ON THE VERTICAL MOVEMENTS OF THE EARTH'S CRUST

DOUGLAS E. COX*

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One of the major problems facing the Creationist is how to account for the source of the waters of the world-wide flood described in Genesis. The possibility of a major source of these waters existing within the earth, immediately below the earth's crust, is explored in this article. This hypothesis can explain the extensive geologic evidence for vertical uplift, that should be taken into account in any geophysical model of the earth's interior.

Introduction

The feasibility of crustal subsidence followed by uplift, as a possible mechanism of the flood, was discussed in a recent article by Morton.[1] He posed certain challenges to those Creationists who have considered this to be a major contributory factor in the flood.

This problem of the cause of the flood is probably the most crucial question facing the modern Creationist.

The scriptures seem to indicate two main sources of the flood waters: rain, and the breaking up of the fountains of the great deep. This latter source, the subterranean waters of the "great deep", has yet to be thoroughly investigated in the light of the available geological and geophysical data. One of the possible interpretations of these Biblical statements requires new concepts about the composition of the earth's interior.

The Fountains of the Deep

The possible interpretations of the meaning of the Biblical "fountains of the great deep" seem to be:

(1) These waters were groundwaters within sediments and other rocks, such as one encounters in wells;

(2) The waters were contained in lavas that were extruded during the flood;

(3) The waters were from some zone within the earth that consists primarily of H_20.

In the first of these interpretations the water would presumably have been a minor component of the source material. According to Darcy's law,[2] the flow of pore fluids through the host rocks would require some pressure gradient, and the quantities required to flood the earth in a short time seem to rule out this source as a major contributory factor.

The second possibility, that the waters came from lavas extruded from the interior, seems to imply the flood waters would have been extremely hot, if this was a source of great volumes of flood water.

One objection to this interpretation is the fact that marine creatures such as fish were apparently not taken upon the ark, and survived the flood in the seas. Although vast numbers of marine creatures evidently perished, some survived. So the waters could not have been at a high temperature, or else the oceans would have boiled and all species of fish, and other marine animals would have become extinct.

The third interpretation, that the waters were from some zone within the earth consisting of H_20, has received relatively little consideration from Creationists as a possible solution to the problem of the fundamental cause of the flood. This concept has seemed unattractive for two main reasons: the earth's average density is about 5½ times the density of water, and the geophysical evidence indicates the interior is solid to depths of about 2,900 km.

Humphreys has discussed several scriptures that seem to indicate a significant supply of water exists within the earth.[3] He proposed that these waters are located at the earth's core.

A concept of subterranean waters, providing a source for the waters of the deluge, was proposed by Thomas Burnet in the 17th century. His *Sacred Theory of the Earth* was highly regarded for more than a century.

The possibility of subterranean waters existing in the zone immediately below the earth's crust is investigated in this article. This would provide a more readily available source for the waters which engulfed the continents during the deluge, than waters from depths as great as the earth's core. The hypothesis would accommodate rapid vertical movements, including differential movements, in the earth's crust, at the time of the flood. The waters could have been in a fluid state at the time of the flood, but it is suggested that the interior waters were subsequently frozen, due to the high pressures existing in the interior.

Morton argued that the rate of uplift and subsidence of continents would be too slow to have been accomplished in the time span of the flood and a youthful earth.[4] The viscosity of the earth's interior that was assumed in his calculations was 2.4×10^{22} poise. This would not be applicable to vertical movements which occurred during the flood, if there was freezing of the interior material following the flood. The interior viscosity has been estimated on the basis of the historical measurements of the rate of elevation of the Scandinavian Peninsula. According to Zharkov and Trubitsyn:[5]

> The viscosity of the earth's interior can be approximately determined on the basis of the following geophysical data. The post-glacial rising of Fennoscandia gives for the mean viscosity of the subcrustal layer, η, a figure of 10^{20} to 10^{21} poise.

In contrast, water at 30° C and at atmospheric pressure has a viscosity of 8.01×10^{-3} poise, and smaller values at higher temperatures.[6] Thus there would be no problem from the point of view of the time required for uplift and subsidence with this model.

For the purpose of investigation of a possible mechanism of the flood, it is proposed that the subcrustal material consists partly of H_20 which is now in some solid form, but melted at the time of the flood

*Mr. Douglas E. Cox's address is P.O. Box 18, Petersburg, Ontario, Canada.

when "the fountains of the great deep were broken up."[7] Water from below the earth's crust may have burst forth to the surface, causing the flooding of the continents. This would be accompanied by subsidence of the crust.

In the following sections, evidence for vertical movements of the earth's crust is cited, and it is shown that subsidence and uplift are essential ingredients in the required mechanism of the flood, as well as in any valid interpretation of the earth's composition and past history. An earth model in which the subcrustal zone consists partly of H_20 is consistent with this sort of evidence, and can be shown to be compatible with data on the earth's mass and average density.

The Depth of Sedimentary Material

The presence of sedimentary rock over much of the continents is an indication of former vertical movements of the earth's crust. The abundance of sedimentary materal in some regions requires enormous depths for the accumulation of sediment piles. Accumulations of as much as 60,000 feet of sediment are known, and the average thickness of sedimentary material on the continents is about 7,000 feet.[8]

Before compaction, the thickness of sediment would have been considerably greater. The uppermost sedimentary layers must have been below sea level at the time of deposition. These facts seem to clearly indicate former vertical movements of the earth's crust.

In creationist interpretations, the accumulation of vast piles of fossiliferous sediment has been attributed to the erosive power of the currents of the flood waters.

Marine Sediments in High Mountains

The existence of high mountains composed of marine strata is another indication of vertical uplift. Not only are many mountain ranges chiefly composed of marine sediments, but these regions are among the most eroded of the earth's strata. The laminations in the sedimentary rocks comprising the mountain peaks can be seen to terminate in "thin air."

The continuation of these laminations can be traced across wide valleys and between the peaks, as can be seen, for example, in Jasper National Park in Canada. This implies vast quantities of sediment are missing. Not just sedimentation at depth, but erosion was necessary for the formation of the features of the mountain chains. They provide evidence for vertical uplift that must be measured in miles. Joly stated:

> The most striking fact known about mountains is that they are largely and often mainly composed of sedimentary rocks, that is, of rocks which have been deposited originally in the seas. True, these sediments may be contorted, folded, metamorphosed almost beyond recognition, but none the less they have risen from the sea floor to form the mountain chain.
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> It is a universal fact. Even of the volcano-tipped Andes and Caucasus it is true. In the great precipices of the Alpine heights the limestones, folded as if made of wax, reveal themselves in giant arches. The hard slates, (often changed to mica-schist) telling of former deep waters, buttress such giants as the Matterhorn, and overlie or intermingle with the granites of the Himalayas.[9]

These facts about the mountains provide some indication of the scale of the flood catastrophe. The evidence for erosion can be explained by the action of currents of the flood waters when the sediments were submerged and still partly unconsolidated. Sediment was removed to distant regions by the currents and redeposited. It is nowhere to be seen in the valleys and lakes in the vicinity of the mountains.

The flood waters provide an agency of erosion and sediment transportation far more effective than any geologic process now acting on the earth's surface. In contrast, almost nothing that has been learned about the origin of the mountains can be understood in terms of existing processes.

The world's mountains, then, provide strong support for former submergence and uplift of the earth's crust.

Tectonic Evidence of Uplift

In most environments of sedimentation, the attitude of the bedding tends to be generally horizontal. Where the sediments that occur in the earth's crust are tilted at some angle, or have been folded, faulted or contorted, the deformations may reveal the degree of differential vertical movements that have occurred.

Such movements are particularly evident from the complex structure of mountain regions. These vertical movements are also evident in the continental cratons. The differential movements indicated by the downwarping of the crust in the Michigan Basin, for example, was 1,500 meters.[10]

Describing the process of subsidence that is supposed to have occurred during Silurian time, that caused the Michigan Basin, Dott and Batten wrote:

> In Michigan, especially, subsidence accelerated in a circular area beneath the state that is simply called the Michigan Basin. Subsidence commenced rather suddenly here in the craton far from any rising arch or mountainous uplift. An increase in density or a decrease in thickness of the crust beneath Michigan must have upset the local isostatic equilibrium.[11]

Raised shorelines at the coasts of continents, and around inland lakes, also indicate former large-scale tilting and warping of the earth's crust.

Uplift Indicated by Mineralogic Evidence

Evidence for the former deep burial of rocks is also available from mineralogic relationships, that are diagnostic of high pressure conditions. Ernst has discussed the evidence for former deep burial of Franciscan rocks in California.[12] These rocks contained minerals that seemed to require high pressures and low temperatures for their formation. In particular, the presence of glaucophane-crossite, jadeitic pyroxene, lawsonite, pumpellyite, and aragonite were diagnostic of "low temperature production at relatively high pressures resulting from very deep burial."

The conditions required for the formation of these minerals involve pressures of up to 5 to 8 kb, for the temperature range 150° C to 300° C. Since the rock strengths limited the possible tectonic overpressure to less than 1 kb, Ernst concluded that the former conditions involved burial to depths of 20 to 30 km under water.

Similar indicators of very high pressures at relatively low temperatures have been recognized from other regions. Kennedy wrote:

> The most startling thing from the geological point of view is that high-pressure polymorphism of common silicate phases known at the surface of the earth appears to be the rule rather than the exception. In general, however, the depth at which the common polymorphs are formed appears to be greater than current geological thinking would permit. Of particular importance are the considerable depths in the earth's crust needed to form the dense phases grossularite, zoisite, lawsonite, kyanite, and jadeite.[13]

Geophysical Evidence for a Low-Density Layer

The well established increase in the velocity of both primary and secondary seismic waves at the Mohorovicic discontinuity has been interpreted as the lower boundary of the earth's crust. The seismic velocities are related to the density of the medium by the following formulae:

$V_p^2 = (K_s + 4\mu/3)/\varrho$; and $V_s^2 = \mu/\varrho$. Here ϱ = density, V_p = primary wave velocity, V_s = secondary wave velocity, K_s = bulk modulus, μ = shear modulus.[14]

Clearly, the increase in the velocity of these seismic waves at the base of the earth's crust could be due to a decrease in density.

If the sub-crustal material were less dense than the crust, the thinnest or lightest parts of the crust would tend to be the most elevated, for isostatic compensation. There would be no need for thick mountain "roots" to compensate for the lower density of sedimentary rocks of mountain areas.

Measurements of the earth's gravity field have shown there are characteristically large negative Bouger anomalies (> 150 mgals) in the earth's mountainous areas.[15] This could be another indication of a low density interior, and thinning of the earth's crust in the elevated regions.

The shape of the earth has been determined to a high degree of accuracy since the advent of artificial satellite geodesy. When compared with the appropriate ellipsoid of revolution, the earth has four "high" points, and four "low" areas. Its radius at the equator is 21 km greater than at the poles.[16]

However, according to Stacey, the earth has an ellipticity about 0.5% greater than that which would exist in terms of a hydrostatic theory.[17]

This implies the interior is not in a state of hydrostatic equilibrium. Oppenheim pointed out the rigidity of the interior required for the maintenance of the equatorial bulge rules out the possibility of convection currents, as assumed in recent plate tectonics theories.[18] Other considerations by Jeffries support this conclusion.[19]

The amount of flattening of the earth, according to hydrostatic theory, is approximated by:[20]

$$f_H = \frac{{}^5/_2\, m}{1 + {}^{25}/_4 \left[1 - {}^3/_2 \left(\frac{C}{Ma^2}\right)\right]^2}$$

In this formula, C is the axial moment of inertia of the earth. The present ideas about density distribution within the earth provide the basis for a calculation of the earth's ellipticity.

It seems possible that with the assumption of a low density layer below the earth's crust, the estimated flattening would be closer to that which is observed. The excess flattening of the earth, then, may provide additional evidence for an interior layer consisting of ice.

These observations have been interpreted as evidence for a greater rate of rotation in the past.[21] It seems that an increase in the rate of rotation would be likely during the flood, when the continents were submerged, due to the conservation of angular momentum. Subsequent freezing of the interior, uplift of the continents, and readjustment of the earth's speed of rotation could result in the present configuration of the earth.

In this connection, it seems relevant that continental shelves are submerged at increasingly greater depths towards the poles, and are relatively elevated near the equator.[22]

An Earth Model for the Creationist

An earth model in which the interior layers below the crust consist of some form of ice can allow vertical movements of the earth's crust. The melting of the ice would absorb heat and would permit the crust to become mobile. The vertical movements of sections of the crust-which may have even been torn apart in places—can occur in a short time in this model, since the viscosity of the liquid water is much less than that of the solid.

The model supplies abundant water to cause the flood, and seems consistent with the present data about the earth's interior, as far as is known with any precision. Of course, it is not consistent with the earth models of the uniformitarians or other opposing models. It should not be tested against these hypothetical models but against experimental data and observations of the available facts.

In the present section, it is demonstrated that this model is consistent with what is known about the earth's mass and average density, and the seismic data available on the properties of the earth's interior. The data are taken from Zharkov *et. al.*[23]

The average density of the earth is 5.52 g/cm^3 so of course if there is a significant amount of ice of some kind inside there must also be matter of density greater than the average, which is assumed in all earth models.

The earth's crust and oceans represent only 0.8% of the total volume of the earth. The mass in this zone is 2.2×10^{25}g, about 0.42% of the earth's mass.

It is proposed that the layer immediately below the crust consists largely of ice of some kind. This layer extends for some depth, perhaps a few hundred km. It is not suggested that this region is composed of pure water; it could contain sediments, or other solids such as frozen CO_2, or CH_4, or rocks and minerals of various kinds—the composition is completely unknown. If impurities were present the density would be increased.

The high-pressure varieties of ice are all denser than water and will sink in it. We may assume, then, some value for the density of ice for the purpose of investigating the present model. In the extreme case, it could be supposed that the material consisted of pure ice and a density of one of the varieties selected. I will assume a value of 1.2 g/cm^3 for the average density of the hypothetical ice layer.

Next we have to determine the probable depth of this layer. The region below the crust is the mantle, which is sub-divided into several layers. The upper mantle extends from a depth of 19 km to 420 km, and the seismic wave velocities steadily increase with depth in this zone. It is referred to as the low velocity zone since there appears to be a layer at which the speed of sound is less than that of overlying material. Also the rate of increase in the speed of sound is small.

The upper mantle is divided into three layers. The upper part extends from depths of 19 to 80 km; the low velocity zone extends from 80 - 220 km; the lower part is 220 - 420 km. (Incidentally, the stratification of this zone within the earth is a strong argument against the hypothesis of convection currents as a mechanism for sea-floor spreading.)

In all, the upper mantle region comprises 17.6% of the earth's volume. In present models, it is considered to be 10.9% of the earth's mass; i.e., 6.51 × 10^{24}g. Density in this region is assumed to be about 3.5 g/cm^3 in the present models.

If the upper mantle is assumed to consist of ice with density of 1.2 g/cm^3, the mass of this region would be 3.7% of the total, and the interior layers would contain a greater proportion of the total. The increase would imply a relatively small increase in the density of one of the lower layers.

Below the low velocity zone, there is a transition zone extending from a depth of 420 km to 670 km. This zone is 9.8% of the earth's volume, with a mass of 4.15 × 10^{26}g, or 6.9% of the total.

The lower mantle extends from 670 to 2885.3 km. This is 55.3% of the earth's volume. Its mass, in present models, is 2.945 × 10^{27}g, or 49.2% of the earth's total mass.

Suppose the density of this zone should be slightly higher, to compensate for the low density zone of the upper mantle that was postulated. Then the mass of this layer would be increased to 3.3728 × 10^{27}g. The layer would now represent 56.45% of the total mass of the earth. (This may alter some of the estimates of the earth's moment of inertia; however, this difference may be small since the increase would be offset by the lower figure for the density of the upper mantle.)

The average density for this zone would increase from 4.918 to 5.63 g/cm^3, which is reasonable considering the core density is assumed to range from 10 g/cm^3 to 12.5 g/cm^3 in the present models.

This model would comply with the known mass of the earth and the known average density. It provides an abundant supply of waters for the flood, amounting to 2.97 × 10^{11} km^3.

Earthquake Mechanisms at Island Arcs

With the assumption of a sub-crustal layer composed of ice of some kind, new explanations may be proposed to account for the long recognized occurance of deep oceanic trenches adjacent to volcanic island arcs and mountain chains.

These areas are the most seismically active regions of the earth. Isacks and others stated:

> Nearly all the world's earthquakes in the deep and intermediate range, most of the world's shallow earthquakes, and the largest departures from isostatic equilibrium are associated with island arcs or arc-like structures.[24]

The occurrence of earthquakes at depths as great as 700 km in the vicinity of the island arcs and associated deep oceanic trenches is compatible with the concept of an upper mantle consisting of a high pressure variety of ice.

The island arcs are regions of anomalously high heat flow.[25] It is suggested that the heat within the rocks of the oceanic crust may cause melting of the underlying ice. The fluids produced by melting may migrate laterally beneath the crust and penetrate adjacent crustal rocks. As the ice melted, subsidence could occur, forming deep oceanic trenches. In harmony with this concept, grabben structures, interpreted as evidence for subsidence, occur within oceanic trenches, (for example the Japan trench.)[26]

The process of melting and subsidence would result in a continual transfer of heat and mass, which could possibly initiate earthquakes at these tectonically active zones. Lateral mass movements could result in differential strains developing in subcrustal ice. Earthquakes could result from shear fractures as stresses were relieved by sudden adjustments to changes in load.

Characteristically, a long, narrow, negative gravity anomaly occurs at the site of an oceanic trench, indicating a deficiency of mass. A positive anomaly occurs in the adjacent volcanic arc.[27] These facts tend to support the present interpretation.

The high heat flow at these regions is apparently not in harmony with the proposed mechanism of sea floor spreading and subduction at oceanic trenches.[28]

An alternative to the above is that the heat source is deep within the mantle. Volatiles ascending the steeply dipping Benioff zones may cause melting, which could result in subsidence at the site of the trench.

Volcanoes and the Earth's Interior

Many people assume that volcanoes are evidence for a very hot interior of the earth. However, most active volcanoes are located in the narrow seismic regions, in particular at island arcs. They may represent local hot spots in the earth's crust rather than a generally hot interior.

There is evidence that volcanoes in close proximity are not connected to a common magma source, since eruptions within adjacent volcanoes are usually not simultaneous.

Various mechanisms for the generation of volcanic magmas may be suggested, in the present model. Sources of heat may exist within the rocks of the earth's crust, rather than the underlying ice layer. The heat may result from seismic movements, which generate heat by friction, or exothermic chemical reactions, or

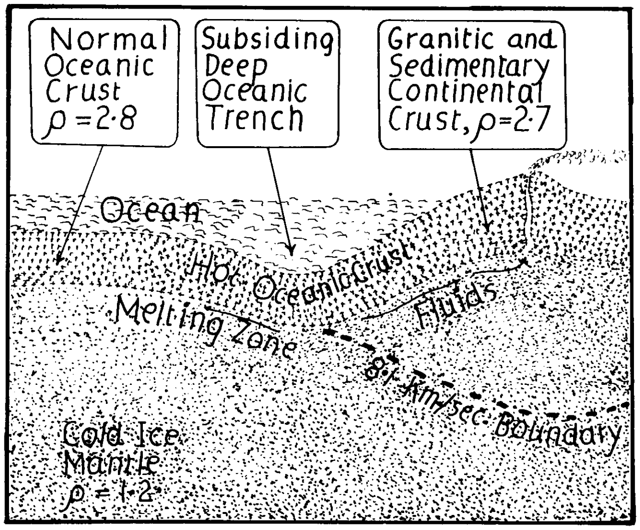

Figure 1. This diagram shows the mechanism which, it is suggested, is involved in subsidence in deep ocean trenches adjacent to volcanic arcs. The sub-crustal material is composed of a dense form of ice.

the rocks may have been heated at the time of the earth's formation.

The ascent of fluids from the subcrustal layer through the hot rocks of the earth's crust could generate volcanic magmas. A mechanism of volcanism in association with subsiding deep oceanic trenches is illustrated in Figure 1.

The Significance of Volcanoes: Additional Thoughts

With the assumption of a sub-crustal layer composed of ice of some kind, a new explanation may be proposed to account for the long recognized occurrence of deep oceanic trenches adjacent to volcanic island arcs and mountain chains.

It is suggested that heat within the basaltic ocean crust may cause melting of the ice upon which the oceanic crust rests. The fluids produced by melting may then migrate laterally underneath the crust, and penetrate adjacent crustal rocks. In this way, heat would be continually transferred from the zone of melting and subsidence. These fluids may also initiate uplift of the crust adjacent to the deep trenches, due to hydrostatic pressure, from time to time. Vertical uplift, for example, seems to be a continuing process along the Pacific coast of South America.

As the fluids from the sub-crustal zone rose through rocks of the crust, heating could occur, resulting in the formation of magmas from the rocks of the deep crust. These would be the source of volcanic magmas. (See Figure 1.)

In this interpretation of volcanic activity, the ejection of water from the subcrustal zone, that was heated during ascent through the crust, is considered the primary cause of volcanic phenomena. The formation of magma is considered to be secondary.

With continued subsidence over a long period, the melting temperature of the sub-crustal ice would rise, due to increased pressure at greater depths.

There would tend to be a decline in the rate of subsidence over a long period, as a result. The cooling of the rocks of the oceanic crust would also tend to cause a decline in activity.

This hypothesis could account for the association of deep ocean trenches with volcanically active belts. The heating of the sub-crustal material occurs beneath deep-ocean trenches, which are regions of subsidence. Uplift occurs in the adjacent crust.

Such a hypothesis would require that the crustal rocks of the deep ocean trenches would also be areas of high heat flow.

This suggestion also provides an alternative to the supposed "subduction" mechanism that is postulated in current theories of sea-floor spreading.

Conclusion

Wherever evidence exists for vertical movements of the earth's crust, lateral movements of the subcrustal material are also required to fill up the hole that would otherwise be created. This seems to require that this substance was formerly fluid, and has since been frozen into a solid state.

The hypothesis that the subcrustal material is largely H_2O, now frozen into some variety of ice, could allow for the former vertical movements that are implied by geologic evidence. It has been shown that this hypothesis is not inconsistent with certain known properties of the earth's interior, and such a hypothesis seems to be supported by several Biblical statements about the earth's interior.

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