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Unveiling the Geological Divide: Contrasts Between Intraplate and Plate Boundary Earthquakes.

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Abstract

This review compares the distinctions between interplate earthquakes, primarily situated at plate boundaries, and intraplate earthquakes occurring within the interior of tectonic plates. While plate tectonics effectively explains the mechanisms of interplate seismicity, intraplate earthquakes, notably observed in northeast Asia, pose a more intricate puzzle with no overarching model. This study tackles the fundamental question of whether these two seismic categories exhibit similarities, exploring their respective origins and variations. Despite the challenges associated with understanding intraplate earthquakes due to their infrequency compared to plate-boundary seismic events, this comparative analysis seeks to provide insights into the shared and unique aspects of these significant geological occurrences.

Keywords: Interplate earthquakes; Intraplate earthquakes; Plate tectonics; Seismic hazards; Plate Boundary

1. Introduction

The borders of geological plates are the principal home of earthquakes, nominated as interplate earthquakes that are “well described by plate tectonics as a consequence of horizontal motion gradients within the surface boundary layer of thermochemical mantle convection.” (1)Subduction zones are among the best areas that show interplate earthquakes and a good place for study these types of events, for instance, there are numerous large earthquakes along the northern Cascadia plate boundary that shows monotonic rupture behavior (2).

On the other hand, the term, intraplate earthquake, refers to a variety of earthquakes that occur within the interior of a tectonics plate. One of the famous areas that such earthquakes have been recorded so many times is northeast Asia (NE). As this region is affected by strong interaction of the Eurasian, Indian, Amur, Okhotsk, Pacific, and Philippine plates, has highly active and complicated structure (3). Moreover, Although the majority of large tsunami occur because of plate boundary rupture, some of them are generated by submarine intraplate faults that have vertical displacement (4).

As earthquakes have always been a catastrophic phenomenon and have numerous direct and indirect effects on human life, seismologists and geologists must understand the various types and the main reasons that cause them. Although there are countless studies about the intraplate and interplate earthquakes and their reasons, scientists are still investigating whether these earthquakes are fundamentally look like each other or not. To answer this question thoroughly, first you need to consider an important point that the earth is a dynamic planet. Therefore, perpetually changes externally and internally and leads to surface altering by endogenic processes, resulting in volcanism and

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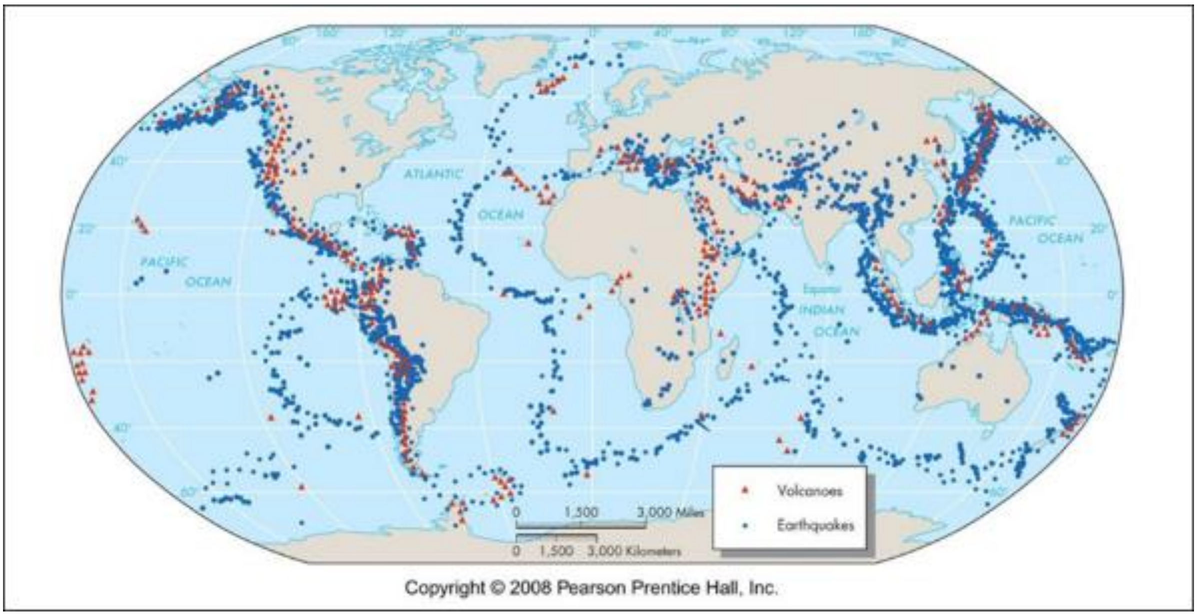
tectonism and exogenic processes (i.e., of external origin) such as erosion and deposition (5,6) Among them, an earthquake is one of the most known events that have an internal origin. The first and most important reason for seismicity is mantle convection, or its heat-driven movements. The mantle flow causes stress to accumulate in cold and solid crust, wherever crust has less resistivity has been cracked and release these stresses, consequently led to blooming fractures and faults (1)

2. Methodology

In this matter, the study about the intraplate earthquake is much more challenging than the other one. Plate tectonics gives us a good insight into the reasons an interplate earthquake occurs, but such an overarching model for intraplate events does not exist yet. Another challenge in understanding intraplate earthquakes is that the number of them is much less than plate-boundary ones and consequently our information about them is limited (7,8) A glance at a global earthquake distribution map (Figure 1) shows that the number of earthquakes is much greater at plate boundaries than in plate interiors, so we have better information to understand them.



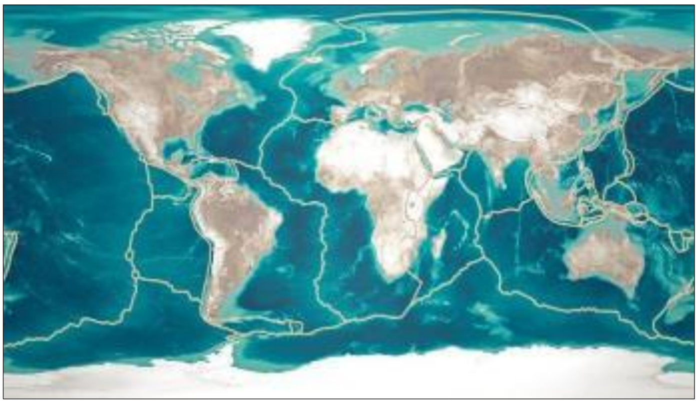
(https://clarkscience8.weebly.com/patterns-of-earthquakes-and-volcanoes.html)

Figure 1 Location of earthquakes and volcanoes on Earth

In this study, we are going to make a comparison of the main differences between these two types of earthquakes based on the other scientists' investigations and results. Furthermore, the reasons that cause them to take place and whether they are originated in the same way or not.

3. Plate tectonics and Earthquakes

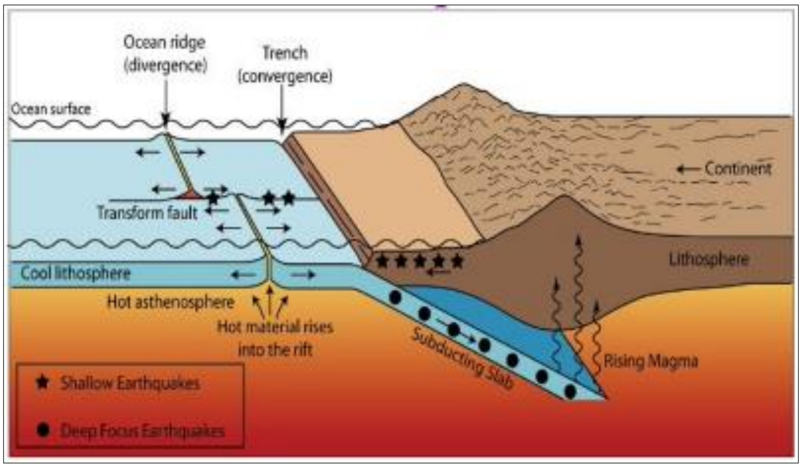
Most earthquake originated in deep fractures in the crust, miles beneath the surface. These giant fractures crisscross the globe, splitting the planet's 50-miles thick crust into around dozen huge, rocky slabs. In the other word, the Earth enclosed in a rigid shell, made up of rocky plates which move around, about the same speed as a fingernail grow. There is a sort of movement of these plates going on all time around the planet's surface. Geologists, call this movement, plate tectonics (figure 2).



(https://www.nationalgeographic.org)

Figure 2 Tectonics Plate Map The movement of Earth's tectonics plates shape the planet's surface. This three-dimensional image shows a map of Earth's tectonics plates.

The Earth's internal heat led to mantle flow and moves those huge plates. Above the hottest zones, molten rock rises and solidifies, creating new crust, the new crust jostles for space forcing plates on cooler edges to grind against other plates or push beneath them.



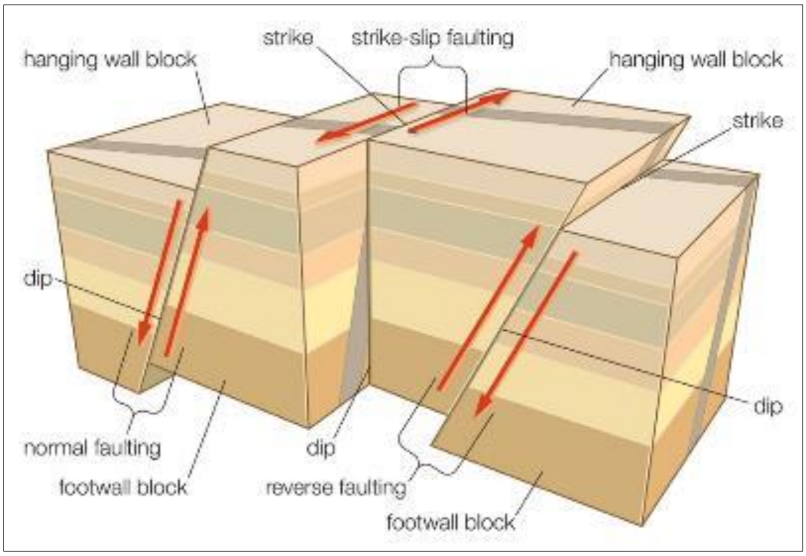
(https://image.slidesharecdn.com/platetectonics)

Figure 3 Tectonic setting of earthquake

Whenever plates collide, they generate earthquakes. Therefore, earthquakes happen because these vast chunks of the rucks which form the earth plates do not smoothly slide each other. Instead, they stick and lock. Consequently, we are getting an enormous accumulation of stress and then is released in a matter of seconds during an earthquake. The earthquake can originate ten miles down, but their energy creates deadly vibrations on the surface. Depending on how much pressure has built up during plate collisions, the ground may tremble slightly or shake forcefully (5).

4. Type of faulting

faults can be separated into three broad classes based on the direction of the stress that caused the fault offset. When extensional stress is applied, the rocks extend, initially forming fractures usually at an angle of less than 70 degrees to the surface. when the hanging wall drops relative to the footwall, it is called a normal fault. If compressive stress is applied to the rock the effect is to shorten it. The fracture that form look a lot like normal faults, but the motion is in the opposite direction. these are called reverse fault. When the rock is pushed horizontally in opposite directions, the shearing produces strike-slip faults. most strike slip faults are close to vertical and involve little to no vertical motion (Figure 4)



(https://www.thoughtco.com/fault-types-with-diagrams-3879102)

Figure 4 Various type of faulting (Normal, Reverse and Strike-Slip)

5. Interplate (Plate Boundary) Earthquake

The stress regimes that act locally on faults, also act at a larger regional scale to create three basic types of plate boundaries. Extensional stress occurs at divergent plate boundaries, where two plates move away from each other. examples include Oceanic spreading Ridge that form the longest mountain ranges in the world. As the plates pull apart hot and therefore lower-density, mantle rock rises to support the 3,000 to 9000 ft high spreading ridges. as the plates move away from the Ridge, they cool become brittle and break in normal Faults. compressive stresses occur at convergent plate boundary, where two plates move toward each other. if two continental plates collide, they produce a broad uplift like Himalayan Mountain range with reverse faults parallel to the plate boundary. If an oceanic plate subducts beneath the continental plate most of the faults occur within the overlying plate as it is compressed and buckles forming coastal mountain ranges parallel to the plate boundary. the sloping contact between the plates is under high friction as the subducting plate shoves the overlying plate backwards. shear stress occurs at transform boundaries where two plates slide horizontally past each other with strike-slip motion (2) Transform faults link offset boundary segments. most transform faults are found in the ocean basin, where they connect offsets in mid-ocean ridges. transform faults can also connect a spreading ridge with the subduction zone such as the San Andreas fault that separates the Pacific and the North American plates. geologists have defined plate boundaries by the dominant forces acting on the plates these are usually shown on maps as continuous connected segments. while shown as lines, they are broad zones of deformation that are affected by the regional stress from constant plate motion. for example, the San Andreas fault is not a simple long strike slip fault, but it is actually a fault zone that includes over 200 related faults that generate thousands of earthquakes every year.

These kinds of earthquakes that take place on plate border called interplate earthquakes. On the other hand, we have another kind of earthquake that are rare but important. We are going to explain them in next paragraphs (9).

6. Intraplate earthquake

Earthquakes' locations are not limited to the plate boundaries, they are also observed away from the plate edges. To understand them we should consider the dynamic of continental deformation by extending plate tectonic theory (1) Intraplate earthquakes take place around the globe causing several factors, like reactivation of old rift, dynamic topography, gravitational body force, ridge push, and etc. Soleymani et al. present a regiospecific synthesis method for iodocyclization, indirectly contributing to understanding intraplate earthquakes. Khalil et al. employ geophysical methods to map a hazardous gypsum mine, shedding light on seismic hazards associated with intraplate earthquakes and differences between intraplate and interplate seismic activity (10,11).

The relationship between seismicity and the rate change of 'dynamic topography' (that is, vertical normal stress from mantle flow) is one of the factors that could illustrate intraplate earthquakes in some places. Horizontal motion gradient within the surface boundary caused by mantle convection that we mentioned before as plate tectonics theory can describe interplate earthquake very well; on the other hand, recent studies show for seismicity away from plate boundaries, mantle convection is one of the fundamental causes as well. Although, there are numerous uncertainties in finding a clear path for the location and rate of seismicity that comes from mantle flow. Becker et al. 2015 (1) focused on the rate of seismicity in the Western US mobile belt, where we can see several intraplate earthquakes associated with the deformation in crust. (Figure 5)

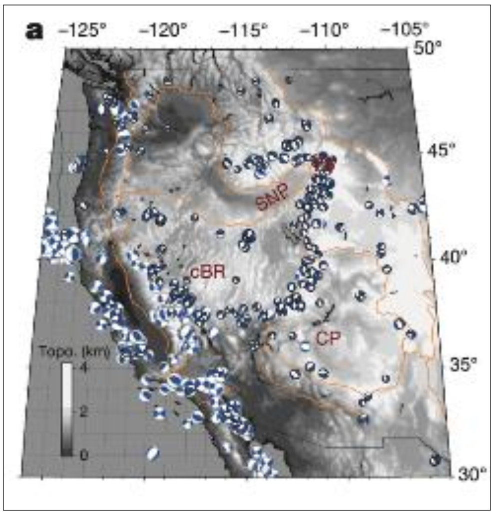


Figure 5 Topography (Topo.), topographic provinces (orange lines) and focal mechanisms (grey and black from the global Centroid-Moment-Tensor (gCMT)

Mantle flow cause to a lateral variation in density that is expected to have a role in releasing seismic stress (1,12). As a consequence of this density variation, a lateral variation in gravitational potential energy take place that are associated with deviatoric stress and can be connect with crust deformation in this region. Besides, several factors like mass transport processes caused by plate tectonics and the dynamic feature of the sublithosphere come from mantle flow and lithosphere thickness variation, leading to the evolution of earth crust heterogeneity. Figure 6 shows a good agreement between earthquake distribution and rate of topography changes in studied region.

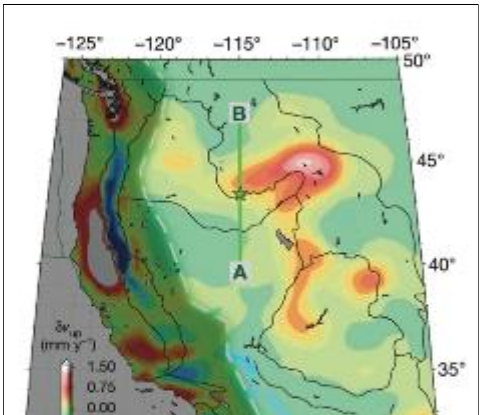


Figure 6 The rate of change in topography

Also, overlapping between old rift set and mid-continent earthquakes states that the ancient rift system are among important factor in intraplate events happening. In the other word, crustal heterogeneity originated from old rift system associated with a dense seismic network suggests a new insight into potential seismogenic structures (13).

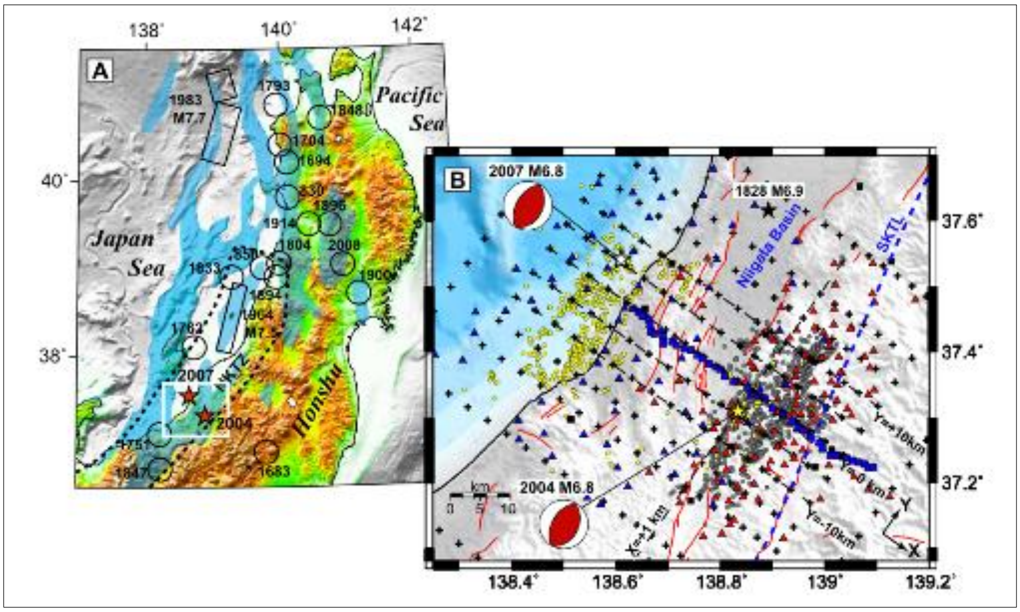


Figure 7 Seismotectonic setting in northern Honshu, Japan

Presenting tomography image of seismic velocities in contractional zone at the eastern margin of the Japan Sea back-arc basin shows the evidence of existing Miocene rift system. The majority of aftershocks related to 2007 intraplate earthquake associated with the weaknesses which this rift system generated (14)

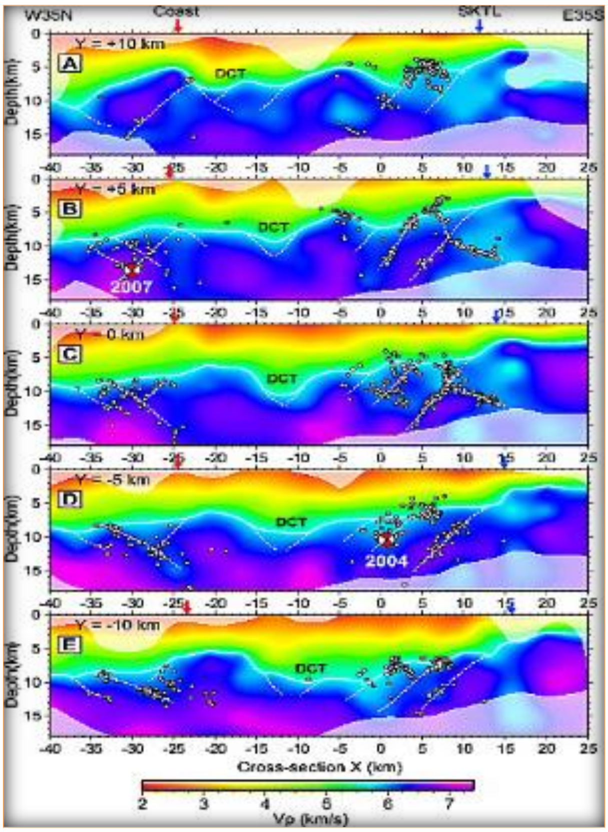


Figure 8 Depth sections of the V_p model

Kato et al. 2009 (13) suggest the stress loading transfer by weak fractures within ancient rift system, lead to intraplate earthquake in the studied area. Measuring P_wave velocity shows significant lateral heterogeneity. As the measured seismic velocity values in hanging wall were lower than those in the footwall, they consider that velocity body as existence of soft sediment material which the rift system buried beneath. Figure 8 shows this agreement between aftershocks and the old rift system. Therefore, activation of old rift network can be another factor for intraplate earthquakes. Among other reasons which can originate intraplate earthquake we can refer to active geological structure like salt domes or charge or declared the dams that cand trigger old fractur and cracks.

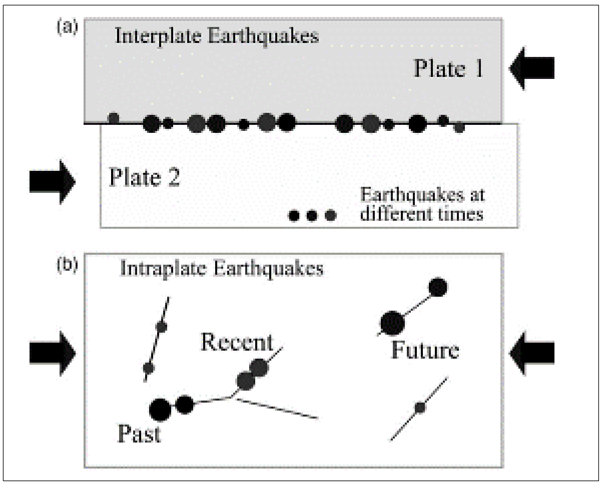


Figure 9 Conceptual models for the differences between interplate (a) and intraplate (b) earthquakes

7. Conclusion

There are fundamental differences between these two types of earthquakes. As earth's plates move at a constant rate, the faults in plate boundaries evolve at a steady rate, leading to periodic earthquakes along the plate edge; sometimes, they have a sophisticated pattern; but we can say they are expected. In contrast, mid-continent earthquakes have a complex system of faults that interact and can transfer seismicity to other faults. Since the amount of stress accumulated in the mid-continent is not as high as stress accumulation in plate boundaries, intraplate fault can be dormant for many years. (Figure 9) (15)

Interplate earthquakes are well described by plate tectonics theory. The edges of the oceanic and continental plates are always unrest and continually meet numerous interplate earthquakes bypassing the time. Almost 90% of earthquakes that happen around the globe are interplate. While the intraplate earthquakes are rare and study about them is more complex as the number of their recorded data is lower than the former. So far, scientists could find the factors like dynamic topography, gravitational potential energy, lateral density changes, changes in stress rate, reactivation of old rift, etc. for intraplate happening. By looking at the previous studies, we can say the main reason for interplate, and intraplate earthquake occurrence is the substantial internal force from mantle convection. However, some external reasons, such as erosion, isostatic adjustment and charge/recharge of dams remain that could trigger faults system in the middle of plates.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

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