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Seismic Zones Analysis by Growth Plate Kinetics to Break Up Pangaea

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Abstract

We have found that earthquakes occur frequently where were the coast when the supercontinent Pangaea existed, and that earthquakes occur rarely where were the land when Pangaea rifted, through analyzing seismic zones in the whole world. We believe plate tectonics, but we thought we would like to add two concepts. Those are coalescent boundaries and growth plate kinetics. After we analyzed several seismic zones in the world by using plate tectonics including the new concepts, we have obtained six inferences as follows. Growth and subduction of oceanic plate with continental drift are surface parts of mantle convection. Energy of earthquakes will be increased at the boundaries between continental plates pushed by oceanic plates. Energy of earthquakes in eastern Japan will be increased gradually. Energy of earthquakes in western Japan will be larger because of large normal force to produce friction. Energy of earthquakes will be the largest and volcanic eruptions will occur frequently when the next supercontinent will form, unless the speed of mantle convection slows down. Total eruption rate is equal to total subduction rate, and the rate is proportional to temperature of Earth. Based on the above inferences, the energy of earthquakes on the Earth will increase, so we would like to strongly emphasize the importance of disaster prevention. As Pangaea's break-up progresses, also energy of inland earthquakes will be larger. The Turkey-Syria Earthquake of magnitude 7.8 occurred on February 6, 2023 and the Japan's Noto Peninsula Earthquake of magnitude 7.6 occurred on January 1, 2024, so disaster science is needed to prepare for larger earthquakes.

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Introduction

The Turkey-Syria Earthquake occurred on February 6, 2023, with its epicenter in southeastern Turkey [1]. The depth of the epicenter was 17.9 km. The magnitude of the earthquake was moment magnitude 7.8. Near the epicenter is the triple junction of the Anatolian, Arabian, and African tectonic plates. The total death toll in both Turkey and Syria is more than 56,000 [2]. The Erzincan earthquake was a magnitude 7.8 earthquake that occurred in Erzincan province in eastern Turkey on December 27, 1939. The depth of the epicenter was 20.0 km. It was said that the Erzincan earthquake was the most severe natural loss of life in Turkey in the 20th century, with 32,968 dead [3], and some 100,000 injured [4]. However, the death toll from the Turkey-Syria earthquake is much higher than the death toll from the Erzincan earthquake. The Anatolian, Arabian, and African tectonic plates are each pushed by different oceanic plates and are thought to be colliding with each other, as Pangaea's break-up proceeds.

On October 8, 2005 a major earthquake occurred in Kashmir, northern Pakistan [5]. The depth of the epicenter was 26 km, the moment magnitude of the earthquake was 7.6 and the resulting death toll was 84,000 in both Pakistan and India. Kashmir is where the Indian and Eurasian tectonic plates collide. The collision began around 55 million years ago, creating the Himalayas, the highest mountains on the Earth.

Inland Earthquakes in Japan

The Noto Peninsula Earthquake [6] occurred on January 1, 2024. It was similar to the Southern Hyogo Prefecture Earthquake (Great Hanshin-Awaji Earthquake) that occurred on January 17, 1995. Those were due to an inland active fault [7], and the magnitude of the earthquake was bigger at the most recent Noto Peninsula earthquake.

Southern Hyogo Prefecture Earthquake

Magnitude 7.3 Epicenter depth 16km [8]
Seismic intensity 6: Kobe City, Sumoto City
Seismic intensity 5: Toyooka City, Kyoto City, Hikone City
However, in 1995, a seismic intensity of 7 was not applicable to measured seismic intensity meters, so based on field survey Kobe City, Nishinomiya City, Ashiya City, Takarazuka City, etc. were judged to have a seismic intensity of 7, and Osaka City (Nishiyodogawa Ward), Toyonaka City, Ikeda City were judged to have a seismic intensity of 6. The death toll was 6,434.

Noto Peninsula Earthquake

Magnitude 7.6 Epicenter depth 16km
Seismic intensity 7: Shika Town,
Seismic 6+ Nanao City, Wajima City, Suzu City, Anamizu Town
Seismic intensity 6- Nakanoto Town, Noto Town
The death toll was around 300. The number of deaths on the Noto Peninsula is low because it is a depopulated area.

Reason For Submitting Revised Manuscript

Since epicenter earthquakes in the Japanese archipelago tend to gradually increase in magnitude, I am resubmitting a revised paper from the original paper, which was submitted in 2014 with co-author Takasuke Yamasaki just after the Great East Japan Earthquake 2011.3.11 [9]. That time the paper was not accepted in the peer-reviewed journals. This time, I provide a detailed explanation of the theory and many references. People need to be more careful because the magnitude of current earthquakes on the Earth may increase faster than the speed of mantle convection [10] decreases as the Earth cools according to the knowledge of thermodynamics [11]. In 1862 William Thomson (Lord Kelvin) [12] concluded that the Earth's age is tens of millions of years old, no more than 400 million years old by using the theory of thermodynamics. But now the age of the Earth [13] is estimated to be approximately 4.6 billion years based on radiometric dating data from meteorites. This means that the Earth may not have gotten much colder since 200 million years ago, when Pangea began to break up. In other words, the speed of mantle convection will not decrease significantly, and the magnitude of earthquakes will become even larger for some time, approximately several hundred million years.

No! Nuclear power plants in earthquake zones - the geologist's ultimatum

Since 1975, there have been plans to build a nuclear power plant in Suzu City, at the tip of the Noto Peninsula, but the plan was finally frozen in 2003 due to opposition from local residents. After that, the Noto Peninsula earthquake occurred in 2007, and a series of earthquakes occurred starting in 2022. We are lucky that no nuclear power plant has been built at the tip of the Noto Peninsula. In 2023 Kazumi Doi [14] published a book entitled "Nuclear power and the Japanese archipelago", in which he stated the truth he can tell because he was involved in nuclear power plant design as a geologist, and that nuclear power expansion policy is wrong and that is the Geologist's ultimatum to nuclear power plants.

World Earthquake History and Distribution

By the Great East Japan Earthquake magnitude 9.0 [15] that occurred on March 11, 2011, Japan was heavily damaged even physical also human, then resources and efforts of many people are required for the recovery [16]. In Japan earthquakes occur frequently, that is earthquakes of magnitude 5 or greater have occurred approximately every 245 days [17] as shown in Fig. 1. Many studies have been done for cause of earthquake, prediction [18] and disaster prevention measures. By investigating the histories of earthquakes in the whole world, we have been able to reach a clear understanding of the relation between the occurrence zone and the history of earthquake, and also a recognition that the occurrences of earthquakes are based on the Earth's dynamics. Fig. 2 shows how many earthquakes have occurred in the whole world, and it is found that earthquakes have occurred approximately every 148 days.

Figure 1: Earthquake history of magnitude 5 or greater in Japan since 1900. Slope of the regression line: 0.6701 shows that earthquakes occur about every 245 days in Japan. Coefficient of determination of regression line is so high that we feel the orderliness of earthquakes.

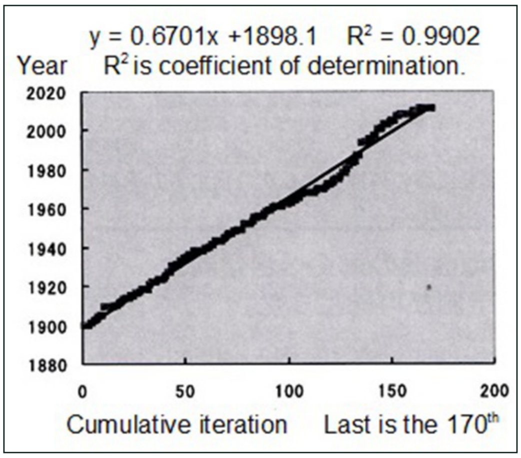
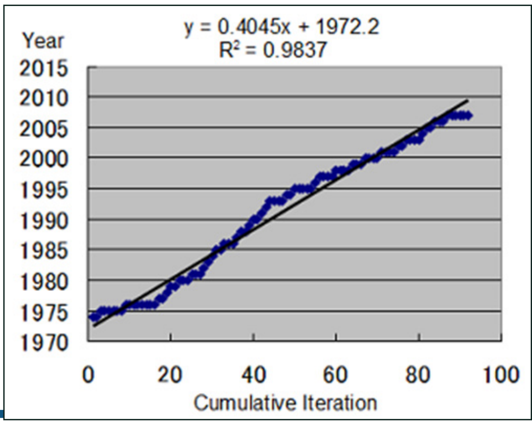


Figure 2: Earthquake history of magnitude 5 or greater in the world since 1974. Slope of the regression line: 0.4045 shows that earthquakes occur about every 148 days in the world. Coefficient of determination of regression line is high but lower than that in Japan, therefore we feel that the history may include other types of earthquakes in addition to subduction earthquakes.



The break-up of Pangaea and the history of earthquakes

We have investigated the history of continental drift from when the supercontinent Pangaea [19] existed 200 million years ago to understand the history of earthquakes.

Many epicenters in the world earthquakes distribution map as shown in Fig. 3 are the places of the hatching in Pangaea as shown in Fig. 4, which brilliantly correspond to the zones along the coast of Pangaea. By comparing two figures it is suggested that the cause of earthquake have been involved in the history of the Earth's dynamics from 200 million years ago, and that the history is related to the location of earthquakes to date. The fact that Pangaea has broken up is the placement of oceans and continents in the current world, and also the break-up is on going, which causes the earthquake zones distributed unevenly. Fig. 5 shows the break-up of Pangaea, and we can understand visually how Pangaea has broken up. Places which are indicated by red arrows in the figures are where the continents are approaching each other and the oceans are coming smaller. Currently the Atlantic is spread by 4 cm/year, the Pacific Ocean is smaller by 8 cm/year [20, 21], therefore we can see that earthquakes occur rarely where the continents are spread by the oceans, and that the earthquakes occur frequently where the continents are advancing to the oceans. In the next chapter we will show that the seismic zones can be analyzed by growth plate kinetics named in this paper.

Figure 3: World earthquakes distribution map (M 4.0, 100km or less depth, 1975 to 1994). Epicenter are distributed unevenly in the whole world.

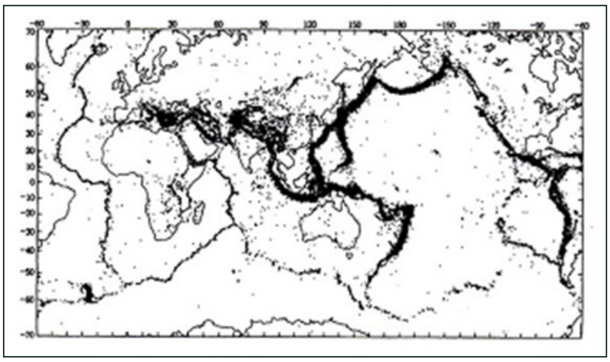


Figure 4: Pangaea 200 million years ago. Hatching lines show the relevant location of the epicenters in the current world map. Those are coasts of Pangaea and Panthalassa.

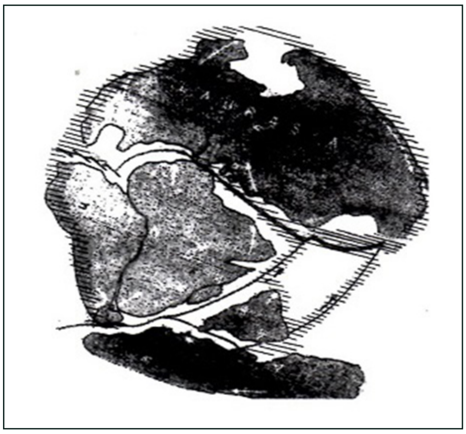
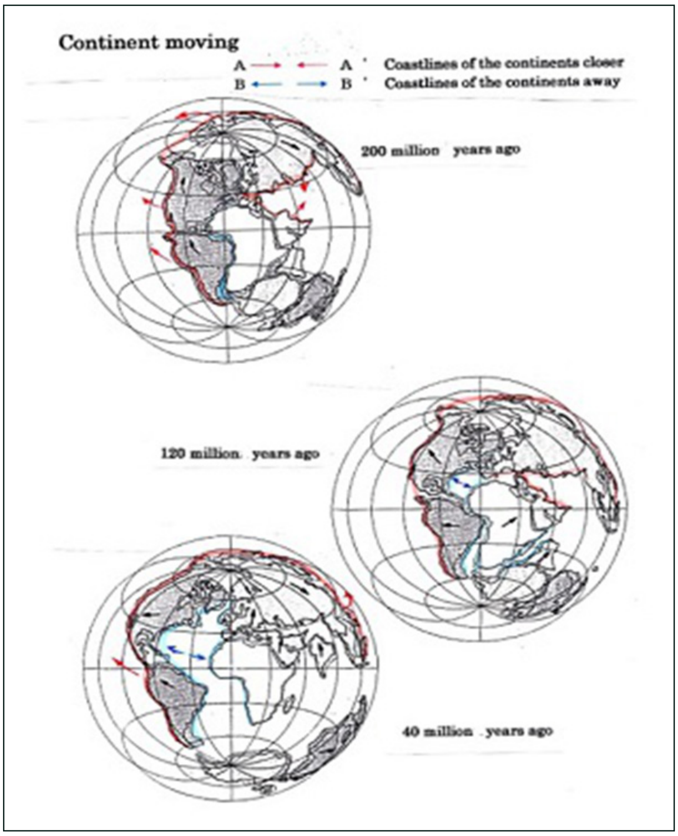


Figure 5: The break-up of Pangaea. Red arrows show that continents are advancing into oceans and blue arrows show that oceans are spreading continents. Red coastlines show seismic zones.



Growth plate kinetics explaining the break-up of Pangaea

We use the following propositions as assumptions, axioms and definition of tectonic plate, and then derive inferences, where axioms are empirical facts.

Assumption 1: The major driving force of plate motions is the growth of oceanic plates.

Explanation: Oceanic plates are growing by the eruption of magmas from the hotspots of mid-ocean ridges to push continental plates, which becomes a driving force of the entire plate motions. It is said that gravity, tidal forces and pulling forces at the subduction zones are the driving forces [22, 23]. But we assume that the major driving force is the growth of oceanic plates. There is also thought that pulling force is working on the whole oceanic plate, because the normal faults occur at the ridges. It is considered that normal faults can be made by the force of gravity at the slope near the ridges. Even though normal faults are made at the slope, eruptive magmas from the hotspots can make the oceanic plates grow. After the continents rift, the oceanic plates continue to grow. In other word the hotspot of mid-ocean ridge is the growth point of the oceanic plate.

Assumption 2: The oceanic plate adheres to the continental plate where the continent rifts, which is a coalescent boundary.

Explanation: When the hotspots occur in the middle of the continent, the continent rifts, then the hotspots will become mid-ocean ridge. And the oceanic plates grow by continuous eruption of magmas to break up the continents. The continental plate and the oceanic plate move together with magmas adhered and cool fixed. This means that the growth of oceanic plate is pushing the continental plate. There are three types of plate boundaries in plate tectonics [24, 25, 26], which are transforming boundaries, divergent boundaries and convergent boundaries. Here we add a type of plate boundaries named coalescent boundaries. It's a boundary like welded with lava.

Axiom 1: Earthquakes occur rarely in the coalescent boundaries.

Explanation: Earthquakes occur rarely at the places where Pangaea rifts, those are the west side of the Eurasian continent, the east side of the North American continent, the west side of the African continent, the east side of South American continent, the east side of the African continent, the coast of the Indian sub-continent, the coast of Australian continent and the coast of Antarctic continent. This is because the continental plates are moving with the growth of oceanic plates. In other word, the continental plates are welded to the oceanic plates by lava.

Axiom 2: Earthquakes occur frequently in the convergent boundaries.

Explanation: Earthquakes occur frequently at the subduction zones where the oceanic plate subduct beneath the continental plate and at the collision zones where the continental plates collide, which is evident in seismology.

Definition of the tectonic plates

We agree to plate tectonics, but we define the plates with the different method in growth plate kinetics to produce the driving force of the tectonic plates. We present the following three recommendations for the definition of plates.

The continental plate and the oceanic plate should be defined separately as the same meaning of the continental lithosphere and the oceanic lithosphere.

Explanation: In plate tectonics the Eurasian continental plate is united with the northeast Atlantic plate to be a big Eurasian plate, and also African continental plate is united with the southeast Atlantic plate to be a big African plate. But we don't agree that the continental plate is united with the oceanic plate. The reasons are as follows.

- Thickness is different, that is the continental crust is 20 km to 70 km thick, 35 km in average and the oceanic crust is 6 km thick in average.
- The continental crust is composed mainly of granite, and the oceanic crust is composed mainly of basalt.
- Density is different, that is the continental crust is about 2.8 g/cm^3, and the oceanic crust is about 3.0 g/cm^3.
- Age is different, that is the age of the oldest oceanic crust is less than 200 million years, and the age of the oldest continental crust is about 3.0 billion years to 4.4 billion years, where the average age of the continental crust is about 2.0 billion years. The continental lithosphere is associated with the continental crust and the oceanic lithosphere is associated with the oceanic crust. Therefore, we define the continental plate and the oceanic plate separately.

The oceanic plates grow at the hotspots, and there are two cases after growing, one is that they push the continental plates to move and the other is that they submerge into the asthenosphere at the subduction zones. We suppose that this driving flow is the mantle convection itself including the lithosphere and the asthenosphere.

Explanation: This is the same as what is explained in the assumptions and axioms. Here we estimate the size of the oceanic lithosphere using the eruption amount of magma for 200 million years.

Let the amount of eruption from 20 hotspots be $4km^3$ each year in the mid-ocean ridge.
In 200 million years it becomes $4km^3$ x 200,000,000 = 800,000,000 km^3.
If we think of the distance of 4,000 km, 800,000,000 km^3 / 4,000 km = 200,000 km^2
Assuming the width of 2,000 km, 200,000 km^2 / 2,000 km = 100 km
That is, the oceanic lithosphere is possible to grow 100 km thick in average.

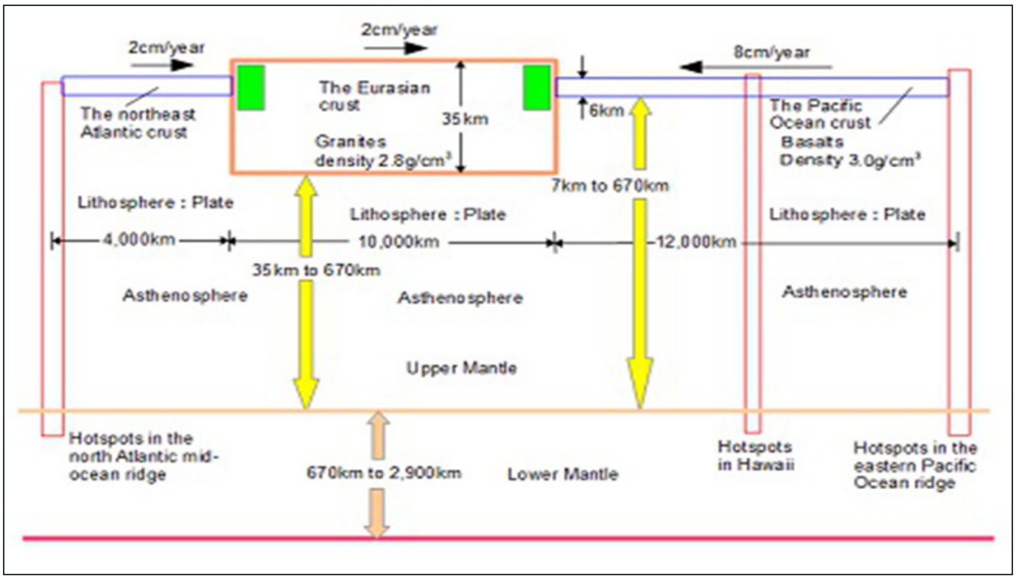
Definition of Back-Arc Basin Plate

Explanation: There is not a hotspot in the Philippine Sea plate [27], but magma erupted from volcanoes and submarine volcanoes cools and becomes rocks to spread and form the plate. One portion of the plate acts as the oceanic plate with heavy rocks and the other portion of the plate acts as the continental plate with light rocks at the boundary of the other plates. Magmas erupted from volcanoes and submarine volcanoes in the back-arc basin cool to be basalts and grow to subduct beneath the Eurasian plate like an oceanic plate, then big earthquakes occur, therefore we define it as a back-arc basin plate. At the Mariana trench the Pacific Ocean plate subducts beneath the Philippine Sea plate as a back-arc basin plate like a continental plate. It should be noted that the density of basalt erupted from the submarine volcanoes is smaller than that of normal basalt of the oceanic plate, therefore the Philippine Sea plate collides or rides on Taiwan and the Izu Peninsula.

Earthquakes Occur Frequently in The Vicinity of Japan

Figure. 6 shows an illustration of the north Atlantic mid-ocean ridge, the northeast Atlantic plate, the Eurasian plate, the Pacific Ocean plate and the eastern Pacific Ocean ridge. We can clarify the cause of the earthquake by using Fig. 6. The northeast Atlantic plate is currently growing at 2 cm/year to the east. The growth contributes half the width of the Atlantic Ocean, that is around 2,500 km since the break-up of Pangaea 200 million years ago. The northeast Atlantic plate and the Eurasian plate move together by the growth of oceanic plate with adhered and fixed according to Assumptions. Therefore, the velocity of the Eurasian plate will be 2 cm/year, the same as that of the northeast Atlantic plate. Note that there is some data of 1.1 to 1.4 cm / year about the velocity of the Eurasian plate near Japan with measured as the North American plate fixed. In that case it is possible that the Eurasian plate is being compressed with 2.6 to 2.9 cm/year, as the North American plate is moving west at 2 cm/year.

Figure 6: Illustration of the north Atlantic mid-ocean ridge, the northeast Atlantic plate, the Eurasian plate, the Pacific Ocean plate and the eastern Pacific Ocean ridge. West side of the Eurasian plate is the coalescent boundary and east side of it is the convergent boundary.



The growth rate of the Pacific Ocean plate is currently 8 cm/year to the west as shown in Fig. 6, therefore earthquakes occur frequently at the subduction zone beneath the Eurasian plate according to Axiom 2. We consider after 2 million years from the start of the break-up of Pangaea that the Pacific Ocean plate has 4,000 km reduction, because the northeast Atlantic plate has spread 4,000 km to the east. How can we guess the age of basalts at the subduction zone soon after Pangaea started to break up? It is difficult but it is supposed that the age was about 400 million years, because the time was when the vast global ocean Panthalassa [28] that existed at that time was at its maximum [29]. It should be noted that the growth rate of the Pacific Ocean plate is 8 cm/year in the east Japan, which is about two times faster than that in Mariana at 3 to 4 cm/year. It is necessary to consider the growth of basalts from Hawaii hotspot for this reason. We suppose that the Japan Trench is shallower than the Mariana Trench for this and that the magnitude of earthquakes is greater than that of earthquakes in Mariana.

Cause of the Great Lisbon earthquake

The Great Lisbon earthquake occurred on November 1, 1755, Feast of All Saints. The magnitude of the earthquake is estimated to have been 8.5-9.0M_w and the epicenter was about bout 200 km west-southwest of Cape St. Vincent and about 290 km southwest of Lisbon. The epicenter of this earthquake was within the Azores-Gibraltar fault zone. And The Azores-Gibraltar Fault is a transform boundary between the African and Eurasian plates. The situation of the collision between the African plate and the Eurasian plate at the transform boundary can be confirmed by looking at the distances between cities on the Earth in Table 1. and Figure 7.

The area of the Eurasian continent is 54.9 million square kilometers. The area of the African continent is approximately 30.3 million square kilometers. Eurasia is the largest continent, and Africa is the second largest. Earthquakes caused by the collision of transform faults between Eurasian continent and African continent are also large.

		Distance between two cities on world map									
	Radius of										Distance
π /180	the earth (km)		Latitude			Longitude			Latitude	Longitude	between
0.017453293	6371.008	Coordinates	Deg	Min	Sec	Deg	Min	Sec	Degree	Degree	two cities
Tokyo, Japan		35° 41′ 23″ N 139° 41′ 32″ E	35	41	23	139	41	32	35.68972	139.69222	★
Royal Greenwich Observatory		51° 28′ 40″ N 00° 00′ 05″ W	51	28	40	0	0	5	51.47778	0.00139	9556.81851
Lisbon, Portugal		38° 43′ 31″ N 09° 09′ 00″ W	38	43	31	9	9	0	38.72528	-9.15000	1586.67390
New Bern, North Carolina, USA		35° 05′ 45″ N 77° 04′ 20″ W	35	5	45	77	4	20	35.09583	-77.07222	5910.99783
San Francisco, California, USA		37° 46′ 39″ N 122° 24′ 59″ W	37	46	39	122	24	59	37.77750	-122.41639	4027.66735
Honolulu, Hawaii, USA		21° 18′ 25″ N 157° 51′ 30″ W	21	18	25	157	51	30	21.30694	-157.85833	3854.27260
Tokyo, Japan		35° 41′ 23″ N 139° 41′ 32″ E	35	41	23	139	41	32	35.68972	139.69222	6205.56073
Total from Tokyo to Tokyo											31141.99092
Lisbon, Portugal		38° 43′ 31″ N 09° 09′ 00″ W	38	43	31	9	9	0	38.72528	-9.15000	★
Cape St. Vincent, Portugal		37° 01′ 30″ N 08° 59′ 40″ W	37	1	30	8	59	40	37.02500	-8.99444	189.55503
Ceuta, Spain (Africa)		35° 53′ 18″ N 05° 18′ 56″ W	35	53	18	5	18	56	35.88833	-5.31556	352.42990
Cape Town, South Africa		33° 55′ 31″ S 18° 25′ 26″ E	33	55	31	18	25	26	-33.92528	18.42389	8145.05545
Auckland, New Zealand		36° 50′ 26″ S 174° 44′ 24″ E	36	50	26	174	44	24	-36.84056	174.74000	11772.50841
Tokyo, Japan		35° 41′ 23″ N 139° 41′ 32″ E	35	41	23	139	41	32	35.68972	139.69222	8839.33426
Reykjavik, Iceland		64° 08′ 48″ N 21° 56′ 24″ W	64	8	48	21	56	24	64.14667	-21.94000	8796.93340
Lisbon, Portugal		38° 43′ 31″ N 09° 09′ 00″ W	38	43	31	9	9	0	38.72528	-9.15000	2949.52840
Total from Lisbon to Lisbon											41045.34485

Table 1: Distance between Two Cities on World map

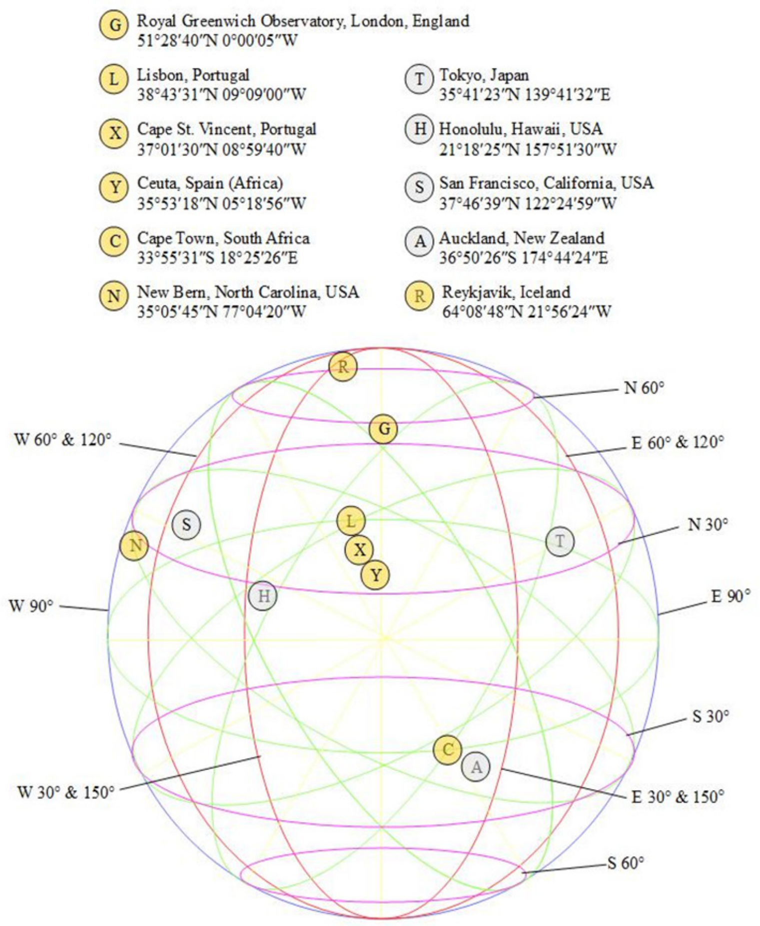


Fig. 7 Distance between Cities on the Earth (View of Royal Greenwich Observatory from the Moon)

Earthquakes in Chile and Mariana Islands

Energy of the earthquake in Chile is very large, it is said that the largest earthquake [30, 31] in history was magnitude 9.5 in Chile in 1960. However, the big earthquake of magnitude 7 or greater does not occur almost in Mariana. Currently the Pacific Ocean plate is subducting beneath the Philippine Sea plate in the vicinity of the Mariana Trench at 3 to 4 cm/year and the Nazca plate is subducting beneath the South American plate at 16 cm/year. We suppose that the fastest growth rate of the Nazca plate causes the largest earthquake. It is possible that the energy of earthquake in Chile has been increased gradually according to the size reduction of the Nazca plate. The reason is that the South American plate rides on and sinks the Nazca plate.

Earthquakes in Indian subcontinent and ocean

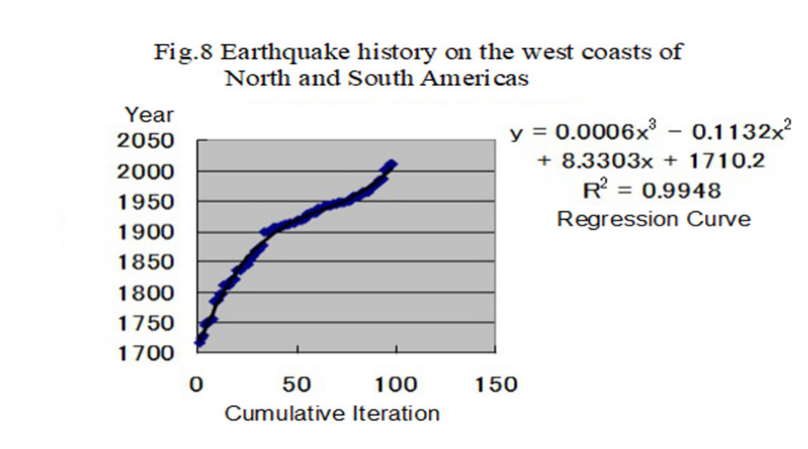
After the break-up of Gondwana continent [32, 33], the Indian subcontinent rapidly moved northward away from Madagascar and the east coast of Africa. The reason is the same as the fact that the Northeast Atlantic Plate, which is created by the hot spot eruptions of the Mid-Atlantic Ridge, is attached to the Eurasian continental plate and continues to push it. The eruption of hot spots of Central Indian Ridge creates oceanic plates on both sides. One oceanic plate is attached to the Indian subcontinent and pushes it, and another oceanic plate is attached to Madagascar and the east coast of Africa and pushes them. The pushing force caused by the growth of the Indian oceanic plate is quite strong, pushing the Indian subcontinent northward at about 15 cm/year after the Indian subcontinent broke up, and continues to push the Indian subcontinent at about 5 cm/year even after colliding with the Eurasian continent. And then the Himalayas has become very high and is still higher today [34, 35].

In the eastern part of the Indian Ocean, the Indo-Australian plate [36] is subducting as an oceanic plate into the Eurasian plate, which includes submerged Sundaland and Sumatra, Java and other islands, causing huge earthquakes. If the age of basalts at the subduction zone is about 90 million years, the basalts of Panthalassa already had been submerged. Because the basalts in the subduction zone were erupted from the hotspots when the Indian subcontinent began to go north. Generally, the younger the age of the basalt, the greater the energy of a subduction earthquake. On 26 December 2004, the Sumatra–Andaman earthquake with a magnitude of 9.1–9.3 Mw occurred at an epicenter of the west coast of northern Sumatra [37]. The total number of deaths due to the earthquake and tsunami was estimated 227,898.

If Himalaya will be no longer higher and the Indian subcontinent may be pushed back by the Eurasian plate due to the hot spots of the mid-Atlantic ridge, which are north of the Eurasian plate, it is possible that the oceanic plate may begin to subduct beneath the coast of the Indian subcontinent before the end of the break-up of Pangaea. At that time, earthquakes may begin to occur along the coastline of the Indian subcontinent.

The formation of San Andreas Fault

Until about 50 million years ago, there was an oceanic plate called the Farallon Plate [38] that was created by the East Pacific Ridge. The Farallon Plate collided with the North American continental plate, which was being pushed westward at a rate of 2cm/year by the Mid-Atlantic Ridge, and was sunk. The Rocky Mountains are thought to have been formed due to the stress on the North American continental plate at that time. After that, the North American continental plate continued to move westward, submerging the hot spots of the East Pacific Ridge, which is thought to have formed the San Andreas Fault [39]. Currently, the North American continental plate is pushing the Pacific plate from behind and sinking it. This means that the amount of eruption from the hot spots on the mid-Atlantic ridge are much stronger than the amount from the hot spots on the East Pacific ridge. This is a proof that Pangea continues to be broken up with the great force. The hot spots on the East Pacific Ridge might have played a major role during the formation of Pangea, but now its eruption volume has weakened and continues to be surpassed by the hot spots on the mid-Atlantic Ridge. This shows that the break-up of Pangea is progressing. Fig. 7 shows the history of earthquakes on the west coasts of North and South America. The third-order polynomial approximation best fits to the history of earthquakes. The reason may be that the North American continental plate is crushing the East Pacific Ridge on the San Andreas Fault, and that the Cocos Plate is subducting into the North American Plate on the Pacific side of Mexico, causing the 1985 Mexico earthquake of magnitude 8.0 [40], and also that the world's greatest earthquakes occurred in Chile.



Here we describe six inferences obtained in this study.

Inference 1: Growth and subduction of the oceanic plate with the continental drift are the surface parts of mantle convection.

Explanation: Refer to previously mentioned Definition of the tectonic plates.

Inference 2: Energy of earthquakes will be increased at the boundaries between continental plates pushed by oceanic plates.

Explanation: Oceanic plates continue to push continental plates at the coalescent boundaries. Therefore, Northeast Atlantic oceanic plate continues to push Eurasian and Anatolian continental plate, Indian oceanic plate created by the hot spots of Central Indian Ridge continues to push Arabian and Indian continental plate and another Indian oceanic plate created by the hot spots of Southwest Indian Ridge continues to push African continental plate. As a result, energy of earthquakes in southeastern Turkey at the triple junction of the Anatolian, Arabian, and African tectonic plates will be increased.

Inference 3: The magnitude of earthquakes in the eastern Japan Pacific Ocean side will be increased in accordance with the size reduction of the Pacific Ocean plate.

Explanation: Magmas erupted from the hotspots are growing the Pacific Ocean plate. If the eruption rate of magmas is a constant, the growth rate of the Pacific Ocean plate is increased, because the part of it at the subduction zone sinks by its own weight then the size of the Pacific Ocean plate is reduced. Consequently, the magnitude of earthquakes will be increased. The Great East Japan Earthquake on March 11, 2011 (magnitude 9.0) was the largest in the historical records in Japan.

Inference 4: The energy of earthquakes in the western Japan Pacific Ocean side are as large as those in the eastern Japan, even though the growth rate of Philippine Sea plate is much smaller. Because the normal force to produce the kinetic friction force is larger at the subduction zone.

Explanation: The growth rate of the Philippine Sea plate is 4 to 5 cm/year, that is much smaller than that of the Pacific Ocean plate. Because the density of basalts in the back-arc basin plate is smaller than that of the oceanic plate, the normal force to produce the kinetic friction force between the continental plate and the back-arc basin plate is larger, therefore the energy of earthquakes is larger than supposed by the growth rate.

Inference 5: The energy of earthquake in the subduction zones of Pacific Ocean becomes the largest when the next supercontinent is formed. Earthquakes and volcanic eruptions begin to occur frequently in the subduction zones being made at the side of Atlantic along with the break-up of the next supercontinent.

Explanation: This might be consistent that the 90% of the species of organisms became extinct [41] when Pangaea formed 300 million years ago and began to break up 200 million years ago. However, this assumes that the eruption rate is constant as described in Inference 1 above. Therefore, if the eruption rate is decreased, the impact is mitigated and if the eruption rate is increased, the impact is larger.

Inference 6: Total eruption rate from all hotspots in the entire surface of the Earth is equal to total subduction rate in all subduction zones, and the rate is proportional to the temperature of the Earth.

Explanation: If total eruption and total subduction are the convection of mantle including lithosphere and asthenosphere, the velocity of convection is proportional to the temperature. In case the Snowball Earth happens such as when Rodinia supercontinent formed [42, 43, 44], both total eruption and total subduction will be decreased. Even when it is that time, Inference 6 holds true.

The End of The Break-Up of Pangaea as A Prediction

Here we make a prediction about the end of the break-up of Pangaea. To simplify the problem, we assume that eruption rate of all hotspots remains a constant, then the prediction is as follows. Currently Atlantic is being larger at 4 cm/year and Pacific Ocean is being smaller at 8 cm/year, that is Pangaea continues to break up, but someday the next supercontinent begins to form. There are two ideas, one is that the next supercontinent will be formed at the Pacific Ocean side with Pacific Ocean being smaller as it is, and the other is that the next supercontinent will be formed at the Atlantic side with Atlantic being smaller unlike now. According to the supercontinent cycle hypothesis supercontinents had been formed 4 or 5 times over the past 2 billion years. The hypothesis is also called the Wilson cycle [45, 46], because John Tuzo Wilson who was a pioneer of plate tectonics proposed the concept that supercontinents have been formed repeatedly over the period of 400 to 500 million years. Here we assume that the next supercontinent will be formed at the side of Pacific Ocean, because Rodinia supercontinent before Pangaea was at the side of Pacific Ocean. The next supercontinent which will be formed at the side of Pacific Ocean is named Amasia by researchers [47]. It is supposed that the energy of earthquake will be the largest just before Amasia will complete to be formed, because the energy of earthquake will be increased with the size of the Pacific Ocean plate being reduced, as described in Inference 2 above. If Amasia will be formed at the low-latitude region like Rodinia, it is possible that the Snowball Earth will happen, because most solar energy will be reflected by the supercontinent formed at the low-latitude region. But it is difficult to predict it, because the Snowball Earth did not happen, when Pangaea was formed. Under the supercontinent asthenosphere will be overheated, then magmas will break lithosphere to be erupted, that is hotspots will begin to rift Amasia. The vast global Atlantic like Panthalassa will start to subduct beneath the break-up of Amasia just like the current Pacific Ocean plate, then earthquakes will occur frequently, a lot of volcanoes will erupt and deep trenches will be dug. Or it is also possible that the vast global Atlantic might start to subduct beneath Amasia, just after Amasia is formed. If the next supercontinent will be formed at the side of Atlantic, the northeast Atlantic oceanic plate will subduct beneath the Eurasian continental plate when Atlantic will start to be smaller. In other word it is possible that the coalescent boundaries will be changed to the convergent boundaries.

Conclusion

We would like to say that it is important to measure the velocity of all plates. Above scenario is made by the assumption of constant eruption rate of all hotspots. We suppose that the temperature of mantle will go down in the long term gradually, then total eruption rate will go down to mitigate above scenario except for Snowball Earth. We can measure the velocity of all plates instead of measuring eruption rate of the related hotspots, and by the accurate measurement for current plate velocities [48] we can forecast whether energy of earthquakes will be increased or not. In this study we show that earthquakes which occur momentarily are the proof of the break-up of Pangaea. Therefore, it is important to recognize that earthquakes and tsunamis certainly come in both short term and long term. The recognition will serve to prevent disaster and to protect everyday life.

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Author Contributions

Takasuke Yamasaki: Representative of seismic history data analysis study group, research initiative, Idea, Figures of earthquakes histories, Pangaea break-up drawings

Noboru Kubo: Idea, Theoretical considerations, Diagrams of Continental plate and Oceanic plate, Writing papers

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