A Mystery in the Tohoku-Kitakanto Earthquake in Japan, 2011

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A hypothesis is proposed to understand an unusually large shift of the sea bottom (24 m) in the recent Tohoku-Kitakanto Earthquake, which means the suppression of the slip at the contact surface of the North American and the Pacific plates for about 300 years. The key point of the hypothesis is the effect of the global warming, which has melted the ice on the northern part of the North American plate (Greenland and Canada). It changed the gravity distribution of the plate, and the plate tilted so that the North American plate covering the northern part of Japan began to press the Pacific plate downwards. A simple experiment was made to observe this plate motion. Records of past earthquakes in the eastern Asia are compared to the climate change, where the sun-spot numbers are used as a measure of mean temperature.

Key words: Earthquake, Plate Motion, Shift of Sea Bottom, Buoyancy of Plate, Global Warming

1. Introduction

We were shocked by the earthquake and the tsunami which attacked the northern part of Japan in March 2011. Since then many of Japanese people seem to be conscious of what is happening in the earth. Recently the present author was asked by an editor of a journal, Physics Education in University (published by the Physical Society of Japan, in Japanese) to write an article for introductory explanations of earthquake and tsunami. It is already submitted and is going to appear (Takaki, 2012).

In this article the present author mentioned briefly on a mystery in that earthquake, which is concerned to an unusually large shift (about 24 m to the east) of a part of the sea bottom just above the center of earthquake and was reported by the Maritime Safety Agency (2011). If the shift is caused by the release of stress in a part of the North American plate pushed by the Pacific plate (moving westwards with speed of about 8 cm per year), this shift length would mean that the contact surface of both plates in this part did not slip for about 300 years! This period is much longer than the average interval of earthquakes in Japan, and there must be an unknown mechanism to suppress slipping. The present author has an idea on this mechanism of suppressing, but did not write on it in the article because it is not established yet. The idea is based on a hypothesis resented in the next section.

2. A Hypothesis: Effect of the Global Warming on the Slip of Contact Surface of Colliding Plates

Plates are floating on the mantle and receive buoyancy forces. For the North American plate the balance of the gravitational and the buoyancy forces is affected by the quantity of the ice on the Greenland and the Canadian islands near the North Pole. If the ice melts owing to the global warming, the North American plate will tilt so that its edge near the North Pole elevates and the opposite edge sinks.

As shown in Fig. 1 the North American plate extends a narrow tail to Japan covering its northern part. The eastern edge of the tail sinks owing to the global warming, so that it presses the western edge of the Pacific plate downwards. This effect should result in suppression of slip at the contact surface of both plates. This is the hypothesis by the present author.

Although the tilting of the North American plate would be very small, it will govern the condition of slipping to a considerable degree, because the maximum frictional force between solid objects is affected sensitively by the pressure between them. Therefore, the hypothesis given above is not without reasoning.

In the next section result of a simple experiment is shown to convince ourselves of the occurrence of tilting of the North American plate when the ice near the North Pole has melted.

3. Experiment of Tilting the North American Plate

Figure 2 shows a model of the North American plate made of a styrofoam plate (thickness 5 mm) covered with a thin plastic plate with drawings of coast lines. The weight of the model was 11 gram. In order to measure the degree of tilting of this model a vertical pole of thin wire was put at the point corresponding to Japan, and a small weight was hung from the top of the pole.

Figures 3(a), (b) and (c) show the model floating on the water without weight, with a light weight (13 gram) and a heavy weight (40 gram), respectively. The positions of the weights were approximately at the center of the ice-covered islands near the North Pole, i.e. the Greenland and Canadian islands (within the north latitude of 70 degree). The angles between the wire pole and the thread in (a), (b)

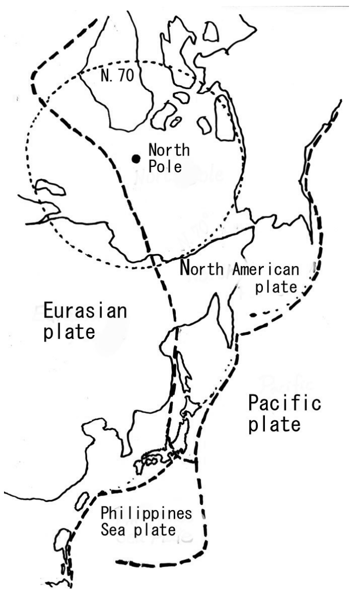

Fig. 1. The North American and the neighboring plates. The dotted circle is the north latitude of 70 degree.

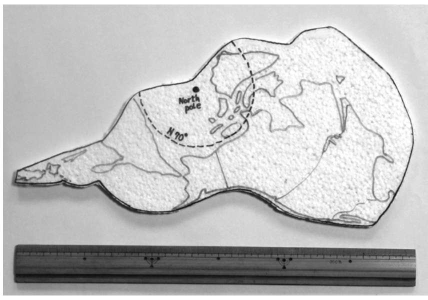

Fig. 2. Simple model of the North American plate. The spot near the upper edge is the North Pole, and the dashed circle is the north latitude of 70 degree.

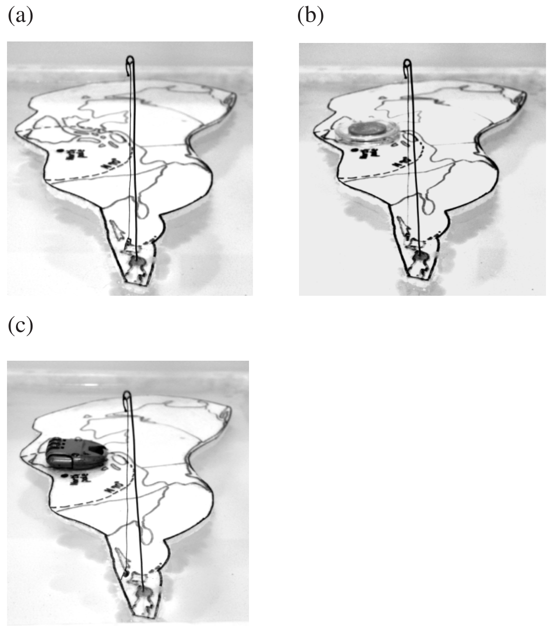

Fig. 3. The model of plate floating on the water with a pole for measuring the angle of tilting, (a) without weight, (b) with a light weight (13 gram) near the North Pole, (c) with a heavy weight (40 gram).

and (c) were about 1, 3, 5 degrees, respectively. We can see from this result that the melting of ice near the North Pole (corresponding to Fig. 3(a)) tends to tilt the North American plate near Japan so that its eastern edge sinks and presses down the Pacific plate. This effect should have suppressed the slip at the contact surface and allowed integration of stress in the North American plate.

Of course, what is happening in the plates is much more complicated than that shown in this experiment. For example, the North American plate touches also to the Eurasian plate and the Philippines plate, the North American plate has flexibility and will deform while tilting, and the plate is not flat but is a part of sphere, and so on. However, the result presented here will work as a trigger of more precise researches, such as a computer simulation of behavior of the North American plate with melting ice.

4. Comparison of the Earthquake Frequency and the Average Temperature

The average atmospheric temperature has been measured precisely only since about 100 years. On the other hand, in order to consider of the effect of the global warming we need information of the average temperature for a period including the age of global cooling, i.e. at least since 17th century. For that purpose the numbers of sunspots are reliable, because they are considered to have a positive correlation with the average temperature.

Figure 4 shows a comparison of the sunspot numbers since the year of 1600 (Hoyt and Schatten, 1997) and the years of recorded earthquakes with magnitude more than 7 (Homepage of GRW). Magnitudes (M) of earthquakes are indicated by the fonts of numbers; normal fonts for M 7.0–7.9, bold-type fonts for M 8.0–8.9 and large bold-type fonts for M 9.0–9.9. If the magnitude is expressed with interval in the reference, like 7.9–8.2 for example, the value of the lower limit (7.9) is used.

The data of GRW includes earthquakes in the whole world, but here those in the following three regions are picked up; (A) the northern part of Japan (Tohoku, Hokkaido) and the Okhotsk Sea and the Bering Sea areas (the area near to Alaska is not included) corresponding to the boundary of the North American and the Pacific plates, (B) the central part of Japan (Kanto, Chubu) corresponding to the boundary of the North American and the Philippines plates and (C) the southern part of Japan, Taiwan, the south coast of China and Philippines corresponding to boundary of the Eurasian and the Philippines plates (the area near Indonesia is not included). A few inner plate earthquakes are included in these regions.

The data of sunspot numbers show that we had the global warming since about 1720 with a short cool period of 1800–1830 (called Dalton minimum). Before that we had a long cool period of 1620–1720 (called Mounder minimum). On the other hand, there is a delay in the melting of ice after the warm period has begun. According to the data of change of glacier thickness since 1960 (Durgerov and Meier, 2005), the thickness decreased in the global warming with a rate

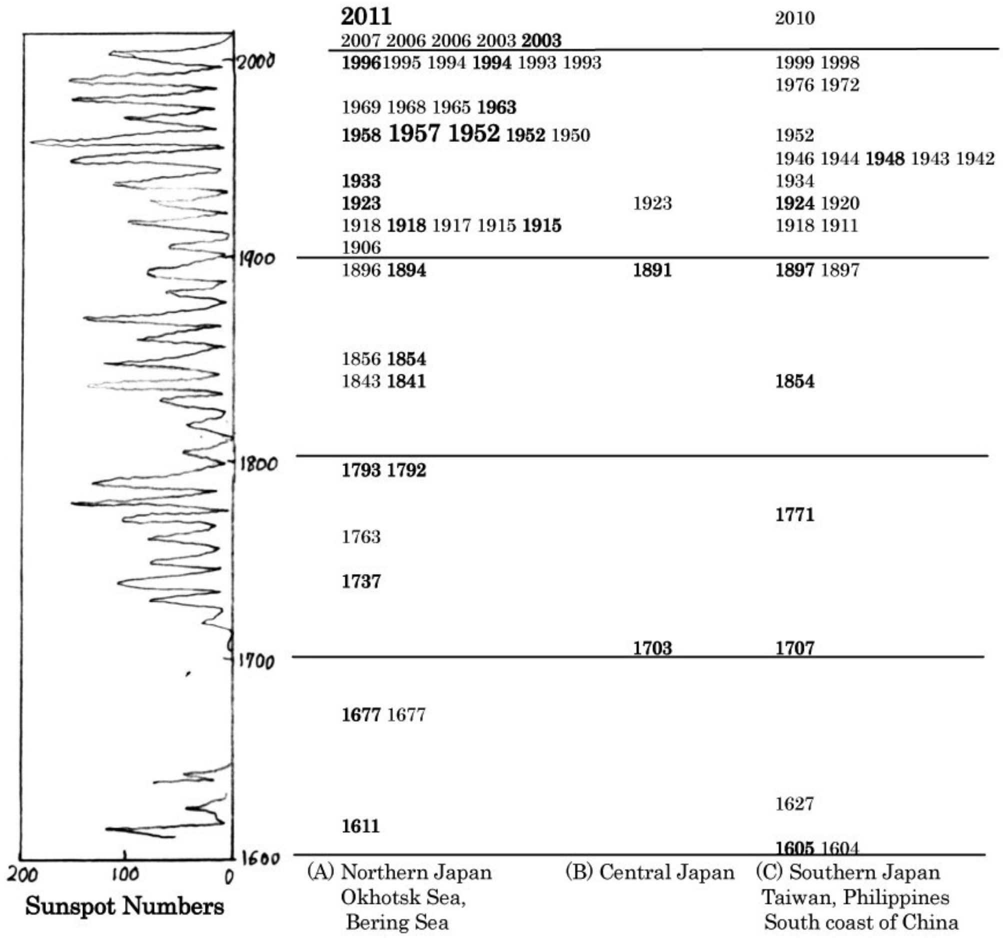

Fig. 4. Change of the sunspot numbers since 1600 (sketch by the present author from the Homepage of GRW) and the earthquakes in the eastern Asia. The years with normal fonts, bold face fonts and large bold face fonts indicate earthquakes with magnitudes 7.0–7.9, 8.0–8.9 and 9.0–9.9, respectively.

Table 1. List of the earthquakes around Japan in the regions (A), (B) and (C) before 1600 and the climate. These symbols for regions and the fonts of numbers indicate the same as in Fig. 4.

Climate	Years of Earthquakes	Regions
warm	**1000, 900, 500, 300, 0 BC**	(A)
(–0)	**1000**	(B)
	0 BC	(C)
cool	**4–5 c.**	(A)
(0–800)	762	(B)
	684, 8c.	(C)
warm	**869**	(A)
(800–1400)	878, 1293	(B)
	887, 1096, 1099, 13c., 1361	(C)
cool	**15c.**	(A)
(1400–1600)		(B)
	1498	(C)

of 30–60 cm/y. Therefore, we should see at least several tens of years until the global warming affects the gravity distribution of plates. With these factors in mind let us observe Fig. 4 and try to interpret these data.

First, a simple conclusion is derived that there are very few earthquakes in the region (B). This is surprising because we have not forgotten the Kanto earthquake in 1923 with M 7.9. The reason for this small frequency would be that the boundary of plates in this region is quite short compared to those in regions (A) and (C), and that the Philippines Sea plate is small in size. However, it will be dangerous to predict that we will not have big earthquake in this region for many years.

Secondly, we had frequent earthquakes in regions (A) and (C) after the end of 19th century. Before that we had big earthquakes about every 70 years. The increase in the region (A) can be explained in term of the tilting of the North American plate and suppression of the slip for a long period. It would explain why big earthquakes of M 9 happened three times. But the increase in (C) is puzzling although it is weaker in both frequency and magnitude. One possibility might be given by assuming that the Eurasian plate tilted also because of melting of ice in Russia, Scandinavia and Himalayas.

Thirdly, the occurrences of several strong earthquakes just after the gigantic ones (1952, 1957) in the region (A) would mean that the local slips of contact surfaces in these gigantic ones have produced new strong stresses at other points and triggered the following earthquakes. It is a similar mechanism as that of aftershocks associated with a big earthquake. Then, a possibility can not be denied that big earthquakes may come several years after the recent gigantic one in 2011.

Seismologists are predicting the next earthquake in the southern part in Japan (Tokai, Tonankai and Nankai areas) because there has been no big earthquake for many years. However, there would be also a possibility that the next is again at a point in the region (A).

Before the year of 1600 we have no precise data of the average temperature except for a rough estimation up to the 1st century AD based on those by a lot of researchers including that of Moberg, *et al.* (2005). Before the 1st century BC we had a warm period for about 8000 years after the last ice age. These estimations show that the climate before 1600 did not change drastically, and roughly speaking it was warm until 1st century BC, cool in 0–800, warm in 800–1400 and cool in 1400–1600. The records of earthquakes (Homepage of GRW) contains several big ones ($M > 7.0$) in Japan and some other countries (China, Indonesia, South America and Greece) between 10th century BC–16th century AD, but no record in Philippines, the Okhotsk sea and the Bering Sea areas. These data are listed in Table 1.

In the warm period in BC we had relatively many earthquakes (probably much more, if unfound ones are included). In the cool period in 0–800 we had few earthquakes. These facts match to what is claimed in this paper.

On the other hand, in the warm period in 800–1400 we had larger frequency in the central and the southern part of Japan than the northern part, which contradicts to what is claimed in this paper. However, there might have been many unrecorded earthquakes in the Okhotsk and the Bering Sea areas before 1400.

5. Concluding Remarks

It is proposed as a hypothesis in this forum paper that the global warming since the 18th century changed the gravity distribution of the North American plate and produced its tilting. It has been suppressing the slip at the contact surface with the Pacific plate and caused a strong earthquake with a long shift of the sea bottom. The frequencies of earthquakes in the past (up to 10th BC) seem to be interpreted based on this hypothesis.

This claim would be reasonable, but is not supported by evidences from observations or measurements. Hence, at present it remains to be a hypothesis. Strong support might be given by a computer simulation to follow the behavior of plates with melting ice owing to the climate change. The present author hopes that a new breakthrough will be made in future by considering such a hypothesis as is proposed in this paper, or another one which includes more precise behavior of plates based on various geological factors.

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Note added in proof. Recently, the term "asperity" is becoming popular. It means a local strong adhesion between colliding plates. The present forum paper is claiming that the global warming increases the number and sizes of asperities in the region (A) in Fig. 4.