2011 東北日本Ｍ９地震に対する１数学者の理解と見解

An Understanding and a View of a Mathematician for the 2011 East-North Japan Ｍ９ Earthquake

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Abstract

(This paper was written so that mathematicians can read easily)

On March 11 in 2011, Japan was attacked by a huge earthquake of Magnitude 9.0 (⇒ M9), probably the largest earthquake recorded so far in Japan. It should be noted that most Japanese seismologists (地震学者) believed that such a big earthquake would not occur in Japan, because a world-famous Japanese seismologist had said so. After the M9 Earthquake, many Japanese seismologists studied the mechanism of the M9 Earthquake, but their theories seem to be not reasonable for the author. In this paper, the author proposes a simple and clear mechanism which can explain various critical data observed by many Japanese institutes and so many seismologists; such as "200km×500km" epicenter distribution map (震央分布図), the subsidence (沈降) of the East-North district of Japan, and the eastward movement (東方移動) of the East-North crust (地殻) of Japan.

1 Introduction

In this paper, we abbreviate the word earthquake to EQ.

Part-I **Author's understanding of the occurrence of big EQs**

In the first part of this paper, the author describes his understanding of the occurrence of big EQs so that mathematicians can understand big EQs. Hence, the seismologists may skip **Part-I**.

I.1 Modern seismology (地震学) is based on the **plate-tectonics** (プレートテクトニクス) which says that the surface of the earth (neglect sea water) is covered by the **continental(大陸) plates** and the **ocean(海洋) plates**. The former are thick, almost non-moving, and composed of rather light and soft rocks such as granite (花崗岩). The latter are of widths 100km or less and moving with speeds of several cm/year, and composed of basalt (玄武岩) mainly; basalt is an igneous rock (火成岩) and hard and heavy. The same type plates may collide each other, and an ocean plate may **subduct (沈み込む)** a continental plate, because the ocean plate is heavier than the continental plate.

I.2 In this paper, the author is interested in the **subduction (沈み込み)** of the **pacific plate** under the **North-American plate** (**N.A. plate** in short) which covers the north half of Japan, and he studies the 2011 Japan M9 Earthquake which occurred during this subduction. The subduction was observed clearly by Hasegawa et al., and their results were published in [5]. The purpose of Hasegawa et al. was to show the EQs aligned at about 1/3 depth from the upper surface of the plate, but the author is interested

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in the bending of the Pacific plate at the depth 10km∼80km. In Section 2, we show a figure of Pacific plate observed by Hasegawa et al., and explain it in details.

I.3 The author was interested in the mechanism of the 2011 Japan M9 Earthquake by an introductory lecture on the EQ in the Web [14]. The lecture said that *Before the M9 Earthquake, Japanese seismologists had a large mystery that, summing the energies of all the known EQs occurred in recent hundreds years at East-North of Japan, we got only about 30% of the energy that the Pacific plate is giving to North-East of Japan. Where the rest 70% disappeared? After March 11 in 2011, people knew that the 70% was the energy of the M9 Earthquake.* Furthermore, the lecture pointed out that *Before the M9 Earthquake, most Japanese seismologists believed that such a huge EQ as the M9 would not occur in Japan*, because a world-famous Japanese seismologist said so based on his paper [13]. This lecture inspired the author very much to find a reasonable mechanism of the 2011 Japan M9 Earthquake. As a physicist mathematician, the author thought that it would be **not difficult** to find the mechanism, because the M9 Earthquake is **so peculiar** from the ordinary EQs.

I.4 A gross mechanism of EQs occurring in the subduction of an ocean plate under a continental plate is as follows (resulting EQs are called *plate-boundary type*). First, the rocks must be **elastic (弾性的)** and there must be a thin **fault**(断層) between the continental and the ocean plates; its width was measured near the Japan Trench to be $\leq$ 5m [8]. The fault is filled with "fault matters" which are water and very fine cray (粘土). During the subduction, if both continental and ocean plates slide each other with no friction then there occurs no EQ between them. However, there occur frictions by many reasons. A place of plate-boundary causing a friction is called to be **locked** (固着している), may strongly or weakly depending on the situation. We mentioned that the ocean plate is composed of hard and heavy rocks and moving to some direction, while the continental plate is composed of light and soft rocks. So, if both plates are locked, the ocean plate pushes the continental plate to the direction of subducion, storing some amount of **strain** (歪み; ひずみ) to the continental plate. When the amount of the stored strain reaches a limit, the strained part of the continental plate moves suddenly to the reverse direction of the subducion, along the plate-boundary. This is nothing but an EQ of the plate-boundary type. The above sudden movement of the (continental) plate is called the **slip** (滑り); we express the average value of slip by θ. Then, the energy of the EQ is expressed as $E_{\rm EQ} = \mu\theta S$, where μ is the rigidity (剛性率) of rocks of continental plate and S is the area of the fault surface which slips. The θ is usually about 10m or so.

I.5 A very famous image of plate-locking is the **asperity** (アスペリティ) proposed by Thone Lay and Hiroo Kanamori [7] in 1981. The asperity is the 凸凹 on the earth surface, and was said to be the origin of 2011 Japan M9 EQ (see Section 3). However, the asperity is a very **obscure** concept and it seems too weak for causing the M9 EQ. The readers will see how the asperity is used for explaining the 2011 Japan M9 EQ in Section 3. We do not use the asperity in this paper. Instead, we use a very strong force caused by bending of the Pacific plate (to be called **bigBEND**, see Section 5).

I.6 The following surprising phenomena occurred at Japan 2011 M9 Earthquake. **i**) The **rupture zone** (地震の破壊領域) is a clear rectangle of about 200km width and 500km length, and tilted along the East Coast of East-North Japan. **ii**) There occurred large **subsidence** (土地の沈降) at East-North district of Japan; for example, 75cm, 107cm, 30cm, 31cm at Ohfunato(大船渡), Ojika Peninsula (牡鹿半島), Sohma(相馬), Hitachi(日立), respectively. **iii**) There occurred large eastward **crust movement (地殻移動)** at East-North district of Japan, for example, 5.4m, 4.24m, 2.78m, 1.2m at Ohfunato, Ojika Peninsula, Sohma, Hitachi, respectively. **iv**) Very tall "Tsunami"(津波) attacked the East coast of East-North Japan. All the above phenomena must be explained reasonably by the **proposed mechanism**.

I.7 Considering **ii**) and **iii**) in **I.6**, Geo-spatial Information Authority (GIA in short) (国土地理院) of Japan proposed a recurrence model of the movement of E-N.Crust of Japan (E-N.C in short), as follows: Step-1) Pacific plate pushes E-N.C to the west and upward. Step-2) A huge EQ like the M9 Earthquake causes a large subsidence and an eastward movement of the E-N.C. Repeat (Step-1 ⇒ Step-2).
The author saw this recurrence model as an animation video at the homepage of GIA. The GIA, however, mentioned nothing on how the huge EQ like the M9 occurs.

Part-II **Author's view for the 2011 East-North Japan M9 Earthquake**

II.1 It is well known that the Pacific plate has 凸凹 s (= typical asperities) on its surface. We will explain how the 凸凹 s had been constructed. This point is clarified in Section 4.

II.2 Fig. 1 in Sec. 2 shows a large bending of the Pacific plate. We will see that this bending leads to an effective mechanism of the 2011 M9 EQ. This point is explained in Section 5.

II.3 The rupture zone of the 2011 Japan M9 EQ will turn out to be a clear rectangle being tilted in parallel to the East-North coast of Japan. This point is clarified in Section 6.

II.4 We explain how to estimate the amount of slip at 2011 Japan M9 EQ concretely. This makes the readers understand the M9 EQ well. Actual explanation is done in Section 7.

2 A figure of Pacific Plate subducting the East-North of Japan

The author wanted to know how the Pacific plate subducts the N.A. plate; in particular, how the Pacific plate bends during the subduction. We found such a figure at 16 page of book [1]. The figure was given in a paper by Hasegawa et al. [5], but the author could not gain access to this paper. Since the figure is now well known, we show the figure by copying it from the book.

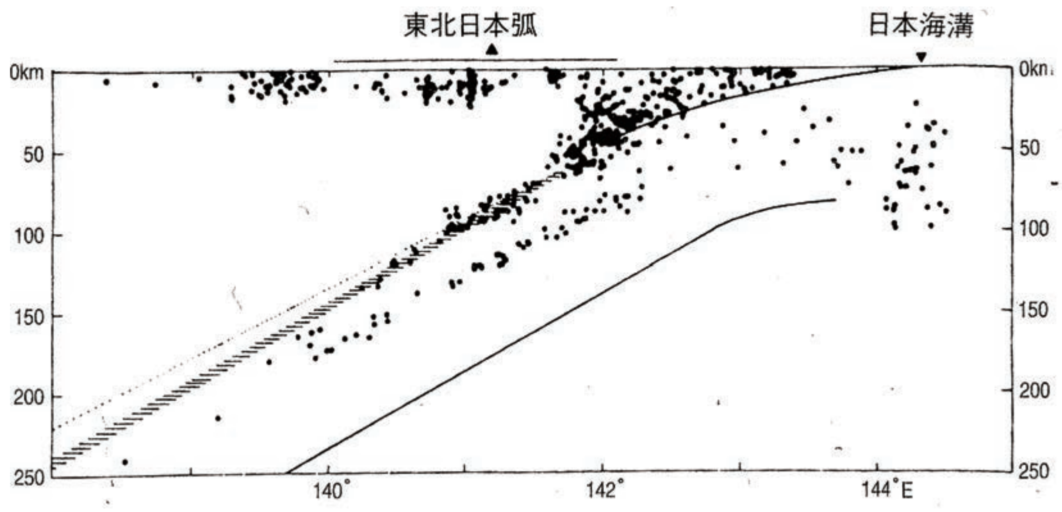

Figure 1 by Hasegawa et al., 1978. Each dot shows an EQ and two curved lines show the Pacific plate. (東北日本孤 and 日本海溝 mean the East-North district and the Japan Trench. respectively.)

Figure 1 shows that the left-half part of the Pacific plate is quite stable. The movement of the subducting plate is very difficult to analyze, because many forces are acting on the plate. Such analyses were done actively in "Earth and planetary physics" (地球惑星物理学); we do not enter into details but introduce a theory of "isostacy" (アイソスタシー). The theory says that there is an equilibrium (均衡) on the pressure between the mantle (マントル) and the crust, called the crust equilibrium.

3 Overview of Wikipedia on 2011 Mag.9 Earthquake in Japan

(The Wikipedia was written wholly in Japanese, so the author translated it into English.)
The Wikipedia is titled "The Mechanism of East-North district off-Pacific Earthquake and Tsunami", and composed of 27 pages, including 8 pages for comments and references. This Wikipedia is the recent most comprehensive survey of 2011 M9 Earthquake in Japan, hence **we must refer to it absolutely**. We, however, do not discuss on the **Tsunami** in this paper. (underlines are due to the author.)

Before going into details, we list 3 Key-points of the Wikipedia.

KeyPoint-1 : 2011 M9 EQ starts at about 25km underground ⇒ a key-point of our mechanism.

KeyPoint-2 : Speed of the 1st Rupture of 2011 M9 EQ ≈ 1.5km/sec ⇒ may cause large slips?!

KeyPoint-3 : Very large slips occurred near the Japan Trench ⇒ we explain a reason physically.

In its summary, the Wikipedia says that, *In Proceedings of "Japan Coordinating Committee for Earthquake Prediction (日本地震予知連絡協議会) (2007)" [4], it was said that, owing to the asperity model, we were now able to predict where and of what strength each EQ would occur in future.* Following this statement, the Wikipedia says that *However, the M9 Earthquake which nobody had imagined made the 2011 Autumn Conference of Japan Society of Earthquake full of regrets.*

Wk1(page 2∼) Wikipedia first surveys **the plate activity at the East-North district of Japan**. The survey starts at 20 million years ago, and explains how Japan had moved to the current place about 15 million years ago. About 3 million years ago, the tectonics on Japan had changed largely: previous tensile force (引っ張り力) in the East-West direction had changed to compressible force (圧縮力). By this, the previous subsidence (土地の沈降) of the crust changed to the uplift (土地の隆起); Wikipedia is sensitive to the subsidence and uplift of the crust, because so are many earth scientists.

As for EQs in recent several hundred years, Wikipedia explains their occurrence by the asperity model. For example, at off-Miyagi Prefecture, EQs of Mag. 7∼8 occurred each 30∼40 years since 1973. Furthermore, the existence of places became clear by the analysis of earthquake waves, where the values of slips are big. Seismologists considered such phenomena to be due to asperities. They considered that, if several asperities are destructed together then we will have much bigger EQs. On the other hand, by investigating evidences of "big Tsunamis", it became clear gradually that huge EQs which were never due to asperities had occurred in the span of (several∼10)$\times 10^2$years.

Wk2(page 7∼) Wikipedia surveys **forshocks(前震) of the M9 EQ** briefly. It first introduces a relation $\log(N) = a - b\log(M)$, where $N =$number(EQ), $M =$bigness(EQ), and a, b are constants; $b \approx 1$ usually, but $b \approx 0.47$ on March 9 to 11, showing the occurrence of many forshocks. Wikipedia also introduces a noticeable theory which may cause "super-big EQ". *After M7.3 forshock on March 9, the EQ-occurrence area expanded to* $50 \times 50\,\mathrm{km}^2$*, located at East-North of epicenter of the M9 EQ. Due to such aseismic* (非地震性の) *slip and slips due to a number of EQs, strong strain is stored continuously into a very strong asperity in the area of epicenter, then surrouding asperities are involved together, and a super-big EQ occurrs.* (This opinion was proposed in Journal of Geological Society of Japan (2017)). We are sure that the theory proposer tried to devise as strong mechanism as possible to cause the 2011 M9 EQ. Still, he hesitated to call his mechanism as the mechanism of 2011 M9 EQ.

Wk3(page 9∼) Wikipedia surveys **the mechanism of main EQ**, and says that the features of main EQ are **1)** as an EQ of Mag.9, the slip amount (滑り量) is large, but the slip area (滑り域) is narrow (South-North ≈ 400 ∼500km, East-West ≈ 150∼200km), and **2)** regions emitting long-period waves and short-period waves are different. In addition, we had many waves of extreme short (period<0.5 sec.);

conversely, we had few waves of long period s.t. (2 or 3)∼(20 or 30)sec.

Wikipedia divides the **rupture process** (破壊過程) into three processes: first one, second one, and third one, where they continued about 40 sec, 60 sec, and 50 sec, respectively.

The first rupture of period 40sec started the epicenter of M9 EQ (⇒ KeyPoint-1) and expanded to every direction, in particular to the West diretion (= to deeper place of the plate boundary). The rapture speed ≈ 1.5km/sec (⇒ KeyPoint-2), and the rapture scale is much smaller compared with the second rapture. However, the amount of slip was analyzed to be **15m**, and considerably large.

The second rupture of period 60sec is **extremely big** and occurred at relatively narrow area. About 60% of the total energy was emitted at a narrow area **120km×40km**. In addition, the second rupture caused very big **Tsunami** (*we do not consider* **Tsumani** *in this paper*). **A big surprize** is that very large slips more than **30m** (may be **85m** at maximum) were measured. Wikipedia says that big slips have occurred mostly **near the axis of Japan Trench** (⇒ KeyPoint-3).

As for the large slips mentioned aove, Wikipedia describes **the following four models**.

Model-1 *At a place where a big slip has occurred, there is an asperity of extremely strong coupling, and when the asperity will be destroyed many hundred years later, the asperity involves many surrounding ones and causes an extremely big earthquake.* (**Question**: *How is the target asperity formed?*)

Model-2 *Assume that the East-North off-Pachific region is not an asperity usually but small and very strong asperities are distributed. When some conditions are satisfied then all the strong asperites are desproyed together.* (**Problems**: *many assumptions unnatural/uneasy to happen.*)

Model-3 *At the 2011 East-North M9 EQ, the water between mutually sliding plates was heated by the friction, which increases the inter-plate pressure and causes a very big slips.* (Is big-slip Main?)

Model-4 *At the 2011 East-North M9 EQ, the sliding surface of upper plate (= continental plate) is soft, hence the rupture proceeded to the shallow Japan Trench (the phenomenon called "dynamic over-shoooting" had occurred).* (**Noticeable** for Big-slip, but **Never enough** for Mag. 9.)

In the third rupture of period 50sec, the EQ proceeded to the South area of the epicenter, that is off-Fukushima and off-Ibaraki Prefectures. Though the rupture scale was smaller than the second one, it provided strong seismic shaking (地震動) to Fukusima-Prefecture ∼ Kanto-region. Furthermore, it is noticeable that Wikipedia points out us that the occurrence area of strong seismic shaking is located at deep underground and arround the boundary between the crust and the mantle.

Author's comment to "big-slip surprize" mentioed above. Considering how the continental plate is compressed by the ocean plate at the subduction, **the big slips are never surprize**. We first note that the big slips occur only in shallow area -10km ≤ depth ≤ 0km; cf. Figure 1. *Starting at the Japan Trench, let us trace the subduction of the Pacific plate. First, the N.A. plate is pushed to the west very slowly. Since the N.A. Plate is very thin there, it will be compressed and uplifted considerably. As a result, a thin part of the N.A. plate will be shrinked considerably. At the ruptures, an opposite phenomenon will occur very rapidly (⇐ rapture speed = 1.5km/sec). Because of the law of momentum conservation, the N.A. plate will be stretched more and more as it becomes thin and shin. Furthermore, there is a possibility that the devices for the slip measurement having been set on the sea bottom were washed away by the strong Tsunami caused by the 2011 M9 EQ.*

Wk4··(page 13∼) We omit survey on the Mechanism of Tsunami and big changes of the earth-crust.

Author's summary of Wikipedia from the viewpoint of Mechanism of 2011 M9 EQ Japan. The author must say that the Wikipedia describes quite many phenomena of the 2011 Japan M9 EQ but no **clear mechanism** of it. The Wikipedia may mean that the above Model-1∼Model-4 are mechanisms, but they are not mechanisms. In fact, Model-1 and Model-2 require very unrealistic conditions without showing any fact, and Model-3 and Model-4 are not related directly with Mag.9 EQ but related with only the big slips; the big-slip is not a sufficient condition of the big EQs.

The Wikipedia says that most large EQs of Mag. 7 or less are treated by the asperity model; the seismologists are familiar with the asperity. However, the 2011 Japan M9 EQ requires 1000 times bigger energy than the Mag. 7 EQs. The author thinks that we had better forget the asperity and **search for a completely new mechanism** for the 2011 Japan M9 EQ.

4 What happens on the surface of Pacific plate at Japan Trench?

Let us see Figure 1 given in Sec. 2 carefully. Just below the [日本海溝] at the ritgt-top corner, we can see about 30 dots in 20km ∼ 100km depth. These dots make us think that something happened in this area. On the other hand, we notice that the Pacific plate bends a little bit just at the [日本海溝]. We expect naturally that this small bending will create 凸凹 s on the surface of Pacific plate, because the 30 dots suggest us that the "reverse fault (逆断層)" situation has occurred just below the [日本海溝]. (This situation should be proved mathematically from Euler's equations.)

If so then we see the horst(地塁) and the lift-valley(地溝) on the surface of the Pacific plate at the [日本海溝], where the horst and the lift-valley are nothing but 凸 and 凹, respectively. The reader can see many horsts and lift-valleys in a figure presnted in the paper [8] published by Weiren lin et al.

5 We show a reasonable Mechanism for 2011 N-E Japan M9 EQ

As we have mentioned at **I.3** in the **Introducion**, the total energy of the 2011 Japan M9 Earthquake is related closely with the subduction energy of the Pacific plate under the N.A. plate. Hence, we consider the subduction of the Pacific plate from various viewpoints.

Following Web-lectures on the "Physics of Earth and Planetary Interiors (地球惑星内部物理学)" [15], we understand that the movement of the ocean plate subducting the continental plate is determined mostly by two forces. One is a downward **pull force (引っ張り力)** due to the subduction of ocean plate. The other is a **resistance force (抵抗力)** due to the plate-bending. Compared with these forces, other forces are weaker by 1/10 or less. Hence, the subduction speed is determined by the balance of these two forces. This tells us that the plate-bending generates a quite big force, although we cannot feel it.

For us who are amateurs in geology (地質学), it is very astonishing that the thick and hard ocean plate seems to be bent easily at the subduction. However, the Earth and planetary physics tells us that the ocean plate can be bent naturally so long as very strong forces are given.

Let us consider the details of the Pacific plate, by looking at the Figure 1 by Hasegawa et al. [5]. The most characteristic point of the Pacific plate in Figure 1 is the big bending (we call it **bigBEND**) at early stage of the subduction. Note that the bigBEND is never an extra part of the Pacific plate but the name of **the most curved part** of the Pacific plate. Since the Pacific plate is of **positive curvature upwardly** at the bigBEND, it must give mostly **upward force** to the N.A. plate there.

Here, we must notify the readers two important facts. **Fact1**: The Pacific plate being started at the Japan Trench is ∼**500km wide in the N-S direction**. **Fact2**: On the other hand, the bigBEND is ∼**180km wide in the W-E direction**. We will see soon that these facts play an important role.

We notify the readers two observations. **Observation1**: The epicenter of the 2011 Japan M9 EQ is about 25km deep from the sea surface. This is because that the bigBEND which causes the M9 EQ exists at 25km depth from the sea surface. **Observation2**: We will see in Section 7 that the epicenter distribution map is a clear rectangle. The map will be derived by the bigBEND model below.

Finally, we comment on the width d of the fault between the Pacific and N.A. plates. The latest measurement of d was done about one year later than the 2011 Japan M9 EQ, and found to be $\boxed{d < 5m}$ [8]. Since the measurement was done at the 8000m depth from the sea surface, where the gravitation (重力) is weak. What we must consider is the gravitation at $8 \sim 50$km depth under the sea floor.

Summarizing the above discussions, we show a detailed mechanism of the 2011 Japan M9 EQ by **assuming only the Figure 1**, in order not to make the situation complicated[1)]

Now, let POINT be a point fixed on the Pacific plate, and start at the Japan Trench. Moving together with POINT, we watch what happens on the N.A. plate at the POINT by the bigBEND. Note that the POINT moves westward with a speed about 8cm/year.

Main Mechanism that the Pacific plate gives FORCE to the N.A.plate

(Θ be the angle (measured from deep to shallow) of)
(tangent plane at POINT on the surface of P. plate)

(The bigBEND pushes N.A.plate **gently** & **surely**)
(West-East-length of the bigBEND is about **180km**)

Befor BEND: 凸凹 at POINT moves Westward along the bottom of the N.A.plate &
($\Theta \lesssim 8°$): the gauge (破砕物質) at the bottom of the N.A.p is pushed Westward.
Volume is unreduced ⇒ East-North Japan is uplifted by some amount.

atThe BEND: | All jobs in this step are done **parallelly** over all the bigBEND area |
($\Theta \gtrsim 8°$): ⇒ (As a whole, very BIG force is gererated at the bigBEND area)
($\Theta \lesssim 30°$): **FORCE** by bigBEND = **vertical** and **parallel** to **P.plate surface**.
vertical FORCE ⇒ pushes the bottom of N.A.plate Upward,
| see Fig.1 | ⇔ many EQs between bigBEND and sea surface.
parallel FORCE ⇒ pushes the bottom-layer of N.A.p along fault,
| see Fig.1 | ⇔ many small EQs in the bottom-layer of N.A.p.
⇒ Bottom-layer of the N.A.plate stores **strain** continuously.
⇒ | **Strain area** ≈ 180km (W-E range) × 500km (N-S range) |.

After BEND: We can see that the subduction of P-palte is fully in a stationay state.
($\Theta \gtrsim 30°$): The form of subducting P-plate was damaged little by [atThe BEND].

| Note: The above 3 Steps are performed **parallelly** over all the plete boundary |

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at ONCE: | when the **STRAIN** reaches a **LIMIT** ⇒ **VANISH** |
(**STRAIN** had kept the Uplift and Westward crust Movement)
event1: The bottom-layer of N.A. p moves Eastword at once (2011 M9 EQ).
(Very wide area (West-East: 180km, North-South: 500km) slips.)
event2: ⇒ The uplifted East-North district of Japan **subsides (沈降する)**.
event3: ⇒ The East-North district had moved west **moves to Eastward**.

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1) Readers may think that not only the bigBEND but also other parts of Pacific plate may increase the strain. We see, however, no dot along the plate surface below 150km depth. This is probably due to the isostacy.

6 What occurs on the Pacific plate at the East of Japan Trench?

Many readers will ask that "what does this title mean?". The best answer to this question is to show the epicenter distribution map which contains the Japan Trench (JT). Such a map had been obtained by the Japan Meteorological Agency (気象庁) (abbreviated to JMA). Note that JMA observes not only the weather but also the EQs, and JMA is the NO. 1 institute for both phenomena in Japan.

The epicenter distribution map of The 2011 Japan M9 EQ
(We ask the reader to download a paper from the WWW site of JMA [6])
The paper consists of many pages and the map is shown in the first page as a tilted rectangle (長方形). The rectangle contains a thin winding line which runs South to North and divides the rectangle into 2 : 1 in the area. The **tilted rectangle** is the map. The winding line is the Japan Trench.

Figure 2: The epicenter distribution map (made by JMA)

We note that the POINT being defined in Section 5 has started from the JT and moved westward. However, looking at the epicenter distribution map, we see that about one-third of the map area is occupied by the east of JT. Therefore, in order to complete the mechanism given at the last part of Section 5, we must include the effect of force which originats at the east of JT, to the mechanism.

The above Figure 2 shows 12 very big EQs, many medium-sized EQs, and countless small EQs. Among 12 big EQs, 3 EQs occurred on March 11 and at the West of JT, 1 EQ on March 11 and at the East of JT. Other 8 EQs occurred on March 12 or later. Among these, we consider the fourth EQ that occurred on March 11 and at the Eest of JT. This EQ may be related closely with 2011 Japan M9 EQ. Hence, we must clarify the mechanism of occurrence of such EQs as the above fourth EQ[2)].

In order to accomplish the above clarification, we need the geographical(地理的) data on the JT, the Pacific ocean, and the Pacific plate at the East of JT. **Data1)** The JT is of depth (7000 ∼ 8000)m, with the deepest 8058m. The length is about 800km. **Data2)** The average depth of the world sea is about 3,700m (⇒ most part of the world sea is not deep). **Data3)** The third data is "Global Sea Floor Topography(地形)" which has been measured by Smith and Sandwell [11]. We can see from this data that a very wide ocean plate is moving toward the Japan land from the east, and begins to subduct the N.A. plate at about 80km (= longitude 1°) east of the JT. The final one is **Data4)** The Japanese Wikipedia on "Records on Forshocks, Mainshock, and Aftershocks in North-East District OffPacific Earthquake" [3].

Now, we consider the fourth EQ mentioned above. According to **Data4**, the EQ is characterized as follows: [(DayTime: March11, 15:25), (epicenter: OffSanriku, (N37°.54, E144°.45)), (depth: 11km), (Mag: 7.5), (types: IntraOcean plate type, Normal-fault)]. Following **Data3**, the very wide ocean plate just begins to subduct at E144°. Hence, the forth EQ is regarded to be on the ocean plate.

The **Data3** gives us a very important imformation. Let us see the shape of very wide Pacific plate in [E140°, E145°]. The Pacific plate faces three different regions, North: Hokkaidoh and Chisima Islands, Middle: North-East Japan, and South: Izu Islands. Since these three regions are differently oriented, the wide Pacific plate must be separated into three parts and each subducts one of three regions. That is, the middle Pacific plate subducts the N.A. plate as one flat plate, causing a **bigBEND surface** in the North-South direction. This leads us to a tilted rectangular epicenter distribution map.

[2)] The plate earthquakes are classified as follows. **1)** IntraContinental crust type (内陸地殻内型), **2)** Plateboundary type (プレート境界型; see **I.4** in Sec. **1**), **3)** IntraOcean plate type (海洋プレート内型), **4)** IntraSlab type (スラブ内地震; the Slab is an Ocean plate having subducted through the Continental plate).

7 On the estimation of the value of Slip

In order to estimate the value of Slip, the starting parameter is "how many years the Strain has been stored?". We set, for example, $N := 1707$ [Houei EQ (宝永地震)] - 869 [Jougan EQ (貞観地震)] = 838. With 838 years, the Pacific plate subducts 838×8cm ≈ 67m. The total energy **M9EQ** being input by the Pacific plate is equal to the enegy of 67m subduction. Acording to the Main Mechanism, this total energy of the M9 EQ is divided into "**nonM9EQs**", $\mathbf{E}_\perp$ = "**Vertical component of M9EQ**", and $\mathbf{E}_\parallel$ = "**Parallel component of M9EQ**" $\Longrightarrow$ We have **M9EQ = nonM9EQs** + $\mathbf{E}_\perp + \mathbf{E}_\parallel$.

The reader may wonder that, although the amount of subduction length is only 67m, why the epicenter distribution area is so wide? The reason is that, in our Main Mechanism (see the 9th line from the top), the job of pushing the N.A. plate is executed **parallelly** over all the bigBEND area.

Remembering **I.3** in Sect. 1, we may set $\|$ **nonM9EQs** $\| = 0.3\times \|$ **M9EQ** $\|$.

The $\mathbf{E}_\perp$ causes the **uplift** and the **westward movement** of the crust of N.A. plate. (Our mechanism is nothing but that the Pacific plate pushes the continental plate upward against the gravitation force.) The $\mathbf{E}_\parallel$ increases the **westward strain** in the bottom-layer of the N.A. plate. As for $\mathbf{E}_\perp$ and $\mathbf{E}_\parallel$, the former will be computed numerically, but the latter needs trials-and-errors because the thickness of the bottom layer of the N.A. plate, to which the strain is stored, is unknown. Finally, we can determine $\mathbf{E}_\perp$ and $\mathbf{E}_\parallel$ if we determine the ratio of them. For example, if $\|\mathbf{E}_\perp\| = 3\times\|\mathbf{E}_\parallel\|$ then we can fix the ratio of two components to be $0.7 \times (3/4) : 0.7 \times (1/4)$. By this, we find that the $\mathbf{E}_\parallel$ occupies about (0.7/4) part of the **M9EQ**. Therefore, the amount of the slip will be $67 \times (0.7/4) \approx 12$m.

Author's career in seismology

March 2022: Started learning Euler's theory and understanding the occurrence of big earthquakes.
April 2023∼: Study of the role of fault by introducing semi-singular plane into Euler's system.[9]
April 2024∼: Study of 2011 Japan M9 EQ, from the viewpoint of physicists ⇒ current paper.

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