Catastrophic plate tectonics: the geophysical context of the Genesis Flood

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Any serious model for the Genesis Flood must account for the massive tectonic changes evident in the geological record since the point in that record where metazoan fossils first appear. These tectonic changes include the complete replacement of the world's ocean lithosphere, lateral displacements of continents by thousands of kilometres, significant vertical motions of the continental surfaces to allow deposition of thick and laterally extensive sediment sequences, and large local increases in crustal thickness to generate today's high mountain ranges. Without a mechanism that can account for these major tectonic changes in a logical and consistent manner, any claims about understanding, much less modelling, the Flood cataclysm are hollow at best. The correct mechanism, on the other hand, will provide a framework into which the vast accumulation of detailed geological observations can be understood in a unified, coherent, and comprehensive manner. A major claim of this paper is that the mechanism of catastrophic plate tectonics, enabled by runaway subduction of negatively buoyant ocean lithosphere into the Earth's mantle, does account for the main tectonic changes associated with the Flood and provides the best candidate framework currently available for integrating and understanding the vast store of geological observational data.

The scientific revolution in the Earth sciences that unfolded during the decade of the 1960s established the plate tectonics paradigm as the reigning framework for explaining not only present day geophysical processes but also the large-scale geological change in the past. A major point of this brief paper is that while this scientific revolution correctly recognized many important aspects of the Earth's dynamics and how near surface processes are coupled to phenomena in the Earth's deeper interior, the prevailing uniformitarian mindset prevented the revolution from reaching its logical end, namely, that Earth had experienced a major tectonic catastrophe in its recent past.

The primary new observational data that precipitated this revolution was from the world's ocean floors. Sonar technology developed to detect and track submarines during World War II, for example, had provided the means after the war to map the topography of the ocean bottom at high resolution for the first time. The results were startling. Not only did accurately determined margins of continental shelves reveal the striking jigsaw puzzle fit of North and South America with Europe and Africa,[1] but the global mid-ocean ridge system, running like a baseball seam some 60,000 km around the Earth, was also unveiled.[2] This ridge system, representing a long chain of mountains on the ocean bottom, contained topography some 2,000 m higher than the ocean's abyssal plains.[3] Moreover, its axis displayed curious lateral jumps that came to be known as fracture zones.[4–6] As technology became available to measure heat flow from the ocean bottom, it was found that exceptionally high values of heat flow occurred along the axis of the mid-ocean ridge system.[7] A logical inference was that the elevated topography of the ridge was a consequence of higher temperatures and hence lower densities in the rock beneath.

Another key observation from the seafloor was the discovery of 'magnetic stripes' oriented parallel to the mid-ocean ridges and displaying a near mirror symmetry across the ridge axis.[8] Although evidence for reversals of the Earth's dipole magnetic field had been reported in the early 1900s from studies of successive lava flows on volcanoes,[9,10] it was not until after WWII that careful investigation of rock magnetism established the reality of magnetic reversals in the geological record. Therefore, the discovery that basaltic rocks forming the ocean floor basement were magnetized in alternating directions in a spatially coherent pattern of stripes parallel to the ridge axis generated considerable interest. It was realized this pattern suggested a means for mapping the relative time of formation of vast areas of the ocean floor basement rocks and correlating this history with the record of continental volcanism. (This correlation can be done without any reference to or use of radioisotope methods or time-scale.) The correlation is achieved simply by counting magnetic reversals backward in time from the present.

These observations were compelling enough by the mid-1960s for significant numbers of Earth scientists to embrace the proposition that sea-floor spreading was genuine. However, it was data from the first deep sea drilling expedition by the *Glomar Challenger* in 1968 in the South Atlantic that for many removed all doubt. Nine sites from the east side of the Mid-Atlantic ridge to a point just off the continental shelf southeast of Rio de Janeiro were drilled to basaltic basement.[11] Most of the sediment cores contained abundant microfossils—calcareous nannoplankton and planktonic foraminifera—of species already known from studies in continental shelf environments. These microfossils ranged in stratigraphic affinity from lower Cretaceous to late Pleistocene, with stratigraphic age of the fossils just above basaltic basement increasing progressively with distance from the ridge axis. These data now made it possible to correlate the age of the basaltic ocean basement with the sediment record on the continental shelves. They revealed the South Atlantic Ocean floor to be younger, relatively speaking, than early Mesozoic sediments on the continents and implied South America and Africa had been joined prior to that point in Earth history. Subsequent deep sea drilling of more that 2,000 holes through the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP) have served to confirm to an overwhelming degree of confidence that none of today's ocean floor basement anywhere on Earth is older than Mesozoic relative to the microfossil record[12] (a well documented record that exists independent of radioisotope methods).

Yet another feature from the ocean floor played a crucial role in the acceptance of the plate tectonics framework, namely, the deep trenches that ring much of the Pacific Ocean and north-east Indian Ocean. Associated with these deep trenches, almost without exception, is the occurrence of spectacular volcanic activity and large earthquakes. Careful study of earthquake locations and depths by H. Benioff in the late 1940s revealed earthquakes occur on giant fault-like surfaces 650 km in depth and up to 4,500 km in length beneath western South America and the Tonga-Kermadec region in the western Pacific.[13] Investigations by Benioff in the early 1950s showed similar planar distributions of earthquakes beneath the Sunda arc adjacent to Indonesia, inboard of the Kurile-Kamchatka trench, the Bonin-Honshu trench, the Aleutian arc, and beneath Mexico and Central America, the New Hebrides, and the Philippines.[14] He found an average dip angle of 33° for zones under continents in the depth range from 70 to 300 km and of 60° for greater depths. Benioff further determined a thrusting sense of motion in all these zones. He also reported a remarkably constant relationship between the surface location of volcanoes and the depth of the inclined planar seismogenic zone below. These planar features became known as 'Benioff zones'.

With the evidence for seafloor spreading so compelling, it became clear in the early 1960s that unless the Earth is expanding, the new ocean floor generated at a mid-ocean ridge must be compensated by the loss of ocean floor by subduction at an ocean trench. The evidence first compiled by Benioff was recognized as strong support for ocean plates plunging into the mantle at boundaries with other plates. Since the 1980s the field of seismic tomography[15] has been able to image the plunging slabs of ocean lithosphere, in some cases all the way to the core-mantle boundary.[16] With the clear evidence from seismology for subduction and the lack of a mechanism for large differential expansion of the Earth's interior relative to its surface, discussion of the possibility of Earth expansion has now all but disappeared from the Earth science community.

Logical imperatives

The items discussed in the previous section deal primarily with observational data, much of it from the ocean basins, that led to acceptance 30–40 years ago of a new understanding of the Earth known as plate tectonics, a conceptual framework that includes the notions of continental displacement, seafloor spreading, and subduction of oceanic lithosphere. How do these observations and this conceptual framework relate to the Genesis Flood of the Bible?

First, I am convinced the Biblical text requires the beginning of the metazoan fossil record to coincide with the beginning of the Genesis Flood, and most of the subsequent fossil record to be a product of that year-long event. The observational data of the previous section then implies a staggering amount of tectonic change must have accompanied the Flood cataclysm. In attempting to put the pieces of this geological/tectonic puzzle together, I consider the piece with the greatest importance to be the set of observations that constrain the present ocean basement to be no older than the Mesozoic portion of the continental fossil record. This requires, from a logical standpoint, the entire pre-Flood ocean floor, as well as any generated when the Paleozoic fossils were being deposited, to have vanished from the Earth's surface.

It therefore seems a logical imperative that any viable candidate model for the Flood catastrophe accounts for this monumental fact. That is, explaining where the pre-Flood ocean floor went and how the present ocean floor came to be is an inescapable logical requirement for any serious Flood model. If one also includes the compelling evidence the present ocean floor was formed progressively and simultaneously with the deposition of Mesozoic and Cenozoic fossils, then any successful model must also account for thousands of kilometres of seafloor spreading and continental displacement. In summary, the data responsible for the plate tectonics revolution within the secular Earth science community places major logical constraints on how people who realize the Bible is indeed God's Word seek to interpret the geological record. But instead of a hindrance, the observations responsible for the plate tectonics revolution provide a dramatic conceptual breakthrough for defending the Genesis Flood to a sceptical world in ways not possible in previous centuries. In a nutshell, I am persuaded the Genesis Flood was primarily a *tectonic catastrophe* that effectively resurfaced the planet in a few months' time, destroyed all the non-marine air-breathing life except that providentially saved by God, and left a powerful testimony of that cataclysm in the rocks all around us.

Can plate tectonics happen quickly? Clues from mineral physics and Venus

At least as far back as the early 1960s it has been known that for materials whose effective viscosity is described by an Arrhenius-like relationship[17] the phenomenon of thermal runaway can potentially occur. The viscosity of such materials varies as $e^{(E^*/RT)}$, where T is absolute temperature, E* is the activation energy, and R is the gas constant. A large variety of materials including silicate minerals behave in this manner. In particular, Gruntfest in 1963 showed that, with this type of temperature dependence of viscosity, both the deformation rate and the temperature of a viscous fluid layer subject to constant shear stress increase without limit, that is, run away.[18] What is required is that the time constant associated with viscous heating be much smaller than the characteristic thermal diffusion time of the layer. Several investigators explored the possibility of thermal runaway of lithospheric slabs in the mantle in the late 1960s and early 1970s. Anderson and Perkins, for example, suggested that the widespread Cenozoic volcanism in the southwestern US might be a consequence of thermal runaway of chunks of lithosphere in the low viscosity upper mantle with resulting surges of melt expressed in episodes of volcanism at the surface.[19] Such lithospheric slabs, because of an average temperature some 1,000 K or more lower than that of the upper mantle but with a similar chemical composition, are several percent denser than the surrounding rock and therefore have a natural ability to sink. The gravitational body forces acting on a slab lead to high stresses, especially within the mechanical boundary layer surrounding the slab. As a slab sinks, most of its gravitational potential energy is released in the form of heat in these regions of high stress. If conditions are right, the weakening arising from heating can lead to an increased sinking rate, an increased heating rate, and greater weakening. This positive feedback can result in runaway.[20]

Experimental studies of the deformational behaviour of silicate minerals over the last several decades have revealed the strength of such materials also depends strongly on the state of stress. At shear stresses of the order of 10^{-3} times the low-temperature elastic shear modulus and temperatures of the order of 80% of the melting temperature, silicate minerals deform by a mechanism known as dislocation creep in which slip occurs along preferred planes in the crystalline lattice.[21] In this type of solid deformation, the deformation rate depends on the shear stress in a strongly nonlinear manner, proportional to the shear stress to approximately the third power. At somewhat higher levels of shear stress, these materials display plastic yield behaviour, where their strength decreases in an even more nonlinear way, in this case inversely with the deformation rate. When these stress-weakening mechanisms are combined with the temperature weakening discussed above, the potential for slab runaway from gravitational body forces is enhanced dramatically. A point many people fail to grasp is that these weakening mechanisms can reduce the silicate strength by ten or more orders of magnitude without the material ever

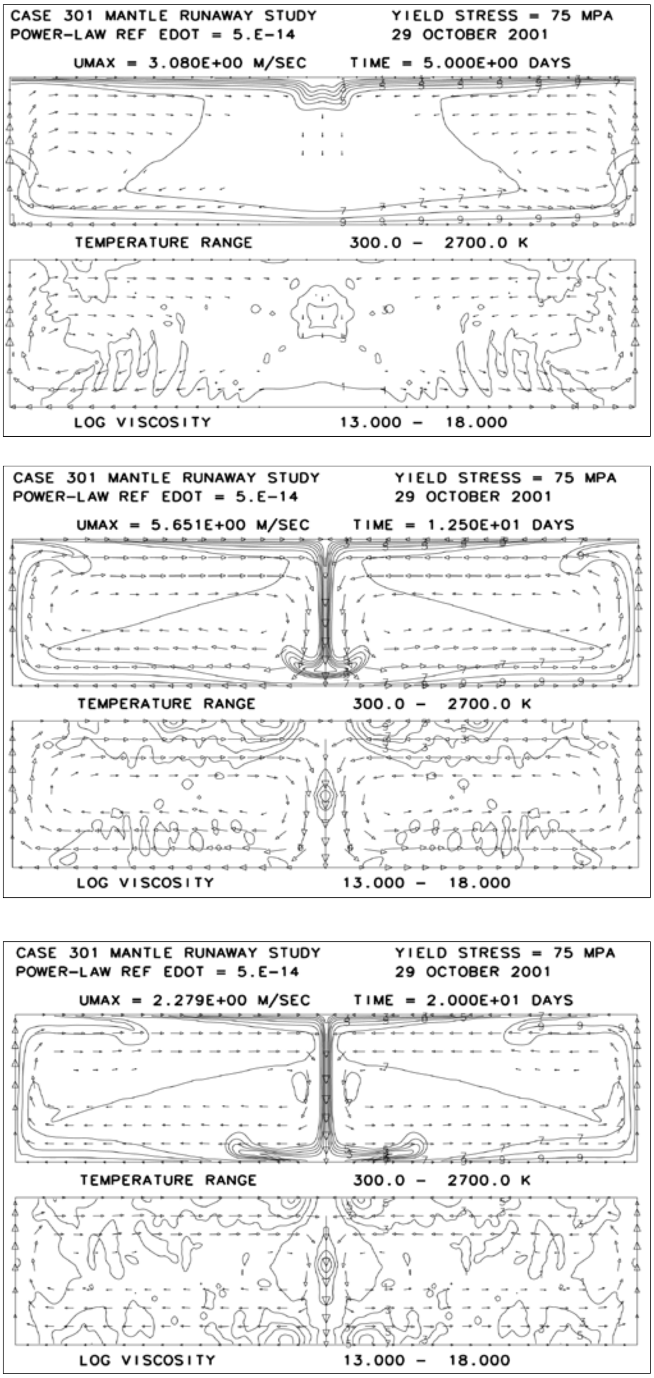

Figure 1. *Three snapshots from a 2-D mantle runaway calculation in a box 11,560 km wide by 2,890 km high at problem times of 5, 12.5, and 20 days. Arrows denote flow velocity and are scaled to the peak velocity 'umax'. Contours denote temperatures in the upper panel and base 10 logarithm of viscosity in the lower panel of each frame. Numbers on the contours correspond to a scale from 0 to 10 for the range of values indicated beneath each plot. A viscosity of* 10^{13} *Pa-s, corresponding to the minimum value in the viscosity plots, represents a reduction in the viscosity by a factor of one billion relative to the strength of the rock material when the velocities are negligible. Much of the domain exhibits viscosity values near this minimum during the runaway episode. Deformation rate-dependent weakening, observed experimentally in silicate minerals, is the crucial physics underlying the runaway process.*

reaching its melting temperature.[21]

The NASA Magellan mission to Venus in the early 1990s revealed that Earth's sister planet had been globally resurfaced in the not so distant past via a catastrophic mechanism internal to the Venus mantle.[22] Magellan's high-resolution radar images showed evidence of extreme tectonic deformation that generated the northern highlands known as Ishtar Terra with mountains having slopes as high as 45°.[23] More than half of the Venus surface had been flooded with basaltic lava to produce largely featureless plains except for linear fractures caused by cooling and contraction. Runaway sinking of the cold upper thermal boundary layer of the planet seems the most plausible mechanism to explain such catastrophism at the surface.[22] Given such clear and tangible evidence for runaway in a planet so similar in size and composition as Venus, it is not unreasonable to consider lithospheric runaway as the mechanism behind the global scale catastrophism so apparent in the Earth's Phanerozoic sedimentary record.

Numerical modelling of the runaway mechanism

Numerical methods now exist for modelling and investigating this runaway mechanism. Considerable challenge is involved, however, because of the extreme gradients in material strength that arise.[24,25] W.-S. Yang focused much of his Ph.D. thesis research effort at the University of Illinios on finding a robust approach for dealing with such strong gradients in the framework of the finite element method and an iterative multigrid solver. He showed what is known as a matrix dependent transfer multigrid approach allows one to treat such problems with a high degree of success. Although his thesis dealt with applying this method to 3-D spherical shell geometry, he subsequently developed a simplified 2-D Cartesian version capable of much higher spatial resolution within current computer hardware constraints. Details of this method together with some sample calculations are provided in a recent paper.[26] Figure 1 shows three snapshots using this 2-D code from a case in which runaway occurs. Note that runaway diapirs emerge from both top and bottom boundaries. The upwelling from the lower boundary releases gravitational potential energy stored in the hot buoyant material at the base of the mantle. Such upwellings from the bottom boundary have dramatic implications for transient changes in sea level during the Flood since they cause a temporary rise in the height of the ocean bottom by several kilometres.

Toward a full 3-D simulation

In a paper presented at the 1994 *ICC* in Pittsburgh, I showed that a 3-D spherical shell model of the Earth's mantle initialized with surface lithospheric plates corresponding to an approximate Pangean configuration of the continents and bands of cold rock along the Pangean boundary yields a pattern of plate motions that resemble in a remarkable way the inferred Mesozoic-to-present plate motions for the Earth.[27] This solution was obtained simply by solving the conservation equations for mass, momentum, and energy in this spherical shell domain starting from relatively simple but plausible initial conditions. Such a calculation confirms that subduction driven mantle flow, with very few other assumptions, generates the style of plate motions recorded in the rocks of today's ocean floor. Although this calculation simply adopted the reduced viscosity observed in high resolution 2-D calculations during runaway, with continued improvements in computer technology it should soon be feasible to achieve the required resolution in the 3-D spherical model to capture the runaway behaviour in a fully self-consistent fashion. The advantage of a 3-D spherical model, of course, is that its output can be compared directly with geological observation. Therefore realization of this crucial objective should be an extremely high priority for those who desire a credible defence of the Flood to a sceptical world.

Geological consequences of a catastrophic plate tectonics episode

What are the consequences at the Earth's surface when the ocean plates, like giant conveyor belts, slide into the mantle in a runaway manner? Let us consider some highlights. First, there is a spectacular eruption of molten rock on the ocean bottom at sites where ocean plates are moving apart at several kilometres per hour. Decompression melting generates the magma as previously solid rock rises to fill the gap and decreasing pressure reduces the rock's melting temperature. With temperatures of the order of 1,500 K, the magma causes the adjacent ocean water to flash to steam at a huge rate. The steam in turn organizes into buoyant supersonic jets that penetrate the overlying layer of ocean water as well as the atmosphere above. Peak velocities in these jets, which form as a more or less continuous sheet above the zone between the diverging plates, can exceed the Earth's escape velocity, and much of the steam escapes to space.[28] Jet velocity is related in a simple way to the ocean depth. These jets are powerfully effective in cooling the newly forming ocean floor while keeping the temperatures in the bulk of the ocean at modest values.

The jets also provide a potent source of water for the 40 days and nights of rain described in Genesis 7. Simple radiation at 373 K of the latent heat of water vapour condensation to space limits the rainfall rate to about 1.75 mm/hr, or 4.4 cm/day. But the high-speed jets entrain vast quantities of liquid water as they rise through the ocean. Droplets launched into ballistic trajectories spread this water over the entire Earth and increase the rainfall rate dramatically. Along the ocean bottom, water feeding the jets reaches velocities in the range of tens to hundreds of meters per second, well beyond the threshold for cavitation. Some of the erupted rock is therefore pulverized and rapidly decomposed into silt- and clay-sized particles that can be entrained by the jets as well.

Another key consequence of the runaway subduction of the pre-Flood ocean lithosphere is a dramatic rise in the sea level relative to the continental surfaces. This occurs mainly because of the pattern of vertical stress near the Earth's surface that the flow inside the mantle induces. Downwelling flow associated with the rapidly sinking lithospheric slabs, mostly below regions of continent, tends to pull the surface down. Similarly, upwelling flow associated with diapirs emerging from the core-mantle boundary, mostly beneath oceanic regions, tends to generate elevated surface topography. These surface deflections are on the order of several kilometres during the runaway episode. The consequence is dramatic flooding of the continent surface. When the gravitational potential energy driving the catastrophe is exhausted, the flow velocities in the mantle diminish to small values, and the stresses responsible for the large surface deflections likewise decrease toward zero. Gravity then restores the surface topography to that given by isostatic balance such that the continents rise and the ocean floor subsides. Water covering the continents then drains into the enlarging ocean basins.

A notable consequence of the flooding of the continental regions is an emergence of giant cyclonic eddies, driven by the Earth's rotation, that circulate over the flooded continents.[29] These water currents are similar in origin to the jet streams in the atmosphere and display comparable velocities of several tens of meters per second. Such currents have the power and scale to transport and distribute the quantities of sediment required to form the thick and laterally extensive sediment blankets that characterize the Paleozoic and Mesozoic portions of the continental sediment record. Since their velocities exceed the threshold for cavitation, these eddies also have considerable erosive power, sufficient for example to erode thousands of meters of crystalline rock from continental shield regions, as the field evidence indicates has occurred. Other sediment sources include the pelagic material scraped from subducting ocean plates at continent margins. In addition to clay this pelagic inventory would contain halite, gypsum, and other salts formed by rapid evaporation of seawater at the base of the steam jets.

Another major consequence of the rapid subduction of the pre-Flood ocean plates is the pulling apart of a pre-Flood supercontinent and the dispersal of the resulting continental blocks. A 3-D calculation previously described[27] shows subduction around a Pangean-like supercontinent causes the supercontinent to pull apart and the resulting continental blocks to move toward their present locations. Such calculations demonstrate the basic fluid dynamics that give rise to the forces responsible for the observed plate motions. Under conditions of runaway, the effective viscosity throughout the mantle is reduced by some eight to ten orders of magnitude, and the velocities are consequently increased by this ratio relative to presently observed plate speeds.

The energy driving this catastrophe is the gravitational potential energy both of the cold, dense pre-Flood ocean plates and of the hot, buoyant rock in the thermal boundary layer at the base of the mantle. When the rock comprising these plates subducts and sinks to the bottom of the mantle and the hot rock at the core-mantle boundary rises to near the Earth's surface, this energy is all converted to other forms and is no longer available to drive the process. The rapid motions in the mantle and in the plates at the surface come to a rather abrupt halt. When this occurs, the steam jets shut down and the high stresses associated with the rapid motions relax. This relaxation of stress has several effects. One is that the continents, which have been pulled downward by the lithosphere sinking beneath them, rebound. Another is that the ocean bottom, which has been dynamically elevated by the rapid upwelling of rock from the base of the mantle, subsides. Yet another is that ocean trenches which previously had depths of tens of kilometres also rebound and shallow dramatically. This reduction in topographic relief of the trenches results in extensional deformation of the sediments they contain.[30] The net result is a decrease in global sea level and a dramatic retreat of the floodwaters from the continents. Retreating floodwaters strip away sediments from continent interiors and redeposit them on continental shelves still below sea level. Continental zones where crustal thickness has been significantly increased from tectonic processes such as subduction bob up like a cork because of buoyancy to form the present day high mountain ranges including the Andes, Rockies, Alps, and Himalayas.

A final consequence is that the resulting increase in ocean temperature produces vigorous atmospheric circulation, increased moisture carried to high latitudes, and the formation of massive ice sheets near the poles following the catastrophe.[31,32]

Conclusion

A major barrier to a credible technical defence of the Genesis Flood for well over two centuries has been the lack of a mechanism consistent not only with the scale and character of the change evident in the geological record but also with the Biblical time frame. The mechanism of catastrophic plate tectonics now provides a coherent explanation for the unique observed character of the record as well as for its short duration.[33] It has a built-in source of energy to drive the process. This mechanism accounts for the data of conventional plate tectonics but also much more, including the ubiquitous evidence in the continental Paleozoic and Mesozoic record for rapid, high-energy, globally-correlated sedimentary processes radically different in character from processes occurring today. Just as the discovery that a genetic language mediates the astounding complexity of all living systems now provides an irrefutable apologetic for the existence of God and His undeniable role as Creator of these systems, catastrophic plate tectonics promises to provide a positive and unstoppable apologetic for the

Genesis Flood and a time-scale consistent with a literal reading of Scripture. Considerable effort yet remains in reorganizing and reinterpreting geological field observations in terms of this new paradigm. As is the case in many other related enterprises, the opportunities are great but the labourers are few.

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