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Is plate tectonics occurring today?

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In this brief article I focus on the question of whether or not the primary plate tectonic processes of seafloor spreading and subduction are occurring in the present day. Restricting the scope to the present moment eliminates many of the issues arising from uniformitarian bias on the part of the secular earth science community. I discuss the GPS determinations of present-day plate motions, the present-day distribution of seismicity, the topography and elevated heat flow along the present-day mid-ocean ridge system, the slip and fault plane orientation of present-day mega-earthquakes, and the close association of most present-day volcanism with deep ocean trenches. I conclude that these multiple, largely independent, lines of observational evidence support strongly the premise that coherent plate motions, commonly on the order of centimeters per year, are occurring and that seafloor spreading and subduction are close to undeniable realities.

GPS testifies to the reality that plates are currently moving

I frame my discussion of these topics around several claims Michael Oard made in his response[1] to my letter[2] in *Journal of Creation* **25**(2) where I outlined my reasons for concluding that rapid cooling of the ocean lithosphere was responsible for the rapid sea level drop in the later portion of the Flood.

In his response to my letter, Oard claimed that present-day GPS measurements, which I had offered as definitive evidence that plate tectonics is occurring today, admit "other, non-PT, explanations." Yet he provides no hint as to what those other explanations might be. In this context it seems useful to summarize the present status of GPS determinations of plate motions. Currently, the Jet Propulsion Laboratory, under contract with NASA, collects and compiles precise geodetic position measurements of each of over 2000 GPS receiver stations distributed worldwide utilizing a constellation of 30 GPS satellites. Fig. 1 displays the relative latitude and longitude measured from 2002 to 2011 as a function of time for the Cook Islands GPS station in the western Pacific. Lines fit through these points over that time interval give an average northward velocity for that station of 3.5 cm/yr and an average westward velocity of 6.3 cm/yr relative to the GPS reference frame for the earth. Because the noise in these data is so small, the confidence level in the velocity implied by the change in the station position with time is high.

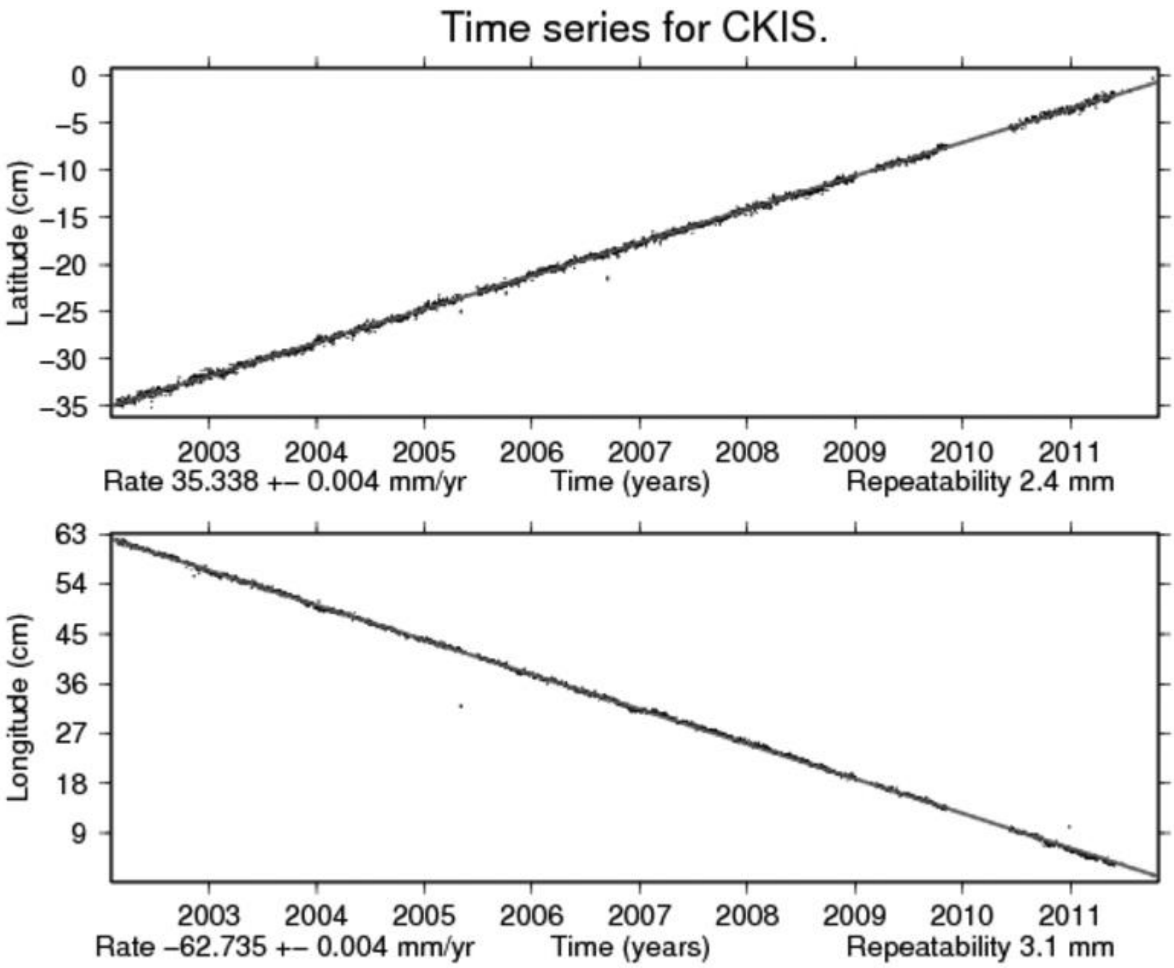

Figure 1. Time history of location of the Cook Islands station in the western Pacific as determined by GPS over the interval 2002–2011. (Source: sideshow.jpl.nasa.gov/mbh/series.html)

The time history data for each of these more than 2000 stations is available on the JPL website sideshow.jpl.nasa.gov/mbh/series.html, together with an interactive global map that summarizes these data in a visual way. Fig. 2 is a portion of this map that displays the western Pacific, southeastern Asia, and Australia. These GPS measurements show that the Pacific Plate currently is moving coherently to the west-northwest relative to the trenches on its western margin at a rate of about 7.5 cm/yr. They show that India is moving as a coherent block to the northeast relative to the region to the north. They show that Australia is moving north-northeastward as a coherent block toward the ocean trenches to its north.

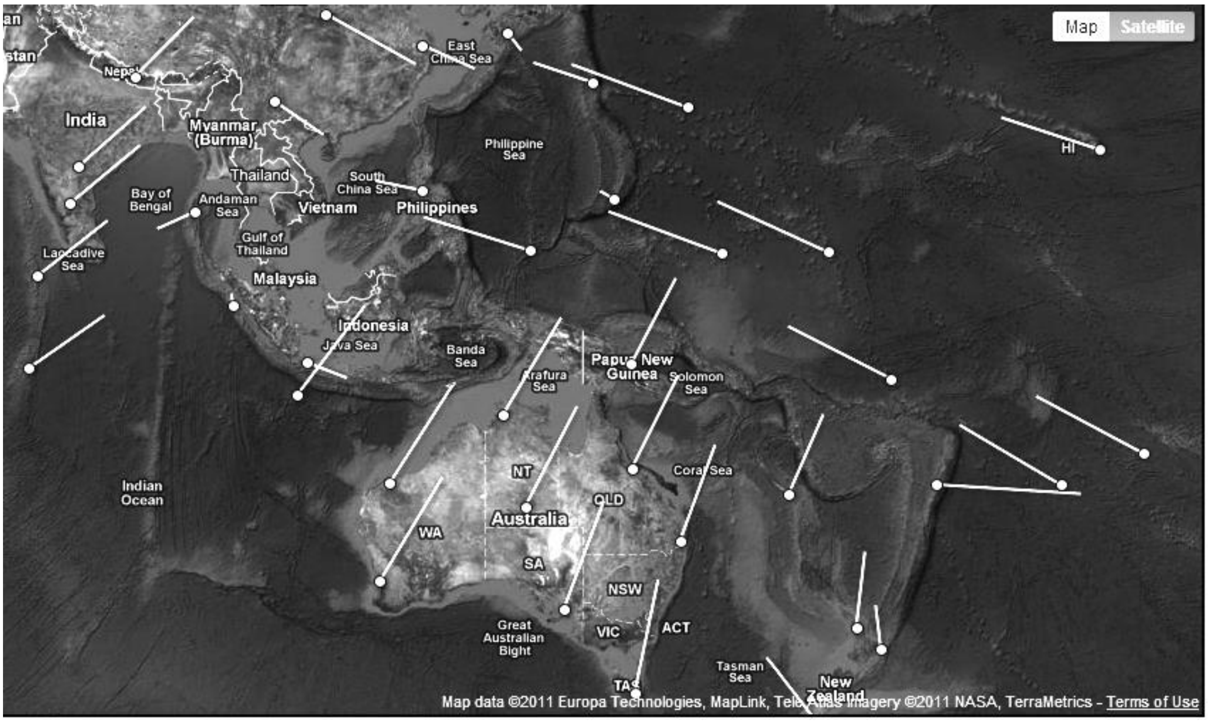

Figure 2. Displacement rates of GPS stations in the western Pacific region as compiled by JPL. (Source: sideshow.jpl.nasa.gov/mbh/series.html)

Elsewhere these data show that sites west of the San Andreas Fault are moving northwestward relative sites to the east of the fault by several cm/yr. They also document that Easter Island on the Nazca Plate in the southeastern Pacific is currently moving eastward at about 7 cm/yr. This implies seafloor spreading is occurring across the East Pacific Rise to the west of Easter Island at a rate of about 14 cm/yr.

These measurements demonstrate, with little room for debate, that plates are real entities and that they are currently in motion across the face of the earth. The measurements document the reality of plate divergence, or spreading, across the mid-ocean ridge system. With equal clarity they document the reality of plate convergence, that is, subduction, at deep ocean trenches. They also document the reality of transform faults, such as the San Andreas, along certain portions of plate boundaries. In other words, these data document the reality of the defining aspects of plate tectonics in operation in our world today. It is hard for me to imagine an alternative explanation. Nevertheless, I am eager to learn about the ones Oard mentioned but did not describe.

Earthquakes reveal lithospheric deformation is localized at plate boundaries

Oard makes the further claim that the inclined zones of intense seismicity adjacent to the deep ocean trenches, known as Wadati-Benioff zones, likewise admit "other, non-PT, explanations." Again, he provides no clue as to what those other explanations might be. Like the GPS measurements, the distribution and character of earthquakes that occur on a daily basis across the world testify powerfully to the present reality of plate motion. Fig. 3 shows the distribution of earthquakes of greater than 4.5 magnitude for the period 1991–1996 as compiled by the U.S. Geological Survey. These earthquakes display a strong correlation with plate boundaries. Furthermore, the deep events are associated exclusively with the zones of plate convergence.

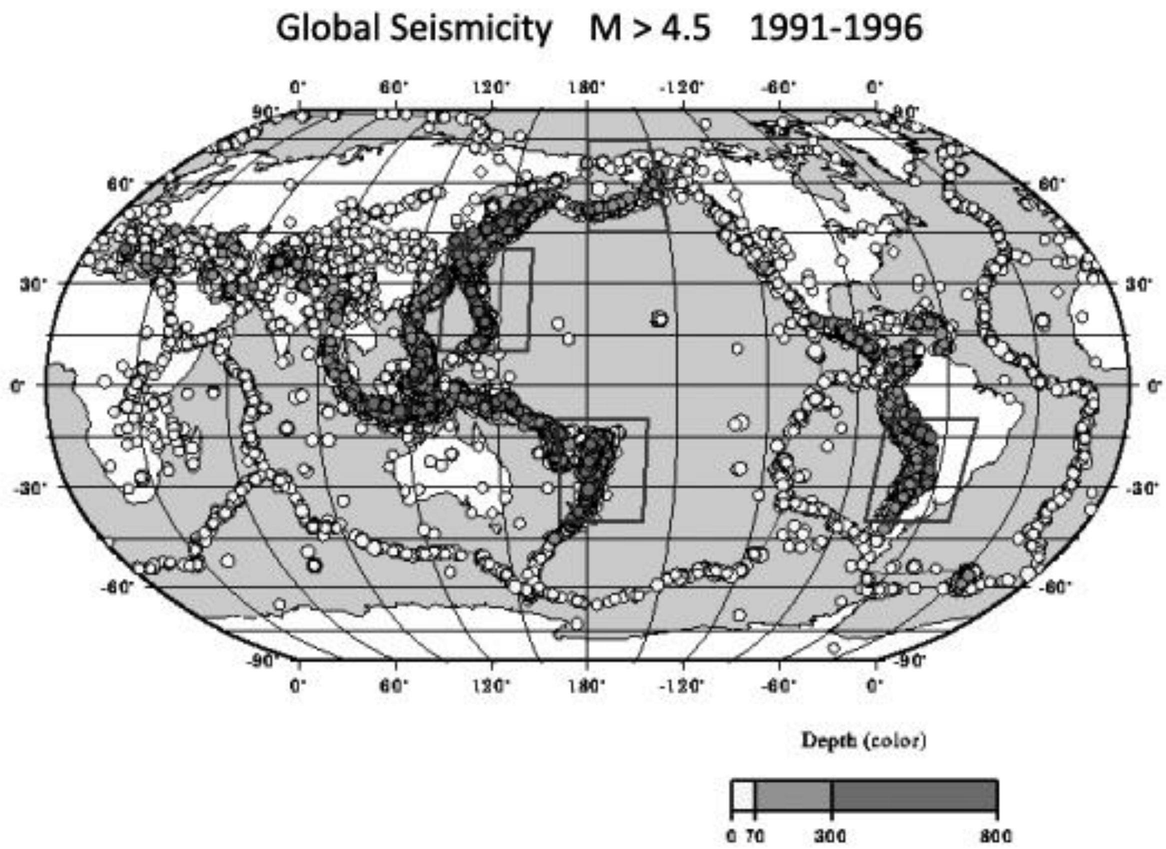

Figure 3. Global distribution of earthquakes with magnitudes greater than 4.5 during years 1991–1996, as compiled by the U. S. Geological Survey. (Source: earthquake.usgs.gov/earthquakes/world/world_density.php)

Earthquakes represent an important diagnostic of zones of deformation in the lithosphere. For an earthquake to occur, the rock must be cool enough to deform in an elastic manner. In general this means that to support earthquakes rock temperature must lie below the brittle–ductile transition temperature, which for granitic crust is about 300°C and for olivine-rich ocean lithosphere is about 600°C.[3],[4] Below this transition temperature, rock behaves elastically and stores elastic energy as it is deformed. Above this transition temperature, rock deforms in a ductile or plastic manner, and there is no storage of elastic energy. Earthquakes therefore indicate that the surrounding rock is at a sufficiently low temperature to be able to store elastic energy.

Earthquakes are also diagnostic in that they reveal where deformation is actually taking place. If there is no deformation, there is no accumulation of elastic energy and hence none to be released in an earthquake. The general paucity of earthquakes in plate interiors indicates that there is little deformation occurring there. By contrast, the high density of earthquakes at plate boundaries reveals that most of the deformation occurring across the earth's surface today is taking place precisely along these boundaries.

So what do the zones of intense seismicity which deepen with distance from an ocean trench, that is, the Wadati-Benioff zones, represent? From what we know from rock physics, the high seismicity means that cooler rock is present and also that this rock is undergoing active deformation. Is it not an entirely reasonable inference that the cooler rock in which these earthquakes occur is cool because it is part of a subducted oceanic lithosphere slab, especially in view of the geometry of these zones? Laboratory experiments indicate that deep-focus earthquakes, 300–700 km below the surface, occur by a somewhat different mechanism than shallow earthquakes, but this mechanism also involves rapid sliding on a fault plane in cold elastic rock as in the shallower events.[5] I am currently not aware of alternative explanations for the presence of cold, actively deforming rock in such a special geometrical relationship to the ocean trenches at depths up to 700 km, so I am eager to learn about them.

On the other hand, the GPS measurements, which now have such high precision and such wide coverage, in concert with the earthquake data, which reveal so precisely where and how the lithosphere is currently deforming, to me testify in a convincing way the reality of active plate tectonics in our world today.

Black smokers and ridge topography testify to the reality of seafloor spreading

Additional evidence supporting this conclusion are the hot water vents, or 'black smokers', observed along the mid-ocean ridges, as shown in Fig. 4.[6] Moreover, the elevated topography of the ridges also indicates elevated temperatures in the underlying rock column at the present moment, consistent with the spreading process.[7]

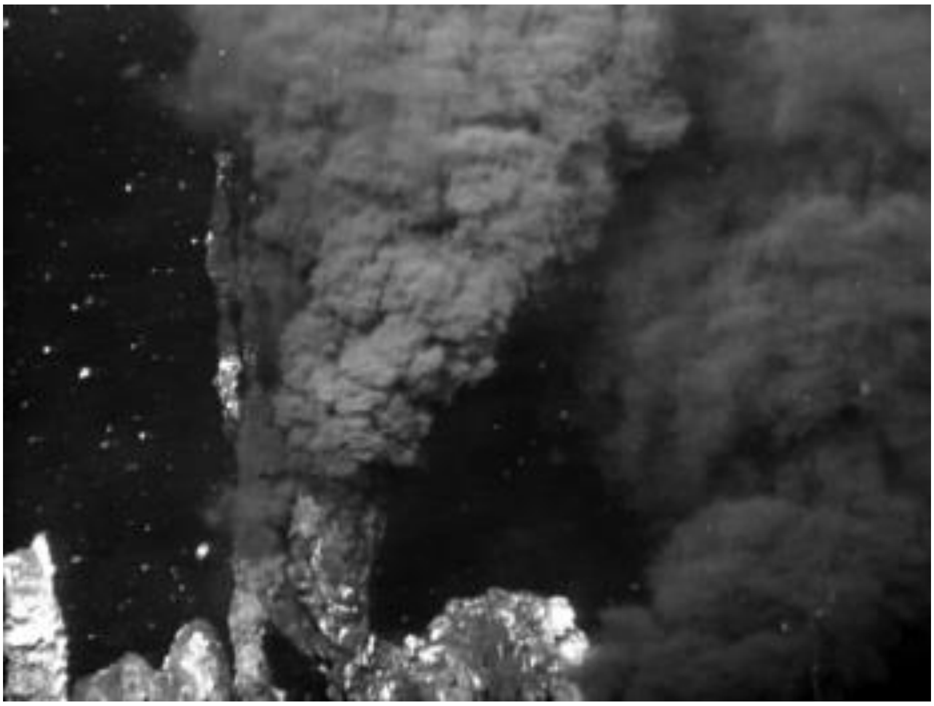

Figure 4. High-temperature black smoker vent at South Cleft, Juan de Fuca Ridge, NE Pacific. July 2000 ROPOS dive 542. Photo courtesy of NOAA PMEL Vents Program, www.pmel.noaa.gov/vents/gallery/smoker-images.html.

Mega-earthquakes testify to the reality of subduction

In addition, the mega-earthquakes occurring in the world today, including the magnitude 9.0 Tohoku event off the coast of Honshu, Japan, in March 2011, likewise testify to the present reality of plate motion and subduction.[8] Figure 5 shows the displacement of the land surface in Honshu in response to the Tohoku earthquake as documented by the change in location of

451 separate GPS stations. This east-southeasterly motion represents elastic rebound of the body of rock of which Honshu is a part that resulted from the slip and stress release on the fault plane below. The elastic rebound of the downgoing plate presumably was of similar amplitude but in the opposite direction. This means that the downgoing plate in some places slipped, or subducted, some 8 m (26 ft) relative to Honshu into the mantle beneath. With this portion of the fault locked for more than a century, the westward motion of the Pacific Plate relative to Honshu produced considerable accumulated elastic shortening in both plates. The presently measured rate of 7.5 cm/yr implies 7.5 m of total shortening per century. Analysis of the seismic waves generated by this event yielded a dip angle for the fault plane of 14° to the west-northwest. The rectangular box in Fig. 5 encloses the portion of the dipping fault plane over which most of the slip occurred. The Global Seismographic Network, with more than 150 state-of-the-art digital seismic stations, currently provides real-time open access data from which details concerning the focal mechanism, the slip plane, the area and magnitude of slip on the slip plane, and the earthquake magnitude can be determined. Such analyses reveal, as in the case of the Tohoku event, the reality of subduction in these contexts.

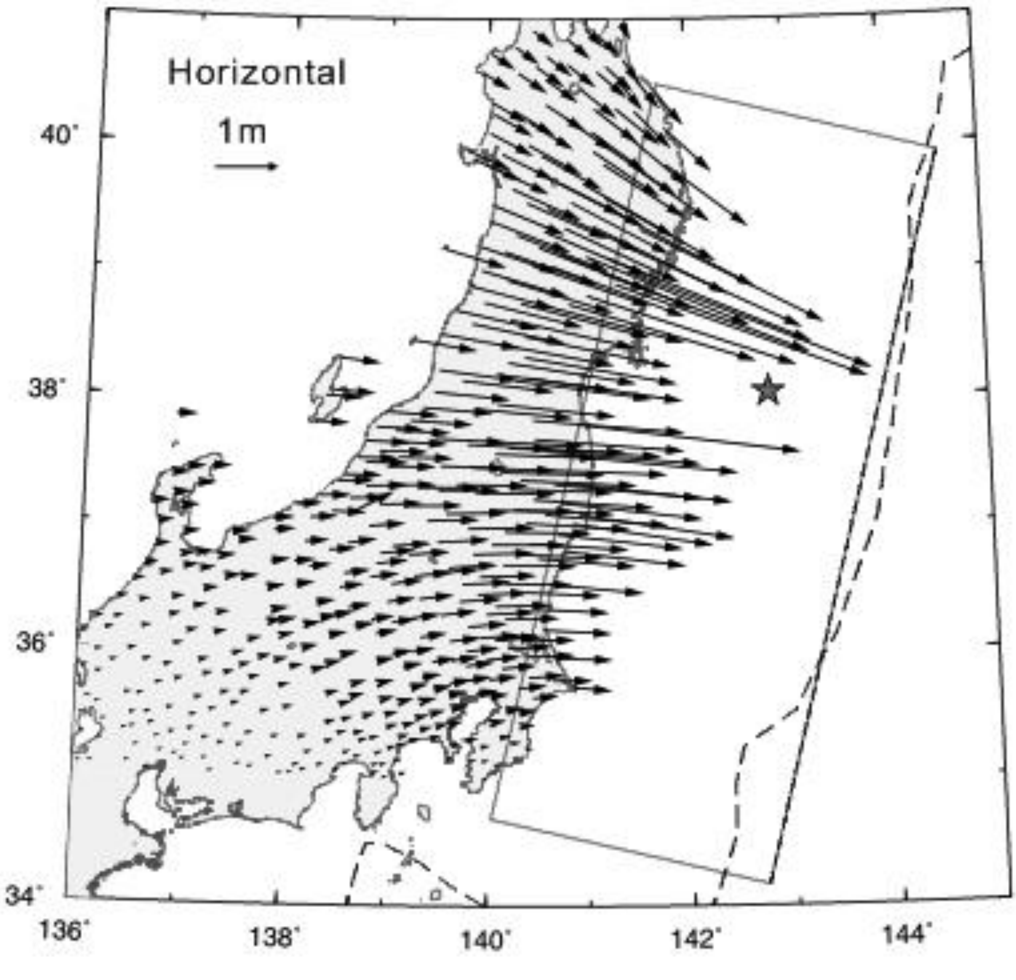

Figure 5. GPS coseismic surface displacements of the 2011 Tohoku earthquake using 2-day site positions of 451 stations before and after the main shock, whose epicenter is marked by the star. Dashed line marks trench location. (Source: www.earth.sinica.edu.tw/~sjlee/eqks/20110311v2/index.htm)

Volcanoes behind trenches confirm the reality of subduction

Additional evidence that points to the present reality of plate tectonics is the current pattern of volcanic activity occurring across the face of the earth. Fig. 6 displays the locations of volcanoes that have erupted since 1964. The vast majority of these volcanoes are adjacent to deep ocean trenches where active plate convergence is currently taking place. Many of the remainder are on ocean islands, such as Iceland, Hawaii, Cape Verde, and Tristan da Cunha, or in regions of continental extension such as in East Africa. Why should there be volcanism associated with plate convergence? The basaltic crust of the downgoing slab generally contains a moderate amount of water in its pores and fractures as well as within its hydrated minerals. As the slab descends to depths on the order of 100–150 km, its basaltic crust encounters sufficient temperature and pressure to cause this water to be released into the hot mantle rock above.[9] Water, in turn, has the effect of lowering the melting temperature of this overlying mantle rock sufficiently to initiate partial melting. The buoyant basalt magma which this partial melting generates has a low viscosity and is usually able to rise to the surface to produce volcanoes. The volcanism we observe today so closely associated with the deep-ocean trenches, particularly along what is known as the 'Pacific Ring of Fire', hence has a simple and plausible explanation. As such, it represents another important complementary strand of observational evidence that plate tectonics is indeed a truthful description of the dynamics of the earth's lithosphere in the present day.

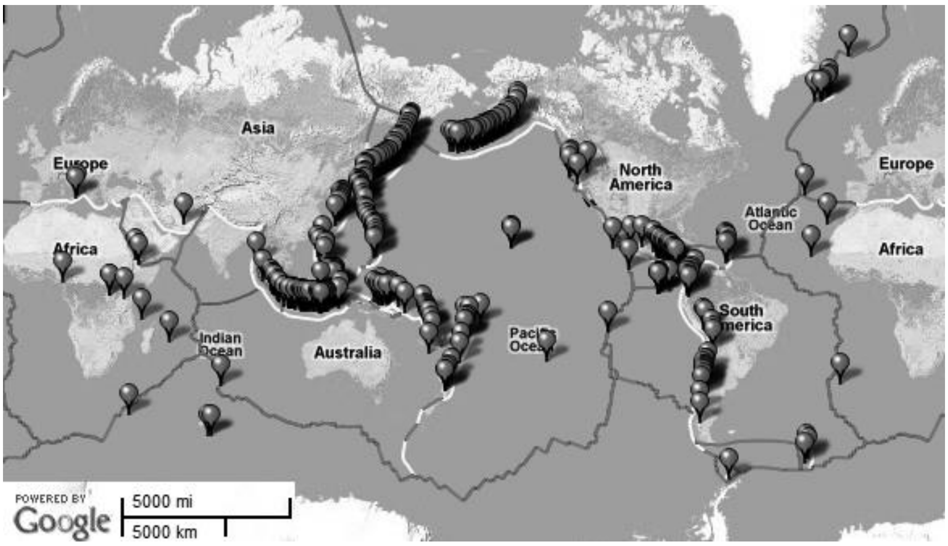

Figure 6. Global distribution of volcanoes that have erupted since 1964. (Source: Smithsonian Institution, Global Volcanism Program, from www.geocodezip.com/v2_activeVolcanos.asp)

50–100 km of magma beneath mid-ocean ridges?

In his response to my letter in *Journal of Creation* **25**(2), Oard raises what he considers a problematic issue for plate tectonics. Somehow he concluded that a 700°C higher average temperature in a 50–100 km rock column beneath a mid-ocean ridge, compared with such a column in the lithosphere well away from the ridge, would require the column beneath the ridge to be *molten*. I certainly never intended to give this impression. Nothing in the professional literature suggests this even as a possibility. Perhaps the sketch in Fig. 7 showing the relationship of a plate and the asthenospheric mantle beneath as the plate migrates away from a ridge will help clarify the issue. This trend of rapidly increasing lithospheric thickness as a function of distance from a ridge is constrained by seafloor heat flow, by seafloor topography, and by Love and Rayleigh seismic surface wave velocity measurements.[10] These datasets indicate that oceanic plate thickness reaches a maximum value of about 90–100 km.[10]

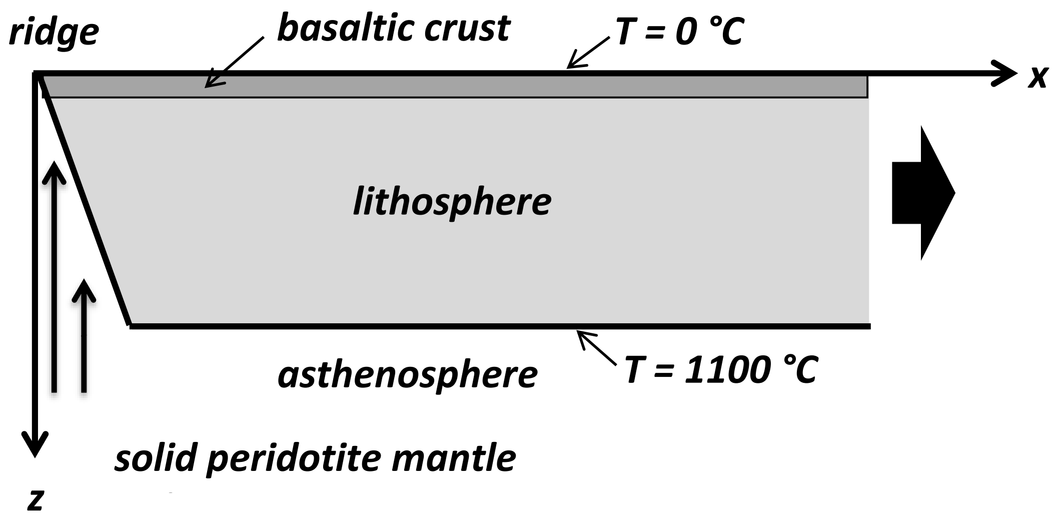

Figure 7. Sketch showing slab of oceanic lithosphere bounded by 0°C and 1100°C isotherms adjacent to a mid-ocean ridge. Passive upwelling of solid peridotite mantle rock from the asthenosphere fills the volume displaced by the slab as it moves to the right relative to the ridge. Peridotite is composed mostly of the minerals olivine and pyroxene. Partial (up to 20%) melting of peridotite beneath the ridge produces basalt that rises to the surface to form the ocean lithosphere crust typically 5–7 km thick.

The 1100°C isotherm is here used to define the base of the thermal lithosphere. At temperatures of 1100°C and below, mantle rock displays considerable strength to resist deformation, especially with warmer and much weaker asthenospheric rock below it. A uniform vertical temperature gradient across the slab, consistent with conductive cooling, implies an average slab temperature of about 550°C, independent of its distance from the ridge.

The temperature, known as the solidus, at which the mineral with the lowest melting temperature in a rock first begins to melt, is about 1200°C for the peridotite mantle rock at shallow depths beneath a ridge.[7] Solidus temperature generally increases with increasing depth and pressure. With rock solidus temperatures below a ridge in the range of 1200–1400°C, it should be evident how the average temperature beneath a ridge can indeed be 700°C higher than within the corresponding depth range in the adjacent oceanic lithosphere and the rock still be mostly solid.

From an observational standpoint, the actual amount of melting that does occur at mid-ocean ridges is tightly constrained by the observed thickness of the oceanic crust, which is the uppermost portion of an oceanic lithospheric plate as shown in Fig. 7. This crustal layer, typically 5–7 km thick, is composed of basalt. Basalt is formed by partial melting of the peridotite mantle rock. From the bulk chemistry differences between mid-ocean ridge basalt and peridotite, laboratory studies constrain the melting fraction of the source rock to be 20% or less.[7] To generate 5–7 km of basalt therefore requires only 10–14% partial melting of a 50 km thickness of mantle rock. Melting temperatures of silicate minerals, as mentioned above, decrease with decreasing pressure or depth. As asthenospheric rock rises passively beneath a ridge as the lithospheric plates move apart, some of the minerals in the upward moving rock which had been fully unmelted can suddenly find themselves above their individual melting temperatures and begin to melt. This process is commonly known as *decompression melting*. After only a few percent partial melting, the molten fraction begins to mobilize, move between mineral grains, and migrate toward the earth's surface. According to the best diagnostics available, this is the way in which the basalt currently forming today's new ocean crust is being generated.

Apparently, Oard's failure to understand these aspects of mid-ocean ridges allowed him to construct a straw man picture of 50–100 km of *fully molten rock* beneath a ridge, a picture which he then used to ridicule the process of seafloor spreading.

An appeal to move forward

In conclusion, given that the case that plate tectonics—as a present-day reality—is supported by such compelling observational evidence, why should this issue be a subject for debate in creation journals any longer? I find it bewildering why Oard is opposed to the possibility that seafloor spreading and subduction might actually be occurring even in the present day. In his mind, just what in regard to creation science and the Biblical account of earth history is at risk? When one rejects uniformitarianism with its time scale, just where do any remaining conflicts reside? On the other hand, as I have stressed many times before, the plate tectonics picture, involving the earth's mantle as it does, seems to represent a gigantic breakthrough in understanding earth history from a Biblical standpoint. It provides the key to understanding how a cataclysm as dramatic as the Genesis Flood, with the staggering tectonic changes it brought to the earth, could unfold in a moderately orderly way and in so brief an interval of time. With the current ferocity of the attacks on the truthfulness of Genesis 1–11, how can we any longer afford to debate an issue that is already fundamentally resolved? Is it not time to focus our efforts earnestly toward applying the astonishing resources God has provided to realize the defense of a young earth and a recent global Flood that His honor deserves? Never before have such resources existed to accomplish this task as are available today.

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10. Fowler, ref. 7, pp. 288–298.