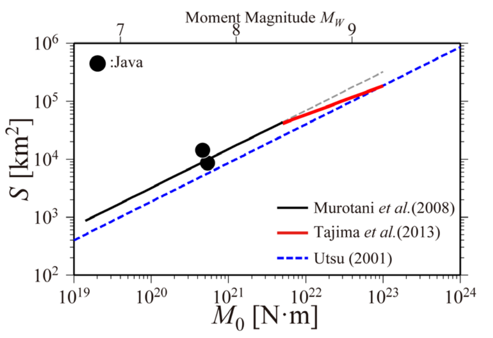

Fig.26 – *S-M*$_0$ relations of earthquakes in Java

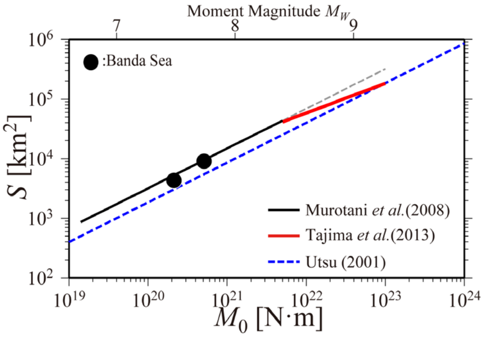

Fig.27 – S-M_0 relations of earthquakes in Banda Sea

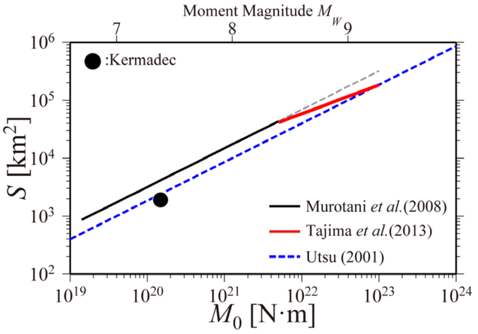

Fig.28 – S-M_0 relations of earthquake in Kermadec

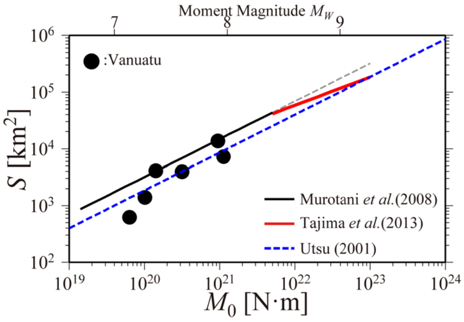

Fig.29 – S-M_0 relations of earthquakes in Vanuatu

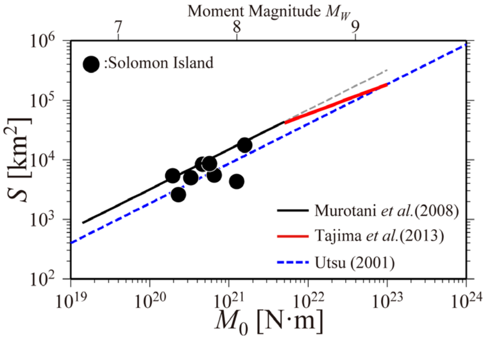

Fig.30 – S-M_0 relations of earthquakes in Solomon Island

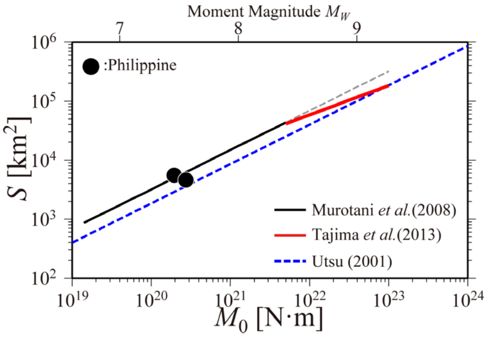

Fig.31 – S-M_0 relations of earthquakes in Philippine

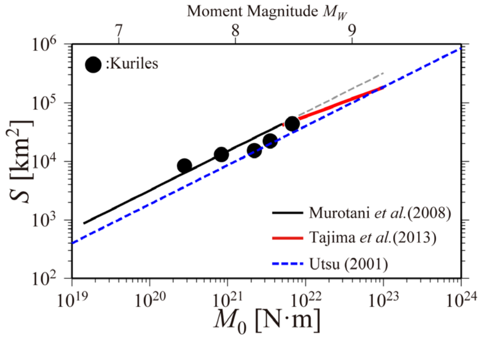

Fig.32 – S-M_0 relations of earthquakes in Kuriles

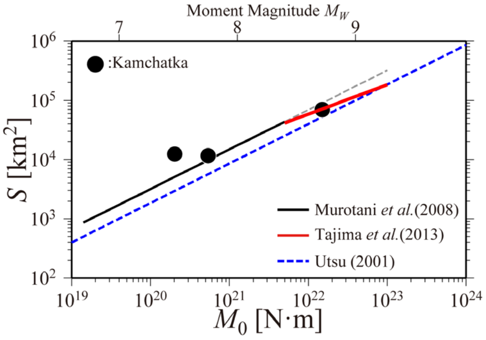

Fig.33 – S-M_0 relations of earthquakes in Kamchatka

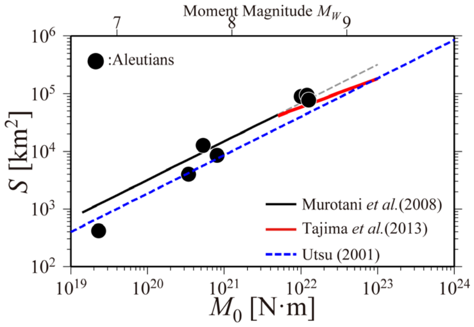

Fig.34 – S-M_0 relations of earthquakes in Aleutians

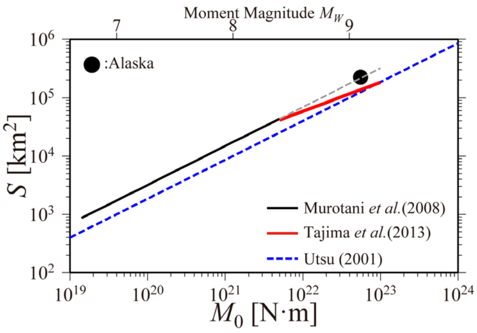

Fig.35 – S-M_0 relations of earthquake in Alaska

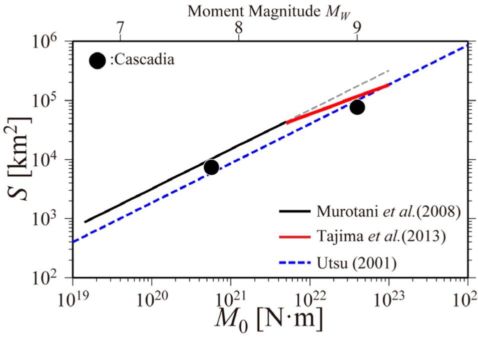

Fig.36 – S-M_0 relations of earthquakes in Cascadia

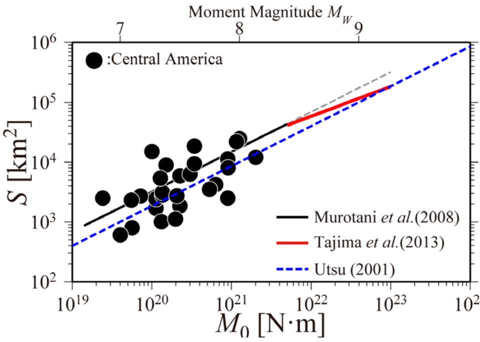

Fig.37 – S-M_0 relations of earthquakes in Central America

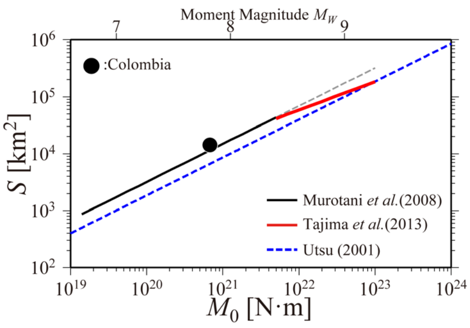

Fig.38– S-M_0 relations of earthquake in Colombia

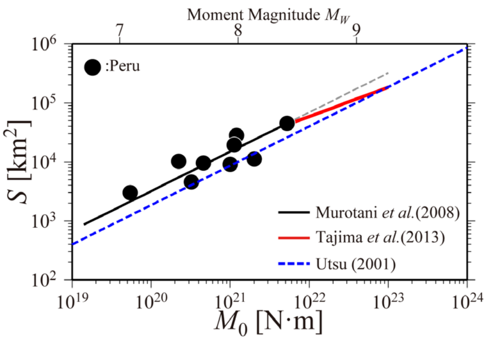

Fig.39 – S-M_0 relations of earthquakes in Peru

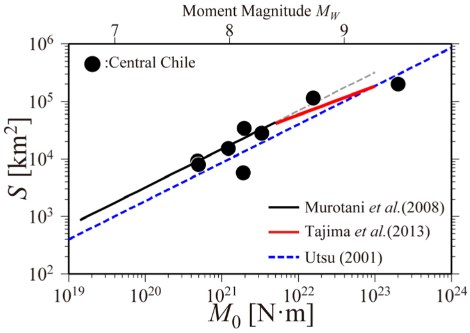

Fig.40– S-M_0 relations of earthquakes in Central Chile

Table 1 – Ratios of compiled fault areas to those by Tajima *et al.* (2013)[4] (geometric means)

Inside Japan	Pacific Plate		Philippine Sea Plate		Total
	0.84		0.31		0.39
Outside Japan	Sumatra	Kuriles	Kamchatka	Aleutians	Total
	1.62	0.92	0.98	1.40	1.23
	Alaska	Cascadia	Peru	Central Chile	
	1.65	0.66	1.07	1.10	

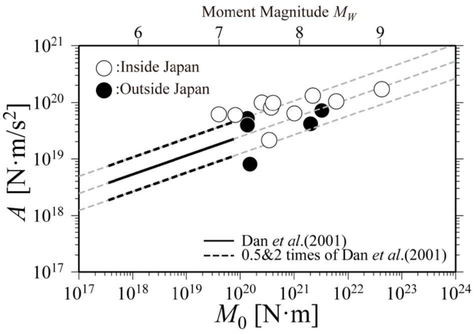

Fig.41 – A-M_0 relations of all earthquakes compiled

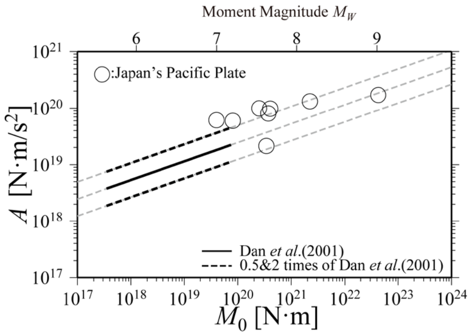

Fig.42– A-M_0 relations of earthquakes in Japan's Pacific Plate

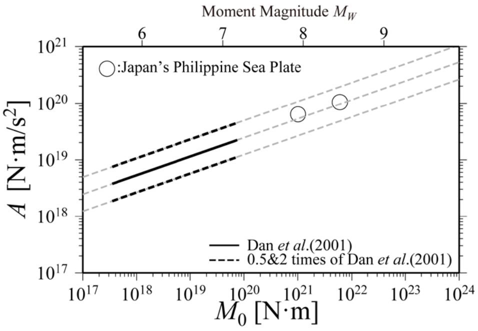

Fig.43 – A-M_0 relations of earthquakes in Japan's Philippine Sea Plate

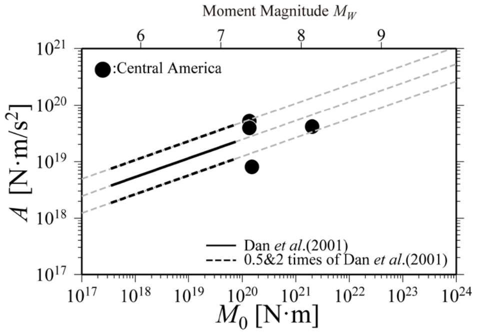

Fig.44 – A-M_0 relations of earthquakes in Central America

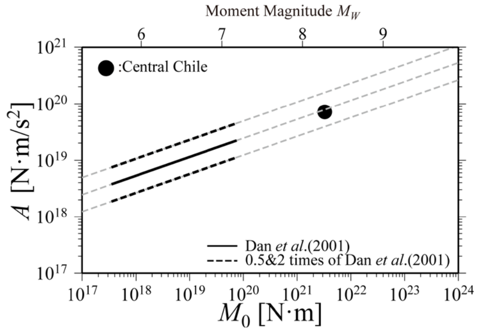

Fig.45 – A-M_0 relations of earthquake in Central Chile

Table 2 – Ratios of compiled short-period levels to those by Dan *et al.* (2001)[5] (geometric means)

Inside Japan	Pacific Plate	Philippine Sea Plate	Total
	1.87	1.15	1.69
Outside Japan	Central America	Central Chile	Total
	0.84	0.92	0.86

4. Conclusions

We collected 184 literatures on the subduction inter-plate mega-earthquakes to obtain their fault length (L), fault width (W), fault area (S), seismic moment (M_0), and short-period level (A), and compared them with the past scaling laws, especially focusing on the regional differences and the second stage of the scaling relations. We conclude our results as follows.

1) The average W-L relations were consistent with the empirical relation of Watanabe *et al.* (2002)[3]. The fault width of the second stage depends on the regions, and it is larger than 150km in Sumatra, Alaska and Central Chile, and smaller in Cascadia and Aleutians.

2) The average S-M_0 relations were consistent with Tajima *et al.* (2013)[4], which is applied to the second stage relations. The fault areas of Sumatra, Alaska, and Aleutians are larger than those by the empirical relation, and those of Philippine Sea Plate in Japan and Cascadia are smaller.

3) The A-M_0 relations compiled were scattered between the range of 0.5 to 2.0 times of Dan *et al.* (2001)[5]. The short-period levels of the earthquakes on the Pacific Plate in Japan were larger than those in the other regions, i.e. Philippine Sea Plate in Japan, Central America, and Central Chile.

4) The collected data indicate that the second stage as the scaling relations should be applied to the subduction inter-plate mega-earthquakes, analogiously to crustal earthquakes.

5. Acknowledgements

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