# NUMERICAL SIMULATION OF THE LARGE-SCALE TECTONIC CHANGES ACCOMPANYING THE FLOOD

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## ABSTRACT

This paper addresses briefly some of the major difficulties in attempting to understand and model the geological and tectonic change of the Paleozoic and Mesozoic portions of the rock record as occurring during the span of but a single year--the year of the biblical Flood. A relatively simple tectonic model is proposed that assumes a pre-Flood earth with a single supercontinent, an intact lithosphere (that is, a lithosphere not broken into plates), and a convecting mantle somewhat warmer than at present. The main energy source for the catastrophe is the gravitational potential energy of the cold, dense lithosphere relative to the warmer mantle below. At the onset of the catastrophe, the lithosphere fractures, and its oceanic portions sink and induce a flow throughout the mantle. Replacement of the pre-Flood oceanic lithosphere with hot, buoyant material from the mantle raises the sea level some 2000 meters. Flow in the mantle pulls the supercontinent apart and induces significant vertical tectonic motions--especially in areas where oceanic lithosphere is being subducted beneath continental regions. Results from a numerical simulation are presented.
Keywords: deluge, tectonic catastrophe, mantle dynamics.

## INTRODUCTION

The biblical Flood described in Genesis 6-8 was an event that resulted in death to essentially all the air-breathing life on earth except for the creatures preserved by God in Noah's ark. The physical consequences of the catastrophe of this magnitude must have been preserved in the geological record. A crucial question then is, where in the earth's geological history does the evidence for the biblical Flood appear?

Students who accept the biblical account as genuine and who have sought the answer to this question generally have concluded there is but one viable possibility. It is that the beginning of the Flood must correlate with the abrupt discontinuity in the fossil record at the Precambrian-Cambrian boundary (1). This point in the geological record not only marks a sharply-defined beginning to the abundant occurrence of fossils, but it also represents a nearly worldwide stratigraphic unconformity in the rocks themselves.

Two obvious major difficulties in identifying the onset of the Flood with this point in the geological record are, first, that a staggering amount of geological change is implied between the beginning of the Flood and now and, second, that radiometric dating techniques place this point in the record at approximately 600 million years ago. Nevertheless, during the first 90% of this portion of the geological record (as measured by radiometric methods) there is dramatic physical evidence for global geological catastrophe. Austin (2) has assembled compelling evidence that the world's major coal deposits are derived from huge mats of floating plant debris. Ager (3) has pointed out the surprising uniformity worldwide in the lithographic units during Paleozoic and Mesozoic portions of the the geological record. A sizable fraction of the sedimentary rocks for this major portion of earth history are turbidites (4), that is, rocks formed as the result of catastrophic underwater sediment slides. Furthermore, the frequent occurrence of fossils themselves in the sediments testify to catastrophic, as opposed to tranquil, conditions. Indeed, the assertion that a large fraction of the geological change in the earth's past is the result of catastrophic processes is not as radical as was believed a few decades ago (5).

In regard to the half-billion year time scale for this segment of earth history as given by radiometric techniques, it can only be pointed out that these methods are predicated on the assumption of time invariance of the natural laws. If the nuclear decay rates have not been constant with time, then the dates obtained by these methods do not represent a correct absolute measure of time. Although the evidence is limited at this point, the work by

Gentry (6,7,8) on radiohalos from the decay of polonium suggests that nuclear decay rates have not been constant during the earth's past. On the other hand, there is strong evidence that there has been much more radioactive decay since the Cambrian rocks were formed than can be accounted for in only a few thousand years at present rates. The logical conclusion if the Flood is responsible for Cambrian geology is that the rates where much higher during the Flood catastrophe than are measured today.

One of the most fundamental questions arising from the proposal that onset of the Flood correlates with the Precambrian-Cambrian boundary is, what was the mechanism responsible for such massive global upheaval? A number of mechanisms have been proposed, including direct impacts by extra-terrestrial bodies (9), tidal effects from close encounters with such bodies, rapid radiogenic heating within the earth, earth expansion caused by change in the electric permittivity (10), as well as many others. This author believes a critical clue in identifying the correct mechanism is the style of the large-scale tectonic change associated with the Flood itself and the period since.

The revolution in the earth sciences that occurred in the 1960's with the acceptance of the concepts of plate tectonics sensitized the scientific community to several important observations. One is that large displacements (11) among the continents have occurred, particularly since the beginning of the Mesozoic part of the geological record. Evidence is strong that a single supercontinent, Pangea, existed at that point in the earth's past (12). Furthermore, ocean floor older than Mesozoic no longer seems to exist (13), which implies that all present day ocean floor has been formed since that time. Closely related to these observations is the fact that a 40,000 mile long system of mid-ocean ridges exists today. Transverse to these ridges both the ocean depth and the ocean floor age increase, as one moves away from the ridge. Finally, adjacent to the deep ocean trenches there is compelling evidence, mostly seismic, that oceanic lithosphere is plunging back into the mantle (14). Although these conclusions were understood and widely accepted over twenty years ago, the mechanism responsible for driving the lithospheric motions has remained obscure. It is generally assumed that thermal convection in the mantle is responsible for the dynamics observed at the surface, but to date no one has been able to produce an acceptable model connecting mantle convection with the observed pattern of plate motion (15).

Placing the beginning of the Flood at the Precambrian-Cambrian boundary implies that dramatic tectonic change including the breakup of the supercontinent Pangea, the subduction of all the pre-Mesozoic oceanic lithosphere, and the formation and cooling of all the present-day oceanic lithosphere must have occurred during and since the Flood. It is the author's firm conviction that any credible model for the Flood catastrophe must be able to account for these major tectonic phenomena and do so on a brief time-scale.

## THE ENERGY SOURCE

One of the most basic questions involved with understanding the Flood catastrophe is, what mechanism was responsible for the tremendous amount of tectonic work that took place? What was the nature of the forces that pulled Pangea apart and overcame the mantle's resistance to deformation to disperse the fragments by thousands of kilometers in a brief period? What could produce such dramatic tectonic change and yet permit the sedimentary record to develop with its astonishing degree of uniformity and correlation from point to point on the planet? Clearly, conditions in the mantle must have played a central role.

An important clue in discovering what unfolded in the mantle is the observation that no pre-Mesozoic ocean floor is known to exist on the earth today. The simplest conclusion to be derived from this observation is that all of the pre-Flood oceanic lithosphere has been subducted. Assuming that the end of the Flood year corresponds approximately with the end of the Mesozoic portion of the record, it follows that a significant portion of the pre-Flood ocean floor sank into the mantle during the Flood year itself. Let us consider the energetics of rapidly sinking slabs of lithosphere.

The lithosphere represents the mantle's cold upper thermal boundary layer. Since the density of oceanic lithosphere (which lacks the layer of buoyant continental crust that distinguishes the continental lithosphere) is higher than the underlying hot mantle, it is gravitationally unstable, that is, it has a natural tendency to sink. This cold layer of rock possesses gravitational potential energy relative to the mantle below. The amount of this energy per unit volume can be readily estimated as the product of excess density and the gravitational acceleration and the depth of the mantle. The fractional excess in density is the product of the volume coefficient of thermal expansion and the temperature difference between the underlying mantle and the lithosphere. It is here convenient to assume the material sinks in an adiabatic fashion, which is reasonable if we are dealing with a time scale on the order of a year. Let us assume that amount of lithosphere that could sink to the bottom of the mantle to represent a layer 100 km thick covering 30% of the earth's surface. If we further assume a volume coefficient of thermal expansion of $2.5 \times 10^{-5} K^{-1}$, an uncompressed density of 3400 kg/m$^3$, a mean temperature difference of 1000 K, gravitational acceleration of 10 m/s$^2$, and a mantle depth of 2500 km, we obtain a value for the potential energy of 3 x 10$^{28}$ J. This is equivalent to the kinetic energy of approximately 100 asteroids each 100 km in diameter moving at 20 km/s. Clearly the sinking of a significant fraction of the earth's oceanic lithosphere in a brief period provides a huge supply of energy for performing tectonic work. In regard to an energy source, it would therefore appear that none besides the sinking oceanic lithosphere is required, provided the process can somehow be initiated and the mantle viscosity is sufficiently low.

## THE VISCOSITY ISSUE

Of course, a crucial question is how could the mantle possibly be deformable enough to allow 100 km thick slabs of lithosphere to sink through it in a year's time? First of all, for nonspecialists it may seem strange to treat the silicate rock that comprises the mantle as a viscous fluid. Experimental investigation (16) of the deformation properties of the silicate minerals such as olivine at high pressures, however, reveal that they flow under stress as a result of propagation of dislocations. The process of dislocation creep is a thermally activated one, that is, the creep rate depends exponentially on temperature. The temperature dependence has the form $\exp(E^*/RT)$, where $E^*$ is an activation energy per mole, $R$ is the universal gas constant, and $T$ is absolute temperature. For the mineral olivine the value for $E^*$ is on the order of 500,000 J/mole (17) and so the ratio $E^*/R$ is about 63,000 K. A change in temperature from 1500 K to 1800 K increases the creep rate by three orders of magnitude. This example shows how extremely sensitive the deformation properties of mantle rock are to temperature. A few hundred degrees change in temperature implies several orders of magnitude change in the viscosity.

Let us now consider how large a temperature rise should be expected as the gravitational potential energy of the cold lithosphere is converted to heat as the lithosphere sinks through the mantle. Using the values from the preceding section, one finds the energy per unit volume of lithosphere to be 2.1 x 10$^9$ J/m$^3$. If we assume the volume in which significant shear deformation occurs to equal the volume of the sinking slab and assume a value for the specific heat of 1000 J/kg/K and a density of 3400 kg/m$^3$, we obtain a temperature rise in the deformation zone of 600 K. Such a large temperature rise, of course, implies a dramatic decrease in the viscosity. This calculation suggests that the effect of shear heating can play a major role in the physics of large slabs of lithosphere sinking through the mantle.

Figure 1 shows contours of the shear heating rate associated with a vertically sinking slab 100 km by 500 km in cross section. The arrows represent the velocity field. This calculation was performed on grid by 64 × 64 cells using a two-dimensional finite element code. The temperature dependence of the viscosity for this case was weak (the activation energy was only about 30% of the value estimated for the mantle rock). The contours show that the heating is concentrated in a zone immediately adjacent to the slab. As the strength of the temperature dependence was increased, a numerical instability appeared which could not be overcome even by severe limiting of the time step. Since a physical instability under such circumstances is plausible, it is suspected that the numerical instability does indeed reveal the conditions for which a thermal runaway effect can be expected. Under such conditions, the shear heating reduces the viscosity in zones of large shear and the reduced viscosity in turn concentrates the deformation in these zones which leads to even greater shear heating there. As far as sensitivity to instability is concerned for this problem, two parameters appear to be critical. These are the thermal activation energy for the viscosity and the background value of the viscosity itself. Experimental evidence (16) strongly indicates activation energies for mantle minerals are well beyond the threshold for which instability was observed in the numerical experiments. The issue of background viscosity has to do with the ability of conduction to diffuse the shear generated heat. When the sinking time for the slab is brief relative to the thermal diffusion time associated with the shear heating zone, then thermal diffusion may be neglected. Consider the case of a sinking sphere. The Stokes velocity (18) $v$ for a sphere (apart from any shear heating effects on viscosity) is given by $0.22R^2\Delta\rho g/\mu$ where $R$ is the radius, $\Delta\rho$ is the density difference between the sphere and the fluid, $g$ is gravitational acceleration, and $\mu$ is dynamic shear viscosity. The thermal diffusion time is on the order of $L^2/\kappa$ (19), where $L$ is the half-width of the thermal anomaly and $\kappa$ is the thermal diffusivity. The condition for negligible thermal diffusion is $L^2/\kappa \gg 2R/v$ or $\mu \ll 0.11RL^2\Delta\rho g/\kappa$. If we take $R$ = 100 km, $L$ = 25 km, $\Delta\rho = \rho\alpha\Delta T = (4500\ \mathrm{kg/m^3})(2.5 \times 10^{-5}\mathrm{K^{-1}})(1000\ \mathrm{K})^3 = 113\ \mathrm{kg/m^2}$, $g = 10\ \mathrm{m/s^2}$, and $\kappa = 10^{-6}\mathrm{m^2/s}$, we find that the dynamic viscosity must be small compared with 8 × 10$^{21}$ Pa-s. This value is near to the current estimates for the mean viscosity of the mantle. Therefore, conditions in the present mantle are only modestly unfavorable for this mechanism to operate. If the pre-Flood mantle were warmer than present by a few hundred degrees and its mean viscosity consequently lower by a few orders of magnitude, then it appears that the potential for such a tectonic catastrophe indeed would have been indeed favorable. Clearly, more numerical simulation is needed to resolve the details of this process. In particular an estimate for the terminal velocity of the slab would be useful.

## CONFLICT WITH RADIOMETRIC DATING

One of the most obvious points of conflict between the Flood model presented here and views commonly held in the science community at large is the time scale associated with the geological record. Since the commonly accepted time scale is based almost exclusively on radiometric methods, the issue reduces essentially to the one of whether the radiometric methods provide a correct measurement of absolute time.

Since there appears to be abundant evidence that much more radioactive decay has occurred during the earth's history--even since the beginning of the Cambrian--than can be accounted for in just a few thousand years at present rates, it seems clear that the issue further reduces to the constancy of the decay rates themselves. Evidence for vast amounts of nuclear decay includes the physical evidence from radiohalos and fission tracks and well as geochemical evidence for higher quantities of daughter products in rocks containing larger quantities of radioactively unstable isotopes. The isotope data in general also show a distinct scarcity of isotopes with half-lives currently measured as less than $10^8$ years.

It is therefore relevant to inquire if there is any evidence that might suggest nuclear decay rates have not been constant during the earth's history. Such evidence does exist, although more evidence is needed in the author's opinion to make the case a compelling one. This evidence for variation in the nuclear decay rates is primarily through the work of R. V. Gentry on radiohalos. These halos, also referred to as pleochroic halos, are formed as alpha particles emanating from a mineral grain containing high concentrations of unstable elements such as uranium and thorium penetrate and damage the surrounding crystalline lattice. In crystalline rocks like granite there is a tendency for the large-ion elements like uranium, because of their size, to be highly concentrated in certain special minerals like zircon, xenotime, and monazite (6). If their concentration is high enough, the radiation damage in the surrounding crystal gives rise to a distinctive pattern of colored rings concentric to the radioactive mineral, when viewed in thin-section under a microscope with polarized light. Because the alpha particle has a precise range of travel in a given mineral for a given initial energy, it is possible to identify the isotope emitting the alpha particles responsible for a given halo ring simply by measuring its radius.

The most common radiohalos are those from uranium-238 that display eight rings corresponding to the eight alpha transitions as uranium-238 decays to lead-206. Halos having only the rings of one or more of the isotopes of the element polonium, however, have been reported by a number of workers. The most extensive work on these halos has been done by R. V. Gentry (6,7,8). The reason that polonium halos are of special interest is that the three common isotopes of polonium, Po-210, Po-214, and Po-218, have half-lives of only 140 days, 64 microseconds, and 3 minutes, respectively. The beta-precursors of Po-214, Pb-214 and Bi-214, have half-lives of 27 minutes and 20 minutes, respectively. The beta-precursors of Po-210, Pb-210 and Bi-210, have half-lives of 22 years and 5 minutes. It is difficult to imagine what mineralization process could yield mineral grains with high concentrations of polonium inside much larger grains of other minerals in a granitic rock on a time scale short enough such that any significant quantity of the polonium or its beta-precursors remained after the rock became cool enough for a halo to form--unless the nuclear decay rates when the granite crystalized were much lower than at present. Since the polonium isotopes are all in the uranium-238 decay chain, it was originally proposed (20) that the polonium was preferentially fixed out of uranium-bearing solutions at localized deposition sites along small conduits or veins within the host mineral. Gentry, however, using highly sophisticated techniques, including fission-track analysis, scanning electron microscope x-ray fluorescence, and the ion microprobe has established that polonium halos commonly exist well removed from potential uranium sources. He appears to have eliminated the possibility that these halos are of secondary origin from aqueous solutions. These studies indicate that the polonium must have been present when the rock was in molten form and must have been isolated and concentrated in the process of crystalization of the magma.

The occurrence of polonium radiohalos in igneous rocks is restricted to Precambrian material. They are readily found in granites from the Canadian and Scandinavian shields. The implication of Gentry's work is that there were periods during the earth's Precambrian past when the nuclear decay rates were much lower than presently observed. It is interesting to note that the radiometric dates from Precambrian rocks from all over the earth have a spiked distribution (21), which suggests the possibility that there may have been episodes of abnormally high rates of nuclear decay punctuating longer periods of quite low rates of decay.

In any case, any significant variation in the decay rates means that the radiometric methods cannot be trusted to provide absolute ages for the geological formations.

Another type of radiohalo also has important bearing on the issue of the constancy of the nuclear decay rates. P. Ramdohr has identified uranium halos in which the radioactive mineral, usually zircon, has expanded and fractured the surrounding host mineral. The expansion fractures are striking in that they do not lie along grain boundaries but form a random pattern of cracks that suggest explosive failure of the host crystal. One interpretation (22) of this phenomenon is that an episode of very high nuclear decay produced rapid thermal and/or isotropization expansion of the radioactive inclusion that led to sudden elastic failure of the surrounding crystal lattice.

## THE THERMAL PROBLEM

A further major problem in interpreting geologic history in light of the biblical Flood concerns the cooling of vast bodies of rock on a short time scale. Since all the present-day ocean floor is no older than Mesozoic, placing the onset of the Flood at the Precambrian-Cambrian boundary means that the present oceanic lithosphere must have cooled from near the molten state to its current temperature distribution in only a few thousand years. Based on measured values for the thermal conductivity of mantle rocks and minerals, conductive cooling of the lithosphere to depths of tens of kilometers on a time scale of a few thousand years is negligible.

An estimate of the cooling rate can be obtained using the idealized problem of the cooling of a semi-infinite solid initially at a uniform temperature $T_0$ bounded by a plane whose temperature is fixed at zero (19). The temperature distribution in the solid as a function of time and position is given by $T = T_0 \operatorname{erf}(x/2\sqrt{\kappa t})$, where erf denotes the error function, x is the distance from the surface plane, $\kappa$ is the thermal diffusivity, and t is the time. The temperature reaches a value of $0.5\ T_0$ when $x/2\sqrt{\kappa t} = 0.477$ or when $t = 1.10x^2/\kappa$. If this simplified model is applied to cooling ocean floor, the temperature at a depth of 50 km reaches a temperature representing half the original temperature difference between the mantle and ocean at a time of 87 million years. Here the thermal diffusivity is assumed to be $1.0 \times 10^{-6} m^2/s$. Although there is abundant evidence for significantly enhanced cooling rates near the midocean ridges as a consequence of hydrothermal circulation of ocean water through the growing lithospheric layer, this mechanism appears not to be important after a modest blanket of sediment is present on the ocean bottom. It appears that some additional mechanism is required for cooling the oceanic lithosphere to its present thickness on a brief time scale.

A similar problem exists in the cooling of the large magmatic bodies in the continents known as batholiths. A good example is the granite body that comprises the Sierra Nevada mountain range of California. The crystalization age for this rock is Cretaceous, which means the body has cooled form the molten state since the onset of the Flood. Again thermal conduction alone simply cannot cool a body so vast in the span of a few thousand years. Although hydrothermal fluids undoubtedly were present and played a role in the cooling history, the geological evidence does not reveal any large scale hydrothermal plumbing which could have been the primary means for removing the heat. Some other mechanism seems to be needed.

A third observation that points to a need for special cooling is the viscosity of the mantle. Estimates for the present mantle viscosity make tectonic velocities greater than a few centimeters per year implausible. It appears almost essential to conclude the average mantle viscosity during the Flood and probably for many centuries afterward was several orders of magnitude lower than present to allow the large displacements of the continental blocks to their present positions. This would have been the case if the pre-Flood mantle were a few hundred degrees warmer than now and if there were volume cooling of the mantle following the Flood to its present temperature.

These observations all point to the need to remove large amounts of heat from extensive bodies of rock in the earth in order to account for the geological change proposed for the Flood. It is the author's conclusion that this cannot happen within the framework of time-invariant physics. Therefore, an important clue as to the nature of the change that occurred seems to be that it involved a decrease in thermal energy throughout the planet.

## THE PROPOSED MODEL

To attempt to account for the main large-scale tectonic features of the Flood catastrophe the following model is presented. The pre-Flood earth is assumed to have a single supercontinent, an intact lithosphere, and a convecting mantle a few hundred degrees warmer than at present. Seismic evidence (23) indicates lithosphere beneath present continental Precambrian shield areas may extend to depths of 400 km. If the model is correct, these regions represent preserved remnants of the pre-Flood continental lithosphere, and they suggest that conditions in the pre-Flood mantle favored the growth of thick lithosphere. A lack of plate tectonics, that is, no subduction and no seafloor spreading at this point in earth history would be consistent with such thickened lithosphere. Christensen (24) in extensive numerical investigations of mantle convection has shown that the strong temperature dependence of mantle rock leads to only a weak coupling between mantle temperature and heat transport to the surface. His calculations indicate that the dynamics of the lithosphere are controlled, no so much by the bulk temperature or viscosity of the mantle, but rather by the rheology or deformation properties of the lithosphere itself. Therefore, a regime in which the lithosphere is frozen into a single plate enveloping the whole earth does not appear to violate what is known about mantle dynamics. Indeed, numerical simulations that include temperature-dependent viscosity inevitably lead to such a solution unless special measures are taken to enforce plate-like behavior (25).

As discussed earlier, oceanic lithosphere, which lacks the nominally 30 km thick layer of buoyant crust that distinguishes continental lithosphere, can easily reach thicknesses that make it gravitationally unstable relative to the mantle below. The potential energy stored in this gravitationally unstable material, it was shown, can reach exceedingly high values capable of performing significant amounts of tectonic work. Furthermore, the combination of the effects of shear heating and the sensitive temperature-dependence of viscosity results in the possibility of unstable behavior as slabs of oceanic lithosphere sink through the mantle. Preliminary numerical simulations as well as analytical estimates indicate that increasing the bulk mantle temperature only a few hundred degrees should produce conditions favorable to such unstable sinking of oceanic lithospheric slabs and hence to tectonic catastrophe, provided enough lithospheric material exists at the surface and the process can be initiated.

The pre-Flood earth of the proposed model meets the prerequisites for tectonic catastrophe of thick oceanic lithosphere covering some 60% of the surface and a warmer, less viscous mantle. The nature of the triggering mechanism is less clear. If indeed the lithosphere were intact, initiating the catastrophe would involve fracturing the lithosphere into several pieces. One possible way of accomplishing this would be global heating of the earth leading to stresses in the lithosphere sufficient to produce rupture. Since in the author's view, interpretation of the nuclear decay data in light of the Flood requires very high rates of nuclear decay during the Flood, the rupturing of the lithospheric shell by thermally-induced stresses generated by such high rates of decay appears to be a consistent possibility.

What are some of the more obvious consequences of the rapid subduction of a major portion of the earth's ocean floor? One is a rise in the global sea level relative to the continental regions due to the replacement of the cold, dense ocean lithosphere with hot mantle rock. If we assume a temperature difference of 1000 K, a lithospheric thickness of 100 km, and a coefficient of thermal expansion of $2.5 \times 10^{-5}$, we obtain an increase in the height of the ocean bottom as the old lithosphere is replaced of 2500 meters. A second effect would be violent tidal waves from the exceedingly intense seismic activity associated with the lithospheric disruption and subduction. A third effect would be massive volcanic activity, especially in the ocean where lithospheric slabs were moving apart and magma from the mantle was filling the gaps. It is possible that the magma may have been charged with significant volatile components, principally water and carbon dioxide, which when erupted violently on a global scale would produce a rain of water and ash over the entire planet.

Still another consequence would have been vertical tectonic upheaval of the continental regions themselves. The viscous drag of a subducting lithospheric slab at a continent margin would tend to depress the surface height of the continental margin. The mantle circulation induced by sinking slab would also tend to pull the edge of the continent away from the interior--that is, produce back-arc spreading on a massive scale--even to the extent of tearing a supercontinent apart.

A notable reduction in the intensity of the violence of the tectonic upheaval would be observed once most of the gravitationally unstable lithosphere had settled at the bottom of the mantle. Although conditions would still be catastrophic by anyone's measure, the end of this phase of the event ought to be discernible in the rock record. It is conceivable, however, that the lithospheric blocks sank in a small number of episodes, and if so, this also should be evident in the record.

If the primary cause for the elevated sea level in the Flood was the replacement of cold lithosphere with hot material from the mantle, then it follows that the subsiding of the sea level involved the cooling of the newly formed ocean floor. As already discussed, the cooling of such a vast body of rock by thermal diffusion alone is implausible on a time scale of a few thousand years. The viability of the proposed model then appears to depend on a volumetric loss of thermal energy, not only from the newly forming ocean floor but probably from the bulk of the entire planet.

## A GLOBAL SIMULATION

A numerical simulation of the rapid sinking of the oceanic lithosphere into the mantle will now be described. The code employed in these calculations is a three-dimensional Eulerian spherical finite element formulation (26,27,28) that utilizes the multigrid method for efficient implicit solution of the velocity field at each time step. The computational mesh is based on the regular icosahedron and, for these calculations, has 2562 points on each of 17 radial layers (Fig. 2) for a total of 43,554 nodes and 81,920 elements in the shell used to represent the mantle and lithosphere. The code was developed as part of the author's dissertation research at UCLA.

The hydrodynamics formulation is based on conservation equations for linear momentum, mass, and energy together with a rheological law and an equation of state. Since the viscous forces associated with the solid-state creep of mantle rock are so vastly greater than the inertial forces and the Coriolis force arising from the earth's rotation, these latter forces are neglected in the momentum equation. Under these assumptions, the following equations describe the local behavior:

$$0 = -\nabla p + \rho \underline{g} + \nabla \cdot \underline{\underline{\tau}} \tag{1}$$

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \underline{u}) \tag{2}$$

$$\frac{\partial T}{\partial t} = -\nabla \cdot (T\underline{u}) - (\gamma - 1)T\nabla \cdot \underline{u} + [\underline{\underline{\tau}} : \nabla \underline{u} + \nabla \cdot (k \nabla T) + H]/\rho c_v \tag{3}$$

where

$$\underline{\underline{\tau}} = \mu[\nabla \underline{u} + (\nabla \underline{u})^T - 2\underline{\underline{I}}(\nabla \cdot \underline{u})/3] \tag{4}$$

and

$$p = p(\rho, T) \quad . \tag{5}$$

Here $p$ denotes pressure, $\rho$ density, $\underline{g}$ gravitational acceleration, $\underline{\underline{\tau}}$ deviatoric stress, $\underline{u}$ fluid velocity, $T$ absolute temperature, $\gamma$ the Grüneisen ratio, $k$ thermal conductivity, $H$ volumetric radiogenic heat production, $c_v$ specific heat at constant volume, and $\mu$ dynamic viscosity. Equation (1) describes the balance among pressure gradient, buoyancy, and viscous forces. Equation (2) expresses the conservation of mass. Equation (3) describes the conservation of energy in terms of the absolute temperature. Equation (4) is the rheological law, and (5) represents the equation of state as a suitable function of density and temperature.

For the three-dimensional calculations described in this paper several simplifications are made. The most important is the use of constant rather than variable (i.e. temperature-dependent) viscosity. A practical reason is computational cost of the variable viscosity treatment. Other simplifications include neglect of the elastic properties of the lithosphere, the phase transitions between the upper and lower mantle, and compressibility of the mantle itself. On the other hand the calculations do allow buoyant material over portions of the surface representing the continental crust. Therefore distinct regions of continental lithosphere and oceanic lithosphere are included in the simulation.

Since the constant viscosity treatment does not permit the viscosity-reducing mechanism described earlier, a simulation was performed in which the viscosity for the whole mantle was set to a low value of $10^{14}$ Pa-s. The calculation was initialized with a cool layer 100 km in thickness at the mantle's outer surface representing the lithosphere. A single circular region 30 km thick covering 40% of the surface with reduced density corresponding to continental crust was included to represent an initial supercontinent (Fig. 3a). The initial temperature distribution in the mantle was from a convection solution obtained at higher viscosity and characterized by several hot upwelling plumes that originate at the lower boundary of the mantle. The objectives of this numerical experiment were to obtain a qualitative picture of the pattern of flow induced in the mantle as the lithosphere from the non-continental portion of the surface sank and to observe the manner in which the supercontinent was affected. Figures 3b-d show the distribution of continental material and the surface velocities at times of 0.09, 0.35, and 0.71 years, respectively. The calculation shows that the supercontinent is dramatically disrupted as the cold surface layer corresponding to the oceanic region sinks to the bottom of the mantle. Obviously, this experiment is but a beginning attempt to model the hypothesized tectonic catastrophe. Essential to the proper treatment of the problem is the inclusion of variable viscosity. Efforts to improve the efficiency of the variable viscosity calculations are currently in progress.

## CONCLUSIONS

If the onset of the biblical Flood corresponds to the profound stratigraphical and paleontological discontinuity at the Precambrian-Cambrian boundary, then a number of logical deductions follow. Not only were huge quantities of sediment deposited on the continental surfaces, but a staggering amount of tectonic change also accompanied the Flood. Not only did the earth's surface participate in this tectonic change, but the mantle also must have played a critical role. That no pre-Mesozoic ocean floor currently exists means that the entire pre-Flood oceanic lithosphere has been recycled into the mantle since the beginning of the Flood just a few thousand years ago.

The logical requirements for the rapid sinking of the pre-Flood oceanic lithosphere is an important clue to unraveling the fundamental nature of the catastrophe. Indeed, it points to a likely driving mechanism. It was shown that the magnitude of the gravitational potential energy associated with nature oceanic lithosphere is sufficient to drive global tectonic catastrophe. It was then argued that runaway behavior of the sinking lithospheric slabs is plausible as a consequence of the strong temperature-dependence of viscosity of mantle rock coupled with its shear heating. The brief time-scale of the Flood seems to demand that this phenomenon did in fact occur.

The quick replacement of the oceanic lithosphere with hot, buoyant rock from the mantle implies a rise in the global sea level on the order of two kilometers. It also implies an extreme intensity of both volcanic and tsunami activity. The style of flow induced in the mantle by rapidly sinking lithosphere furthermore has the tendency to tear a pre-Flood supercontinent apart and to disperse the resulting fragments.

Subsidence of the global sea level following such a lithosphere replacement requires a cooling of the newly formed ocean floor. Rapid volumetric removal of heat by some mechanism seems to be a logical necessity, not only to cool the oceanic lithosphere to its present state, but also to cool large batholiths in the continents as well as to raise the bulk mantle viscosity to its present high value.

Finally, it seem evident that the Flood catastrophe cannot be understood or modeled in terms of time-invariant laws of nature. Intervention by God in the natural order during and after the catastrophe appears to be a logical necessity. Manifestations of the intervention appear to include an enhanced rate of nuclear decay during the event and a loss of thermal energy afterward. Although many scientists do not readily entertain such possibilities, Scripture indicates that God has indeed on rare occasions intervened in the laws of nature on a grand scale. II Peter 3:3-6 states that one of these occasions was during the Flood. May this point prove not to be a stumbling block to involvement for many in one of the most exciting areas of discovery in the history of science.

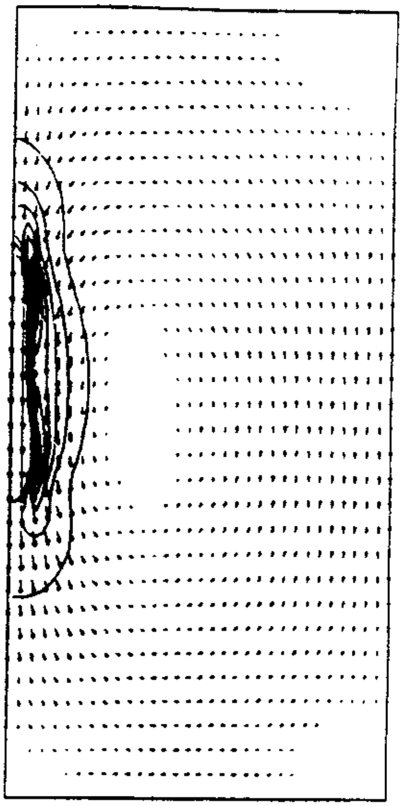

Figure 1 Numerical simulation of a sinking slab. Contours of shear heating rate show that heating is localized in the region immediately adjacent to the slab. The velocity field is represented by arrows.

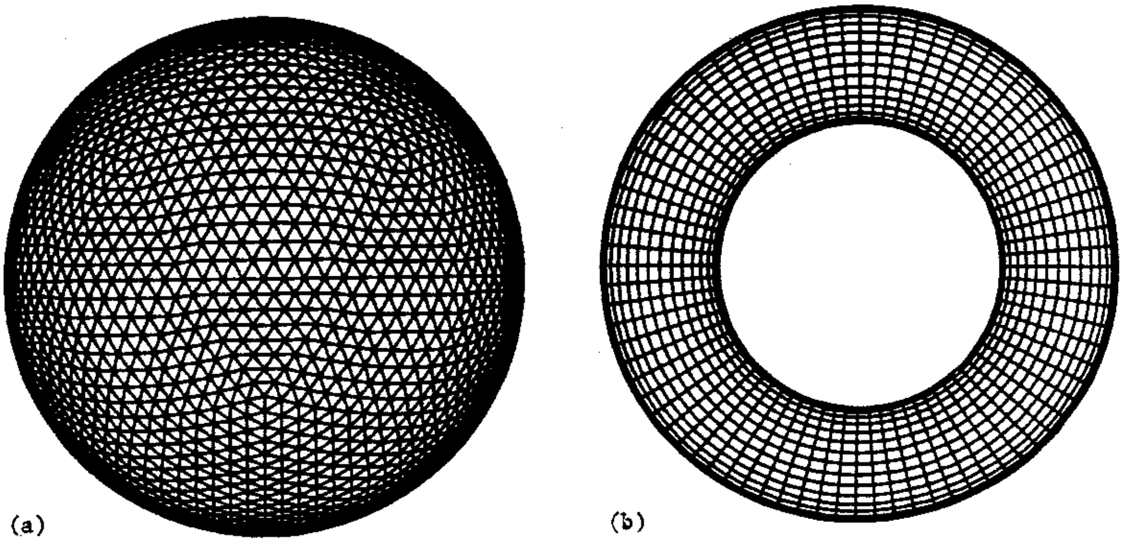

Figure 2 Computational mesh for the three-dimensional calculation. On spherical surfaces (a) the mesh is derived from successive refinements of the twenty spherical triangles obtained by projecting the regular icosahedron onto the sphere. Replication of this spherical mesh at seventeen radial positions yields a three-dimensional mesh whose equatorial cross-section is shown in (b). The three-dimensional mesh has 43,554 nodes and 81,920 cells.

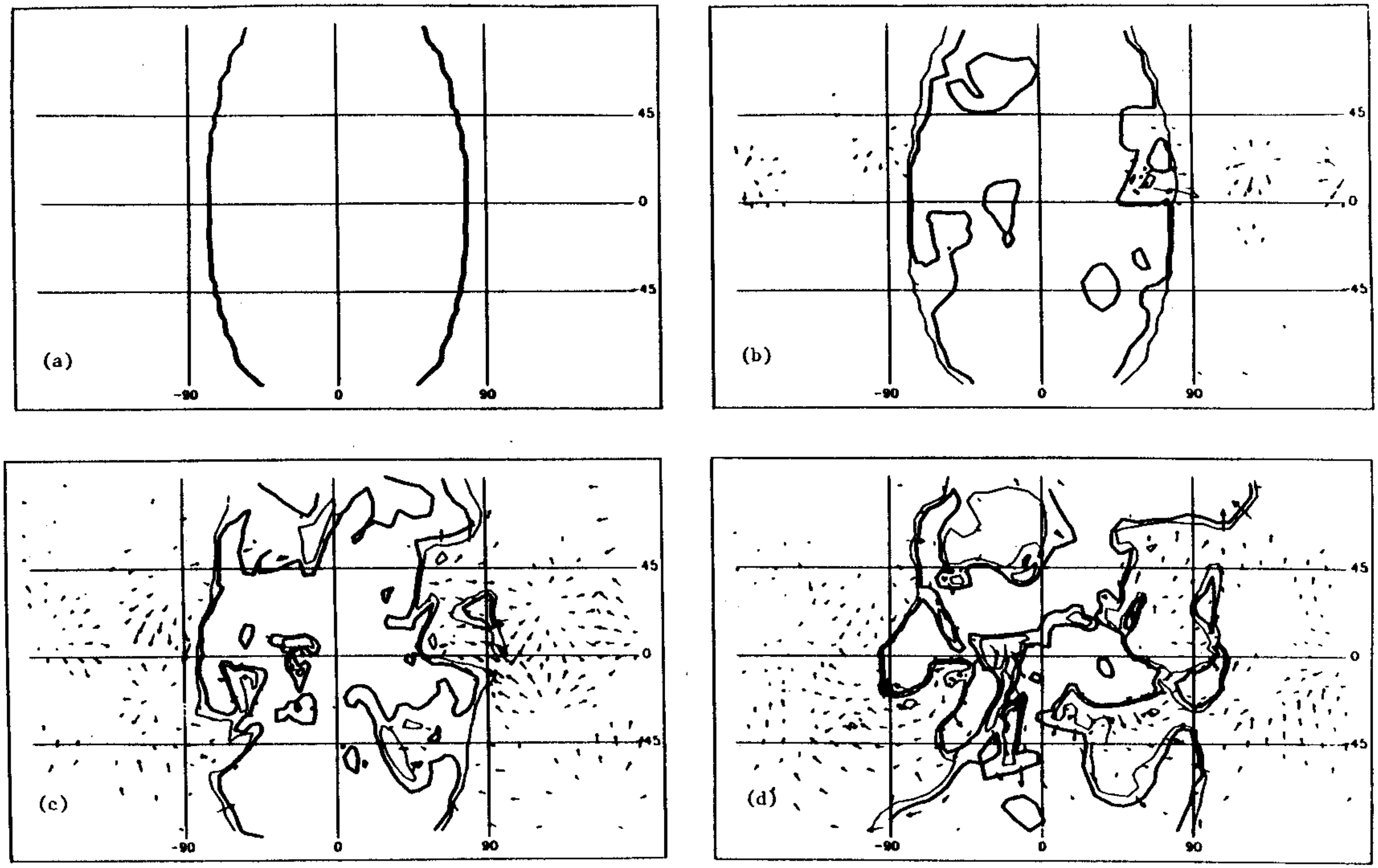

Figure 3 Results from a three-dimensional simulation of rapid sinking of the oceanic lithosphere into the earth's mantle. Initial density and temperature conditions are from a mantle convection solution with an essentially stationary upper thermal boundary layer approximately 100 km thick. At time t=0 for this calculation, the viscosity is reduced to $10^{14}$ Pa-s and the dense upper boundary layer begins to sink into the mantle. Contours denote continental crustal thickness. The heavy contour represents a crustal thickness of 27 km; the light contour marks a thickness of 18 km. Arrows display the surface velocity field. Maximum velocities in (b)-(d) are 0.28, 0.76, and 0.46 m/s, respectively. Times for (a)-(d) are respectively 0.00, 0.09, 0.35, and 0.71 years. Note the severe disruption of the original circular supercontinent.

REFERENCES

1. Whitcomb, J. C., Jr. and H. M. Morris, The Genesis Flood, Presbyterian and Reformed Publishing Co., 1961.

2. Austin, S. A., "Depositional Environment of the Kentucky No. 12 Coal Bed (Middle Pennsylvanian) of Western Kentucky, with Special Reference to the Origin of Coal Lithotypes," Pennsylvania State University, unpublished Ph.D dissertation, 1979.

3. Ager, D. V., The Nature of the Stratigraphical Record, Macmillan Press, 1973.

4. Roth, A. A., "Turbidites," Origins, Vol. 2, 1975, pp. 106-107.

5. Austin, S. A., Catastrophes in Earth History, ICR Technical Monograph 13, Institute for Creation Research, El Cajon, California, 1984.

6. Gentry, R. V., "Fossil Alpha-Recoil Analysis of Certain Variant Radioactive Halos," Science, Vol. 160, 1968, pp. 1228-1230.

7. Gentry, R. V., "Radiohalos in a Radiochronological and Cosmological Perspective," Science, Vol. 184, 1974, pp. 62-66.

8. Gentry, R. V. et al., "'Spectacle' Arrays of 210 Po Halo Radiocenters in Biotite: A Nuclear Geophysical Enigma," Nature, Vol. 252, 1974.

9. Unfred, D. W., "Astroidal Impacts and the Flood-Judgment," Creation Research Society Quarterly, Vol. 21, Sept., 1984, pp 82-87.

10. Morton, G. R., "The Flood on an Expanding Earth," Creation Research Society Quarterly, Vol. 19, 1983, pp. 219-224.

11. Bullard, E. C., Evertt, J. E., and Smith, A. G., "The Fit of the Continents Around the Atlantic," Philosophical Transactions of the Royal Society of London, Ser. A, Vol. 258, 1965, pp. 41-75.

12. Dietz, R. S. and Holden, J. C., "Reconstruction of Pangea: Breakup and Dispersion of the Continents, Permian to Present," Journal of Geophysical Research, Vol. 75, 1970, pp. 4939-4955.

13. Sclater, J. G. Jaupart, C., and Galson, D., "The Heat Flow Through Oceanic and Continental Crust and the Heat Loss of the Earth," Reviews of Geophysics and Space Physics, Vol. 18, 1980, pp. 269-311.

14. Isacks, B., Oliver, J., and Sykes, L. R., "Seismology and the New Global Techtonics," Journal of Geophysical Research, Vol. 73, 1968;, pp. 5855-5899.

15. Boss, A. P., "Convection," Reviews of Geophysics and Space Physics, Vol. 21, 1983, pp. 1511-1520.

16. Goetze, C., "The Mechanisms of Creep in Olivine," Philosphical Transactions of the Royal Society of London, Ser. A., Vol. 288, 1978, pp. 99-119.

17. Weertman, J., "The Creep Strength of the Earth's Mantle," Reviews of Geophysics and Space Physics, Vol. 8, 1970, pp. 145-168.

18. Bird, R. B., Steward, W. E., and Lightfoot, E. N., Transport Phenomena, John Wiley and Sons, 1960, p. 60.

19. Carslaw, H. S. and Jaeger, J. C., Conduction of Heat in Solids, Oxford University Press, pp. 50-62, 1959.

20. Henderson, G. H., "A Quantitative Study of Pleochroic Haloes," Proceedings of the Royal Society of London, Ser. A, Vol. 173, 1939, pp. 250-264.

21. Gastil, G., "The Distribution of Mineral Dates in Time and Space," American Journal of Science, Vol. 258, 1960, pp. 1-35.

22. Gentry, R. V., "On the Invariance of the Decay Constant Over Geological Time," Creation Research Society Quarterly, Vol. 5, 1968, pp. 83-85.

23. Jordon, T. H., "Composition and Development of the Continental Tectosphere, Nature, Vol. 274, 1978, pp. 544-548.

24. Christensen, U. R., "Thermal Evolution Models for the Earth," Journal of Geophysical Research, Vol. 90, 1984, pp. 2995-3007.

25. Jacoby, W. R. and Schmeling, H., "On the Effects of the Lithosphere on Mantle Convection and Evolution," Physics of the Earth and Planetary Interiors, Vol. 29, 1982, pp. 305-319.

26. Baumgardner, J. R., "A Three-Dimensional Finite Element Model for Mantle Convection," UCLA, unpublished Ph.D dissertation, 1983.

27. Baumgardner, J. R. and Frederickson, P. O., "Icosahedral Discretization of the Two-Sphere," SIAM Journal of Numerical Analysis, Vol. 22, 1985, pp. 1107-1115.

28. Baumgardner, J. R., "Three-Dimensional Treatment of Convective Flow in the Earth's Mantle," Journal of Statistical Physics, Vol. 39, 1985, pp. 501-511.