101 Questions and Answers Concerning Catastrophic Plate Tectonics

This set of questions and answers is an outcome of a peer review process that began in early 2009 and continued through the summer of 2011. The review was initiated, organized, and directed by Joe Bardwell, president of In Jesus' Name Productions (IJNP). As described on the IJNP website at www.IJNP.org, IJNP is "a not-for-profit ministry created to be the world's first Christian movie studio. The IJNP vision is to bring together the worldwide body of Christ and leading Hollywood filmmakers to create and release films designed to be both compelling entertainment and high-quality ministry tools for the purpose of maximum spiritual impact throughout the world."

One IJNP movie project currently under development and consideration is a scientifically accurate feature film on the Genesis Flood. As a preliminary step in this project, to explore more fully the science behind the Flood, IJNP hosted a scientific peer review of the leading Flood models and pre-Flood world concepts.

On IJNP's website you can find more details on this peer review process as follows:

An Overview of the Flood Science Review
The Objective of the Review
The Authors who participated
The Panelists who were selected to review each Author's work
The Panel selection process
The Review process
Quotes from Authors and Reviewers concerning the Review

In summary, the peer review process involved, first, the posting of materials describing each Flood model on a special website by the author who would represent the model in the review process. The next step involved the selection of ten scientists to serve as review panelists. The third step was the determination of the set of Flood models to be reviewed. Six models were chosen. These included the vapor canopy model, the catastrophic plate tectonics (CPT) model, the hydroplate model, the solid canopy model, the impact vertical tectonics model, and the collapse tectonics model.

The next step was the actual review. For this process, each review panelist provided a written question to each of the six Flood model authors. Each author then had a specified amount of time, generally a month, to respond in writing to each of the ten questions. Each of the panelists and authors could then review all the questions and answers prior to the next round of questions and answers. There were four such rounds. In the fifth and final round, the panelists could ask as many questions as they desired of each author.

This document is derived from the set of questions and answers pertaining to the catastrophic plate tectonics model which was generated by this review process. Editing mostly involved a shortening of the questions to make them more succinct, since some panelists sometimes included commentary and background which was peripheral to their actual question.

It is hoped that these questions and answers will help elucidate many points which have previously not been so clear for those who have had an interest in the mechanisms associated with the Genesis Flood in general and CPT in particular.

What is not included in this document are my own critiques of the other Flood models, the other author's critiques of CPT, and the panelist's questions to the other authors. Should you desire to download the full Flood Science Review (download), it is available at IJNP, free of charge for a donation of any size to the IJNP ministry.

John Baumgardner

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Questions and Answers

1. How do your efforts to model and understand the tectonics of the Flood square with the historic orthodox Christian view of the authority and sufficiency of Scripture?

Response: I am earnestly persuaded from Scripture that not only is Christian apologetics a legitimate enterprise but it is also an urgent imperative and non-negotiable duty for every generation of those belonging to the Lord Jesus. The apostle Paul points out in 2 Cor. 10, for example, that believers are in a very real war with the forces of darkness and that "destroying speculations and every lofty thing raised up against the knowledge of God" is genuine part of our responsibility in this struggle. Paul himself is an example in his aggressive confrontations against the Judaizers who were advocating a substitute 'gospel'. Both he and the apostle John took an uncompromising stand against the Gnostic errors that were being introduced in their day. Jude admonished his readers to "contend earnestly for the faith which was once for all delivered to the saints." The apostle Peter in the third chapter of his second letter warns his readers of a devastating heresy of the last days, a prediction that indeed has been fulfilled during these past two centuries. This heresy has largely paralyzed the church in our day. One can hardly find a believer anywhere in Western society today, for example, who is willing to quote God's Word in a public venue and to assert its divine authority. The primary reason for this shocking erosion in the confidence in Scripture is, at least in my assessment, is precisely the heresy about which Peter wrote. This heresy, which represents a frontal assault on the truthfulness of Scripture, has gone effectively unchallenged, at least in any serious way, now for more than two hundred years.

Just what is this heresy, and why has it been so difficult to refute? The deception, in Peter's own words, is that "all continues just as it was from the beginning of creation." It is clear from the context that his error has to do with the manner in which the physical history of the earth is to be interpreted. Specifically, it involves a willful denial of the Flood cataclysm. If the reality of the Genesis Flood is the central issue relating to the viability of this heresy, why is it then that the church has been so impotent in demonstrating its reality to the skeptics? After all, the water-laid sedimentary rocks almost everywhere around us commonly contain fossils, with frequent evidence that animals were buried while still alive. Moreover, such thick sequences of sedimentary rocks blanketing such vast areas of the normally high-standing continents should obviously be testifying that some drastically different circumstances must have prevailed in the past compared to what we observe occurring today. So, again, why have Christians been so impotent in defending the reality of this world-destroying event so prominent in Scripture?

The answer, in my assessment, is fairly simple. The reason is that until not so long ago Christians were *utterly at a loss for a mechanism* that could produce the staggering amount of geological change evident in the fossil-bearing portion of the rock record within the short span of time provided in the Genesis account. Without a credible mechanism, they were at a distinct disadvantage in the contest to provide the best explanation for the rock record. As decade after decade and generation after generation passed without an effective answer to the challenge laid down by James Hutton in 1795 and refined by Charles Lyell through a large part of the nineteenth century, the tendency for Christian believers was to withdraw, to retreat more and more, and to allow the uniformitarian side to win by default.

However, in what I believe was God's providence, about fifty years ago there was a major discovery within the mainstream earth science community. The discovery was that the earth's interior was not as strong and rigid as seismologists had been claiming and that, in fact, the solid earth was a much more dynamic entity than even most specialists had ever imagined. The decade of the 1960's witnessed a genuine paradigm shift like Thomas Kuhn had just described in his 1962 book, *The Structure of Scientific Revolutions,* within the earth science community. By 1970 the vast majority in that community were persuaded that the new concept of plate tectonics, which included the formation of new ocean floor along the mid-ocean ridge system and subduction of older ocean floor into the deep ocean trenches, was basically correct. This new framework unleashed a huge amount new effort to explore and seek to understand the

world's seafloor. Already by 1970 the conclusion seemed to be secure that all of seafloor crustal basement rocks were basaltic in composition, that this basalt had been generated at a mid-ocean ridge via partial melting of mantle rock below as part of the seafloor spreading process, and that all of crustal basement rocks of today's ocean floor were no older than Mesozoic in age. Among the implications were that the entire Atlantic ocean floor had formed since the early Mesozoic and that both North America and South America had moved westward away from Europe and Africa by some three thousand miles since that point in the geological record.

Let me connect these dots with my own life. I was saved at age 26 in 1970, mainly through a verse-by-verse study of the gospel of John in a college Sunday School class while in an electrical engineering Ph.D. graduate program. My conversion was a dramatic one. My desire to understand spiritual things prompted me to begin reading though the New Testament approximately once per week as well as several books per week from the local Christian bookstore. After a few months I found that the primary motivations I had had for my academic pursuits were simply no longer that relevant. Through my undergraduate participation in ROTC I had earned an Air Force commission and with it a four-year active duty obligation. I therefore asked the Air Force to terminate the educational delay which I had earlier requested in order to attend graduate school and to assign me to active duty. I was assigned to the Air Force Weapons Laboratory at Kirtland Air Force Base in New Mexico where I served for four years engaged in classified research. This was an especially exciting time of Christian growth for me as a young Air Force officer. As I approached the end of the four years, I sensed Christ calling me to some sort of full-time ministry work.

I sensed His leading to join the staff of Campus Crusade for Christ and was assigned to campus ministry at the University of Kentucky. One very distressing thing I noticed almost immediately on campus was the rampant devastation that was taking place in the lives of students from Christian homes, as atheist professors, beginning with the first freshmen semester, were deliberately seeking to destroy their faith. For many of these students from rural Kentucky, it was the first generation that anyone in their family had attended college. Girls from these Christian homes were becoming pregnant and having abortions. The primary tactic these professors were using was to press the claims of evolution to argue that the Bible was nothing more than a collection of fables. Witnessing this tragedy caused righteous anger to rise within me. I still remember the feelings.

Because of my scientific background, the campus director had assigned me the responsibility to help organize an outreach activity by Probe Ministries from Dallas that involved classroom lectures by guest speakers on their staff. One outcome of this outreach was securing a speaking opportunity for myself the following semester in a freshman zoology class under a professor who could not fit the Probe speaker into the current semester's schedule. I got a copy of the Probe speaker's slides, added some of my own, and did my first creation/evolution lecture that next semester to about 300 mostly freshmen students. The professor asked me for five questions for his next hour exam and told the students they were responsible for the content of my lecture. That launched my career in speaking on this very important topic.

I next began doing evening forums on the creation/evolution issue on other campuses where, before the event, we would saturate the campus with flyers advertising the meeting and pointing out that evolution was scientific nonsense. That plan never failed to bring out crowds of several hundred people. In these forums I began with about 45 minutes of slides and then opened the meeting to questions from the audience. I sensed I made most of my points with the audience during the question time. Whereas I could go on the attack in biological areas with almost no concern about challenge from the audience, I took what was basically a defensive tact in the domain of geology. In my slides I would show a number of field examples of catastrophic and large scale water processes in order to make the case that catastrophism on large scales in the geological record was essentially undeniable. This approach somehow always seemed to preempt the serious challenges on the geological front during the question time. Nevertheless, I was keenly aware that, if asked whether or not I had a positive alternative to the standard uniformitarian model for how the earth came to be as it is today, I would have to admit that I did not.

Although my speaking on the origins issue was a small part of my overall campus ministry, the word did get out about it. I was invited to speak at a few Campus Crusade retreats and some people in leadership roles heard my presentations. They inquired if I might be able to make my materials transferable so that other staff might be able to use them. It was suggested I spend my third year on staff at Campus Crusade Headquarters in California to undertake this project, which I accepted. During that year I was able to research some of the issues I had not had the opportunity to research before. One topic I explored was what connection if any the new concept of plate tectonics might have to the Genesis Flood. The result was an acute realization that, not only did this new understanding about the earth relate to the Flood, it had the potential for explaining it as no one had been able to do before. I realized that if all today's ocean floor is Mesozoic or younger in age, then a massive amount of seafloor spreading and subduction logically must have taken place during the Flood. Moreover, if all of today's seafloor formed during the Flood, then all the pre-Flood seafloor must also be missing from the earth's surface today. The only plausible place it could have gone is into the mantle by rapid subduction. This implied that the Flood must have been a huge tectonic catastrophe involving extremely rapid subduction and seafloor spreading. I realized this insight was profoundly significant for defending the Genesis account of the Flood specifically and the Biblical time scale in general. So my prayer to God was that He earnestly move upon a believing geologist to allow this exciting result to impact the world. But somehow I did not have a sense of peace. This was in the springtime of 1978.

After a few weeks I visited a creationist geologist whom I had met previously, Dr. Ariel Roth, at Loma Linda University, not far from where I was living in San Bernardino. I shared the conclusions I had reached concerning the implications that plate tectonics observations had for the processes involved in the Flood. I also acknowledged my own almost complete lack of background in earth science since most of my training had been in physics and engineering. I wanted his candid opinion as to whether or not, given my lack of expertise in earth science, I might have missed some vital point that would render my conclusions invalid. Dr. Roth displayed genuine interest, and while mentioning some aspects of the Flood that he felt this style of tectonics did not seem to resolve, he nevertheless left me feeling greatly encouraged. I then sought counsel from several other individuals I respected. As a result of these contacts I began to wonder if perhaps God might somehow be calling me to do something with this idea, despite the fact I had never taken even one undergraduate course in geology.

To make a longer story short, by the summer of 1978 I made the decision to leave Campus Crusade for Christ and to enroll in a Ph.D. program in the Department of Earth and Space Sciences at UCLA. The objective was to obtain the training and credentials to work on the mechanism behind the Genesis Flood at a professional level. I was keenly aware that this was an extremely high risk venture. The task was so huge that, if God was not truly calling me to it, I was on a course to waste some of the best years of my life. It was a conscious step of faith. Whereas I had genuine uncertainty at first, after the doors I saw to open at UCLA, doubt was no longer an honest option. Whereas when I entered the program at UCLA, I could not even conceive how dissertation research I might undertake relating directly to the Genesis Flood might be accepted and approved, I witnessed that very thing take place in a relatively routine sort of way. I could never have imagined that my thesis work would place me, for a while at least, within the inner circle of the international geophysics community and also would open to me a permanent position in the prestigious Theoretical Division at Los Alamos National Laboratory with ample time to pursue my Flood-related research. From that point until today I have continued to sense and have sought to fulfill the calling Christ placed on my life in the late 1970's.

This then is background from which I come to this question. In summary, I believe that finding and developing the model of the Flood that agrees with what actually took place during that momentous event in the earth's past is extremely important to an effective defense of the Bible and the Christian faith at this moment in history. I am persuaded that the lack of such a model has led to a profound erosion of confidence in the trustworthiness of the Bible over the last 200 years. The awareness of this state of affairs has been a major driving force in my life over the past 32 years. return_to_Contents

2. How can continental plates move laterally given the fact that most continental plates have lithospheric roots that extend to depths of 200-250 km into the asthenosphere?

Response: First of all, lateral motion of continents is possible *only* because there is this weak layer—generally referred to as the asthenosphere—beneath the continental plates whose presence results in a mechanical decoupling of an individual plate from the stronger mantle below. Because the strength of mantle rock varies inversely with temperature in an exponential way, the asthenospheric layer, which is typically several hundred degrees hotter than a lithospheric plate, is normally on the order of a *thousand times weaker*. (Because rock strength also depends on pressure and increases with pressure, below a depth about 300 km rock strength increases despite increasing temperature.) It is the striking contrast in strength between lithosphere and asthenosphere that results in this almost complete mechanical decoupling of the plates from the deeper mantle below. This decoupling occurs even when the base of the continent plate is not smooth and even when it has a 'keel' of strong and also probably buoyant rock (buoyant perhaps because it is depleted in iron). Again, this remarkable mechanical decoupling is because of the presence of such a weak asthenospheric layer.

Next, it useful to point out that continental lithosphere is usually comprised of an upper layer, typically about 35 km thick, of buoyant continental crust with an average density of about 2800 kg/m^3 and a mean composition similar to that of granite and normally a thicker lower layer of ultramafic mantle rock with a density of about 3300 kg/m^3. Most mountains are generally of continental crustal (i.e., granitic) composition and are generally isostatically compensated by means of a crustal root that may extend as deep as 70 km. It is normally the lower ultramafic layer of mantle rock that gives continental lithosphere most of its strength.

So then, what are the forces that cause a continental plate to move laterally? There are several different forces that come into play. First, a plate can have both a continental part and an ocean part. (The difference is that the continental portion has the layer of buoyant continental crust while the oceanic portion does not.) If an oceanic portion happens to be subducting, then the subducted part of the plate, being negatively buoyant relative to the mantle into which it is sinking, exerts what is referred to as a 'slab pull' force on the remainder of the plate. That force tends to drag the plate toward the subduction zone. On the other hand, for a plate that contains both a continental part and an oceanic part, the oceanic part can have a mid-ocean ridge as part of its boundary. If that is the case, there tends to be what is called a 'ridge push' force which acts along that boundary. The ridge push force can be shown to arise from the topographic elevation of the ridge. The other important class of force is the collisional interaction with other plates at their mutual boundaries. Generally speaking, the drag forces on the bases of the plates seem to be small and insignificant in comparison to these just mentioned, because of the extreme weakness of the asthenosphere. This general picture of the relative importance of the various forces is supported by various lines of observational evidence as well as computational modeling of these processes. return_to_Contents

3. Why does not a subducting plate experience so much resistance in diving down through just the top of the mantle that it could never penetrate any significant distance? Would not the blunt front end alone prevent any movement? Would not the force needed to overcome such large resistance (if a pushing force) crush the plate or (if a pulling force) pull the plate apart?

Response: A crucially important issue here is the *strength contrast* between the lithosphere at the earth's surface and the rock layer lying immediately beneath it. This zone, discovered to be very weak relative to the lithosphere above it, is known as the asthenosphere (from Greek *asthenēs 'weak'* + sphere). The British geologist Joseph Barrell in 1914, in connection with his studies of post-glacial rebound, first introduced the idea of a strong outer layer (which he named the lithosphere) overlying a much weaker layer (which named the asthenosphere)[1]. He realized such a weak zone in which lateral flow of rock could occur was required for isostatic compensation to take place. Seismologists, beginning notably from their analyses of the large 1960 Chilean earthquake, have identified that low seismic wave speeds

characterize this region. They now refer this portion of the upper mantle as the 'low velocity zone'. Since seismic wave speeds depend on the shear strength, or rigidity, of the rock, the strikingly lower seismic wave speeds at asthenospheric depths imply significantly lower rock strength in that region. Just how weak is the asthenosphere relative to the lithosphere? Various lines of observational evidence indicate that thicker oceanic lithosphere has an inelastic or viscous strength on the order of 10^{22}-10^{23} Pa-s, while the asthenosphere has a viscosity on the order of 10^{18}-10^{19} Pa-s. In other words, the lithosphere typically is at least a thousand times, and more typically ten thousand times, stronger than the asthenosphere.

Why is the asthenosphere so weak relative to the overlying lithosphere? The primary reason is its high temperature. Rock strength depends very strongly (exponentially) on temperature, and the difference in the strength due to temperature alone is huge. Indeed, since the temperature of the asthenosphere is not that far below the melting (solidus) temperature of its lowest melting point minerals, it is not that surprising that its strength is so far below that of the overlying lithosphere. Laboratory experiments show that the viscous strength η of silicate minerals[2] obeys an Arrhenius law of the form $\eta = \eta_0 exp[(E^* + pV^*)(1/T - 1/T_0)/R]$, where E^* is the mineral's activation energy, V^* is its activation volume, p is the pressure, T is the absolute temperature, R = 8.3145 J/mol-K is the ideal gas constant, and η_0 is the reference viscosity at reference temperature T_0. For the upper mantle mineral olivine, E^* is about 500 kJ/mol and V^* is about 4 x 10^{-6} m^3/mol. However, yet another factor contributing to asthenospheric weakness is the likely presence of water and carbon dioxide, at 100 ppm or so levels, within the lattices of the minerals of the asthenosphere rocks[3,4]. Laboratory experiments show that the presence of these volatiles leads to a further dramatic reduction in rock strength. To summarize thus far, the layer of rock that underlies the lithospheric plates is dramatically weaker than the plates themselves. Hence, lithospheric plates should be readily able to penetrate into the layer of rock beneath them. Moreover, given the extreme contrast in rock strength between the asthenosphere and lithosphere, the drag forces on the base of the plates also should be small compared to the plate strength.

A useful tool that can be brought to bear on the mechanics of subduction is numerical simulation. Many numerical simulations of these mechanics over the last 30 years, including my own, clearly demonstrate that subduction is a robust and viable physical process. To understand the basic mechanics, several points are important to grasp. First, rocks not only can and do display reversible elastic deformation when subjected to stresses (as do most solids) but also can and do undergo *inelastic* non-reversible changes in shape. (Inelastic deformation is a standard and important topic included in most every graduate level mechanical engineering curriculum.) In subduction not only does the slab itself bend inelastically, it can also stretch or compress inelastically in its downward journey. But not only does the slab deform inelastically, but the mantle rock into which it sinks also deforms inelastically to accommodate the downgoing slab. The numerical methods that simulate these mechanics typically guarantee perfect conservation of mass and energy while enforcing perfect consistency of forces acting on each parcel of material throughout the computational domain. These methods also usually allow the material strength to vary from cell to cell as a function of temperature and also, in many cases, the local stress conditions. These methods are highly developed and are routinely applied in a broad spectrum of engineering applications, from the mechanical designs of turbine blades to anti-tank projectiles to nuclear weapons. The methods work. Applied to the earth and to the deformation that occurs as rock rises and sinks in the mantle as a result of differences in its buoyancy, the methods show clearly that subduction can and does take place when physically realistic values for densities, temperatures, and various material parameters are applied. Simulations confirm that the large contrast in strength between the asthenosphere and the lithosphere leads to traction forces on the base of the lithosphere which are relatively small. This in turn implies that not much pushing or pulling is required to move a plate over the underlying mantle. It also means that the stresses within the horizontal portion of a plate are generally small and well below the stress levels needed to fracture the plate.

These basic conclusions apply both to the case of uniformitarian plate tectonics (UPT) and to the regime of catastrophic plate tectonics (CPT). In the case of UPT, stress weakening in the rock deformation law is either omitted or switched off, and therefore the rocks remain strong and the deformation rates remain at the levels we observe in the

present. However, when stress weakening is included (as it ought to be), the potential for runaway exists and CPT can occur. In the CPT regime, the strength contrast between lithosphere and asthenosphere remains; lithosphere subducts and behaves in largely the same way as in the non-CPT case, except that velocities are dramatically higher and the time scale is dramatically shorter.

[1]Barrell, J., "The strength of the Earth's crust. I. Geologic tests of the limits of strength," *J. Geol., 22*, 28–48, 1914.
[2]A relatively simple tutorial on rheological models can be found at http://ocw.mit.edu/NR/rdonlyres/Earth--Atmospheric--and-Planetary-Sciences/12-001Spring-2008/Handouts/rheological_mod.pdf
[3]Hirth G. and Kohlstedt D.L., "Water in the oceanic upper mantle: Implications for rheology, melt extraction and the evolution of the lithosphere," *Earth Planet. Sci. Lett. 144*, 93-108, 1996.
[4]Rychert, C. A., Fischer, K. M., and Rondenay, S., "A sharp lithosphere-asthenosphere boundary imaged beneath eastern North America," *Nature, 436*, 542-545, 2005. return_to_Contents

4. What evidence supports the idea that sediments, volcanoes, and plateaus have been scraped off subducting plates at trenches?

Response: There are thousands of papers documenting the reality of accretionary wedges at subduction zones in the standard literature. Let me pick just one published 16 August 2009 in *Nature Geoscience* by M. Strasser *et al*. entitled, "Origin and evolution of a splay fault in the Nankai accretionary wedge" (available athttp://www.soest.hawaii.edu/moore/Origin+eolution_of_Nankai_splay_fault.pdf). This paper deals with the faulting history within the accretionary wedge that lies within the Nankai Trough, where the Philippine Sea plate is actively subducting below southwest Japan and repeatedly producing destructive earthquakes and tsunamis. Figure 1 from this paper is reproduced below. Panel a, which is a shaded relief map of the region, shows the corrugated upper surface of the wedge, spanned by the red line segment, between the relatively smooth sediment covered top of the Philippine Plate to the southeast and the smooth floor of the Kumano Basin to the northwest. Panel b shows the result of a seismic transect along this line segment. This figure shows a portion of the Philippine Plate that is actively subducting (as indicated by 13 major earthquakes during the last 1300 years, 11 of which are estimated to have been greater than magnitude 8.0) beneath a thick wedge of accreted sediments which are highly contorted and sliced by numerous internal faults, including the megasplay fault shown in red on the left in panel b. Some of these earthquakes generated tsunamis greater than 25 m high. (For more details, seehttp://en.wikipedia.org/wiki/Nankai_megathrust_earthquakes.) It is believed that slip on the megasplay fault during the large earthquakes is responsible for the large-amplitude tsunamis. Sediments recovered in the three drill cores that were an important part of this study suggest that splay fault activity has varied strongly through time, with alternating high-activity periods during which splay-fault thrusting accommodated a large part of the plate convergence. One possible cause the authors cite for this variation is roughness changes on the incoming plate (such as the presence ridges or seamounts).

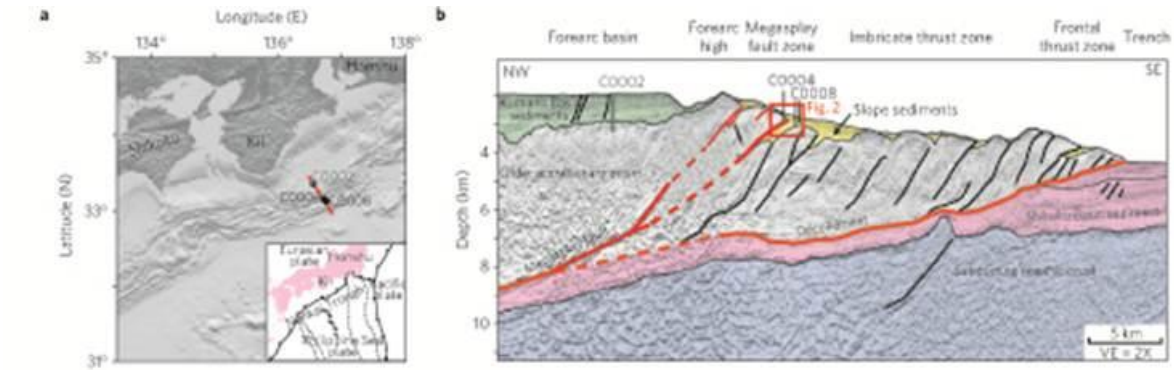


Figure 1 | Geological setting of the Nankai accretionary wedge. a, Shaded relief map of the Nankai Trough showing the regional setting of the IODP NanTroSEIZE (Nankai Trough Seismogenic Zone Experiment) drilling transect[2,19]. The red line through IODP drill Sites C0002, C0004 and C0008 shows the location of the seismic cross-section in Fig. 1b. The inset is a tectonic map of the Philippine Sea region. **b**, Interpreted composite seismic line of the NanTroSEIZE transect, after Moore *et al.*[19]. VE = 2X: twofold vertical exaggeration.

Another example of observational support for the reality of subducted sediment and seafloor volcanic cones accumulating in subduction zones is the classic example of the Franciscan terrane along some 650 km of the California coast mostly north of San Francisco[1,2,3,4]. These Franciscan rocks represent the trench complex of a Mesozoic, east-dipping subduction zone beneath the western coast of North America. During that time period the Farallon Plate was being subducted beneath the overriding North American Plate. Simultaneous with the formation of these subduction zone rocks was the development of a volcanic arc system that produced the Sierra Nevada batholith. The rock units in today's Franciscan terrane are derived from sediments deposited in an accretionary wedge as well as from slices of the underlying oceanic crust and mantle. Rock ages range from uppermost Jurassic through Cretaceous. The sediments of the accretionary wedge are medium- to fine-grained detrital rocks (graywackes, micrograywackes, and dark shales) derived from the Sierran volcanic-plutonic arc. They were deposited into the trench as turbidites. Not only were substantial volumes of these sediments were subducted atop the downgoing oceanic plate, in this subduction process they were also metamorphosed to high metamorphic grade!

How deeply were these sediments subducted to reach this degree of metamorphism? The petrology and geochemistry of the minerals in the metamorphosed graywackes and off-scraped basalts yield the answer. For example, the albite present in the original sedimentary and igneous rock has been converted into jadeitic pyroxene plus quartz. This reaction can only occur in a high pressure, low temperature environment. Laboratory experiments indicate temperatures of about 200°C and pressures of about 0.6-0.7 GPa. This corresponds to depths of about 20 to 30 km in a subduction zone. Another metamorphic mineral that constrains the pressure-temperature conditions of the metamorphism is glaucophane. Glaucophane (meaning 'blue appearing' in Greek) belongs to the amphibole family of minerals and has the chemical formula $Na_2(Mg,Fe)_3Al_2Si_8O_{22}(OH)_2$. Its name comes from its typical blue color. Rocks containing significant amounts of glaucophane are generally referred to as blueschists. The mix of metamorphic rock types commonly associated with blueschist is referred to as the 'blueschist facies.' Blueschist facies rocks generally form under pressures of greater than 0.6 GPa, equivalent to depth of burial in excess of 15-18 km, and at temperatures of between 200 to 500 °C. This is a 'low temperature, high pressure' prograde metamorphic path and is also known as the *Franciscan facies series*, after this Franciscan complex of California where these rocks are so magnificently exposed. Similar blueschists in similar tectonic settings also occur in Greece, Turkey, Japan, New Zealand and New Caledonia.

A major issue associated with the occurrence of these blueschist facies rocks, however, is how they manage return to near the earth's surface after reaching the pressure conditions needed for their formation. Minerals such as jadeite and glaucophane revert to lower pressure phases as they rise to the surface if their temperatures are much above 200 °C. The standard geological community freely acknowledges this is an unsolved problem and has recognized this reality

for the past forty years. Whatever the process, they acknowledge that it must be rapid on order to preserve the high-pressure, low temperature minerals. Most acknowledge that the positive buoyancy of the metamorphosed rocks must be a key factor. Jadeitic pyroxene is less dense and more viscous than olivine that occurs in the mantle. This difference in buoyancy allows the subducted crustal rock to rise. They also marvel at the fact that many of the Franciscan tectonic blocks, some at least 10 km in lateral dimension, have been returned to the surface relatively intact (that is, stratigraphically coherent) although locally very contorted.

One primary difficulty for the mainstream community is how quickly these high-pressure, low-temperature metamorphic minerals must return to the surface in order to escape conductive heating at the depths where the metamorphism takes place. The key issue here is the time scale, and in the uniformitarian framework, the typical time span inferred between subduction and exhumation implies too much heating at depth. This difficulty, of course, disappears in the CPT framework because the subduction and exhumation velocities are orders of magnitude higher and the time scale is orders of magnitude shorter.

A second major issue is the volume of the sediments that are able to be entrained by the downgoing oceanic plate. The higher the speed of downgoing plate, the higher are the shear stresses that act on potentially entrained sediments. The greater these shear stresses are, the thicker in general will be the layer of subducted sediment. Furthermore, the larger the volume of entrained sediment carried to depth, the more readily and faster that volume—because of its buoyancy—will be able to rise again to the surface. Whereas in UPT the subduction and exhumation of huge volumes of blueschist facies rocks observed in the Franciscan complex are nearly impossible to account for, within the CPT framework they are to be expected. For these reasons, the blueschist facies terranes from many places in the world represent powerful support for the reality of CPT.

Why have I devoted so much space to discussion of the Franciscan rocks? First, this complex represents a place on earth where one can actually observe first-hand a sequence of rocks some 100 km wide that accumulated in an ocean trench as an accretionary wedge by subduction processes in the past. As such, these rocks testify powerfully that past subduction is genuine and unambiguous. Second, these rocks reveal clearly that buoyant sediments can be and have been subducted to significant depths, been metamorphosed, and then, because of their buoyancy, rapidly returned to the surface. Third, these rocks indicate that processes different in some way from those acting presently were involved. The simplest way to account for the large volumes of sediment involved as well as the rapidity they returned to the surface is dramatically higher plate speeds. In other words, these rocks testify strongly that past subduction was distinctly different in some ways from what is currently occurring today. By way of summary, these field examples of subduction, while understandable in the framework of conventional plate tectonics, fit more consistently within the CPT framework in that CPT can more readily account for such features as blueschist facies rocks in older accretionary complexes.

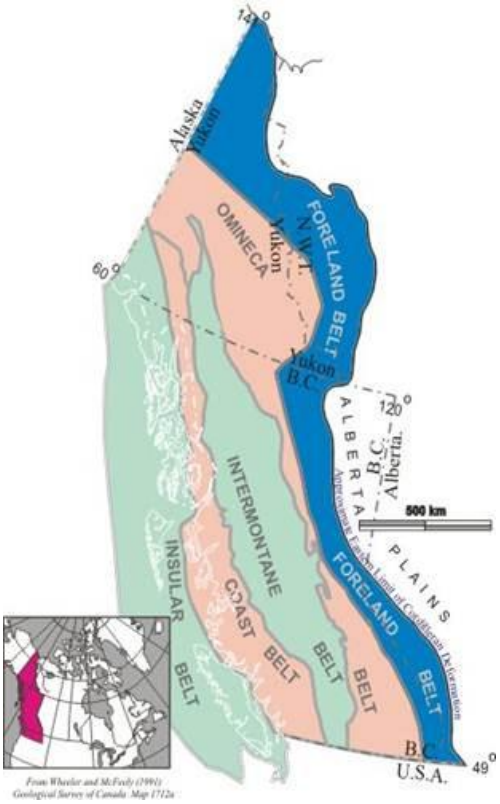
Finally, in regard to whether or not oceanic plateaus have been scraped off by subduction, there are numerous papers that document that a significant portion of western North America is the result of what is sometimes referred to as 'collage tectonics'. Indeed, the recognition that many modern and ancient continental margins are comprised of diverse crustal fragments, each with a distinctive stratigraphy and separated by tectonic contacts, initially occurred for the Pacific coast part of North American in the 1970's. Over 200 distinct terranes have been now been identified in this portion of North America, which includes most of Alaska, much of British Columbia, and major portions of California, Oregon, and Washington. This region is now understood to be a collage of oceanic plateaus, oceanic volcanic arcs, and continental fragments, brought together brought together over large distances (in many cases more than a thousand km) by plate motions and plate convergence. Other continental regions including eastern Siberia, much of China, south-central and southwestern Asia, central Europe, eastern Australia, and southeastern New England, are also now recognized to be the amalgamation of diverse crustal fragments that have been brought together by plate convergence and subduction. Because this literature is so vast, I simply provide below as an example a summary description of the

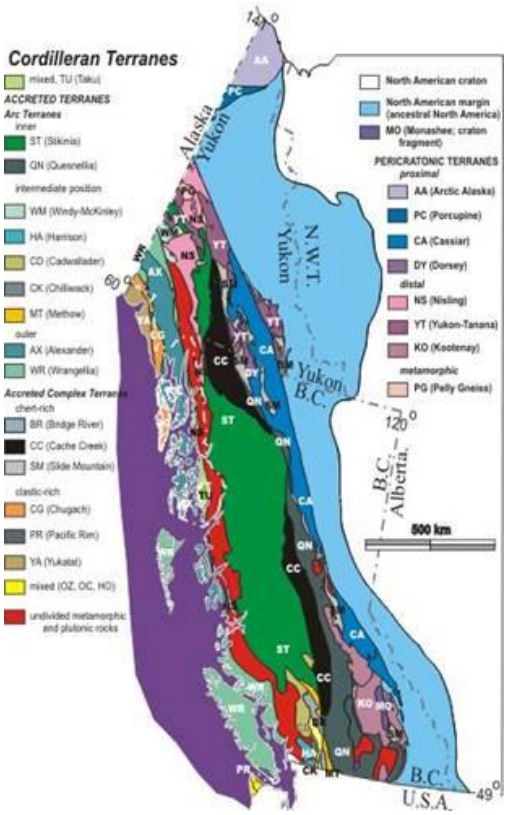
collage tectonics aspects of British Columbia written as a student assignment in 2005 and posted at http://www.emporia.edu/earthsci/student/seigel1/Tectonic_Evolution.htm. I have shortened it slightly and omitted the list of references.

TECTONIC EVOLUTION OF NORTHERN BRITISH COLUMBIA by Chad Seigel

Introduction: Northern British Columbia is mountainous area composed of various faults and orogenic belts which are part of a larger geographic area known as the Canadian Cordillera. This area is composed of ancient cratonic basement, and a collage of terranes which later accreted to this basement as shown in the figures below. This report will focus on a transect cut through northern British Columbia from east to west, starting on the BC/Alberta border, running along the 60th parallel and ending on the Alaskan coast. Although much more complex, the five morphological belts and the ancient cratonic basement which are located along this transect will be briefly summarized in terms of the terranes of which each belt is composed and tectonic origin and time of accretion.

Ancient Continental Margin: The ancient continental margin of North America was formed during late Proterozoic when continental rifting tore the former supercontinent Rodinia apart creating ancestral North America (Laurentia). This resulted in the formation of a passive continental margin much like the present day east coast of North America which persisted until middle Devonian. During this time a thick miogeoclinal deposit of sediment which was eroded from the Canadian Shield to the east was deposited on the continental shelf of the proto Pacific Ocean known as Panthalassa. This supracrustal wedge increases in thickness from east to west where it is approximately 5 km thick at the edge of the Foreland Belt.





Foreland Belt: Moving from east to west along the transect the Foreland Belt is encountered. Although this belt is the next in the sequence of orogenic belts it was the last to form. During the break up of Pangea during the Jurassic the North American continent began to move westward like a giant bulldozer accreting terranes which lay just off the coast of the continent. In doing so these terranes were squeezed in a giant vice between the subducting oceanic lithosphere off the coast of North America, and the wedge shaped North American craton. These terranes were squeezed upwards and downwards which resulted in the detachment of the thick miogeoclinal sequences deposited during the late Proterozoic and Paleozoic from the cratonic basement. These sequences were upthrust onto the edge of the North American craton forming the Foreland Belt.

Omenica Belt: Next along the transect is the Omenica Belt. The Omenica Belt is the region of overlap between the Intermontaine Belt to the west and the Foreland Belt to the east. During the late Devonian, it is thought that an oceanic trench was created at the continent ocean boundary caused by the enormous weight of the old dense oceanic crust combined with the weight of sediments deposited on the continental shelf. Stratigraphic and U-Pb age constraints indicate that this episode of magmatism was Devonian-Mississippian and has been interpreted as subduction related magmatism at a convergent margin. Today, nowhere on Earth is there evidence of subduction being initiated, and the cause of change from a passive, intra-plate margin to a convergent, inter-plate margin is uncertain. This newly formed convergent boundary created magmatic island arcs which formed on the edge of the North American craton not far from the continental margin. These arcs are the Slide Mountain, Cassiar, and Yukon-Tanana Terranes which make up the Omenica Belt. These two arcs with their associated back arc basins have gone through numerous metamorphic events throughout their history, and today represent the once deeply buried roots of this ancient magmatic arc assemblage.

Intermontaine Belt: The Intermontaine Belt is composed of the Cache Creek, Nisling, and Stikine terranes. The Cache Creek and Nisling terranes were formed in the western Pacific during the Permian to Middle Triassic. Sedimentary rocks of the Cache Creek Terrane contain a particular assemblage of fossils that are found in Asia and not in ancient North American rocks. This suggests that the Cache Creek Terrane likely originated far from North America and may have existed on the other side of the Pacific Ocean. The Stikine Terrane is a Carboniferous to Early Jurassic island arc which was formed in the east Pacific. The Stikine Terrane is believed to have evolved in the east Pacific of the Northern Hemisphere and moved northward to dock with ancestral North America sometime during the Middle Jurassic. During the Early to Middle Jurassic the two terranes joined to form the Intermontaine Belt. After this time arc related magmatic activity continued into the Tertiary. Late Triassic through Tertiary plutons intrude structurally imbricated Stikine and Cache Creek terranes in the Atlin-Bennett Lake area of northern British Columbia.

Coast Belt: The Coast Belt is the suture zone between the Intermontaine Belt and the Insular Belt and is composed of plutonic and metamorphic rock. During the mid Cretaceous, the exotic Insular superterrane collided with North America, further deforming the Intermontaine terranes. The deformation compressed the upper crust of the Nisling and Stikine terranes by more than 160 km, approximately the width of the Coast Belt.

Insular Belt: Westernmost is the Insular Belt which is composed of the Wrangel, Alexander, Chugach, and Yukatat terranes. The Wrangel and Alexander terranes are island arcs having formed in the Pacific during the Devonian. These arcs amalgamated during the Carboniferous and collided with the continent during the Cretaceous. It is uncertain exactly when the Insular Islands finally arrived on North American shores. Some evidence suggests they persisted as an offshore volcanic chain for some time, much like the islands of Japan do today. In any event, the final collision between the islands and the continent did not occur until mid-Cretaceous time. The Chugach and Yukatat terranes are composed of sedimentary rock of Tertiary age. Products of erosion were deposited in Pacific Ocean floor and carried northward on the oceanic plate to be accreted as major components of Chugach and younger accretionary terranes southern Alaska.

Summary: The collage of terranes and faults that make up the continental crust of northern British Columbia are extremely complex and have been simplified here for clarity. Much is currently known about the complex geology of this

area and many questions still remain unanswered. With new theories and geoscience techniques more questions and answers will be brought to light, once again changing our understanding of the tectonic evolution of northern British Columbia. (End of article)

Although these striking evidences for long distance transport and assembly of these terranes in a collage-like manner is accepted within the UPT framework by the mainstream earth sciences community, it is a major stretch to imagine that the slow and gradual plate motions we observe today could have achieved such incredible tectonic feats. It is dramatically more reasonable, however, that these sorts of amalgamations could and did take place if the plate velocities were orders of magnitude higher than they are today during a brief but intense cataclysm.

[1]Ernst, W. G., "Tectonic contact between the Franciscan mélange and the Great Valley Sequence—crustal expression of a late Mesozoic Benioff zone," *J. Geophys. Res., 75*, 886-901, 1970.

[2]Ernst, W. G., "Petrologic reconnaissance of Franciscan metagraywackes from the Diablo Range, central California Coast Ranges," *J. Petrol., 12*, 413-437, 1971.

[3]Ernst, W. G., "Metamorphism of Franciscan tectonostratigraphic assemblage, Pacheco Pass area, east-central Diablo Range, California Coast Range," *Geol. Soc. America Bull., 105*, 618-636, 1993.

[4]Tembayashi, M., S. Maruyama, and J. G. Liou, "Thermobaric structure of the Franciscan Complex in the Pacheco Pass Region, Diablo Range, California," *J. Geol., 104*, 617-636, 1996. return_to_Contents

5. Is there evidence that sediments in trenches are deformed and contorted as one should expect if subduction is genuine?

Response: There are hundreds of articles in the peer-reviewed literature that document mélange structure in subduction zone accretionary wedges. I have already described the complex and contorted structure observed both by drilling and seismic profiling of the accretionary wedge that lies within the Nankai Trough where the Philippine Plate is actively subducting beneath southwestern Japan. Similarly, I have already described the classic example of a fossil subduction zone, the Franciscan terrane along the central and northern California coast, which displays strongly contorted sediments and ocean crustal rocks that have been subducted to depths of 20-30 km, metamorphosed to blueschist grade, and then amazingly have risen up the subduction channel back to the surface. One of many other examples I could point to is in Guatemala, similar in many ways to the Franciscan, and described in the recent paper by Marroni, M., et al., "Deformation history of the eclogite- and jadeitite-bearing mélange from North Motagua Fault Zone, Guatemala: insights in the processes of a fossil subduction channel," *Geological Journal, 44*, 167-190, 2008, whose abstract I reproduce as follows.

> In Guatemala, along the northern side of the Motagua Valley, a mélange consisting of blocks of eclogite and jadeitite set in a metaserpentinitic and metasedimentary matrix crops out. The metasedimentary rocks display a complex deformation history that includes four tectonic phases, from D1 to D4. The D1 phase occurs only as a relic and is characterized by a mineral assemblage developed under pressure temperature (P-T) conditions of 1.00-1.25 GPa and 206-263°C. The D2 phase, characterized by isoclinal folds, schistosity and mineral/stretching lineation, developed at P-T conditions of 0.70-1.20 GPa and 279-409°C. The following D3 and D4 phases show deformations developed at shallower structural levels. Whereas the D1 phase can be interpreted as the result of underplating of slices of oceanic lithosphere during an intraoceanic subduction, the following phases have been acquired by the mélange during its progressive exhumation through different mechanisms. The deformations related to the D2 and D3 phases can be regarded as acquired by extrusion of the mélange within a subduction channel during a stage of oblique subduction. In addition, the structural evidences indicate that the coupling and mixing of different blocks occurred during the D2 phase, as a result of flow reverse and upward trajectory in the subduction channel. By contrast, the D4 phase can be interpreted as related to extension at shallow structural levels. In this framework, the exhumation-related structures in the mélange indicate that this process, probably long-lived, developed through different mechanisms, active in the subduction channel through time.

While mélange formation is expected in places like the Nankai Trough today under the slow rates of convergence assumed in UPT because the sediments are inherently soft, many of the other striking features of the fossil accretionary wedge deposits, such as large volumes of blueschist rocks returned to the surface, are not readily explained in the framework of UPT, but instead seem to require the catastrophic conditions associated with CPT. return_to_Contents

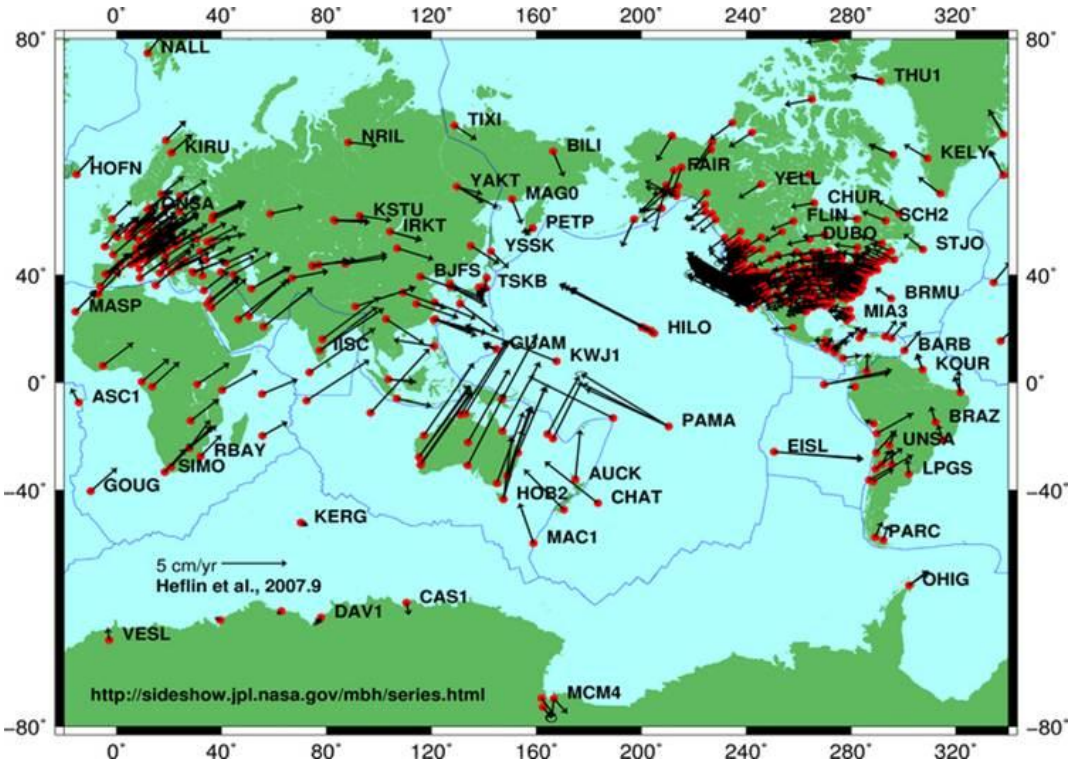
6. How can plates rift apart, and should they do so, how could they move over the underlying rock?

Response: While plates in general display considerable strength, there is impressive observational evidence that they can and do rift, or split apart, under the right circumstances. A good example is the rifting of the Arabian block from Africa with the formation of the Red Sea and the Gulf of Aden. Just what the forces were that initiated the rifting may not be so clear, but the reality that a once coherent plate has split into two pieces and that the two pieces are presently moving away from each other is documented by many lines of evidence, including GPS measurements. Another example of continental rifting is the separation of Baja California from Mexico and the subsequent migration of this block several hundred kilometers to the northwest. The cause in this case seems to be clearer, given that according to present GPS measurements the motion of this block is essentially identical to that of the Pacific Plate. The implication is that some of the western portion of the North American Plate has overridden the ridge that earlier formed the southeastern boundary of the Pacific Plate and that the forces associated with the divergence at this ridge were sufficient to cause the rifting away of this sliver of North American Plate. Careful numerical simulation indicates that lithospheric plates can also fail in compression. The most common circumstance is when a slab of oceanic lithosphere becomes sufficiently thick through cooling, it begins to founder under its own weight, initially producing a broad depression above it and then fracturing and sinking into the weaker and less dense mantle beneath it.

In regard to the issue of a lithospheric plate moving relative to the asthenospheric layer beneath it, I pointed out earlier that the case is compelling that this layer is on the order of a *thousand to ten thousand times weaker* than normal lithosphere and that the drag forces exerted by the asthenosphere on the base of the lithosphere tend to be extremely small. return_to_Contents

7. How can a plate even begin its dive under an adjacent plate that is 30-60 miles thick if cliffs cannot be higher than 5 miles?

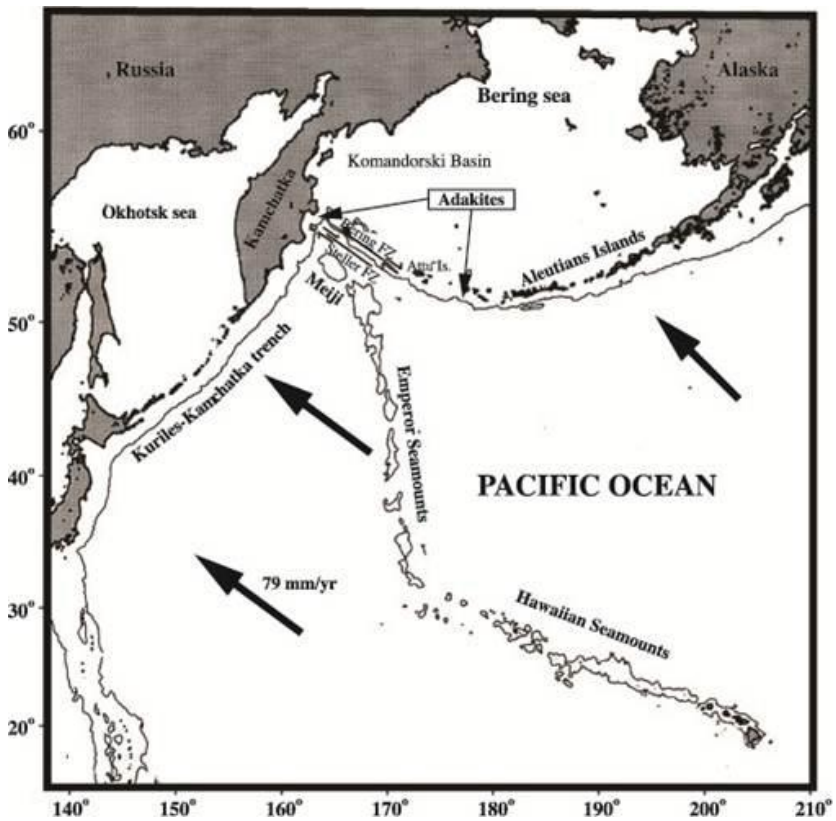
Response: Because rock at sufficient depth under stress does indeed begin to *deform inelastically* or plastically, the boundary below a few km depth between a subducting plate and the overriding plate is never vertical but instead is inclined, typically, at an angle of 30-45 degrees. Inelastic deformation of the edge of the overriding plate readily allows this to occur. The fact that plates are subducting today means that one plate diving beneath another plate not only is possible; it is an undeniable reality. Below is a figure from the NASA website at http://sideshow.jpl.nasa.gov/mbh/series.html showing velocities of more than 900 GPS stations worldwide. The velocity discontinuities at mid-ocean ridges and also subduction zones is to me indisputable evidence that both seafloor spreading and subduction are occurring on our earth today.



Caption: Station velocities determined by integration of their GPS observations over the period 1999-2007. Data were analyzed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. return_to_Contents

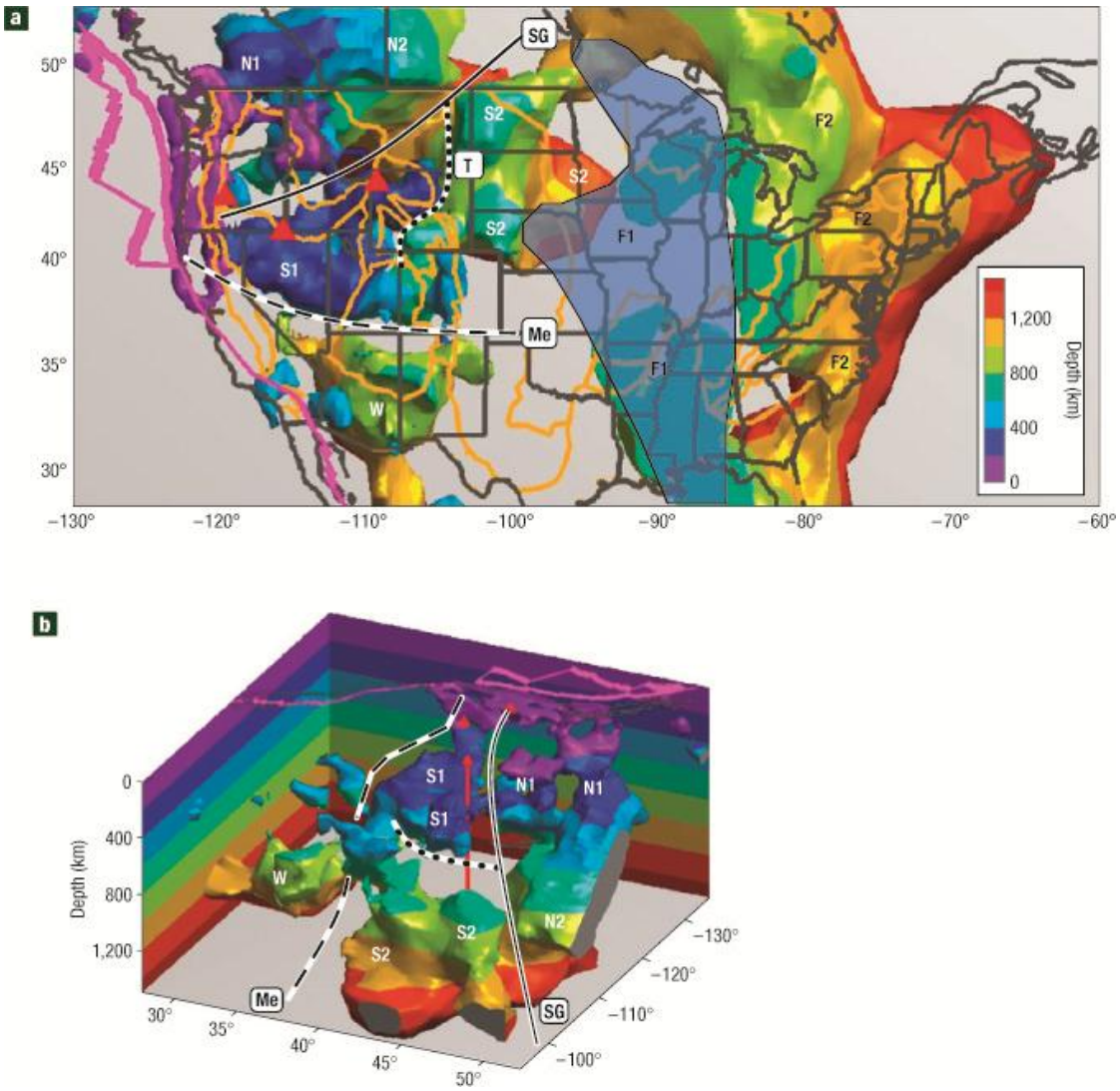
8. Is subduction geometrically possible only along a straight line?

Response: According to GPS measurements, subduction is taking place today into the arc-shaped Aleutian Trench, the arc-shaped Sumatra Trench, and many other trenches that are far from straight lines. The error in the belief that subduction can occur only along a straight line is a failure to recognize that a subducting plate deforms as it plunges into the mantle. Many papers in the peer-reviewed literature provide strong seismic evidence that subducted slabs tear and deform dramatically in their journey downward into the mantle. One location where slab tear is almost a certainty is at the Aleutian-Kamchatka corner. In the paper by A. Davaille and J. M. Lees, "Thermal modeling of subducted plates: tear and hotspot at the Kamchatka corner," *Earth Planet. Sci. Lett. 226* 293-304, 2004, the authors ask, "How can the Pacific Plate, which is subducting at an oblique angle in the western Aleutians, physically connect to the relatively steeply dipping Kamchatka slab to the west?" They continue, "The surficial manifestation of the connection is the massive Bering transform zone (TZ), extending from Attu Island westward towards Kamchatka (see figure below). In Kamchatka the margin between the Pacific Plate and North America takes a sharp turn southwards, towards the Kurile Trench and Japan. How does the Pacific Plate accommodate this sharp apparent bend? Does the Pacific plate drape over the corner as a tablecloth folds around a table corner, or is the Pacific Plate torn at the corner along the TZ to accommodate the deformation? In this paper we explore evidence and implications for the latter hypothesis." The authors do make a strong case that there is a tear in the Pacific Plate along the Bering Fracture Zone.



Caption: Map view of the northwest Pacific. The 3000-m depth contour from the ETOPO5 database outlines the Pacific Plate boundaries and the Meiji–Emperor–Hawaiian chain starting east of the Kamchatka subduction region. The Bering transform zone comprehends the Steller and the Bering faults extending from Kamchatka to east of Attu Island. The arrows show the present-day Pacific Plate motion. High heat flux values are found on and around Meiji seamount.

The extreme deformation that subducted slabs undergo is beautifully illustrated in a recent paper by K. Sigloch, N. McQuarrie, and G. Nolet, "Two-stage subduction history under North America inferred from multiple-frequency tomography," *Nature Geosciences, 1*, 458-462, 2008. Figure 2 from this paper, reproduced below, shows via seismic tomography the present shape of the Farallon Plate, which has subducted beneath the western coast of North America since the earliest Jurassic and continues to do so as the modern Juan de Fuca Plate along the coasts of Oregon and Washington. The authors infer from the seismic data as well as from numerous surface observations that this plate underwent a large amount of tearing in its complicated history.



Caption: Three-dimensional views of the subducted Farallon Plate under North America. Isosurface is rendered where P-velocity is 0.4% faster than expected; color indicates depth. (a) Map view of the Cascadia subduction system (S1, S2, N1, N2, W), and its predecessor (F1, F2) to the east. Shallow fast structure that would obstruct the view (for example, the craton) is not rendered. East of 100_ W, only structure below 800 km depth is rendered; extent of slab material F1 in the transition zone is shaded blue. 'Me' (dashed line) is the continuation of the Mendocino fracture zone underground. 'SG' (solid line) marks the slab gap, a 2,500-km-long tear that subdivides the currently subducting plate. A lateral tear 'T' between upper and lower mantle (dotted line) is best appreciated in b. (b) A bird's eye view of the Cascadia system from the northeast.

Studies on the way slabs deform after they subduct reveal that they can and do undergo extreme deformations, including tears. Most of the studies utilize seismology to provide actual images of these deforming masses of rock inside the earth. The fact that subducted slabs can and do deform means that geometrical constraints that would apply to perfectly rigid slabs do not apply to the real ones. This conclusion is valid not only in the case of the uniformitarian framework but also in the case of CPT.

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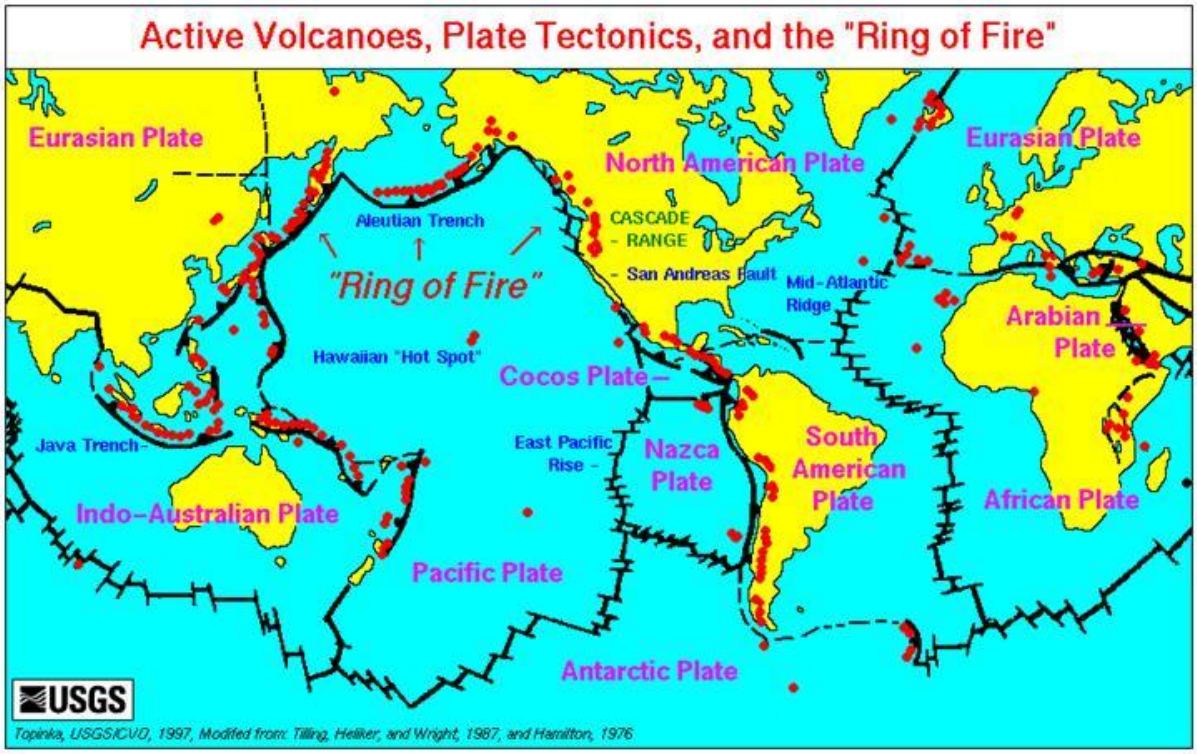
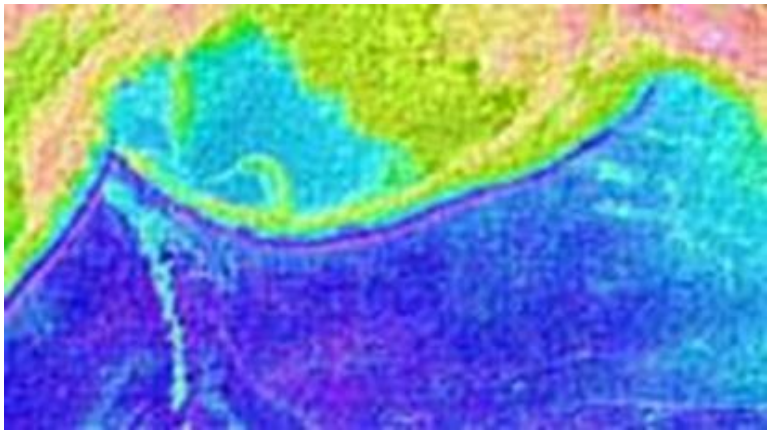
9. If subducting plates produce volcanoes, why are there so many volcanic seamounts on the interior of the Pacific Plate?

Response: More than half of the world's active volcanoes above sea level today encircle the Pacific Ocean to form what is frequently referred to as the circum-Pacific "Ring of Fire." This horseshoe shaped belt, some 40,000 km long, is associated almost exclusively with nearby ocean trenches, as indicated in the map below produced by the USGS. Almost without exception, the volcanoes are on the side of the trench beneath which the subduction is occurring.

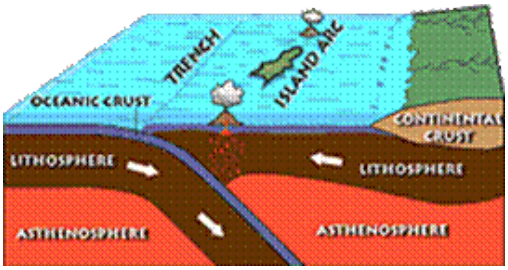


The following discussion of the reason that volcanoes are so commonly associated with subduction is copied from the San Diego State University geology department website http://www.geology.sdsu.edu/how_volcanoes_work/subducvolc_page.html:

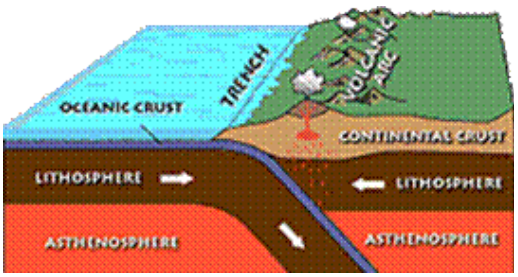


The Pacific Plate descends into the mantle at the site of the Aleutian Trench. Subduction zone volcanism here has generated the Aleutian island chain of active volcanoes. *Courtesy of NOAA.*

The crustal portion of the subducting slab contains a significant amount of surface water, as well as water contained in hydrated minerals within the seafloor basalt. As the subducting slab descends to greater and greater depths, it progressively encounters greater temperatures and greater pressures which cause the slab to release water into the mantle wedge overlying the descending plate. Water has the effect of lowering the melting temperature of the mantle, thus causing it to melt. The magma produced by this mechanism varies from basalt to andesite in composition. It rises upward to produce a linear belt of volcanoes parallel to the oceanic trench, as exemplified in the above image of the Aleutian Island chain. The chain of volcanoes is called an *island arc*. If the oceanic lithosphere subducts beneath an adjacent plate of continental lithosphere, then a similar belt of volcanoes will be generated on continental crust. This belt is then called a *volcanic arc*, examples of which include the Cascade volcanic arc of the U.S. Pacific northwest, and the Andes volcanic arc of South America.



Island arc formed by oceanic-oceanic subduction

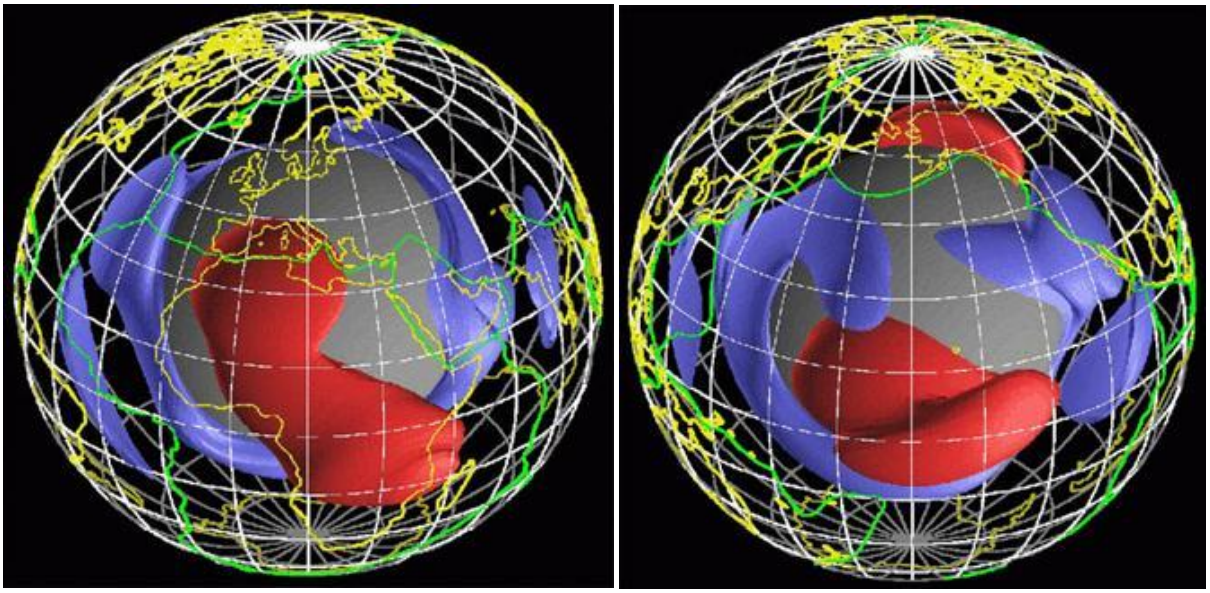


Volcanic arc formed by oceanic-continental subduction

The volcanoes produced by subduction zone volcanism are typically *stratovolcanoes*. Incipient island arcs tend to be more *basaltic* in composition, whereas mature continental volcanic arcs tend to be more *andesitic* in composition.

The point here is that the basic mechanism by which subduction so commonly generates volcanism is well understood. One aspect of the process that the above simple article did not include is the so-called 'corner flow' that occurs in the asthenospheric wedge between the subducting plate and the overriding plate. This flow, driven by drag from the subducting plate, brings fresh, hot asthenospheric rock, like a blow torch, into the very zone where the volatiles are being released and partial melting takes place.

What about the volcanoes, mostly inactive and below sea level, in the western and central Pacific? These are almost certainly a consequence of the massive hot thermal anomaly in the lower mantle beneath the south central Pacific known as the Pacific superplume. This feature, as well as a similar feature on the opposite side of the earth beneath Africa, together with a ring of anomalously cold and dense rock beneath the perimeter of the Pacific, shown in the figure below, were some of the most visible and robust features in 3D seismic images of the lower mantle from the earliest days of seismic tomography in the 1980's.



Eastern Hemisphere Western Hemisphere

Caption: Mantle density structure derived from seismic tomography. Blue represents low temperature rock and red high temperature rock. Inferred temperature difference is about 3000 °C. The red feature beneath the south central Pacific in the western hemisphere view is known as the Pacific Superplume.

It is noteworthy that observational evidence is compelling that a huge pulse of volcanism occurred in the central Pacific in the mid-Cretaceous. Some of the evidence is described in the paper by R. L. Larson, "Latest pulse of Earth: Evidence for a mid-Cretaceous superplume," *Geology 19*, 547-550, 1991. The abstract for this paper is as follows:

> A calculation of Earth's ocean crustal budget for the past 150 m.y. reveals a 50% to 75% increase in ocean crust formation rate between 120 and 80 Ma. This "pulse" in ocean crust production is seen both in spreading-rate increases from ocean ridges and in the age distribution of oceanic plateaus. It is primarily a Pacific Ocean phenomenon with an abrupt onset, and peak production rates occurred between 120 and 100 Ma. The pulse decreased in intensity from 100 to 80 Ma, and at 80 Ma rates dropped significantly. There was a continued decrease from 80 to 30 Ma with a secondary peak near the Cretaceous/Tertiary boundary at 65 Ma. For the past 30 m.y., ocean crust has formed at a nearly steady rate. Because the pulse is seen primarily in Pacific oceanic plateau and ridge production, and coincides with the long Cretaceous interval of normal magnetic polarity, I interpret it as a "superplume" that originated at about 125 Ma near the core/mantle boundary, rose by convection through the entire mantle, and erupted beneath the mid-Cretaceous Pacific basin. The present-day South Pacific "superswell" under Tahiti is probably the nearly exhausted remnant of the original upwelling. How this superplume stopped magnetic field reversals for 41 m.y. is a matter of speculation, but it probably involved significant alteration of the temperature structure at the core/mantle boundary and the convective behavior of the outer core.

It turns out that most of the seamounts that are so numerous in the western Pacific today were formed precisely in the time window described by Larson. This is documented in the paper by Stepashko, A. A., "Origin of West Pacific seamounts and features of the Cretaceous dynamics of the Pacific Plate," *Oceanology 46*, 411-417, 2006, as summarized in the abstract:

> A correlation between the age and position of 25 seamounts in the West Pacific Ocean formed, judging from the $^{40}Ar/^{39}Ar$ data, in the period from 120 to 65 My B.P. was recognized. The seamounts studied are joined into linear zones with extensions up to 5000 km; the age of the seamounts decreases in the southeastern direction. In the interval 93–83 My B.P., the seamount formation was extremely rapid; this interval coincides with the period of acceleration in the Pacific Plate movements. In the middle of this interval, 87 My B.P., an intensification of the magmatic activity accompanying the seamount formation was observed simultaneously with the extinction of the Isanagi Plate and the appearance of the Kula Plate.

What about this south central Pacific region today? A widely referenced paper on this topic is by M. K. McNutt and A. V. Judge, "The Superswell and Mantle Dynamics Beneath the South Pacific," *Science* 25, 969 – 975, 1990, summarized in its abstract as follows:

> The region of sea floor beneath French Polynesia (the "Superswell") is anomalous in that its depth is too shallow, flexural strength too weak, seismic velocity too slow, and geoid anomaly too negative for its lithospheric age as determined from magnetic isochrons. These features evidently are the effect of excess heat and extremely low viscosity in the upper mantle that maintain a thin lithospheric plate so easily penetrated by volcanism that 30 percent of the heat flux from all hot spots is liberated in this region, which constitutes only 3 percent of the earth's surface.

To summarize, (1) seismic topography shows what appears to be a massive hot thermal anomaly in the lower mantle presently beneath the south central Pacific; (2) a huge pulse of volcanism in this very region during the mid-Cretaceous generated the seamounts that currently populate the Pacific Plate in the western Pacific region; (3) a high level of volcanic activity continues in this region today, but at a level greatly diminished from that of the Cretaceous. In regard to the claim, the western Pacific seamounts are the result of this thermal anomaly and not to the subduction-related processes which generate the Pacific Ring of Fire volcanoes.

Finally, how do UPT and CPT compare in accounting for these features? First, partial melting and volcanism in subduction zones is to be expected in both versions of plate tectonics. But the huge volumes of subduction-generated silicic volcanism that formed the Sierra Nevada and related granites, for example, are extremely difficult for UPT to explain but readily accounted for within the CPT framework. Uniformitarianism in general has difficulty with non-uniform phenomena like the Cretaceous pulse in central Pacific volcanism, so in terms of accounting for the Pacific seamounts, CPT again displays superior explanatory power.
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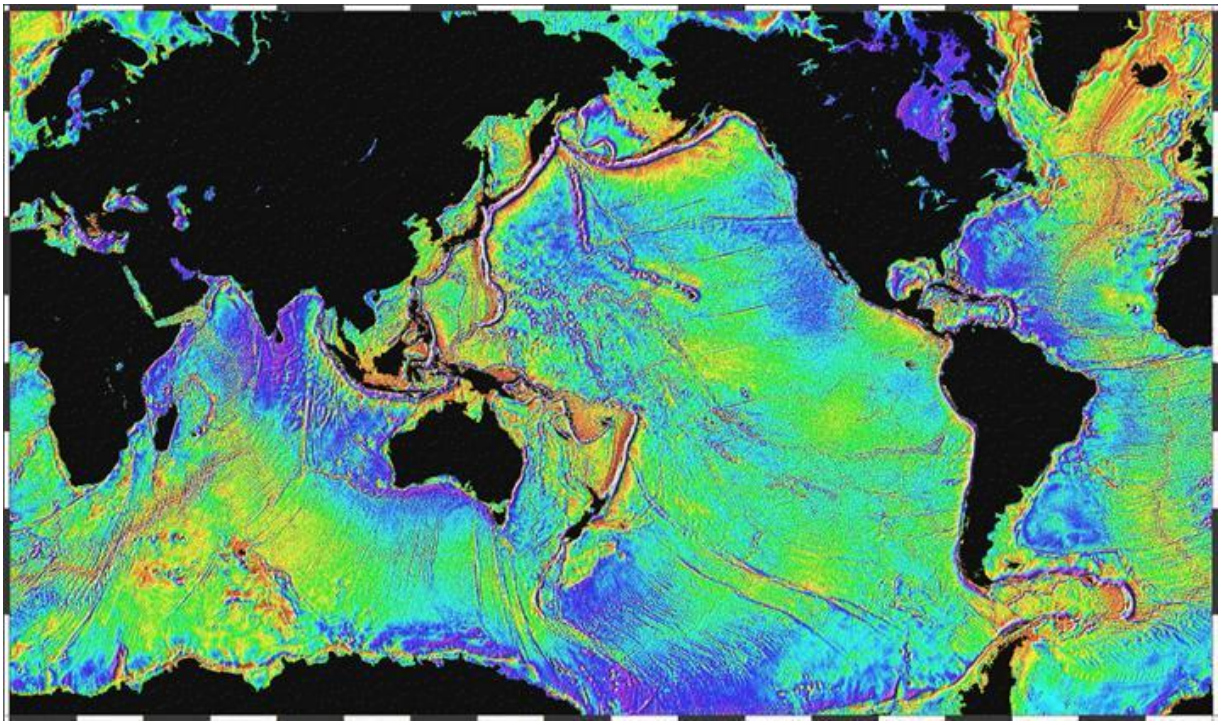
10. Why is it that in gravity surveys trenches display mass deficiencies, not mass excesses, as subducted slabs would be expected to produce?

Response: Trenches *themselves* represent huge mass deficiencies, where, instead of rock, there is water. The free-air gravity anomalies observed over trenches are typically in the range of -100 to -300 milligals (one milligal is 10^{-5} m/s^2), depending on the amount of sediment fill. One can verify that mass deficiencies corresponding to those associated with trenches do indeed produce these sorts of free-air gravity signatures. The formula for the gravity anomaly Δg produced by an infinitely long line of excess mass γ per unit length at depth b below the surface and observed directly above the line is given by the definite integral from $-\infty$ to ∞ of the integrand $G\gamma dx/(x^2 + b^2)$, which is equal to $\pi G\gamma/b$, where $G = 6.673 \times 10^{-11}$ is the universal gravitational constant. Approximating the cross-sectional area of a trench as a triangle of height h and width 2h/3, with its center h/3 below the surface, yields the formula $\Delta g = \pi G h \Delta\rho$, where $\Delta\rho$ is the density contrast between what is filling the trench and normal crustal rock. For a trench depth h of 6000 m and a $\Delta\rho$ of -1700 kg/m^3, corresponding to the trench being filled with water, we get a resulting gravity anomaly of -214 milligal. The extra

density of the slab immediately beneath the trench, because of its cold average temperature, can readily be shown to be negligible in comparison.

However, the higher density of subducted slabs often does produce a discernible gravity signature *behind* the trenches. This can be seen from a visual inspection of the free-air gravity anomaly map of the world's ocean floors shown below. Positive gravity anomalies shown in orange are evident behind the Tonga-Kermadec Trench east of Australia and behind the Izu-Bonin and Marianas Trenches south of Japan. Again, this gravity signature is the result of the subducted slabs greater density, because of their lower temperature, relative to the surrounding mantle rock. These principles apply equally well to both UPT and CPT.



Caption: Free-air gravity anomaly map of the world's oceans. This map was generated from geoid height measurements from 4.5 years of measurements by the U.S. Navy's Geosat satellite and 2 years of measurements by the European Space Agency's European Remote Sensing ERS-1 satellite. (http://www.ngdc.noaa.gov/mgg/bathymetry/predicted/explore.HTML) return_to_Contents

11. Why is it that beneath trenches, earthquakes sometimes occur across a much broader region than the width of a plate?

Response: Earthquakes that occur well behind the trench location tend to be deep-focus earthquakes which occur at depths between 300 and 700 km beneath the earth's surface. Because subducted lithosphere should not exhibit brittle behavior at such depths, the mechanism responsible for these deep earthquakes has stirred controversy since their actual depth was first verified more than 70 years ago. Because mineralogical phase changes occur in the lower part of the upper mantle where these earthquakes are most frequently observed, a possible and leading candidate mechanism has been the catastrophic transformation of metastable olivine into the higher density spinel phase. Because of the low temperatures in the core of the subduction slab, this phase transition likely may not always spontaneously occur as the slab passes through the depth where the phase transition otherwise ought to take place. When this is the case, metastable olivine is transported to greater depths and has the potential to transform rapidly to the spinel phase, provided there is some process to initiate this transformation. However, a simple volumetric implosion of the low

density olivine phase to produce the higher density spinel phase does not match the pattern of earthquake waves these earthquakes radiate—a pattern which typically implies a large amount of shear deformation.

However, about 20 years ago H. W. Green and P. C. Burnley in "The failure mechanism for deep-focus earthquakes," *Geological Society, London, Special Publications* 54, 133-141, 1990, described the mechanism now generally thought to account for these deep focus earthquakes. In the abstract of this paper they summarize their findings:

> Experimental deformation of Mg_2GeO_4 olivine at pressures between 1 and 2 GPa in the spinel stability field has led to discovery of a faulting instability that develops at the kinetically-controlled threshold of transformation. Very fine-grained olivine and spinel are found in fault zones. Deformation at lower temperatures is ductile; transformation is inhibited and specimens are very strong. Deformation at higher temperatures also is ductile but transformation is rapid and specimens are much weaker. Detailed examination of the microstructures of specimens deformed in the faulting regime lead to an anticrack theory of faulting that explains the experimental data and provides a fundamentally new mechanism for deep-focus earthquakes. The new mechanism is analogous to the Griffith theory of fracture; nucleation and growth of spinel under stress produces spinel-filled microanticracks normal to the maximum compressive stress that link up to produce faulting. The friction paradox for deep earthquakes is resolved because this faulting process provides a fine-grained, superplastic, 'lubricant' for faults. The temperature distribution within subducting slabs of lithosphere requires that the conditions of instability are reached as a natural consequence of subduction; metastable olivine in the interior of deep slabs warms to a critical temperature where faulting ensues in the presence of a shear stress.

To summarize, Green and Burnley used the germanium analog mineral, Mg_2GeO_4, instead of silicate olivine, $(Mg,Fe)_2SiO_4$, to investigate the mechanics of this phase transition in the laboratory in a large enough volume to be able to observe and characterize the actual faulting process. The germanium analog is softer and changes to the spinel structure at much lower pressure than the silicate mineral. Their experiment appears to elucidate how this phase transition can unfold extremely rapidly and also generate large-scale shear motions within the core of a subducting slab.

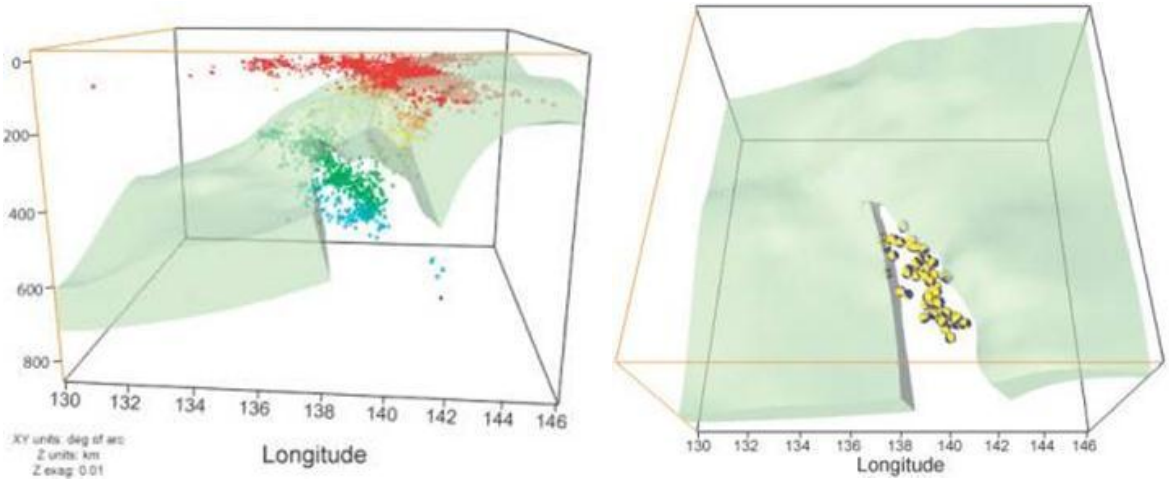
Another observation that points to the likelihood of the mechanism involving the rapid transformation of olivine to spinel and possibly other lower density phases such as pyroxene transform to their higher density phases is that deep focus earthquakes cease abruptly below a depth of about 680-700 km, which represents the boundary between the upper and lower mantle. This is the depth at which the major upper mantle phases are converted to the yet higher density phases perovskite and magnesiowuestite. Hence, whatever the mechanism is, it shuts down when these transitions between upper mantle mineral phases no longer can occur.

These observations and conclusions apply equally to both UPT and CPT. return_to_Contents

12. Just how conclusively has seismic tomography demonstrated the reality of subducted plates in the mantle?

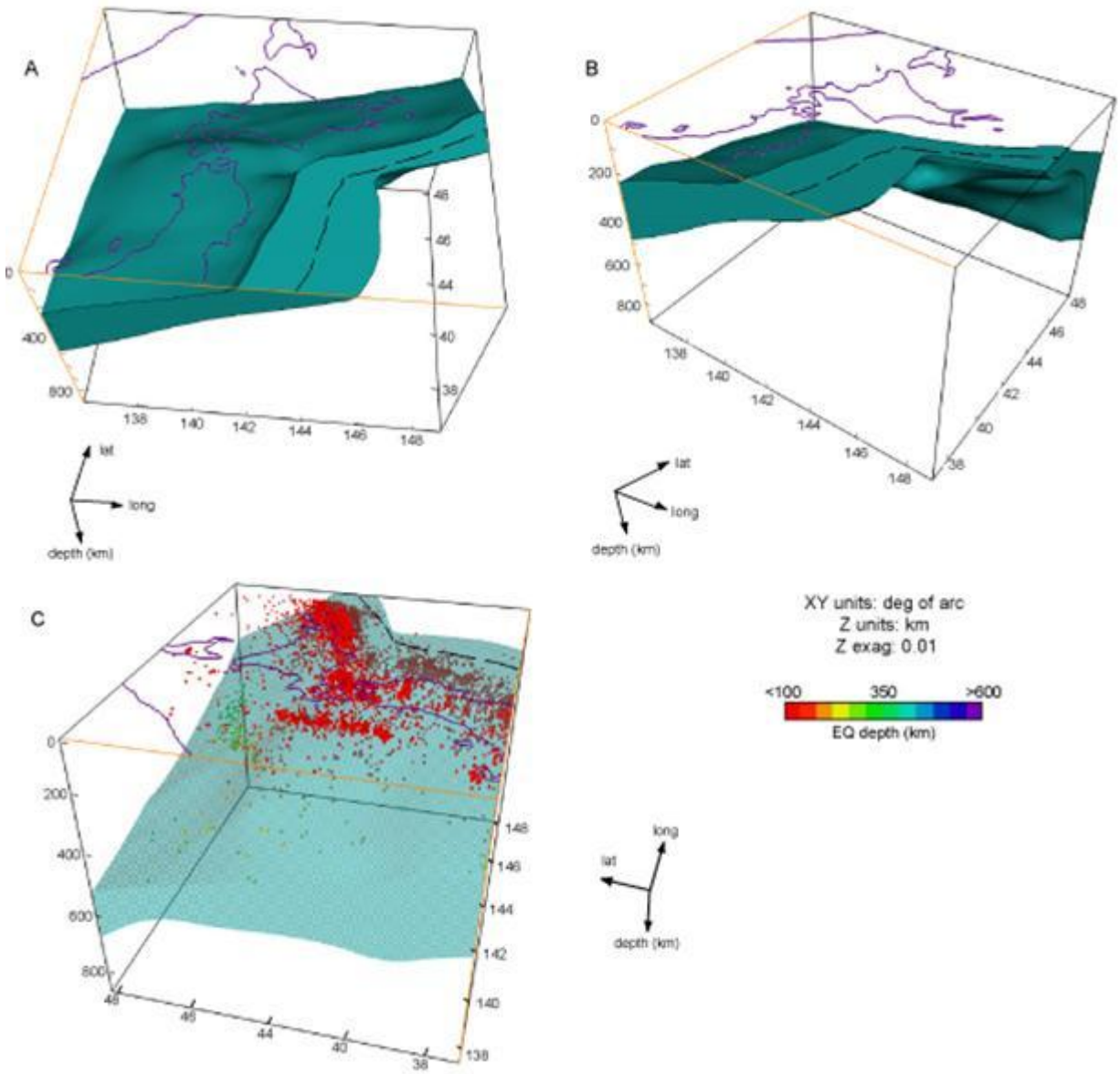
Response: The paper by K. Sigloch, N. McQuarrie, and G. Nolet, "Two-stage subduction history under North America inferred from multiple-frequency tomography," *Nature Geosciences, 1*, 458-462, 2008, mentioned above in my response to question 8 (Q8), provides a dramatic example of the ability of current generation seismic tomography methods to convincingly reveal the 3D structure of subducted slabs. Figure 2 from this paper, reproduced above, shows the present shape of the Farallon Plate which, not only subducted beneath the western coast of North America since the earliest Jurassic in the past, but continues to do so as the modern Juan de Fuca Plate along the coasts of Oregon and Washington.

The paper by Miller, M.S., Gorbatov, A., Kennett, B.L.M., "Imaging changes in morphology, geometry, and physical properties of the subducting Pacific Plate along the Izu-Bonin-Mariana arc," *Earth and Planetary Science Letters 235*, 331-342, 2004, shows the geometry of the portion of the Pacific Plate that is currently subducting in the Izu-Bonin Trench south of Japan. Two figures from their paper, shown below strongly suggest that the slab is in the process of tearing as it subducts.



Caption: (Left) 3D morphology and geometry of the subducting Pacific slab beneath the Izu-Bonin arc. The missing section of slab corresponds to the region with distinctive seismic characteristics where slab tear seems to be occurring. The earthquakes acquired from the NEIC catalog for events from 1967-1995 illustrate a cluster of events positioned within the anomalous region. (Right) The focal mechanisms from the Harvard CMT earthquake catalog indicate extension within the anomalous region and imply mechanical failure in the slab that is accommodating its change in geometry.

These same authors, Miller, M.S., Kennett, B.L.N., Gorbatov, A., in another paper entitled "Morphology of the distorted subducted Pacific slab beneath the Hokkaido corner, Japan," *Physics of the Earth and Planetary Interiors 156*, 1-11, 2006, provide a 3D image, displayed below, of the subducted slab beneath Japan which gives rise to so many large earthquakes in that region.



Caption: Three dimensional representation of the morphology and geometry of the subducting Pacific Plate beneath the Hokkaido corner. The Japanese coastline is in purple and events greater than 4.0 during 1967-2002 from the USGS/NEIC catalog are color coded with depth in (c).

These papers provide a sample of the work currently being done which is providing an expanding catalog of 3D seismic imaging of subducted slabs from many places around the world. return_to_Contents

13. Why are some Benioff zones nearly horizontal when subducting plates should be expected to plunge downward at a finite angle?

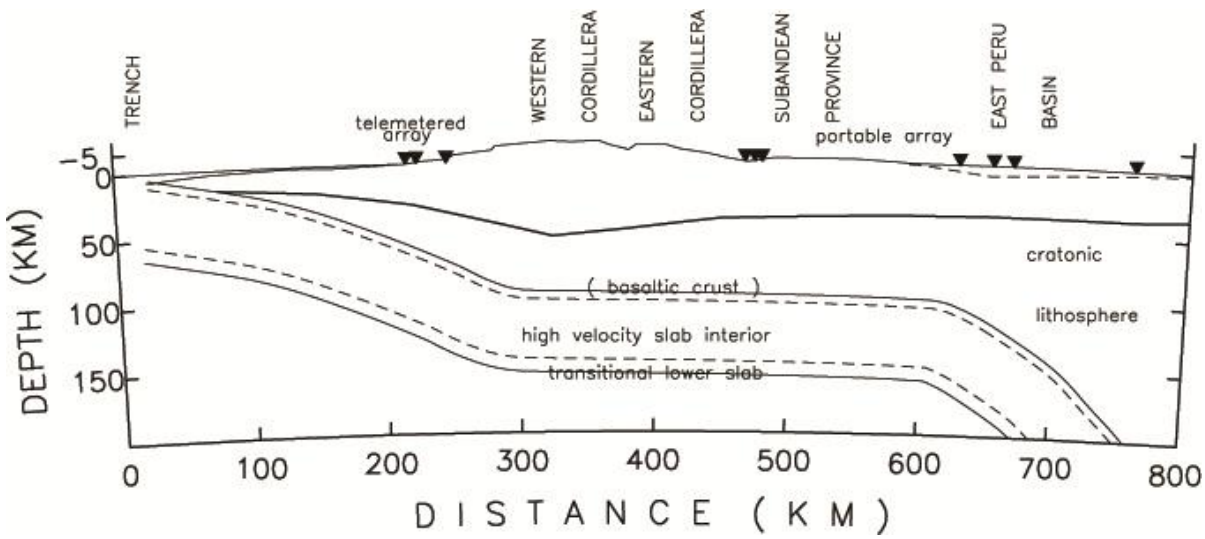
Response: This question is motivated by the sentence from the abstract of the 2004 paper by Booker et al., "Low electrical resistivity associated with plunging of the Nazca flat slab beneath Argentina," *Nature 429*, 399-403, 2004, that reads, "But between 28° and 33° S the subducted Nazca Plate appears to be anomalously buoyant, as it levels out at about 100 km depth and extends nearly horizontally under the continent."

The full abstract reads,

> Beneath much of the Andes, oceanic lithosphere descends eastward into the mantle at an angle of about 30°. A partially molten region is thought to form in a wedge between this descending slab and the overlying continental lithosphere as volatiles given off by the slab lower the melting temperature of mantle material. This wedge is the ultimate source for magma erupted at the active volcanoes that characterize the Andean margin. But between 28° and 33° S the subducted Nazca Plate appears to be anomalously buoyant, as it levels out at about 100 km depth and extends nearly horizontally under the continent. Above this 'flat slab', volcanic activity in the main Andean Cordillera terminated about 9 million years ago as the flattening slab presumably squeezed out the mantle wedge. But it is unknown where slab volatiles go once this happens, and why the flat slab finally rolls over to descend steeply into the mantle 600 km further eastward. Here we present results from a magnetotelluric profile in central Argentina, from which we infer enhanced electrical conductivity along the eastern side of the plunging slab, indicative of the presence of partial melt. This conductivity structure may imply that partial melting occurs to at least 250 km and perhaps to more than 400 km depth, or that melt is supplied from the 410 km discontinuity, consistent with the transition-zone 'water-filter' model of Bercovici and Karato.

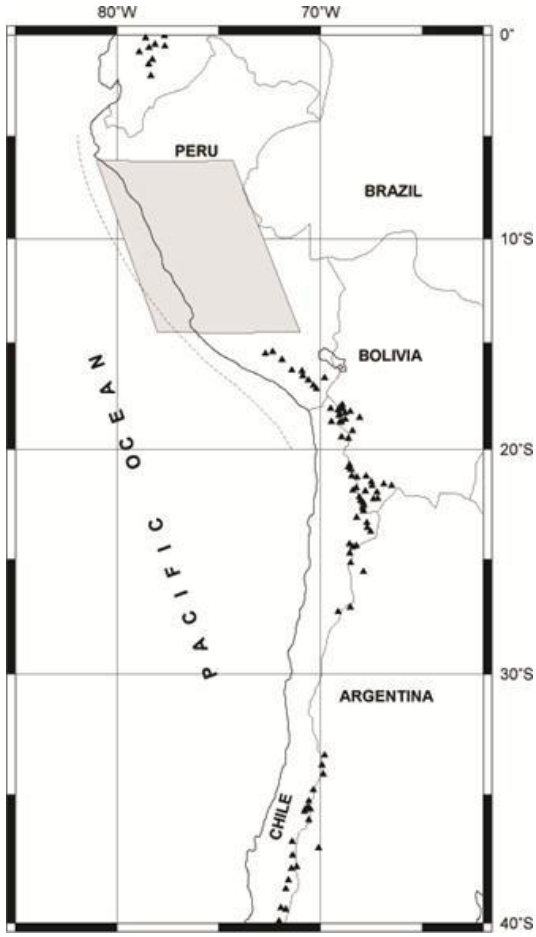
Note that beyond that flat zone the slab "finally rolls over to descend steeply into the mantle."

Flat subduction has been shown by seismic studies to be occurring today in several places in the world, two separate segments in fact beneath South America including the one just described. A seismic investigation of the northern segment beneath Peru is contained in a 1992 Virginia Tech master's thesis by E. O. Norabuena entitled "Velocity structure of the subducting Nazca Plate beneath central Peru as inferred from travel time anomalies" (http://scholar.lib.vt.edu/theses/public/etd-385113359611541/etd.pdf). The findings of this study are summarized in the figure below.



Caption: Structure of the Nazca Plate subducting beneath central Peru. The model suggests a thin basaltic crust (unconverted to eclogite) on the slab top, a cold high velocity slab interior, and a transitional region below. The 800 km cross section has its origin at 11° 25' S and 79° 8' W and a 62° azimuth. The inverted solid triangles indicate the geometry of the seismic networks.

Note that like the similar zone beneath Chili and Argentina, the slab after moving nearly horizontally, in this case for only about 300 km, then plunges downward at a steep angle. This thesis also includes a map showing the tectonic setting, shown below.



Caption: This map delineates the volcanic regions developed along the western coast of South America (solid triangles). Beneath the regions bounded by (0°S - 2°S), (15°S - 27°S) and (33°S - 45°S) the Nazca Plate subducts at normal angles of about 30°. The regions of no volcanoes correspond to the flat subduction zones of northern-central Peru and central Chile. Shaded area marks the area of study and the Peru-Chile Trench is indicated by a dashed line.

There is also a strong case that the Farallon Plate that subducted beneath the western coast of North America. This was first proposed more than 20 years ago by P. Bird in "Formation of the Rocky Mountains, Western United States: A Continuum Computer Model," *Science 239*, 1501-1507. The abstract of this paper is as follows:

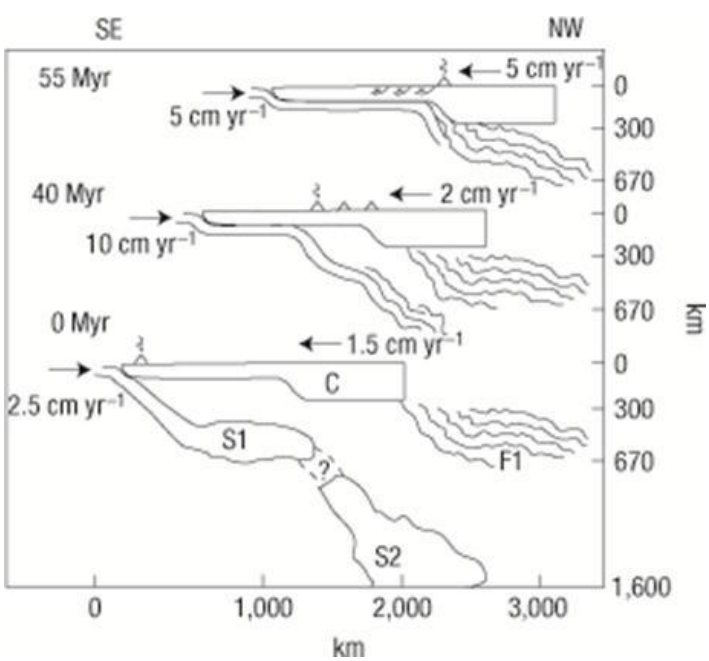
> One hypothesis for the information of the Rocky Mountain structures in late Cretaceous through Eocene time is that plate of oceanic lithosphere was underthrust horizontally along the base of the North American lithosphere. The horizontal components of the motion of this plate are known from paleomagnetism, and the edge of the region of flat slab can estimated from reconstructed patterns of volcanism. New techniques of finite-element modeling allow prediction of the thermal and mechanical effects of horizontal subduction on the North American Plate. A model that has a realistic temperature-dependent rheology and a simple plane-layered initial condition is used to compute the consequences of horizontal underthrusting in the time interval 75 million to 30 million years before present. Successful prediction of this model include (i) the location, amount, and

direction of horizontal shortening that has been inferred from Laramide structures; (ii) massive transport of lower crust from southwest to northeast; (iii) the location and timing of the subsequent extension in metamorphic core complexes and the Rio Grande rift; and (iv) the total area eventually involved in Basin-and-Range style extension.

In a broad sense, this model has predicted the belt of Laramide structures, the transport of crust from the coastal region to the continental interior, the subsequent extension in metamorphic core complexes and the Rio Grande rift, and the geographic region of late Tertiary Basin-and-Range extension. Its principal defects are that (i) many events are predicted about 5 million to 10 million years too late and (ii) the wave of crustal thickening does not travel far enough to the east. Reasonable modifications to the oceanic plate kinematics and rheologies that were assumed may correct these defects.

The correspondence of model predictions to actual geology is already sufficiently close to show that the hypothesis that horizontal subduction caused the Laramide orogeny is probably correct.
The Rocky Mountain thrust and reverse faults formed in an environment of east-west to northeast-southwest compressive stress that was caused by the viscous coupling between the oceanic plate and the base of the North American crust. Nonuniform crustal thickening by simple-shear transport also caused relative uplifts; therefore, this model is consistent with both of the range-forming mechanisms that have been inferred. A new proposal that arises from this simulation is that horizontal subduction also caused the subsequent extensional Basin-and-Range taphrogeny by stripping away the mantle lithosphere so that the crust was exposed to hot asthenosphere after the oceanic slab dropped away.

This landmark paper has been widely referenced in subsequent work on the geology of the western United States. The inference of a period of flat subduction by the Farallon Plate beneath western North America is prominent in the much more recent paper by Sigloch, McQuarrie, and Nolet (previously mentioned in my response above to question 8 [Q8]) that presents the 3D seismic tomography image of the strongly contorted Farallon Plate. The author's interpretation of the 3D tomographic image in terms of the subduction history of the Farallon Plate is provided in the figure below, reproduced from their paper.



Caption: Proposed explanation for the big break and the establishment of the current subduction system. The x axis parallels the direction of relative plate motion. Plate velocities are given in the hotspot reference frame. 55 Myr ago: 'Flat-slab subduction' during the late Laramide era. Direct contact with the continental lithosphere causes basement thrust faulting hundreds of kilometers inland. The flat slab is forced downward at the cratonic keel, dehydrates and causes volcanism, but cannot penetrate the endothermic phase boundary at 670 km depth owing to its low subduction angle. Bending of the slab at the keel combined with the gradual westward motion of North America has caused the plate to repeatedly break off at the edge of the craton. 40 Myr ago: The 'big break.' As retrograde trench migration slows to 2 cm yr−1, the subduction angle steepens. Material S2 disconnects from F1 and passes into the lower mantle. Surface volcanism migrates westward as the slab steepens; thrust faulting ceases. Today: Fully independent, steeply dipping subduction under Cascadia. Stalled material F1 is still foundering on the 670 km discontinuity.

Of course, the interpretation in this article as well as in the previous one is in terms of the uniformitarian time scale, which is to be rejected in regard to absolute dates are concerned. In summary, the case for flat subduction of slabs is compelling, not only in the present but also in the past. Numerical models show that it is mechanically plausible. The main driving force for moving the slab is the slab pull arising from the negative buoyancy of the cold dense material that comprises the slab. These conclusions apply equally for UPT and CPT. return to Contents

14. Why would thick, buoyant continents not entirely prevent subduction?

Response: This question is motivated by a statement in a paper by P. Molnar entitled "Continental tectonics in the aftermath of plate tectonics," *Nature 335*, 131-137, 1988, available without cost at http://www.colorado.edu/GeolSci/faculty/molnarpdf/1988Nature.ContinentalTectonics.pdf,

> …the buoyancy of thick continental crust keeps it afloat. If continental lithosphere were strong enough to maintain its integrity at a subduction zone, the buoyant continental crust would not only resist being subducted, but the subducting plate would abruptly grind to a halt when the continental "passenger" reached the trench.

The paragraph containing this quote is the first paragraph in a section entitled "Differences between continents and oceans" and focuses on the contrast in buoyancy. The next paragraph focuses on their contrast in strength. It reads,

> The strength of the continental lithosphere also contrasts with that of the oceanic lithosphere. The strongest part of the oceanic lithosphere seems to lie in the mantle, between 20 and 60 km depth, between a brittle upper part and above its increasingly ductile lower part, which grades downward into the asthenosphere (Fig. 3). In the same depth range where oceanic lithosphere is strongest, however, continental lithosphere consists of crust, not mantle. At temperatures typical of the lower crust (400-700 °C), the minerals comprising the crust appear to be much weaker than olivine, the strong mineral that comprises most of the upper mantle. Consequently, continental lithosphere could be much weaker than oceanic lithosphere. Oceanic lithosphere behaves as a virtually rigid plate because of its strong core, but, as the late C. Goetze noted in the mid-1970s, continental lithosphere might consist of three layers: a brittle upper-crustal layer, a weak lower crust and a stronger uppermost mantle, which, nevertheless, would not be as strong as the strongest part of the oceanic lithosphere. This jam-sandwich-like rheological profile (Fig. 3) is also suggested by the frequent occurrence of earthquakes (brittle deformation) in the upper crust, their nearly complete absence in the (presumably weak, ductile) lower crust, and their occasional presence in the underlying upper mantle.

The point of this paragraph is that in regard to overall strength continental lithosphere contrasts strongly with the oceanic lithosphere. Indeed, the strength profile of continental lithosphere has frequently been referred to as a "jam sandwich" because of the weakness of the warm lower crust. So the original quote, taken in its context,

does *not* suggest or imply that continental lithosphere is strong enough to maintain its integrity at a subduction zone and therefore that subduction should abruptly grind to a halt. It is just the opposite. The author in the following paragraph is providing reasons why continental lithosphere is weak and deformable and why this grinding to a halt state of affairs does *not* generally take place. This observation applies equally to UPT and CPT. return_to_Contents

15. Why is it that the total length of trenches does not approximately match the total length of ridges, as one might expect from plate tectonics theory?

Response: This perception is simply not true. Detailed estimates of plate convergence and divergence is provided in a 20 paper by Peter Bird, "An updated digital model of plate boundaries," Geochem., Geophys, Geosys., 4(3) at http://peterbird.name/publications/2003_PB2002/2001GC000252.pdf. Below is a table that summarizes the results.

Table 3. Collective Properties of Plate Boundaries by Class

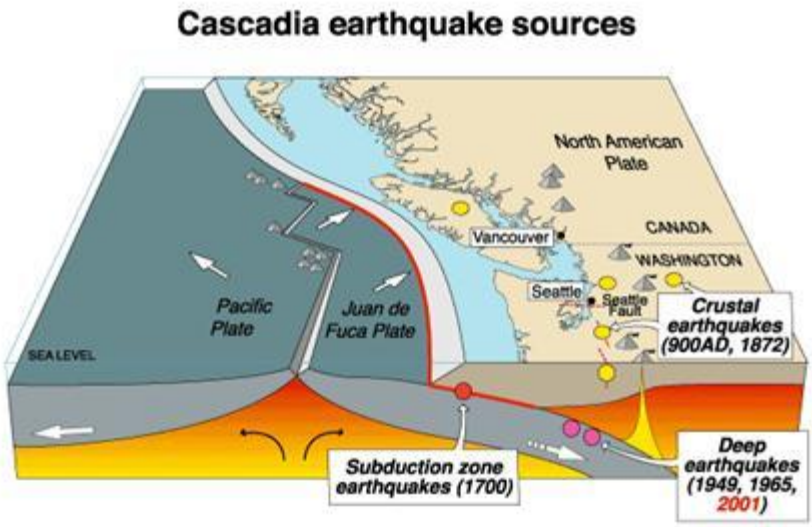
Class	Total length (km)	Mean velocity (mm/yr)	Area production (m^2/s)
Continental Convergent	23,003	26.2	-0.013616 (-12.6%)
Continental Transform	26,132	24.7	-0.000599 (-0.5%)
Continental Rift	27,472	17.6	+0.011502 (+10.7%)
Oceanic Ridge	67,338	46.6	+0.095348 (+88.4%)
Oceanic Transform	47,783	40.5	+0.001022 (+1.0%)
Oceanic Convergent	17,449	17.6	-0.007141 (-6.7%)
Subduction Zone	51,310	62.3	-0.086516 (-80.1%)
Totals	260,487	39.6	0

The total length of convergent boundaries is 91,762 km, while the total length of divergent boundaries is 94,810. If we neglect the continental convergent and rift boundaries and consider only convergent and divergent boundaries in the oce basins, the total length of subduction zones and other convergent segments is 68,759 km, while the total length of ocean ridges is 67,338 km, again very similar.

The current rate of area increase along the oceanic ridges is 0.095 m^2/s is very close to the current rate of area loss along convergent boundaries in the oceans, 0.094 m^2/s. While there is no logical or geometrical requirement for the total lengt of convergent and divergent boundaries to be identical, they are amazingly similar. return_to_Contents

16. Why is it that at three locations on earth, a trench (where rock presumably is descending) purportedly intersects a ridge (where material is presumably rising)? How can material be going up and down at the same time?

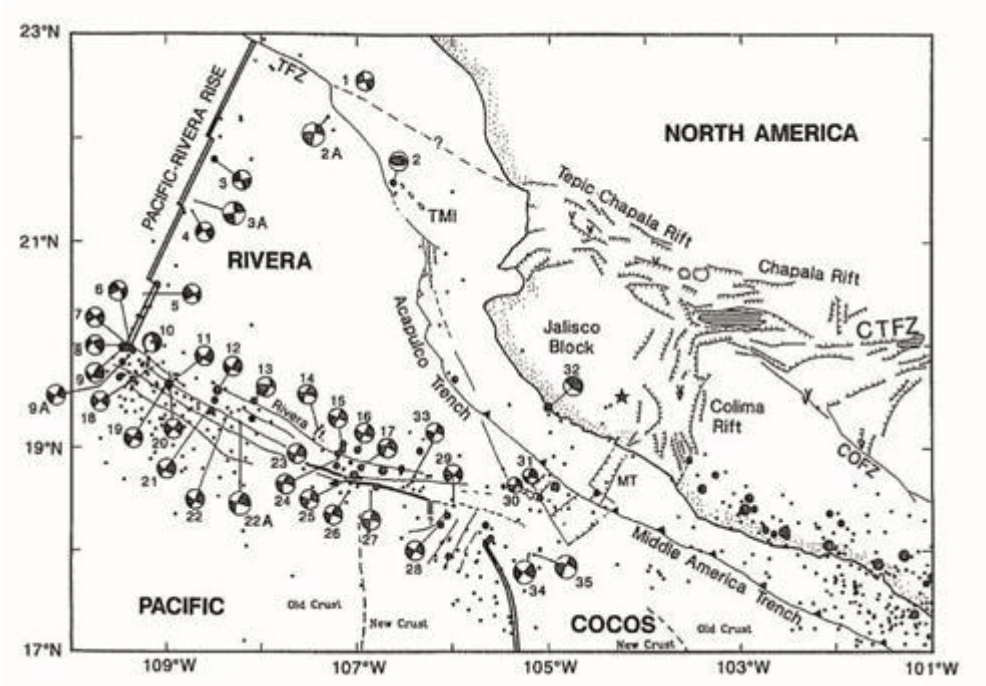
Response: The first of these sites is the north end of Explorer Ridge, located off the coast of British Columbia just south of Queen Charlotte Island and northwest of Vancouver Island, where it forms a triple junction with the Queen Charlotte Fault and the north end of the Cascadia Trench. The location is indicated in the figure below by the black arrow. As far as can be determined from observation, both the Explorer Ridge and the Cascadia Trench terminate at this triple junction. There is nothing which seems to indicate that the ridge continues toward the continent beyond the trench. New plate produced by spreading at the end of the ridge appears to be accommodated by oblique subduction into the trench. So this site does not appear to correspond to a case of a ridge itself subducting into a trench.



Source	Affected area	Max. Size	Recurrence
Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Caption: 3D perspective view of subduction of Juan de Fuca Plate into the Cascadia Trench along the coasts of Washington and southern British Columbia. Black arrow marks the triple junction of the Explorer Ridge, the Queen Charlotte Fault (to the northwest), and the Cascadia Trench (shown in red).

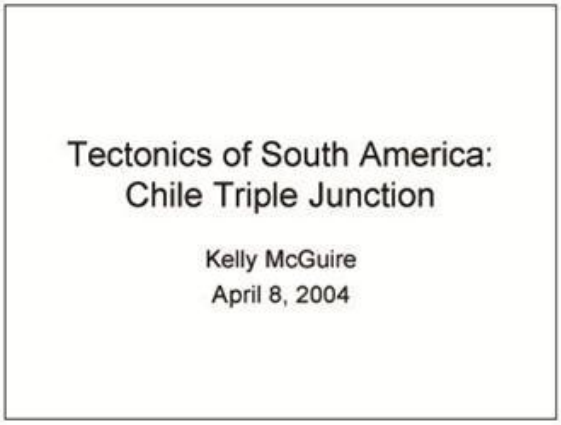
The second site, at 20.5 °N, 107 °W, is near the northern end of the East Pacific Rise along the western coast of Mexico just below the mouth of the Gulf of California. The region is shown in the map below.

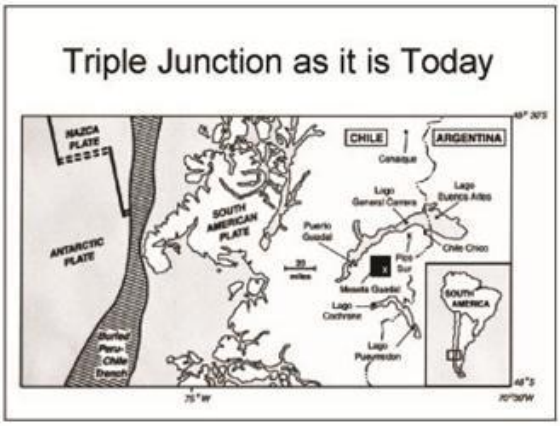


Caption: Neotectonics of Rivera Plate region (from C. DeMets and S. Stein, "Present-day kinematics of the Rivera Plate and implications for tectonics in southwestern Mexico," *J. Geophys. Res. 25*, 21931-21948, 1990).

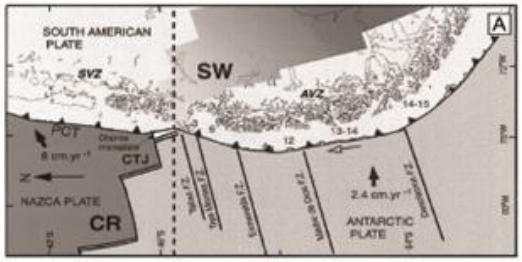
One notes that the location 20.5 °N, 107 °W is in the middle of the small Rivera Plate and not on a ridge, although it is near the Acapulco Trench. So it is not clear what feature was intended here.

The third site is along the western coast of southern Chile, where the Chile Rise, an oceanic ridge between the Nazca and Antarctic Plates, is indeed being subducted into the Peru-Chile Trench. A PowerPoint geology class presentation of this remarkable feature is available at http://www.nsm.buffalo.edu/courses/gly481-581/McGuire05_2.pdf. Below are some of these slides.





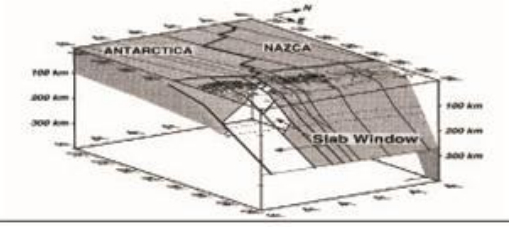
*Chile Triple Junction 46.5°S, 75.5°W
*Nazca Plate Motion 8 cm/yr, NE direction
*Antarctic Plate Moving 2.4 cm/yr, E direction
*Spreading Ridges form between Nazca Plate and Antarctic Plate



Subduction

- Flat Slab Subduction Suggested for the Nazca Plate.
  - Young, less dense oceanic crust gets subducted under continental crust.
  - Relatively low angle of subduction (5-15°)
  - Relationship of flat slab subductin and fold belts were developed further into plates interior
    - By foreland basement thrust systems
- Steep Slab Effects
  - Intense Young, Calc Alkaline Volcanism

- Where Rise Enters the Trench it is Very Shallow
- Trend of Rise is WNW
  - Ridge Segments striking West of North
- Ridge Segments Approach Trench at Shallow Angle
- Chile Rise Transforms Enter Ridge at a High Angle



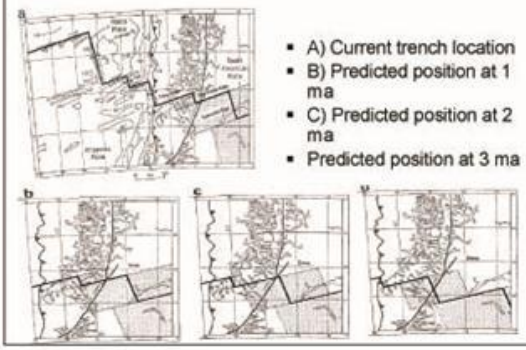
Recent Subduction

- Just off the Taitao-Tres Montes Peninsulas
- Between the Taitao and Darwin Fractures. Associated with:
  - Structure of continental forarc
  - Obduction of a Plio-Pleistocene ophiolite sequence
  - Recent Volcanism of the Tres Montes Pen.
  - Gap in active Pantogonian Volcanic arc
  - Eruption of plateau basalts in W. Argentina

What Has Been Found on the Taitao Peninsula

- Plutons- ~17 km East of the Trench Axis
  - Biotite–hornblende-bearing granodiorite or tonalite
- Bimodal Dike Complex
- Volcanic Edifices on Eastern Peninsula, With Little Deformation

Predicted Positions of Slab Window



- A) Current trench location
- B) Predicted position at 1 ma
- C) Predicted position at 2 ma
- Predicted position at 3 ma

Effects of Ridge Subduction

- Pliocene Near-Trench Magmatism,
  - Intrusion of calc-alkaline stocks within the forearc basement
  - Creation of the Taitao Ophiolite at leading edge of SA
- Distribution and Kinematics of Faulting
  - Reflects the plate margin kinematics
  - Strongly influenced by the thermal, topographic and kinematic heterogeneities related to the CTJ
- 1000 km Long, Trench Parallel, Liquifie Ofqui Fault.
- All These Effects are Found Within 100 km of the Trench

Effects of Ridge Subduction Cont.

- Cenozoic Uplift of the Andean Divide Appears to be Dramatically Different N & S of the Triple Junction
- Back Arc Fold and Thrust Belt of Southernmost Patagonia Appears to End at the Present Latitude of the Triple Junction
  - Corresponds to a change in thickness of Miocene molasse.
  - Passage of slab windows corresponding to ridge
- Slab Window Movement Corresponds to Ridge Segments Subducted in the Late Cenozoic

What's so cool about the CTJ?

- Ridge-Trench-Trench (RTT) Triple Junction
  - Where active oceanic spreading ridges enter a subduction zone.
  - Instead of mature oceanic crust subducting, younger crust created from the extension of the triple ridge is subducting.
  - Repeated passages can develop high thermal gradiants.
    - Can allow rocks or oceanic or continental origin to melt at:
      - T= 800-900°C and Pressure corresponding to depths of 10-20km

What is going on?

- Calc-Alkaline Acidic Rocks are not Expected to Occur in this Type of Margin.
- Possible Scenario
  - Tectonic coupling along with repeated passage of thermal anomalies which is due to successive subduction of short ridge segments.
  - Tectonic coupling leads to the underplating of very young hot lithosphere to the continental margin.
  - Repeated ridge subductions favor the re-melting of the underplated oceanic material.
  - This would result in calc-alkaline acidic rocks, associated with MORB-type lavas.

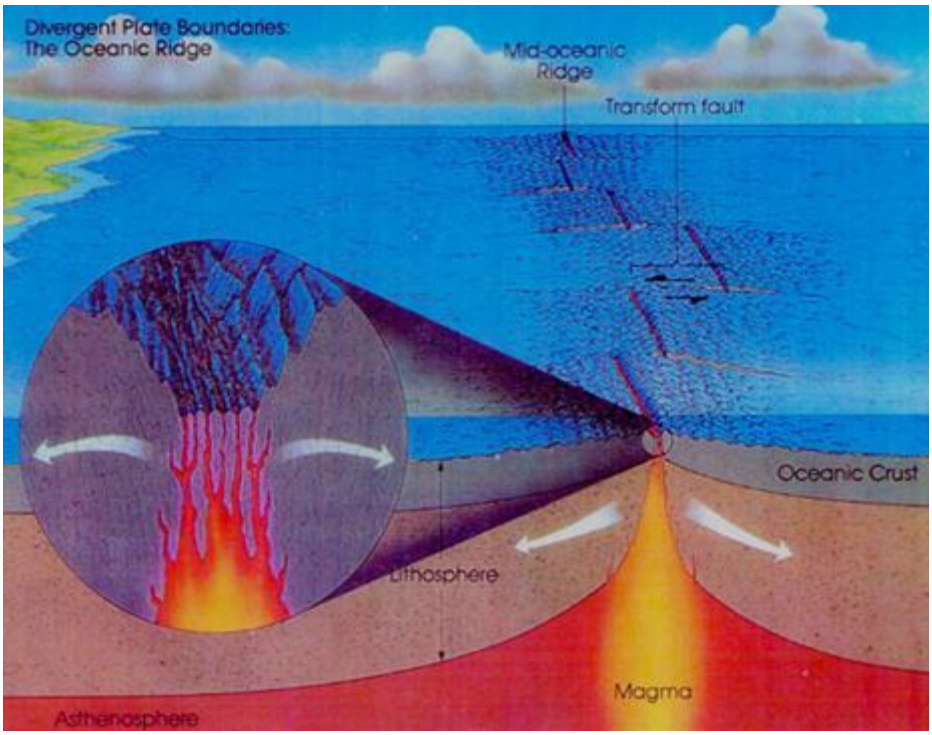
Why is it possible for this portion of the Chile Rise to subduct? The main reason is that the plates on either side of the ridge, the Antarctic Plate and The Nazca Plate, are sufficiently strong to carry this ridge segment along as they move into the trench. What happens to the rock in the ridge as it migrates into the subduction zone? To the extent that the Antarctic and Nazca Plates continue to diverge from each other, which their strength away from the ridge would cause them to tend to do, there will be flow of warm rock from below to fill the resulting gap. But this flow is *relative* to the movement of the gap into the trench and beneath the South American Plate. So whether the net motion is actually upward or downward depends on which of the two vertical components of motion is greater. This conclusion is the same for both UPT and CPT. return_to_Contents

17. Have ancient trenches ever been found?

Response: The Franciscan terrane in California, as was mentioned in my response to question 4 (Q4) above, is a classic example of a fossil subduction zone complex that has been in the geology literature for the past 40 years. With only a short drive north of San Francisco, one can inspect these rocks first hand. Similar fossil subduction zones containing high grade metamorphic blueschist rocks have been described in Greece, Turkey, Japan, New Zealand, and New Caledonia east of Australia. Another such example mentioned in my response to question 5 (Q5) above is the North Motagua Fault Zone in Guatemala. There are dozens of other spectacular examples well documented in the standard literature. return_to_Contents

18. What are the physical mechanisms responsible for the distinctive features we observe in the mid-ocean ridge system, specifically, the segmented ridge axis, the medial rift valley that is often present, and the transform faults that offset the ridge axis segments at close to 90° angles?

Response: These features are evident in the schematic diagram below.

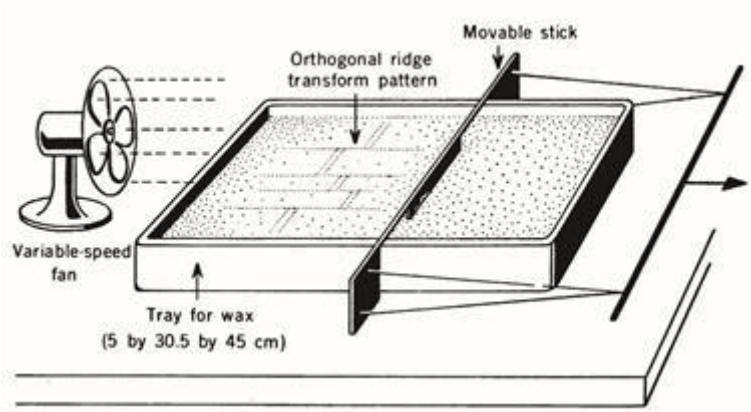


Laboratory experiments conducted now for almost 40 years have shed some extremely important light on these questions. The experiments involve the use of molten wax to investigate on a laboratory scale the mechanics of how a medium consisting of a brittle upper layer and a ductile lower layer deforms when pulled apart. The classic paper that launched this approach is by D. W. Oldenburg and J. N. Brune, "Ridge transform fault spreading pattern in molten wax," *Science 178*, 301-304, 1972.

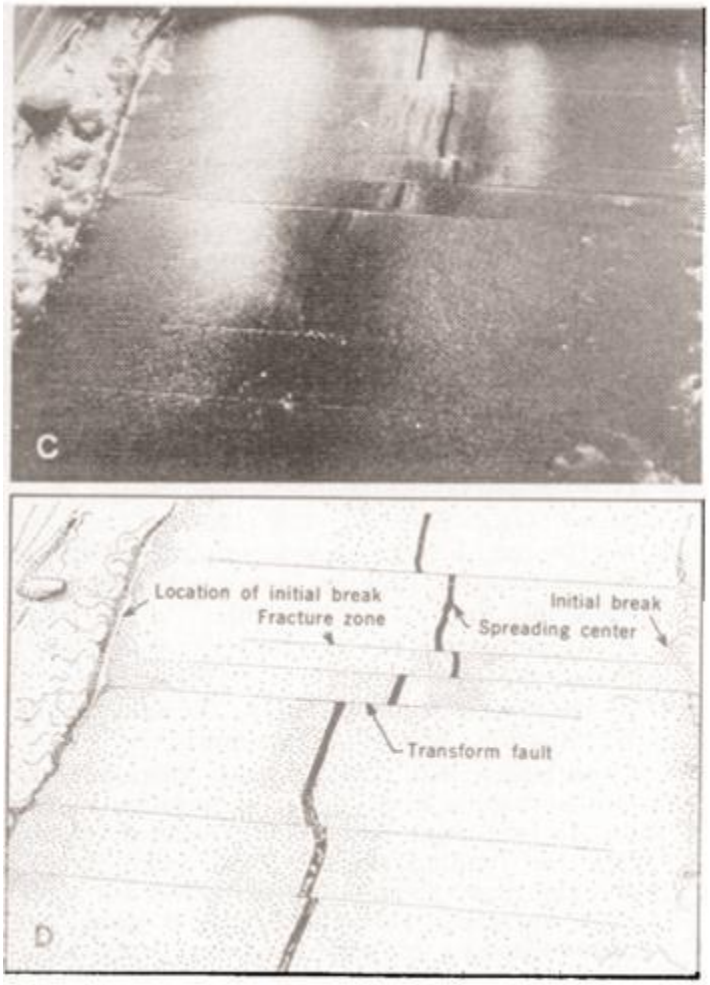
The abstract of this paper reads as follows:

> A laboratory experiment shows that ridge-ridge transform faults, inactive fracture zones, and other features characteristic of spreading oceanic ridges can be produced in a variety of paraffins. Although the resultant pattern depends upon the temperature of the wax and the ratio of spreading rate to surface cooling, the characteristic orthogonal ridge transform fault system is a preferred mode of separation. Symmetric spreading occurs under conditions of no tensile strength across the ridge, and the stability of transform faults is a consequence of their lack of shear strength. The experiment also shows that properties characteristic of oceanic ridges occur under conditions of passive convection where upwelling of material at the ridge crest is a result only of hydrostatic forces in the fluid; that is, the plate separation is caused not by large convective forces beneath the ridge but rather by tensile forces in the plate.

The figure below shows the apparatus and basic results of the experiment.



Caption: (Above) Experimental apparatus. A tray of melted paraffin was cooled with a variable-speed fan until a film of solidified wax formed between one end of the pan and a movable stick. The stick, representing the edge of a moving plate, was then drawn at a uniform rate through the wax by a variable speed a-c motor. (Below, upper panel) For moderate ranges of cooling rate, spreading rate, and initial wax temperature, the characteristic segmented ridge/transform fault pattern shown in this photo developed. (Below, lower panel) Diagrammatic representation of photo, for clarity.

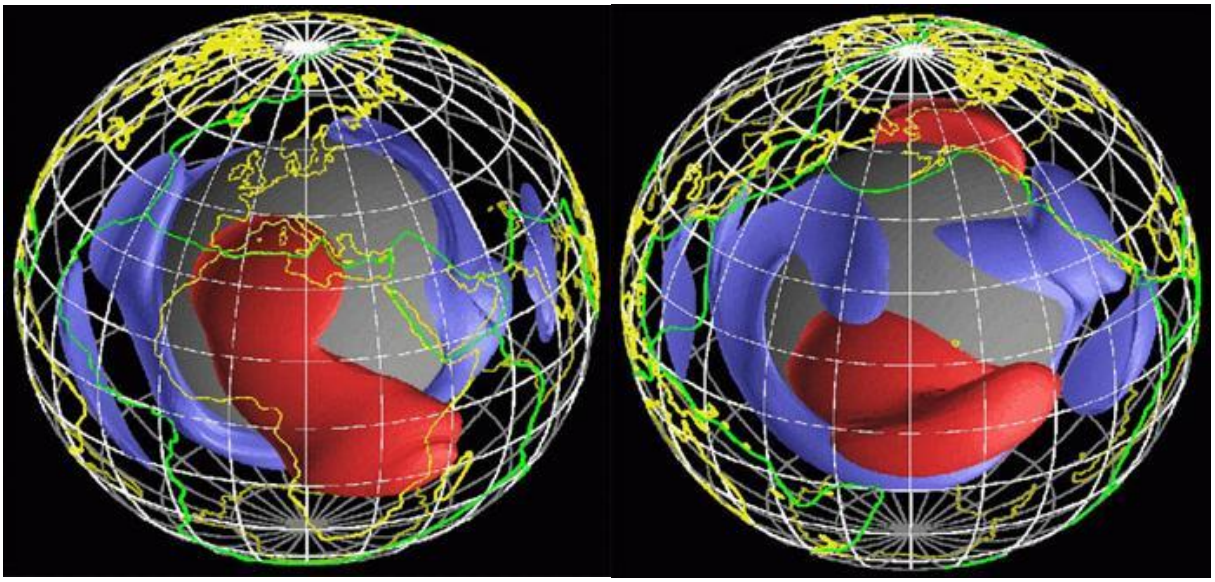


What this experiment and many similar ones since reveal is that the essential physics responsible for the segmented ridge/transform fault geometry is the presence of a strong brittle upper layer and a much weaker ductile lower layer, with surface cooling causing the brittle layer to thicken with time, yet with sufficient spreading motion to keep the divergent zone weak by replenishment with hot ductile material from below. To the extent that this experiment represents an analog to ridge tectonics on the earth, the authors conclude that "spreading ridges may be formed under the influence of tensile stresses only, and forces from an active convection cell located beneath the ridge axis are not required." Let me here emphasize that subsequent observation strongly confirms that this generally is the case for the earth—that mid-ocean ridges are mainly the product of the divergent motion of the plates on either side *and not a result of the upwelling limb of a convection cell below*. In other words, the spreading ridges are largely passive features—the result of plate divergence. (This is very much contrary to many popular characterizations of plate tectonics concepts.) A second major conclusion of the authors of this paper is that "the stability of transform faults is a consequence of their lack of shear strength."

To summarize up to this point, the picture provided in this 1972 experiment with molten wax comes close to describing the essential physics responsible for symmetric spreading at ridges and for the fracture zones that offset segments of ridge at approximately 90° angles, both within the framework of uniformitarian plate tectonics (UPT) and catastrophic plate tectonics (CPT). The very weak asthenosphere reaches almost to the surface at a spreading ridge. Partial melting of asthenospheric rock generates the basaltic magma that fills the gap as the oceanic plates diverge along the ridge axis. The circulation of sea water within this hot rock cools it rapidly and causes a strong and brittle surface layer to develop away from the ridge axis. However, the slip along the active portion of the transform faults keeps these active faults weak. Hence, there does seem to be a solid correspondence between the crucial aspects of the molten wax experiment and the mid-ocean ridge/transform fault environment. return_to_Contents

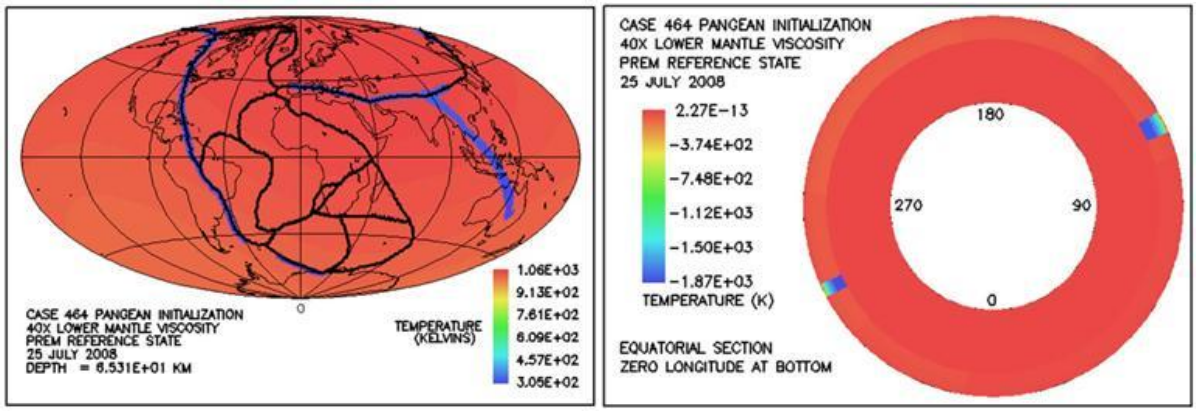
19. How do *vertically-acting* buoyancy forces, mainly from sinking slabs of lithosphere, generating what you refer to as 'flow in the mantle', result in *horizontal* motions at the earth's surface?

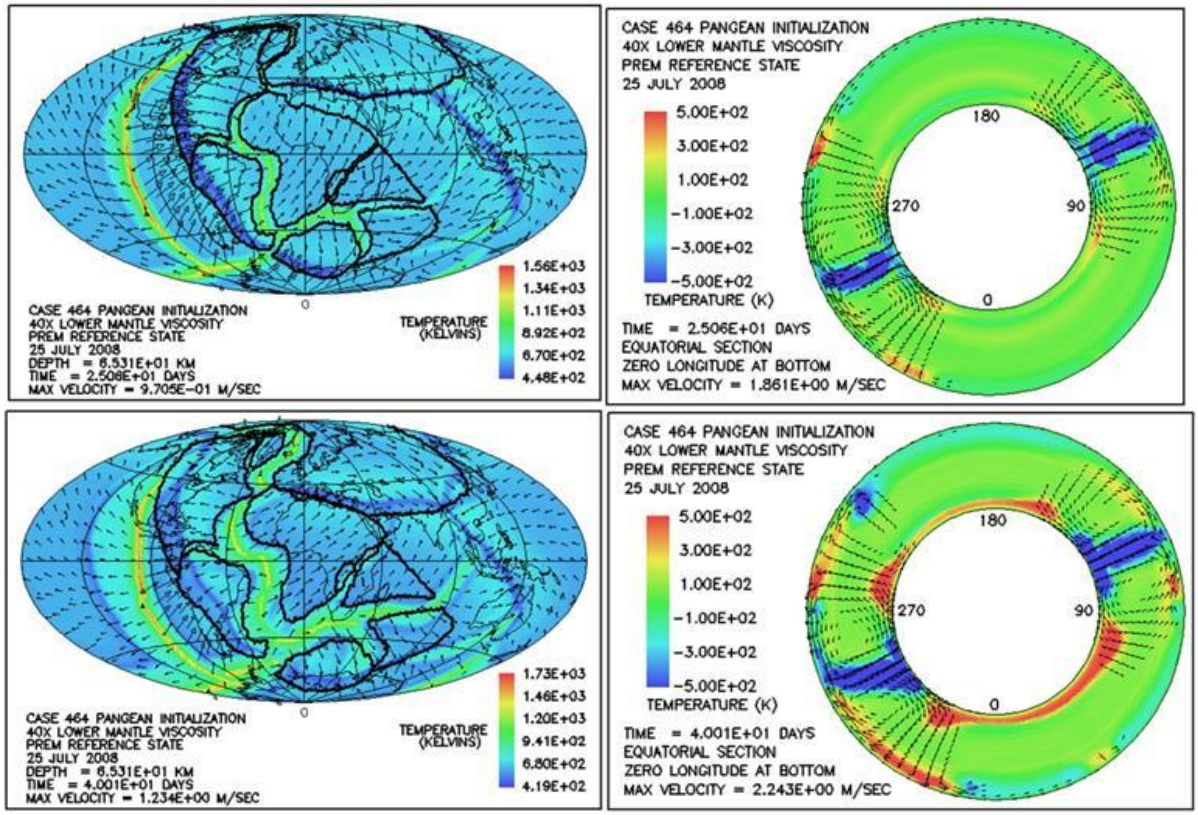
Response: Usually when I have used this wording I have had in view the numerical simulations of the supercontinent breakup that I have undertaken over the years. These calculations are initialized with a zone of cold material around much of the perimeter of the supercontinent to initialize motion within the spherical shell domain. This results in a large component of spherical harmonic degree two flow inside the domain. The 3D seismic tomography images below of the earth's actual lower mantle density distribution that prominently displays this degree-two pattern. Blue corresponds to higher density, presumably cold, mantle rock, while red corresponds to low density, presumably hot, mantle rock.



Eastern Hemisphere Western Hemisphere

The type of flow characterized by downwelling mostly around a great circle, to conserve mass, leads to upwellings on either side of the circle, as suggested by the red features in the images above. The presumed upwelling in the middle of the eastern hemisphere beneath Africa was near the center of the original supercontinent. If this interpretation is correct, then this upwelling flow would have had the tendency to cause the supercontinent to pull apart. Below are some snapshots from one of the computer simulations that shows the dynamics that result from the initial temperature perturbation as conservation of mass and energy is enforced and forces are balanced everywhere throughout the domain and velocity, pressure, and temperature are recomputed at each grid point time step after time step in the calculation. Although the motions are driven solely by gravity that acts in the radial direction, there are significant horizontal forces and velocities, especially near the boundaries, that naturally arise in order to conserve mass.





In summary, the downwelling flow around the perimeter of the continental region leads to upwelling flow beneath that region which results in an overall tendency to pull the supercontinent apart. return_to_Contents

20. How could the plates have accelerated to CPT velocities without ripping apart and without being impeded by drag from the underlying asthenosphere?

Response: As I have mentioned previously in answers to earlier questions, the fact that mantle rock weakens so dramatically with increasing temperature means that the hot asthenosphere is a thousand times, or more, weaker than most lithosphere. The presence of water at levels of 100 ppm or so within the lattices of asthenospheric minerals is likely a cause for even greater asthenospheric weakness. This is true for the earth today—even without the runaway stress weakening that kicked in to allow CPT to take place during the Flood. Here I am using weakness synonymously with low viscosity. This huge contrast in strength between lithosphere and asthenosphere means that drag forces on the base of the lithosphere tend to be *negligible* compared to plate strength. This contrast tends to persist as runaway rapidly reduces rock strength everywhere throughout the mantle. This contrast allows in today's earth, for example, for the Pacific Plate to move in a highly coherent plate-like fashion—that is, with essentially no deformation internal to the plate—over a distance of more than 10,000 km (6000 mi). This represents the distance from where the Pacific Plate is forming via seafloor spreading at the East Pacific Rise—not that far west of the South American coast—to where it plunges into the Kurile-Japan-Izu-Bonin-Marianas trench in the western Pacific—roughly a quarter the distance around the earth. There is no indication of any failure in tension with regard to the huge Pacific Plate today as it moves at approximately 8 cm/yr relative to the no-net-rotation reference frame for the earth. Again, such motion is possible only because the asthenosphere is so extremely weak in comparison with the Pacific Plate, which leads to near perfect decoupling of the Pacific Plate with respect to the deep mantle except along its subducting boundary.

What about plate failure because of sudden acceleration? Even for the sorts of peak plates speeds implied by the CPT framework, which are on the order of a few meters per second, if these are realized in as little time as an hour, the acceleration implied is only a tiny fraction of one g. For example, a change in speed of 3.6 m/s spread over an hour (3600 seconds) is only 0.001 m/s^2, or 0.0001 g. The level of stress associated with such small acceleration is negligible compared with the strength of a lithospheric plate. return_to_Contents

21. Would a ring of cold material in the earth's upper mantle that was on the verge of catastrophic runaway, as you postulate, if part of God's original construction of the earth, be consistent with God's declaration at the end of creation Day 6 that all He had made was 'very good'?

Response: This is certainly a valid concern. Involved with this issue is the reality that God has purposes and plans about which we have little or no inkling. "For as the heavens are higher than the earth, so are My ways higher than your ways and My thoughts than your thoughts," He declares to us in Is. 55:8. Furthermore, God has, and has always had, perfect foreknowledge. "For I am God, and there is no other; I am God, and there is no one like Me, declaring the end from the beginning and from ancient times things which have not been done, saying, 'My purpose will be established, and I will accomplish all My good pleasure.'" (Is 46:9-10) So the certainty of the Flood as well as its precise timing were without any doubt in God's mind as He was in the process of creating the earth and filling it with plants and animals, with birds and fish, and with Adam and Eve. To be sure, there was no sin or death in the world that existed at the end of Day 6. I personally suspect strongly that the earth was so constructed that the processes that would eventually unleash the Flood cataclysm were *not* already in motion at that point in time, that is, at the end of creation Day 6. I strongly suspect (but cannot demonstrate) that it was not until Adam sinned that any preexisting mechanism was potentially set into motion. So would the inclusion of a ring of cold material in the upper mantle in the originally created earth necessarily be in conflict with a creation God could declare to be "very good"? I personally do not think so, especially if this aspect of the earth's structure were created in a stable initial state.

Therefore, an important related question is whether or not the presence of a ring of cold material in the earth's upper mantle that was on the verge of catastrophic runaway could actually be stable for an indefinite period of time. I can imagine the answer to be yes. The mineralogical phase boundary at about 660 km depth in the earth—the boundary that separates the upper mantle from the lower mantle—provides a moderate barrier to flow crossing it. The main reason is that the main phase changes are endothermic, that is, they require energy from the surrounding environment in order to take place. So it is at least conceivable that God could have designed things such that the cold material in the upper mantle was in a mechanically and thermodynamically stable state requiring some sort of trigger, such as some radiogenic heat, to become unstable. return_to_Contents

22. Would a ring of cold material in the upper mantle sufficient to produce the rotational instability you talked about in your 2008 ICC presentation, if present from the earth's creation, not cause rotational instability immediately from the beginning of history instead of waiting some 1650 years between Creation and the Flood?

Response: Actually, it can be shown that, if there are no external torques or internal perturbations, the earth will spin *indefinitely* about its initial spin axis, even if an orthogonal axis has a larger moment of inertia. Indeed, in my numerical solution of Euler's equations, starting with this sort of initial state, I must intentionally introduce a perturbation to trigger the rotationally unstable behavior. If I do not, the system continues happily forever in its initial state. return_to_Contents

23. Why should density differences due to temperature differences even matter in the mantle when the density differences among the different minerals are so large by comparison? Would not the minerals rise and sink in accordance with their specific gravities during the 1650 pre-Flood years to establish a stable vertical density stratification which lithospheric slabs afterward would be incapable of penetrating?

Response: The answer actually is quite simple. The rock material of the mantle is in the *solid*, not liquid, state, except for some extremely tiny pockets near the surface where some partial melting is taking place. Where the rock is solid, no density stratification can occur! Almost everywhere in the mantle, the ultramafic rock consists of an *interlocking matrix of solid mineral grains*. Moreover, the rock consists of a *mixture* of different mineral types. In the upper mantle above the transition zone, for example, the dominant mineral types are olivine and pyroxene, but there are commonly smaller amounts of several other minerals such as garnet. In the lower mantle, the dominant minerals are magnesiowuestite and silicate perovskite. As one goes deeper into the mantle, the mineral assemblages change because of the increasing pressure, but available observational evidence indicates that the *bulk chemical composition remains very close to uniform*.

Even in the small volumes where partial melting is taking place, for example, just below spreading ridges and about 100 km deep just above the top side of a subducting plate, the rock is still, for the most part, a coherent solid of interlocking mineral grains. In these volumes, it is only the minerals with the very lowest melting points that are melting. The remainder of the crystals in the solid matrix are unmelted and solid. Typically, the degree of melting in these special places in the uppermost mantle is only on the order of a few percent.

How do we know that the mantle is solid and that the rock is strong? The primary evidence comes from seismology. Waves of the type known as shear waves propagate throughout the entire mantle. From the shear wave speeds we observe, it is possible to determine the shear modulus of the rock material and to conclude that, on the time scale of seismic waves, the rock strength is comparable to that of high grade steel. By contrast, shear waves fail to propagate at all in the outer core, that is, in the region just below the mantle. From this we infer with a high level of certainty that the outer core is liquid. From its density and other characteristics, in view of high pressure/temperature measurements we can make in the laboratory, we can further infer that its composition is largely molten iron.

Significant chemical contrast does exist, however, between the mantle and the crust. While the oceanic crust is basaltic in composition and derived from the partial melting of mantle rock, continental crust is radically different from mantle rock. Its density (about 2700-2800 kg/m^3) is about 15-18% less than that of mantle rock (about 3300 kg/m^3), and it tends to have dramatically higher concentrations of what are called incompatible elements. Such elements are referred to as incompatible because they do not conveniently fit into the lattices of most common rock-forming mantle minerals. These incompatible elements includes those with a large ionic radius, such as potassium, rubidium, cesium, strontium, and barium, as well as those with large ionic valences such as zirconium, niobium, hafnium, the rare earth elements, thorium, uranium and tantalum. Because of its high concentration of incompatible elements, continental crust typically displays at least 100 times the level of the main radioactive elements relative to rock from the mantle.

In summary, why is the mantle not stably stratified according to mineral density? The basic answer seems to be that God created it nearly chemically homogeneous and solid. Being solid and nearly homogeneous, there is no significant tendency for denser minerals within a small local parcel of rock to sink relative to the others. return_to_Contents

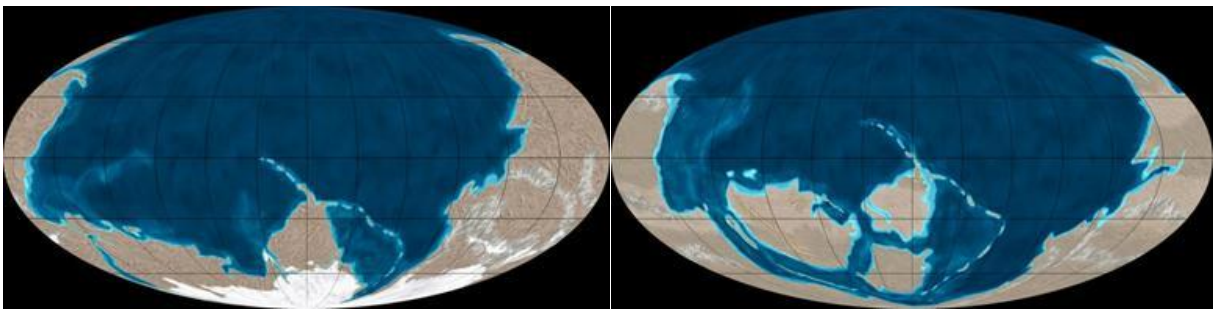
24. Did the continents separate only once or more than once? Were the water jets at the mid-ocean ridge something that only happened once at the beginning of the Flood? Does your model assume that the subducting plates all started their movement at the same time? Is there evidence to support this?

Response: How many times the continents experienced separation depends on which portion of the original supercontinent configuration one considers. The available evidence seems to indicate strongly that Gondwana portion—involving present-day South America, Africa, Antarctica, India, and Australia—remained intact from the beginning of the Flood cataclysm through the entire part of the geological record known as the Paleozoic and then

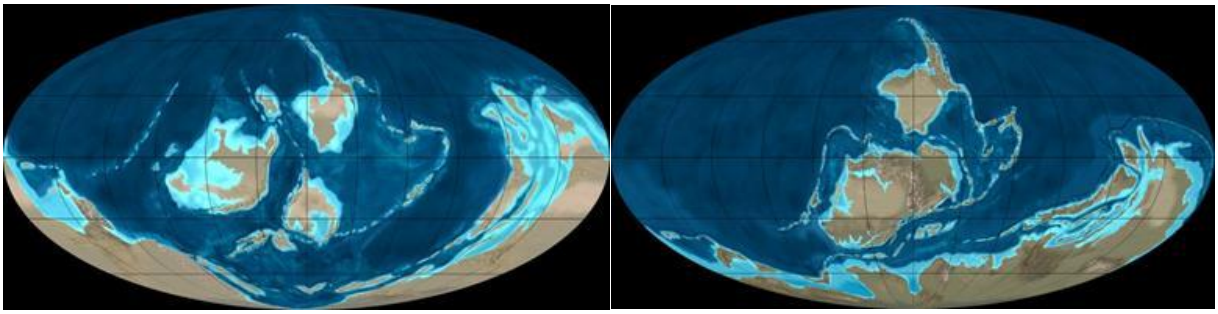
experienced a *single* breakup during Mesozoic part of earth history. By contrast, the evidence also strongly suggests that the rest of today's continents, that is, North America and Eurasia, while apparently joined to Gondwana at the very beginning of the Flood to form a giant supercontinent known as Pannotia, soon afterward broke away from Gondwana as the three separate blocks of Laurentia, Baltica, and Siberia. During the middle and later parts of the Paleozoic, these three blocks came together again and rejoined Gondwana to form the supercontinent Pangea, which then split apart during the Mesozoic. Therefore, the northern continents have experienced two separations. The following images provide one of the best visualizations in my opinion of this history of the continental motions from the time of Pannotia to the present. The images can be freely downloaded from the web at http://jan.ucc.nau.edu/~rcb7/mollglobe.html. This is the website of Ron Blakey, emeritus professor of geology at Northern Arizona University.

The following twelve images (out of a total of 27 available on the website) depict this history of continental movement. These images by Blakey agree closely with the reconstructions produced by Chris Scotese over the past twenty years as part of the Paleomap Project. These reconstructions are viewed favorably by most of the secular earth science community. The website for the Paleomap Project is http://www.scotese.com. The reliability of these reconstructions in my opinion is reasonably good from the middle Mesozoic (i.e., Jurassic) to the present, mainly because of the constraints provided by features such as fracture zones in today's ocean floor. However, for the history earlier than Mesozoic, no seafloor still remains at the earth's surface. Therefore, the reconstructions must rely on clues from continental rocks, such as the presence of earlier mountain belts, other evidences of earlier tectonic deformations, and paleomagnetic directions locked into igneous rocks and certain sediments. I personally consider the tectonic indicators much more reliable than the paleomagnetic ones. I therefore consider the motions of the continental blocks *relative* to one another as reasonably reliable for this earlier portion of earth history, as opposed to the absolute locations, because the relative motions rely more on the geological field observations and less on the paleomagnetic interpretations.

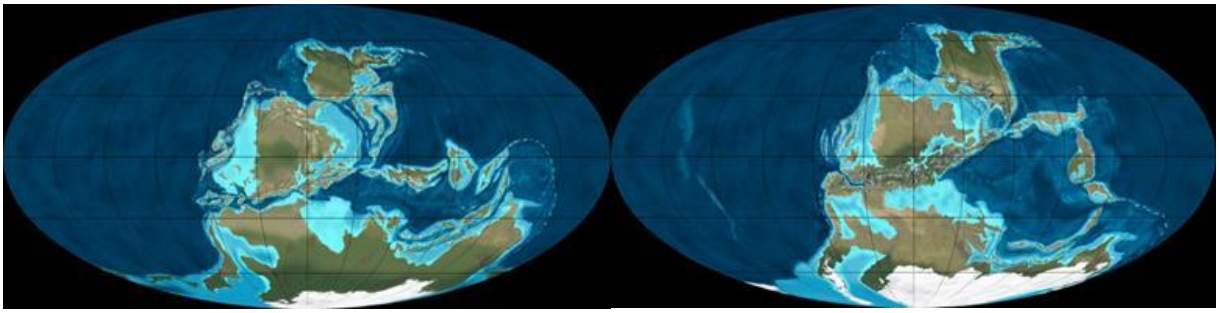
The numbers in parentheses in the captions of the figures below represent the uniformitarian age in millions of years. Of course, my conviction is that all the change that unfolded in this sequence, except for a little between the final two frames, occurred within the span of the year of the Flood as described in Genesis 7-8.



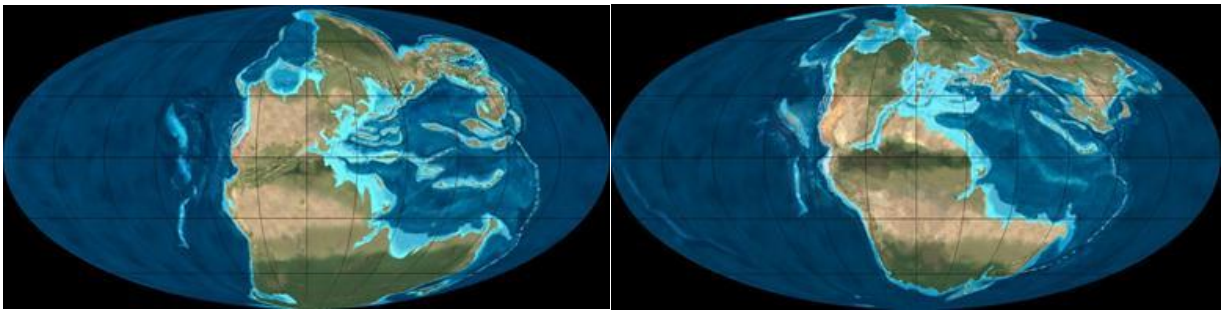
(a) Late Proterozoic – Pannotia (600) (b) Early Cambrian (540)



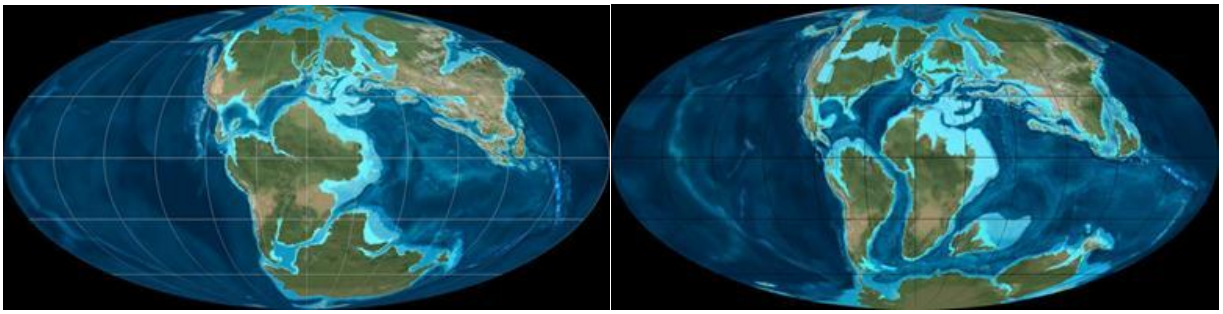
(c) Late Ordovician (450) (d) Early Devonian (400)



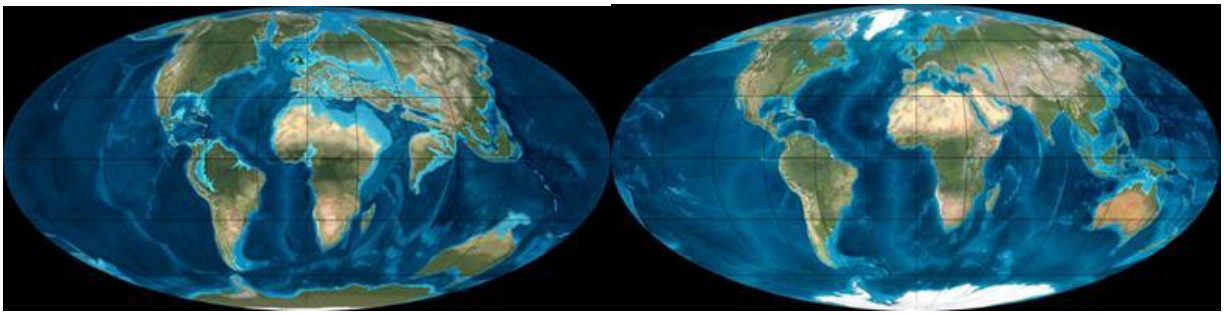
(e) Mississippian (340) (f) Pennsylvanian (300)



(g) Early Triassic (240) (h) Early Jurassic (200)



(i) Late Jurassic (150) (j) Mid Cretaceous (105)



(k) Eocene (50) (l) Present (0)

Note that one prominent aspect of these reconstructions is that the Pannotia supercontinent at the beginning of the sequence is centered approximately at the earth's South Pole, while the supercontinent Pangea that is in place at the beginning of the Mesozoic is centered approximately on the equator. It was in 2006, while I was grappling with just how

such a 90° of true polar wander might occur within the short time scale of the Flood for all the continental regions, that I discovered the potential for rotational instability. My own view now is that if such an episode of rotational instability did in fact take place during the Flood, as I am now convinced it did, then the paleomagnetic data that are used to locate Pannotia at the South Pole may simply reflect the fact that the extra rotation that occurred about the axis perpendicular to the spin axis took the supercontinent through the South Pole location multiple times and gave rise to the particular paleomagnetic alignments that are being relied upon. Therefore, my present suspicion is that at the onset of the Flood, Pannotia's center was near to the equator, and that the placement of the continental blocks within it was strikingly similar to the distribution of blocks which characterized Pangea. In particular, the Gondwanaland block would have been close to identical in its makeup, location, and orientation on the earth relative to its spin axis in both Pannotia and Pangea. If this suspicion is correct, then the continent distribution in figures (a) through (g) should actually be rotated counterclockwise such that the center of mass of the continents lies near the equator throughout the entire sequence. Also, if this suspicion is correct, none of the glaciation depicted for Pannotia or during Mississippian or Pennsylvanian times would have existed.

Now let me address the issue of the timing of the steam jets at the mid-ocean ridges relative to this plate motion history. First let me emphasize that for plates to be able to move fast enough for these motions to occur during the time span given in Scripture, *runaway motion within the mantle must be occurring to produce the stress-weakening required to reduce the viscosity throughout the mantle by many orders of magnitude*. Otherwise mantle rock would display the sorts of viscosities it does today with the result that plate velocities would be on the order of only cm/yr instead of m/s. This leads me to infer that essentially all the plate motion history depicted in the figures above, at least through frame (j), occurred during the main runaway phase of the cataclysm. This main runaway phase would have been accompanied by very rapid seafloor spreading, a curtain of violent supersonic steam jets emerging from the zones of spreading, and consequent heavy rain resulting from water entrained by the jets. The time interval for this main runaway phase would therefore seem to correspond to the forty days and nights of heavy rain described in Genesis 7.

What about the issue of whether all the subduction began at the same time? My guess is that the answer is no. First of all, let me point out that guessing the initial state for the mantle which is required to yield the sort of plate motion history described above is an extremely difficult, if not impossible, problem. However, in papers I have presented over the years I have shown that a ring of cold material around much of the perimeter of a Pangean-like supercontinent can indeed lead to a subsequent post-Pangean plate motion history similar to that depicted in the above figures. In the model calculations new zones of rapid subduction grow and develop during the course of the calculation. But what about the Paleozoic or pre-Pangean plate motion history that is depicted in these reconstructions? It is my suspicion that the breakaway of the Laurentia, Baltica, and Siberia blocks from Pannotia was likely caused by a runaway upwelling plume of hot material from the bottom of the mantle similar to that observed on the right-hand edge of the 2D calculation that I discuss in the following question (Q24). This first pulse of upwelling would then plausibly be followed by runaway sinking of a cold ring of material as I have included in earlier modeling. This sinking and the associated subduction, however, may have begun earlier in some places than in others. There is nothing in this overall picture that requires the cataclysm to be unfolding at full speed everywhere from the very beginning.

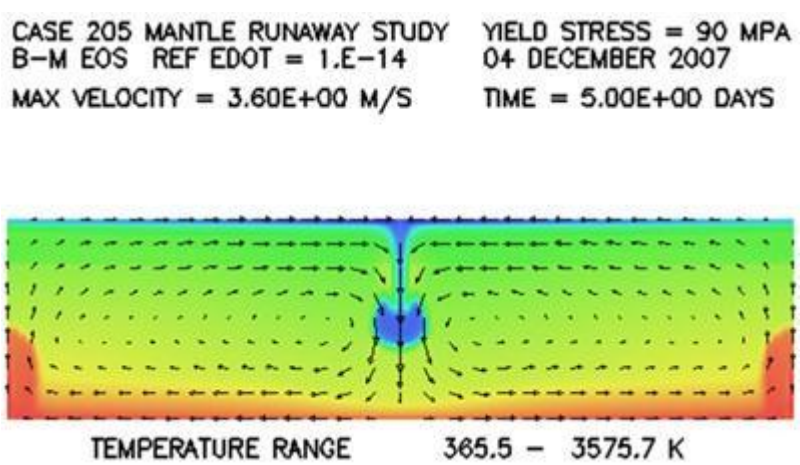
Finally, let me take this opportunity to emphasize that CPT, *both as a concept and as a model for the Flood,* is grounded in the compelling observational evidence that seafloor spreading and subduction are real processes which not only are occurring today but have also occurred on a massive scale in the past to generate today's ocean floor basement rocks. *As a concept and Flood model*, CPT in addition relies on many lines of observational evidence that a huge amount of subduction and seafloor spreading occurred simultaneous with the formation of the fossil-bearing sedimentary record and therefore logically must have played a major part in the cataclysm. Understood in these terms, *CPT has nothing to do with computer models!* Computer modeling is merely an auxiliary tool to gain deeper insight into the physics and processes involved. The validity of CPT therefore should be judged primarily on the strength and

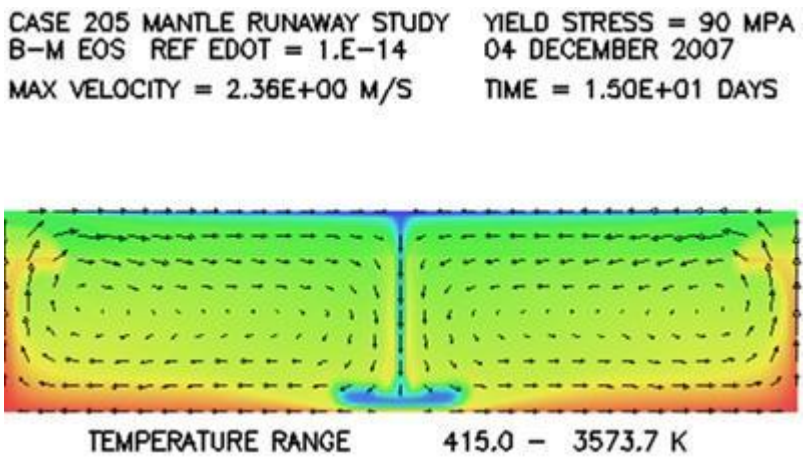
consistency of the observational data and how well this body of data agrees with the constraints of the Biblical text and not on the degree to which the processes can be simulated on a computer. return_to_Contents

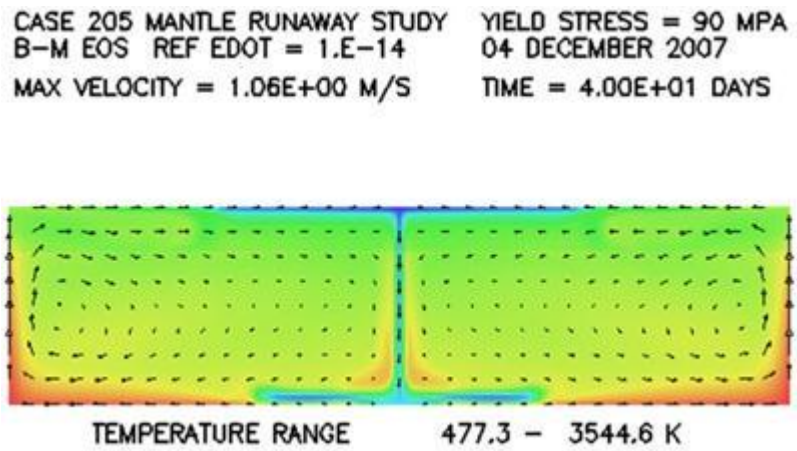
25. CPT posits that cold material from near the earth's surface at the beginning of the Flood (essentially at surface temperature) now rests at the bottom of the mantle just above the liquid core. Why would molten material not have intruded this cold rock as it descended and warmed it as it did so? And as the cold material "pancaked" at the bottom of the mantle, would its kinetic energy been converted into substantial thermal energy?

Response: First of all, the mantle through which the cold material descends is *solid, not molten*. Although the surrounding mantle is solid, it nonetheless is considerably hotter and therefore weaker than the colder descending rock. So the stronger, denser sinking rock has the tendency simply to push the weaker rock out of its way as it makes its way to the bottom of the mantle. Slides 69-71 in the 2008_ICC_CPT_Talk, reproduced below, do a nice job in visualizing this sinking process and also the manner in which the sinking material deforms as it makes its way to the bottom. These slides show very little entrainment of the surrounding hot material. Neither is there any significant deformational heating, because the surrounding rock is weak.

In regard to the amount of heating resulting from the dissipation of kinetic energy as the slab interacts with the base of the mantle, even though the descent of this material is extremely fast by uniformitarian standards, in absolute terms the speed is only on the order of a meter per second (about 2.2 miles/hour) as the cold blob encounters the base of the mantle. Therefore its kinetic energy is essentially negligible as far as its being able to increase the rock temperature in any significant way. At 2 m/s, its specific kinetic energy (equal to 0.5 u^2, where u is the speed) is 2 J/kg. By contrast, the specific heat for mantle rock is about 1000 J/kg-K. So the temperature increase resulting from the kinetic energy being converted to heat is only 2 J/kg/(1000 J/kg-K) = 0.002 K.







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26. You appear to accept the chronostratigraphic validity of the geologic time scale. But the fundamental assumption behind this time scale is that rocks can be correlated by global correlative synchronous time. For example, 'Cretaceous' should be the same everywhere independent of lithology and structure. How do you justify this assumption biblically as well as apart from the Bible? Can you explain how time can be the key to correlation if much of the rock record was emplaced during a one-year catastrophe in which local processes and their relative timing would be inherently unpredictable and variable? Gould (1987, pp. 157-158) asserted that the only possible correlation constant between rocks and time was evolution. Since we reject evolution, on what basis then are strata to be ordered and correlated? Furthermore, given the a priori commitments of 18th and 19th century intellectuals to deep time, please explain why their time scale should not be viewed as a philosophical assumption, rather than as an empirical conclusion, and how later attempts to justify it empirically were not circular? Finally, recent publications of the International Commission on Stratigraphy have stated that chronostratigraphy and geochronology are merging into one integrated discipline and one integrated time scale. How might this affect your perception of the time scale's chronostratigraphic validity and its value for your model?

Response: This question fundamentally deals with the issue of whether or not there is a reliable means for dating rocks, or even correlating them across long distances, apart from the fossils they happen to contain. First of all, distinctive lithologies that correlate across continents, in some cases across most of the earth's continents, go a long way toward establishing that global correlations indeed are real. Derek Ager, in very first chapter of his book, *The Nature of the*

Stratigraphical Record, MacMillan, 1973, provides several striking examples of distinctive lithologies that appear in the same place in the vertical stratigraphic sequence on multiple continents across the globe. These examples include the extremely pure coccolithic limestone that forms the White Cliffs of Dover in England, but also extends across northern France, the Netherlands, northern Germany, southern Scandinavia, Poland, Bulgaria, and Georgia. This same distinctive chalk formation is also found on the Black Sea coast in Turkey, in Israel, and in Egypt. It is found across the Atlantic in Texas (as the Austin Chalk), in Arkansas, Mississippi and Alabama, as well as in Western Australia as the Gingin Chalk.

Another example is the highly distinctive Triassic sequence of rocks, originally described and named in Germany, which are also prominently exposed in England, in Spain, and on the other side of Europe in Bulgaria. Essentially identical Triassic rocks are found, as the Newark Group, along the eastern seaboard of the U.S. and across the U.S. south and southwest, in Oklahoma, Texas, New Mexico, Colorado, Utah, and Arizona. I personally grew up in western Texas where these rocks are prominently exposed and have spent most of my life living in the southwestern U.S. The continuity and lateral uniformity of these distinctive red Triassic rocks has never ceased to amaze me.

Yet another example Ager describes is what in England was originally called the 'Mountain Limestone,' which is a distinctive feature of Lower Carboniferous, or Mississippian, rocks throughout the world. Outside of Europe, this distinctive limestone includes the limestone of Empire State quarry in Indiana that produced the facing for the Empire State Building in New York City, the Redwall Limestone of the Grand Canyon, the Rundle Limestone that forms the impressive escarpment of Mount Rundle above Banff in Alberta, Canada, the Lisburne Limestone in Alaska, and the even limestone that caps Mt. Everest in Tibet. In this first chapter of his book, Ager catalogs nine other deposits with highly distinctive lithologies, which occur at well-defined positions in the vertical sedimentary sequence from late Precambrian upward and are nearly global in their lateral extent. These distinctive units appear to provide a solid lithological basis for concluding that the stratigraphic record has global and temporal coherence.

To me, however, there is an even more convincing category of evidence which points to this same conclusion. I am persuaded that radioisotope methods, applied carefully and interpreted in terms of the relative (not absolute) dates they yield, provide a highly reliable means for correctly ordering rock formations in a temporal manner, across the entire face of the earth, *independent of their lithology and fossil content*. Much of my confidence on this issue comes from the research my colleagues and I undertook as part of the Radioisotopes and the Age of the Earth (RATE) project during the period 1997-2005.

One of the very basic issues our team addressed had to do with the overall amount of nuclear decay that has occurred since the earth was created and also since the first sedimentary rocks containing fossils of multicellular animals were deposited. The essential question here is, since the earth was created, just how much radioactive decay has occurred—is it billions of years' worth at present rates, or only a few thousands of years' worth? Our firm conclusion was that indeed several billions of years' worth of nuclear decay, at presently measured rates, has taken place since the earth's rocks were originally created.

One of the cleanest lines of support for this conclusion lies in the uranium and lead isotope concentrations found in zircon crystals, which are abundant in granitic rocks. The zirconium atoms in the zircon ($ZrSiO_4$) lattice can be readily replaced by other high field strength atoms such as uranium and thorium. Zircons therefore typically contain significant concentrations of uranium, up to about 1% by weight. On the other hand, the zircons, when they crystallize and grow, strongly exclude atoms like lead. Therefore essentially all the lead found in a zircon is radiogenic lead— ^{206}Pb from ^{238}U decay, ^{207}Pb from ^{235}U decay, and ^{208}Pb from ^{232}Th decay. Because zircons in essentially all cases contain no detectable non-radiogenic lead, that is, ^{204}Pb, one can be confident that the radiogenic lead present is indeed the product of nuclear decay of the uranium and thorium originally resident within each individual zircon. Moreover, zircons are extremely hard and have a high melting temperature and so are resistant to degradation. They are therefore ideal

candidates for U-Pb dating and have been used widely to date crystalline crustal rocks. For basement granitic rocks it is common to obtain zircon U-Pb dates exceeding a billion years. (Such dates, of course, are predicated on the assumption that nuclear decay rates have been constant since the earth's formation, an assumption our RATE research showed not to be true.)

Zircons not only capture and preserve the lead generated from uranium alpha decay, but they also commonly preserve the physical evidence of much rarer uranium spontaneous fission. When a uranium nucleus fissions, or splits, inside a zircon, the two fragments fly apart at high velocities and produce tracks of damage in opposite directions in the surrounding zircon lattice. If an interior surface of a zircon is exposed by grinding, then polished, etched with acid, and examined under a light microscope, one can count the number of tracks within a given field of view to determine the density of tracks per unit of surface area. If one also measures the uranium concentration in the zircon, it is possible to calculate an age for the zircon from the density of fission tracks. Many studies, including one which our RATE team conducted, confirm that the zircon fission track age closely matches the U-Pb age, provided the zircons have not been heated above the fission track annealing temperature, which is on the order of 250 °C. The main point here is that fission tracks represent *tangible, physical evidence* of millions to billions of years' worth of nuclear fission, in terms of fission rates we measure today. Hence one simply cannot deny that billions of years' worth of nuclear decay has occurred over the span of earth history.

The uranium in zircons also often generates physical damage in the form of radiohalos in minerals hosting the zircons such as biotite and fluorite. For uranium concentrations commonly found in zircons, about 100 million years' worth of nuclear decay at today's rates are typically required to produce a mature radiohalo. The RATE research documented thousands of such radiohalos in granitic plutons emplaced during the Flood and also in Flood sediments metamorphosed during the cataclysm. The existence of uranium radiohalos in rocks formed during the Flood further testifies that several hundred millions years' worth of nuclear decay, at present rates, during the span of that year.

Another important line of evidence for a vast amount of nuclear decay in the earth's rocks since creation is the high levels of radiogenic helium we documented still to reside inside zircons from continental basement granitic rocks having U-Pb dates of 1.5 billion years. In one case we found some 80% of the helium from 1.5 billion years' worth of uranium decay still physically present within the tiny zircon crystals. The remarkable finding, of course, was that the diffusion rate of helium we measured for these zircon crystals constrained the time that the helium could have persisted at these levels to be only about 6000 years.

Our RATE team concluded the only way all these observations could be fit together in a consistent manner, one that also happens to agree with the Biblical record, is for a large amount of nuclear transformation—some four billion years' worth at today's rates—to have occurred as God fashioned the material earth, but before He created plants on creation Day three. Moreover, to account for the large additional amounts of nuclear decay products, fission tracks, and other evidences of nuclear decay such as radiohalos across the portion of the geological record produced by the Flood, there had to be a second episode of accelerated nuclear decay, corresponding to 500-600 million years' worth of decay at today's rates during the year of the Flood. The logic to me for these conclusions seems nearly air-tight. If anyone can suggest another way to fit these main pieces of the puzzle together, I am certainly eager to listen and to engage on this topic.

Returning to the original question, I conclude from our RATE research that radioisotope dating methods in most, but not all, cases provide reasonably accurate *relative* dates for the earth's rocks, at least to those to which they can be applied. As such, these methods do indeed provide a coherent global chronostratigraphic framework, which, albeit not absolute in terms of time, nevertheless is not circular, is not based on fossils, and is not based on evolution. Is it justifiable from a Biblical standpoint? The description I provided in the preceding paragraph appears to be harmonious as far as I can discern. As to the importance of having or not having such a coherent chronostratigraphic framework, I

believe it is nearly essential to have such a framework, if we, who believe that all Scripture is given by inspiration by God, desire to account for the details of the geological record in terms of the Flood and defend Genesis 1-11 in a credible manner. return_to_Contents

27. How can the oceans avoid being heated to the boiling point as all the present ocean crust is rapidly generated via seafloor spreading along the mid-ocean ridges during the Flood?

Response: The question of how the oceans might escape being heated to the boiling point as the process of seafloor spreading during the Flood generates enough new ocean floor to more than replace the entire area of today's deep ocean basins is indeed an important one. The best answer I have at this point is that the contact between the ocean water and the molten rock was restricted to an extremely small surface area, namely, the bottom of the V-shaped rift valleys between adjacent diverging oceanic plates. Here ocean water would quickly reach temperatures near to that of the molten rock, about 1100 °C. Water at these temperatures at depths of 5-10 km below the ocean surface would, of course, be super critical. The result would be the formation of a tight linear chain of steam jets originating from near the bottom of the V-shaped rift. What sort of velocities might the steam within these jets have? One can obtain an upper limit for the steam velocity at the core of the jets as they emerge from the ocean surface by assuming that the kinetic energy equals the change in thermal energy minus the change in potential energy. Let's assume the jets form 5 km below the surface and that the temperature in the jet core, as a result of expansion, at the ocean surface is 100 °C. Using the value for the specific heat of steam at 100°C of 2080 J/kg-°C, we obtain a value of the specific kinetic energy of [(1100°C – 100 °C) x 2080 J/kg-°C] – [5000 m x 10 m/s^2 x 1 J/(kg-m^2/s^2)] = 2.0 x 10^6 J/kg. Given that the specific kinetic energy is 0.5 u^2, where u is speed, one obtains an estimate for peak core speed of 2000 m/s, or 4500 mph, which is clearly supersonic.

A numerical simulation of this process would be extremely helpful in exploring many of the interesting details. (If anyone knows of someone with the expertise and desire to model these jets and their interaction with the water column they penetrate, I would deeply appreciate making contact.) However, even without a numerical simulation to explore the details, several general conclusions I believe can be reached that bear on how much heat gets transferred to the oceans. The first conclusion has to do with the path of the water which supplies the jets. Because the jet is basically expanding into the near vacuum of space, there is a pressure drop inside the jet that persists down to the base of the jet itself. Thus the small region at the base of the jet is almost certainly at a pressure substantially below the hydrostatic pressure of its surroundings. This means that there is a strong tendency for the water supplying the jet to be drawn out of the rock immediately surrounding the jet. Basalt contracts and cracks as it cools, and therefore pathways for water to migrate from the nearby ocean bottom toward the bottom of the rift would tend naturally to form as that water cooled the basalt in the near vicinity of the rift. Note that the water heated by this process migrates *downwards* toward the bottom of the rift where the pressure is low and not upwards to heat the nearby ocean bottom water.

A second important conclusion is that cooling by circulating water which occurred in the near vicinity of the rift was sufficient at least to solidify what had been molten basalt. That is, the cooling was sufficient to produce a solid rind on the rock surfaces on the sides of the rift, within the fractures in the adjacent rock volume, as well as on the top of the newly formed ocean floor away from the rift. Because solid basalt has low thermal conductivity, heat transfer from the newly formed ocean floor away from the rift and into the overlying ocean water, though considerable, was dramatically less than what was occurring within the rift itself.

A third general conclusion is that with little uncertainty the vast majority of the heat associated with the jets was transported through the oceanic layer very quickly, at highly supersonic speed, in the core of the jets. The mixing of steam with the ocean water in the edges of each jet, although important to quantify in a numerical model, almost certainly represents a small fraction of the total heat and mass flux of the jet.

A fourth, qualitative conclusion is that shocks must play a major role in the overall interaction of the supersonic steam with the surrounding ocean water. The large pressure jumps between the interior of the jet and the surrounding water must be maintained by a structure of more or less steady-state supersonic shocks. It is likely that these shocks will serve to reduce mixing significantly beyond what would occur otherwise.

The overall conclusion here is that a large fraction of the heat transferred from the hot basaltic rock to the ocean water plausibly escaped to space via these supersonic steam jets, without large scale heating of the bulk ocean. A careful numerical simulation is clearly needed to obtain a more quantitative assessment of this issue.

Another consideration entirely separate from the mechanics of the steam jets is the fact that the oceans today are very *strongly stratified* with respect to density. This makes the parcels of water with different densities in today's ocean very difficult to mix together. As a result of this stratification, very little mixing occurs today in the vast majority of the ocean volume. Ocean currents tend to be relatively restricted in their lateral and vertical extent. Most of the mixing that does occur takes place in the topmost 25-200 m in what is called the 'mixed layer' and is largely a result of wind exerting tractions on the ocean surface. There is no reason to suspect that the ocean before the Flood was not also strongly stratified. If this conjecture is correct, then at least some volumes of the pre-Flood ocean, along with some of the sea life they contained, may well have survived the violence of the Flood relatively unmixed and intact. return_to_Contents

28. Can you explain the 'viscosity floor' parameter you mention in your papers on CPT and describe how it affects the time scale of the TERRA calculations?

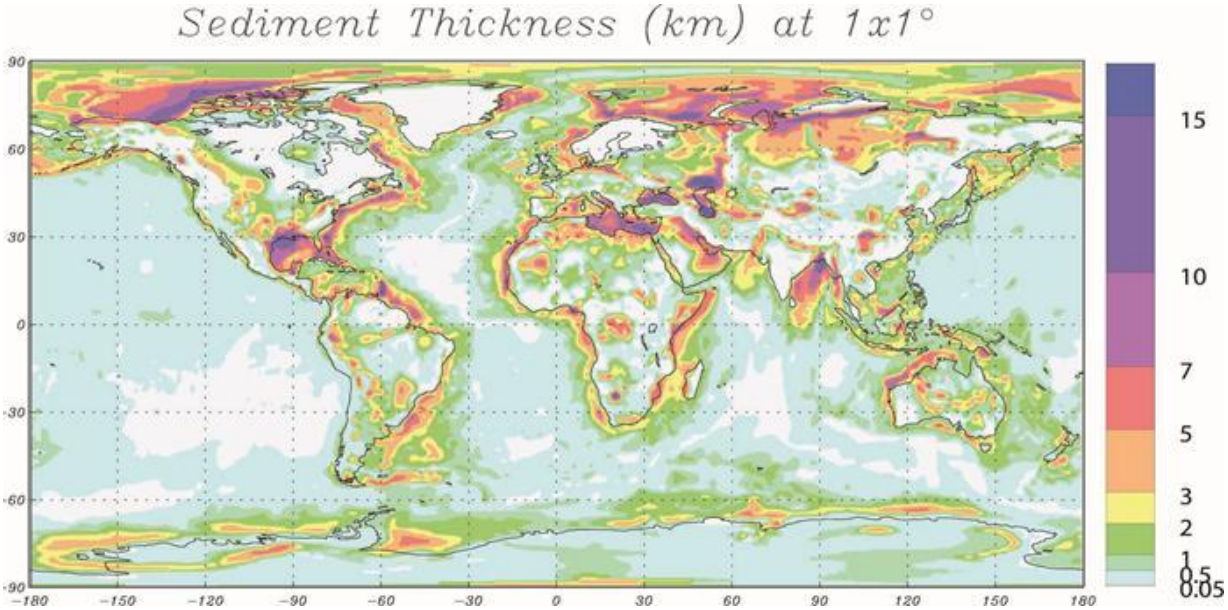
Response: What I have referred to as a 'viscosity floor' in TERRA is a limiting minimum value on the viscosity. It is an input parameter, vscmin, that multiplies the reference viscosity to establish a lower bound on the viscosity everywhere in the computational domain. Hence, as the rheological law—which determines the local viscosity as a function of temperature, strain rate, and yield stress—causes the local value of viscosity to become small, it is restrained to become no smaller than this lower bound. When 'vscmin' is set to a modest value of, for example, 0.01, the viscosity can fall only two orders of magnitude below the reference viscosity value and no runaway takes place. However, if other conditions are right and a 'vscmin' value on the order of 10^{-10} is used, then runaway will indeed take place. When this runaway behavior arises, the flow velocities become dramatically larger and the time scale for material traversing the depth of the mantle becomes dramatically shorter. One might ask whether such small values for vscmin are justified. As I have pointed out in many of my publications, there is strong experimental evidence that silicates do display such large reductions in strength as shear stress levels increase, within the range of stress levels that can exist in the mantles of planets the like the earth. Please note that this feature currently exists only in the 2D version of TERRA because at present only the 2D version has the ability to handle the extreme gradients in material properties that arise under runaway conditions.

Let me make one final comment is that a major research goal is to improve the numerical methods in the 3D version of TERRA such that it matches the ability of the 2D version to handle extreme gradients in material strength. I myself as well as some of my European collaborators are working earnestly to reach this goal. return_to_Contents

29. How does CPT, especially the most recent version which includes rotational instability and intense tsunamis sweeping across the continents, result in the thick continental sediment deposits we observe and very little sediment on the ocean floor?

Response: The issue of how thick sediment sequences were deposited on top of today's continents during the Flood and managed to be preserved there, while relatively little sediment on average is found today in the deep ocean basins, is definitely an important one. This would seem to be even more of an issue if the earth underwent multiple flips that

produced gigantic tsunami-like waves that swept across the continents, as I have recently suggested. Before I address that issue specifically, I think it helpful to consider the actual distribution of sediment we find on the earth today. The map below, prepared by Gabi Laske and Guy Masters at the Scripps Institution of Oceanography at the University of California, San Diego, provides a global view of this distribution. It is noteworthy that the thickest accumulations of sediment actually occur in the ocean basins immediately adjacent to continental areas, for example, in the Gulf of Mexico off the Texas coast, in the Arctic off the coasts of Alaska, Canada, and Russia, in the Indian Ocean at the mouth of the Ganges River, and in the Mediterranean, Black, and Caspian Seas. So while the vast majority of the ocean bottom has very little sediment accumulation, near many of the continent margins sediment thickness in the ocean basins can be extreme.



Caption: A global digital map of sediment thickness, produced by Gabi Laske and Guy Masters, 2009 (http://igppweb.ucsd.edu/~gabi/sediment.html#ftp).

In regard to this question, let me affirm strongly that understanding the processes which generated the thick and commonly quite laterally extensive sedimentary deposits that blanket the continents represents an exceedingly important research task crucial to defending the Flood. Recognizing this as an urgent task, ICR in 2006 initiated a new research thrust entitled Flood Activated Sedimentation and Tectonics (FAST) to begin to address the many issues involved. Leading this research initiative is Dr. Steve Austin of ICR. The first FAST workshop was held in St. George, Utah, in May, 2006, and an annual workshop has been held in each of the successive years.

One emphasis of FAST is to understand concentrated gravity driven flows of different types such as mudflows, hyperconcentrated flows, and debris flows. It is Steve Austin's conviction that a considerable fraction of the sedimentary deposits formed during the Flood are in this category. It is my conviction that many other deposits were generated by tractive currents and less concentrated suspensions of particles. Our understanding of all these processes, however, in my assessment is still quite rudimentary. Our grasp of the topography of the continental regions during the Flood and how this topography was changing with time as the Flood unfolded is also still in its infancy. Moreover, the forcing that could have generated coherent currents thousands of kilometers in lateral scale across the continental regions is still largely speculative. In short, our ability to account for the continental sediment record in terms of the Flood at this point in time is meager at best. I believe we should be praying earnestly for the financial resources as well as qualified and motivated people to undertake this research.

Despite our ignorance on many of these crucial issues, the question remains as to how such thick sediment sequences managed to accumulate on the continents and also why so little sediment is to be found on most of the ocean bottom. I believe there are some rather simple answers that go a long way toward accounting for these observations. First of all, the sediment load that water can transport depends strongly on water velocity. And for a given water flux, measured in kg/m^2, water velocity increases as the water depth decreases. Generally speaking, especially if one is thinking of sheet flow as opposed to channelized flow, high velocity is associated with shallow water, and vice versa. At the interface between continent and ocean basin, as water depth increases abruptly, velocity associated with sheet-like flow has a strong tendency to decrease abruptly. Hence, particles maintained in suspension due to high velocity turbulence will tend to drop out of suspension and be deposited as water velocity decreases. Similarly, particles of a given size class on the bottom which are being moved along by the traction of rapidly moving water move forward no longer when the water velocity drops below a certain threshold value. In short, deep water represents a sort of barrier to several types of sediment transport.

Even in the case of concentrated gravity flows that occur because of topographical relief in a continent interior, once the slope flattens out, the flow eventually loses it coherence, dissipative processes begin to take over, and transport comes to a halt. This is not to say that gravity collapse at the edge of a continental shelf does not produce spectacular gravity flows into the deep ocean. But even these flows can run out only so far once the relief disappears. Certainly such flows must have occurred during the Flood just as they happen today. Yet, I believe the case can be made that the shallower water over the continents during the Flood led to distinctly higher water velocities over the continent surfaces, which, in turn, produced much more intense erosion, much more effective sediment transport, and thicker deposits of sediment on top of the continents relative to the ocean basins.

One prominent reason for the paucity of sediment over most of the ocean bottom, in addition to the great water depth, is that all the pre-Mesozoic ocean bottom, and even much of the ocean floor formed in the Pacific since that point, has been recycled into the mantle by subduction. For the most part, there are no significant sources of sediment near the mid-ocean ridges where the new ocean floor is generated. Generally speaking, it is only on what are referred to as 'passive margins' of ocean basins, where no subduction is presently occurring, that sediments eroded from adjacent continent areas can accumulate. This can be clearly seen on the map of sediment thickness shown above for the cases of North and South America. Off the west coasts where subduction is active or has recently been active, there is generally no significant sediment accumulation. By contrast, off the east coasts of these continents, which are passive margins, there are thick accumulations of sediment.

Where did all the sediment from the subducted ocean plates go? The evidence from subduction zones active during the Flood, such as the one corresponding to the Franciscan terrane along the central California coast (discussed in my answer to question 4 [Q4]), strongly suggests that huge amounts of sediment were actually carried down the subduction zones during the Flood. The case is strong that melting of these subducted sediments generated the staggering volume of granitic magma that was emplaced along the western margin of North, Central, and South America during the Flood. (See the maps of these massive plutonic bodies along the west coasts of North and South America in my answer to question 30 [Q30] below.) This granite includes, for example, that forming the Sierra Nevada range in California today as well as the Peninsular Ranges Batholith that extends into much of Baja California. My house in the foothills northeast of San Diego is built on this Cretaceous granite, derived from melted sediment and emplaced in crustal rock above the rapidly subducting Farallon Plate during the Flood. return_to_Contents

30. It has been asserted that "fundamental tectonic mechanisms of global geology are vertical" and that horizontal tectonic mechanisms play only a minor role. Would you please provide your view regarding that assertion?

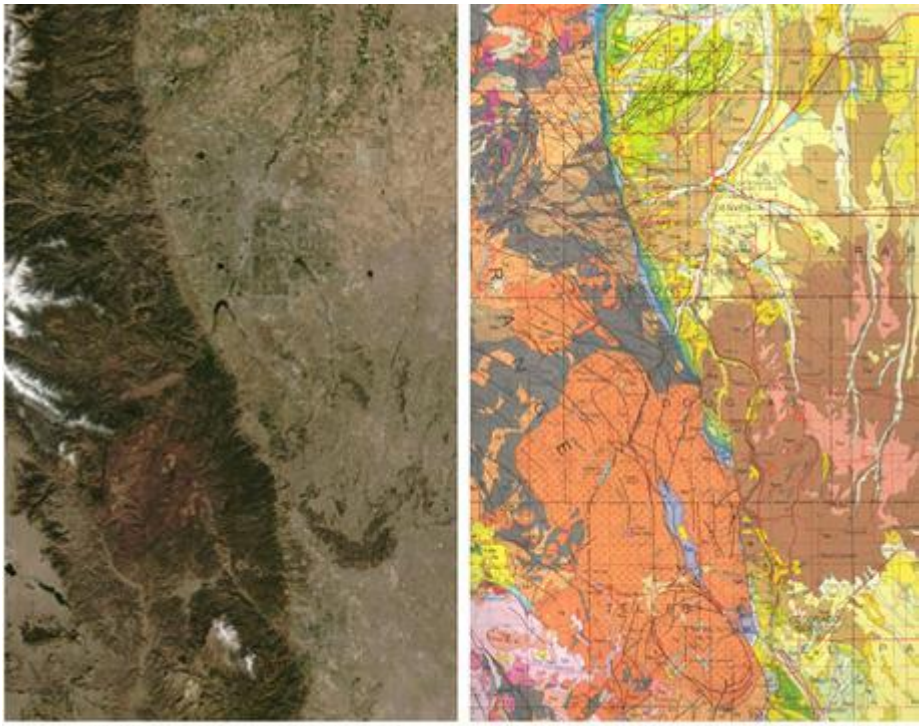
Response: In regard to the issue of vertical versus horizontal tectonics, let me submit that it is not really a matter of either/or, but that horizontal tectonics and vertical tectonics are intimately tied together. However, when a person excludes the possibility that any significant horizontal tectonic changes could have occurred during the Flood, such a person it seems to me has also excluded most of the available options for explaining the vertical tectonic changes that took place. The two main examples of vertical tectonics cited by the advocate of that view include 1) the uplift of the Rocky Mountains in Wyoming and Montana and 2) the formation of the abyssal hills that cover so much of the deep ocean floor.

Let me first note that the uplift of the young mountain belts of the world—not only of the Rockies, but also of the Andes, the Alps, and the Himalaya—represents spectacular examples of vertical tectonics. So any serious discussion of vertical tectonics must include the mechanics responsible for the uplift of these mountain chains. Amazingly, most of the actual uplift has occurred very recently, much of it during the Pliocene and Pleistocene, corresponding to the very end of the Flood and the centuries immediately following. Moreover, all of these mountain belts today are very near to being in isostatic balance, which implies the considerable mass of rock corresponding to the mountain that lies above nearby ground level is being supported and compensated by a low-density crustal root. For the world's highest mountains, the roots extend as deep as about 70 km, whereas the typical continental crustal thickness is about 35-40 km. Hence, somehow beneath all these mountain belts there has occurred a considerable increase in the thickness of the continental crust, which has a density some 15% less than the underlying mantle.

When and by what process did this crustal thickening occur? As I will discuss below, almost in all cases it involved *horizontal tectonics*, specifically, subduction. In some cases, the crustal thickening occurred by lateral transport of lower crust by traction of a horizontally subducting slab below. In many cases it was largely a result of subduction-related volcanism that emplaced significant volumes of low density crustal rock into existing continental crust in a narrow belt not far inland from a subduction zone. In a rare circumstance, one continent subducted beneath another, resulting in a crustal thickness double the normal value.

The fact that the uplift occurred nearly simultaneously for all these mountain chains is a strong argument in favor of the Biblical account of the earth's physical history and against the uniformitarian account. The time constant for isostatic response is relatively short. In the Biblical framework, the crustal thickening all occurred during the few months of the Flood, and it is logical that most of the isostatic response would be afterward and also be essentially synchronous. By contrast, in the uniformitarian framework, the thickening is stretched out over tens of millions of years, and the isostatic response should have been as well.

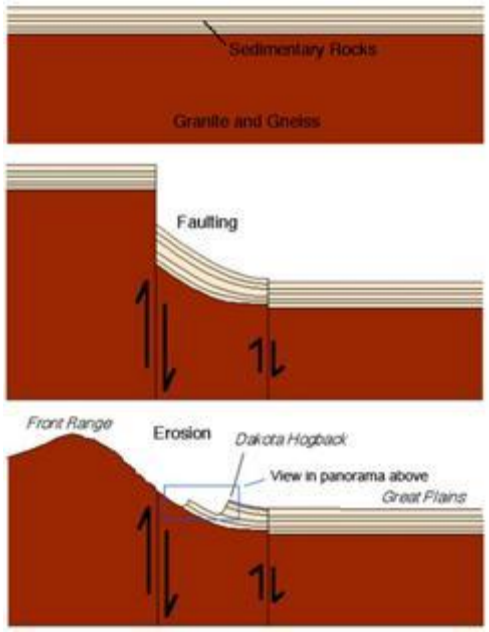
Let us first consider the uplift of the Rocky Mountains, which was indeed a spectacular process. I will focus on the Colorado Front Range, since I am personally more familiar with that area, but the same basic mechanics were involved in Wyoming and Montana further to the north. Below are a satellite image and a geological map of part of Colorado showing the abrupt transition between the Great Plains to the east and the Colorado Front Range immediately to the west.



NASA MODIS true-color image September 20, 2002 USGS 1979 Geologic Map of Colorado compiled by Ogden Tweto

Caption: Satellite image (left) and geologic map (right) showing the abrupt transition from the Great Plains to the mountains of the Colorado Front Range. This transition involves a nearly vertical set of faults with a total vertical displacement of 15,000-25,000 feet. In both maps Denver is a little above center and Colorado Springs is toward the bottom.

Caption: View of fault area from Red Rocks Vista west of Denver, looking north. Bear Creek and Colorado Highway 74 run left-to-right in the foreground, and Red Rocks Park is in the background.

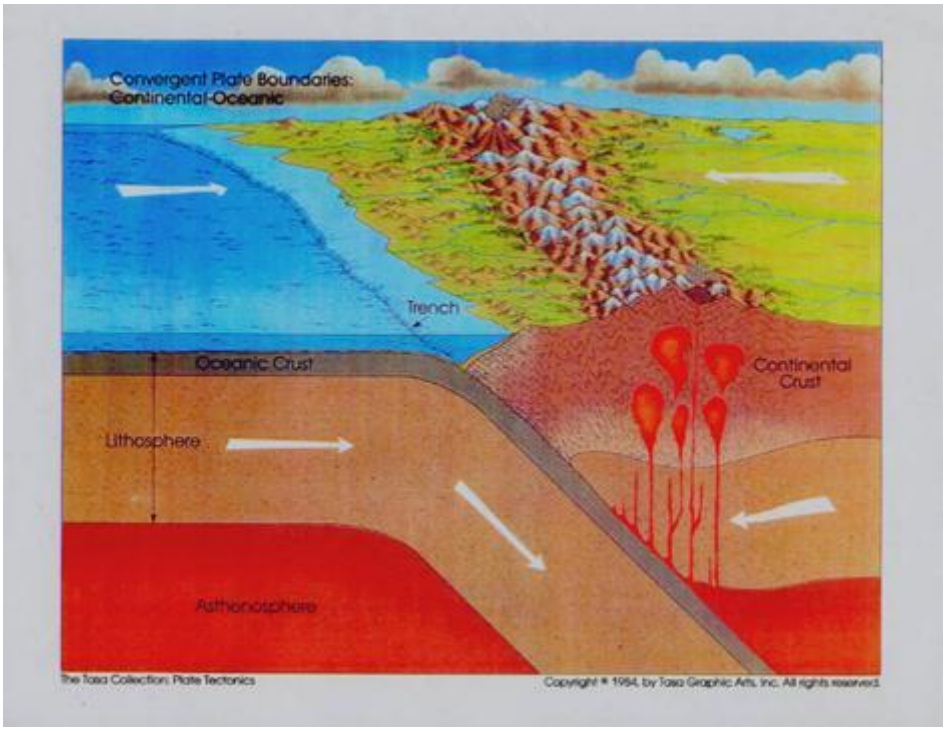


Caption: Sketch showing in three steps how the Front Range has been uplifted along a major fault, or a series of faults. Uplift west of the main fault has exhumed granites and gneisses from deep in the crust, and any sedimentary layers on top of them have since been removed by erosion. East of the fault systems the sediment layers have survived.

In terms of the Flood, based on geological relationships, this dramatic uplift occurred near the end of the Flood to a few years afterward. But what could possibly cause significant crustal thickening far inland near the middle of the continent? Do we have any insight as to what the cause might have been? I believe the answer is an unqualified yes. In short, the dramatic uplift of the Rockies represents the isostatic adjustment of a wedge of buoyant lower crust that had been bulldozed eastward by the flat-subducting Farallon Plate before it dropped into the deeper mantle. Details of this scenario are described in a paper by Peter Bird, "Formation of the Rocky Mountains, Western United States: A Continuum Computer Model," *Science 239*, 1501-1507, 1988.

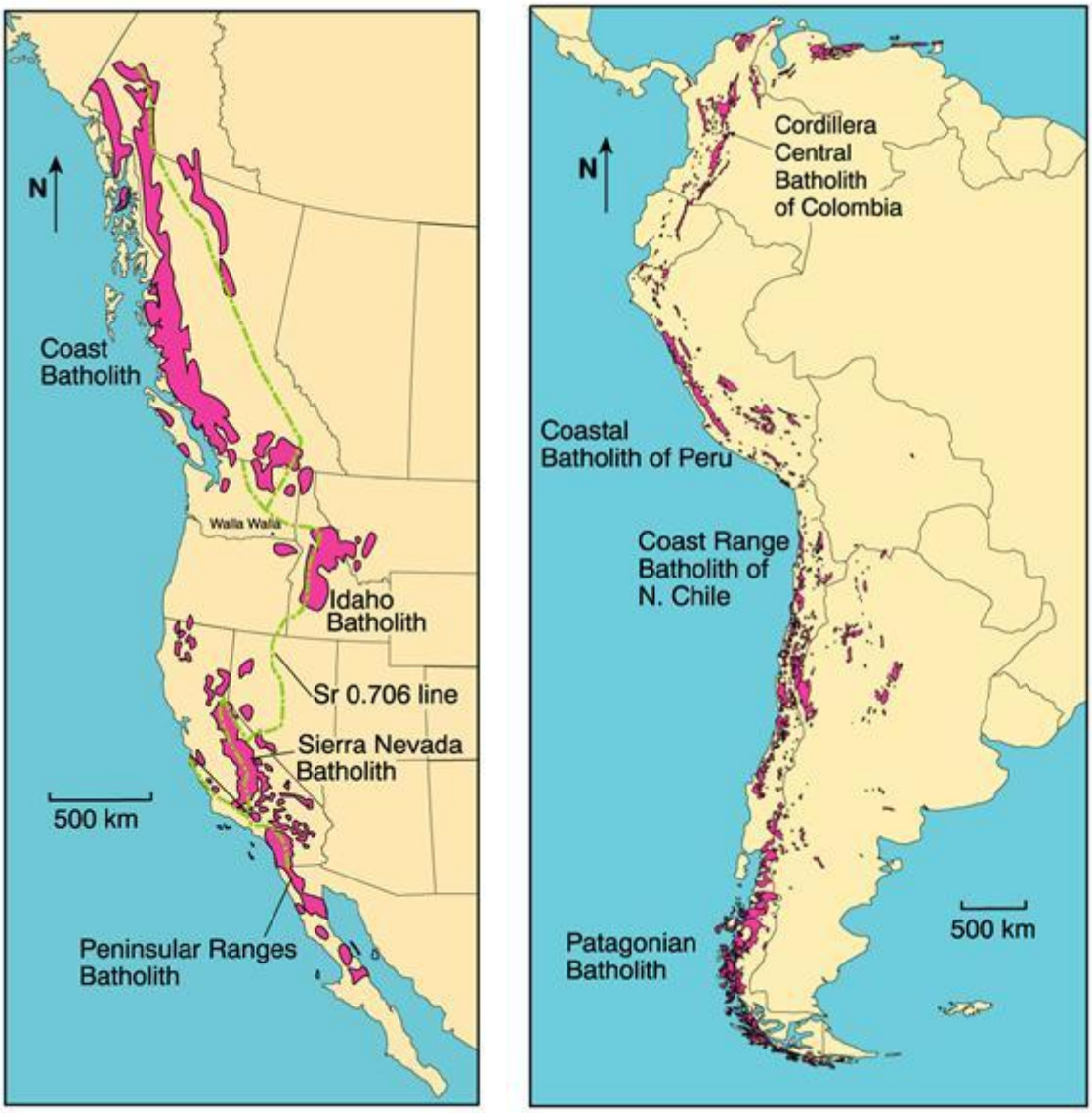
Stated in other words, the Farallon slab, which was subducting horizontally beneath western North America during the latter stages of the Flood (Cretaceous time in the standard chronology), exerted tractions on the base of the overlying granitic crust, dragging some of the warm and ductile lower crust eastward as it went, thus forming a growing wedge of material concentrated at the front of the horizontal section of slab. When the slab finally fell away, it left this relatively narrow zone of buoyant low density material behind, below the existing North American crust, beneath what are now the Rocky Mountains. As the slab sank deeper, its dynamic influence subsided, and this zone with its extra crustal thickness rose isostatically, punching up the mountain belt, much of it along near-vertical faults like those observed today along the Colorado Front Range.

This is one example of how horizontal tectonics can result in significant crustal thickening and subsequent vertical tectonic expression. A simpler and more common example arises from the volcanism commonly associated with subduction. The magmas commonly rise to form plutonic bodies within the overlying continental crust inboard of the subduction zone. This has occurred along much of the western coast of both North and South America, as indicated schematically in the figure below.



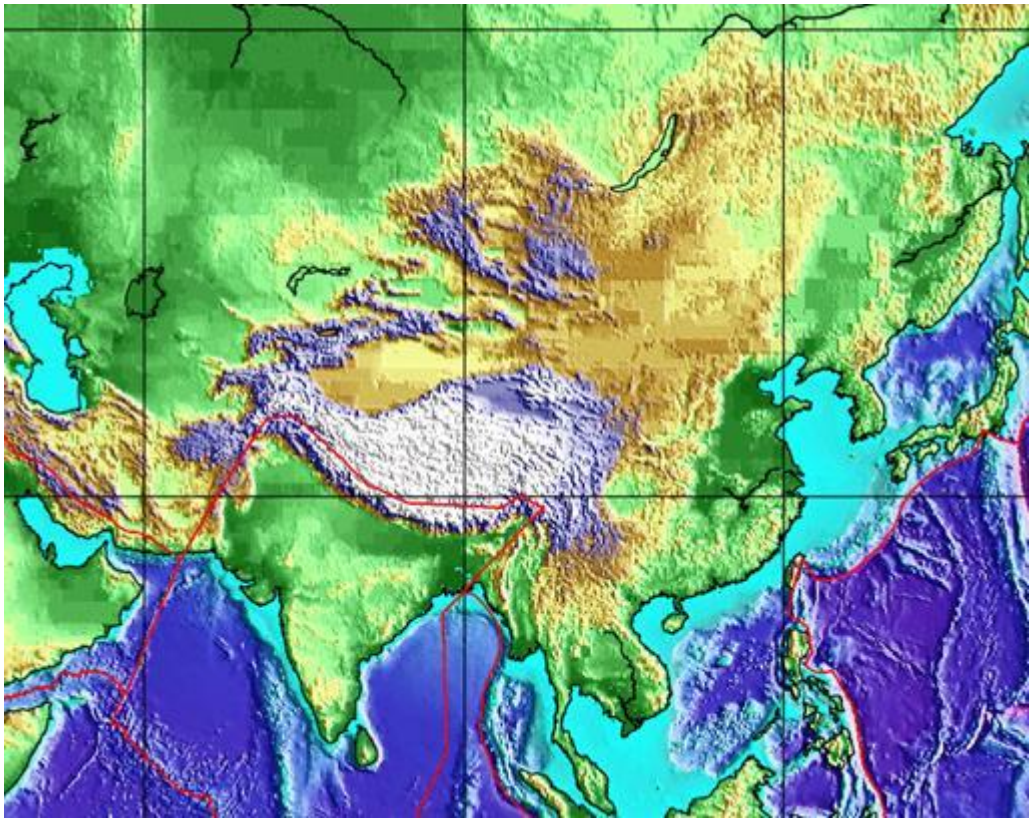
Caption: Sketch showing subduction of oceanic lithosphere along a continent margin. As hot asthenospheric rock comes in contact with the top of the subducting slab, melting commonly occurs. Such melting is aided by water carried down by the slab because it reduces significantly the rock melting temperature. Any sediment carried down by the slab melts quite readily in this zone, producing strongly buoyant silicic magma.

The belt of Mesozoic-Tertiary plutonic rocks extending from Alaska to Antarctica, forming much of the mountain belt known as the American Cordillera, was produced by this subduction-caused melting beneath the western margins of these continents. The maps below display the main sites of this plutonic emplacement of new crustal material. Isostatic adjustment in these belts has resulted in the mountains we see there today.



Caption: Major plutons of the North American Cordillera (left) and of the South American Cordillera (right), principal segments of a continuous Mesozoic-Tertiary belt from the Aleutians to Antarctica. Reproduced from J. D. Winter, *An Introduction to Igneous and Metamorphic Petrology*, Prentice Hall, 2001.

Probably the most spectacular example of horizontal plate motions resulting in dramatic vertical tectonics involves the formation of the Himalayan Mountains and the Tibetan Plateau. Many lies of evidence indicate that more than 1000 km of the Indian subcontinent has subducted beneath southern Asia. Although seismic studies are still seeking to determine the fates of the mantle portions of the two plates involved, it currently appears that the mantle lithosphere from both plates has detached from the crustal portions and is currently sinking below Tibet, continuing to drive convergent motion as indicated by present-day GPS measurements.



Caption: Topographic map of southern Asia that shows abrupt front separating the plains of northern India and the high Himalaya and Tibetan Plateau to the northeast.

From seismology it is clear that the crustal thickness is between 60 and 75 km in most of this region, which is twice the typical continental value. There are many lines of evidence indicating this increase in crustal thickness and the resulting uplift of the Himalaya and Tibetan Plateau are relatively recent, with the crustal thickening having begun no earlier than Eocene. The uplift of the Himalayas and the Tibetan Plateau must be the isostatic response to dramatic crustal thickening that seismology indicates is genuine. In terms of the Flood, this thickening seems to have taken place near end of the cataclysm. Horizontal tectonics that thrust the Indian plate beneath Asia for about a thousand kilometers appears to be the only plausible way to account for this doubling of the crustal thickness in this region.

Up to this point I have focused on vertical tectonics associated with uplift. But horizontal tectonics can also lead to downwarping of the continental surface when the negative buoyancy of an oceanic plate is coupled mechanically in sufficient degree to a continental plate. This situation can occur when an oceanic slab subducts horizontally beneath a continental plate. Such downwarping was one of the several consequences of the Cretaceous near-horizontal subduction of the Farallon Plate beneath western North America. The resulting depression is known as the Western Interior Seaway, or the North American Cretaceous Seaway, shown in the figure below. It was a relatively shallow sea, but the sediments which filled it preserved abundant marine life, including predatory marine reptiles known as mosasaurs up to 18 meters in length.

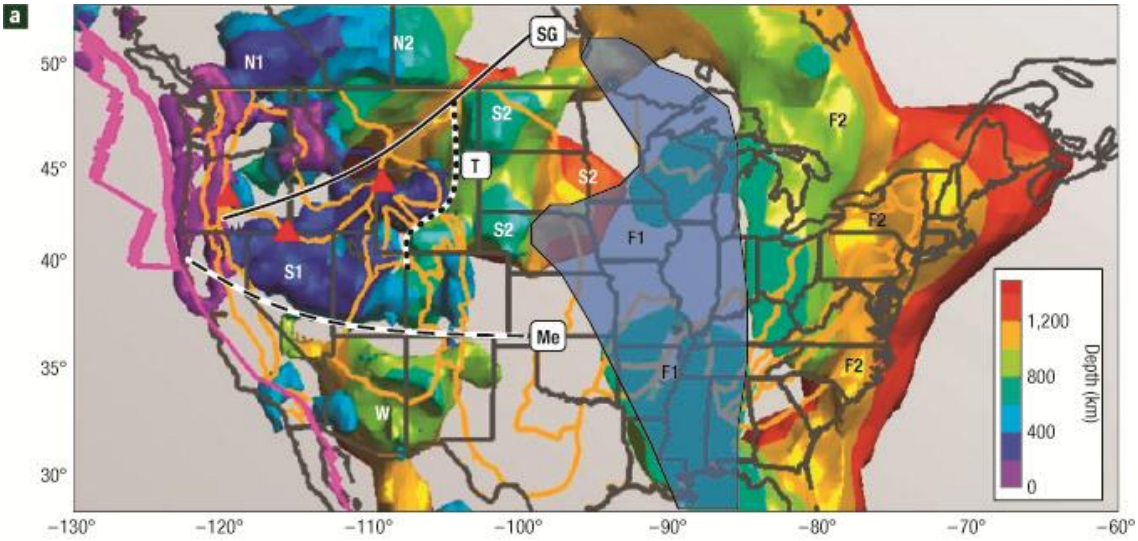
Caption: Location of the Cretaceous Western Interior Seaway, a shallow depression extending from the Arctic to the Gulf of Mexico, which coincided in time and space with the presence of the flat-subducting Farallon slab beneath.

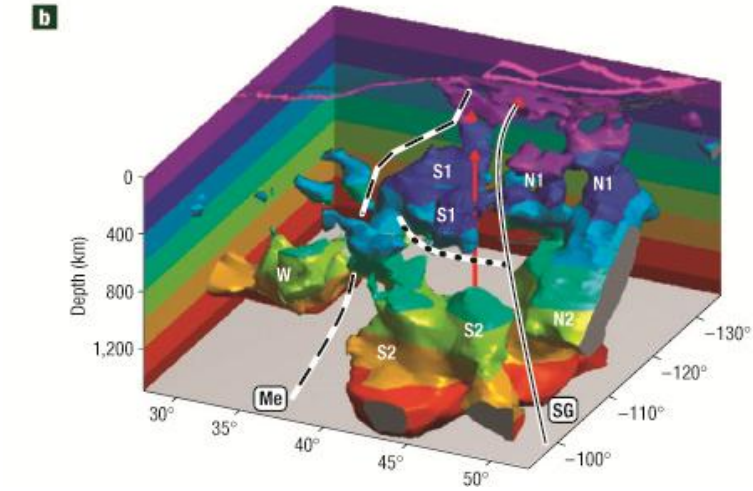
To this point we have examined important aspects of vertical tectonics that seem to require horizontal tectonics to account for them. What about the reasons the advocate for vertical tectonics gives for his own rejection of horizontal tectonics in general and plate tectonics in particular? These include 1) the character of the sediments found in trenches 2) the complexity of the magnetization patterns found in ocean bottom basalts, 3) the small amounts of magma beneath the mid-ocean ridges, 4) no subduction zones associated with the Ural and Transantarctic Mountains, and 5) various reasons to him that subduction seems unlikely. These in my view are all trivial objections, especially given the many and powerful lines of evidence that both seafloor spreading and subduction are real. I discuss most of these issues in my answers to questions 3-17 that deal mostly with the topic of subduction. In these answers I address, for example, the characteristics of sediments in the Nankai Trench off Japan and the reality of fossil subduction zones. I also address the reason for the small amounts of magma beneath mid-ocean ridges by pointing out that mid-ocean ridges are generally passive features. I discuss the character of the magnetization of seafloor basalt in question 34 (Q34) below.

Since I have mentioned the Farallon Plate in so many contexts in this response, let me again include the seismic tomography images I included in my answer to question 8 (Q8) from a recent paper by K. Sigloch, N. McQuarrie, and G. Nolet, "Two-stage subduction history under North America inferred from multiple-frequency tomography," *Nature Geosciences, 1*, 458-462, 2008. Figure 2 from this paper, reproduced below, shows via seismic tomography the present shape of the Farallon Plate, which has subducted beneath the western coast of North America since the earliest Jurassic and continues to do so today as the modern Juan de Fuca Plate along the coasts of Oregon and Washington. The Farallon Plate today is extremely deformed and contorted, as these tomography images reveal. The paper provides a

great deal of discussion on the history of subduction of this plate and what can be learned from its configuration today. The abstract from the paper is as follows:

> Eastward subduction of oceanic tectonic plates has shaped the geologic history of western North America over the past 150 million years. The mountain-building and volcanism that brought forth the spectacular landscapes of the West are credited to the vast ancient Farallon plate, which interacted mechanically and chemically with the overlying continent as it plunged back into the mantle. Here, we use finite-frequency travel-time and amplitude measurements of teleseismic P-waves in seven frequency bands to obtain a high-resolution tomographic image to ~1,800 km depth. We discover several large, previously unknown pieces of the plate which show that two distinct stages of whole-mantle subduction are present under North America. The currently active one descends from the Pacific Northwest coast to 1,500 km depth beneath the Great Plains, whereas its stalled predecessor occupies the transition zone and lower mantle beneath the eastern half of the continent. We argue that the separation between them is linked to the Laramide era 70–50 Myr ago, a time of unusual volcanism and mountain-building far inland generally explained by an episode of extremely flat subduction.

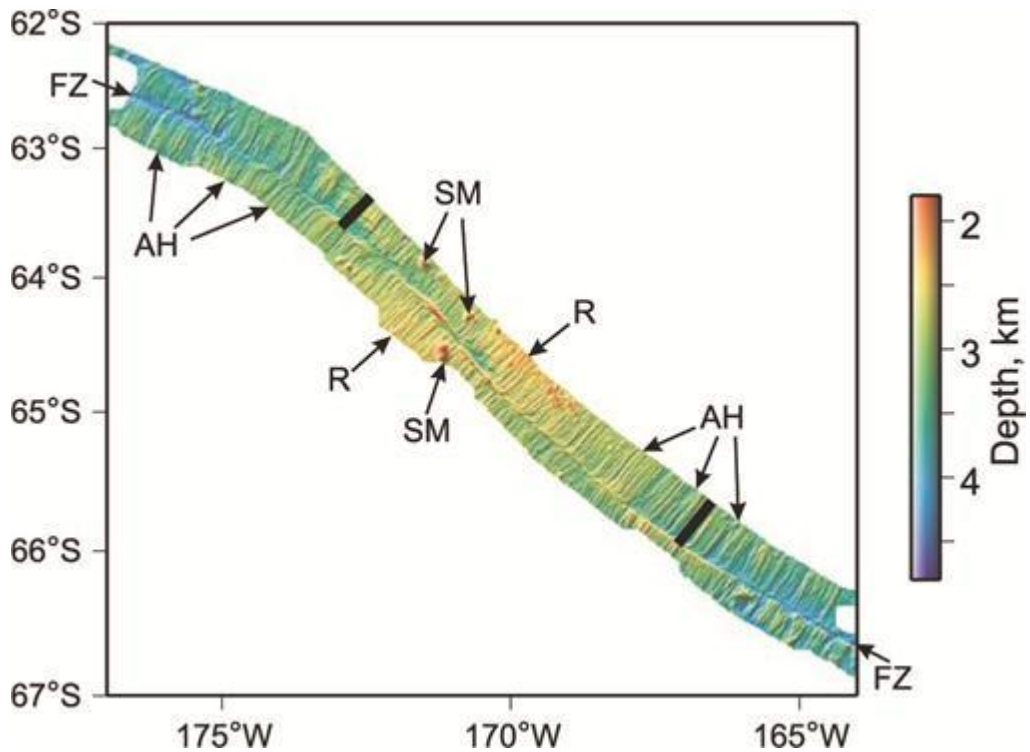




Caption: Three-dimensional views of the subducted Farallon Plate under North America. Isosurface is rendered where P-velocity is 0.4% faster than expected; color indicates depth. (a) Map view of the Cascadia subduction system (S1, S2, N1, N2, W), and its predecessor (F1, F2) to the east. Shallow fast structure that would obstruct the view (for example, the craton) is not rendered. East of 100_ W, only structure below 800 km depth is rendered; extent of slab material F1 in the transition zone is shaded blue. 'Me' (dashed line) is the continuation of the Mendocino fracture zone underground. 'SG' (solid line) marks the slab gap, a 2,500-km-long tear that subdivides the currently subducting plate. A lateral tear 'T' between upper and lower mantle (dotted line) is best appreciated in b. (b) a bird's eye view of the Cascadia system from the northeast.

This seismic tomography image to me is strong documentation of the reality of the subduction process and of the profound impact that the subduction of the Farallon Plate had on the geological history of the western North America.

Next, what about the topography associated with abyssal hills, which was offered as a noteworthy example of vertical tectonics? Below is a high resolution sonar image of these low-amplitude, nearly parallel, rill-like features in a portion in the southeastern Pacific Ocean.



Caption: Multibeam acoustic swath bathymetry image of seafloor topography from the southeastern Pacific. 'R' denotes mid-ocean ridge, 'FZ' fracture zone, 'SM' seamount, and 'AH' abyssal hill. Note that the abyssal hills form a fabric whose grain is parallel to the ridge. From J. A. Goff et al., "The contributions of abyssal hill morphology and noise to altimetric gravity fabric," *Oceanography 17*, 24-37, 2004.

These features which are aligned with the nearby spreading ridge are almost certainly product of the seafloor spreading process at the ridge, possibly as magma is emplaced there in quasi-periodic episodes. Once formed, they remain part of the seafloor surface texture until they are buried in sediment. The varying height across them likely has to do with the manner in which the slab-like volume of injected magma cools, with the slowest cooling zone in the center having the highest final elevation.

Finally, what about overthrust faults and strike-slip faults such as the San Andreas which seem to imply larger horizontal motions than vertical tectonics processes can provide? Yes, there is good field evidence that overthrusts like the Keystone Thrust west of Las Vegas, Nevada, pictured below, represent significant horizontal displacements of large sheets of rock of at least several tens of kilometers. Most of the displacement occurred in the late Cretaceous when the Farallon slab was subducting horizontally beneath western North America. However, in my opinion, the force responsible for motion of the upper block on this fault must have been gravity from elevated topography to the west, with this dynamic topography arising from the rapidly moving Farallon slab below.

Caption: The Keystone thrust west of Las Vegas, Nevada, is a spectacular example of a thrust fault. The dark-gray Cambrian limestone of the Bonanza King Formation on the left moved to the right and over the pink Jurassic Aztec Sandstone in the center. Movement on this thrust fault, which is part of the extensive Sevier fold-thrust belt, appears to have been almost 100 km. The thrust fault was most active in the late Cretaceous.

In regard to the San Andreas Fault, observations indicate at least 500 km (300 miles) of displacement along it since it formed. Such distance corresponds, for example, to the distance of Cabo San Lucas lies from the point on the Mexican coast where Baja California broke away. How much clearer evidence should an open minded person require to be persuaded that large-scale horizontal tectonics motions are indeed real? return_to_Contents

31. If in the CPT framework the main sea level rise associated with the Flood was in response to the formation of the present-day ocean plates, a process which
postdates the deposition of the continental Paleozoic sediment record, how then were the continents sufficiently below sea level before the modern ocean floor formed to allow these Paleozoic sediments to be deposited?

Response: I can understand why some people are confused on this. Although I have sought in my papers and talks to emphasize that my crude 3D numerical simulations model only the Mesozoic/Cenozoic portion of the Flood and not the Paleozoic portion, many people seemed to have missed this important qualification. One reason that I have not as yet been able to include that earlier portion is that, to have any chance of success, I need to be able to guess what the initial internal state of the earth was at the beginning of the Flood to a fairly high degree of fidelity. That perhaps might be compared in difficulty with the challenge for the wise men of Babylon in declaring to King Nebuchadnezzar both his

dream and its interpretation. In both cases, some very specific revelation from God is needed. Not having these crucial details as yet, I have settled for the more modest enterprise of modeling only the Mesozoic/Cenozoic portion.

But suppose one takes what the simulations I have been able to do and applies the results to the plate motion history implied by the sequence of twelve maps by Blakey which I provided in my answer to question 24 (Q24). What would that look like? First of all, the Biblical brief time frame requires that CPT runaway motions in the mantle begin at the very outset of the Flood to enable the Laurentia, Baltica, and Siberia blocks to move away from the Pannotia supercontinent quickly. Hence this scenario involves rapid seafloor spreading, rapid subduction, as well as supersonic steam jets rising from the mid-ocean ridges *from near the very beginning*. Since new seafloor is replacing old seafloor at a rapid pace, a progressive rise in sea level and progressive flooding of the continent areas is almost a certainty. My guess is that the rapid motions in the mantle also unleash unstable rotational dynamics of the earth in the earliest stages of this cataclysm, displacing the volumes of water filling the ocean and resulting in tsunami-like waves which quickly begin to invade the continents.

These waves and the rising sea level conspire to cause water to reach further and further into the continent interior, destroying habitat at higher and higher elevations and generating first the Paleozoic sediment record and then the Mesozoic one. The new seafloor formed during the time when the Paleozoic sediments are being deposited gets subducted as the cataclysm continues such that, by the time the Flood waters recede from the continents, none of it remains. Similarly, even most of the seafloor formed while the Mesozoic sediment was being deposited is subducted before the end of the cataclysm, since little of that remains today.

Hence, in regard to your question, the sea level rise that enabled the oceans to invade the land and produce the Paleozoic sediment record was *not* a result of seafloor spreading during the Mesozoic and Cenozoic portions of the Flood. Obviously that is impossible from a time standpoint. Rather, it was a result of seafloor spreading that unfolded during the Paleozoic portion of the cataclysm.

Let me comment on a couple of related matters. One is that my outlook on the amount of sea level change that may have taken place during the Flood has itself changed over the years. Whereas I once thought that perhaps as much as 1000-1500 m may have occurred, more recently I have come to suspect that the overall changes in sea level were likely much more modest. The main reason for this shift in my outlook is my realization a bit over three years ago that the earth may have experienced rotational instability during the Flood, as I mentioned above and outlined in the original materials I made available for this review process. Although the modeling of the ocean response to such rotational instability is admittedly still primitive and preliminary, it nevertheless does suggest that the resulting currents are powerful enough to erode away the regions of higher topography on the continents rather effectively. So my present guess is that perhaps only 100-200 m of sea level rise above the pre-Flood sea level may have been involved.

Another realization that has emerged from the 2D numerical modeling experiments is that runaway motions in the mantle not only can originate by cold dense material plunging down from above but also by hot buoyant material rising up from below. In the 2D animation included in the 2008 ICC PowerPoint presentation on the Flood, the runaway begins with the upwelling on the outside margins of the domain. As yet I have not attempted any 3D models of the Flood in which a hot plume (or plumes) from the base of the mantle initiates the runaway dynamics, but I consider this a genuine possibility. Especially as I have pondered just what sorts of mantle motions might have caused, at the very beginning of the Flood, Laurentia (North America), Baltica (northwestern Europe), and Siberia to break away from a pre-Flood supercontinent, I have wondered if a mantle upwelling might have been involved. (Again I urge the reader to refer to the sequence of maps contained in my answer to question 24 [Q24].) It should be fairly obvious that if a mantle upwelling beneath the pre-Flood ocean initiated the Flood, or was an immediate effect of the initiation, such an upwelling would have produced a sea level rise at the very beginning of the cataclysm. return_to_Contents

32. Your 1986 paper for the first ICC you wrote that the requirement for cooling the newly forming ocean floor in the short time span during and after the Flood seemed to require God's supernatural intervention to remove the heat. Since then, has anything changed that assessment? Do you have any additional insight as to how that might have happened?

Response: In my assessment nothing has changed since 1986 when I emphasized the problem of cooling the ocean lithosphere from near a molten state to its present state within the time constraints of Bible history. Subsequent to 1986, the Radioisotopes and the Age of the Earth (RATE) team undertook an eight-year research program to attempt to understand why radioisotope methods commonly yield dates of hundreds of millions to billions of years for the earth's rocks, when the Bible indicates that God created the earth only a few thousand years ago. Multiple independent lines of radioisotope evidence led this team (of which I was a member) to conclude that the basic answer to this extremely important question was, quite simply, that nuclear decay rates were much higher during two episodes in the past than they are today. We identified the first of the episodes as occurring during the formation of the earth but before plant life was created on Day 3. The second episode occurred during the Genesis Flood. The first episode involved a total of approximately four billion years' worth of nuclear transmutation at today's rates, while the second involved some 500-600 million years' worth. We judged these conclusions to be extremely firm.

Moreover, we concluded that there is likely no natural explanation that can account for such dramatic changes in the rates of nuclear decay. Even how God *might* have done it was not at all obvious to us, although we speculated that His intervention may have involved a temporary change in the strong nuclear force. Since Scripture indicates in at least seventeen places that God, among His mighty deeds, "stretches out the heavens," Russ Humphreys has conjectured that God's intervention may have involved this aspect of His governance of the cosmos. If so, such an intervention may well have also removed some of the heat in the rocks during the Flood. But, again, these possibilities at this point are in the realm of conjecture and speculation.

Nevertheless, because we of the RATE team have taken the bold step of rejecting the materialist dogma of no interventions by God in the realm of nature with regard to nuclear decay during the Flood, it makes it a bit easier for me to do the same with regard to the cooling of the ocean lithosphere. For those among us who might be uncomfortable with such dramatic interventions by God in the natural realm, I would remind them of the words of the apostle Peter in 2 Peter 3:3-6. Here Peter warns of a major deception of the last days which we today refer to as uniformitarianism. In refuting this error, Peter points to intervention by God in the natural order both during creation and *also during the Flood*. The implication to me is that Scripture is likely telling us that it is *impossible* to account for the physical aspects of the Flood exclusively in terms of the principles of physics and process rates we observe operating today. In my view wisdom dictates that we can make this appeal only when our case is exceedingly strong. My colleagues and I are persuaded that the scientific case is sufficiently secure to appeal to God's intervention in regard to the issue of accelerated nuclear decay. I am also now convinced the case is strong enough in regard to the cooling of the ocean lithosphere. return_to_Contents

33. In your 2003 ICC paper you wrote that steam from the fountains of the deep might have reached escape velocity. However, later you included a note saying that a further calculation had shown there would not be sufficient energy. Please explain how you arrived at the lower 2×10^6 J/kg number for the specific energy available.

Response: The error was that I incorrectly included a factor of density when I calculated the amount of thermal specific energy available. The density of water is about 1000 kg/m^3, so I overestimated the available thermal specific energy by a factor of 1000. It was an embarrassing error, but at least I caught it not long after the conference.

The lower 2 x 10^6 J/kg value for the amount of thermal energy available is obtained by multiplying an estimate for the temperature drop in the jet, which I took to be 1000 °C, by the specific heat of steam at 100 °C, 2080 J/(kg-°C). return_to_Contents

34. Could you clarify your view on the magnetic "stripes" on either side of the mid-ocean ridges and describe how catastrophic plate tectonics differs from uniformitarian plate tectonics in its interpretation of this phenomenon?

Response: My view on the more or less symmetric pattern of magnetic 'stripes' detected on either side to the mid-ocean ridges is, in short, that the pattern is genuine, but the signal is extremely noisy. Some creationists deny the reality of geomagnetic reversals altogether. In response to that position, I would point to the abundant and to me unambiguous evidence for reverse magnetized rocks in continental environments. In 1906 Bernard Brunhes, a French scientist published the first report of volcanic rocks with reversed magnetization. Since then, there have been so many measurements made on continental basalts documenting reversed magnetic polarity that in my opinion the reality of magnetic reversals is beyond dispute.

On the other hand, recent studies of rock magnetization are showing that the earth's magnetic field has had an extremely complex time history, with many so-called 'magnetic excursions' that typically also involve dramatic fluctuations in field amplitude. Just to provide a glimpse into the current conversation on the topic of magnetic excursions I copy below the abstract of a recent paper by J.-P. Valet, G. Plenier and E. Herrero-Bervera, "Geomagnetic excursions reflect an aborted polarity state," *Earth and Planetary Science Letters 274*, 472-478, 2008.

> Geomagnetic excursions represent short episodes of a few thousand years at most during which the field considerably exceeds its normal range of variability during a polarity state. Paleomagnetic records have now been obtained with extremely high temporal resolution which have improved our knowledge of these short events. We have compiled the most detailed records of excursions that had occurred during the Brunhes and Matuyama chrons. We show that virtual geomagnetic poles (VGPs) of at least one record of each event are able to reach the opposite polarity. In the next step, we have computed different simulations of excursions during which the dipole progressively vanishes before growing back without reversing. This scenario produces very few reversed directions which are only visible at some latitudes. We infer that it is impossible to reach the ratio of reversed to intermediate VGPs present in the paleomagnetic records if the excursions were not associated with a short period of reversed dipole field. Therefore, excursions should be regarded as two successive reversals bracketing an aborted polarity interval. We propose that the same underlying mechanisms prevail in both situations (excursions or reversals) and that below a certain strength the field reaches an unstable position which preludes either the achievement of a reversal or its return to the former polarity.

What these recent high temporal resolution studies seem to be showing is that the history of earth's magnetic field has not been one of, say, about 50-100 or so clean reversals, with the field amplitude more or less of constant except during the reversal, but instead a history with exceedingly more fluctuation and variation. Of course, the authors of this paper are uniformitarians, so what they interpret as 'a few thousand years' is in reality dramatically briefer in terms of the Biblical time scale.

With the earth's surface magnetic field undergoing such rapid fluctuations, both in its orientation and in its amplitude during the Flood, it is not surprising that the basalts being rapidly emplaced at the mid-ocean ridges and cooling on small spatial scales at strongly varying rates would lock in a very noisy magnetization pattern. But the fact that we know, based on the magnetization record of continental basalts as well as the alternating alignment of the magnetic minerals in lake and deep sea sediment columns, that the earth's field did indeed undergo a significant number of magnetic reversals means that the reversal pattern detected by ship-towed magnetometers in seafloor rocks is also certainly genuine, with a high degree of confidence.

In regard to how CPT differs from uniformitarian plate tectonics (UPT) in its interpretation of these observations, my view is that the only significant difference is the time scale. In CPT the magnetic reversals associated with all but the topmost portion of the fossil-bearing rock record took place during the year of the Flood, while people adhering to the UPT framework believe it unfolded over some 540 million years. return_to_Contents

35. Oreskes et al., "Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences," Science, Vol. 263, 4 February 1994, p. 641-646, present a succinct summary of what is faced in any model-building exercise: "The additional assumptions, inferences, and input parameters required to make a model work are known as 'auxiliary hypotheses'. The problem of deductive verification is that if the verification fails, there is often no simple way to know whether the principal hypothesis or some auxiliary hypothesis is at fault. If we compare a result predicted by a model with observational data and the comparison is unfavorable, then we know that something is wrong, and we may or may not be able to determine what it is. Typically, we continue to work on the model until we achieve a fit. But if a match between the model result and observational data is obtained, then we have, ironically, a worse dilemma. More than one model construction can produce the same output. This situation is referred to by scientists as nonuniqueness and by philosophers as underdetermination."

In light of Oreskes *et al.*, how do you view your own modeling work?

Response: I see the quest to understand just what took place during the Flood as similar to that of putting together a complicated puzzle. There are literally tens of thousands of professional peer-reviewed papers on various aspects of geology, geophysics, geochemistry, and many other aspects of earth science. These today provide a wealth of observational data plus a wide spectrum of interpretive schemes, which in many cases conflict with one another, attempting to fit these data together into a coherent and consistent framework. As Christian believers we have additional extremely important data in the form of eyewitness accounts of certain key aspects of the earth's past.

One of the biggest challenges in the quest to understand the Flood for a believer is that of not getting utterly overwhelmed by the sheer magnitude of the available observations, observations which presumably need to be accounted for, at least at some level, in any serious attempt to understand and describe the Flood. For many, I'm sure it seems that there are so many trees that determining the scope and larger character of the forest is nigh to impossible.

Given this state of affairs, to me the primary issue is not really model building or model validation. To me the primary task is much more basic. It requires sorting through the vast number of observations, many involving highly complex phenomena and processes, to identify the mere handful that are most significant and strategic in assembling the big picture. Some of these critical observations might well include, for example, the large-scale topographic features of the earth such as the continents and ocean basins, the major continental mountain belts, and the mid-ocean ridge system. A next plausible step would be to identify candidate hypotheses or conceptual frameworks that offer a reasonable likelihood for successfully integrating these most significant pieces of the puzzle. To me it is not until this stage that it makes any sense at all to begin applying some of the standard modeling tools available for the purpose of perhaps fitting together a few more of the major pieces of the puzzle.

In an extremely brief way that is how I would characterize my efforts over the years to try to begin to understand what took place during the Flood, that is, mainly of trying to identify the most strategic issues and from these to seek to fit some of the most important pieces of the puzzle into place. return_to_Contents

36. Was all the land in one place at the end of creation week? If so, then how and when did it come to be in its current configuration? What role do Rodinia, Pannotia and Pangea play in this history?

Response: As to whether or not all the land was together in one place at the end of creation week, I have a moderate level of confidence that the answer is yes. Genesis 1:9 seems to suggest a single body of water, which could also possibly imply a single connected body of land. But to me the text by no means requires this inference. I note that Genesis 1:10 uses the word 'seas' (plural) to describe the gather of the waters. So while I hold as a working hypothesis that there was a single connected body of land at the end of creation week and at the beginning of the Flood, I recognize that Scripture does not explicitly demand it. Similarly, the geological observations seem to suggest that all the continents were joined together within a single landmass which some refer to as Pannotia at the time when the early Cambrian fossils abruptly appear in the sediment record. On the other hand I acknowledge that the observational data on which this Pannotia reconstruction rests is fraught with uncertainty.

As to when the continents came to be in their current configuration, it seems clear to me that the only interval in the Biblical account of earth history that such a dramatic change could possibly take place is during the Genesis Flood. As to the how, given the many persuasive lines of evidence the current basaltic ocean crust is younger than a large fraction of the continental fossil-bearing rocks, in addition to compelling evidence from seismic tomography and many other indicators that vast amounts of ocean lithosphere have subducted into the mantle and presently reside there, I conclude that there must have been rapid recycling of ocean lithosphere into the earth's interior and an associated migration of the continental blocks to their present locations during the Flood.

As to the roles of Rodinia, Pannotia, and Pangea play in this scenario, let me refer to my answer to question 24 (Q24), where I include a sequence of twelve maps of Ron Blakey, emeritus professor of geology at Northern Arizona University. These maps present Blakey's reconstruction of continent motions over the interval from Pannotia to the present. In that answer, I pointed out how in my assessment the case is strong that Gondwana, comprised of what is now Africa, Arabia, India, Australia, Antarctica, and South America, remained intact from the time of Pannotia until Pangea broke apart, that is, throughout the entire Paleozoic. I also gave my reasons for concluding that Pannotia was likely centered, not near the South Pole as shown in Blakey's reconstruction, but instead near the equator.

It is important to appreciate that as one moves backward in time these reconstructions are constrained by less and less by observational evidence and therefore become more and more subjective and speculative. One notable reason for this state of affairs is that ocean floor older than early Mesozoic simply does not exist today. Reconstructions for the plate motions since the breakup of Pangea near the middle of the Flood rely heavily on clues from the modern seafloor. By contrast, reconstructions for the earth's history prior to that point in earth history must rely entirely on clues preserved in the continental rocks.

One type of clue is paleomagnetic inclination, or dip, which, if accurately preserved in an igneous rock, can constrain the paleolatitude (but not paleolongitude) of the rock when it cooled through its Curie temperature for the last time. But the magnetic properties of a rock can be altered or reset completely if the rock undergoes heating due to deformation and metamorphism. Such clues thus become less reliable the further back in earth history one goes. It is not surprising therefore that only weak consensus exists in the uniformitarian community regarding the details of Rodinia, which is dated by most in that community well before the abrupt appearance of multicellular life in the sediment record.

Because I currently identify the onset of the Flood with the Great Unconformity in the continental stratigraphic record, I choose Pannotia, which coincides in time with the Great Unconformity, as representing the arrangement of the continental blocks at the onset of the Flood. Earlier continent arrangements, including Rodinia, I interpret to have existed briefly during creation week, prior to the end of Day 3, as God was actively forming the material earth and before He created life upon it. return_to_Contents

37. CPT offers an interesting explanation for the 40 days of rain at the beginning of the Flood. It proposes that runaway subduction created supersonic steam jets at the MORs which carried significant amounts of water into and above the

atmosphere which was precipitated back as the global rain. However, the current version of CPT seems to imply two episodes of runaway subduction. How could another period of extensive rain have occurred during the middle of the Flood when the Bible clearly notes that the last 221 days of the Flood were a time of wind and isostasy returning the waters to their new basins? If there were two periods of rain of such magnitude, why is the second not mentioned in the biblical text?

Response: Nowhere that I am aware have I suggested that there were two separate episodes of runaway subduction. The inference that there were two episodes likely arises from the fact that the 3D computer modeling I have done up until now has been a simplified version of the runaway subduction history, which begins, not with the pre-Flood continent assemblage, but with a Pangean assemblage instead. In answers to earlier questions I outlined my reasons for concluding that a supercontinent configuration corresponding roughly to Pannotia in the secular literature, but centered approximately on the equator and similar to Pangea, existed prior to the Flood. Evidence suggests that early during the interval of geological history known as Paleozoic, corresponding to the early part of the Flood, the continental blocks often referred to as Laurentia (basically North America), Baltica (basically western Europe), and Siberia broke away and migrated from this supercontinent's northwestern margin. Later during the Paleozoic interval, however, these blocks approximately reversed their paths and rejoined what remained of the earlier supercontinent (basically Gondwana) to form Pangea.

I have stressed in the past and want to emphasize once again that mantle rock, in the absence of some process occurring to weaken it, is *exceedingly strong*. Currently observed plate speeds on the order of only centimeters per year testify to this strength. Five centimeters of plate motion per year, for example, is equivalent to one kilometer of displacement in 20,000 years. The only way that the large tectonic displacements which the geological record requires to have occurred during the brief few months of the Flood is for the strength of the mantle to have been reduced by roughly nine orders of magnitude during the entire time these large displacements were taking place.

Laboratory studies on how silicate minerals deform at high temperatures under stress reveal that they weaken by many (at least nine) orders of magnitude under the levels of stress that can arise inside a planet with the mass and hence the gravity of the earth. As I have shown in my papers, this intrinsic weakening behavior in mantle minerals implies the potential for catastrophic runaway of both cold material from above and hot material from below in the earth's mantle. An important result from the 2D modeling in my 2003 ICC paper is just how widespread throughout the mantle the weakening becomes once runaway begins.

In light of the physical processes involved, is it likely or even possible for more than one episode of runaway to have occurred? The short answer is no, else the mantle strength would rise and the time scale would be much longer than the few months implied by the Genesis text. Thus, the Paleozoic plate displacements, as well as the Mesozoic and Cenozoic ones, must all be part of a *single* runaway episode. In other words, for CPT to be viable and logically account for the large-scale tectonic changes documented for the metazoan fossil-bearing portion of the geological record there can be only one runaway episode.

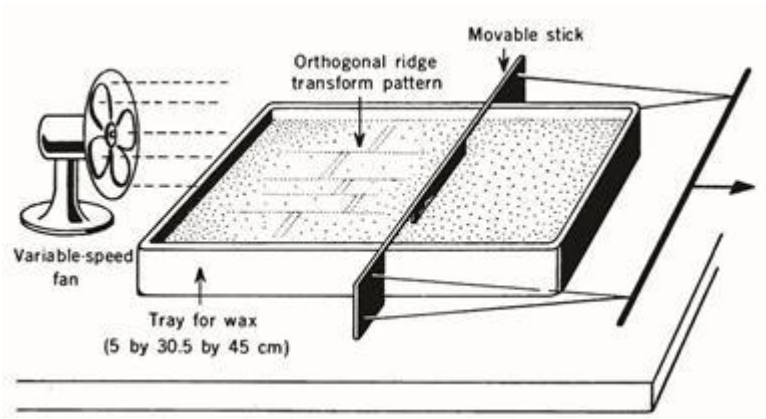
Although I have stressed this before, I want to emphasize again that *CPT as a candidate mechanism for the Flood has almost nothing to do with computer modeling.* CPT's essential support comes from geological and geophysical observations together with laboratory measurements relating to how silicate minerals deform under mantle conditions. Thus its central tenets can be evaluated apart from any computer calculations. CPT is primarily anchored in the observational data that testifies powerfully that the present-day seafloor is all younger than the Paleozoic portion of the geological record. This logically implies that all present-day ocean floor has been generated since the onset of the Flood cataclysm. Given the overwhelming evidence that subduction is real, the absence of pre-Mesozoic ocean floor on the earth today suggests strongly that all the pre-Flood ocean floor as well as all the Paleozoic ocean floor must have been

recycled into the mantle by subduction during the brief span of the year of the Flood. That, in a nutshell, *is* CPT--apart from any computer calculation whatever.

Nevertheless, what are the prospects of including the Paleozoic portion of the cataclysm in a computer simulation? Although I have commented on this several times before, the reason I have not yet included the Paleozoic is simple. It is because finding an initial condition that is close enough to the actual one to produce a continent configuration which resembles the present one is exceedingly difficult. It involves, for one thing, guessing the temperature distribution inside the mantle at the onset of the Flood with a moderate degree of correctness. Only with lots of trial and error and many 3D computer calculations was I able to do this for a Pangean starting condition. But to go back further in time and find an initial condition that first causes Laurentia, Baltica, and Siberia to break away from a Pannotia-like supercontinent and then causes these blocks to reverse direction and return to close to their original places to form Pangea is an even more daunting task. My present guess is that a viable initial condition will likely involve an upwelling plume beneath the northwestern part of the initial supercontinent plus some zones of cold material sequestered in the upper mantle, probably around much of the supercontinent's perimeter. But the possibilities are vast. Thankfully, the viability of CPT does not depend on the success of that enterprise. Nevertheless, I welcome anyone who wants to help in undertaking it. return_to_Contents

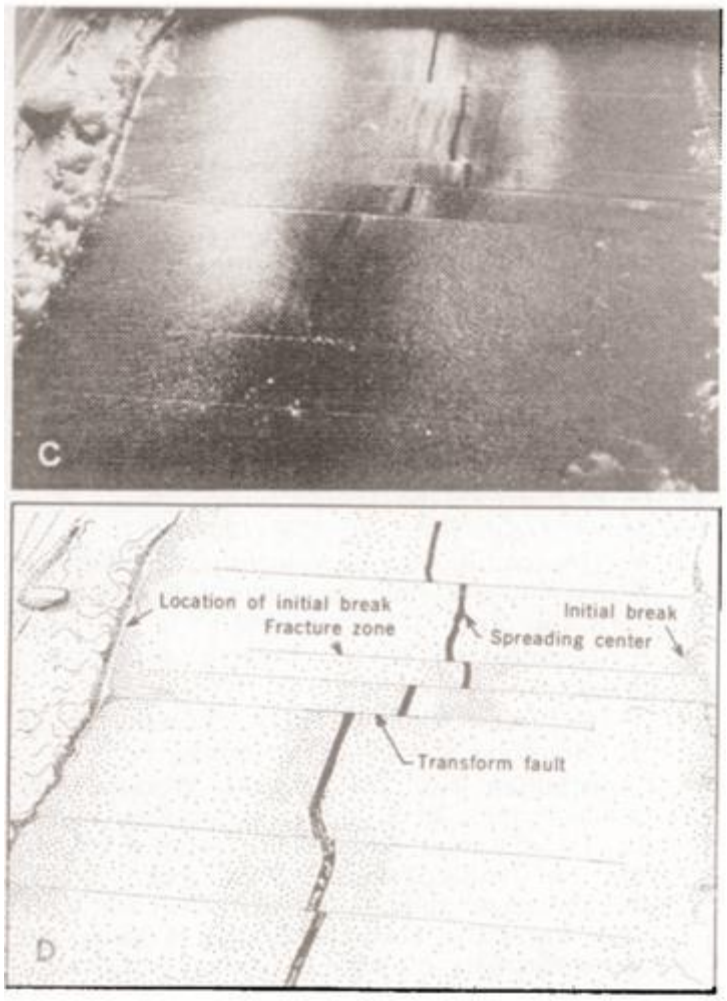
38. The African Plate is generally assumed to be relatively stable with regard to its east-west movement. Does this mean that the Mid-Atlantic Ridge itself is moving westward at half the speed of the Atlantic seafloor west of the ridge? If so, why do standard textbooks show a thermal plume of mantle material ascending at the Mid-Atlantic Ridge and spreading symmetrically both west and east, implying the Ridge is stationary?

Response: That the Mid-Atlantic Ridge itself is moving westward at half the speed of the North American Plate, including the Atlantic seafloor west of the ridge is the standard understanding today, both in the CPT framework and according to conventional plate tectonics. Unfortunately, as you point out, the explanation still found in many textbooks of a thermal plume of mantle material ascending at the Mid-Atlantic Ridge and spreading symmetrically both to the west and to the east (toward Africa) is out of date—by about 40 years! The response I provided to question 18 (Q18) included a description of a set of laboratory experiments reported in 1972 which shed some extremely important light on this topic. The experiments involved the use of molten wax to investigate on a laboratory scale the mechanics of how a medium consisting of a brittle upper layer and a ductile lower layer deforms when pulled apart. The classic paper is by D. W. Oldenburg and J. N. Brune, "Ridge transform fault spreading pattern in molten wax," *Science 178*, 301-304, 1972. I reproduce the key figure from their paper which shows the apparatus and basic results of their experiment.



Caption: (Above) Experimental apparatus. A tray of melted paraffin was cooled with a variable-speed fan until a film of solidified wax formed between one end of the pan and a movable stick. The stick, representing the edge of a moving

plate, was then drawn at a uniform rate through the wax by a variable speed a-c motor. (Below, top) For moderate ranges of cooling rate, spreading rate, and initial wax temperature, the characteristic segmented ridge/transform fault pattern shown in this photo developed. (Below, bottom) Diagrammatic representation of photo, for clarity.



What this experiment and many similar ones since reveal is that the essential physics responsible for the segmented ridge/transform fault geometry is the presence of a strong brittle upper layer and a much weaker ductile lower layer, with surface cooling causing the brittle layer to thicken with time, yet with sufficient spreading motion to keep the divergent zone weak by replenishment with hot ductile material from below. To the extent that this experiment represents an analog to ridge tectonics on the earth, the authors conclude that "spreading ridges may be formed under the influence of tensile stresses only, and *forces from an active convection cell located beneath the ridge axis are <u>not required</u>* (emphasis added)."

Let me here stress that subsequent observation strongly confirms that this generally is the case for the earth—that mid-ocean ridges are mainly the product of the divergent motion of the plates on either side *and not a result of the upwelling limb of a convection cell below*. In other words, the spreading ridges are largely *passive features*—the result of plate divergence. As you point out, this is very much contrary to many popular characterizations of plate tectonics concepts, even in current textbooks. Also, it is helpful to note that in the experiments described above, the stiff upper

layer of wax is being pulled from one side only; the weak zone where the spreading takes place moves to the right at very close to half the speed at which the stick is being drawn to the right. return_to_Contents

39. Wikipedia has the following definition for "Creation Science": “Creation Science or scientific creationism is a branch of creationism which attempts to provide scientific support for the Genesis creation myth, and disprove generally accepted scientific facts, theories and scientific paradigms about the history of the Earth, cosmology and biological evolution. Its most vocal proponents are fundamentalist Christians in the United States who seek to prove Biblical inerrancy and nullify the scientific evidence for evolution. The main ideas in creation science are: the belief in "creation ex nihilo"; the conviction that the Earth was created within the last ten thousand years; the belief that mankind and other life on Earth were created as distinct fixed "baraminological" kinds; and the hypothesis that fossils found in geological strata were deposited during a cataclysmic flood which completely covered the entire Earth. As a result, creation science also challenges the geologic and astrophysical evidence for the age and origins of Earth and Universe, which creation scientists acknowledge are irreconcilable to the Genesis account. While creation science purports to be a genuinely scientific challenge to historical geology, the antiquity of the universe, and the theory of evolution (which creation science proponents often refer to as Darwinism or as Darwinian evolution), is a religious, not a scientific view. Creation science does not qualify as science because it lacks empirical support, supplies no tentative hypotheses, and resolves to describe natural history in terms of scientifically untestable supernatural causes.”

Would you say that your model is based on or relies on "scientifically untestable supernatural causes" or events? If so, which portions of your model rely on the supernatural? Would you agree that Creation scientists should not invoke the supernatural without Biblical evidence that clearly indicates that God overrode the natural laws?

Response: I would say that for the majority of the aspects of CPT, such as describing the present physical features of the seafloor, including its topography, its mid-ocean ridges, transform faults, deep ocean trenches, island arcs, seamounts, sediment thickness distribution, heat flow distribution, and magnetic reversal pattern; inferring the present structure and state of the earth’s interior from seismic, GPS, gravity, and geoid datasets and the chemical compositions of magmas; inferring the deformational properties of silicate minerals under mantle conditions through laboratory experiments; and even inferring the magnitude and types of geological and tectonic changes which have taken place in the earth’s past, there is no invocation of the supernatural. The place in CPT where the supernatural must be invoked, as far as I can presently discern, is in regard to the removal of heat from the rapidly forming oceanic lithosphere. The measured thermal diffusivity of rock is much too low to cool the newly forming lithosphere at the rate implied by CPT. Moreover, there is no adequate sink for so much heat even if the thermal diffusivity were somehow much higher. The only solution I can envision is a rapid volumetric removal of heat, at least in the top 50-100 km of the earth, during the Flood. This, as far as I can see, represents a supernatural solution.

Although CPT, strictly speaking, does not specifically include the issues associated with the history of nuclear decay, the overall worldview framework based on a literal understanding of Genesis 1-11, which CPT seeks to defend, certainly does. As pointed out in the conclusions of the Radioisotopes and the Age of the Earth (RATE) project, a consistent interpretation of the history of nuclear decay in terms of a literal understanding of Genesis 1-11 requires invoking the supernatural in two ways, first, in the acceleration of nuclear decay rates during two episodes, during creation and the again during the Flood, and second, in the rapid removal of most of the radiogenic heat generated during both of these episodes. The RATE team speculated that these two departures from uniformitarian natural law might simply represent two sides of same coin, so to speak. In other words, whatever temporary change God made in the natural order to cause the rates of nuclear decay to increase by many orders of magnitude may have simultaneously resulted in a volumetric removal of the heat that was released from the accelerated nuclear decay. The RATE team concluded that the observations and logic behind its conclusions were extremely solid.

The reason for including the issue of radioisotope decay in this answer is to point out that the one point at which supernatural intervention seems to be required for CPT, namely, rapid removal of heat, overlaps with where supernatural intervention is required to make sense of the radioisotope history. Let me emphasize here that the RATE experimental findings (which themselves do not rely on any suspensions of the laws of physics) represent glaring problems for the uniformitarian framework, basically contradicting its guiding axiom that all (especially the laws of physics) has continued just as it was from the beginning of creation.

Finally, would I agree that creation scientists should not invoke the supernatural without Biblical support that clearly indicates that God overrode the natural laws? Yes, in general, I agree. However, I earnestly believe that 2 Peter 3:3-6 reveals that God *did* intervene in the natural order during the Flood. Therefore, to exclude all intervention on God's part when seeking to understand the Flood in terms of the currently observed laws of nature is to ignore this revelation. I therefore conclude any model for what took place during the Flood that has any significant overlap with reality will contain at least one aspect where uniformitarian explanations simply cannot be made to work. return_to_Contents

40. You have repeatedly referred to the Franciscan formation as good evidence of rapid subduction and exhumation. The UHP rocks within that formation are a classic example that would appear to support what you are saying. However, amongst these rocks are unmetamorphosed rocks, and even ichthyosaur and plesiosaur fossils - which should have been metamorphosed/destroyed by the rapid subduction, heating and exhumation you are suggesting. How do you propose to preserve fossils and unmetamorphosed rocks during such subduction and exhumation events?

Response: The obvious answer is that not all the sediments that comprise the Franciscan formation were subducted, metamorphosed and exhumed. Let me reproduce the Wikipedia description given for the Franciscan Assemblage:

> The **Franciscan Assemblage** is a geological term for an accreted terrane of heterogeneous rocks found on and near the San Francisco Peninsula. It was named by geologist Andrew Lawson who also named the San Andreas Fault which bounds the Franciscan Assemblage. Also known as the "Franciscan Formation," "Franciscan Series," "Franciscan Group," "Franciscan assemblage," or "Franciscan Complex," it includes altered mafic volcanic rocks (greenstones), deep-sea radiolarian cherts, greywacke sandstones, limestones, serpentinites, shales, and high-pressure metamorphic rocks, all of them faulted and mixed in a seemingly chaotic manner. It forms the major component of the Pacific Coast Ranges of California. Wentworth and others interpreted the juxtaposition of the Franciscan Assemblage and the section consisting of the Coast Range ophiolite and the Great Valley sequence to have happened through landward movement of the Franciscan Assemblage as a tectonic wedge.

The geological setting, as I have noted earlier, was the trench resulting from the subduction of the Farallon Plate off the section of the North American coast which is now California. The high-pressure metamorphic rocks visible today in this highly contorted assemblage represent only the small fraction of the wedge material exhumed out of the relatively larger fraction which was dragged into the mantle by the subducting Farallon Plate. Moreover, it is also clear that a significant fraction of the wedge rocks present today in the Franciscan Assemblage were not among those subducted, metamorphosed, and exhumed. The types of rocks in this assemblage indicate this subduction zone was receiving a high input of eroded sediment from the continent. For ichthyosaurs and plesiosaurs to be buried and preserved as fossils in this dynamic setting is not surprising. return_to_Contents

41. Why do you conclude that the Sierra batholith must have been molten during the Flood?

Response: Geological investigations of the rocks of the Sierra Nevada over the past fifty years have revealed that the granitic rocks that form what is called the Sierra Nevada Batholith crystallized a few kilometers beneath the surface from molten magma that had risen from below and had ponded as hundreds to thousands of individual pancake-shaped plutons at the shallower depths. Careful and extensive radioisotope dating indicates these plutons were emplaced

during the *Mesozoic*, mostly during the Cretaceous, which implies that the melting and cooling took place during the Flood.

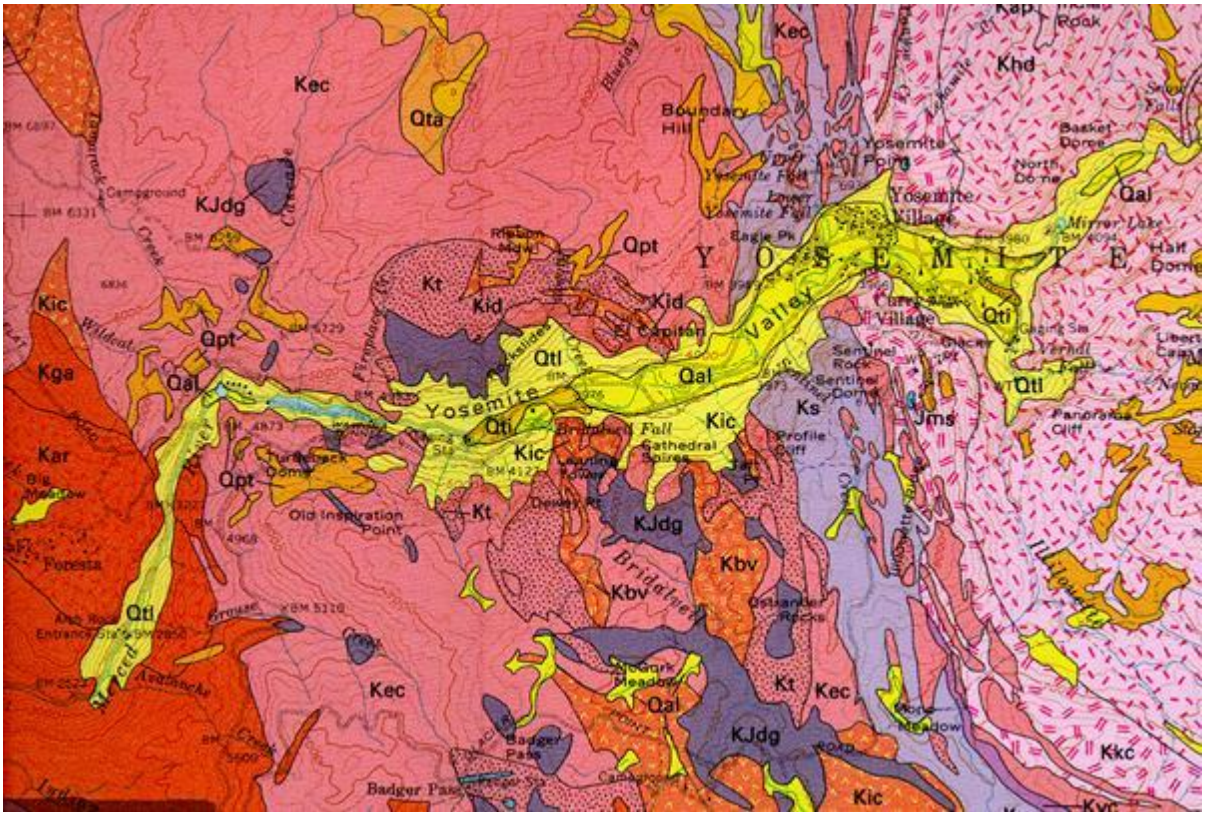
Let me quote the beginning three paragraphs from an article entitled, "The Sierra Nevada Batholith as exposed in the Yosemite Valley area and western foothills of the Sierran Nevada," by Marty Giaramita from California State University, Stanislaus, available at http://virtual.yosemite.cc.ca.us/ghayes/granite.htm, which provides a good summary description of the rocks of the Sierra Nevada Batholith in the region around Yosemite National Park:

> The terrane of Yosemite National Park is characterized by abundant light-colored and less common dark-colored rocks that crystallized slowly from molten rock kilometers beneath the Earth's surface. The present exposure of these relatively coarse-grained rocks is the result of uplift and removal of the overlying rock by erosive agents such as rivers and glaciers long after their intrusion into the crust due to tectonic-plate conversion during Mesozoic time.
>
> Igneous rocks are those that crystallized from melt. They are broadly subdivided into volcanic (extrusive) rocks, if they were erupted on the surface and hence rapidly cooled, and plutonic (intrusive) rocks, if they crystallized slowly at depth beneath the Earth's surface and cooled slowly. Although volcanic rocks are present in the Sierra Nevada Mountains (and we will drive through some en route to Yosemite), the predominant rock type in the region of Yosemite National Park is plutonic. Exposed bodies of plutonic rock are referred to as plutons that are further subdivided on the basis of their shape. A stock is a roughly equidimensional pluton; a dike is a fracture filled with plutonic rock. A batholith is a large composite of many individual plutons.
>
> The intrusive rocks of the Yosemite Region are part of the Sierra Nevada Batholith consisting of hundreds of individual plutons intruded from the Triassic through the Cretaceous periods (See the geologic map of Yosemite Valley below). Most geologists now agree that the batholith owes its existence to the process of tectonic-plate convergence during which melting occurred as a consequence of subduction of oceanic lithosphere (the rigid crust and upper part of the mantle) beneath the margin of the North American continent during Mesozoic time. A present-day analogue for this process is the subduction of the Nazca oceanic plate beneath the western margin of the South American continent.

Below is a photo of some granitic rock typical of that which comprises the entire batholith.

Caption: Half Dome granodiorite in Yosemite National Park near Vernal Fall.

Below is a geological map of the Yosemite area that shows the extent of the individual plutons which can be distinguished by their distinctive chemical compositions and mineralogies. Most of these plutonic rocks are of Cretaceous (K) age. Most of the Quaternary (Q) rocks are associated with the glacial processes of the Ice Age. This map provides a representative sampling of the geological character of the entire batholith.



Caption: Portion of Geologic Map of Yosemite National Park and Vicinity, California, U.S. Geologic Survey Miscellaneous Investigations Series Map I-1874 by N. King Huber, Paul C. Bateman, and Clyde Wahrhaftig, published in 1989. Complete map is available from the U.S. Geological Survey at http://mapping.usgs.gov/esic/to_order.html#map**.**

Explanation of Symbols:

Qal: Quaternary Alluvium Includes stream deposits, meadow deposits, and glacial outwash. (Quaternary)
Qtl: Talus Rock waste derived from cliffs. Only especially extensive areas shown. **(Holocene)**
Qti: Tioga Till Moraines usually sharp crested with abundant boulders at surface. (Pleistocene)
Qta: Tahoe Till Moraines usually crested, but subdued, with scattered, weathered boulders at surface. (Pleistocene)
Qpt: Pre-Tahoe Till Moraines hummocky and dissected. May include Sherwin tills. (Pleistocene)
Khd: Half Dome Granodiorite Medium grained biotite hornblende granodiorite with conspicuous crystals of sphene. Locally porphyritic with abundant large phenocrysts of potassium feldspar. Age 86-88 Ma
Kkc: Granodiorite of Kuna Crest Dark-colored, fine- to medium-grained, biotite-hornblende granodiorite. Age 88 Ma
Ks: Sentinel Granodiorite Coarse-grained, dark-gray, biotite-hornblende granodiorite with abundant sphene. Age 93 Ma
Kbv: Bridalveil Granodiorite Fine-grained hornblende-biotite granodiorite and granite.
Kic: Granodiorite of Illilouette Creek Medium- to coarse-grained mafic hornblende-biotite granodiorite, tonalite and granite. Age about 100 Ma
Kid: Quartz Diorite Dark fine-grained rock rich in hornblende. Occurs as irregular intrusive masses cross-cutting El Capitan and Taft Granites on north side of Yosemite Valley.

Kt: Taft Granite Fine- to coarse-grained white to gray biotite granite and biotite granodiorite. Locally porphyritic with phenocrysts of potassium feldspar. Age 96 Ma
Kec: El Capitan Granite Coarse-grained, white to light-gray biotite granite and biotite granodiorite. Commonly porphyritic with blocky phenocrysts of potassium feldspar and conspicuous quartz grains. Age about 102 Ma
Kga: Tonalite of the Gateway Also known as Bass Lake Tonalite. Medium-grained biotite-hornblende tonalite. Varies to granodiorite and quartz diorite. Age 114 Ma
Kar: Granodiorite of Arch Rock Medium-grained, biotite granodiorite, commonly with poikilitic potassium feldspar. Age 116 Ma
KJdg: Diorite and Gabbro Occurs as generally small, irregularly shaped bodies throughout map area, including the Rockslides adjacent to El Capitan. Age Jurassic to Cretaceous
Jms: Metasedimentary rock Hornfels and other metamorphic rocks. Jurassic

The massive volume of granitic magma was generated via subduction of the Farallon Plate beneath the western edge of North America and likely involved the melting of a significant volume of *sediments entrained by the subducting slab*. As I noted in my answer to question 30 (Q30),

> The belt of Mesozoic-Tertiary plutonic rocks extending from Alaska to Antarctica, forming much of the mountain belt known as the American Cordillera, was produced by this subduction-caused melting beneath the western margins of these continents. The maps below display the main sites of this plutonic emplacement of new crustal material. Isostatic adjustment in these belts has resulted in the mountains we see there today.

Caption: Major plutons of the North American Cordillera (left) and of the South American Cordillera (right), principal segments of a continuous Mesozoic-Tertiary belt from the Aleutians to Antarctica. Reproduced from J. D. Winter, *An Introduction to Igneous and Metamorphic Petrology*, Prentice Hall, 2001."

Let me here emphasize that not only was the Sierra Nevada Batholith generated by upwelling granitic magma during the Flood, but *all* the batholiths shown in the figure above were produced by the same subduction-driven process during the Flood. return_to_Contents

42. Please further explain why we do not see more sedimentary deposits in ocean basins, especially given the massive amount of runoff that occurred at the end of the Flood.

Response: The essence of the answer is that, generally speaking, water speed is inversely related to water depth. That is high speed flow in shallow water turns into low speed flow when the water becomes deep. (I realize that some people have difficulty grasping this idea. But computational models such as the one I used to model the response of the ocean water to flipping of the earth's spin axis show this effect in a striking way, namely, of high speeds on the continent where the water is shallow but of extremely low speeds beyond the continent edge.) This means that water on the continent which is racing toward the coast slows down dramatically when it encounters deeper water offshore. Water's ability to keep its sediment load in suspension depends very strongly on its speed. When the water speed becomes low, it has almost no ability to carry sediment, and the sediment falls out of suspension. This implies that, at least *in a general sense, deep water represents a severe barrier to sediment transport*.

In regard to where sediments resulting from the Flood runoff reside today, there are indeed huge thicknesses of these sediments on the continental shelves. This is not surprising, in light of my comments above about the effects of increasing water depth, since a significant increase in water depth would have existed on the continental shelves during the Flood, resulting in a reduction of water speed and a dropping of the sediment load before the runoff water reached the edge of the continental shelf. return to Contents

43. In the paper, "Catastrophic Plate Tectonics: The Physics Behind the Genesis Flood," presented at the Fifth ICC in 2003 on page 15 you cite your preference for a subduction trigger "grinding inexorably toward catastrophe" during the pre-Flood years. Heat flow from Earth's interior to Earth's surface is extremely slow on a time scale of 1650 years, based upon standard thermodynamics. How can temperatures in the mantle change enough during that brief interval to trigge runaway subduction?

Response: What I had in view with this remark was *not* a change in the temperature structure of the mantle nor an increase in density of the cold material in the upper mantle around the perimeter of the supercontinent, but rather the mechanical motion of this cold rock, i.e., its progressive sinking, and as a consequence, steadily increasing stress levels in the rock immediately around the cold rock, until the critical stress level was achieved at which runaway could begin.

This possibility was addressed in a separate 2003 ICC paper, which I referenced in the paragraph you quote as reference [16], M. F. Horstemeyer and J. R. Baumgardner, "What initiated the Flood cataclysm?" in *Proceedings of the Fifth International Conference on Creationism*, R. L. Ivey, Jr., editor, Creation Science Fellowship, Pittsburgh, PA, 155-164, 2003 available athttp://www.icr.org/article/flood-cataclysm/. Let me provide the highlights from that paper by quoting the abstract and the conclusions below.

> Abstract: We report results from a parametric study of various weakening mechanisms that can occur in olivine aggregate materials to help understand how an episode of runaway subduction could be initiated. We use a finite element analysis employing an internal state variable plasticity/damage model to show that temperature contrasts, loading rate, crystallographic damage, water content, and initial anisotropy can all induce significant mechanical instability in olivine rock. Our results indicate that each of these weakening/localization effects may have played an important role in fashioning an initial state for the earth from which the Flood cataclysm could easily emerge.
>
> Conclusions: We have shown numerically that several mechanisms can enhance the potential for instability that ultimately led to the Genesis Flood. Recall our question at the beginning: Did God establish conditions in the earth during creation week such that catastrophic plate tectonics would eventually occur at the precise time Noah's day, or did He have to employ additional special means to initiate the cataclysm? Our study suggests it is plausible from a material science standpoint that the earth, as originally created by God, could have been close to the point of instability as far as the state of its lithosphere was concerned, and that during the period between creation and the time of Noah slow deformation was taking place that eventually caused the system to cross the boundary into the regime of full-blown instability and catastrophe. In this case no additional special action was required on God's part for the Flood cataclysm to unfold. return to Contents

44. I would like a bit more explanation regarding your comment below from your response to question 32 (Q32):

> We identified the first of the episodes as occurring during the formation of the earth but before plant life was created on Day 3. The second episode occurred during the Genesis Flood. The first episode involved a total of approximately four billion years' worth of nuclear transmutation at today's rates, while the second involved some 500-600 million years' worth. We judged these conclusions to be extremely firm.

I would like to know how this conclusion was arrived at regarding how much accelerated radioactive decay took place in the first episode compared to the second episode. Is this judged from the volumes of rock of different geological periods? Are there rocks which were affected by both episodes of decay? If so how would we know which episode represents more decay? Also, a related question is, how do you envision the second episode of accelerated radioactive decay influencing the Flood?

Response: Let me begin by addressing the issue of just how much nuclear decay has occurred in the earth since God began to form it. Was it just a few thousand years' worth at present rates, or much more than that? At the beginning of the RATE project, the team members had a divergence of viewpoints on that very crucial question. So one of the first projects we undertook was to apply fission track dating to an assortment of samples from different parts of the geologica record. Fission tracks represent tangible, physical evidence for nuclear decay. The outcome of that preliminary fission track investigation was that indeed many tens of millions of years of nuclear decay, at presently measured rates, had taken place since the onset of the Flood in these rocks. Moreover, the fission track ages we obtained for these samples were in close agreement with the radioisotope dates for these same rocks. This study convinced those members of the RATE team who earlier had been somewhat uncertain about the reality of huge amounts—millions and even billions of years' worth—of nuclear decay during earth history to accept this reality and to move on to the important task of explaining how this had occurred within the time span given by God in Scripture.

I do not want to go into detail summarizing the RATE project other than a few key points. Of course, our primary conclusion was that so much nuclear decay could fit into the Scriptural account of earth history *only* if it took place in highly accelerated episodes that did not entirely destroy the earth's life. This seems to restrict the bulk of nuclear decay to two windows—(1) prior to the point in Day 3 when God created plant life and (2) during the Flood when the continent were covered by water which acted as a radiation shield.

Another important question is, how much nuclear decay products have the earth's crustal rocks accumulated? If we consider igneous rocks erupted since the onset of the Flood, which is marked by the sudden appearance in the sediment record of fossils of multi-cellular organisms, we find such rocks contain as much as 550-600 million years' worth of nuclear decay products. Hence, our working conclusion is that approximately that much accelerated nuclear decay must have accompanied the Flood event.

What about nuclear decay products in rocks that crystallized before the Flood? How much decay products to we find in these rocks? In our RATE studies, we did extensive analysis of zircons extracted from a drill core from the granitic basement at a site in north central New Mexico. The amount of accumulated radiogenic lead in the zircons from this core was consistently 1.5 billion years' worth at today's decay rates. (The truly exciting discovery was the large amount of radiogenic helium which these zircons still contained required that all the 1.5 billion years' worth of nuclear decay must have taken place within the last 6000 years, based on the diffusion rate of helium through zircon.) Other RATE projects measured daughter products in other rocks which gave radioisotope ages even greater than that obtained for the New Mexico granite.

In 2001 S. A. Wilde et al., in a paper entitled "Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago," *Nature, 409*, 175-178, 2001, reported a zircon enclosed in a metamorphosed sandstone conglomerate in the Jack Hills of the Narryer Gneiss Terrane of Western Australia with a Pb-Pb age of 4.4 Ga. These authors in the same paper report several other zircons from the same formation with almost the same Pb-Pb age. The RATE team concluded that there is no good reason to question the reality of this much nuclear decay having occurred since the earliest moments of the earth's existence. Zircons, because they are so hard, have such a high melting temperature, and, when they form exclude lead and helium, are entirely capable of recording this decay history.

So in regard to the first question, namely, how our conclusion was arrived at regarding how much accelerated radioactive decay took place in the first episode compared to the second episode, basically, our RATE studies verified that the measured radioisotope 'age' in most cases does indeed give the amount of nuclear decay in terms of today's rates that a rock sample has experienced since it was formed or last metamorphosed. The earliest Flood rocks yield 'ages' of about 500-600 million years, while oldest rocks for the earth as a whole yield 'ages' approaching 4.5 billion years. This implies 500-600 million years' worth of decay occurred in the second episode, and about 3900 million years occurred in the first episode.

Is this judged from the volumes of rock of different geological periods? No, it is a matter not of rock volume but rather of the radioisotopes and decay products the rocks contain.

Are there rocks which were affected by both episodes of decay? Certainly. Essentially all rocks with radioisotope ages greater than 600 million years were affected in their radioisotope patterns by both episodes of accelerated decay.

If so, how would we know which episode represents more decay? The decay products *accumulate* unless the rocks are metamorphosed, heated strongly in some other way, or strongly leached. Thus, apart from such confounding factors, the decay products generated in the first episode are still around and add to those produced in the second episode.

Also, a related question is, how do you envision the second episode of accelerated radioactive decay influencing the Flood? As we mention in our RATE books, the amount of heat released in this accelerated decay episode is so vast that God must have intervened to remove it, just as He must have intervened to cause the acceleration of the decay rates. We find little evidence for any significant heating of the rocks as a consequence of this decay acceleration. Thus, I do not include any influence of this accelerated nuclear decay in my modeling of the mechanics and thermodynamics of the Flood. return_to_Contents

45. The "dolomite problem" imposes some severe issues with regard to both mechanical and geochemical constraints on any model. This includes the evolutionary model or models that have a difficult time explaining dolomite's occurrence. No evolutionary modeler can simply exclaim, "Dolomite occurs here and was formed in this manner!" Too little is actually known about the process. Creation models are not without similar problems. These problems include:

1. The large amounts of magnesium required to form dolomite, whether it be considered to be "primary" (formed directly from solution" or secondary (as the result of diagenetic processes). The issue – sources of concentrated magnesium.

2. The incorporation of fossil material into the content of the dolomitic rock. The fossil content can be often seen directly in hand specimens and in thin section where they occur as preserved replacements, as molds (moldic porosity having the morphology of a recognized fossil specimen) or as ghost forms, where recrystallization of the dolomite, or perhaps its preceding mineralogy has obliterated details of the original specimen. These ghost forms are apparent by their outlines, which in many cases are created by remnant organic material which crosses grain boundaries and fractures. Ultraviolet imagery reveals more detail in these fossil forms. The issue – fossils are found in many more dolomite beds than generally acknowledged.

3. Carbonates in general show an inverse solubility constant (Ksp), so solubility is reduced in higher temperature environments. The issue - this imposes restrictions on direct precipitation processes especially from hot solutions that are cooling.

4. Massive thicknesses of dolomite in the stratigraphic column. This poses problems in terms of direct precipitation or diagenetic alteration. The precipitation processes are extremely tricky, and massive amounts of

dolomite imply that the conditions for precipitation and transformation were in place over a period of time. The issue – huge volumes of dolomite restricted by geochemical, thermal conditions and the kinetic barriers to dolomite formation.

How does your model accommodate the formation of enormous amounts of dolomite, either by means of direct precipitation or by geochemical (diagenetic) alteration? Please explain chemical and potential transportation processes into your model and how your model may provide superior explanatory power to dolomite's occurrence within a Flood context. Reference:
http://www.scitopics.com/Sedimentary_dolomite_a_reality_check_on_the_Dolomite_Problem.html

Response: Certainly I acknowledge the reality of this "dolomite problem," not only for the uniformitarian framework but for models that seek to conform to the time frame of Biblical history. Frankly, although I have long been aware of the problem, I have not given much attention to solving it. The first sub-problem you mention, that of an adequate source of magnesium ions, is crucial. In the context of CPT, one obvious possibility as a source for magnesium ions is in the context of the supercritical water circulating in the newly forming basalt at the rapidly spreading V-shaped depressions where ocean plates are diverging and along which the supersonic steam jets are emerging.

I have not yet searched the chemical engineering literature in a serious way, but a quick Google search turned up several papers concerned with metal corrosion in supercritical water systems such as those used in waste water treatment. One paper stated that "especially severe corrosion occurs when halogens are present." So I suspect that under the conditions occurring as the water, at depths substantially greater than those required for water to be supercritical, circulates through extremely hot basalt, that there could well be substantial quantities of magnesium dissolved from the basalt by the supercritical water. Basalt typically contains 5-12 percent MgO by weight, so the amount of magnesium potentially available via this process is vast—conceivably adequate to resolve this aspect of the "dolomite problem."

Moreover, it is conceivable that this dissolved magnesium would be carried along as the supercritical water flashed to steam, rapidly reached supersonic speed, and entrained adjacent ocean water, carrying it high above the earth before this entrained fell back to earth as dispersed rain. So there seems to be a plausible way to transport and disperse the magnesium from the fairly restricted zones where it is extracted to a more global distribution. I recognize all this is speculative at this point, but it seems coherent enough to merit further study.

I would like to mention at this point that, in the context of the Flood, there is not only a "dolomite problem," but there is also a similar "limestone problem." A source for all the limestone we find in the Phaneozoic record is a huge issue. It is at least conceivable that much of the calcium required might also be available through this same mechanism that provides the magnesium.

What about an adequate source of carbonate ions? Again, this is not an issue I have looked at in any serious way, even though I have been aware of it for a long time. One possibility I have entertained in the past is that perhaps in the earth God originally created or from organisms in the pre-Flood seas there were vast deposits of calcium carbonate at the time of the Flood which were somehow pulverized and/or dissolved and suitably transported and/or precipitated to form the vast limestone beds so prominent in the Phanerozoic sediment record. A serious research initiative using the isotopes C-13 and C-14 and possibly others to try to decipher the origin of the carbon in the world's major limestone deposits might provide some important clues.

As far as the changes in ocean chemistry required to allow the rapid precipitation of so much dolomite and limestone, my training in chemistry is simply too thin to offer any constructive ideas other than to point out the obvious fact that the Flood cataclysm likely altered ocean chemistry in a major way while the cataclysm was taking place.

These, then, are my thoughts on this difficult but important issue. return to Contents

46. I would like to follow up on an earlier question, number 37 (Q37), which addressed the likelihood of multiple steam jet episodes contrary to the biblical record of one 40-day period of intense rain. It appears that I either do not understand your response or your previous publications. And since the issue presents a potential logical problem for your model, I would like to make sure that we all understand it. Thank you for your patience.

In your response, you begin by stating: "Nowhere that I am aware have I suggested that there were two separate episodes of runaway subduction." Let me explain how I (and possibly others) arrived at that conclusion. I perceived CPT as proposing multiple episodes of plate motions, similar to the uniformitarian concept of Wilson Cycles, which would have included reversals of plate motions (i.e., the Atlantic opening and closing and opening again). Perhaps the fault is mine; I had always assumed that plate motion along a single vector implied the creation of crust at a rift zone at one boundary and the offsetting destruction of crust by subduction (to preserve Earth's size) at another. If multiple episodes of rifting and subduction took place during the Flood, I therefore took this to indicate more than one episode of runaway subduction, because that was your proposed mechanism for any plate motion.

Given the limited time of the Flood, any cycle before the Pangean breakup you show in your modeling would also require accelerated rifting and subduction. Since the only catastrophic mechanism proposed is runaway subduction, then I assumed that there were multiple episodes of that phenomenon. How else could CPT be a model for the *entire* Genesis Flood?

The bottom line for me is the need to explain: (1) how one episode of runaway subduction would cause the complex plate motions of at least two Wilson Cycles, (2) how multiple iterations of catastrophic rifting would not create corresponding periods of steam jets, and (3) how your mid-to-late Flood breakup of Pangea would create steam jets correlating to the first 40 days of the Flood. I would appreciate your clarification of this issue.

Response: I will attempt to cut directly to what I discern to be the source of this confusion. I suspect it merely has to do with perspective. I have been describing the processes from a global perspective. I suspect you are viewing them from a regional perspective, say, from the eastern coast of North America. Yes, from the perspective of, say, New York, the scenario I am describing involves continental rifting and the opening of the Iapetus Ocean just after the onset of the Flood, with steam jets erupting along the mid-ocean rift in the middle of this newly forming ocean basin. Then, when the mid-Paleozoic sediments are being deposited in various places, what today is North America reverses course and eventually slams back into Europe and northwestern Africa to form Pangea. And, yes, when the spreading in the Iapetus basin ceases, the steam jets in that basin also shut down. Then, as the early Mesozoic Flood sediments begin to be deposited, rifting again takes place between what is today North America and Europe/Africa, and the North Atlantic Ocean basin begins to form, with a second generation of steam jets rising from its median rift. So, from the perspective of this hypothetical observer located somewhere on what is today the U.S. East Coast, there were one and a half "Wilson Cycles" with two distinct nearby episodes of rapid seafloor spreading and two intervals of nearby steam jets, all during the first 40 days of the Flood.

However, the perspective I have been assuming in every paper I have written is the global one. From this global perspective there is but one episode of CPT, one that persists with sufficient vigor for a period of 40 days to produce the violent steam jets everywhere on earth where rapid seafloor spreading was occurring. And for a rapid opening even of the Iapetus Ocean to take place, most of the earth's mantle must be weakened by many orders of magnitude. This strongly suggests that there was rapid subduction and seafloor spreading in many regions of the earth's surface simultaneous with the opening and closing of the Iapetus Ocean. Certainly, as the Iapetus basin was closing, to accommodate the subduction of the Iapetus seafloor, there almost certainly had to be seafloor spreading with

accompanying steam jets in the vast oceanic area west of Laurentia. Likely, rapid subduction and compensating seafloor spreading were also occurring in several other locations at the same time.

This global perspective is what I have been assuming in all of my papers and presentations since 1986. Because the supersonic steam jets in this framework are causally linked with the very rapid seafloor spreading and because these jets seem to be the logical source for heavy global rainfall, it seems plausible that the 40 days and nights of heavy rainfall mentioned in the Genesis text give us the length of time in which this rapid seafloor spreading and rapid subduction of oceanic lithosphere was occurring on the earth as a whole and hence the length of time the mantle was in this state of being orders of magnitude weaker than it is today. The many types of observations we have that correlate the large-scale tectonic changes that accompanied the Flood with the fossil-bearing sediment record lead me to infer that most of this record likely was formed during this 40 day period. The correlations logically seem to require it.

To be sure, the plate motions as well as the motions of rock within the mantle had to be complex during the Paleozoic portion of the cataclysm to be able to open and then close the Iapetus Ocean and then to open the Atlantic Ocean. On the other hand, the geological observations in both North America and Europe seem to require such a complex tectonic history, with little room for uncertainty, do they not? And this earlier tectonic history must occur during the Flood cataclysm because of the obvious presence of so many spectacularly preserved Paleozoic plant and animal fossils in the resulting layered sediments.

This scenario of a single episode of CPT lasting 40 days that includes the opening and closing of the Iapetus Ocean, where that region represents just a portion of the overall global process, is implied in what I have written during the past ten years. I trust this reiteration will help you grasp that my descriptions and discussion of the CPT process have consistently had this global perspective in view. return_to_Contents

47. Catastrophic Plate Tectonics (CPT) not only distinguishes itself from Uniformitarian Plate Tectonics (UPT) in terms of time-scale reduction facilitated by subduction-rate acceleration, but would also appear to reject UPT's foundational concept of ocean-basin and supercontinent formation—the Wilson cycle. Driven by the heat of radioactive decay, this essential UPT process relies on subduction zones flanking continental rifting to each oppose the plate motions of the divergent land mass, thereby closing an ocean basin and rejoining the separated supercontinent. Even though uniformitarians believe that this cycle averages 600 million years in duration and has occurred at least a half-a-dozen times since the alleged Precambrian, am I correct in assuming that CPT's runaway subduction process would allow for only the first half of only one Wilson cycle due to its being a one-way, irreversibly-downward, mantle-directed mechanism? If this is the case, how does CPT explain the origin of the Appalachian Mountains which UPT claims is the indisputable result of a Wilson cycle involving Mid-Silurian continental collision to form this orogenic belt, thereby closing up the Iapetus Oceanic Basin, the precursor to today's Atlantic Ocean (supposedly now in the third of the six stages of the Wilson cycle— Embryonic, Youth, Adolescence, Maturity, Old Age, Death)?

Response: As I indicated in my answer to question 46 (Q46) above, the observational evidence for the opening and closing of the Iapetus Ocean and the associated tectonic signature in the continental rock record, including the Appalachian orogeny, is close to indisputable. Moreover, because of the presence of abundant metazoan fossils in the associated continental sediments, this spectacular tectonic activity must be part of the Flood cataclysm. As I also indicated in that answer, for such large-scale tectonic change to occur during the short time span of the Flood seems to require that the strength of the mantle to have been orders of magnitude smaller than it is currently. Hence, as I indicated in that answer, based on the observational evidence, "Wilson cycle" behavior, at least in the case of the Iapetus Ocean, logically must be part of the CPT description for the Flood.

Your question as to the mechanics of how this can happen is a valid one. My response to that is that the primary driving forces for plate motions over the earth's surface are buoyancy anomalies in the mantle. Slabs of cold oceanic

lithosphere represent one important type of buoyancy anomaly. Hot blobs of rock from near the core-mantle boundary represent the other important type. Based on previous 3D numerical experiments, I am convinced that the most of the possible initial thermal states for the mantle that will yield the sort of "Wilson cycle" type motions required for the three continental blocks, Laurentia, Baltica, and Siberia in a CPT scenario for the Flood are relatively complex and not that easy to guess or even find by a trial and error process. Nevertheless, I believe a trial and error approach might eventually succeed. Good candidate initial thermal states should probably include zones of cold rock in the upper mantle and zones of hot rock just above the core mantle boundary. My present conjecture is that an initial state consisting of a zone of cold rock around much of the perimeter of the Pannotia supercontinent plus a volume of hot rock just above the core mantle boundary beneath the northwestern portion of Pannotia might be a good point to begin the quest to find viable candidates. The CPT scenario, of course, would rely on gravitational potential energy stored in this initial temperature state and not on heat from decay of radioactive elements. Please see my response to question 95 (Q95) below for details on the geological observations that so strongly support the reality of the opening and subsequent closing of the Iapetus Ocean. return to Contents

48. In the context of the various Flood models being advocated today, please comment on the points with which you as a Flood modeler can agree regarding the other models.

Response: In regard to the hydroplate model, I agree with the conclusion that vast amounts of tectonic change accompanied the Flood cataclysm. I agree that major features of the earth's surface today such at its mountain belts, its canyons and other large-scale erosional features, its fossil-bearing sediment record, the ocean trenches, the mid-ocean ridges, the fracture zones, the volcanic island chains are products of the Flood cataclysm and require of any serious Flood model an adequate explanation. I agree that it is very likely that fountains of water associated with the mid-ocean ridge system were the source of the heavy rainfall of the Flood described in the Genesis text.

In regard to the vapor canopy model, I agree that evidence from the fossil record is strong that the pre-Flood climate was dramatically different from that of today. I agree that this evidence suggests strongly there were greenhouse-like conditions pole-to-pole in the pre-Flood world. I also agree that, in terms of the present laws of physics, the amount of liquid water equivalent in a viable vapor canopy appears to be limited to no more than a few feet. I agree that such a small volume of water could have played only a tiny role in the overall hydrodynamics and other geological aspects of the Flood.

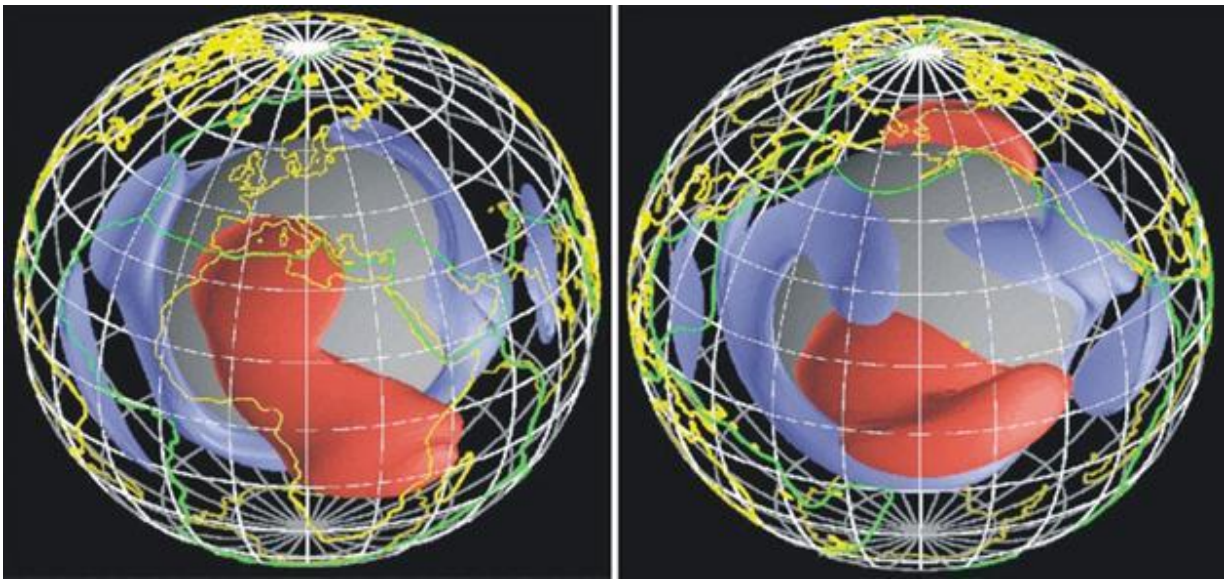
In regard to the solid canopy model, most of the description involves possible physical explanations for how hydrogen and oxygen might have formed a pre-Flood crystalline canopy. Each of these candidate explanations is speculative, so there is little of real substance with which to agree. Each of these candidate explanations seem to imply that the total mass of water in the hypothesized crystalline canopy was small, in most cases, no more than a liquid water equivalent layer a few inches thick. From this I infer that a conversion of a solid crystalline canopy to liquid water would have contributed little to the hydrological aspects of the Flood cataclysm, and with this I agree.

In regard to the collapse tectonics model, I can agree that from the beginning of Creation Week forward, God has used a great deal of genuine physical process to bring the earth to its present state.

In regard to the impacts/differential vertical tectonics model, I can agree that vertical tectonics played a significant role in the overall tectonics of the Flood, especially in the latter portion of Flood as Flood waters were retreating from the continent interiors. I agree that massive volumes of Flood-deposited sediments, in many areas thicknesses corresponding to many thousands of feet, were stripped away from the continent surfaces by retreating Flood waters. I agree that planation surfaces represent powerful evidence for the runoff stage of the Flood. I agree that the continental shelves, as geomorphologic features, testify eloquently to rapid mass runoff from the Flood, with sediment transport and deposition perpendicular in direction to the coastline. I agree that the uniform depth of the edge of the continental

shelves points to the simultaneous end of the Flood for all the continents. I agree that water gaps are powerful evidence for large-scale runoff of water from continent interiors as Flood waters retreated. I agree that the end of the Flood itself must be in the late Cenozoic part of the geological record. I agree with the reality of a post-Flood Ice Age caused primarily by the fact that the oceans were much warmer, pole-to-pole and top-to-bottom at the end of the Flood than they are today. return_to_Contents

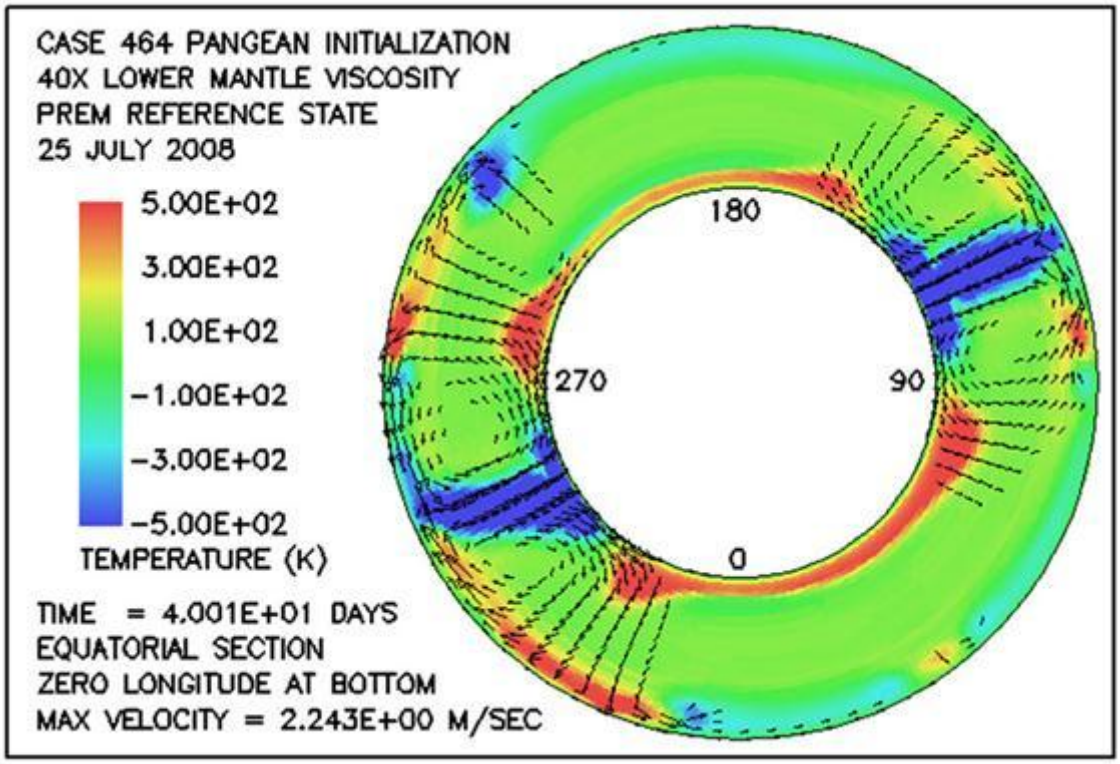
49. Please explain how the 3D seismic tomography mantle map you have been using, shown below, correlates with the distribution of volcanism we observe today. Specifically, the hot mantle plumes do not seem to line up with the major volcanism – i.e., the larger hot superplume is underneath Africa, which has far less volcanism than the ring of fire, but even the hot superplume underneath the Pacific does not appear to correlate with the volcanoes in the ring of fire.



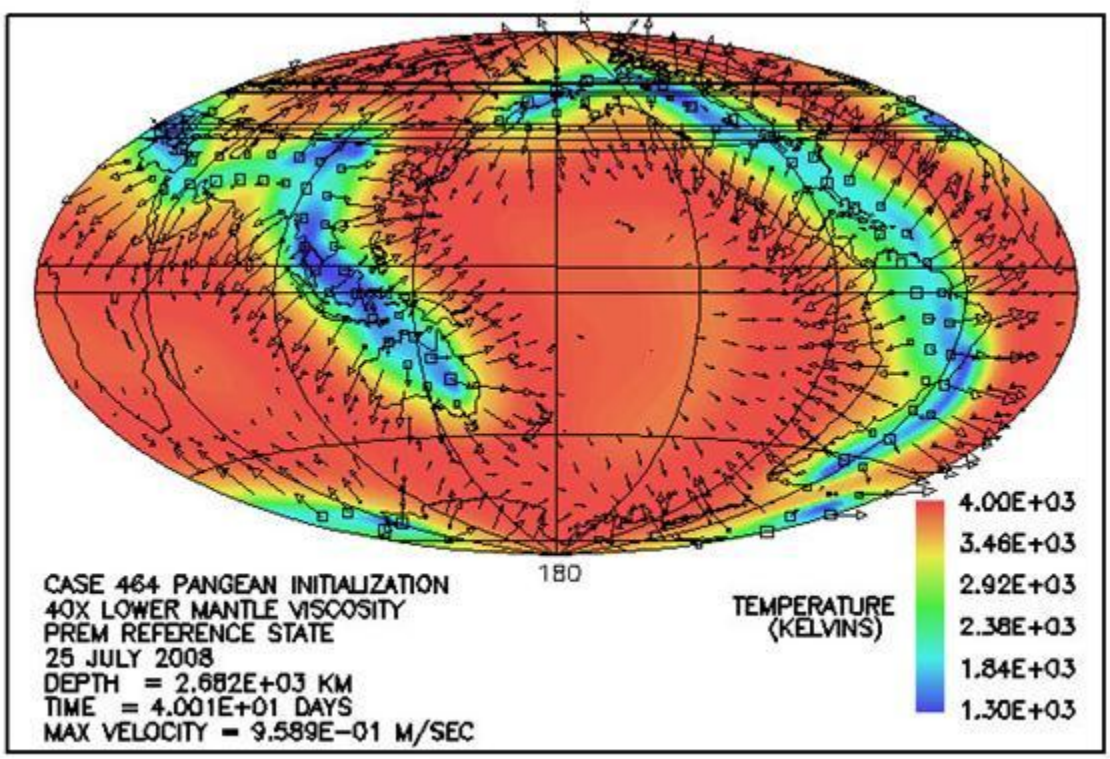
Response: As I have been emphasizing for several years now, the sort of seismic velocity structure displayed in the figure is amazingly close to what one should expect if there has been a recent episode of CPT associated with the Genesis Flood that produced the fossil record at the earth's surface. Keep in mind most of the structure depicted in the figure is in the lower regions of the lower mantle. Although oceanic plates at the surface are sheet-like, by the time this material reaches the base of the mantle it becomes blob-like. This blob-like character of the cold material at the base of the mantle is evident in the figures from the 3D calculations I described in my 1994 and 2003 ICC papers and included my 2008 ICC PowerPoint presentation.

Although the plate motion history of the Paleozoic, corresponding to the earlier portion of the Flood cataclysm, is poorly constrained, particularly because of the lack of any modern ocean floor from that segment of geological history, the post-Paleozoic plate motion history is reasonably certain. When one applies that later, reasonably well-known plate history with its implied subduction zone locations, one gets a distribution of cold material in the lower mantle that correlates strikingly well with the blue regions in the figure shown above.(See, for example, Bunge, H.-P., C. R. Hagelberg, and B. J. Travis (2003), "Mantle circulation models with variational data assimilation: inferring past mantle flow and structure from plate motion histories and seismic tomography," *Geophys. J. Int., 152(2)*, 280-301.)

My own calculations yield a similar result. The case I highlighted in my 2008 ICC presentation, at a time of 40 days into the run, yields the following temperature field in a cross-sectional view through the equator:



The following plot is a plot of absolute temperature for the spherical surface about 200 km above the bottom of the mantle centered at 180° longitude:



This temperature distribution, of course, represents a single snapshot in time. At later times the cold material displayed in the cross-sectional view, shown in blue, settles and spreads to cover more of the bottom boundary of the mantle. The rock at the base of the mantle which this cold rock displaces, of course, is much hotter. It is not difficult to imagine how, when most of the more rapid motions have ceased, the resulting temperature distribution would resemble that implied by seismic tomography methods for today's earth.

Hopefully, this brief explanation helps to clarify that the blue features in the seismic tomography image are located, from a depth standpoint, in the lower part of the lower mantle, and from a lateral standpoint generally beneath the margins of the Pangean supercontinent. This means these features are somewhat displaced from the locations of the subduction zones on earth today. The red features, beneath Africa and the south central Pacific, indeed are *not* associated with that much active volcanism presently. However, the huge number of extinct volcanic seamounts which cover so much of the floor of the Pacific basin does suggest that this large hot feature beneath the central Pacific did cause significant melting and widespread volcanic activity in that region during the Flood.

By contrast, the ring of fire volcanism, closely associated with active subduction around the perimeter of the Pacific, is understood by almost all earth scientists, including most creationist earth scientists, as the result of water and sediments carried down into the mantle by the subduction process. Water significantly reduces rock melting temperatures, and when introduced into the setting of the asthenosphere where rock is already close to its melting temperature, it can and does result in substantial partial melting of the mantle rock and consequent ring of fire volcanism. Understood in this way, it is then plausible why the ring of fire volcanism is associated with currently active subduction zones and also with the blue features in the seismic tomography image if indeed these features represent cold rock subducted during the Flood.

Let me conclude with a question. Since the pre-Flood ocean lithosphere all seems to missing from the earth's surface today, where else might it be except at the bottom of the mantle? To me at least, as I have emphasized many times in the past, the discovery by modern seismology of this ring-like distribution of high seismic velocity and presumably low-temperature material at the base of the mantle represents exciting and awesome support for the dramatic tectonic catastrophism associated with the Genesis Flood. return_to_Contents

50. Since the viability of the CPT model rests heavily upon the stress-strain mechanics of crustal and mantle materials, can you supply additional references for research on the dislocation creep properties of mantle minerals, beyond the one you have cited for olivine?

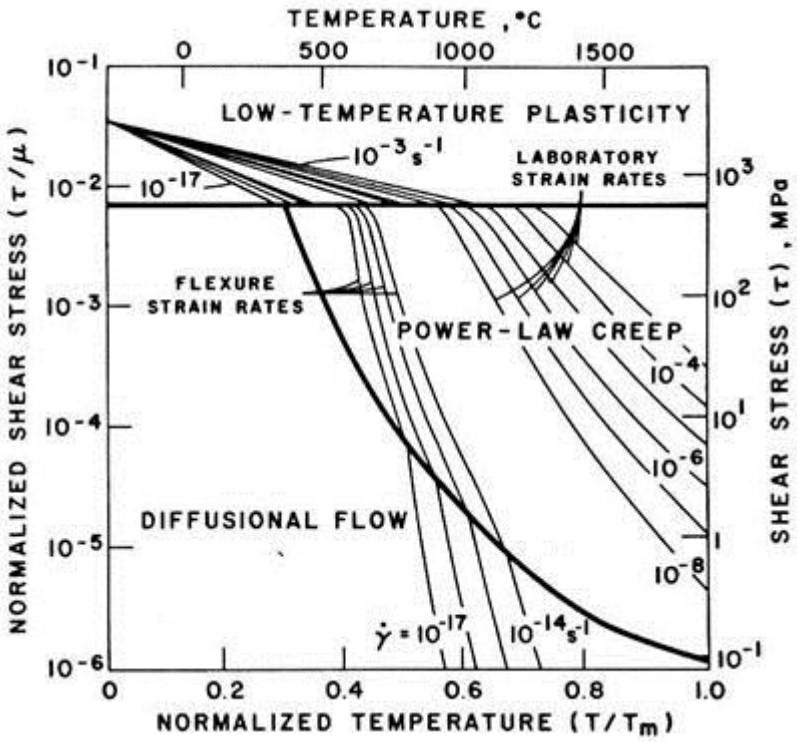
Response: Indeed, there is absolutely no disputing the fact that the viability of CPT depends critically upon the stress-strain behavior of mantle materials. In response to your query, yes, there are many more recent references than the ones I have cited in my papers. This field of the rheology of mantle materials is a relatively large and technical one. So I will provide some references that give a summary overview and also some that focus in on the issues particularly relevant to CPT. One of the leading and most active researchers in the field of the rheology of mantle materials is Shun-Ichiro Karato at Yale University. Many of the recent papers by him and his collaborators and students are posted on his website http:///earth.geology.yale.edu/~sk388. A summary paper that can be downloaded from this site under the tab "Recent Publications" is one by Karato and Weidner (who is also a leading senior researcher in this field) entitled "Laboratory Studies of Rheological Properties of Minerals under Deep Mantle Conditions." This paper provides a relatively readable overview of the history of the experimental techniques that have been applied since the 1960's to characterize the deformational behavior of mantle minerals and rocks under mantle-like conditions. It also emphasizes the challenges that continue to exist in this quest, especially at the pressures which exist even in the deeper parts of the upper mantle, not to mention the lower mantle. Here is the introduction from that paper:

> Plastic deformation of rocks occurs during the large relative translation of rock masses that has important control over large-scale geologic phenomena such as mantle convection, plate tectonics and formation of a mountain belt. Consequently, the knowledge of rheological properties of (mantle) minerals is critical to understand these geodynamic processes.
>
> Rheological properties that we need to know for geodynamical applications include the relationships between the creep strength (or strain-rate) and various physical/chemical parameters and the relationship between deformation microstructures and deformation conditions. In both cases, experimental studies play a major role but the experimental approach is not straightforward because of the complex nature of rheological properties and the large difference in timescale between geological deformation and deformation in laboratory experiments. Consequently, the developments of new techniques and careful evaluation of the validity of extrapolation of experimental data to geological applications have played a major role in the advancement of our knowledge on rheological properties.
>
> In this article, we first present a brief summary of nature of experimental studies on rheological properties followed by a historical review of experimental studies of plastic deformation. Then we describe the developments of new experimental techniques at pressures beyond 10 GPa, and finally summarize the important issues that are needed to be explored. Due to the limited space, we will focus on experimental studies on rheological properties under deep mantle conditions. For a more comprehensive review, a reader is referred to other textbooks such as (Karato 2008; Poirier 1985).

I recommend this 2008 paper to help someone not that familiar with the field to acquire some general perspective, including historical perspective, on the how the deformational properties of mantle materials are experimentally determined.

For a deeper and more comprehensive view of the current state-of-the-art I recommend the textbook by Karato mentioned in the final sentence of the introduction quoted above which is entitled, *Deformation of Earth Materials: An Introduction to the Rheology of the Solid Earth*, published in 2008 by Cambridge University Press. Chapter 9, pp. 143-167, entitled "Dislocation creep," is particularly relevant.

Let me now attempt to relate more recent experimental work to the primary reference I have utilized in my previous papers, namely, Kirby, S.H., "Rheology of the Lithosphere," *Rev. Geophys. Space Phys., 25*, 1219-1244, 1983, including a figure from that paper shown below.



Caption: Deformation mechanism map for olivine with a 1 mm grain size. Shear strain rates $\dot{\gamma}$ (in s^{-1}) are contoured over shear stress τ normalized by shear modulus μ and absolute temperature T normalized by temperature of melting T_m.

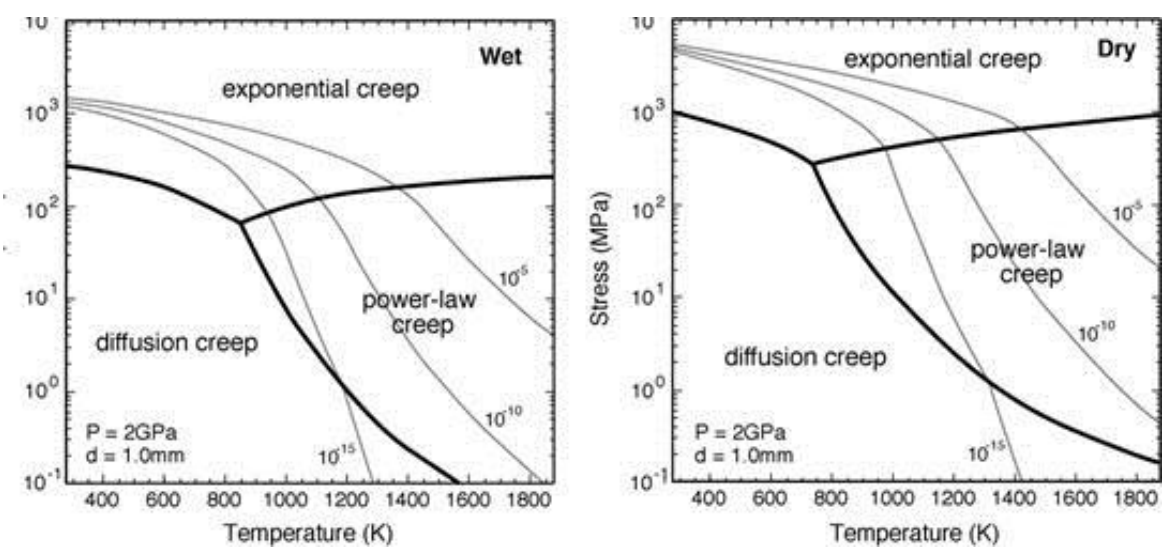
This deformation map for dry olivine with 1 mm grain size shows three main deformation regimes, namely, that of diffusional creep which occurs in the lower stress/lower temperature part of the map, that of power-law dislocation creep in the higher stress/higher temperature part of the map, and that of low-temperature plasticity for stresses above about 500 MPa (largely independent of temperature).

In my efforts to model the runaway process over the years, I have progressively included more and more realism in the deformation model. In my 1986 and 1990 ICC papers I included only the diffusional regime. In my 1994 ICC paper I added the power-law regime and consequently observed more realistic runaway behavior. Then in my 2003 ICC paper I also included the so-called low-temperature plasticity regime and obtained truly dramatic runaway results. These results were also made possible by a major advance in numerical techniques which allowed the numerical code to handle much more extreme spatial changes in rock strength. It was this discovery of the importance of the low-temperature plasticity regime that caused me to realize it is *primarily* this mechanism that enables the runaway process.

Since the late 1990's this so-called 'low-temperature plasticity' regime in the earth science community has instead generally come to be referred as the 'Peierls mechanism' regime, which is more appropriate since this mechanism is largely independent of temperature. Deformation by the Peierls mechanism occurs due to glide motions, without recovery, of dislocations in the crystalline lattice. Since it appears that this mechanism is the one that is so crucial to the runaway motions in the mantle, I will focus on it in the following discussion. I will highlight a few representative papers that deal with a range of relevant issues. The first is a paper that reports results experimental deformation measurements on olivine entitled, "Low-temperature, high stress deformation of olivine under water-saturated conditions," by I. Katayama and S. Karato, *Phys. Earth Planet. Interiors, 168*, 125-133, 2008. The abstract is as follows:

Low-temperature high-stress rheology of olivine was investigated under water-saturated conditions by large strain shear deformation experiments using the Griggs-type apparatus. Samples at *T*=1273–1373K and *P* = 2GPa under water-saturated conditions deformed under a significantly lower applied stress than expected from the power-law relation and the strain rate increases more rapidly with stress. These observations suggest that an exponential flow law operates under the present experimental conditions, in which the stress dependence of activation enthalpy is characterized by the Peierls stress. The Peierls stress is determined between 1.6 and 2.9 GPa depending on the choice of the form of stress dependence of the activation enthalpy. These values are significantly smaller than the Peierls stress under dry conditions (9.1GPa). We suggest that water (hydrogen) incorporated in the olivine lattices decreases the Peierls stress, and hence the rate of deformation in the exponential creep is significantly enhanced by the presence of water. The reduction of the Peierls stress by water results in the highly anisotropic weakening effect of water that causes the fabric transitions in olivine. The transition between the power-law and the exponential creep occurs at relatively low stress ~100MPa at a geologically relevant strain rate of 10^{-15} s^{-1} when temperature is lower than 1273K and under water-rich conditions. Hence, the exponential creep might be dominated in olivine-rich rocks at low-temperature and high-stress under water-rich conditions, and such regions could be widespread in the subduction zone upper mantle where the cold lithospheric plates sink into the mantle.

The main significance of this paper is that it shows that with some water present, as many lines of evidence now indicate for the upper mantle, the threshold stress required for the Peierls mechanism to dominate the stress-strain behavior is a factor of about 3-5 lower than for the dry case. This value for wet olivine (~100 MPa) is close to what I have used in my 2D cases that yield spectacular runaway. So this experimental result is highly relevant. Below are the deformation mechanism maps summarizing the results of this study. Note the similarity of the map for dry olivine with the one shown above from the 1983 Kirby paper.



Caption: Deformation mechanism map of wet and dry olivine as functions of stress and temperature at *P* = 2GPa and grain size of 1.0 mm.

What about the other minerals of which mantle rocks are comprised? Besides olivine, the dominant upper mantle minerals are pyroxene and garnet. Laboratory measurements of the rheologies of these minerals indicate that they both are consistently *stronger* than olivine for essentially all upper mantle conditions. Because it is the weakest of the main constituent minerals that determines the rheology of a polycrystalline aggregate, most researchers conclude that the rheology of the upper mantle is controlled in large measure by that of olivine.

What about the lower mantle, whose dominant mineral phases are (Mg,Fe)SiO_3 perovskite and (Mg,Fe)O ferro-periclase? Important issues are the relative strengths of these two phases under lower mantle conditions. A paper entitled, "Some mineral physics constraints on the rheology and geothermal structure of Earth's lower mantle," by D. Yamazaki and S. Karato, *American Mineralogist*, *86*, 385-391, 2001, shows that MgO periclase is significantly *weaker* than $MgSiO_3$ perovskite. The paper's abstract is as follows:

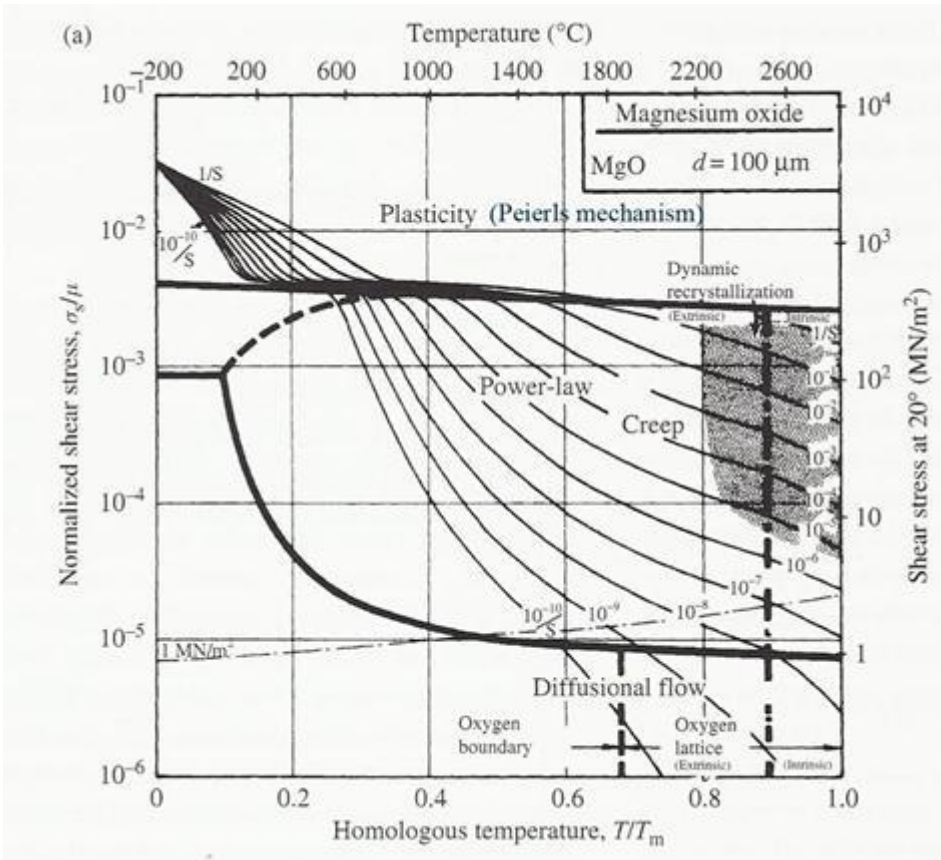
> We explore the implications of recent mineral physics measurements of diffusion coefficients and melting temperatures of lower mantle materials on the rheological and geothermal structure of Earth's lower mantle. We show that $MgSiO_3$ perovskite is significantly stronger than MgO periclase and therefore the rheology of the lower mantle depends strongly on the geometry of a weaker phase, periclase. We calculate viscosities of the lower mantle for two cases: (1) where periclase occurs as isolated grains and (2) where periclase occurs as continuous films, using mineral physics data and models of two-phase rheology. We find that the effective viscosity for the former is about ~10–1000 times higher than the latter. We therefore suggest that the rheology of the lower mantle is structure- and hence strain-dependent, leading to weakening at large strains due to the formation of continuous films of periclase. Overall depth variation of viscosity depends not only on the pressure dependence of creep but also on the geothermal gradient. Both $MgSiO_3$ perovskite and periclase have relatively small activation energies ($E^* = gRT_m$ with $g = 10^{-14}$, where R is the gas constant and T_m is melting temperature), and therefore the depth variation of viscosity is rather small, even for a nearly adiabatic temperature gradient. However, the geothermal gradients consistent with the geodynamical inference of nearly depth-independent viscosity are sensitive to the pressure dependence of viscosity which is only poorly understood. A superadiabatic gradient of up to ~0.6 K/km is also consistent with mineral physics and geodynamical observations.

A more recent paper entitled, "Texture of (Mg,Fe)SiO_3 perovskite and ferro-periclase aggregate: Implications for rheology of the lower mantle," by D, Yamazaki et al., *Phys. Earth Planet. Interiors, 174*, 139-144, 2009, deals directly with the issue of whether the periclase tends to occur as isolated grains or whether it forms continuous films. The experiments reported strongly support the latter. Therefore, because (Mg,Fe)O is several orders of magnitude weaker than (Mg,Fe)SiO_3 perovskite, its rheological properties almost certainly dominate the rheology of the lower mantle. The abstract of this paper is as follows:

> Rheology of the lower mantle characterizes the dynamics of the earth's interior and it is often controlled by the textures of the constituting material which are (Mg,Fe)SiO_3perovskite and ferro-periclase aggregate. We conducted high-pressure experiments to synthesize the (Mg,Fe)SiO_3 perovskite and ferropericlase aggregates and measured two important textures of "grain size" and "dihedral angle". The grain growth rates of perovskite and (ferro-)periclase in two phase aggregates were influenced by the iron content and increased with factors of ~1.5 in iron-rich system. This difference in grain growth rates indicates that the viscosity of aggregates of iron-rich system is only a few times greater than that of iron-poor system for likely diffusion creep in the lower mantle. In contrast, the change of the dihedral angle of perovskite – periclase – perovskite at triple grain junction with variation of iron content was not observed systematically, but the dihedral angle decreases from ~110° to ~105° with an increase of temperature from 1673 to 2273K. The dihedral angle of 105–110° would imply the interconnected network spatially of ferro-periclase in the aggregates and the connectivity increases with temperature. As a result, at higher temperature, ferro-periclase plays more important role for understanding the rheology of the lower mantle because ferro-periclase is a few orders of magnitude softer than (Mg,Fe)SiO3 perovskite.

A number of other investigators have shown that the Peierls mechanism is prominent in the rheological behavior of MgO (periclase) and that the associated Peierls stress is relatively insensitive to pressure. The 2008 textbook by Karato

has a deformation map on page 166 for MgO (reproduced from Frost, H.J. and Ashby, M.F., *Deformation Mechanism Maps*, Pergamon Press, 1982). This deformation map is very similar to those shown above for olivine, including the shape of the region and stress levels where the Peierls mechanism dominates. This map for MgO for a grain size of 0.1 mm is provided below.



One concludes, therefore, based on present experimental determinations, that extrapolating the Peierls mechanism to the rocks of the lower mantle is indeed reasonable.

In regard to first-hand knowledge of or experience with this phenomenon of strain-rate weakening, the closest I have is the man-months or years I have spent seeking to develop numerical techniques to solve the very unstable partial differential equations which describe the response when a gravitational body force acts on a volume filled with this type of material and its density varies with position. I have visited labs where the sorts of mineral physics measurements described in this discussion are performed, and I know personally some of the researchers involved, but I have not been involved directly myself in these types of measurements. return to Contents

51. I would like to bring up some energy considerations based on some crude calculations I made using your 1994 ICC paper "Computer Modeling of the Large-Scale Tectonics Associated with the Genesis Flood." Using your Figure 3 and estimating the total length of the blue cold material at 1.5 times the earth's circumference, its width as 1/40 the earth's circumference and its depth as 400 km, and using information in your reference graphs in Figure 1, I estimated the amount of gravitational potential energy available to be 2.58 x 10^{28} J. (This included taking a buoyant force into account from the surrounding warmer mantle.) This is a large amount of energy, enough to provide the kinetic energy for the plates and the mantle to move. It would be expected to end up as heat, and probably dispersed through the mantle. Since this much heat would only raise the temperature of the mantle by about 3.5°C (using an average specific heat of 1100 J/kg/K and an average density of 4500 kg/m^3), I am not sure why you feel there is a major heat problem. More of a

problem, it seems, is the resurfacing of the oceans with basalt, since that requires the latent heat of fusion for the 2 km or so of basalt to be melted from mantle rock for the entire ocean floor, or by my estimation about 8.6 x 10^{26} J (using 4 x 10^5 J/kg for the latent heat and 3000 kg/m^3 for the density). Although this is still small compared to the gravitational potential energy, it would need to be available at the specific locations of the mid-ocean ridges, instead of spread throughout the mantle, and in the narrow time window when the continents were moving rapidly (about 100 days). Isn't it unlikely the ocean floors could have been resurfaced within these constraints?

Response: First of all the most glaring energy problem relating to CPT is the rapid cooling required for the new ocean lithosphere that is generated at the mid-ocean rift zones. Not only must approximately 6 km of vertical thickness of basalt be cooled from the molten state to the solid, but some 80 km or so of the mantle must be cooled from the conditions existing near the rift to those characterizing mature lithosphere, which means reducing the average temperature of this lithospheric layer by some 500 K.

A basic concept in heat transfer is that of thermal skin depth, which is given by $\sigma = (\kappa t)^{0.5}$, where σ is the skin depth, κ is the thermal diffusivity, and t is time. Skin depth has the following meaning. If one applies a temperature change ΔT to the surface of solid, the skin depth is the depth below the surface to which the temperature change has penetrated after time t. More specifically, in the case of cooling, it is the depth at which the local temperature has dropped by $\Delta T/e$, where e = 2.718 is the base of the natural logarithm, also known as Euler's number. Let us apply this to the ocean lithosphere. The thermal diffusivity of the rock is on the order of 10^{-6} m^2/s. For this value for diffusivity, we find that after 5000 years, the skin depth for the lithosphere is $(10^{-6}\ m^2/s \times 5000\ yr \times 3.2\times10^7\ s/yr)^{0.5}$ = 400 m, in other words, less than one km. This shows that the process of thermal diffusion is seriously incapable cooling 80,000 m of oceanic lithosphere in the time available during and since the Flood. To the extent we can be confident that all of today's ocean lithosphere has been formed by the seafloor spreading process at a mid-ocean rift zone (and I personally believe the case in favor of this conclusion is compelling), then this rapid cooling of the ocean lithosphere is a huge issue not just for CPT but for every serious Flood model.

To address your question directly, the primary energy or heat issue in CPT is *not* that of heating the mantle excessively. Nor is it in having sufficient energy to produce the 6 km of basalt that today forms the oceanic crust via partial melting of mantle rock. In that regard, the mantle is hot enough on its own to supply this amount of heat with little impact on its overall thermal energy inventory. Decompression melting generally readily does the trick, as solid but deformable mantle rock rises to fill the gap between diverging ocean plates. No, for CPT, the primary energy issue is that of cooling the ocean lithosphere quickly, much more quickly than thermal conduction, with measured values of thermal diffusivity, allows. Some might inquire whether hydrothermal circulation might here come to the rescue. Hydrothermal circulation appears not to be a viable option because the quantity of heat that must be removed to cool 30-80 km thickness of lithosphere by 500 K would vaporize the oceans several times over. return_to_Contents

52. I would like to better understand the processes you envision happening at the mid-ocean ridges and on the ocean floor at the start of the Flood especially regarding the water jets. In your 1994 paper 1, the six author paper, you stated "Rapid emplacement of isostatically lighter mantle material raised the level of the ocean floor, displacing ocean water onto the continents." Then regarding the water jet from your 2003 paper, bottom of page 14, it states "Another aspect of these jets is that seawater is converted to supercritical steam as the water penetrates downward through the fractured and porous newly formed seafloor, and then emerges almost explosively at the throat of the jet." In your response to question 27 (Q27) you described the water being exposed to molten rock in V-shaped rifts at the spreading center. I can see how the water could initially be a jet when water penetrates into the rift where molten rock is exposed. However, would not these fractures fill with lava and the lava spread out from the ridge over the 40 days? It seems the molten rock exposed to the water would widen over the initial few weeks of the Flood so that a wider and wider band of molten material would be exposed to the sea floor. Isn't molten rock covering the sea floor from the ridge outward? As the molten material fills the V-shaped ridge and spreads out across the ocean floor, would this stop the jet?

It seems to me it would set off convection currents and heat the ocean strongly near the ridges. I don't see how the water would remain exposed to only a narrow strip of molten material. As I understand it, the lava erupting spreads outward from the ridge making the seafloor rise as molten less dense mantle material is replacing the old ocean floor. You indicate that there is not much mixing of the supercritical water with the surrounding ocean water. But it seems to me the steam and supercritical water would mix with the ocean as the molten rock spreads out across the ocean floor. Please clarify.

Response: The main issue in view here is the mechanism and nature of the cooling of the rock column beneath the ocean bottom as this rock comprising new oceanic plate migrates away from an ocean rift zone during the Flood. As I have mentioned before, normal thermal conduction, or diffusion, of heat is simply incapable of cooling the ocean lithosphere as it exists today, either during the Flood itself or in the few thousand years that have elapsed since the Flood. If the many lines of observational evidence which indicate that today's ocean lithosphere—every bit of it—has formed since the early Mesozoic part of the earth's sedimentary record are trustworthy (and I believe these evidences are trustworthy), then this young age of the ocean lithosphere represents a major difficulty, not only for CPT, but for every model of the Flood cataclysm. This difficulty is that uniformitarian physics simply cannot account for such a rapid removal of heat. Honesty drives me to infer that God must have intervened in the physical laws He ordained in this particular aspect of the Flood cataclysm.

Regarding the history of radioactive decay, the Radioisotopes and the Age of the Earth (RATE) team came to a similar conclusion, namely, that God must have intervened during the Flood in the normal operation of the physical laws He ordained, both to increase dramatically the rates of nuclear decay and also to remove the heat which these accelerated decay rates unleashed. I as well as the other members of the RATE team did not take this step of resorting to the supernatural to account for the observations lightly or without earnestly exploring every other conceivable alternative. But the multiple lines of evidence logically seemed to admit no other alternative. It seems to me that the cooling of the ocean lithosphere to its present thermal state since it was formed during the Flood is a closely related issue that drives me to the same conclusion. Peter's words in 2 Peter 3:3-6 seem to provide Scriptural confirmation that God did intervene supernaturally in the operation of His natural laws during the Flood.

With this background let me now address your question more directly. You ask, "Isn't molten rock covering the sea floor from the ridge outward?" My answer is no. I base this answer on my conclusion that the seafloor rock had to be cooling at an elevated rate during the Flood itself. I reach this conclusion mainly from the observation that the lithospheric thickness, which is expressed in the current depth of the seafloor, varies smoothly as one moves laterally away from a mid-ocean rift. Lithospheric thickness in turn reflects the thermal state of that layer of rock. The greater the lithospheric thickness, the more cooling that has occurred since this rock was present at the rift. This seems to imply that during the main phase of the Flood, when exceedingly rapid motions within the mantle were occurring, somehow the rate of cooling of the newly formed lithosphere was also dramatically enhanced. This enhanced lithospheric cooling must have been an ongoing process during the Flood such that new lithosphere became progressively cooler with time as it moved away from the rift.

Although I have made this point before, let me make it here again, namely, that very little of the earth's present seafloor likely formed in the post-Flood era. The reason is that, apart from some process that weakens the mantle (such as that responsible for CPT), plate velocities revert to those we observe occurring today, typically on the order of a few centimeters per year. A full spreading rate of 10 cm/yr, for example, means that a zone of new ocean floor *only 0.45 km* wide forms in a span of 4500 years. The conclusion that essentially all the present ocean lithosphere was formed during the Flood proper in turn suggests that the thermal state of *today's* ocean lithosphere is representative of the thermal state of the oceanic lithosphere *during the Flood itself*. This implies that the rock very near to the rift zone was not molten, but solid.

Let me remark on your quote from the 1994 ICC joint paper, "Rapid emplacement of isostatically lighter mantle material raised the level of the ocean floor, displacing ocean water onto the continents." Never was this intended to imply that this warmer, lighter mantle material was *molten*. Indeed, in the present mantle, most of the rock column even beneath a mid-ocean rift is solid! The 5-6 km of basaltic composition rock that is emplaced as molten magma primarily as dikes below the surface but also erupted to form pillow basalt on the surface is the product of *partial* melting (typically 15-25%) of some of the solid mantle rock below. In this setting, melting is primarily a consequence of the fact that rock melting temperature decreases as pressure decreases (also referred to as decompression melting).

More specifically, as plates on either side of a rift move apart, *solid* rock from beneath, deforming plastically, rises to fill the resulting gap. As this rock rises, it experiences a decrease in pressure. If this rock was near its melting temperature, as is generally the case for rock in the asthenosphere, this reduction in pressure causes some of the constituent minerals suddenly to find themselves above their melting temperatures, and partial melting begins. Once the melt fraction reaches a few percent there is enough porosity in the rock for the melt to migrate, because of its buoyancy, toward the surface. The resulting magma, formed by partial melting of the lowest melting temperature minerals in mantle rock, is basalt. It forms the top 5-6 km of a new oceanic plate. Below that basaltic layer is the solid residuum from the partial melting process as well as solid mantle rock whose temperature never exceeded the melting temperatures of its component minerals. Outside the zone into which basalt is being actively injected, all that is needed for the entire column to be solid is for the injected basalt to cool and crystallize. The sort of cooling I mentioned at the beginning of my response to your question above accomplishes this relatively close to the spreading rift.

This is the perspective I had in view when I wrote what you quoted from my 2003 ICC paper, "Another aspect of these jets is that seawater is converted to supercritical steam as the water penetrates downward through the fractured and porous newly formed seafloor, and then emerges almost explosively at the throat of the jet." I was assuming a cooling rate for the oceanic lithosphere sufficiently high such that, within a few hundred of meters of the centerline of the V-shaped rift, the basaltic wall rock was completely crystallized, solid, and cool enough to have cracked and fractured and thus able to provide paths for ocean water from above to be sucked into the throat of the jet.

Finally, I would like to comment on the issue of a temporary rise in global sea level produced by warmer ocean lithosphere temporarily replacing colder. For upper mantle rock the volume coefficient of thermal expansion is on the order of $3x10^{-5}$/°C. This means that an 80 km thick layer beneath the ocean bottom that is on average 400°C warmer will cause the ocean bottom to stand 1 km higher. While I once believed a rise in global sea level of several hundred meters or more was needed to account for the sedimentation and erosion patterns on the continents, I am no longer convinced this is so. The main reason for my change in outlook is my recent awareness that the earth may have been rotationally unstable during the Flood. As I have indicated elsewhere, such rotational instability causes large amplitude, high velocity tsunami-like waves to sweep over the continents with only small overall changes in sea level. return_to_Contents

53. Given that according to your model, there could have been six or more “flips” of the poles, could you expand on the effects that would have on the water that occupied the ocean basins at the time, and what effects the presumed massive tsunamis would have on brittle crustal rocks that would presumably undergo almost instantaneous isostatic displacement with the passing of each wave? My thinking is that this might provide a mechanism for massive breakup of basement and lithified rocks at the onset of the Flood. Also, what might be the frequency of the waves at any given locality?

Response: My first response is that numerical exploration of these questions is still at an extremely primitive level. The model behind the animation I provided as part of the review materials was intended to obtain a first idea of the types of fluid motions that might arise in such a scenario and what some of the important flow mechanics might be. It was not that surprising, given that the earth is spinning, that eddy-like structures would be prominent in the dynamics. In

addition, given the frequency if the 'flips', the water velocities and wave amplitudes, though large, are not that surprising. My current assessment is that these velocities and amplitudes are both unrealistically large, so it therefore would be useful to explore cases with a smaller number of 'flips'—say, one or two. The effects of more realism in regard to continent shapes and locations and changes in continent locations with time also seemed rather urgent to explore. Since I submitted the original materials for review, I have modified the program to include an arbitrary number of circular continent patches in order to investigate the effects of different continent distributions. My preliminary conclusion is that a distribution of continents similar to what exists today yields water flow dynamics solutions qualitatively similar to the one I obtained with a single large circular continent.

At this point, I think the highest priority issue to address is that of reducing the number of 'flips' of the earth to only one or two. Some questions then to be answered include:
(1) Do the water velocities fall into a more plausible range of only a few tens of meters per second?
(2) Are the overall dynamics complex enough conceivably to account for the complexity of the continental sediment record?
(3) Are all areas of all the continents eventually affected by high velocity water?
(4) How do the solutions depend on the assumed sea level?
(5) How does topography on the continents such as linear mountain belts affect the flow dynamics?
(6) How does the distribution of continents over the earth affect these issues? That is, are the flow dynamics appreciably different for a single supercontinent compared with the case of dispersed continents like the earth has today?

I feel certain that in the course of exploring these issues many new and unexpected details, in addition to insights to the additional issues you raise in your question, as well as new research directions, will emerge. Let's pray for a motivated, energetic, and capable young person to spearhead this research endeavor. return_to_Contents

54. In your answer to question 46 (Q46) you responded that you were viewing the processes that supposedly opened and closed and then reopened the Atlantic Ocean from what you call a global perspective, while you claim that I have been seeking to comprehend these dynamics from a regional perspective.

A global perspective does not change the fact that events are regional. For example, you have spreading in one region and subduction in another. I see two problems with this answer: (1) you have not explained how the "global," single-runaway-subduction-episode can produce the disparate regional plate tectonic events in one coordinated symphony of crustal motion directly related to the proposed lithospheric motions brought on by the episode, and (2) you have not explained how the timing of these events fit your theory. In particular you have explicitly related the opening of the present Atlantic Ocean to the Mesozoic (later Flood). Yet the Bible does not mention the resulting rainfall from the second steam jet at that later stage of the Flood. And taking the global perspective, if we accept the relative chronology of the geological column and your proposed plate motions, steam jets, and by inference, other periods of intense rainfall would occur throughout the Flood. But the Bible only specifies one – the first 40 days.

Response: Somehow there seems to a breakdown in communication. Within the portion of my answer to question 46 (Q46) to which you refer I thought it was expressing clearly that the opening of the Iapetus Ocean, its closing, and the Mesozoic opening of the present Atlantic occurred "all during the first 40 days of the Flood." I just do not know how I could have been much clearer. Nowhere in my answer, so far as I can discern, do I intimate in any way that the Mesozoic correlates with the "later Flood". While this perhaps reflects your own thinking, I do not think it can be construed in any sense from the words in my answer.

Having said that, let me acknowledge that I have struggled over the years regarding the question of just how long the episode of rapid plate tectonics lasted. Up until about ten years ago, based on Genesis 7:24-8:3, I assumed the answer

was most likely 150 days. Following immediately after 7:17-23 which summarizes the violent destruction of "every living thing that was upon the face of the land," apart from what was in the ark, this subsequent passage states:

> 7:24 "And the water prevailed on the earth one hundred and fifty days."
> 8:1 "But God remembered Noah and all the beasts and all the cattle that were with him in the ark; and God caused a wind to pass over the earth, and the water subsided.
> 8:2 "Also the fountains of the deep were closed and the floodgates of the sky were closed, and the rain from the sky was restrained;
> 8:3 "and the water receded steadily from the earth, and at the end of one hundred and fifty days the water decreased."

To me, and I think for most people, the simplest way to unpack the chronology in these verses is first to interpret the beginning of these 150 days as coinciding with the day mentioned in 7:11 when "all the fountains of the great deep burst open, and the floodgates of the sky were opened." Verse 7:12 then states, "And the rain fell upon the earth for forty days and forty nights." This 40 day period also presumably begins on the day described in 7:11. Because verses 7:24 and 8:3 both mention the 150 days (which presumably is the same 150 day interval in both), and because verses 7:24 and 8:3 surround verse 8:2 so closely, the simplest conclusion is that the events of verse 8:2 occur at the end of the 150 days, or 150 days after the onset of the Flood described in 7:11. In other words, these verses seem to indicate that the fountains of the great deep and the floodgates of the sky were open for this entire 150 day period, These verses also seem to indicate there was substantial rain throughout the 150 days as well, persisting past the initial 40 days during which presumably it was especially intense.

So what has pushed me in recent years to place not only the Paleozoic but also the Mesozoic portions of the geological record into the initial 40 days of the cataclysm? The answer is relatively simple. CPT interprets the data from today's seafloor to conclude that a vast amount of seafloor spreading, much more even than what generated today's ocean floor, occurred during the Flood cataclysm. Seafloor spreading sufficiently rapid to generate even today's ocean floor, whether in 40 days or 150 days, logically implies extremely energetic steam jets emerging from these narrow zones of rapid seafloor spreading. These jets, with velocities along their centerlines several times supersonic, have sufficient power to carry large volumes of entrained liquid water into the stratosphere and therefore almost certainly result in heavy rain over much of the earth.

In earlier years I did not give much attention to the significance of the 40 days and nights of rain, and I therefore saw no need to restrict the CPT time frame to less than 150 days. However, more recently as I have realized more keenly just how powerful these steam jets likely must have been and their ability to entrain so much liquid water, I have concluded that the case is strong (but certainly not air-tight) that the 40 days and nights of rain, so prominent in the description of the Flood, likely corresponds to the interval in which rapid seafloor spreading was occurring. To me this is the best way to mesh CPT with the Biblical text, despite the fact that it requires the vast amount of geological change which most people struggle to fit within 150 days to unfold in an even briefer interval. I am not irrevocably committed to this conclusion. I just feel it is the most consistent way to fit the pieces together if one gives priority to Scripture.

Another consideration that pushes me toward this conclusion is that because of the strong nonlinearity of the rheological weakening mechanism which allows CPT to occur, CPT tends to be either on or off. As soon as most of the buoyancy anomalies driving the runaway reach the boundary to which they are headed, mantle velocities diminish, the stress levels start dropping, the stress weakening that depends of these high stress levels drops, the mantle strength begins to return and the velocities drop rapidly in the face of increasing mantle rock strength. As the surface plate velocities diminish sufficiently, the steam jets shut down. In summary, rapid seafloor spreading tends to be either on or off, steam jets tend to be either on or off, and the rainfall caused by the steam jets tends to be either on or off. Because so much seafloor spreading took place during the Mesozoic, I conclude that the Mesozoic must be part of the primary

CPT episode. I conclude the shutdown portion of CPT correlates the Tertiary portion of the rock record. return_to_Contents

55. In your response to question 46 (Q46) you state:

> However, the perspective I have been assuming in every paper I have written is the global one. From this global perspective there is but one episode of CPT, one that persists with sufficient vigor for a period of 40 days to produce the violent steam jets everywhere on earth where rapid seafloor spreading was occurring.

Does this not then imply that all rifting must have occurred during the first 40 days of the Flood? Or is there some special feature of early Flood rifting that produces steam jets while later rifting does not? What is that factor? Also, what would be the lag time between steam jets and rain? The Bible tells us that the rain lasted forty days. If it takes one day for water to travel as supersonic steam into the upper atmosphere or higher, and then fall back to earth as rain, then the steam jets would only be operating 39 days. Is that time frame minutes? Hours? Days? Also, if everything took place in the first forty days, does that not contradict your earlier work that discussed the Mesozoic rifting of the Atlantic in terms of later Flood?

Response: Yes, if indeed the intense steam jet activity was limited to first 40 days, this implies that almost all of the rapid rifting likewise was restricted to these 40 days. The speed of the rifting depends of the global strength of the mantle which, as I mentioned above, tends to be either low or high, depending on whether the CPT weakening is on or off. As for how long it takes the rain to appear once the steam jets turn on, that is reasonable easy to estimate. The speed in the core of the jets is supersonic. The speed of the ocean water entrained in the fringes of the jets is likely just below sonic, say, 800 km/hour. Therefore for such water to reach stratospheric height requires only a couple of minutes. For it to fall back to earth at 20 km/hour in the lower troposphere where air density is high means it generally takes less than an hour for it to reach the earth's surface again.

In regard to my earlier modeling of the Mesozoic/Cenozoic breakup of Pangea, the time scales I showed in these computer calculations were in the range of 40-60 days, which fit well within the 150 days I had in mind at that point for the entire CPT event, an interval that also included the Paleozoic portion of the cataclysm which I was not yet able to model. return_to_Contents

56. In your response to question 46 (Q46) you further state:

> And for a rapid opening even of the Iapetus Ocean to take place, most of the earth's mantle must be weakened by many orders of magnitude. This strongly suggests that there was rapid subduction and seafloor spreading in many regions of the earth's surface simultaneous with the opening and closing of the Iapetus Ocean. Certainly, as the Iapetus basin was closing, to accommodate the subduction of the Iapetus seafloor, there almost certainly had to be seafloor spreading with accompanying steam jets in the vast oceanic area west of Laurentia. Likely, rapid subduction and compensating seafloor spreading were also occurring in several other locations at the same time.

Exactly. The global effects of the Flood in your model would have produced many different regional effects, including rifting, plate motion, subduction, continental collision, island arc formation, mountain building, etc. I have no argument at all with that – it is consistent with your model. However, this still does not explain how plates could move in opposite directions absent rifting and subduction zones switching places (roughly). Otherwise, what would be the driving force? And back to the original question: any new rift zone would imply new steam jets. If we accept the biblical account, that would imply no rifting after day 40.

Response: On the issue of the opening and subsequent closing of the Iapetus Ocean, given the geological evidence recor in the continental rock record today on either side of the Atlantic, how do you fit the pieces together? Would you not ag that the observations are compelling that such a tectonic history is likely, if not certain? In my assessment, the issue is no so much whether these tectonic events occurred, since the evidence is so compelling, as it is the mechanism responsible them. My comment on that issue is that today, except at plate boundaries, the asthenosphere is at least a thousand time weaker, and in most cases at least ten thousand times weaker, than the lithospheric above it. Hence, plate motion is controlled primarily by the forces acting at the plate boundaries. This was also likely the case during the Flood. So the primary forces responsible for the closing of the Iapetus do not need to be local to the Iapetus itself but may have been, a likely were, on the opposite side of the Laurentian plate, many thousands of kilometers away. Please see my answer to question 95 (Q95) below for more specifics regarding the geological observations that support so strongly the opening a closing of the Iapetus Ocean. return_to_Contents

57. In your response to question 46 (Q46) you state:

> This global perspective is what I have been assuming in all of my papers and presentations since 1986. Because the supersonic steam jets in this framework are causally linked with the very rapid seafloor spreading and because these jets seem to be the logical source for heavy global rainfall, it seems plausible that the 40 days and nights of heavy rainfall mentioned in the Genesis text give us the length of time in which this rapid seafloor spreading and rapid subduction of oceanic lithosphere was occurring on the earth as a whole and hence the length of time the mantle was in this state of being orders of magnitude weaker than it is today. The many types of observations we have that correlate the large scale tectonic changes that accompanied the Flood with the fossil-bearing sediment record lead me to infer that most of this record likely was formed during this 40 day period. The correlations logically seem to require it.

So the Paleozoic = somewhere in the first 20 days of the Flood and the Mesozoic and Cenozoic the next 20? Adjust the da however you want, this creates vast problems of explaining why there would be no rock record representing the next 331 days of what would have been intense hydraulic action at a minimum. I do not understand the timing of your model. Ca you provide a time line of the 371 days of the Flood showing the timing of runaway subduction, as tied to the eras of the rock record and the major regional events that we know occurred (orogenies, rifting, subduction, plate motion, etc.)? It would help clarify this problem, especially since most modern mountain chains were formed relatively recently.

Response**:** I'm not sure I can honestly provide much more detail on the timing than I have already provided in my answers above. Yes, if indeed the interval of rapid seafloor spreading coincides with the 40 days and 40 nights of heavy rain, then roughly a 50/50 split of that interval between Paleozoic and Mesozoic would seem reasonable. Then the early Cenozoic would coincide with the remainder of the 150 days and the middle Cenozoic until roughly the end of the Miocene when most of the regression of the flood waters was occurring would correlate with the remaining 221 days. Most of the uplift of the modern mountain belts occurs in the Pliocene and Pleistocene part of the record, which in my assessment is post-Flood. return_to_Contents

58. Why should DSDP and ODP dates be accepted as reliable, especially given that only a handful of indisputable off-ridge dates were obtained, that there is testimonial evidence that drilling program officials ignored contrary evidence, and that the programs were terminated because it was concluded that current technology would not be able to drill to the depths necessary to reach true basement? You seem to accept at face value the DSDP scientists' assertions that they drilled to basement in many of their sites. Yet Storevedt (1997) noted that they simply assumed that Layer 2 basalt was basement. Furthermore, Pratt (2000) documents that the vast majority of the sites did not hit basement. He also showed that the trend of dates off ridge had a wide scatter, even ignoring data contrary to DSDP conclusions, citing age scatter of tens of millions of years along a single magnetic anomaly. There have been many citations of samples

recovered by dredge and drilling near and along the ridge that showed ages that were widely discrepant from those predicted (see summary in Pratt, 2000).

Response: I can sympathize with your bewilderment in trying to sort out the various issues and make sense of all the conflicting truth claims if you are giving serious credence to Pratt's (2000) paper. If a person has a sufficient grasp of the big picture, many of the anomalies to which Pratt is pointing indeed provide useful leads from the standpoint of research on the Genesis Flood. But it is important to keep in mind that Pratt in no way is thinking in terms of a recent global tectonic and hydrologic cataclysm, so he is severely handicapped in his ability to make sense of the anomalies himself. For example, all the dramatic up and down motions, not only of the continents, but also of the ocean floor are a complete bewilderment to him. Pratt is correct that conventional plate tectonics has no good explanation for these up and down dynamics, but that is not the case with catastrophic plate tectonics.

In regard to the section of his paper dealing with deep sea drilling, he points to several noteworthy anomalies, but he himself is at a loss as to how to make sense of them. If we consider the case of the continental rocks dredged in the late 1960's from the area around Bald Mountain at about 45° N latitude just west of the Mid-Atlantic Ridge, I find this data extremely fascinating. I do not dismiss out of hand that Bald Mountain itself possibly might be a sliver of continental crust, way out of place in this location. However, upon reading the original papers which describe these dredged rocks, I conclude that such an inference is far from certain. Essentially all of these rocks of continental affinity are well-rounded and lack the thick coating of manganese oxide that covers most of the other seafloor rocks in the area. Moreover, they seem to be widely scattered in the larger vicinity, even on the opposite side of the Mid-Atlantic Ridge, and not localized to Bald Mountain. At 45° N latitude it is not farfetched to suspect that many if not most of these rounded rocks without manganese coatings are indeed glacial erratics, that is, rocks scoured from a continent surface by glacial action, incorporated into the glacial ice, set adrift within icebergs as the glacier reached the coastline and calved off icebergs into the sea, and then dropped to the sea bottom when the icebergs melted.

In regard to the small number of deep sea drill holes to reach basement which Pratt cites—that was as of 1977! Since 1977 there have been more than a thousand additional holes drilled, with a much larger fraction reaching basement because of better technology. Most of the uncertainties that existed as to the structure of the oceanic crust as of 1977 have now been resolved. The deepest hole into the basaltic basement is now more than a kilometer. The earlier conjecture that the present oceanic crust might resemble the rock assemblages known as ophiolites that are exposed at the earth's surface in many places and readily sampled and studied has now been substantiated by the drilling results. Ophiolites are now interpreted as former pieces of ocean floor that have been tectonically emplaced, or obducted, onto a continent. The confidence behind this interpretation is derived primarily from the ocean drilling results obtained over the past 30 years. Moreover, from the vast number of holes drilled since 1977, the case to me is incontrovertible that the age of the ocean crust increases in a systematic way as one moves away from the spreading ridges. How can anyone now doubt that basic finding? return_to_Contents

59. You have said: "The wealth of new data…that precipitated the acceptance of plate tectonics during the 1960's simultaneously also opened the door for the first time in more than 200 years to a technically credible defense of the Genesis Flood" (Baumgardner, 2003, p. 113). Is plate tectonic theory a data-driven necessity or the result of a perceived need for a grand synthesis by geologists? If the former, then why were the basic ideas in place in the early 1960s, well prior to the data that supposedly proves the theory?

Response: A ridge of mountains on the floor of the Atlantic Ocean was first discovered during the expedition of HMS *Challenger* in 1872 while investigating the future location for a transatlantic telegraph cable. Its presence was confirmed by sonar in 1925. During a 1925-1927 research cruise, the German research ship *Meteor*, equipped with early sonar equipment, produced the first detailed survey of the South Atlantic Ocean floor. This survey established that the Mid-Atlantic Ridge was continuous through the South Atlantic and continued into the Indian Ocean beyond Cape of

Good Hope. The advances in sonar technology during World War II, driven by the need to hunt and track submarines, was applied beginning in the 1950's to map the topography of the ocean bottom in great detail for the first time. These topographical maps of the world's seafloor brought to the attention of the world's earth science community the astonishing presence of a mountain chain some 65,000 km in length running like a baseball seam through the world's ocean basins. The fact that the geological picture of earth history prevailing at that time had no explanation for such a prominent feature prompted many earth scientists to seek an explanation and to begin gathering new types of data from the ocean bottom to address this issue.

I believe it is fair to conclude that the state of affairs in 1960 was that there was a significant body of observational data for which there was no viable explanation, at least in the minds of the broader earth science community. I believe it is fair to say that it was this body of unexplained data that caused many researchers to be willing to consider new and bold hypotheses. It also created a desire throughout the community to acquire more data. I also believe it is fair to say that the scientific revolution that subsequently unfolded in the 1960's was strongly data driven. It is also of interest to note that there were multiple hypotheses at the time, earth expansion as an example, in addition to the one which ultimately prevailed. return_to_Contents

60. You have said: "In his second contribution to this forum, Michael Oard asserts I am profoundly misinterpreting several prominent features of the Earth. But in making this accusation, Oard is placing himself under serious obligation to provide the correct explanations" (Baumgardner, 2002b, p. 78). Why is this statement not an example of the "best-in-field" fallacy?

Response: I believe my statement was legitimate. This quote corresponds to the initial two sentences of the abstract of an article entitled "A Constructive Quest for Truth," *TJ* (now *Journal of Creation*) *16(1)*, 78–81, April 2002, which was part of a forum on plate tectonics and available online athttp://www.answersingenesis.org/tj/v16/i1/plate_tectonics5.asp. For context let me quote more of that abstract:

> In his second contribution to this forum, Michael Oard asserts I am profoundly misinterpreting several prominent features of the Earth. But in making this accusation, Oard is placing himself under serious obligation to provide the correct explanations. Since I have already addressed most of his technical objections in my earlier contributions, I think it proper to focus a bit more attention on Oard's own explanations. Indeed, if the plate tectonics paradigm is as defective as he would have us believe, then it should not be that difficult for him to provide a positive alternative. And if he had such an alternative, he would surely be focusing more of his attention on its superior explanatory power. But Oard does not have any serious alternative. He offers no coherent explanatory model for the primary tectonics features of the Earth. He has no answers for the structure, location, or origin of the mid-ocean ridge system, or of the continental mountain chains, or of the ocean basins themselves. He provides no explanation for the distribution of sediment on the ocean floor or its fossil content or the correlated orientation of its magnetic mineral grains. He has no credible energy source or mechanism that could have produced the young tectonic features we observe on our planet today within the Biblical time constraints of the Genesis Flood. In short, Oard gives little indication he is engaged in a constructive quest for truth. I firmly believe it is time for creationists to move beyond such negative tactics, especially when God in our day has given us a compelling outline of how a global tectonic cataclysm can occur.

I continue to be strong in my conviction that, as Christians concerned about the assaults against the authority of Scripture in the guise of science, we need to be providing our generation positive answers to the genuine issues that are being raised. For example, in the context of the Flood model review process, the broader issue before us is how does one square what the Bible says concerning earth history with what we know about the geological record?

I am convinced that the tactic, practiced by many Christians during much of the 20th century, of across-the-board attacks on the anything considered valid by the scientific establishment is no longer effective or appropriate or acceptable. Bible believing Christians played a key role in the rise of modern science. It was a Biblical worldview, which included the understanding that the God of the Bible had created the world around us that operates in a law-like manner, which led to the elucidation of these laws that God Himself had ordained. Just as the Spirit of God enabled believing men and women in earlier generations to unravel what previously had been mysteries as to why things worked the way they did, so I believe God continues to enable whom He desires today to shed new light on things not previously understood. I earnestly believe He is calling us His servants to provide positive answers to the issues relevant to our day. return_to_Contents

61. CPT was introduced nearly two decades ago. How well has it served as a basis for geological research within diluvialism? Would an examination of the technical literature demonstrate that CPT is a strong or a weak model for stimulating investigation in related fields such as sedimentology, structural geology, marine geology, etc.? Why have you co-authors from 1994 not published more about the model within their separate specialties? What spin-off theories within diluvial geology or related sciences have been generated by CPT?

Response: As at many times in the past concerning the things of God, the laborers in this endeavor likewise are few. There just aren't that many of us involved in geological research, regardless of specialty, who take the Genesis Flood as a genuine historical reality. The newly formed Creation Geology Society is a fledgling group with just a handful of people. The Institute for Creation Research in 2006 initiated the Flood Activated Sedimentation and Tectonics (FAST) program. That program originally included orogeny-related projects that indeed relied on CPT for its context, but the program no longer enjoys financial sponsorship. Prior to FAST, between 1997 and 2005 most of the authors of the joint 1994 CPT paper were heavily involved with the RATE project. This was because each deemed the need for finding the explanation for why radioisotope methods gave such disparate ages relative to the time frame of Scripture to be of such extreme priority. Perhaps, we need to need to get serious in asking our God to raise up more laborers and more resources for this aspect of His work at this crucial moment in history. return_to_Contents

62. One of the problems with canopy theories is the latent thermal energy in their collapse. How would the descending water from the steam jets be different if it had been boosted into space?

Response: Water vapor, in order to fall as rain, must lose 540 calories per gram or 2260 kJ/kg at 100° C, which is a whopping amount of latent thermal energy. However, if the water remains in *liquid* form, as is the case of ocean water entrained by the jets and then carried into the stratosphere, it has no need to lose any latent heat of vaporization in orde to fall back to the earth as rain. So this major difficulty for the vapor canopy theories does not apply to the water entrained by the jets in the CPT framework. return_to_Contents

63. CPT posits the flooding of the continents was caused in part by the downward drag of the continents by descending plates. If so, would not the rapid addition of so much volume of new basaltic crust (from the subducting plate) immediately beneath the continents add an upward component of force during subduction?

Response: First of all, the roughly 7 km thick layer of basalt and gabbro, which is the top crustal part of an oceanic plate, converts to a much denser type of rock called eclogite at a depth of only about 50 km. Eclogite is intrinsically denser than normal mantle rock at mantle depths, so it has a strong tendency itself to sink and also to help the slab to which it is attached to sink. So this basalt/gabbro crust generally does not pile up or accumulate because of positive buoyancy beneath a continent. Instead it tends to sink to the bottom of the mantle. On the other hand, when the subduction is very rapid, there is evidence that a significant fraction of the sediment that is on top of the ocean plate can and does get subducted. It tends to melt easily and to generate magma with a more or less granitic composition which commonly forms plutons in the overlying continental plate. So this sediment does act to thicken the edge of continent when it is

subducted beneath it. Volumes appear to have been large enough during the Flood to generate several of the major mountain ranges on earth today. However, while the rapid subduction is occurring, there are downward dynamic forces acting on the edge of the continental plate that more than compensate for that growing thickness of low density rock to keep that strip of continent below sea level. On the other hand, when the rapid subduction ceases, this zone of thickene crust, because of its positive buoyancy, rises rapidly and in most cases forms a prominent belt of mountains. return to Contents

64. How could the Atlantic open and close repeatedly without any effect on the Aleutian-Siberian platform, which is underlain by continental crust?

Response: I encourage you to review the sequence of continent paleolocations produced by Professor Ron Blakely, available at http://jan.ucc.nau.edu/~rcb7/mollglobe.html. I provided most of these images in my answer to question 24 (Q24). What you will notice is that the Aleutian-Siberian platform did not even exist as a single entity until the early part of the Cenozoic portion of earth history, corresponding to the latter stage of the Flood cataclysm. This is *after* most of the latest opening of the Atlantic Ocean had already occurred and certainly after the opening and closing of the Iapetus Ocean had occurred. I also strongly encourage you to read my answer to question 24 which includes my assessment of the realism of Blakey's reconstructions. return to Contents

65. You state that the ocean drilling programs: "…have provided a wealth of data relating to the history of the world's ocean basins. These data make it possible to correlate fossils in the deep ocean sediments with the marine microfossil record on the continental shelves and hence with the overall fossil record". However, the only way fossils can provide an age for any rock unit is by the prior assumption of a singular evolutionary sequence. How can this assumption be squared with creationism?

Response: I would maintain that the claim that a given sequence of distinct fossil types in the rock record is an *evolutionary sequence* is not the same as the claim that a sequence of distinct fossil types in the rock record actually exists. Most creationists acknowledge a genuine sequence of fossil types, at least at some level, indeed does exist in the rock record. For example, trilobites are common in the bottom portion of the fossil-bearing part of the rock record but absent in the upper part. Similarly, mammals are common in the uppermost part but absent in the bottom part. The same is also true of flowering plants. We creationists have long attributed this general pattern to what we refer to as 'ecological zonation' which occurred during the Flood as the Flood waters reached to higher and higher elevations and progressively destroyed habitats distinctive to these elevations. In no sense do we attribute the pattern of fossil types we observe in the rock record to evolution. If one understands the fossil-bearing rock record as the record of the progressive destruction of life in different habitats during a global Flood, then it is not surprising that there would be distinctive trends in the way the different types of organisms are distributed across that record.

Further, creationists who have examined the patterns that exist in the distribution of microfossils such as foraminifera and diatoms have concluded that most of the sequences and correlations discovered by non-creationist researchers are indeed genuine. These sequences and correlations have proved to be extremely useful in a number of practical, economically significant applications such as in the oil and mining industries. Let me quote from an article on microfossil from a U.C. Berkeley website (http://www.ucmp.berkeley.edu/fosrec/Lipps1.html):

> Microfossils are perhaps the most important group of all fossils — they are extremely useful in age-dating, correlation and paleoenvironmental reconstruction, all important in the oil, mining, engineering, and environmental industries, as well as in general geology. Billions of dollars have been made on the basis of microfossil studies. Because they usually occur in huge numbers in all kinds of sedimentary rocks, they are the most abundant and most easily accessible fossils. Indeed, some very thick rock layers are made entirely of microfossils. The pyramids

of Egypt are made of sedimentary rocks, for example, that consist of the shells of foraminifera, a major microfossil group.

How does a creationist account for the observed spectacular and rapid changes in the microfossil types as one moves upward through the record? The most obvious way is to recognize that, during the Flood, the waters were extremely rich in nutrients and that microfossils can multiply extremely rapidly, even explosively. Diatoms which are photosynthetic algae with a siliceous skeleton and found in almost every aquatic environment, for example, can reproduce as often as every three hours. They multiply rapidly in explosive 'blooms' when nutrients are abundant. In the warm, nutrient-rich waters of the Flood it not only would have been possible, but almost certain that massive blooms were occurring almost continuously. Furthermore, as conditions changed, it should be expected that the dominant species would also change. The result would be a distinctive sequence of diatom types appearing and disappearing in the sediment sequence as the Flood progressed. The actual species that appeared and disappeared in the resulting record almost certainly had nothing to do with mutations or genetic changes. Instead the changing dominant species simply reflected the rapid change in environmental conditions. All the different species found across the record almost certainly were present when the Flood began. return to Contents

66. Viewing CPT from a global perspective, what *initially* caused slabs of the pre-Flood oceanic crust to break loose *prior to* the runaway subduction at the Flood onset?

Response: As far as how the cataclysm was initiated, to be honest, I must say I do not know. At the 2003 ICC, Mark Horstemeyer and I presented a paper entitled, "What Initiated the Flood Cataclysm?" (available at http://www.logosresearchassociates.org/Documents/Baumgardner/What-Initiated-the-Flood-Cataclysm.pdf). In that paper we reasoned that the pattern of subduction and continental breakup which occurred during the Flood seems to require a special pattern of density anomalies in the earth's upper mantle prior to the Flood. It is extremely difficult to imagine a physical process by which such anomalies could develop during the interval between creation and the Flood. Therefore, we conjectured that God may well have built such an upper mantle density structure into the original design of the earth, entirely stable at the time of creation, but with the potential for instability and cataclysm should the need arise. At some point after Adam sinned, God could then have gently set things into motion for the cataclysm to unfold at the proper future moment. In our paper we describe several physical processes which could gradually, over many centuries, lead to sudden onset of runaway catastrophe, without any additional special high energy triggering mechanism. That is still my preferred answer to this important question. return to Contents

67. Although 'buoyancy anomalies in the mantle' and 'gravitational potential energy' are envisioned as the vertically-downward forces need for subduction, how would *lateral* force continue to be transmitted by 'trench pull' and 'ridge push' throughout the entire volume of a tectonic plate without completely rupturing or subdividing such a huge crustal slab until it could be dragged, so to speak, "in toto beneath the Moho"?

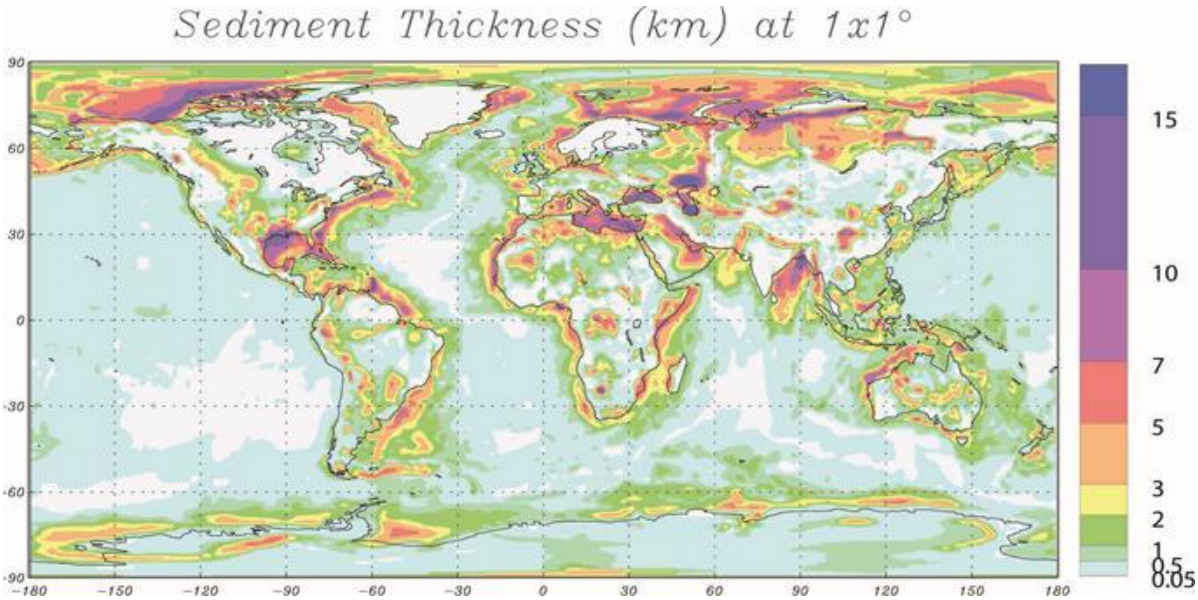
Response: Most people fail to appreciate just how weak the asthenosphere, which lies just beneath the lithospheric plates, really is. Various lines of evidence indicate that the asthenosphere is at least a thousand times weaker and more likely ten thousand times weaker in most places than the overlying lithosphere. This means that the asthenosphere exerts negligible forces on the plates. It also means that the forces responsible for plate motions are the forces acting at their edges, for example, the slab pull and the ridge push forces you mention. Indeed, it seems astonishing that on today's earth, GPS measurements indicate the Pacific Plate, which is some 14,000 km wide but only some 80 km thick, is moving toward the west northwest essentially as a rigid block with no discernible internal deformation. Mechanically, this is possible only if the tractions exerted by the underlying lithosphere are negligible.

Some clarification is in order here regarding the meaning of the term 'Moho'. The Moho is the boundary between crust and mantle, distinguished seismically by an observable change in seismic velocities due to a change in chemical

composition and mineralogy. In ocean lithosphere, this boundary typically occurs at a depth of 6-7 km, while the thickness of an oceanic plate varies between near zero at the axis of a spreading ridge to about 80 km for lithosphere 2000 km or more from the ridge. In the case of continental lithosphere, the depth to the Moho is on average about 35 km, while the thickness of the continental lithosphere, or plate, can be as much as 250 km. Subduction occurs then, not beneath the Moho which is merely a seismological boundary inside a lithospheric plate, but rather into the asthenosphere beneath an adjacent lithospheric plate. return to Contents

68. Can you provide detailed, empirically-based explanations for the following deep-sea trench features: (1) dominance of *continent*-derived sediments (rather than oceanic as UPT would predict); (2) graben-like geomorphology (i.e., being bounded on *both* the ocean side and continent/arc side of the trench by normal/gravity faults); and (3) no *convergence* features within sediments (as expected by UPT theory)?

Response: In regard to (1) as to why continent-derived sediments are dominant in the deep ocean trenches, it is because the continents are the dominant source of sediments generally. As I explained in my answer to question 42 (Q42), the continents are generally where water depths are small, where water speeds can be high, where significant erosion occurs and where longer distance sediment transport can take place. There I state, "Water's ability to keep its sediment load in suspension depends very strongly on its speed. When the water speed becomes low, it has almost no ability to carry sediment, and the sediment falls out of suspension. This implies that, at least *in a general sense, deep water represents a severe barrier to sediment transport*." By contrast, in the ocean depths the water velocities in general are tiny, there is essentially no erosion, and very little sediment transport occurs. I also addressed these issues in even more detail in my answer to question 29 (Q29) where I included the following figure. Note how clear it is that the overwhelming source of sediment in the ocean basins is from adjacent continents.



Caption: A global digital map of sediment thickness, produced by Gabi Laske and Guy Masters, 2009 (http://igppweb.ucsd.edu/~gabi/sediment.html#ftp).

In regard to (2), the vast majority of the deep-ocean trenches, themselves, *do not* display graben-like morphology. Here i quote from the Wikipedia article on 'oceanic trench' (I have added the italics for emphasis):

> Trenches are centerpieces of the distinctive physiography of a convergent plate margin. Transects across trenches yield *asymmetric* profiles, with relatively gentle (~5°) outer (seaward) slope and a steeper (~10–16°) inner (landward) slope. This asymmetry is due to the fact that the outer slope is defined by the top of the downgoing plate, which must *bend* as it starts its descent. The great thickness of the lithosphere requires that this bending be gentle. As the subducting plate approaches the trench, it is *first bent upwards* to form the outer trench swell, then descends to form the outer trench slope. The *outer trench slope* is disrupted by a *set of subparallel normal faults* which staircase the seafloor down to the trench. The plate boundary is defined by the trench axis itself. Beneath the inner trench wall, the two plates slide past each other along the subduction decollement, the seafloor intersection of which defines the trench location. The overriding plate contains volcanic arc (generally) and a forearc. The volcanic arc is caused by physical and chemical interactions between the subducted plate at depth and asthenospheric mantle associated with the overriding plate.

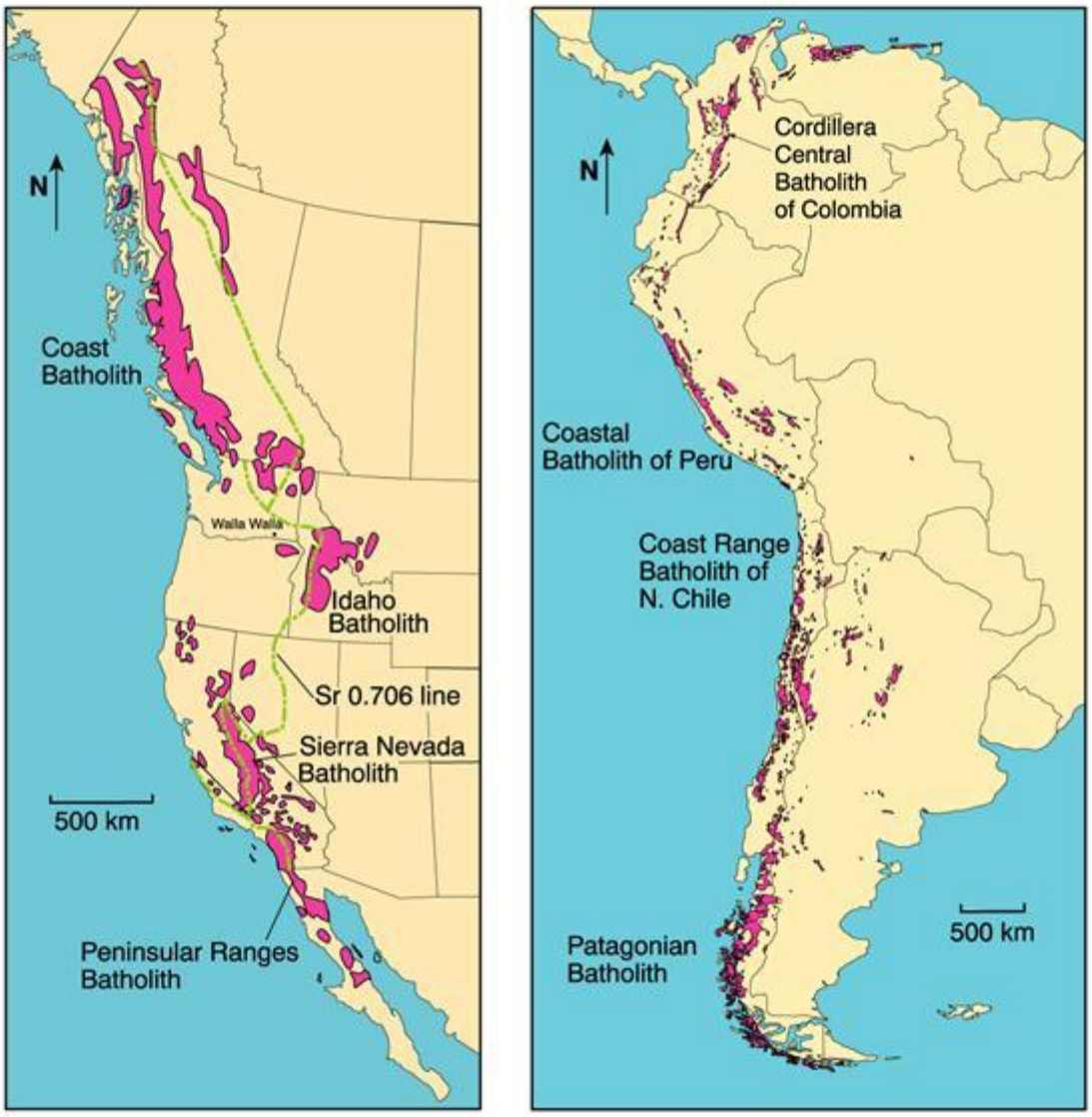
Even though the Wikipedia article is written from a uniformitarian viewpoint in general, I consider this description of ocean trench morphology as accurate and free of uniformitarian bias. One point I want to make here is that grabens bounded by normal faults are indeed common in ocean trench environments as this article indicates. They are parallel to the trench axis and occur on what is called the outer trench slope. These grabens, basically cracks, are a consequence of the *bending* downward of the oceanic plate as it dives into the mantle along the axis of the trench. But these features in no way suggest that the trench *itself* is a huge fault-bounded graben in the normal sense of the term!

In regard to point (3), a lack of convergence features is true for only some of the trenches in the world. Others, such as the Nankai Trough on Japan's east coast, display indisputable evidence for convergence and active development of an accretionary wedge in the present day. (See my answer to question 4 [Q4].) return_to_Contents

69. How does CPT (or UPT) account for the presence of low-density rock at depth beneath mountain belts? Can mountain building really be explained using only natural processes?

Response: As I mention briefly in my answer to question 63 (Q63), a major source of low-density rock at depth beneath mountain belts is the sediment carried down by subduction in a subduction zone adjacent to a continent. Also please refer to my answer to question 30 (Q30) . Below are a brief quote and a figure from that answer.

> The belt of Mesozoic-Tertiary plutonic rocks extending from Alaska to Antarctica, forming much of the mountain belt known as the American Cordillera, was produced by this subduction-caused melting beneath the western margins of these continents. The maps below display the main sites of this plutonic emplacement of new crustal material. Isostatic adjustment in these belts has resulted in the mountains we see there today.



Caption: Major plutons of the North American Cordillera (left) and of the South American Cordillera (right), principal segments of a continuous Mesozoic-Tertiary belt from the Aleutians to Antarctica. Reproduced from J. D. Winter, *An Introduction to Igneous and Metamorphic Petrology*, Prentice Hall, 2001.

In other words, the Coast Batholith, the Idaho Batholith, the Sierra Nevada Batholith, and the Penisular Range Batholith are all examples in North America of this process melted subducted sediments forming plutons which penetrated the overlying continental crust and added to its effective thickness. Subsequent isostatic adjustment produced the prominent mountains that characterize these zones today. The same process occurred in a noteworthy manner along the west coast of South America. return_to_Contents

70. In your response to question 49 (Q49), you asked an excellent, provocative question: "Let me conclude with a question. Since the pre-Flood ocean lithosphere all seems to missing from the earth's surface today, where else might it be except at the bottom of the mantle?" There are at least two flood models which assume a pre-Flood earth that has no ocean lithosphere. For example, in the hydroplate model, the ocean floor became exposed for the first time during the Flood. Would you not agree that the existence of a pre-Flood ocean lithosphere is an assumption?

Response: I would describe its existence as a reasonable inference. The crucial factor that distinguishes the continental regions from the deep ocean basins today is the presence or absence of a 30-40 km thick layer of buoyant granitic crust. Those portions of the earth's surface without this granitic layer are everywhere oceanic, generally covered with 3000-4000 m of seawater. The difference in height of the respective rock columns is a direct consequence of isostasy. Based on clues from today's continental granitic basement rocks such as the presence of radiohalos and measured radioisotope levels, the case seems strong that the continental crust was formed before God created life on earth, which places its formation during the very first days of Creation Week. It further appears that not only the continental crust but also the continental lithosphere, consisting of a keel of about 200 km of strong, anhydrous mantle rock overlain with the 30-40 km thick layer of granitic crust, also must have been formed by God early during Creation Week. This formation would have occurred before the culmination of the events which unfolded in response to God's declaration on Day 3, "Let the waters below the heavens be gathered into one place, and let the dry land appear."

Although the original continental lithosphere appears to have since been fractured into several pieces and kilometers of its original thickness appears to have been beveled away in places, it seems that most of this continental lithosphere did manage to survive the Flood. This survival seems to be largely because of the extreme buoyancy of continental crust. Thi buoyancy tends not only to prevent the crust itself from subducting but, because of the buoyancy it confers to the underlying layer of mantle rock to which it is attached, it also prevents the continental lithosphere from subducting. Given this strong tendency for the continental lithosphere to survive, one can surmise that the fraction of the earth's surface covered by continental lithosphere before the Flood was likely similar to that of today.

What then would the remainder of the pre-Flood surface have been like? Just as today, regions of the earth surface without this special layer of buoyant rock before the Flood almost certainly would be topographically 3-4 km lower than the continental areas. Genesis 1:9, 20, and 21 speak of 'waters' on the earth's surface, so these regions would then surely correspond to ocean basins, and the cool rock layer beneath them would correspond to ocean lithosphere.

To reiterate a bit, continental lithosphere, especially that associated with continental shields and platforms, seems to have survived the Flood cataclysm more or less intact. The reason for this is the striking buoyancy of continental crustal rock relative to mantle rock, with a density difference of about 3300 - 2800 = 500 kg/m^3, or about 15%. This layer of low density continental crust, generally 30-40 km thick, is sufficient to make the entire lithospheric layer, which includes the layer of crust plus a significant layer of underlying mantle rock, buoyant and difficult, if not impossible, to subduct. Since this significant amount of continental lithosphere appears to have survived the Flood cataclysm, it seems likely that, not only did most of the pre-Flood continental crust survive the Flood because of its remarkable buoyancy, but also did most of the pre-Flood continental lithosphere. (Exceptions occur in tectonic belts such as in parts of the southwestern U.S., where it appears, probably because of shallow subduction, the mantle portion of the continental lithosphere has 'delaminated' and fallen away.)

In short, the implication is that the amount of pre-Flood continental lithosphere likely was similar to the amount of continental lithosphere that exists today. The issue, then, is what did the remainder of the surface of the pre-Flood earth look like? Almost by definition it had to be deep ocean basin. Why is this? Basically, it is because of isostasy. Consider two equal diameter columns of rock rising up a common depth in the weak asthenosphere, one through continental lithosphere and the other through what would correspond to oceanic lithosphere. Isostasy requires both columns to weigh the same. Because the oceanic column consists mostly of high density mantle rock, while the continental contains a substantial thickness of low-density crustal rock, the total height of the oceanic column must be substantially less in order for the total weights to be equal. This accounts for why the ocean bottom is several km lower in elevation today than the mean height of the continents. In other words, if the earth's surface is in isostatic equilibrium, portions that do not have the nominal thickness of continental crust will tend to be several km lower in elevation and be covered with several km of water. There is no good reason to believe that this same state of affairs would not have existed on the pre-Flood earth.

Another indicator of the existence of ocean lithosphere in the pre-Flood world is the presence of ophiolites *throughout* the portion of the geological record associated with the Flood. Ophiolites are interpreted to represent pieces of ocean lithosphere that have been tectonically emplaced and preserved in continental environments. Typically, the vertical sequence, from top to bottom, in an ophiolite consists of a layer of pillow lavas, then a laterally extensive sheeted dike complex, transitioning into gabbro, layered gabbro, and cumulate ultramafic rocks. Sometimes there is a layer of chert on top. Ophiolites from the portion of the rock record associated with the earlier part of the Flood almost certainly correspond to actual pieces of pre-Flood ocean lithosphere. In other words, there are places in the world today where one can actually visit and inspect pieces of pre-Flood ocean lithosphere. return_to_Contents

71. Walt Brown's hydroplate model assumes a pre-Flood earth that had no ocean lithosphere. In that model all of today's ocean floor became exposed for the first time during the Flood. What about Flood models which assume that no ocean lithosphere as such was present in the pre-Flood world?

Response: As you point out, Walt Brown posits that the basic structure of the outer layers of the earth prior to the Flood was essentially uniform, with what would correspond to modern oceanic lithosphere everywhere covered with a layer of granitic crust some ten miles in thickness, with a 0.75 mile thick layer of liquid water sandwiched in between. One glaring problem with this idea is the lack of any conceivable mechanism for transforming that distribution of continental crust into the present one. In his book Brown pretends that issue does not exist and therefore provides no explicit answer for it.

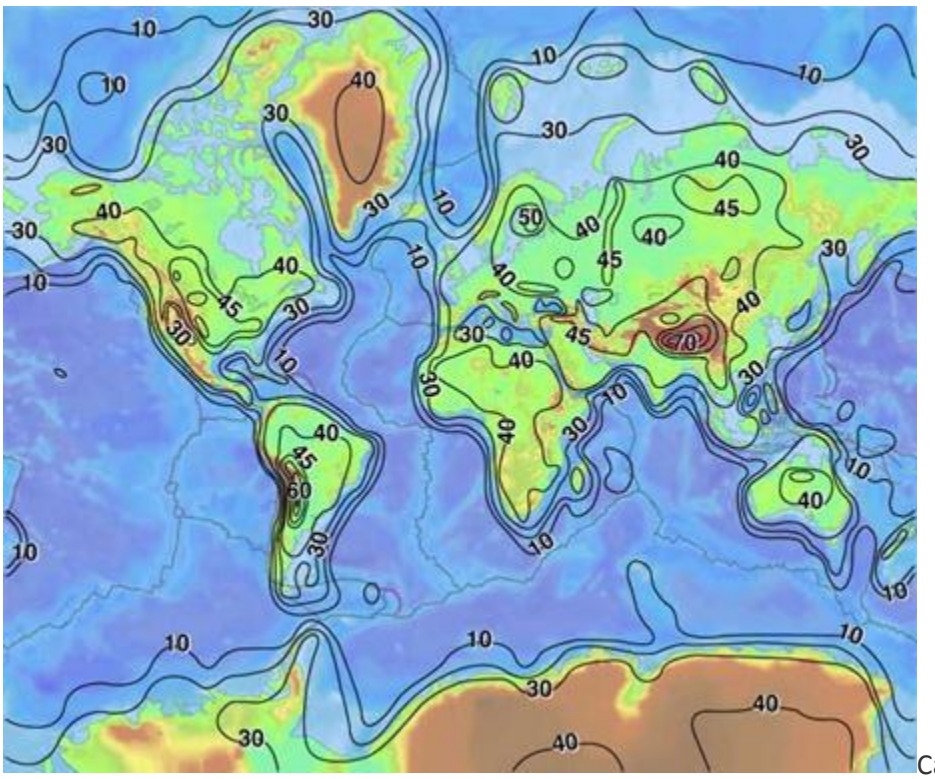
It is noteworthy that through the 5th edition of *In the Beginning*, published in 1989, the thickness Brown assumed for the pre-Flood granitic crust was 10 km instead of 10 miles (16 km). In 1992 the Twin Cities Creation Science Association undertook what they called the Flood Model Project to compare hydroplate theory and catastrophic plate tectonics through a moderated back and forth written exchange between the two authors. In my initial critique of hydroplate theory, I pointed out that a critical requirement for the viability of the theory was an explanation of how the initial distribution of granitic crust, of a layer 10 km in thickness covering the entire earth, could be transformed into a layer roughly three times thicker covering only about a third of the earth's surface. Somehow the initial layer would need to end up being stacked three layers high, like a stack of pancakes, where the continents exist today.

This is extremely difficult to do from a mechanical standpoint. For one thing, the layer of water hydroplate theory invokes to lubricate motion between the initial crustal layer and the underlying rock would not be available to lubricate the motion of one layer of crust onto another. Moreover, the forces and energy required to perform such a feat were far from having any obvious source. Especially problematic, I pointed out in the review, was how today's Eurasian continent had its thickness increased by a factor of three during the Flood. Presumably, most of the crustal material responsible for such thickening had to have been derived for the area of today's Pacific basin. This suggests that some of the crust had to move by some 10,000 km, or about a quarter of the way around the earth. There was no discussion of this problematic issue whatever in that edition of *In the Beginning*. I insisted that if hydroplate theory was to be taken seriously, this very glaring difficulty needed a coherent and satisfying explanation. At that point Brown withdrew from the review process.

Apparently Brown understood that this difficulty I identified during the review process was sufficiently important to prompt him to modify his theory. In subsequent editions of *In the Beginning*, he increased the thickness of the crustal layer from 10 km to 10 miles. Astonishingly, he removed some 30% of the earth's surface corresponding to the present Pacific basin from the hydroplate process of rapid horizontal sliding. Instead, he simply had this crustal material sink a few kilometers into the earth. The increase in the initial crustal thickness, from 10 km to 10 miles, presumably was to compensate for the volume of crust which, in this revised framework, sinks beneath the Pacific basin. However, just as the earlier editions had given no hint that there was any problem in accounting for how the initial distribution of crust

might be transformed into the one represented by the earth's continents today, neither do the later editions. Certainly no serious discussion of this critically important aspect of hydroplate theory is to be found in the current edition.

It is straightforward to evaluate Brown's claim that a layer of buoyant granitic crust currently lies beneath the Pacific basin. The contrast between seismic velocities in granitic crust with those of mantle rock is extreme. Continental crust is readily distinguished from mantle rock by modern seismic techniques. The USGS crustal thickness map, displayed below, is based on such seismic data, primarily surface waves from earthquakes known as Love waves. Note the unmistakable absence of any thick layer of granitic crust in the Pacific basin.



Caption: Contour map of the thickness of the Earth's crust developed from the CRUST 5.1 model (Mooney et al., 1998). The contour interval is 10 km with the additional 45 km contour for greater detail on the continents. There is close agreement between observed and predicted Love waves (surface shear waves) with a period of 40 s. These phases are primarily sensitive to the shear velocity and density structure in the upper 40 km. (http://earthquake.usgs.gov/research/structure/crust/index.php)

Brown does, however, offer a mechanism to increase crustal thickness, one he compares to a train wreck. The process explained on pages 124 and 125 of *In the Beginning* involves first the displacement and acceleration of hydroplates away from the rising Mid-Atlantic Ridge, followed by an abrupt deceleration caused by the depletion of the water lubrication beneath each plate and/or by its encounter with a rigid obstacle. "As each massive hydroplate decelerated, it experienced a gigantic *compression event*—buckling, crushing, and thickening each plate." On page 124 the analogy is made with the collision of a high-speed train with something rigid: "The long train of boxcars would suddenly decelerate, crush, and 'jackknife'." The basic mechanism, then, that Brown offers for thickening the crust is compressive shortening of the existing crust.

In regard to the details, the discussion is vague and qualitative. The only energy source Brown invokes is the kinetic energy of the moving crustal plate. From the words, "To illustrate this extreme compression, imagine yourself in a car travelling 45 miles per hour," one infers a peak plate speed of 45 mph, or 20 m/s. Just how much mechanical work can this much kinetic energy accomplish? Very little. Specific kinetic energy, in terms of energy per unit mass, is given by

$0.5v^2$, where v is the speed. For a speed of 20 m/s, the specific kinetic energy is $0.5 \times 20^2 = 200$ J/kg. This is energy resident in every parcel of rock in the moving plate.

How much energy is needed to deform the layer so as to double its thickness? Let us utilize what is known as Byerlee's law to estimate the stresses involved. This law is a formula Byerlee obtained from experimental investigation that gives the stress conditions in the earth's crust at which fracturing along a geological fault takes place (for slightly more detail, see Wikipedia's article on "Byerlee's law"). Byerlee found that in the upper crust, the fracture criterion can be simplified to $\tau = 0.85\sigma_n$ for normal stresses up to 200 MPa and $\tau = 50 + 0.6\sigma_n$ for normal stresses higher than 200 MPa, where τ is the failure stress and σ_n is the normal stress, with both measured in MPa. A hydrostatic pressure of 200 MPa correspond to a depth of 7.4 km when the crustal density is 2700 kg/m^3. In our case we want to estimate the level of shear stress required in compressing a layer of granitic crust originally 16 km thick to a final thickness of 32 km. Since we are mostly i the hydrostatic pressure range greater than 200 MPa (in other words at depths exceeding 7.4 km), for simplicity let apply the formula $\tau = 50 + 0.6\sigma_n$ everywhere.

A useful approach to applying Byerlee's law is to average the normal stress σ_n (which we take to be equal to hydrostatic pressure) both in space and time. In the initial layer, σ_n at mid-depth in the layer, given by ρgd, where ρ is crustal density (2700 kg/m^3), g is gravitational acceleration (10 m/s^2), and d is depth (8000 m), is 216 MPa. When the layer is compressed to twice its original thickness, σ_n at mid-depth is twice as large, or 432 MPa. Averaged over time, the mean value of normal stress σ_n in the layer is 324 MPa. The mean shear stress τ, given by $\tau = 50 + 0.6\sigma_n$, then is 244 MPa. To convert this value of mean shear stress, which corresponds to work per unit volume done in compressing the layer, we simply divide by density to obtain $(244 \times 10^6$ J/m$^3)/(2700$ kg/m$^3) = 90400$ J/kg. This is some 450 times more energy that the kinetic energy available in a slab moving at 45 mph or 20 m/s, which we found above to be only 200 J/kg. This is not at all surprising, since deforming rock on this scale involves large forces and huge amounts of mechanical work. Thus, hydroplate theory seems to offer no obvious source of energy capable of compressing the original layer of granitic crust to twice its original thickness. This, of course, is a huge issue.

Yet there is an equally if not more serious issue, a geometrical one. Since in Brown's scenario, the hydroplates, comprised of granitic rock, are sliding perpendicularly away from what today we refer to as an oceanic ridge, the volume of rock available for thickening the continent is restricted to the area between the ridge and the final trailing edge location of the thickened continent, multiplied by the original crustal thickness. Even a cursory glimpse of a map reveals the huge mismatches that result in this sort of crustal thickening scenario. So, not only is there no conceivable way from a geometrical standpoint to double crustal thickness in the present continents by moving crustal material in a perpendicular direction from a nearby mid-ocean ridge, but there is also no obvious energy source to allow it to happen.

What about actual physical observational evidence for compressional thickening of the continental platforms? Brown gives the impression that a 'train wreck' style of horizontal compression, which he argues must be responsible for the folding of the Canadian Rockies as shown in Figure 48 on page 112 of *ITB*, must *also* be responsible for increasing crustal thickness in the continent interiors—from 16 km to approximately 40 km—in regions where there are no mountain belts. Brown uses two exposures of the continental basement rocks, one in Black Canyon near Gunnison, Colorado, and the other from the inner gorge of the Grand Canyon in Arizona, shown in Figures 64 and 65 on pages 126 and 127 in *ITB*, to justify his contention that the deformations evident in these rocks occurred during the Flood.

But there is a major problem with this interpretation—even within the hydroplate framework. In hydroplate theory, as outlined on pages 120-127, the 'Flood Phase' occurs <u>*before*</u> the 'Continental-Drift Phase'. The fossil-bearing sediments are formed during the 'Flood Phase', while the abrupt hydroplate deceleration and crustal thickening occurs at the end o the 'Continental-Drift Phase'. As is so apparent in the Grand Canyon itself, and evident in Figure 65, the horizontally-bedded, fossil-bearing sedimentary layers that lie immediately above the crystalline rocks of the inner gorge have *not* experienced any dramatic horizontal shortening or chaotic deformation. If the crystalline basement rocks were compressed horizontally by a factor of at least two, in a 'train wreck' manner after the sedimentary rocks were in place,

surely one would be able also to find evidence in these overlying sedimentary rocks of this same chaotic deformational process. But such chaotic deformation of sediments is systematically absent in all the continental platform regions of the world. Another important indicator that the hydroplate picture is not valid involves the radioisotope dates from these continental basement rocks which, interpreted in a relative sense, show that the rocks themselves, including the younger magmas which have intruded them, were in place *before* the Flood and must have been formed as part of God's creation of the original earth.

In short, Brown's hypothesis for the structure of the uppermost 100 km of the pre-Flood earth is not a viable hypothesis. There is no conceivable way to reconfigure a uniform layer of granitic crustal rock 10 km thick (using Brown's original number) covering the entire earth into its present distribution in the continental cratons. The reality is that continental shield and platform areas display little indication of any significant internal deformation during that interval of geological history associated with the Flood.

Philip Budd's model for the Flood, which like Brown's has no pre-Flood lithosphere, takes a much different approach. It posits that the granite of the present continents formed deep within the mantle and during the antediluvian era rose as 'hypomagma' to the earth's surface, ponding beneath a thin primordial crust beneath regions approximated by the present continents. According to the Budd hypothesis, the 'collapse' of and loss of 'volatiles' from this 'vuggy' hypomagma layer continued progressively 'during the post-Flood millennium'. Accordingly, the continental crust and lithosphere as we know it today did not exist until at least a millennium *after* the Flood. Even more astonishing to me, Budd's hypothesis is that essentially the entire fossil record, along with all the accompanying geologic and tectonic change recorded in that portion of the rock record, belongs to the post-Flood era, largely during the millennium *after* the main Flood cataclysm.

I consider such a scenario to be so strange and in conflict with so many readily available observations that I am at a loss to know where to begin in an evaluation. Certainly this scenario does not square with what seismology tells us about the state and structure of the mantle today, because if so much of it was molten in the recent past, presumably much of it ought to be today also, but it is not. It does not square with the structure of the modern seafloor, with its spreading ridges, its fracture zones, its trenches, its overall topography, its heat flow pattern, and its sediment distribution. It does not square with what is known about the crystalline basement of the continents, including its mineralogy and its distribution of radioisotope daughter products, including helium retaining zircons. In my assessment, Budd does not provide convincing justification for the pre-Flood state of the earth he is proposing. return_to_Contents

72. In your response to question 30 (Q30), you stated: "The case is strong that melting of these subducted sediments generated the staggering volume of granitic magma that was emplaced along the western margin of North, Central, and South America during the Flood."

You also claimed that the majority of creation scientists would agree with you on this matter, to which I must object. In fact, I know that three of the present forum authors, and many of our honorable panelists besides myself would disagree strongly in that granite *cannot form from a melt.* Ollier and Pain would also contend that the composition of the Sierra Nevada batholiths isn't even remotely close to the sediments it was supposed to have been formed from – and they're right: For example, where do the carbonates fit into this picture of granites forming from molten sediments?

There are many good, physical reasons for why granite cannot form from a melt, and the weight of the evidence would be on our side, as granite has never been formed in the lab, nor has it ever been observed to form in the best laboratory around: nature. The onus would be upon yourself and anyone who make such claims to explain and demonstrate how granite can form from a melt. I will go so far as to say that granite forming from a melt must defy physical laws. In order to get the large crystals of granite, the minerals must cool slowly – yet letting the minerals cool slowly means the minerals will separate out by density – and thus you would not get granite.

Response: You certainly seem passionate about this topic. But frankly, I find myself utterly bewildered by your outlook. It would be helpful if I could chat with you regarding these issues. It seems that you have not been keeping up with the creationist thinking on the formation of granite that has been published over the last 10-15 years. Let me point you, for example, to the 2003 article by Tas Walker entitled, "Granite grain size: not a problem for the rapid cooling of plutons," TJ 17(2), 49-55 (http://creation.com/images/pdfs/tj/j17_2/j17_2_49-55.pdf). Let me quote from one section that deals crystal growth rates and crystal size in granitic melts, based primarily on laboratory experiments.

> The science of crystallization has been developing apace because crystallization is widely used in the chemical industry, metallurgy and ceramics and so is of enormous economic importance. Today many books are available on the scientific understanding of the process.[27,28] The size of crystals depends on two factors: the rate of crystal nucleation and the rate of crystal growth. Our present understanding of both these factors is still in its infancy. If the physical and chemical conditions are such that the rate of crystal nucleation is high and the rate of crystal growth is low, then the product will have abundant fine-grained crystals (Figure 6a). To produce large crystals, as occur in granite, the rate of nucleation needs to be low, and the rate of growth high (Figure 6b). Such a situation would be produced if the physical and chemical conditions changed rapidly, not providing time for nucleation to occur but allowing for crystal growth.

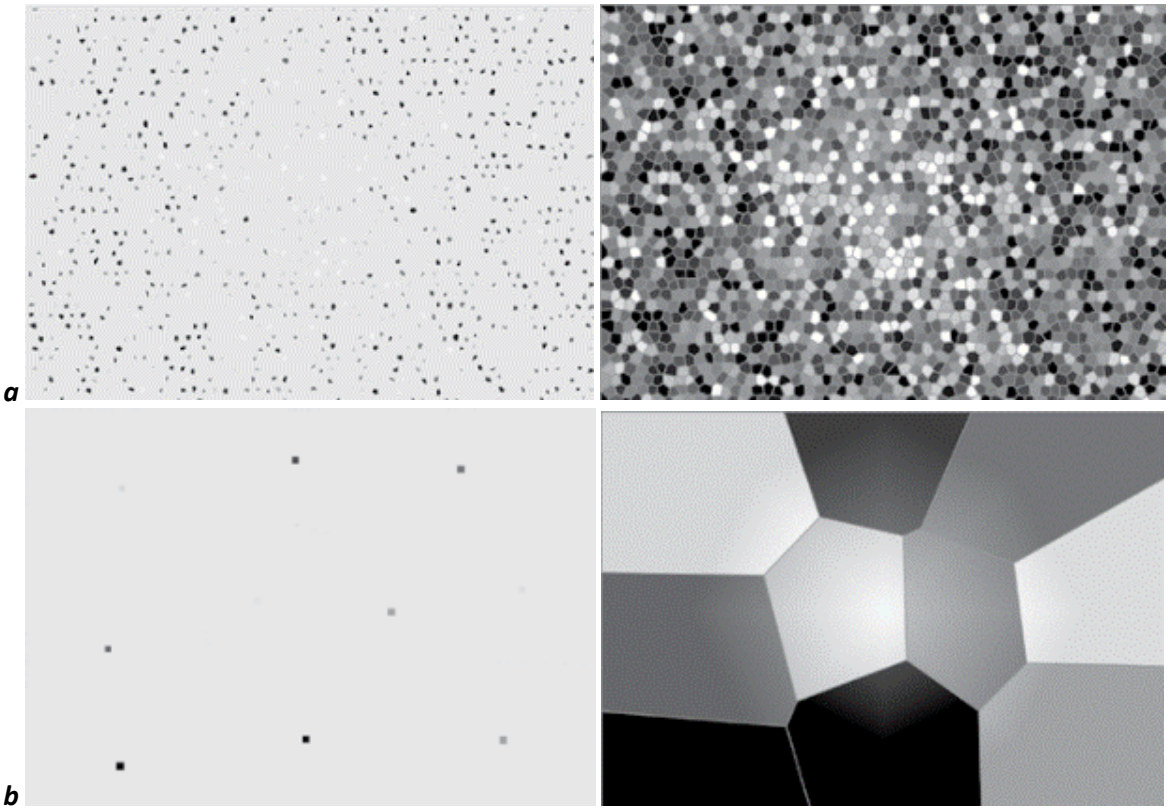


Figure 6. (a) High nucleation rate and low crystal growth rate creates a product with a fine grained texture. (b) Low nucleation rate and high growth rate generates a coarse grained product.

> One laboratory study by Swanson determined that crystal-growth rates could reach several millimeters per day within polyphase granitic systems.[29] With such growth rates he concluded that granite could be produced rapidly. Swanson found that maximum growth rates of crystals are lower in systems which contain a H_2O-rich vapor phase and higher in systems that are undersaturated with H_2O. This means that a sudden loss of volatiles within a magma

chamber would lead to rapid crystal growth. Swanson's work demonstrates that long periods of time are not necessary to produce the coarse-grained granitic textures. Another factor is the degree of undercooling, that is, the extent to which the temperature of the melt is lower than the crystallization temperature. Under conditions of low undercooling, a relatively small number of large crystals could be grown in a few days. The degree of undercooling within a magma chamber would depend on magma chamber pressure and magma volatile content, both of which could be changed quickly by the tectonic processes associated with the Flood. It is worth noting that this work by Swanson has already been discussed in the context of rapid cooling of granite by Snelling and Woodmorappe.[6]

Another laboratory study[30] on silicate melts found crystal growth starts at nucleation sites already present before the magma cools. This produces granitic textures much faster than previously thought.

Crystallization theory and practice reveals other clues that point to granite crystals having grown rapidly. First, when crystals grow rapidly they trap some of the surrounding liquid, forming fluid inclusions inside them.[31] In many industrial applications it is important to grow crystals sufficiently slowly so they do not have inclusions. But mineral crystals in granite contain fluid inclusions, indicating they grew quickly, not slowly over millions of years.

This article makes a number of relevant points. First of all, granitic rocks have indeed been produced from melts in the laboratory by many different investigators over the past 35 years, with no physical laws being violated in the process. Th article also emphasizes that grain size does *not* depend primarily on the cooling rate. Other factors such as the nucleatio rate, volatile content, and abrupt pressure changes can play a much larger role than the cooling rate. Crystal growth rates as high as *several millimeters per day* have been demonstrated in the laboratory. Under conditions of rapid intrusio of magma and rapid crystallization after intrusion, negligible settling of the crystals takes place. The article also alludes t the vast number of intrusive granitic bodies, in many cases, intruding into *fossiliferous Flood sediments* that are exposed and readily available for study at many sites around the world. In other words there are literally thousands of field examples of granite bodies that have intruded near-surface rocks as melt and solidified with a coarse-grained crystalline fabric in nature's (or perhaps more appropriately God's) laboratory.

The Tas Walker article cites a note by J. M. Wampler and P. Wallace in the *Journal of Geoscience Education*, vol. 46, pp. 497-499, 1998 entitled "Misconceptions—a column about errors in geoscience textbooks." These authors state that the common textbook claim that, in igneous rocks, "large crystals form only if they have time to grow slowly," without any further qualification, should be discontinued in view of the large number of exceptions, especially given the fact that coarse-grained igneous rocks frequently give evidence for rapid cooling. They claim this error causes students to misidentify hand specimens, infer the wrong crystallization sequences, and ignore the crucial role of volatiles in rock formation. They attribute the problem to writers of introductory geology textbooks and field guides, and recommend that, in future, writers explain how crystal size depends on many factors other than cooling rate—factors such as nucleation rate, viscosity, original composition of the melt, pressure variation and the amount of volatiles. So this idea that grain size is determined primarily by cooling rate is not only a misconception among some creationists, it is widespread in the uniformitarian community. In fact, defective uniformitarian reasoning is almost certainly how this misconception gained such a foothold in the first place.

Since you mention the granite of the Sierra Nevada, I am curious concerning your thinking as to when and under what circumstances this granite came into existence. Are you aware of careful field studies that have concluded that these granitic rocks from a structural standpoint represent a maze of overlapping horizontal sills, like pancakes, intruded into the surrounding country rock, with each intrusion identifiable from its own distinctive chemical and isotopic signature? Are you aware of the Cretaceous radioisotope ages obtained consistently by many different investigators for these granitic rocks? And are you aware of the work of the RATE team which showed that radioisotope dating, probably in more cases than not, does give generally reliable *relative* ages? The radioisotope dates for the Sierra Nevada granites suggest rather strongly that these rocks were intruded and crystallized during the Flood. This is in addition to the fact

that the surrounding regional geology indicates the country rock into which these intrusive rocks were emplaced corresponds to an incredibly thick sequence of fossiliferous Paleozoic and Mesozoic sediments. On the issue of the fate of subducted carbonates, upon heating calcium carbonate and dolomite readily decompose to CaO, MgO, and CO_2, and CaO and MgO are both readily incorporated into the lattices of most silicate minerals.

In conclusion, I urge you to read the article by Walker carefully, to check out the papers and books he references, and, if i is possible for you, to reconsider this issue of how granites, especially those intruded into Flood sediments, formed. return_to_Contents

73. It seems to me that a major heat problem of both your CPT model and the RATE team's conclusions of accelerated decay, could be resolved simply by removing the highly questionable (many would argue impossible) assumption that granites (and the granite batholiths) formed from a melt. I recognize that there is still the issue of cooling the newly forming ocean lithosphere, but assuming that granites did not form from a melt, would your model (and the RATE team's accelerated decay model) still have a heat problem from radioactivity? How much of a heat problem is dealt with if granites did not form from a melt?

Response: First let me say that I believe the main heat issues in CPT (cooling of the newly forming ocean lithosphere quickly enough) and in the RATE conclusions (not vaporizing the continental crust by the heat released in the amount of nuclear decay that occurred during the Flood) are entirely separate from the issue of whether or not granites form from a melt. As pointed out in a 1998 paper by Snelling and Woodmorappe entitled "The cooling of thick igneous bodies on a young earth," in the proceedings of the fourth ICC and referenced in the article by Walker I cited in my answer to the preceding question, the volume of water required to cool and crystallize a body of granitic magma does not exceed by that much the volume of the magma body itself. This is because the latent heat of crystallizing the magma is 65 cal/g and its specific heat is only 0.3 cal/g-°C, compared with a latent heat of vaporization of water of 540 cal/g and a specific heat of 1 cal/g-°C for water. So it really does not take that much water to cool even the large batholiths in the world. Moreover, there is no requirement that they cool completely during the year of the Flood. So in my assessment, the cooling of the batholiths is a minor issue compared with these other two.

Let me make a brief comment on your proposal that perhaps the approximately 4 billion years' worth of nuclear decay the RATE team places during the first days of creation week might be spread out over the 1656 years prior to the Flood. That scenario would imply that the level of background radiation from the granitic rocks beneath everyone's feet, on average, would have been $4 \times 10^9/1656 = 2.4 \times 10^6$ times higher than it is today. In my assessment, that would have been devastating to life on earth during that time. The fact that human longevity, according to the genealogy of Genesis 5, did not decrease during that interval between the Fall and the Flood, seems to argue against such extreme levels of radiation in the environment.

Finally, it seems to me that you may be unaware of the breadth of evidence the RATE team used in reaching its conclusio that hundreds of millions of years' worth of nuclear decay at today's rates occurred during the Flood itself. You mention the radiohalos, but not our fission track work. The fission track study utilized zircons extracted from volcanic tuff beds in Flood-aged rocks from the Colorado Plateau. Fission tracks are annealed away at high temperatures and do not begin to persist until the volcanic material cools to below the annealing temperature. So the tracks in the tuff beds that exist today in Flood-aged sediments cannot have been inherited from pre-Flood rocks.

Also, I'm not sure that you fully appreciate just how much heat would have been released in the rocks of the continental crust if, as the RATE team concluded, roughly 600 million years of nuclear decay at today's rates occurred during the Flood. The heat generation rate from decay of radioactive elements in typical continental crust rock today is about 1×10^{-9} W/kg (F. Stacey, *Physics of the Earth, 2nd ed.*, 1977, p. 186; R. Rudnick and D. Fountain, "Nature and composition of the continental crust: a lower crustal perspective," *Rev. Geophys., 33*, 267-309, 1995). Six hundred million years' worth of

heat generation at this rate corresponds to 1 x10^{-9} J/s-kg x 3.15 x 10^7 s/yr x 6 x10^8 yr = 2 x 10^7 J/kg. The amount of heat energy needed to raise the temperature of granite from room temperature to its melting point plus the latent heat of fusion to melt it is about 900°C x 800 J/kg-°C + 300 J/kg = 1 x 10^6 J/kg. Hence, the amount of heat released is approximately twenty times the amount that is required to melt granite, and it is about four times what it takes to vaporize granite. This is why the RATE team concluded that, just as supernatural action on God's part is required to increase nuclear decay rates roughly a billion-fold during the Flood, so also is His supernatural action needed to remove the staggering amount of heat that is released in the rocks of the continental crust. Again, the amount of heat involved is enough to vaporize the entire 40-km thickness of continental crust some four times over. return_to_Contents

74. Cliff Ollier and Colin Pain, certainly world authorities on the origin of mountains, threw down the gauntlet regarding plate tectonics, bringing up dozens of major problems with plate tectonics theory. In fact a major thrust on page 323 of their exhaustive book, *The Origin of Mountains,* Routledge, London, 2000, is that mountain formation just simply *does not* fit with the plate tectonics theory. I do realize that some of these points may not apply to CPT, but many do. I bring the whole list and invite your commentary though, as I'm sure I won't be the first or the last to bring up these points. Then your response can be on record as well, and you can even clarify what applies, and what does not apply to your model.

Response: I will insert my responses following each individual difficulty/ objection below.

Difficulties with and objections to plate tectonics:

a. The total length of spreading sites is three times longer than that of subduction sites.

Response: This claim is simply not true. One can refer to their map of plate boundaries in Figure 1.7 and observe by eye that the total length of spreading ridges shown in their map is close to being equal to the total length of the zones of plate convergence also shown in the map (which includes convergence in the Himalayas, south of the Zagros Mountains, through Turkey, and in the Mediterranean Sea. As I pointed out in my response to question 15 (Q15), detailed estimate of plate convergence and divergence is provided in a 2003 paper by Peter Bird entitled "An updated digital model of plate boundaries," Geochem., Geophys, Geosys., 4(3) and posted at http://peterbird.name/publications/2003_PB2002/2001GC000252.pdf. Below is a table that summarizes the results.

The total length of convergent boundaries is 91,762 km, while the total length of divergent boundaries is 94,810. If we neglect the continental convergent and rift boundaries and consider only convergent and divergent boundaries in the ocean basins, the total length of subduction zones and other convergent segments is 68,759 km, while the total length of oceanic ridges is 67,338 km, again very similar. The current rate of area increase along the oceanic ridges is 0.095 m^2/s is very close to the current rate of area loss along convergent boundaries in the oceans, 0.094 m^2/s. While there is no logical or geometrical requirement for the total lengths of convergent and divergent boundaries to be identical, they are amazingly similar.

Table: Collective Properties of Plate Boundaries by Class

Class	Total length (km)	Mean velocity (mm/yr)	Area production (m^2/s)
Continental Convergent	23,003	26.2	-0.013616 (-12.6%)
Continental Transform	26,132	24.7	-0.000599 (-0.5%)
Continental Rift	27,472	17.6	+0.011502 (+10.7%)
Oceanic Ridge	67,338	46.6	+0.095348 (+88.4%)

Oceanic Transform	47,783	40.5	+0.001022 (+1.0%)
Oceanic Convergent	17,449	17.6	-0.007141 (-6.7%)
Subduction Zone	51,310	62.3	-0.086516 (-80.1%)
Totals	260,487	39.6	0

b. Plate tectonic theory does not explain why subduction is located almost entirely around the Pacific, while spreading is present in all oceans.

Response: Actually, the explanation is simple. It is that most of the recent plate motion history is associated with the breakup of the Pangean supercontinent and the opening of the present day Atlantic and Indian Oceans. This plate motio history can be inferred from, among other types of observational data, the patterns of mid-ocean ridges and fracture zones and radioisotope dates of the ocean floor basalts from the world's seafloors.

c. The spreading sites are not static, but move away from continents. The circum-Antarctic spreading site is the best example. It was once just bounding Antarctica, but has moved away in all directions to its present position. Spreading is also symmetrical around most of Africa. As it moved towards the equator, the circum-Antarctic ridge also grew longer. Plate tectonics has not provided any mechanism for spreading sites to grow longer. As a geometric consequence of the mobility of spreading sites, subduction sites are also mobile.

Response: That is correct—a spreading ridge generally does not remain in a fixed location but tends to move with the *average velocity of the two plates* between which it lies. In so doing, seafloor spreading is very close to symmetrical across the ridge, and ridge location coincides with the line of zero plate thickness. In the case of Antarctica, the African plate, Australian plate, and Pacific plate have all migrated in northward directions, away from Antarctica. The mid-ocean ridges which lie between Antarctica and these other plates have therefore all migrated away from Antarctica. The ridge migration velocity is very close to one-half the separation velocity of these other plates relative to Antarctica. It is also true that subduction zones migrate.

d. The North America plate rides indiscriminately over the North Pacific (and other) plates with no regard to spreading sites, plate margins, or transform faults.

Response: Again, that is true. What is known as the Farallon Plate, an oceanic plate which once spanned much of the oceanic region west of North America, has been almost entire subducted beneath it. Only small remnants of it still exist at the earth's surface today. These include the tiny Juan de Fuca plate off the coasts of Washington and Oregon and the Cocos plate off the Pacific coasts of Mexico and Central America. Indeed, North America did migrate westward and did override most of this plate as well as most of the spreading ridge that lay between it and the Pacific plate. Seismic methods are now able to image much of the portions of this plate that still reside beneath North America. What were the forces driving this remarkable behavior? In short, it was primarily the negative buoyancy of this plate but in the context of the other catastrophic forces that were unleashed during the Flood cataclysm.

e. The chemical and petrological work allegedly achieved by subduction is quite remarkable. Subduction sediments are presumed to mix, melt and contaminate basalt to produce granite batholiths and andesitic magmas that are common in collision sites (andesite and granite do not have the same composition). The proportions added from various sources should be quite variable, and the possibilities of reaction numerous.

Response: Again, that is true. In the framework of catastrophic plate tectonics a much larger fraction of sediment that finds its way to a subduction zone gets entrained by the downgoing plate and is carried to depths where it comes into contact with extremely hot mantle wedge rock beneath the overriding plate. In this environment it readily melts, with the resulting sialic magma together with water also carried down in the subduction process rising through the mantle

wedge and penetrating upward into the overriding plate. The water tends to lower the melting points of minerals in the mantle wedge rock, and consequent partial melting generally produces varying amounts of basaltic magma. However, these two types of magma do not tend to mix very well and tend to result in separate magmatic expressions as they penetrate toward the surface.

f. After subduction, the descending slab is supposed to return to the mid-ocean ridge as part of the convection cell. Mid-Ocean Ridge Basalt (MORB) has a very consistent and rather odd composition. How can MORB, with such a complicated history, be so uniform in composition? Also eruptions at the mid-ocean ridge erupt helium, which is so light that it escapes from the Earth and is not recycled, and juvenile (new) water.

Response: No, seismic evidence is compelling that subducted slabs eventually penetrate into the lower mantle and sink to the bottom and so their graveyard is at the bottom of the mantle and not in the upper mantle. The chemical composition of MORB shows it to be strongly depleted in the elements that appear to be concentrated in the granitic rocks of the continental crust. Because of this complementary chemistry of the upper mantle relative to the continental crust, one might speculate that, in the processes God used in fashioning the earth in the very brief period of Day 1 and Day 2 of Creation Week, He may well have melted the upper portion of the earth's mantle to extract and form the continental crust. But regardless of how this chemistry came to be, the distinctive chemistry is genuine. Seafloor spreading simply taps this reservoir of depleted upper mantle rock which seems to be remarkably uniform in its chemical composition. There is no major issue here relative to plate tectonics, catastrophic or otherwise.

g. Most of the world's great rivers drain to passive margins and most sediment is deposited there (Potter, 1978). How do sediments deposited on passive margins ever get back into the rock cycle or the plate tectonic cycle?

Response: The reason most (but certainly not all) major rivers drain to passive margins is that active margins, such as the west coasts of South and Central America, often contain uplifted mountain belts. Especially when prevailing winds bring moisture dominantly from the passive margin side of one of these mountain belts, it is natural for the rivers draining these regions to flow to the passive margin. If one views earth history as spanning some 4.6 billion years, this might be somewhat of an issue. However, in the reliable summary of earth history that God has provided in Scripture—a summary that indicates that earth structure was largely determined at creation and then modified somewhat during a catastrophic year-long Flood only a few thousand years ago—there is no real need to think in terms of rock cycles or plate tectonic cycles.

h. Island arcs in the western Pacific are explained as the result of subduction of the Pacific plate. The collision might be expected to cause compression, but instead of compression we find further seafloor spreading on the other side of the arc, the back-arc basin. 'Subduction roll-over' is the special pleading in this case, but it is hard to apply in three dimensions.

Response: The term 'subduction roll-over' is not a standard term in the geosciences. However, there is a term that is commonly applied in this context, which is 'trench rollback' (or sometimes 'hinge rollback'). Trench (or hinge) rollback tends to occur for a very simple geometrical/physical reason. The reason is that gravity acts in a *vertical* direction on the subducting plate as it bends along the hinge line and plunges into the mantle at a trench. Not only is there the 'slab pull' force acting in the direction in which the slab is moving, but there is also locally the downward force of gravity, a component of which is *not* in the plane of the downgoing slab. It is this vertical component of force that has the tendency to cause the hinge line to migrate backwards, in the direction away from the trench. Trench rollback, in turn, leads to what is called 'back-arc spreading', which corresponds to extension and plate failure and even a new line of seafloor spreading behind the volcanic arc that results from magma production at depth due to water being carried down on the subducting plate. This is a common and observable phenomenon, especially when one oceanic plate subducts beneath another, as occurs in many settings in the western Pacific.

i. Subduction at an island arc. Island arcs are conical surfaces intersecting the Earth's surface. If the direction of plate movement is constant, as seems to be the case, how can it give rise to a conical surface? Alternatively, if the subduction i perpendicular to the arc, as suggested by most cross-sections, all the subducted streams must be meeting at the point of the cone, which gives a space problem as material piles up. But we do not find uplift in such places, but more sea-floor spreading.

Response: This objection is not well worded. This issue is discussed in an article by Brian Bayly entitled "Geometry of subducted plates and island arcs viewed as a buckling problem," *Geology* 10(12), 629-632, 1982. Bayly describes the problem and its consequences in his abstract as follows:

> During subduction, a plate's leading edge is forced to squeeze into a smaller total width than it occupied at the surface, yet the plate resists change of dimension in its own plane. A possible outcome is that the plate buckles as it descends… Before being subducted a lithosphere plate is convex upward at all points, whereas, to buckle, it must become convex downward in a series of plunging synclines.

In many studies undertaken during the almost 30 years since this paper, there is abundant documentation that slabs indeed to in fact deform in dramatic ways after they subduct, including tearing.

j. Subduction around curved mountain ranges. Subduction is invoked to explain curved mountain ranges such as the Apennines and the Carpathians. But if subduction is perpendicular to the mountain range, the subducted slabs must be converging at some place within the arc, which should cause accumulation of material and presumably uplift, but this area is always a relative lowland.

Response: The geology and tectonics of that part of Europe is extremely complex. Here is the abstract of a paper reporting work to try to resolve some of these issues by C. Chiarabba, P. De Gori**,** and F. Speranza entitled "The southern Tyrrhenian subduction zone: Deep geometry, magmatism and Plio-Pleistocene evolution," *Earth and Planetary Science Letters 268*, 408-423, 2008.

> We report on a high-resolution V_p, V_p/V_s and Q_p model of the southern Tyrrhenian subduction zone, obtained by the inversion of P- and S-wave arrival times and t^* values from intraslab seismicity. The arcuate shape of the southern Apennines–Calabrian arc-Sicilian Maghrebides is perfectly mirrored by two rather continuous low and high V_p bands lying beneath the belt system at ca. 25 and 100 km, respectively. Between 100 and 300 km, two independent high V_p slabs lie beneath the Neapolitan region and the southern Tyrrhenian Sea, separated by unperturbed mantle. We suggest that the ca. 150 km-wide slab window beneath the southern Apennines opened after a tear occurring within a composite subduction system, formed by the Apulian continental lithosphere and the Ionian oceanic slab. The abrupt slab rupture induced ultrafast southeastward retreat of the Ionian slab, and the 19 cm/yr spreading of the back-arc oceanic Marsili basin between ca. 2.1 and 1.6 Ma ago. The 25 km low V_p zone beneath the arc denotes continental upper crustal rocks below the chain. Its striking continuity requires a unique orogenic wedge at 25 km depth below the southern Apennines, the Calabrian arc, and the Sicilian Maghrebides. The alternative explanation would imply the ubiquitous occurrence of autochthonous lower plate rocks at 25 km depth, i.e. a puzzling autochthonous continental Calabria. The Ionian slab beneath Calabria shows high V_p, high Q_p and low V_p/V_s anomalies, typical of old oceanic lithosphere. Intermediate depth seismicity is concentrated within its thin oceanic crust, suggesting the occurrence of vigorous metamorphism. The slab dehydration promotes the melting of the overlying mantle, as testified by high V_p/V_s and low Q_p anomalies between the slab and the Aeolian magmatic arc

Part of the basic message here is that careful seismic work looking at the seismic velocity structure in the upper mantle beneath this region reveals the presence of two slabs of mature oceanic lithosphere separated by what the authors infer

to be a tear in the original ocean plate. This work implies that subduction was indeed involved and that the dynamics were dramatic.

k. A rock mass cannot move simultaneously in opposite directions. But the Po Plain appears to be subducted under both the Southern Alps to the north, and the northern Apennines to the south. The Pelvoux Massif appears to be subducted to the north, south and west.

Response: Again, the tectonic processes responsible for this region were so complex that researchers have as yet hardly scratched the surface in identifying all the important pieces of the puzzle, much less putting the pieces together in a correct manner.

l. If subduction is the cause of mountain building, why did mountain uplift occur mainly in the last 5 million years, while subduction is supposedly a continuous process that worked over the past 50 to 200 Ma in different parts of the world?

Response**:** Please read my March 2005 ICR Impact article entitled "Recent rapid uplift of today's mountains," (http://www.logosresearchassociates.org/Documents/Baumgardner/Rapid-Uplift-of-Today's-Mountains.pdf) where I describe much of Ollier and Pain's evidence in a very favorable way and also provide the obvious answer to their dilemma expressed here. That obvious answer is that the 50-200 million years they believe in is an illusion! On the other hand, if this tectonic work occurred, not over tens or hundreds of millions of years, but only within a few weeks' time just a few thousand years ago, the uplift of the mountains during the decades to centuries following this cataclysm corresponds to the reasonable amount of time for isostatic rebound to occur. In other words, in the CPT framework the isostatic response time, instead of being tens of millions of years or more as in the uniformitarian framework, is now plausible, and the puzzle pieces fit together.

To reiterate, the problem of why there was 50-200 million years delay between the time subduction processes dramatically increased crustal thickness in the tectonic belts around the earth and the time when isostatic adjustment kicked in to uplift the mountains in these belts is a *non-problem* if all the subduction occurred as part of a year-long cataclysm and the uplift followed in the century or two following. The problem is the assumption these authors have adopted that the uniformitarian/radioisotope time scale is true, when it is not. To me the evidence these authors have assembled supporting the recent uplift of all the major young mountain belts in the world is some of the clearest available that the uniformitarian time scale is wrong.

m. Subduction fails to explain where there is a period of still-stand, when land was extensively planated before the period of mountain uplift on a global scale.

Response**:** Again, in the framework of CPT and the Flood, the answer is obvious. The planation is caused by the waters of the Flood, most likely, by the waters retreating rapidly from the flooded continents, before isostatic adjustment has had time to uplift the mountains.

n. The symmetry of many mountain ranges, discussed in the last section, presents a further problem. Some advocates of subduction have the same process of subduction causing underthrust on the near side and overthrust on the distal side, with remarkably similar results. Others subduct Brazil, Russia or other continental masses - which is a huge leap from subduction as originally conceived, and for which there is scant evidence.

Response: Ollier and Pain seem to be only vaguely aware that the primary way in which subduction generates continental mountain ranges is by adding buoyant rock from below to increase the overall crustal thickness. Isostasy then operates to uplift the resulting zones of thickened crust. This process often, if not most of the time, generates relatively symmetric mountain belts.

o. Stocklin (1989) pointed out that subduction and spreading had to be equal at the same time, and objected to the plate tectonic concept of subduction of the Indian Plate under Tibet because of the lack of geological evidence for the existenc of the vast Late Paleozoic Tethys Ocean supposed to have been available for Mesozoic subduction. He concludes, rather, that the excess of crustal expansion in the Indian Ocean over crustal shortening in the orogenic belt is evidence for expansion of the Earth.

Response: To me the evidence is close to overwhelming for the formation of the Indian Ocean by the process of seafloor spreading, for the collision of the Indian Plate with the continent regions to the north, and for the disappearance of the Tethys Ocean in that process. There is no need to invoke earth expansion.

p. The real problem with subduction is that it can do everything. Plate collision may be invoked 'to explain uplift (making mountains), or subsidence (making deep trenches). It may make folds by compression, but makes backarc basins by tension. The fact that the subduction hypothesis can account for both uplift and subsidence, compression and tension, means that it has too many degrees of freedom. It can account for opposite effects and it is not testable' (Ollier and Pain, 1988).

Response: The physics involved in all these diverse processes is well understood and well tested.

q. Plate tectonics as a general principle has been enormously helpful in many aspects of geology, but its practitioners have neglected the ground surface, and have often been uncritical in their time scales. The geomorphology of mountains and their recent origin make plate tectonics an improbable mechanism for mountain building.

Response: I have already pointed out that the root cause of their confusion is the long uniformitarian time scale which they are assuming. return_to_Contents

75. You continue to employ what seems to me a confusing 'mix' of deep time terms and concepts in your geology and radiometric age explanations with short time language in connection with Biblical history and the Flood. For example, you date the Sierra batholith pluton emplacements during "the Mesozoic, mostly during the Cretaceous." Your use of geologic eras, periods, etc., postulated by their 19th century authors in deep time stretching over tens of millions of years (and defined by fossil content) to date the events of a one year Flood to me seems to be circular, tautological, and also still non-definitive regarding the actual timing of pluton emplacement.

Response: If there were no reliable chronometer available, capable of providing reasonably accurate time correlations for geological formations across the face of the earth, then I would tend to agree with your assessment. In the 19th century when the labels for the geological eras, periods, etc. were coined and assigned, it was indeed the fossil content that guided the correlations. Whether or not these correlations were done correctly and whether or not they were applicable all over the earth are without doubt important issues. However, in the 19th century the absolute amount of time represented by this fossil record was impossible to determine. It was ultimately nothing more than a matter of speculation and guesswork. Certainly, belief in Darwin's ideas of common ancestry and the efficacy of natural selection drove the guesswork about the time scale into the range of hundreds of millions of years.

The discovery of radioactivity in 1896 and the realization that radioactivity offered a means for dating rocks within the decade following radically changed that state of affairs. Suddenly, methods appeared that seemingly provided a means to obtain absolute dates for geological formations, *independent of their fossil content.* Although these methods were restricted to igneous rocks, igneous intrusions and beds of volcanic tuff were/are common enough in sedimentary environments to provide relatively tight age constraints on sedimentary formations. With this development, the chronological correlations based on fossil content could now be *cross-checked* using radioisotope methods that had no

logical connection with fossils. What was found was that the correlations obtained by radioisotope methods matched with a high degree of fidelity the correlations based solely on fossil content. What in general that did *not* match were the actual ages involved. Those based on 19th century guesswork did not agree that well with those derived from radioisotope methods.

Therefore, if one surveys the various versions of the idealized geological column decade by decade through the 20th century, one finds significant changes in the dates assigned to the various eras, periods, and epochs during the early decades, with the size of the changes becoming relatively small by the end of the century. This trend is mainly the result of the accumulating numbers of radioisotope determinations of igneous intrusive rocks and tuff layers that provided tighter and tighter constraints on the fossil-bearing sedimentary formations. The name designations for the geological eras, periods, and epochs continued to be correlated with their fossil content, but the time scale was now controlled, not by fossil content, but by radioisotope age determinations, whose number has now become quite large.

So is it proper for someone like myself to use the standard designations for the different stages in the geological record, designations originally coined and established in the literature by 19th century geologists who were mostly uniformitarians and Darwinists? Do these designations inherently imply tens and hundreds of millions of years? Are they inherently circular and tautological? Are they therefore worthless in any valid description of what occurred in the year-long Genesis Flood? Let me address these issues in light of the historical background I presented above after I provide some relevant highlights of the Radioisotopes and the Age of the Earth (RATE) project.

The firm conviction on the part of uniformitarians that the earth is some 4.5 billion years old and that multi-celled life forms have existed on our planet for close to 600 million years is based first and foremost on their confidence in radioisotope dating results. This confidence relies, firstly, on many strong lines of evidence that an undeniable record of billions of years' worth of nuclear decay (at presently observed decay rates), is present in the earth's rocks, and, secondly on the assumption that nuclear decay rates have never changed in any significant way since the earth originally formed.

The RATE program was undertaken by scientists like myself who are persuaded from Scripture that God, who cannot lie, has clearly revealed that He created the earth and cosmos from scratch only a few thousands of years ago. The goal of RATE was to uncover the logical flaw in the way in which radioisotope data is commonly interpreted that leads most people to conclude the earth has a multi-billion year long history. Our primary conclusion was that primary flaw is the assumption that either God does not exist at all or if He exists, He has never intervened in any major way in the physical operation of His creation. We noted that the latter error was prophesied by the apostle Peter as one of the (if not the major) deceptions of the last days. Specifically, we concluded that the uniformitarian assumption that nuclear decay rates had been constant since creation was false. The fundamental error is just that simple.

Even more specifically, we concluded that roughly four billion years' worth of nuclear transmutation (at presently measured rates) occurred when God fashioned the physical earth on Days 1 and 2 of Creation Week and possibly also on the early part of Day 3, before He had created any life. We also concluded that roughly 600 million years' worth of nuclear decay took place during the Genesis Flood. We believe it was God who graciously provided us with clear-cut experimental evidence to support these conclusions, which to many continue to be astonishing. For anyone who is not conversant with our research results, I encourage such a person to download the individual chapters of our book, *Radioisotopes and the Age of the Earth: Results of a Young-Earth Creationist Research Initiative*, L. Vardiman, A. A. Snelling, and E. F. Chaffin, eds., ICR/CRS, 2005, from http://www.icr.org/rate2/.

A major secondary conclusion, highly relevant to this discussion, is that radioisotope methods do, on the whole, give reliable *relative* ages for most igneous rocks. This conclusion was based in part on more than a thousand radioisotope analyses the RATE team carefully performed on a large and diverse suite of rock samples utilizing some of the best laboratories in the world. Although we did discover and document some discordance among the various radioisotope

methods, most of this discordance was in crystalline rocks stratigraphically below fossil-bearing sediment layers, rocks presumably formed as part the creation of the earth itself during the early portion of Creation Week. For igneous rocks we infer to have crystallized during the Flood, we found much less discordance.

At a very basic level, the RATE program showed that the amount of nuclear decay, as implied by various *physical* indicators such as fission tracks and radiohalos, which occurred during the interval of time in which the fossiliferous sediment layers were deposited, i.e., during the Flood, equals *several hundred million years' worth* of decay at presently measured decay rates, with little room for uncertainty. There is tangible, visible, physical evidence for this very important conclusion. This evidence is not from just one locality or region, but from many locations around the world. Moreover, we found that the cumulative amount of nuclear decay decreases in a smooth monotonic way from th bottom of the rock record as one goes upward toward the top.

The inescapable conclusion is that nuclear decay processes operated at highly accelerated rates during the Flood cataclysm. Radioactive species in igneous rocks that crystallized early the cataclysm logically experienced larger cumulative amounts of decay than those in rocks which crystallized later. Hence, evidences recorded in rocks that reliably indicate the cumulative amount of nuclear decay which has occurred since each of the rocks crystallized provides a means for reliably determining the order in which the rocks formed. Of course, without a detailed knowledge of the actual time history of the changing decay rates, actual ages for the rocks simply cannot be determined. But relative ages are provided. In other words, the RATE research shows that, with only a few relatively minor caveats, radioisotope datin does provide reliable *relative* dates in many if not most cases. Hence, radioisotope methods can, with logical consistency be usefully applied to unraveling what occurred during the Genesis Flood.

Let me now return to the basic issues at hand, namely, is it proper for someone like myself to use the standard designations for the different stages in the geological record, designations originally coined and established in the literature by 19th century geologists who were mostly uniformitarians and Darwinists? Do these designations inherently imply tens and hundreds of millions of years? Are they inherently circular and tautological? Are they therefore worthles in any valid description of what occurred in the year-long Genesis Flood?

First, if there is an independent means for testing the reality of the correlations in the geological record provided by fossi content, then the charge that these correlations are circular and tautological cannot be logically sustained. Radioisotope methods do provide such an independent test, and these methods overwhelmingly confirm the correlations based on fossil content are genuine. Rocks with Cambrian fossil assemblages consistently display the same radioisotope values all over the globe. Similarly, Triassic fossil assemblages consistently display the same radioisotope values on a worldwide scale. So the overall vertical sequence constructed to some degree by piecing the fossil data from different regions together can be and has been confirmed using techniques, namely, radioisotope methods, which are have no logical connections with fossils. So this claim of tautology and circularity is without basis today.

Next, do the designations for geological eras, periods, etc. inherently imply tens and hundreds of millions of years? Certainly, the period designations, Paleozoic, Mesozoic, and Cenozoic are tinged with Darwinist connotations *if* one is disposed to thinking of them with a uniformitarian mindset. On the other hand, if one has a Biblica mindset, the term, 'ancient world', which the apostle Peter uses in 2 Peter 2:5 to refer to the world before the Flood may come to mind. The majority of the life forms one finds as fossils in the Paleozoic rocks are from that 'ancient world' which perished. By contrast, significant numbers of life forms found as fossils in Cenozoic rocks are present in our world today, that is, the 'present earth' Peter mentions in 2 Peter 3:7. Mesozoic rocks contain representatives from both worlds.

More to the point, I would contend that nothing in these designations logically requires them to mean tens or millions of years. While they generally bear such connotations to a uniformitarian, it is his/her uniformitarian mindset that lends

such time associations to those terms. Recognizing that radioisotope methods independently verify that vertical fossil successions which correlate laterally in a global manner are real, many creationists like myself apply these terms to the specific well-defined portions of the geological record with which they have long been associated. However, accepting th Biblical revelation concerning the earth's physical history as reliable, we deliberately reject the logically unnecessary overlay of the uniformitarian time scale. Use of these well-established terms allows us to communicate effectively with one another and also to secular earth scientists who may be doing work which is proving useful to defend the Biblical perspective. Hence, we find it extremely advantageous to use the existing designations instead of seeking to create a parallel but essentially equivalent set of terms. return to Contents

76. In earlier discussions regarding "two separate episodes" of runaway subduction, you seem to imply that you believe runaway subduction was largely decoupled from the episodes of accelerated nuclear decay. Yet you hold that the latter of the two episodes of rapid nuclear decay occurred during the Flood. Please elaborate on what the connection there may have been between accelerated nuclear decay and other aspects of the Flood?

Response: As I have insisted on several occasions, especially in response to one of the panelists, I have never—ever—proposed or implied "two separate episodes" of runaway subduction. This is an idea that somehow arose in the mind of this panelist in spite of all my efforts to dispel it. Again, let me emphasize as emphatically as I can—in order to satisfy the tight time constraints of 40 days or even 150 days for the large-scale tectonic changes of the Flood to unfold—the mantle must be approximately *a billion times* weaker than it is today. Such dramatic weakening can occur, as far as I can determine, only under the runaway conditions of CPT. Two such CPT episodes, distinguishable from one another, within such a brief time window are for me simply unthinkable. Therefore, I have never even entertained that possibility in my own mind, much less speculated to anyone else that two separate episodes might have occurred.

Furthermore, never have I or any of the other members of the RATE team ever suggested *or even hinted* that there were or might have been two episodes of accelerated nuclear decay *during the Flood*. The first of the two episodes of accelerated nuclear decay we describe occurs—not during the Flood—but during the early portion of Creation Week, before God had created any life on the earth. This first episode accounts for up to as much as roughly 3.7 billion years' worth (at presently observed rates) of nuclear decay products in the earth's pre-Flood rocks. This decay history is nearly indisputable and tends to be especially evident in zircon crystals.

The RATE research also provides compelling evidence for another, a second, episode of accelerated nuclear decay, but this time during the Flood, correlated in time with the deposition of the world's fossil-bearing sediments. Among the lines of evidence for up to about 600 million years' worth of nuclear decay (at presently observed rates) during the Flood cataclysm, are the presence of abundant radiohalos, both from uranium and polonium, as well as high concentrations of fission tracks in crystals in volcanic tuffs and in granitic rocks which crystallized from melts during the cataclysm. These two phenomena, radiohalos and fission tracks, represent tangible, visible—essentially indisputable—physical evidence that vast amounts of nuclear decay occurred during the Flood. Again, based on the record of earth history provided by God in the Scriptures, this episode of rapid nuclear decay must be distinct from the episode that took place as God was forming the earth at the beginning of Creation Week.

What might be the connection between this second episode of accelerated nuclear decay and the spectacular tectonic aspects of the Flood? I do not at this point have a good answer to that question. God's direct intervention seems to be required, without much room for uncertainty, to cause nuclear decay rates to be roughly a billion times higher than they are today during that episode and also to remove the staggering amount of heat released, especially within the continental crust which contains such high concentrations of radioactive elements. CPT primarily involves the rocks in the mantle which contain much smaller quantities of these heat-producing elements. Although it is entirely possible that there could be cause-and-effect connections between the accelerated decay and CPT, just what they might be are not clear to me at this point. The single connection I think might be a good possibility is that the mechanism responsible for

the rapid removal of the radiogenic heat from accelerated decay might also be responsible for the rapid cooling of new ocean lithosphere formed so quickly as part of CPT. This lithospheric cooling also seems to require God's miraculous intervention to explain. Since Peter in 2 Peter 3:3-7 uses the Flood as one of three examples of God's dramatic supernatural interventions in the natural realm in his refutation of the uniformitarian mindset which Peter is predicting to arise in the last days, I make no apology for pointing to such possible ways that God may have so intervened. return to Contents

77. I am pursuing the idea that prior to the Flood there could have been a somewhat higher density atmosphere, subsequently partially removed by the events of the Flood. If such were the case, could we then surmise that original proportions of atmospheric gases (nitrogen, oxygen, CO_2, argon, etc.) were approximately the same as today, but that thi might not be true for water vapor, as outlined below? With respect to water vapor, please consider and comment on its possible lower pre-flood density and partial pressure and any significant impact on pre-Flood greenhouse effect. Genesis 2:6 identifies the "mist" that "used to rise from the earth and water the whole surface of the ground". Would you concur that this implies only fog or low clouds condensing as dew in reasonably close proximity to the ground? What would the effect on dew point be with say, twice today's atmospheric pressure? With vastly reduced water surface areas of pre-flood lakes, streams and oceans (if any) and hence vastly reduced atmospheric water vapor 'recharging' due to evaporation, what meteorological effects would you then anticipate regarding total pre-Flood atmospheric water vapor content, and in particular, what greenhouse effects? Could it then follow that water vapor's pre-Flood greenhouse effect would be proportionately less than today's?

Response: That the earth's atmospheric regime was different before the Flood compared with that of today seems clear from the plant and animal assemblages we find preserved in the fossil record. Such evidence seem to indicate strongly that the pre-Flood climate supported much more abundant vegetation over a larger fraction of the land surface (and possibly also over part of the sea surface in the form of floating mats of plants) compared with today. Moreover, from the large size of pterosaurs and some insects, there is a hint that the atmospheric pressure may well also have been higher than it is today. So what can we surmise from these clues from the fossil record about the pre-Flood atmospheric regime? I myself try to be cautious in my discussions of such matters. However, it seems almost certain to me that the greenhouse effect was stronger than it is today to allow the climate even at high latitudes to be relatively mild. This increased greenhouse effect relative to today would plausibly result from higher atmospheric levels of CO_2 or water vapor, or more likely both.

On the issue of how the earth was watered before the Flood, to me the simplest way is the way it is today, that is, by rainfall. I believe caution is in order in how one interprets Genesis 2:6. The context of that verse is during Creation Week when "there was no man to till the ground," that is, before God created Adam and Eve. Once God creates Adam, however, the constraints surrounding Genesis 2:6 seem to go away. As far as I can determine, there does not seem to be a compelling case either way from Scripture as to whether or not there was rain during the interval between Adam and Noah. Hence, to me the possibility that the earth was watered primarily by rain before the Flood is a real one.

Moreover, given that a large fraction of the earth's surface was almost certainly covered by ocean water before the Flood, as it is today, plus the fact that the average surface temperature was almost certainly higher, to me implies that the amount of water vapor in the atmosphere prior to the Flood was at least as high as it is currently. If so, this implies that water vapor's *absolute* contribution to the greenhouse effect was at least as large as it is today. However, if before the Flood the total amount of CO_2 in the atmosphere was higher than today, as I suspect it was, then indeed the *fractional* contribution of water vapor to the overall greenhouse effect could conceivably have been smaller. return to Contents

78. Please explain how, as you mention in one of your early papers, the earth "expanded' due to replacement of cold lithosphere with mantle. It seems to me this explanation violates conservation of mass and energy. Lacking any net loss o mass or energy (temperature), it seems to also violate conservation of volume.

Response: I am not sure to which paper you are referring, but I am guessing it is the 1994 joint author paper on CPT. I am also guessing that your question is referring to the process that occurs at a mid-ocean ridge where cooling ocean lithosphere is migrating away from the ridge and hot mantle rock is being drawn up from below to fill the resulting void. There is certainly no net gain or loss of mass in this process, and the earth's total mass is not affected.

However, what can easily be affected is *ocean basin volume*. Because of the principle of isostasy, which is closely related to Archimedes Principle, the height of the ocean bottom is dependent of the temperature distribution in the rock beneath it. When the average rock temperature is higher, the average rock density is lower, the resulting height of the rock column to satisfy isostasy is greater, and hence the depth of ocean water above that column is smaller. On the othe hand, if the average temperature is lower, the average rock density is then higher, the resulting height of the rock colum needed to satisfy isostasy is smaller, and the depth of ocean water above the rock column is greater. This implies that, averaged over an entire ocean basin, the average water depth is less if the average temperature of the rock beneath the ocean bottom is higher, and vice versa.

In the case of CPT, if prior to the onset of CPT the ocean lithosphere is relatively cold, then the average depth of the ocean basin will be deeper compared with the later state of affairs after much of the cold ocean lithosphere has subducted and has been replaced, in effect, with warmer rock that has risen from the mantle below beneath a spreading ridge. In other words, if the average temperature of the top 100 km of rock beneath an ocean basin increases, the volume of that ocean basin will decrease relative to some fixed reference condition. The physics involved is, first, the fact that rock density depends on temperature, with the volume coefficient of thermal expansion being about 3×10^{-5}/°C and second, the principle that, above some reference depth where rock can readily deform and flow, all columns of rock (plus any water that may reside on top) have equal weight.

Therefore, the 'expansion' to which you seem to be referring has to do with *thermal expansion* as rock temperature is increased. Also note that the expansion of the ocean floor rock, which likely occurred while CPT was occurring and caused sea level rise, also likely changed to *contraction* as CPT shut down and the ocean lithosphere cooled, with the result of sea level decline. Because rock volume so indisputably depends on temperature, there is no principle requiring "conservation of volume." return_to_Contents

79. To what extent is your computational model(s) understood, shared and used with other research scientists? To what extent is it exclusive to you the author? Has the computational model ever been independently peer reviewed or validated? If so, how, and what are the references?

Response: I developed the 3D finite element program now known as TERRA as part of my Ph.D. research at UCLA in 1981 I collaborated closely with a mathematician, Dr. Paul Frederickson, at Los Alamos National Laboratory in the formulation and implementation of the innovative numerical techniques utilized in this program. My Ph.D. thesis included an extensive suite of tests using cases with exact analytical solutions to validate the correctness of the various aspects of the numerical formulation. The thesis and the work it described had to pass the critical scrutiny of the scientists who comprised my thesis committee. Since then five graduate students have upgraded and applied TERRA as the main focus of their Ph.D. research efforts. The TERRA program is still currently in use by several research groups around the world. In this process it has been checked and validated over the years by a number of different groups and individuals. For a list of the peer-reviewed publications for TERRA and other related programs I have developed and applied see my CV at http://logosresearchassociates.org/team/john-baumgardner/cv/.
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80. Does your model assume rigid "slabs" of cold lithosphere or viscous flow? If rigid, what is the free body diagram you assume for the forces and motions involved? Brown provides such a free body diagram for his assertions and I would like to analyze yours as well. If you assume viscous flow, then could you please similarly provide a free body diagram of the subduction process that pulls the cold lithosphere downward?

Response: My models assume a viscous description of the rock deformations. The viscosity depends on temperature and stress, and rock strength can vary by many orders of magnitude over the computational domain. The numerical codes utilize what is called the finite element method. The computational domain is subdivided into a large number of computational cells or elements. Conservation of mass and conservation of energy is enforced in each of the cells individually. Similarly, all the forces acting individually on each cell are required to balance throughout the computational grid at every time step. So whether one considers a single cell or an arbitrary grouping of cells, a strict balance of all the forces acting upon the volume in question is enforced at every instant in time. These forces include gravitational body force, the forces involved in the viscous deformation of the solid rock, and the forces associated with spatial changes in pressure. So the numerical solutions I have included in my papers represent in a very genuine and literal sense what you are referring to as 'free-body diagrams'. The very essence of the numerical technique I use enforces a balance of forces on every cell at every time step. But this is not trivial. For a TERRA grid with 10 million cells, this means solving 40 million simultaneous equations for 40 million unknowns every time step (three components of force plus pressure for each cell). But computers can do this now relatively routinely.

These methods have been checked and cross-checked by many individuals over many years in many diverse applications. Not only do my programs show, without any room for doubt, that cold lithosphere has a strong tendency to detach from the surface and sink into the deeper mantle, dozens to hundreds of other similar programs also do the same. There is nothing mysterious about the process. Let me just comment in passing that two problems with Walt Brown's simplistic diagrams is that they (a) do not allow for volumetric deformation and (b) do not account for the fact that the region below the plates is at least a thousand (or more likely ten thousand) times weaker than the plate itself.

To reiterate, all the plots I have published showing cold material peeling away from the upper boundary represent just what you are requesting, namely, results based on a continuing precise balancing of all the forces involved, including the forces arising from the volumetric deformation of the solid rock material everywhere in the domain as well as those resulting from spatial variations in the pressure field. Without using some sort of numerical method, how do you envision accounting for these two absolutely crucial aspects of the analysis? return_to_Contents

81. I want to first say that I appreciate the time that you have put into this review process, and I especially appreciate your willingness to answer our questions in detail. Unfortunately, in the last round you broached a subject that I think deserves a detailed response (or at least an educated guess). I am referring to Wilson Cycles. You mentioned that these plate movements would have been "complex," but could you at least provide us with a plausible process that could have resulted in multiple "start and stop" tectonic events that seem to be supported by the geological evidence (i.e., North Atlantic Ocean Basin)? The mechanism in CPT seems to be unidirectional in nature, but how do you reconcile this aspect of your theory with the evidence for multiple Wilson Cycles in various locations in Earth's past? The density differences in ocean floor material due to temperature differentials do not seem to be sufficient to drive additional plate tectonics. Are changes in velocity differentials between multiple subduction zones and seafloor spreading centers and their respective effects (pushing and pulling) acting in the confines of Earth's relatively-fixed surface area during one runaway subduction event the key factor? Please provide at least one plausible series of events and the reasons for the relative motions (in a time progressive cause and effect order).

Response: I do not think there are sufficient clues for me to say much that is definitive. So you are basically pressing me to speculate, which I will do only with reluctance. Let me begin, however, by saying that from my own modeling

experiments to identify which forces play the dominant role in driving plate motions, I have found that forces acting at the plate boundaries overwhelming dominate over the drag forces acting on the bottom of the plates. This is due primarily to the extreme weakness of the asthenosphere. Next, let me remark that I consider forces responsible for the closing of the Iapetus the most problematic aspect of the scenario we are trying to understand. Without too much difficulty, I can imagine the opening of the Iapetus being driven by the upwelling of a large blob of hot material rising rapidly from the core-mantle boundary to rift what is called Laurentia, or the North American craton, away from the pre-Flood supercontinent and push this continental block westward to form the Iapetus Ocean. Similarly, I can imagine another hot blob of material rising soon afterward beneath the oceanic region west of Laurentia and exerting edge forces to drive it back eastward again to close the Iapetus Ocean. This would be a rather clean and simple way for this scenario to unfold. In this case the first stages of CPT would involve the rising of hot blobs from the core-mantle boundary in a runaway manner, action which then triggers the sinking of cold material from the upper mantle to drive the subsequent supercontinent breakup formation of the present Atlantic and Indian Ocean basins. return_to_Contents

82. Does the existence of a 'crossover depth' (which some creationists claim prevents magma from rising above this depth in the mantle) falsify the idea of upward and downward flow in the mantle?

Response: First, let me try to dispel a widespread misunderstanding about the state of rock inside the earth, namely, tha it is not magma!! Except for some extremely tiny pockets near the earth's surface, near the core-mantle-boundary, and possibly just above the top of the transition zone at 410 km depth, mantle rock is solid, not liquid! Again, the mantle is not comprised of molten magma! This basic reality has been confirmed over and over again by seismology on a daily basis for almost the last 100 years. How? By the fact that the rocks essentially everywhere within the mantle propagate shear waves, or S-waves. Because liquids do not support shear stresses, they cannot support S-waves. In fact, the way we infer with confidence that the outer core is molten is from repeated observations that no S-waves propagate within it. But S-waves do propagate throughout the earth's rocky mantle. Hence, it cannot be molten and liquid.

Because the mantle is solid essentially everywhere, the 'crossover depth', which pertains to magma, is largely irrelevant as far as the present earth is concerned. Subduction zones, beneath mid-ocean ridges, and just above the core-mantle boundary are the three places where small amounts of melting of mantle rock is known to take place in the earth today. Melting can occur in a subduction zone as the top side of the subducting slab reaches about 100 km depth and encounters what is called the mantle wedge below the overriding plate. The high temperature of the mantle wedge causes the rock on the top side of the subducting slab to give up its water. This water lowers the melting temperature in the mantle wedge rock, often by a sufficient amount for partial melting to occur and basaltic magma to form. This is basically the cause for the 'Ring of Fire' volcanism inboard of the subduction zones around the Pacific Rim today.

Partial melting of mantle rock also occurs beneath mid-ocean ridges, where divergence of the plates from the ridge axis causes solid hot rock to rise up from below to fill the resulting gap. Rock melting temperature decreases with decreasing pressure. As rock rising beneath a spreading ridge experiences lower and lower pressure, some of its minerals find themselves above their melting temperatures. When this happens partial melting begins and basalt magma forms. This is called decompression melting. It occurs at depths typically between 50 and 120 km below spreading ridges.

Partial melting in a very thin layer in certain patches just above the core mantle boundary seems to be the explanation fo the so-called 'ultra-low velocity zone' (ULVZ) discovered by seismologists about ten years ago. The only other place in th mantle where melting has been hypothesized to occur is immediately above the top of the transition zone at about 410 km depth. If melt does exist there, its volume is inferred to be small. Other than for these special situations, in subduction zones, beneath mid-ocean ridges, immediately above the core-mantle boundary, and possibly just above the top of the transition zone, rock in the mantle is below its melting temperature and therefore a crystalline solid.

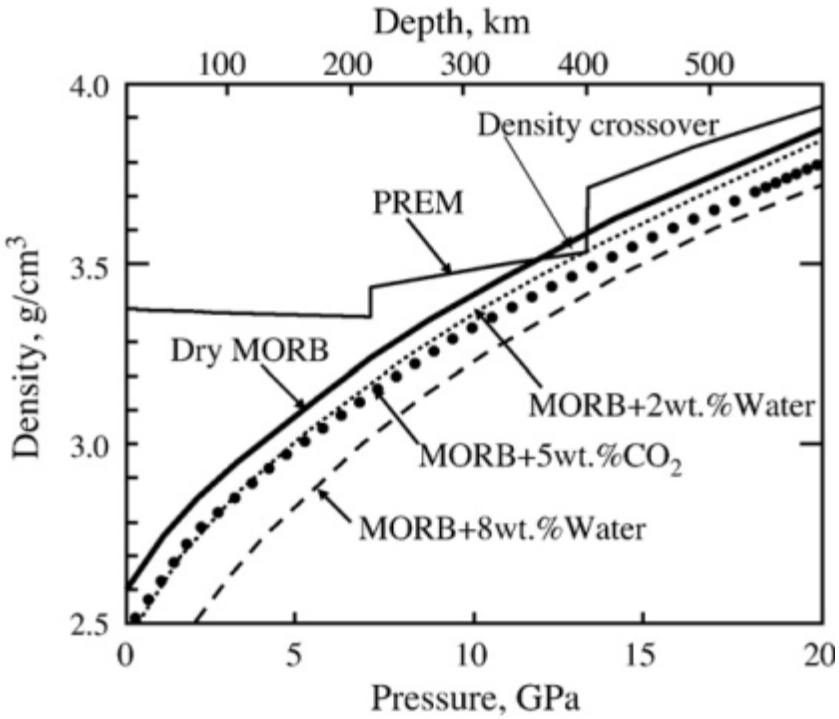
What then is meaning and significance of the 'crossover depth'? In the article referenced by Walt Brown in his book *In the Beginning*, *8th ed.*, the crossover depth is defined as the depth below which the density of liquid basaltic magma exceeds that of solid olivine crystals. The 2006 article is posted at http://www.spring8.or.jp/pdf/en/res_fro/06/113-114.pdf. It is by S. Urakawa, T. Sakamaki, and E. Ohtani and entitled "Anomalous compression of basaltic magma: Implications to pressure-induced structural change in silicate melt." This is simply a web-posted preliminary research report. Based on extrapolation of their actual measurements, they estimate that melt density crossover occurs at a pressure of about 7 GPa, which corresponds to a depth in the earth of about 215 km. A better and more recent article describing similar results is by C. Agee and entitled "Static compression of hydrous silicate melt and the effect of water on planetary differentiation," *Earth Planet. Sci. Lett. 265*, 641–654, 2008. Agee's experiments show a density crossover at about 9 GPa between olivine and silicate liquid with 2 wt.% water. The pressure of 9 GPa corresponds to a depth in the mantle of about 270 km.

In regard to the meaning and significance of these experimental results, the researchers in this field generally relegate their relevance to the era immediately after the earth's formation, when they conjecture that much of the mantle was molten as a 'magma ocean'. In an article entitled "Melting relations and the equation of state of magmas at high pressure: Application to geodynamics," *Chemical Geology 265,* 279-288, 2009, the author E. Ohtani states,

> The melting relation of minerals and the equation of state of magmas are important properties for deducing the formation and differentiation of the Earth, and especially for elucidating the nature of the terrestrial magma ocean and the subsequent formation of the core, mantle, and crust of the Earth. Because these magmas are compressible, we expect that the olivine–magma density crossover played an important role in controlling the geochemical characteristics of the primitive mantle after the magma ocean stage of the primordial Earth. (emphasis added)

The crossover depth, as these authors repeatedly stress, has applicability to the very early part of earth history when they hypothesize that the mantle was largely if not completely molten! In their framework it pertains to that brief era in earth history before the earth's granitic crust had been chemically differentiated from the mantle. This state of affairs certainly does not apply to the present earth. Nor, so far as I can tell, does it pertain to the earth since God created it and filled it with life during Creation Week, including the Flood.

The only contexts in which the crossover depth plays a role in the present earth are the small regions in the mantle below about 250 km where melt may exist, that is, just above the core-mantle boundary and just above the transition zone at about 410 km depth. In the thin patches known from seismology as 'ultra low velocity zones' just above the core-mantle boundary, the dense melt is presumably trapped against the denser core beneath it. The situation at 410 km is more complex. The figure below from the paper by Ohtani is provided to help explain it.



Caption: Density of dry basaltic magma (Ohtani and Maeda, 2001), H_2O-bearing and CO_2-bearing basaltic magmas (Sakamaki et al., 2006; Ghosh et al., 2007), and the mean density of the mantle (PREM) (Dziewonski and Anderson, 1981). There is a density crossover at the base of the upper mantle at a depth near 410 km.

At these depths, water and carbon dioxide can reduce the melting temperature by 200-400°C, plausibly sufficient to produce partial melting. So if there is sufficient water and/or CO_2present to cause melting near 410 km depth, it appears to be at least possible for the magma to have comparable density to the solid phase minerals and thus form a thin gravitationally stable layer. (Such a layer is stabilized from sinking deeper because of the higher density of the transition zone region beneath it.) But it is far from certain that such a layer actually exists, at least in any widespread way, although there is some seismic evidence that it may be present in regional patches. return to Contents

83. Can you comment on the widely accepted idea that the mantle is convecting? Is not the theory of rising convection currents in the earth's mantle fraught with problems that are not being addressed by the secular geologists?

Response: The basic question is, if the mantle is essentially all solid crystalline rock, can it convect like soup boiling in a pan on the stove? The simple answer is, yes. However, some insight concerning how solid mantle rock deforms and flow is helpful in understanding the answer. Experimentally it can be shown that silicate minerals and rocks undergo permanent, or plastic, deformation, especially at higher temperatures, as stress is applied. This permanent deformation occurs as the result of *migrations of defects* within crystals and *motions at mineral grain boundaries*. The process is often referred to as *solid-state creep*. Therefore, when subjected to stresses such as those arising from gravity acting on density variations, mantle rock, though solid, nevertheless deforms in a plastic manner. Although the deformations are extremely slow, the mantle, even though solid, can be treated and understood as an extremely viscous fluid. Here, the more general term *fluid* (as opposed to liquid) is used because crystalline solids (as well as liquids) do deform and flow.

In regard to convection, the simple case known as Rayleigh-Bénard convection occurs when a thin fluid layer in a gravity field is heated from below and cooled from above. This case was first studied experimentally by Henri Bénard, a French physicist, in 1900. In this type of system, gravity acts to pull the cooler denser fluid from the top of the layer toward the bottom and to draw the warmer less dense fluid at the bottom of the layer toward the top. This gravitational force is

opposed by the viscous force involved in deforming the fluid. The balance between these two forces is expressed by a non-dimensional parameter called the Rayleigh number which is defined as $Ra = g\alpha\rho\Delta T d^3/\nu\kappa$, where g is the gravitational acceleration, α is the volume coefficient of thermal expansion, ΔT is the temperature difference between the top and bottom of the layer, d is layer thickness, ν is the kinematic viscosity, and κ is the thermal diffusivity.

Convective motion can occur in this type of system when what is called the *Rayleigh number* exceeds a critical value known as the *critical Rayleigh number*. In 1916 Lord Rayleigh was successful in deriving this value analytically for the case of a plane layer with free-slip boundaries. The value he obtained was $27\pi^4/4 = 657.5$. The critical Rayleigh number can also be determined for the case of a spherical shell. For a shell geometry corresponding to that of the earth's mantle, assuming constant properties throughout the volume and heating from below, the critical Rayleigh number is about 700.

We can use estimates for the average physical properties of the earth's mantle to estimate its actual Rayleigh number. Using 10 m/s^2 for gravitational acceleration, 3×10^{-5}/°C for the volume coefficient of thermal expansion, 2000°C for the adiabatic temperature difference across the mantle, 3000 km as the mantle thickness, 2×10^{18} m^2/s for the kinematic viscosity, and 10^{-6} m^2/s for the thermal diffusivity, we get $Ra = 8 \times 10^6$, a value more than *10,000 times* the critical value! This implies that the earth's mantle is well within the convective regime, and, as far as convective systems are concerned, is convecting vigorously. This value for mantle viscosity is based on present-day GPS observations of the rate at which deformations of the mantle are occurring, a value about *25 orders of magnitude* greater than that of water. In spite of this gigantic value for its viscosity, it is the huge thickness d of the mantle that allows the Rayleigh number to be so large and for convection within the mantle to be so vigorous.

To recap, very simple physical considerations show that the earth's solid mantle must be within the regime of convective flow. Its huge Rayleigh number, which depends on the mantle depth to the third power, requires it. On the other hand, because mantle viscosity is so high, the rates of mantle deformation, or flow, are close to being undetectable to a human observer. They are on the order of a millimeter per week in a few locations on the earth's surface such as across the San Andreas Fault midway between Los Angeles and San Francisco. On the other hand, GPS techniques are now sufficiently sensitive to measure the surface expressions of these motions to a high degree of precision. So flow in the mantle, though slow, is close to indisputable. However, in the framework of Biblical history, the observed rates of convective flow are so tiny that they are insignificant on time scales of only a few thousand years, apart from the earthquakes and tsunamis which these motions produce.

A final comment relating to question 82 (Q82) is that because the earth's mantle is solid practically everywhere, the so-called 'crossover depth', applicable only to molten liquid rock, is not relevant to the question of whether solid-state convection, which involves plastic deformation of the solid rock, is taking place. return_to_Contents

84. In your opinion, how catastrophic was the effect of the runaway slabs contacting the mantle-core boundary? Was the deceleration seen near the surface significant enough to cause continental compression which some creationists (e.g., Walt Brown) believe was very significant? Walt Brown suggests that a rapid deceleration of the continents caused such severe compression that the plates thickened significantly. Do you think that such a compression event could have been caused by slab contact with the mantle-core boundary, or was there sufficient "mantle/slab buffering" to reduce surface deceleration rates? If not, I assume that you believe most continental compression was purely the result of subduction effects.

Response: In my answer to question 71 (Q71) above, I pointed out the specific kinetic energy of a slab moving at 45 mph or 20 m/s is only 200 J/kg. That amount of energy will raise rock only 20 meters in the earth's gravity field. I showed that the amount of energy required to double plate thickness is at least 450 times greater than what Brown is proposing. Therefore, as far as I can determine, Brown has neither an energy source nor a physical mechanism to increase crustal thickness of the continents by the factor of two his hypothesis requires. Besides these difficulties, there

is the geometry problem of not having enough crustal mass between the present continent and the adjacent ridge to achieve such a doubling of thickness, even if an energy source and mechanism were available.

In my runaway calculations I rarely see velocities higher than 10 m/s, and these tend to be in the middle of the mantle. As runaway material approaches either the top or bottom boundary, it tends to decelerate smoothly and have what can be described as a 'soft landing'. More importantly, the material is so weak that decelerations which occur at one boundary have essentially no effect at the other.

Finally, let me say that the evidence seems to be strong that the continental cratons *did not* experience any thickening of their crystalline basements during the Flood. Most of the continental shield areas actually appear to have experienced moderate to severe beveling of their top surface by erosion during the Flood. Large portions of the Canadian Shield, for example, display Precambrian mountain roots exposed at the surface, suggesting a kilometer or more of crystalline rock has been removed by erosion since those Precambrian mountains were present. Nowhere in the continental cratons is there any systematic evidence for the sort of crustal compression and shortening that Brown postulates.

The two primary places where the thickness of the continental crust was increased during the Flood were, first, just inboard of subduction zones along continental margins such as around the Pacific perimeter, as is clearly evident on the western coasts of South and Central America, and, second, in continent-continent collision zones, most notably along the Himalaya-Alpine belt. In both cases subduction is what brings about the increase in the thickness of the crustal layer. In the first case, much of the thickening is due to emplacement of magmatic material from below. In the second, the crusta portions of two continental plates are deformed into one another by the subduction of the mantle lithosphere of one or both of the plates. In neither case does the inertia of the plates play any significant role. The accelerations, even in the case of CPT, are far too small to matter. What drives everything is gravity. Gravity drives the subduction, and it also drives the subsequent isostatic adjustment. return_to_Contents

85. The sources of the enormous amounts of material found in the earth's vast sediment deposits (averaging more than mile in thickness on the continents) as well as of the cementing agents (quartz, calcite, etc.) for these sediments are important issues that concern many Flood geologists. In your opinion, what are the sources for these sediments and cementing agents? Was the majority of sedimentary material from catastrophic processes during the Creation Week, or was most of it generated by processes during Noah's Flood?

Response: This question involves two issues, namely, the source of the sediments deposited during the Flood and the source of the cementing agents which cemented these sediments to produce what in most cases is hard rock today. Let me preface my answer by emphasizing that I am not a specialist in sedimentary geology. However, from the background do have, it is my present conclusion that a moderate volume of sedimentary rock existed in the pre-Flood world. I base that on vestiges of Precambrian sedimentary rocks which still exist and can readily be observed such as those exposed in the inner gorge of the Grand Canyon and the Belt Supergroup rocks in Montana and surrounding areas. These sediments indicate to me that the earth which God created using supernatural processes during Creation Week did indeed contain a moderate amount of sedimentary rock including sandstone, mudstone, and carbonates, in some cases many kilometers i total thickness.

One diagnostic that has come into prominence during the last ten years is U-Pb dating of detrital zircons in sedimentary rocks, especially sandstones. This has proved especially useful in identifying the original crystalline source rocks for the sediments. Although this approach is relatively new and it thus far has been applied to a relatively small number of sedimentary formations, the conclusion I take away from the publications I have reviewed is that a large fraction of the clastic sediments deposited during the Flood represent material eroded and mechanically reduced to sand- and silt-sized particles during the Flood itself. So as a very crude estimate on my part, I would conjecture that something less than 15-20% of the silicic sediment in the rock record today was formed during Creation Week and the remainder was formed

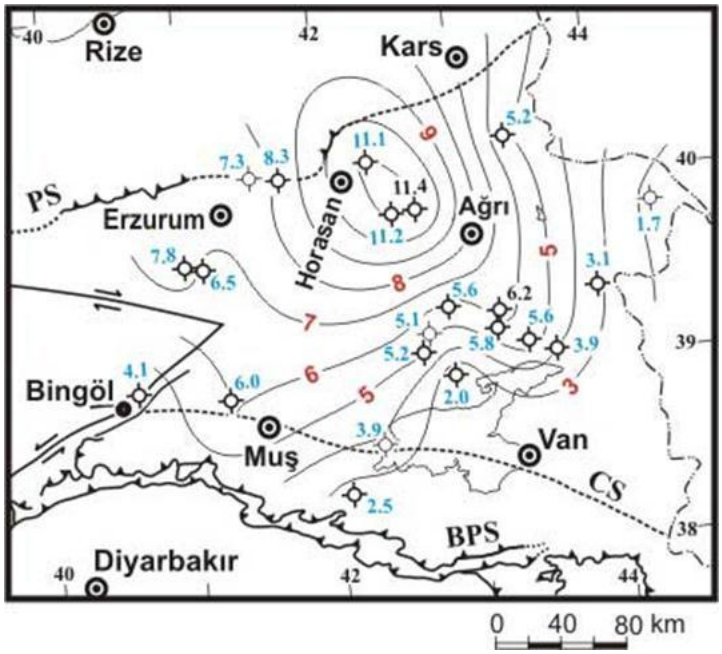
during the Flood. This, of course, implies extreme amounts of erosion of the earth's crystalline basement rocks and extreme mechanical abrasion of the rock fragments into very small particle sizes during the Flood. Roughly two-thirds of the silicic sediment volume is estimated to be mudstone, which means silt-sized and smaller particle sizes.

What about the source of carbonate sediment, which corresponds to roughly a quarter of the total sediment inventory (with silicic sediments comprising most of the rest)? My response to this is definitely in the realm of speculation, but to me the most likely source of new calcium and magnesium carbonate is from the chemical degradation of basalt, which typically consists of about 10 weight percent CaO and 5-12 weight percent MgO, combined with outgassed carbon dioxid from the mantle. Some of the needed chemical degradation of basalt would logically accompany the erosion and mechanical abrasion of basaltic rock in the overall erosive action of the Flood waters at the earth's surface. Another place where some significant chemical degradation of basalt conceivably might also occur is in the rift zones where basalt near its melting temperature is in contact with supercritical water. We certainly could use a good physical chemist to explore this possibility as to how much calcium and magnesium might be extracted from the rock matrix. I would not be surprised if most of the carbonate we observe to be in the sediment record can be accounted for from these sources.

Finally, what about the source of the cementation agents? Sediments, especially mudstones, when they first form, can contain as much as 60-80% water. To me this pore water is the most logical and likely source for the cementation agents The solubility of silica increases markedly at higher temperatures and pressures. The fact that ocean water temperatures were significantly higher during and after the Flood than at present suggests that levels of dissolved silica in sediment pore waters were also higher. Therefore, warm, mineral-laden pore waters, high in dissolved silica, to me represents a plausible way to account for the rapid cementation of the Flood sediment, regardless of where it had been deposited. return_to_Contents

86. What is your conclusion regarding whether or not Noah's Ark could have come to rest upon Mt. Ararat in northeastern Turkey?

Response: I am confident that Mt. Ararat is *not* the landing site of Noah's ark, a view I have held for the past 30 years. Numerous 'volcanic bombs', blobs of molten basalt that have been launched violently from vents near its summit, litter the terrane for miles around this mountain. The piles of basalt are fresh and unweathered and testify to dramatic recent eruptions of this volcano. Of even greater significance are the radioisotope dates for the lavas of Mt. Ararat itself and those of the surrounding region. The map below provides contours of radioisotope age, spaced one million radioisotope years apart, for the oldest volcanic rocks found in each locality. The numbers in aqua are the oldest age, in millions of radioisotope years, for specific volcanoes, each marked by a circle with four spokes. Mt. Ararat is the easternmost volcano on the map with an age for its oldest lavas of 1.7 million radioisotope years. This places its earliest eruption during the Ice Age, after the end of the Flood. These data indicate strongly that this huge volcano, just shy of 17,000 feet high, did not even exist when Noah, his family, and the animals disembarked from the ark.



Caption: Distribution of the oldest radiometric ages of the volcanic units. Ages are from Pearce et al. [1990], Ercan et al. [1990] and Keskin et al. [1998]. Initiation ages of the volcanism are contoured in 1-Myr intervals. PS: Pontide suture, BPS: Bitlis-Poturge suture, CS: inferred cryptic suture between the EAAC and BPS. Figure from Keskin [2003].

The article from which this figure is taken is by Prof. Mehmet Keskin at Istanbul University and entitled, "Domal uplift and volcanism in a collision zone without a mantle plume: Evidence from Eastern Anatolia." It is posted at http://www.mantleplumes.org/Anatolia.html. return_to_Contents

87. What is your view regarding the origin of comets?

Response: If one takes the account of God's creation of the heavens and the earth provided in Genesis as genuine narrative history, as I believe the text itself indicates it should be taken, then it is plain that God worked in a miraculous way not only to create all living things including plants, animals and humans, but also the earth itself as well as the sun, moon, stars, and other celestial bodies. Just as I am persuaded we can never on our own discover what processes God may have used to make a bacterium, similarly, it is my conviction that, on our own, we can never discover how God made the earth, the moon, the sun, the stars, the asteroids, and, likewise, the comets. The Genesis text indicates that the material *earth* in its basic structure as we observe it today, apart for the destruction that took place during the Flood, was fashioned by God within the first three days of Creation Week. As we study the earth's rocks, we seem to detect that a vast amount of processing occurred as God undertook this creation. It appears that much if not most of the mantle may have been molten at some point in the process; that what is now the continental crust may have been chemically extracted from this molten mantle rock; that these huge volumes of rock cooled and crystallized; and that all this elapsed within a few tens of hours. When one takes this sort of perspective on how the earth must have formed and realizes that God must have used similar wonderful processes to fashion the remainder of the bodies in the solar system, the rest of the Milky Way galaxy, and indeed the rest of the cosmos, to me it ought to cause us to have some humility as we consider these questions.

About all I can observe is that from the bodies in our solar system for which we have been able to determine the chemical composition, whether meteorites that have reached the earth's surface, rocks we retrieved from the moon, particles we scavenged from the Wild-2 comet, spectra of elements we detect in the sun's corona, or rocks we can analyze from the earth itself, the chemical composition from all these bodies seems astonishingly similar. It is as if these bodies were all

made from the same basic batch of elements and isotopes. Although this may say a little bit about the larger process God may have used, to me the details are so complex and obscure that these issues are in the category of the "secret things" that "belong to the LORD our God." (Deut. 29:29) To claim understanding of these matters, when our ignorance is so vast, seems to me at this point to be very foolish. So my answer to this question is, I have nothing coherent to offer on how comets came to be other than that God made them. return_to_Contents

88. Can you explain why plate motions are still occurring today?

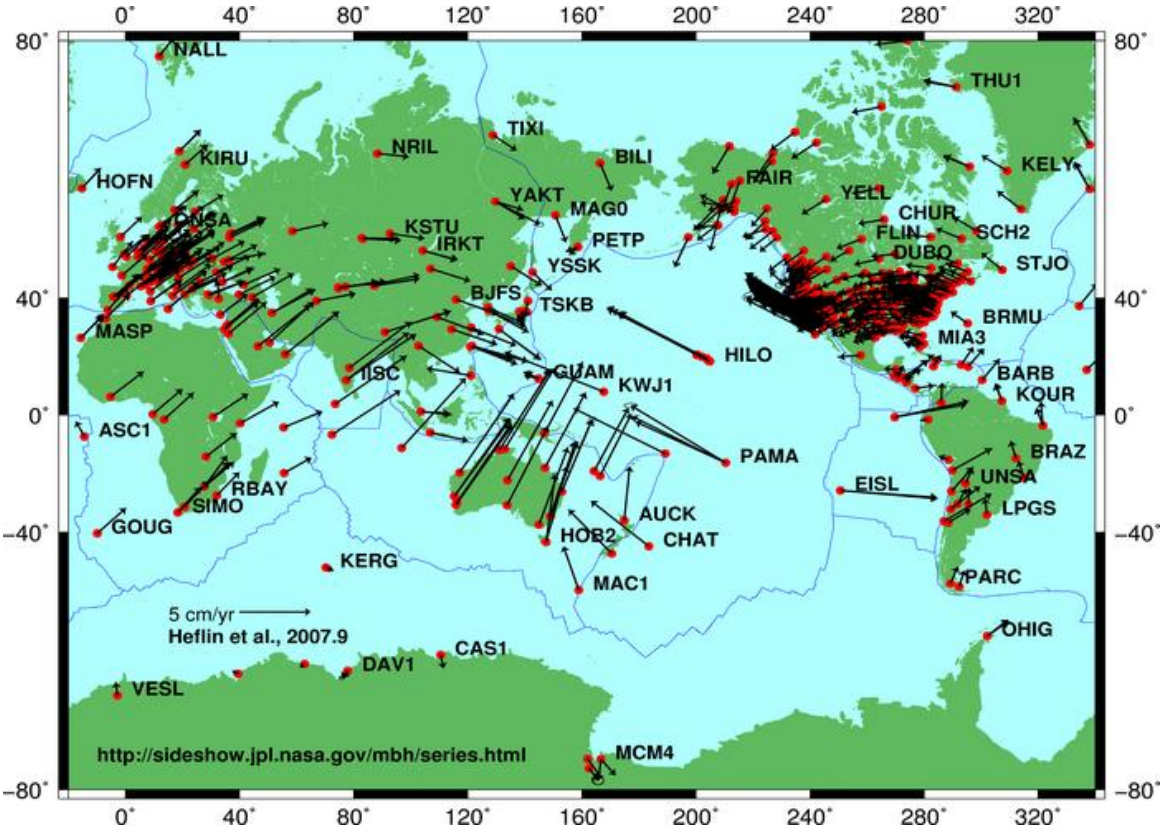
Response: Seismic observations clearly reveal today the presence of subducting slabs that penetrate the upper mantle and in some cases some or all of the lower mantle as well. What the existence of these slabs implies is that, when the CPT runaway process during the Flood came to a stop, there were slabs still in the process of sinking. These slabs were effectively frozen in place as the mantle's viscosity rapidly rose to its non-runaway value. Although this non-runaway value of mantle viscosity is about a billion times higher than it was during the interval during which CPT was occurring, it nevertheless is not infinite. The mantle still undergoes deformation in response to the stresses these slabs generate, despite the fact that the sinking rates of the slabs are only on the orders of a few millimeters per year.

To recap, the plate motion occurring today is a consequence of slabs of cold lithosphere which presently exist in the mantle. These slabs were in the process of sinking through the mantle when CPT shut down and were effectively frozen in place as the mantle rapidly recovered its strength. These slabs, because of their strong negative buoyancy, that is, higher density due to lower temperature, continue to sink today, but the sinking rates are quite small. Mantle rock is strong, but not infinitely so. The stresses these slabs exert cause the surrounding mantle to deform and the slabs to move through it, typically, at rates of only millimeters to centimeters per year. return_to_Contents

89. What solid evidence, if any, do you feel exists for the presence of flow in the mantle?

Response: There are two lines of evidence which seem particularly convincing to me. First are the GPS measurements that show motions at plate boundaries across the earth which are highly consistent with plate tectonics expectations. The noise levels in these measurements are now so small that to me the values are beyond dispute.

I described these measurements in my answer to question 7 (Q7), but let me reproduce the NASA figure which summarizes these results again for convenience. These results exploit the constellation of 24 Global Positioning System (GPS) satellites. Daily position estimates are determined and recorded for each of more than 900 GPS receivers on the ground from the satellite signals. Data from these stations were processed and analyzed at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration. Horizontal velocities, mostly due to motion of the Earth's tectonic plates and deformation in plate boundary zones, are represented on the maps by arrows extending from each of the more than 900 receiver stations shown in the map below.



Caption: Station velocities determined by integration of their GPS observations over the period 1999-2007. Data were analyzed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Notice especially the large velocity of the Pacific Plate, the high rate of convergence (via subduction) in the western Pacific, the high rate of convergence of the Australian Plate with the plates to the north (also via subduction), and the high rate of divergence (via seafloor spreading) along the East Pacific Rise. These surface motions, observable in the present day, imply motions of similar magnitude in the mantle beneath. What are the forces available to drive these surface motions? The primary one is gravity acting on the negative buoyancy of the cold subducted rock currently present in the mantle. These data to me represent persuasive evidence that flow indeed is taking place within the mantle of the earth.

A second related line of evidence concerns the displacements which accompany earthquakes around the earth. With the large numbers of seismic stations around the world today it is possible to process the seismic signals for most earthquakes of at least modest size to recover the orientation of the fault and the direction of motion responsible for the earthquake. Let us consider some recent examples of large earthquakes. The magnitude 8.8 megathrust earthquake tha occurred on February 27, 2010 just off the Chilean coast involved the thrusting of the oceanic Nazca Plate beneath the South American Plate, consistent with subduction occurring along the western margin of South America. The Wikipedia article on this earthquake states:

> The segment of the fault zone which ruptured in this earthquake was estimated to be over 700 km (430 mi) long with a displacement of almost 10 meters. It lay immediately north of the 1,000 km (620 mi) segment which ruptured in the great earthquake of 1960. Preliminary measurements show that the entire South American Plate moved abruptly westward during the quake. A research collaborative of Ohio State and other institutions have found, using GPS, that

> the earthquake shifted Santiago 11 inches (28 cm) to the west-southwest and moved Concepción at least 10 feet (at least 3 meters) to the west. The earthquake also shifted other parts of South America from the Falkland Islands to Fortaleza, Brazil. For example, it moved Argentina's capital of Buenos Aires about one inch (2.5 cm) to the west. Several cities south of Cobquecura were also raised, by up to 3 meters.

Another huge megathrust earthquake occurred on December 26, 2004, off the west coast of Sumatra. This 9.1 magnitude earthquake was caused by underthrusting of the India-Australia Plate beneath the Burma Plate. It triggered a series of devastating tsunamis along the coasts of most landmasses bordering the Indian Ocean, killing over 230,000 people in fourteen countries, and inundating coastal communities with waves up to 30 meters (100 feet) high. It was one of the deadliest natural disasters in recorded history. It is consistent with subduction along the Sumatra Trench. In regard to the mechanics of the earthquake, the Wikipedia article states:

> An estimated 1,600 km (994 mi) of fault surface slipped (or ruptured) about 15 m (50 ft) along the subduction zone where the India Plate slides (or subducts) under the overriding Burma Plate. The slip did not happen instantaneously but took place in two phases over a period of several minutes:
>
> ▪ Seismographic and acoustic data indicate that the first phase involved a rupture about 400 km (250 mi) long and 100 km (60 mi) wide, located 30 km (19 mi) beneath the sea bed—the largest rupture ever known to have been caused by an earthquake. The rupture proceeded at a speed of about 2.8 km/s (1.7 mi/s) or 10,000 km/h (6,300 mph), beginning off the coast of Aceh and proceeding north-westerly over a period of about 100 seconds.
>
> ▪ A pause of about another 100 seconds took place before the rupture continued northwards towards the Andaman and Nicobar Islands. However, the northern rupture occurred more slowly than in the south, at about 2.1 km/s (1.3 mi/s) or 7,600 km/h (4,700 mph), continuing north for another five minutes to a plate boundary where the fault type changes from subduction to strike-slip (the two plates slide past one another in opposite directions). This reduced the speed of the water displacement and so reducing the size of the tsunami that hit the northern part of the Indian Ocean.

Another megathrust earthquake occurred on March 27, 1964 near Anchorage, Alaska. Lasting nearly five minutes, this 9.2 magnitude event was the most powerful recorded earthquake in North American history and the second most powerful ever measured by seismograph anywhere in the world. Across south-central Alaska, ground fissures, collapsing buildings, and tsunamis directly caused about 131 deaths. This earthquake was caused by the rapid underthrusting of the Pacific Plate beneath the North American Plate near College Fjord in Prince William Sound, 78 miles (125 km) east of Anchorage and 40 miles (64 km) west of Valdez.

The purpose in citing these examples is to point out that earthquakes in general yield displacements which are in overwhelming accord with the plate motions provided by GPS measurements. These active displacements represent yet another line of observational support for the conclusion that plate motions are truly taking place across the earth's surface today. Motions in the mantle's top boundary layer mean that motions of similar magnitude are occurring within the volume beneath. return_to_Contents

90. Most geologists claim that the formation (orogeny) of the Appalachian Mountains is the result of continental collisions and that they were essentially pushed up from below. The problem with this view is that it is not able to account for the vast, thick (1-2+ miles thick) layer of younger unbroken sediment layers discovered beneath the mountain chain. If the mountains were pushed up from below, then how did the sedimentary layer get beneath it?

Response: I am not familiar with the "younger unbroken sediment layers discovered beneath the mountain chain" which you describe. I deal with the history of the Appalachian region in moderate detail in my response to question 95 (Q95). Let me refer you to that answer. Perhaps you are referring to the thrust sheets in the Ridge and Valley province in the western part of the belt. Here indeed younger sedimentary rocks do underlie older rock, rock which in

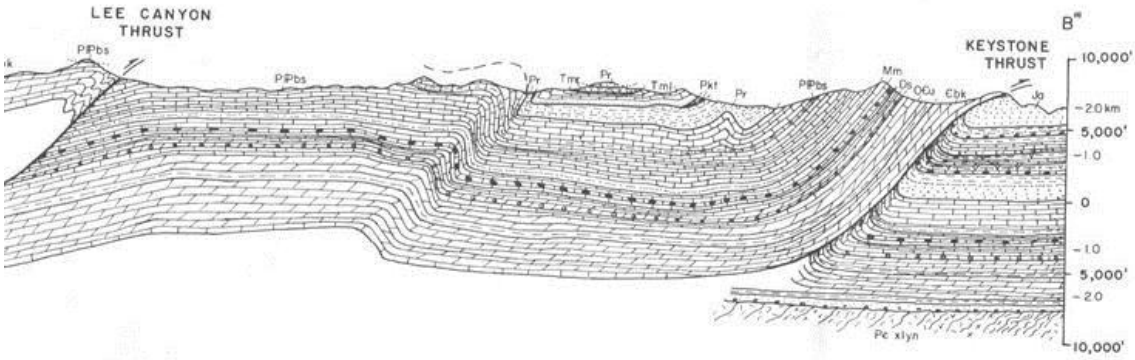
some cases has been metamorphosed. Numerous field studies over the past half century offer strong evidence that large thrusts have occurred throughout that part of the Appalachian belt. As to the basic issues of whether large thrusts have actually occurred and the mechanics of how they might occur, please see my response to question 91. return_to_Contents

91. Do overthrusts and folded mountain ranges represent features that conventional geology cannot explain? Walt Brown is convinced that overthrusts are not possible. I see problems with the conventional view of how mountain rock layers got to be folded. (It is claimed that the layers were once at great depth, but how and why would sedimentary rock ever be at great depth?) Please provide your view on these issues.

Response: Let me begin by discussing overthrusts. Overthrusts are real. As an example, I would point to the Keystone Thrust just west of Las Vegas, Nevada shown in the photograph below, which I am reproducing from my answer to question 30 (Q30). The Keystone Thrust represents a horizontal displacement of a sheet of rock by several tens of kilometers. Most of the displacement occurred in the late Cretaceous when the Farallon slab was subducting horizontally beneath western North America.

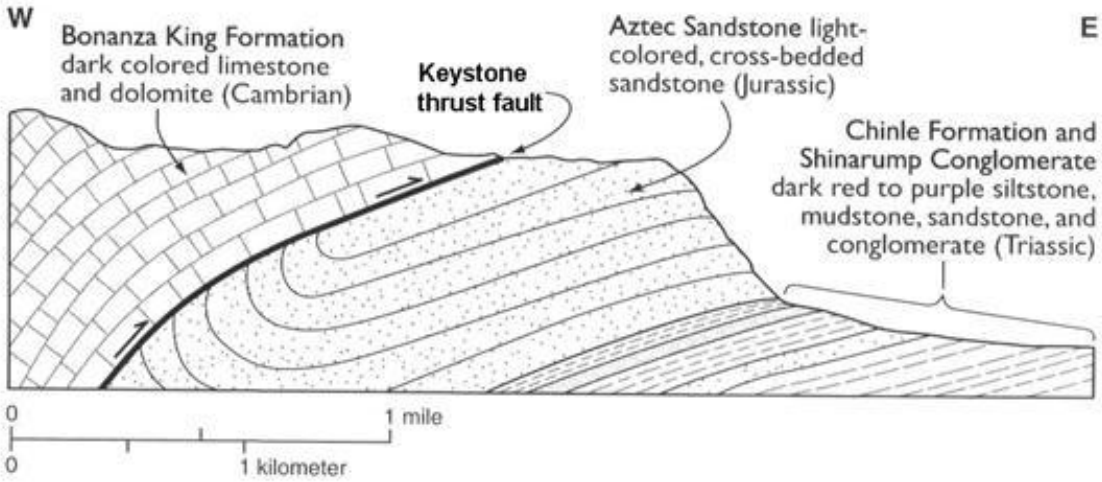
Caption: The Keystone thrust west of Las Vegas, Nevada, is a spectacular example of a thrust fault. The dark-gray Cambrian limestone of the Bonanza King Formation on the left moved to the right and over the pink Jurassic Aztec Sandstone in the center.

Below is a cross-sectional view of the Keystone thrust sheet, some 13,000 feet in thickness. Along its eastern edge, its basal layer of Cambrian Bonanza King Limestone now lies on top of Jurassic Aztec sandstone, which is some 15,000 feet higher in the regional sediment sequence.



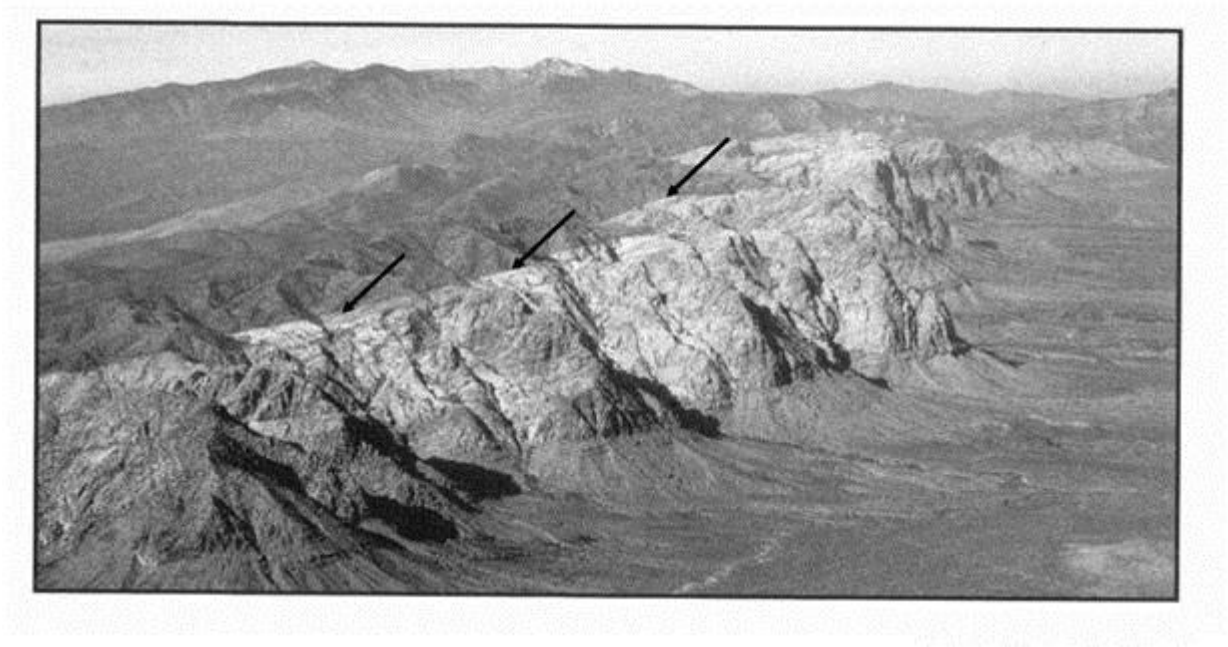
Caption: East-west cross section from just west of Las Vegas, Nevada, showing the Keystone Thrust Sheet, interpreted here as a gigantic gravity slide feature.

Below is a simplified version of this same cross section.



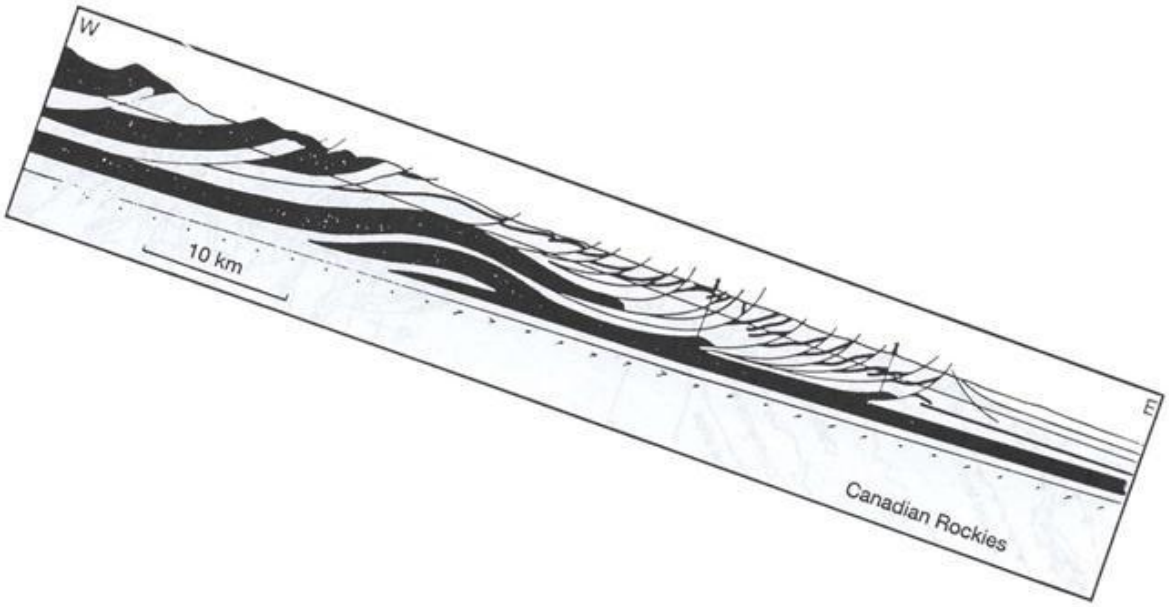
Caption: Cross section of the Keystone thrust, Red Rock Canyon area, west of Las Vegas, Nevada.

Below is another aerial photo showing the fault contact a bit better than the previous color phot



Caption: Aerial photo looking toward the northwest showing the Keystone fault contact between the overlying dark Bonanza King limestone and underlying light-colored Aztec sandstone in the Red Rock Canyon area west of Las Vegas, Nevada.

A simple analysis shows that pushing such a massive sheet of rock from the side is not a viable possibility. Rock simply does not have sufficient compressive strength to support the edge forces required. The only type of force capable of accomplishing such a mechanical feat is a body force. The main two candidates are gravity and inertial deceleration. Gravity sliding in response to tectonic deformation of the earth's surface seems to be the most plausible choice. The figure below attempts to illustrate how gravity sliding in response to tectonic uplift of the western margin of North America associated with the rapid subduction of the Farallon Plate may have produced the complex pattern of imbricated fault sheets and spectacular folding observed, for example, in the Canadian Rockies.



Caption: The violence associated with the rapid subduction of ocean plate beneath the continent likely included a temporary but dramatic uplift of the continent edge causing sections of the recently deposited sediments to collapse downslope along curved faults. Sections of the sediment sequence tens of miles wide slid downslope for tens of miles along the entire western edge of North America as shown in this cross section through the Canadian Rockies.

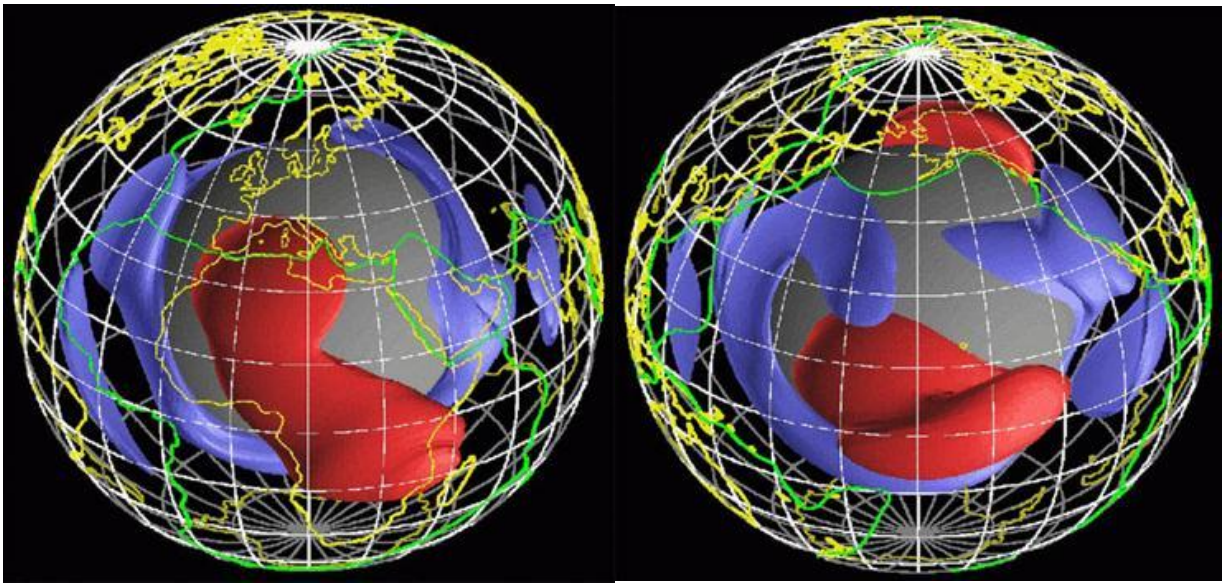
This is how I would account for such features that are moderately common in the world's tectonic belts. return_to_Contents

92. You have made it clear in answering questions of other panelists several times that you see the 40 days of runaway subduction and supersonic jet action as involving both the opening and closing of the Iapetus Ocean and then the breakup of Pangea and the opening of the Atlantic Ocean. However, since the simulation you showed at the 2008 ICC conference showed the breakup of Pangea only, and it took 40 days and still didn't appear totally finished, how can all th other movements in the initial phase fit in that 40 day time frame (when the steam jets were active)?

Response: I addressed this issue in detail in my response to questions 54 (Q54) and 55 (Q55). Let me summarize here by saying that until recently I had equated the entire 150 day period mentioned in Genesis 7:24 and 8:3 as the interval during which CPT had operated. Allocating a 40-60 day portion of that 150 day interval for the breakup of Pangea and th opening of the Atlantic and Indian Oceans thus seemed reasonable to me. However, recently, as I have given more attention to the significance of the 40 days and nights of rain, I have concluded that it is this 40-day interval, not the 150-day one, which more likely delimits the actual CPT episode. This is because the steam jets and consequent heavy rain are so causally connected to rapid seafloor spreading. So I have now tentatively revised my outlook to the perspective that the vast majority of the rapid subduction and seafloor spreading which occurred during the Flood likely unfolded during the first 40 days, when Scripture indicates the rainfall was so intense. I admit that compressing the time interval, from 150 days to 40 days, during which most of the Flood's geological change occurred makes it even more difficult for the human mind to imagine. Yet as I seek to put the puzzle together, this seems to be what Scripture is revealing to us. return_to_Contents

93. I am finding it difficult to confirm the basic features in the seismic tomography image you used in your response to question 19 (Q19). In fact, I found two papers that seem to contradict your image. One paper is "Evidence for deep mantle circulation from global tomography," by R.D. van der Hilst, S. Widiyantoro and E.R. Engdahl (*Nature, 386*, 578-584 1997). This paper does not seem to show any plume rising under Africa, nor a hot plume in the middle of the Pacific. Another paper is "Degree 12 model of shear velocity heterogeneity in the mantle" by Wei-jia Su, Robert L. Woodward, and Adam M. Dziewonski (*J. Geophys. Res., 99*, 6945-6980, 1994). This article also seems to show no rising plumes under Africa nor beneath the mid-Pacific. Please resolve this apparent conflict.

Response: Let me reproduce the seismic tomography image to which you are referring.



Eastern Hemisphere Western Hemisphere

The 1994 paper by Su, Woodward, and Dziewonski most definitely emphasizes these features and even refers to them as "megastructures." In the abstract of the paper one finds the statement, "The model is dominated by a few megastructures of velocity heterogeneity below the depth of 2000 km, in agreement with previous studies. Among these megastructures are the 'Pangea Trough,' 'Great African Plume,' and 'Equatorial Pacific Plume Group.'" The 'Pangean Trough' to which they refer is the ring of cold material at the bottom of the mantle that lies roughly below the perimeter of the Pangean supercontinent as indicated in the image above. The 'Great African Plume' and the 'Equatorial Pacific Plume Group' correspond to the two red features in the image. These megastructures to which Su *et al*. refer are evident in their Figures 5(l), 7, and 21. In discussion of Figure 21, the authors state,

> The largest of negative anomalies in the lowermost mantle: the 'Great African Plume' is shown at the CMB depth in Figure 21c. It demonstrates a 'connection' to the Mid-Atlantic Ridge as well as to the Mid-Indian Ridge. The mantle between the East African Rift and a point just west of Australia is slower than normal down to 1500-2000 km depth. One of the corners of the final panel, Figure 21d, is centered on the middle plume of the EPPG and shows how strongly it affects the velocities (and the temperature field) under the South Pacific. Also shown is an extensive low-velocity column under the southeast Indian Ridge and a part of the 'Tethys Trough,' a high velocity megastructure extending from Gibraltar to the Macquarie triple junction.

Finally, in the last paragraph, as a final point of emphasis in the paper Su *et al*. state, "The clearest and most robust features of model S12 in the lower mantle are several very large-scale anomalies (megastructures or "grand structures"), whose locations and extent are consistent with the results obtained in previous studies [Dziewonski et al., 1991, Dziewonski and Woodward, 1992]."

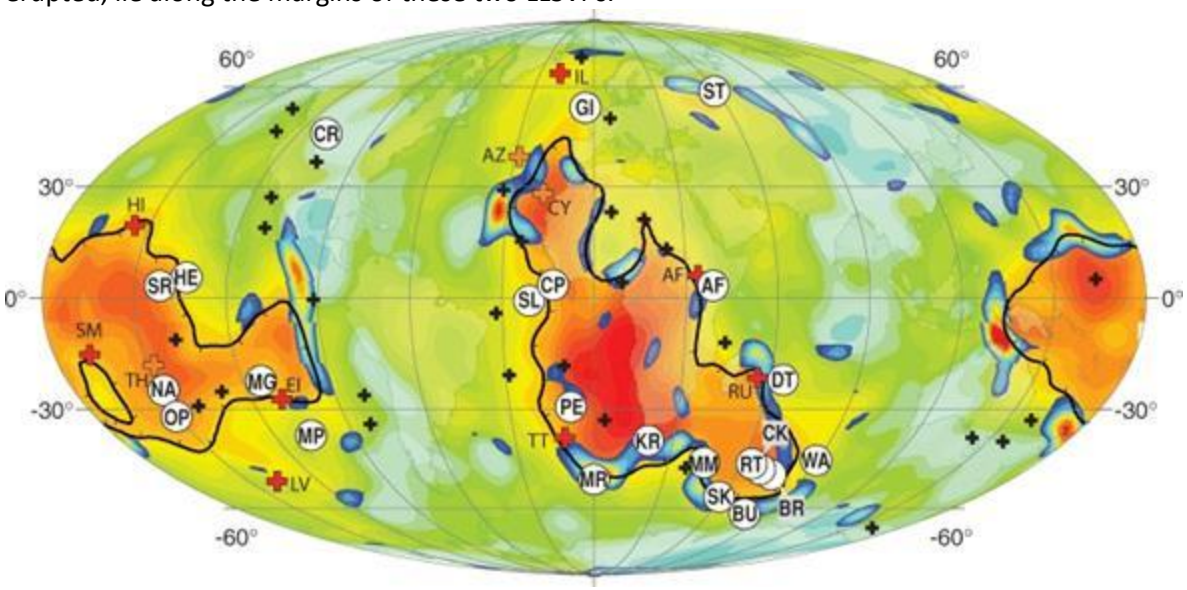
In regard to the paper by van der Hilst *et al.*, the focus is on accurate imaging of subducted slab material. In contrast to the Su *et al*. study, which used S-waves, the van der Hilst *et al*. paper employed P-waves, which do not capture the features at the bottom of the mantle as strongly as S-waves do. Nevertheless, these features are present in their Figure 1(f). They allude to them in their abstract as "long-wavelength heterogeneity near the core-mantle boundary."

The two low seismic velocity features displayed in red in the seismic tomography image shown above have recently received widespread attention in the earth science community. They are now referred to as 'large low-shear-velocity provinces', or LLSVPs for short. This term was introduced in 2008 by Ed Garnero and Alan McNamara in a *Science* paper

entitled “Structure and Dynamics of Earth’s Lower Mantle,” (http://www.mantleplumes.org/WebDocuments/Garnero2008.pdf). Concerning these features they state in this paper:

> Seismic data suggest that two broad regions with lowered shear-wave speeds and higher than average density lie beneath the Pacific and Africa. The African anomaly appears to extend upward from the CMB about 1000 km, whereas the height of the Pacific anomaly is less certain but probably at least 400 to 500 km. Each anomaly is about 15,000 km across, and together they cover nearly 50% of the CMB. The boundaries between these large low-shear-velocity provinces (LLSVPs) and normal mantle are sharp, as implied by seismic waves that graze LLSVP edges.

The figure below is from a PowerPoint presentation on LLSVPs by Bernhard Steinberger, entitled “Large Low Shear Velocity Provinces in the lowermost mantle and Plume Generation Zones at their margins” available at http://www.geodynamics.no/STEINBERGER/papers/talk_ntu.ppt. This figure highlights the observation that most of the world’s hotspots and what are called ‘large igneous provinces’, when mapped back to their locations when they erupted, lie along the margins of these two LLSVPs.



Caption: Large Low Shear Velocity Provinces (LLSVPs), one beneath part of Africa and the other beneath the central Pacific, in the lowermost mantle are outlined with a black contour corresponding to -1% reduction in the seismic shear wave speed. Plot is from the SMEAN tomography model of Becker & Boschi, 2002. Especially steep gradients in shear wave velocity are shown as blobs with blue edges. Reconstructed large igneous province (LIP) eruption sites (circles) and hotspots (crosses) are superimposed on the shear wave velocity plot. The correlation of the plume locations with the edges of the LLSVPs is striking.

So there is now no doubt concerning the reality of these megastructures at the base of the mantle. However, so much attention is now being focused on the LLSVPs that most people in the uniformitarian community seem to be largely ignoring the fact that the high shear wave speed of the material in the so-called ‘Pangean Trough’ is implying anomalousl low temperatures for this subducted material. Of course, I have been using the extremely low apparent temperature of this material to argue that its subduction must have been recent. return_to_Contents

94. In your response to question 31 (Q31), you said you thought the rise of sea level might be only 100-200 m during th Flood. However, how can this be consistent with Gen. 7:19 and 20, where it says the waters prevailed and all the high mountains were covered to a depth of 15 cubits? The word “prevailed” sounds to me like it cannot refer to intermittent tsunami-like waves. The word for “mountains” (*har*) is the same word used for Mount Sinai, for example. If there were no high mountains before the Flood, why would the Hebrew word for “high” (*gabowahh*) be used to modify the word

"mountain"? Also another Hebrew word for "hill" was available (*gibah*) if what was covered during the Flood was not the equivalent of post-Flood mountains, which were familiar to Moses' audience.

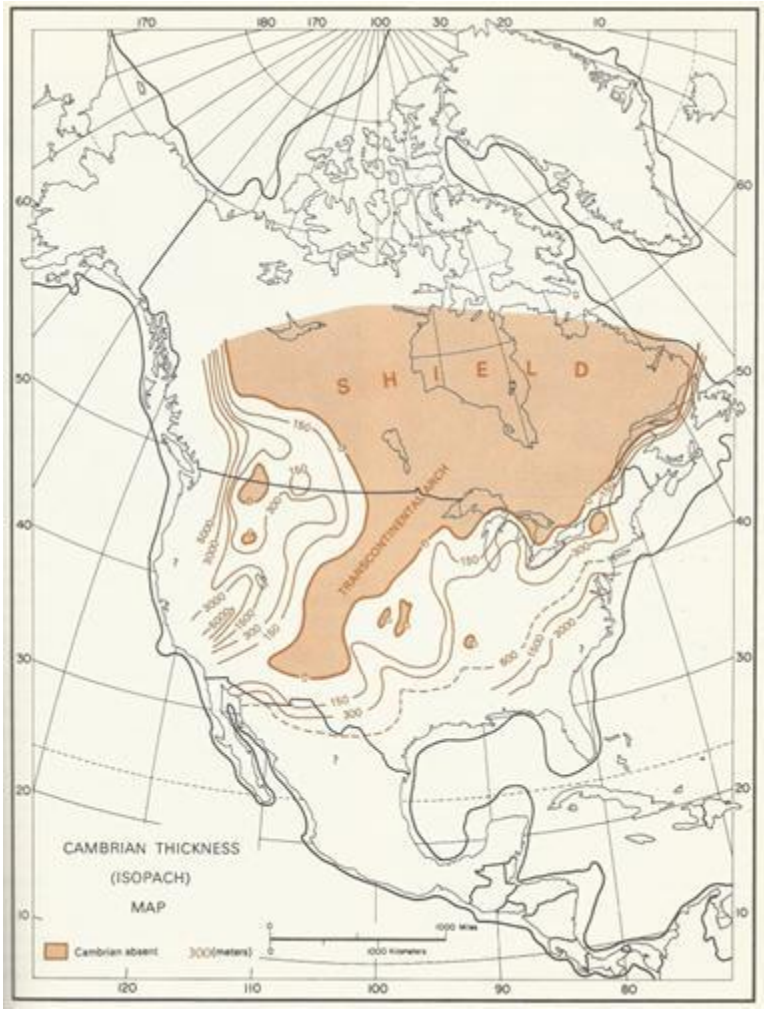
Response: I am persuaded these Hebrew words do indeed mean 'high mountains'. Furthermore, evidence from the geological record suggests that the Appalachian Mountains formed during the earlier part of the Flood were possibly as high as today's Himalayas but were beveled flat by subsequent intense erosion. Incredibly thick sequences of sedimentary rock in the basins to the west of the Appalachians testify to the huge volume of these mountains and the ferocity of the erosive processes. Moreover, in most of the continental shield areas of the world it is common to find roo zones of former high mountains with thousands of meters of rock formerly present apparently beveled completely away. Given these observations it seems likely to me that the waters of the Flood had extreme erosive power, sufficient to erode away huge mountain ranges in a matter of days. If water velocities are sufficiently high for cavitation to occur, the water depth does not need to be that great to degrade topographical features that significantly exceed the mean water depth.

I want to be forthright here in saying that I have no means by which I can with any degree of confidence put tight quantitative constraints on the water depth over the continents during the Flood. Generally speaking, however, water current speed varies inversely with water depth. Sustaining high water velocities seems to require relatively modest water depths. High water velocities seem to be needed to accomplish all the erosion which seems to have occurred during the Flood, especially to erode away the mountain belts which appeared during cataclysm. High water velocities also seem to be needed to abrade rock down to silt-sized particles and transport it over large distances as the sediment record appears to indicate. For these reasons I conclude that water depths of only a few hundred meters are more likely than those of one or two kilometers or more. It is particularly this requirement for so much erosion of crystalline rock and its physical abrasion to small particles that now pushes me toward smaller water depths over the continents during the Flood cataclysm. return_to_Contents

95. Could you please provide a short summary of the evidence and references as to why you think, as you said in your answer to question 47 (Q47), "the observational evidence for the opening and closing of the Iapetus Ocean and the associated tectonic signature in the continental rock record, including the Appalachian orogeny, is close to indisputable." You also characterized the evidence as strong in your response to question 24 (Q24) relative to the continental movements depicted in Blakey's maps, though maintaining these movements happened in a much shorter time frame than is conventionally held.

Response: One reference I have on my shelf is the textbook by R. Dott, Jr., and R. Batten entitled *Evolution of the Earth, 2nd Ed.*, published by McGraw Hill in 1976. What I will do here is to select a few figures from this book to give you what has to be only a sampling of the field work of hundreds to thousands of geologists over the preceding century to assemble the beginnings of a coherent picture of the physical rock record in the North Atlantic part of the world. Grante that most of these geologists had a uniformitarian outlook, the overall sequence of events they have inferred from the relationships of the various rock units to one another seems to be generally correct. It is primarily the time scale which they have assumed that is the problematic issue.

With that important caveat in view, let me attempt to provide a big picture summary. First, let us consider what the rock record seems to indicate about the geography during the early part of the Flood cataclysm. The figure below, Figure 11.19 from Dott and Batten's book, shows the thickness of only the Cambrian sediments over North America. Note that the sediment thickness tends to increase sharply as one approaches the margins of the craton. Also note the highland areas in much of what is today Canada and also along what is known as the Transcontinental Arch that trends south-southwest from what is now Minnesota toward Arizona. For the purposes of the following discussion, note especially that the sediment distribution implies that ocean lies off what is now the U.S. East Coast.



What does the subsequent part of the rock record in this part of the world indicate about the tectonic processes that were unfolding at the same time? The two figures below, also taken from Dott and Batten's book, provide a summary picture. The left hand figure provides snapshots of the rock record off the U.S. East Coast at four successive points from what would be early in the Flood until the formation of Pangea. In the first snapshot (A), we observe what corresponds t an oceanic passive margin, with sediments thickening as one approaches the edge of the craton. Then in the Ordovician, the rock sequence begins to record tectonic disturbance migrating westward from the eastern edge of the craton (B).

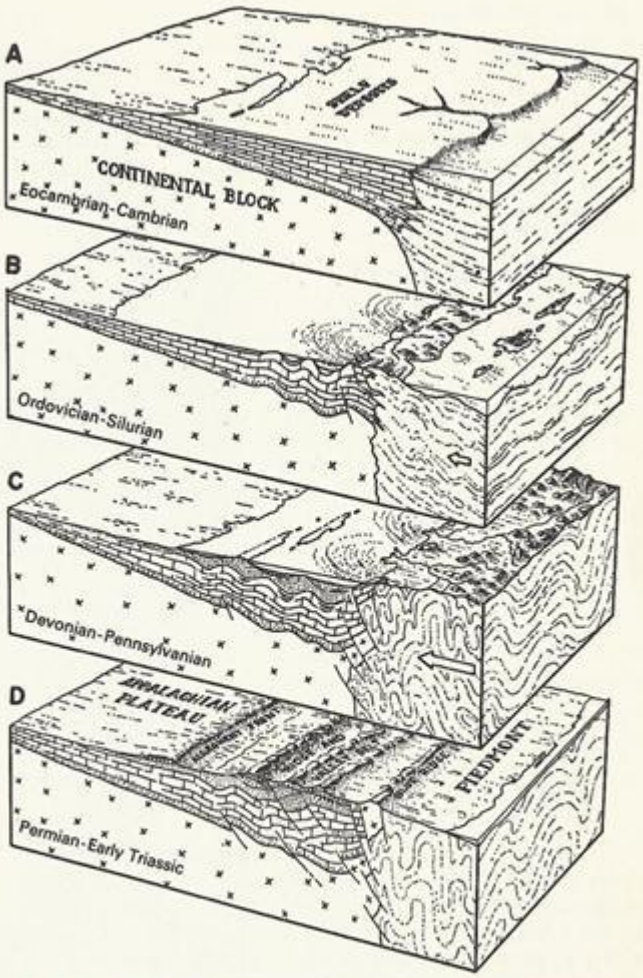


FIGURE 14.26 Diagrammatic summary of Appalachian history showing the gradual development of tectonic borderlands *within* the mobile belt through repeated orogenies and final culminating structural upheaval of the belt by apparent cratonward compression. *(Modified from Dietz and Holden, 1966,* Journal of Geology, *v. 74, p. 581; by permission of University of Chicago Press.)*

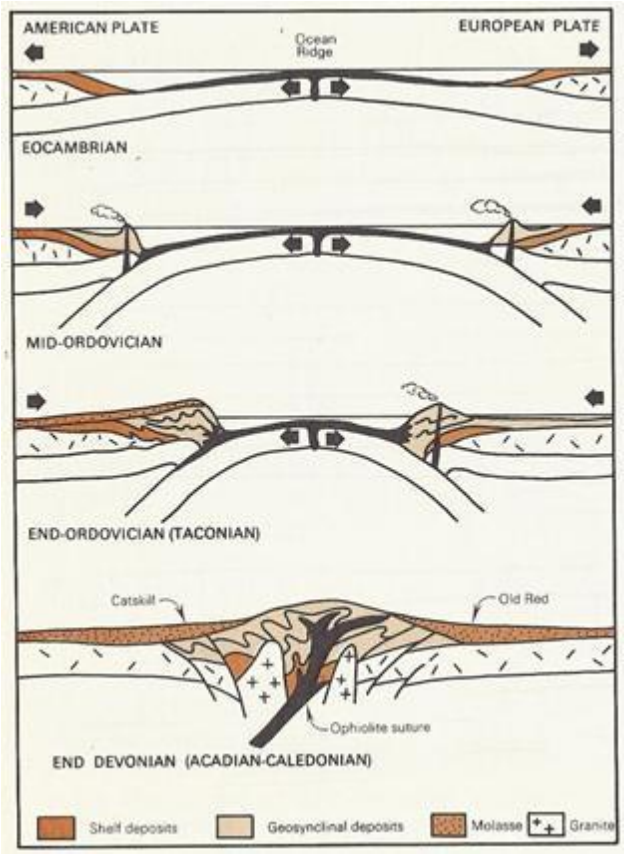


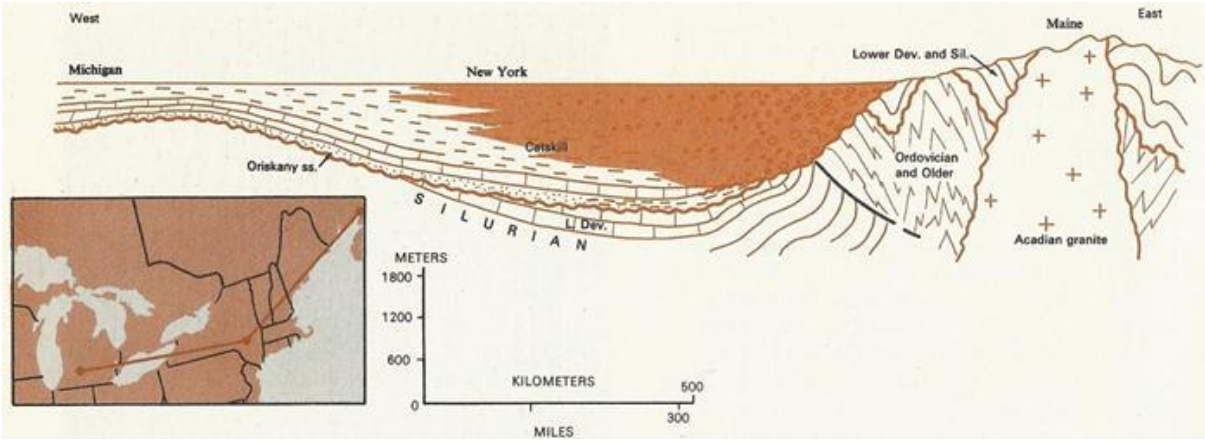
FIGURE 13.37 Hypothetical evolution of northern Appalachian–Caledonian mobile belts during closure of the postulated proto-Atlantic Ocean basin, which culminated in continental collision in Devonian time. Note that both continents had passive trailing edges with carbonate shelf zones facing the proto-Atlantic until mid-Ordovician time when subduction began. The old ocean basin completely disappeared later except for a mafic-rock suture zone (bottom). Note the symmetry of red Catskill and Old Red clastic wedges.

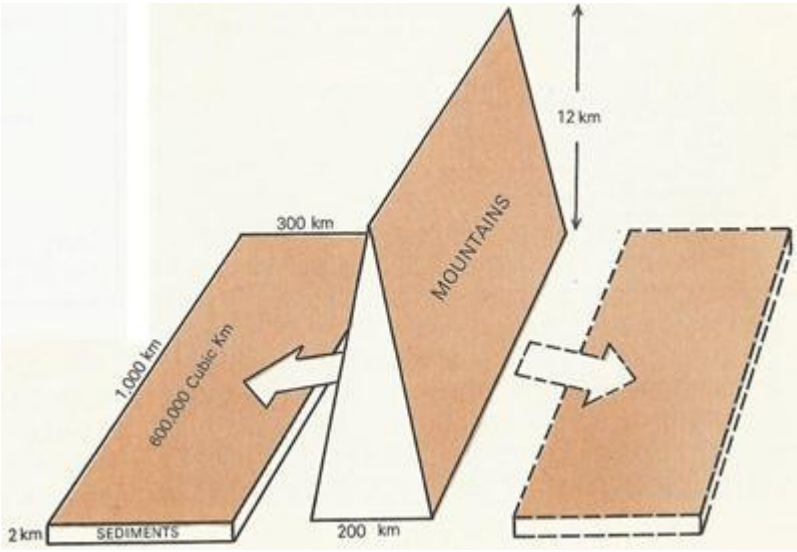
Figure 13.37 from Dott and Batten shows the tectonic regime inferred from the rock records of North American and Europe during this time interval. It shows the sort of highland area inferred for the Late Ordovician based on the types of igneous and metamorphic rocks shed from it. It also shows the symmetry of the rock records in North America and Europe in the spectacular Devonian Acadian-Caledonian Orogeny.

Sediment now begins to be shed toward the west from a new highland area where ocean had previously existed. Then in the Devonian a major pulse of further tectonic deformation occurs which results in huge volumes of sediments eroded from an eastern highland filling basins to the west (C). This Late Devonian pulse is known as the Acadian Orogeny, and what is known as the Catskill clastic wedge in eastern Pennsylvania and New York is sediment derived from the Acadian mountains, as will be described in more detail in subsequent figures. By the time that Pangea is assembled (D), the high topography has been largely beveled away.

The following two figures, Figure 13.30 and Figure 13.33 from Dott and Batten, highlight the immense volume of Devonian sediments eroded westward from the Acadian mountain range. Especially prominent is the Catskill wedge, chiefly composed of metamorphic and granitic rock fragments, feldspar, mica, and quartz. Its striking red color in the eastern part of the deposit is a result of a small amount of iron oxide between the grains. The volume of the Catskill

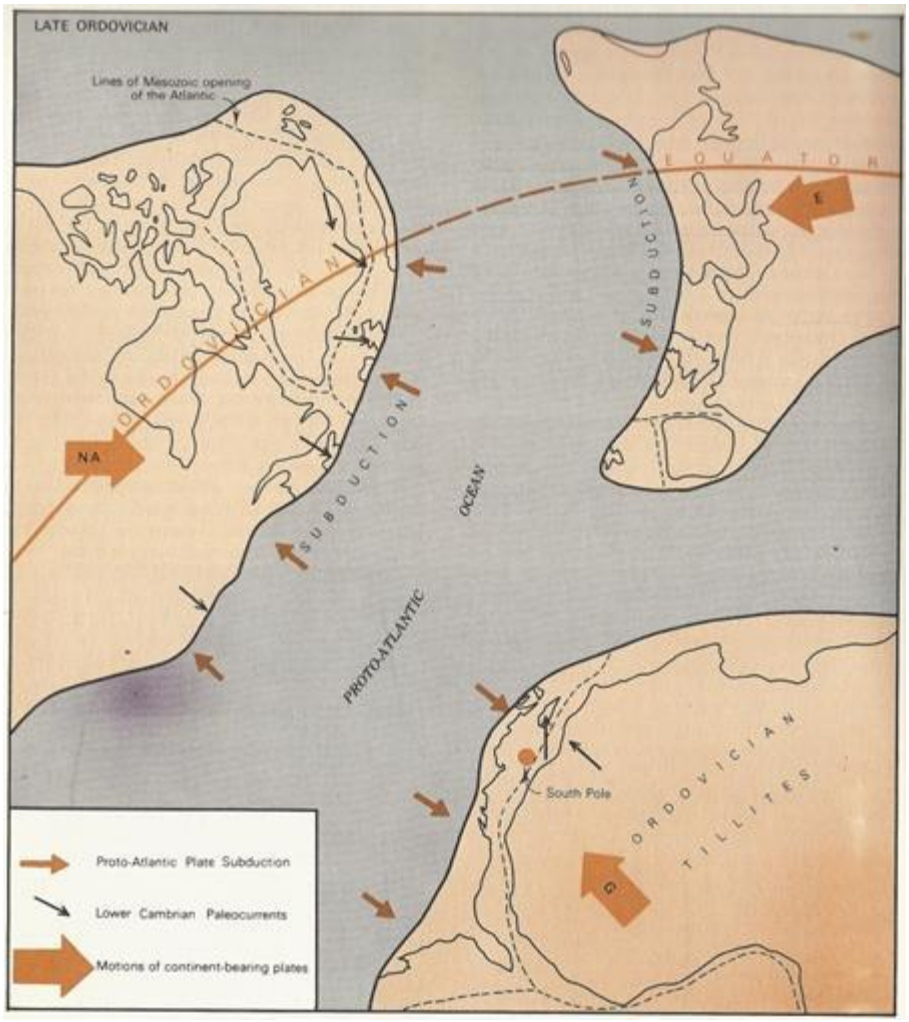
sediments is about 600,000 cubic kilometers. Assuming an equal volume of sediment was shed to the east (and there is good evidence in Europe that this was indeed the case) this sediment volume requires the erosion of a mountainous mas 1000 km long, 200 km wide, and 12 km high, which is 7 km higher than Mt. Everest. Because erosion likely accompanied the uplift, the mountains likely were never this tall.





Caption: Schematic diagram showing the volume of the Acadian mountain belt required as the source for the Catskill sediments and the Old Red Sandstone deposits in eastern Greenland and northwestern Europe.

The next figure, Figure 12.31 from Dott and Batten, is a schematic paleogeographic map showing the subduction of the Iapetus (or Proto-Atlantic) Ocean as North America (NA), Europe (E), and Gondwana (G) began their mutual approach in the Ordovician. All that remains of the Iapetus today are mafic oceanic igneous rocks and deep-sea sediments found within the old tectonic belts on either side of the present Atlantic. Note that at this point in earth history, what is now part of Scotland, Wales, and Norway was part of the North American craton, and what is now the easternmost and southeastern U.S. was then part of Gondwana. Also note the paleocurrent directions observed in the sediments indicate oceanward flow off the North American and Gondwana cratons. Let me mention also that I am highly dubious about the indicated South Pole location apart from the possibility that it represents a transient location due to the earth's rotationa instability during the Flood.

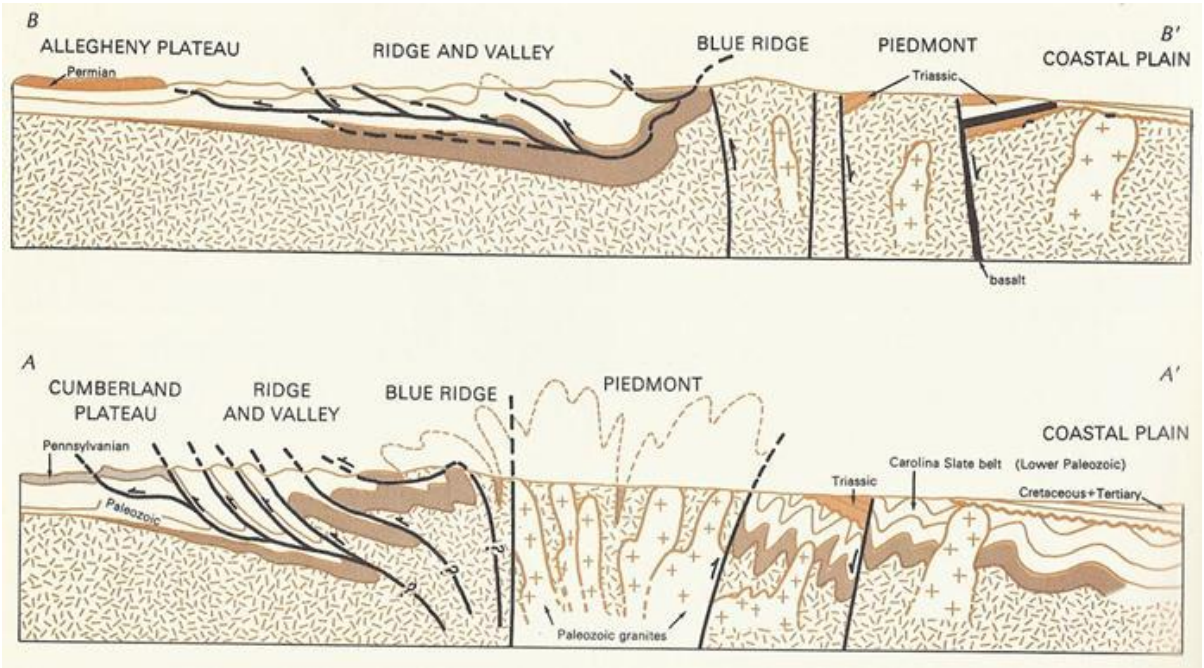


To summarize the preceding portion of my response, let me emphasize that there is considerable support in the sedimentary rocks of eastern North America and Europe for an ocean between these two land areas during the Cambrian part of the record, which corresponds to the very early part of the Flood. Moreover, there is equally compelling support for the subsequent closing of this ocean beginning in the Ordovician and culminating in the Devonian. These conclusions are based on the field work of many hundreds of geologists and a major effort to fit the individual pieces together to obtain a better grasp of the larger scale processes which were responsible for such dramatic change in the surface features of the earth.

As a final figure, I below provide Figure 14.24 from Dott and Batten, which shows two cross sections across the Appalachian belt. The upper one, B-B' is from central Ohio, across West Virginia, to the Atlantic Coast near the southern border of Virginia. The lower one, A-A', is further south, from southeastern Kentucky, eastern Tennessee, across western North Carolina, to the Atlantic Coast of northern Georgia. Note some degree of bilateral structural symmetry across the central Piedmont core of granitic rocks. Also note the interpretation of the western thrust faults as flattening downward so that they involve only the superficial sediment layers.

It is noteworthy that Dott and Batten in the context of this figure comment on the mechanics of thrust faulting and folding, which is so common in the Appalachian region. They state,

At the end of the last century, some European geologists suggested that thrust faulting and much of the associated folding might involve only the weak, superficial sediments and not the more rigid basement. That is, sediments migh wrinkle and slide over the basement like a run pushed across a floor. One of the main reasons for such a suggestion was the apparent weakness of the rocks involved in the thrust sheets. How could they be pushed so far? It was suggested instead that all the crumpling was simply caused by large scale sliding of weak strata off an isostatically upwarped basement ridge merely due to gravity.



It is my conviction that catastrophic processes are required to create the elevation gradients needed for gravity sliding of the sediment sheets to occur. Investigation of these fold and thrust belts around the earth therefore appears to me to be a very fruitful research area for creation scientists interested in strengthening the case for the recent global Flood.

Finally, in regard to underlying basis for Blakey's maps, let me comment that the very same process of synthesizing vast amounts of field observations and associated laboratory analyses to reach the conclusions just described concerning the North Atlantic has been applied by Blakey and others to the rest of the world. Blakey's maps are the result of that extremely laborious synthesis process. Dott and Batten in the 2nd edition of their book cover much of what was known about the rest of the world as of 35 years ago. The 7th edition is now available, and the authors are now Donald Prothero and Robert Dott, Jr. This might be a reasonable introduction to the geological history of the other continents that has been inferred mostly from their sedimentary rock records. return_to_Contents

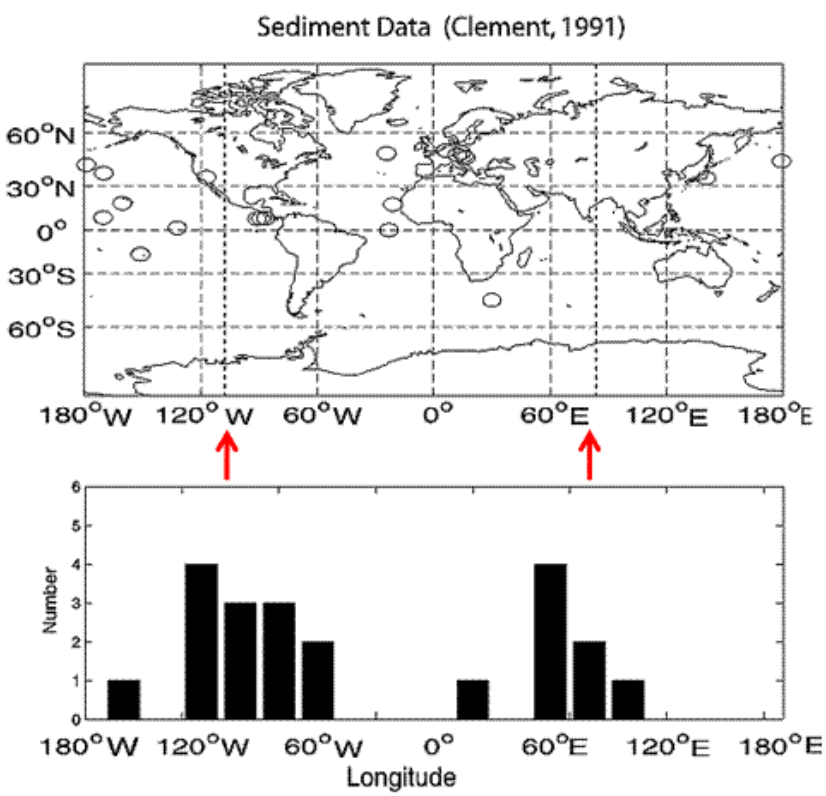
96. What might constitute observational geophysical evidence of rotational changes of the earth? Do you believe there is such evidence? Could curvilinear fracture zones be something that would give clues about rotational axis changes of the earth, or would the effects of it be more in the mantle?

Response: If the earth truly experienced rotational instability during the Flood similar to what I have suggested, there ought to be some clear physical evidence to support this fact. Your question prompted me to add some new diagnostics to the computer code I had originally developed to study these rotational mechanics issues. The new diagnostics output the actual acceleration field over the earth's surface which would have been acting on the surface rocks during the

interval of rotational instability. What I found was that the accelerations at the earth surface were as large as 1.8×10^{-6} m/s^2 in amplitude, or about 1.8×10^{-7} times the acceleration due to gravity.

The total force arising within a plate as a consequence of this acceleration field is the integral of the local acceleration times the rock density over the volume of the plate. To estimate the stress level on a specific plate boundary, one must apportion the total force acting on each of the two adjacent plates to the boundary segment in question, take the vector difference of the apportioned forces, and divide by the area of the boundary. If one were to ignore the actual pattern of accelerations and assume that at least in some cases the forces on adjacent plates might be nearly opposite in direction, one can obtain stress levels on the order of 2×10^7 N/m^2 or 20 MPa, which is not that far from the 100 MPa estimated to be the limiting stress value on many of the deforming plate boundaries on the earth today. However, the pattern of accelerations I observe is very smooth, essentially that simply of a changing the rotation rate for a spinning rigid body (as one should expect). In other words, there are no abrupt changes in acceleration anywhere on the sphere, and hence the stresses on the plate boundaries must be close to zero. From this I conclude the effects of unstable rotational behavior were probably negligible on the orientations of fracture zones and ridge axes during the Flood.

However, another type of geophysical observational data that already seems to be lending a measure of support to this sort of rotational instability is what is referred to as the virtual geomagnetic pole (VGP) paths. In the early 1990's it was found that patterns of paleomagnetism recorded in oriented grains of magnetic minerals in sediment cores seemed to be indicating that, within the intervals during which the earth's magnetic field had reversed its polarity in the past, the magnetic poles usually followed similar paths along the same preferred meridians, 180° apart, as shown in the histogram below.



History of virtual geomagnetic pole (VGP) paths based on the sediment data from Clements, 1991.

What is truly noteworthy about these data is that these preferred longitudes basically conform to the great circle, through the North and South geographic poles, which enclosed Pangea and also corresponds to the circle of subducted cold rock at the base of the mantle as revealed by most global seismic tomographic models. When a ring-shaped density anomaly aligned with this great circle is used to drive the rotational instability proposed for the Flood, the resulting motion of the earth's North and South geographic poles conforms precisely to this same great circle! Although all these things could be coincidental, I doubt that they are. Despite the huge amount of effort which would be involved, further investigations of the magnetic record in sediments from more locations around the world could shed some very significant new light on the locations of the magnetic poles as a function of time. Should such studies reveal that the magnetic poles were migrating along this great circle path, not just during brief episodes, but continuously through most of Phanerozoic history, this would provide stunning confirmation for rotational instability during the Flood and for the Flood itself.

Finally, the type of modeling work I have just barely begun in exploring the patterns of currents on the continents that arise from the forcing the rotational instability exerts on the water in the ocean basins could also conceivably provide some powerful confirmation. This is a daunting task, but a gifted young scientist who is called of God potentially could make a huge contribution to our understanding of the Flood by showing that actual sediment distributions can be explained by the large-scale water currents this mechanism generates. return_to_Contents

97. Would sea floor subduction and continent motion proceed in a more or less continuous manner or a pulsed/episodic manner? Do your computer models give any insight on this question?

Response: The modeling efforts I have undertaken up to now show the process unfolds in a relatively smooth manner, without any noticeable fits and starts. There is a quick ramp up in speed as the runaway begins and a slower ramp down as the cold material reaches and spreads out over the bottom boundary and the hot material spreads out below the lithospheric layer at the top boundary. I expect this will continue to be the case when more complex initial conditions to capture the earlier dynamics of the cataclysm are explored. return_to_Contents

98. Could you comment on Catastrophic Plate Tectonics regarding island chain formation, such as the Hawaiian Islands? Do you take Potassium/Argon radioactive dates as a relative chronology reflecting the ocean floor processes? Did the formation of the Hawaiian Islands take place during the Flood or after the Flood? Can the distances across the Hawaiian Island chain be related to rates of plate movement and subduction in your model? Over what approximate time frame would you envision the Hawaiian Islands forming?

Response: I consider the conventional understanding, namely, that island chains like Hawaii form as the result of an oceanic plate moving over a relatively stationary mantle hot spot/plume, also to be the most obvious and viable explanation within the CPT framework. In regard to whether or not I trust radioisotope dating for providing reliable relative dates for ocean floor processes, including the relative formation times of islands in an ocean island chain, the answer is yes. I gave my reasons in my answer to the first part of question 75 (Q75) above. Translating the published radioisotope ages for the Hawaiian Island chain into the time line for the Flood, I conclude that most of the chain formed during the Flood. Although I am cautious and somewhat tentative regarding the point in the uniformitarian time scale (which relies almost exclusively on radioisotope determinations) which marks the end of the Flood, the number I commonly use is 5 Ma. This means that all of the submerged Emperor Islands, dated roughly from 40 to 85 Ma, were formed during the Flood, as were all the Northwest Hawaiian Islands, collectively referred to as the Leeward Isles, dated from 7 to 30 Ma. (Here, of course, I am interpreting Ma to signify millions of years of nuclear decay *at presently observed decay rates*, with approximately 600 Ma of decay having occurred during a single year of actual time during the Genesis Flood.)

This leaves the Hawaiian Archipelago (also known as the Windward Isles), consisting of the islands comprising the U.S. state of Hawaii as possibly having formed in part or wholly after the Flood. The oldest of these islands, Kauai, ha lavas dated at 5.1 Ma. Kauai's Waimea Canyon, also known as the Grand Canyon of the Pacific, which is 14 miles long, a mile wide, 3600 feet deep, and cut through solid basalt, seems to require some extraordinary process for its formation. Tsunamis large enough to overtop the island at the end of or just after the Flood to me seem to be a plausible possibility. I place the formation of the remainder of the Hawaiian Archipelago within the first century or so after the Flood when the hotspot was more active than it is today and the speed of the Pacific Plate was decreasing to its present value.

The distances across the Hawaiian Island chain do reflect the rates of plate movement and subduction in the CPT framework. The total length of the chain is about 5000 km. The radioisotope ages for the part of the chain formed durin the Flood range roughly from 5 to 85 Ma, which corresponds to the Flood's latest stages, including the regressive stage when the Flood waters were draining from the continents. Taking 200 days as an estimate for this time interval gives an average plate speed during that interval of about 1 km/hr or 0.6 mph.

In regard to the other Flood models, those models which do not include any relative motion of the Pacific Plate over the deeper mantle would seem hard pressed in my assessment to explain such a chain of volcanoes whose radioisotope ages vary in such a systematic manner. To me the Hawaiian-Emperor Island chain testifies rather clearly to the reality of large amounts of actual plate motion during the Genesis Flood and thus to the requirement for some sort of model at least approximating that of catastrophic plate tectonics. return_to_Contents

99. Massive, thick deposits of sediment occur in a variety of places over the earth that are difficult to explain. Rocks fitting this category include the Belt Supergroup of Montana. Here is a set of rocks described as being part of Mesoproterozoic sequences. For many creation geologists these are considered to be part of the pre-Flood rock accumulation. One reason given for this conclusion is that these sediments contain no fossils. However, the Belt Supergroup represents an accumulated thickness of sediments up to 18,000 - 20,000 meters (http://en.wikipedia.org/wiki/Belt_Supergroup). Much of the deposit is composed of fine-grained sands or mudstones with laminations only millimeters thick. Please explain how such sedimentary formations originated, according to your understanding, either during or prior to the Flood.

Response: As I have made clear in my answers to several of the previous questions, I am persuaded by the research of the RATE team that radioisotope dating methods do, as a general rule, give reliable *relative* dates for igneous and metamorphic rocks. What is the logic behind such a conclusion? Very briefly, the RATE research, which included more than a thousand radioisotope analyses on a very wide assortment of rock samples showed, with little room for uncertainty, that—not a little—but a vast amount of nuclear decay has occurred within the earth's rocks since the earth was originally created. There is also an unmistakable pattern that the higher an igneous intrusion or a volcanic tuff bed occurs in the geological record, the smaller are the levels of nuclear decay products it contains. Because of this pattern o diminishing levels of nuclear decay products as one moves upward through the geological record, confirmed with such vast numbers of rocks and radioisotope measurements, it is possible to apply radioisotope methods to determine with a reasonable level of confidence the relative timings of when various igneous intrusions occurred and tuff beds were deposited.

Applying this approach to the Belt Supergroup rocks, in my opinion one must conclude that this extraordinary sequence of sedimentary rocks must have formed prior to the Flood. This conclusion, of course, relies on an assumption regarding the point in the rock record that marks the onset of the Flood. To me that golden spike must correspond to that well-acknowledged abrupt first appearance of multi-celled organisms, which also coincides with a widespread physical unconformity in the rock record. This stratigraphic and paleontological boundary occurs at the base of the so-called Ediacaran layers. Igneous intrusions localized to this point in the record yield radioisotope ages of about 580

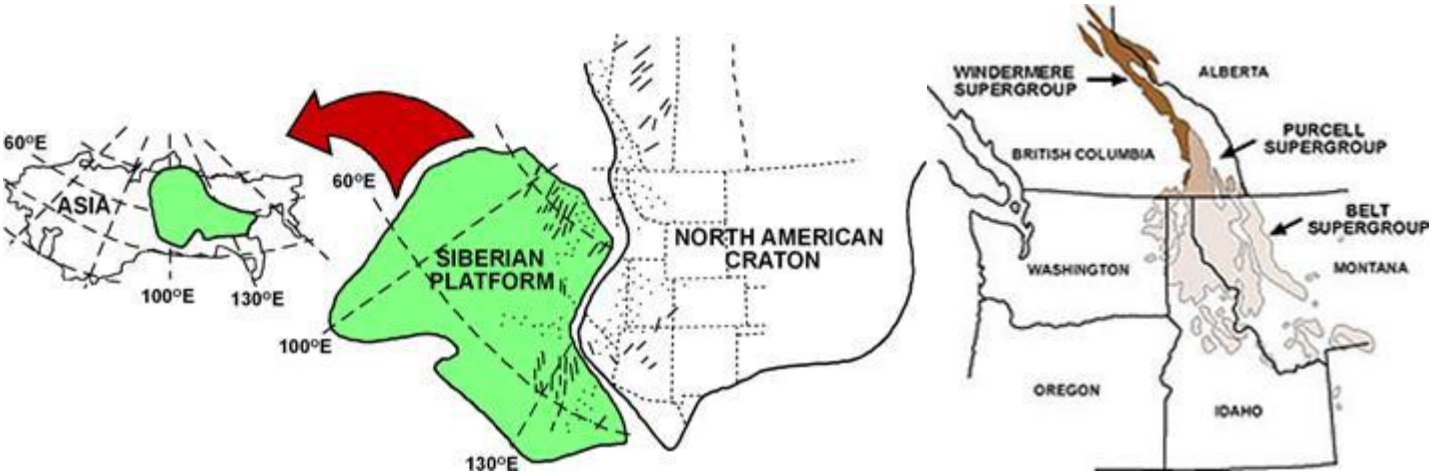
Ma. Therefore, radioisotope ages of igneous intrusions in Belt Supergroup rocks in the range of 1400-1470 Ma logically place the deposition of these rocks prior to the onset of the Flood.

To me the only feasible time these sediments could have been deposited in the framework of the history of the earth given in Scripture is during Creation Week prior to the creation of plant life on Day 3. There are several reasons why I conclude that deposition of the Belt sediments must occur during the early part of Creation Week and not in the interval between Creation Week and the Flood. One is that 900 million years' worth of nuclear decay (i.e., 1470 Ma - 580 Ma) at present rates unfolding during the short span of time between creation and the Flood would have devastating consequences for all living things on earth. Next, the amount of large-scale tectonic changes that occurred during the interval in the rock record between 1470 Ma and 580 Ma compare with, if not exceed, those of the Flood itself. Those catastrophic changes logically must be associated with the events during the early part of Creation Day 3. Scripture gives no hint of such catastrophism in the interval between Creation and the Flood.

I therefore interpret the Belt Supergroup rocks as sediments which were generated in the process of God's fashioning the earth as a suitable habitat for the life forms He created during the remainder of Creation Week. Certainly, God's declaration on Day 3, "Let the waters below the heavens be gathered into one place, and let the dry land appear," must imply mind-boggling tectonic, erosional, and sedimentary activity on a global scale. So to me there is a sound Biblical basis for inferring that formations such as the Belt Supergroup occurred within Creation Week, likely during the early par of Day 3.

Truly, the rate at which 18-20 km total depth of sediment, much of it fine-grained mudstones with laminations only millimeters thick, formed is beyond anything we can imagine in terms of present-day processes. But the whole context o Genesis 1 is that of miraculous, supernatural activity by the Creator. This is the way the God of the Bible introduces Himself on the Bible's very first page. The complexity of living organisms, with their physical makeup specified to the level of each individual atom in every molecule in their being, absolutely requires nearly instantaneous miraculous creation from all we know from science today. If God's supernatural actions in regard to the creation of life are so clear and obvious, is there any serious reason to question that He acted in a similarly miraculous manner when He fashioned the physical earth?

As far as the specific geological/tectonic context is concerned, it appears that the Belt Supergroup sediments were deposited in a deep gash at the edge of the North American craton, produced as some other continental block, possibly the Siberian craton, rifted away from North America's western margin in a manner similar to that proposed by Don Winston of the University of Montana in the left panel below. Again, I take this to have occurred early on Day 3 of Creation Week.



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100. Would not the removal of ocean water by the steam jets result in a lowering of sea level?

Response: Because the thermal energy available is insufficient for steam in the jets to reach the earth's escape velocity, none of the steam and entrained water can leave the earth's atmosphere. The kinetic energy of steam in the jets can be no greater than the thermal energy of supercritical water at the basalt melting temperature at the ocean depths where the jets originate. Even though this thermal energy is sufficient for the steam to reach supersonic speeds, it is far from enough for the steam to reach the earth's escape velocity. Hence, this water vapor must remain within the earth's atmosphere. Moreover, it appears that much, perhaps even most, of the kinetic energy of the jets is converted to gravitational potential energy in the liquid water that gets entrained by the jets and carried aloft. The mixing of the wate vapor aloft with the entrained cool liquid water allows for some of this vapor to give up its latent heat of vaporization to the liquid water and to condense and precipitate as rain. No doubt, some amount of water in the form of water vapor would have been added to the atmosphere temporarily while the jets were active and for some time afterward. Certainly, detailed modeling of these processes would be desirable to quantify just what this extra atmospheric water volume might have been. My sense is that the amount likely would have been relatively small and its temporary effect on the global sea level would not have been significant. return_to_Contents

101. Is it possible that the water which emerged from the 'fountains of the great deep' was from a subterranean source?

Response: First it is important to be clear on the meaning of the phrase 'great deep'. When one looks into the meaning of the Hebrew word 'tehom', generally translated 'deep', in most places it means deep *water*. Examples include Genesis 1:2, "And the earth was formless and void, and darkness was over the face of the deep (tehom), and the Spirit of God wa moving over the face of the *waters*;" Ps. 104:6-7, "You covered it (the earth) with the deep (tehom) as with a garment; the *waters* were standing above the mountains; at Your rebuke they fled, at the sound of Your thunder they hurried away;" Job 38:16, "Have you entered into the *springs* of the *sea*? Or have you walked in the recesses of the deep (tehom)?"; Prov. 8:23-29, "From everlasting I (wisdom) was established, from the beginning, from the earliest times of the earth. When there were no depths (tehom) I was brought forth, when there were no *springs* abounding with *water*. Before the mountains were settled, before the hills I was brought forth, while He had not yet made the land and the fields, nor the first dust of the world. When He established the heavens I was there, when He inscribed a circle on the face of the deep (tehom), when He made firm the skies above, when the *springs* of the deep (tehom) became fixed, when He set for the *sea* its boundary, so that the *water* should not transgress His command, when He marked out the foundations of the land."

I quote these verses not only to highlight the association of the terms 'waters', 'sea', and 'springs' with the word 'tehom',

but also to illustrate that these associations apply during creation (Gen. 1:2, Prov. 8:23-29), through the Flood (Ps. 104:6-7), and after the Flood (Job 38:16). With this bit of backdrop, what are the possibilities for the meaning of the phrase 'fountains of the great deep' found in Genesis 7 and 8? Let's begin with the two words 'great deep'. The Hebrew word 'rab' for 'great' is a common Hebrew word with a meaning very close to the English word 'great' in most cases. To me most natural interpretation, especially given the way 'tehom' is used in so many places, and the way most commentators through the centuries have understood it, is that of the 'deep ocean.' To me it is a real stretch to interpret it as some seem to desire to interpret it as 'waters deep below the land surface', that is, a subterranean water chamber. I recall Job 41:31-32 where God Himself is describing Leviathan to Job, "He (Leviathan) makes the depths (tehom) boil like a pot; he makes the sea like a jar of ointment. Behind him he makes a wake to shine; one would think the deep (tehom) to be gray haired." Surely, it is the open sea that is in view here, not a subterranean water chamber.

So if the 'great deep' is referring to the deep ocean in the sense of the present earth, and I earnestly believe that is the case, then the fountains I describe in the context of CPT are very much from this 'great deep'. In this CPT framework the steam in these spectacular fountain-like jets as well as the water that becomes entrained in the fringes of the jets and lofted high into the atmosphere is *ocean water*. A possibility I have generally not addressed is whether or not these fountains might also be supplying some new water to the earth's surface instead of merely recycling existing pre-Flood ocean water. In regard to that issue, there was almost certainly some water, that had been present within the crystal lattices of the minerals in the mantle rock which melted at the spreading ridges, which in turn was released as water vapor as part of the seafloor spreading process. However, this water would have been partially, if not mostly, compensated for by the water carried back into the earth at subduction zones by the subduction process. I do not dismiss out of hand the possibility that prior to the Flood there may have been more water in upper mantle rock than the roughly 0.1% level currently estimated for these rocks. If that were the case, then there well could have been a net increase in the water in the oceans at the result of the Flood. However, at this point, however, I see no compelling reason, either from Scripture or from any observational data I know of, to include this extra complexity, especially when i is so difficult to constrain in any quantitative way.

In summary, if the term ‘great deep’ in Scripture refers to the deep ocean, as I earnestly believe it does, then the ‘fountains of the great deep’ referred to in Genesis 7 and 8 logically must be originating from the bottom of the pre-Flood ocean basins. To me it is also likely that these fountains have a close connection with the ‘springs of the deep’ mentioned in Proverbs 8 in the context of creation and the ‘springs of the sea’ and ‘recesses of the deep’ mentioned in Job 38 in the context of the earth after the Flood. return_to_Contents