**Presentation:**

Plate tectonic is one of the major factors affecting the potential habitability of a terrestrial planet. The physics of plate tectonics is, however, still far from being complete, leading to considerable uncertainty when discussing planetary habitability.

The role of plate tectonics in planetary habitability is through its influence on atmospheric evolution.

The habitability of a planet depends on a number of factors including, for example, the mass of the central star and the distance from it, the atmospheric composition, orbital stability, the operation of plate tectonics, and the acquisition of water during planetary formation.

Plate tectonics controls the evolution of the atmosphere through volcanic degassing and subduction, and it is also essential for the existence of a planetary magnetic field, which protects the atmosphere from the interaction with the solar wind. Whether or not plate tectonics is operating on a planet, for example, would give rise to vastly different scenarios for its atmospheric evolution, affecting the definition of the habitable heliocentric distance, that is, the habitable zone.

Plate tectonics refers to a particular mode of convection in a planetary mantle, which is made of silicate rocks, and so far it is observed only on Earth. Earth’s surface is divided into a dozen plates or so, and these plates are moving at different velocities. Most geological activities, such as earthquakes, volcanic eruption, and mountain building, occur when different plates interact at plate boundaries.

Under what conditions could plate tectonics emerge on a planet, and how would it evolve through time? Without being able to answer these questions, it would be nearly impossible to predict the atmospheric evolution of a given planet and thus its habitability.

Earth’s mantle in the past was generally hotter and thus probably had lower viscosity than present. Elementary fluid mechanics tells us that this reduction in viscosity should have resulted in more vigorous convection, that is, higher heat flux and faster plate tectonics.

In plate tectonics, the surface is broken into pieces, most of which can return to the deep mantle, enabling geochemical cycles between the surface and the interior. Among the four terrestrial planets in our solar system, Earth is the only planet that exhibits plate tectonics, and the other three (Mercury, Venus, and Mars) are believed to be in the mode of stagnant lid.30 It is easy to explain why plate tectonics does not take place on other planets, because stagnant-lid convection is the most natural mode of convection in a medium with strongly temperature- dependent viscosity, such as silicate rocks that constitute a planetary mantle.

Plate tectonics enhance the planet’s habitability. In other cases, excessive tidal heating may result in Io-like planets with violent volcanism, probably rendering them unsuitable for life. On water-rich planets, tidal heating may generate sub-surface oceans analogous to Europa’s with similar prospects for habitability.

On the Earth, internal heating drives convection in the mantle, and thus, contributes to the process of plate tectonics. Because a stable surface temperature is probably a prerequisite for life, plate tectonics may be required for a planet to be habitable. These considerations suggest that, in order to be habitable, terrestrial planets require a significant source of internal heating.

The Earth emits~0.08W/m of internal (radiogenic and primordial) heat (Davies 1999), which is apparently adequate for plate tectonics. For an estimate of the minimum heating required for tectonic activity, consider the geological history of Mars. When Mars was last tectonically active, its radiogenic heat flux was ~ 0.04W/m^2, perhaps a minimum amount required for tectonics in a rocky planet.

For example, O'Neill & Lenardic (2008) show that plate tectonics may be less likely on terrestrial planets more massive than the Earth, even though they would probably experience more radiogenic heating.

First, we consider requirements for enough heating for plate tectonics, but not so much that there is devastating volcanism. As described above, this range is perhaps  between ~0.04 and ~2 W/m^2. Figure 4 (a) and (b) show that tidal heating might drive plate tectonics on even a Mars-sized planet (*Mp* = 0.3 MEarth) orbiting a star of mass 0.1 MSun even with *e* as small as 0.04. For planets around larger stars (Figure 4c), larger eccentricities are required for sufficient internal heating.

**#### Wikipedia #####**

n 1973, George W. Moore[24] of the [USGS](http://en.wikipedia.org/wiki/USGS) and R. C. Bostrom[25] presented evidence for a general westward drift of the Earth's lithosphere with respect to the mantle. He concluded that tidal forces (the tidal lag or "friction") caused by the Earth's rotation and the forces acting upon it by the Moon are a driving force for plate tectonics. As the Earth spins eastward beneath the moon, the moon's gravity ever so slightly pulls the Earth's surface layer back westward, just as proposed by Alfred Wegener (see above). It has also been suggested recently in Lovett (2006) that this observation may also explain why [Venus](http://en.wikipedia.org/wiki/Venus) and [Mars](http://en.wikipedia.org/wiki/Mars) have no plate tectonics, as Venus has no moon and Mars' moons are too small to have significant tidal effects on the planet.

If the bands on Mars are an imprint of crustal spreading, they are a relic of an early era of plate tectonics on Mars. However, unlike on Earth, the implied plate tectonic activity on Mars is most likely extinct.

There is no evidence on Mars for large-scale [plate tectonics](javascript:locscrollmenu('../earth/tectonics.html','mars',650,450)) as we find on Earth. This is believed to be responsible for the different character of Martian and Terrestrial volcanoes, as illustrated in the following animation. (The image gif)

Com- pared to other terrestrial planets in our Solar System, Earth is unique: it has liquid water on its surface, an atmosphere with a greenhouse effect that keeps its surface above freezing, and the right mass to maintain tectonics.

The two bodies of Earth’s size in the Solar System, Venus and Earth, differ heavily in the number of impact craters. The approximately 100 craters at Earth are much less than the approximately 900 on Venus. Even if some on Earth vanished by erosion processes this means that tectonic processes extinguished most of the craters on Earth, but not on Venus. The question is why Venus did not develop active plate tectonics similar to the Earth? One factor might be the high surface temperature, which weakens the heat flow and slows down the convection.

Plate tectonics should have stopped at Venus after the water inventory was lost

Plate tectonics together with permanent liquid water most likely provided the first environment for the evolution of life, the black smokers. Plate tectonics does not only regulate the composition of a terrestrial atmosphere by the cycling of volatiles including the greenhouse gas CO2 and hence the surface temperature and planet habitability but it is driving evolution by always changing the environment. The chances for being created and being forced to evolve (and probably also for being destroyed) are better on an active planet than on a stable one.

As illustrated in Fig. 4 plate tectonics is also an important factor for the generation of an Earth-like long-time strong intrinsic planetary magnetic dynamo, which protects the atmosphere from solar wind erosion and deflects high energy cosmic rays. Although the driving mechanisms for plate tectonics are not fully understood, the minimum requirements are a sufficient mass relevant for the heat flow to drive mantle convection, and water to lubricate plate motion. Water is the lubricant that allows the plates of the crust to slide and subduct, without water in the mantle the evolution of the planetary mantle and planetary tectonic engine would stop. Water makes the lithosphere deformable enough for subduction of the crust to occur and it reduces the activation energy for creeping and the solidus temperature of mantle rock, thereby enhancing the cooling of the interior and the efficiency of volcanic activity. Large water reservoirs in the mantle and on the surface are interacting. The man- tle loses water and other volatiles like CO2 through volcanic activity, and therefore helps to sustain the atmosphere. On the other hand, water and CO2 are recycled together with the subducting crustal rock.

Furthermore, the recycling of the crust through plate tectonics keeps the crust thin, which seems to be mandatory for plate tectonics to operate. If the crust is too thick, the lithospheric plate comprising the crust will be too buoyant to be subducted because on Earth the cratons became never subducted anymore after formation. Finally, plate tectonics seem to help to establish the right temperature conditions in the interior that are required to maintain the action of a strong magnetic dynamo for several billion years.

For terrestrial exoplanets the conclusion can be drawn that planets with sizes less than Earth or Venus (e.g., Martian sized bodies) lose their ability for plate tectonics very quickly. Water-rich Earth-sized bodies should maintain the convection cycle for a long time, thus forming dry continents and basins with water.

Plate tectonics on “super-Earths” depends on several factors, like the original water contents, the forming of cratons and the distribution of convection cells, all probably individual for each planet.

While there are several observations indicating the existence of early plate tectonics on Mars, representative one is geomagnetism. The shape on the Martian crust seems to be the same origin to that on the Earth, which is created at the mid- ocean ridge through the system of plate tectonics.

Mars may have only transiently passed through the plate tectonic regime early in its history due to its smaller size and lower heat flow(Sleep, 1994). Likewise, Earth-sized planets with a smaller inventory of radiogenic isotopes would also exhibit plate tectonic behavior in their early history.

Could a planet maintain significant geologic activity in the absence of plate tectonics? One possibility is “hot spot”-style volcanism, widely accepted to be a consequence of buoyant plumes ascending from deep within the mantle, perhaps from the core–mantle boundary. Hot spot volcanism accounts for only a small fraction of de- gassing from the modern Earth; however, it may have been important on Venus and early Mars, and contributed to surface volatile budgets.

Without a constant internal energy source, planets cool as they age, eventually terminating tectonic activity and rendering the planet sterile to life. For example, terrestrial life depends on heat-driven plate tectonics to maintain the carbon cycle and to moderate the greenhouse effect. On an Earth-like body, long before reaching twice Earth’s age, plate tectonics would probably have turned off as the planet cooled, primarily because solidification of the core would terminate the release of la- tent heat that drives mantle convection. While plate tectonics may not be essential for life on all habitable planets, an equivalent tectonic process to drive geochemical exchange between the interior and the atmosphere is a likely requirement. The necessary amount of internal heat for such activity is uncertain (even the mechanisms that govern the ontset and demise of terrestrial plate tectonics are still poorly understood and controversial), but it seems likely that a planet ∼10 Gyr would have cooled too much. A previously habitable planet, even if it remains in the classical habitable zone, might now be uninhabitable.

Within the Earth, about 1/3 of the heat comes from phase transitions in the core and the remainder from radiogenic heating in the mantle. As the Earth cools, in another 4 Gyr the core will solidified and radiogenic heating will be halved, reducing the heat flux to 0.03 W/M^2.

Plate tectonics is known to operate, at present, only on the Earth, although Mars may have had a phase of plate tectonics as may have Venus.

Plate tectonics has been suggested to be essential for life (see e.g. [1]) due to the replenishment of nutrients and its role in the stabilization of the atmosphere temperature through the carbon-silicate cycle. Late tectonics also supports the generation of magnetic fields by effectively cooling the deep interior. (In addition, plate tectonics rejuvenates nutrients on the surface and generates granitic cratons.) As plate tectonics is widely believed to require water in the mantle to operate, it can be argued that plate tectonics is another element linking the biosphere to the evolution of the planet’s interior. A magnetic field is argued to serve to protect an existing atmosphere against erosion by the solar wind and thus to help stabilize the presence of water and habitability. Magnetic fields are generated in the cores of the terrestrial planets and thus habitability is linked to the evolution of the interior through magnetic field generation and volcanic activity. Moreover, the interior is a potential source and sink for water and may interact with the surface and atmosphere reservoirs through volcanic activity and recycling. The most efficient known mechanism for recycling is plate tectonics. Plate tectonics is known to operate, at present, only on the Earth, although Mars may have had a phase of plate tectonics as may have Venus. Plate tectonics also supports the generation of magnetic fields by effectively cooling the deep interior.

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