Continental Flood Basalts Indicate a pre-Mesozoic Flood/ post-Flood Boundary

PAUL GARNER

ABSTRACT

Continental flood basalts are remarkably widespread lavas that testify to catastrophic volcanism in the geologic past on a scale far exceeding anything taking place at the present day. Hundreds of cubic kilometres of basalt were erupted in just days or weeks. In many cases, evidences for prolonged periods between individual eruptive events (for example, erosion profiles, soil formation) are lacking. These data are consistent with a short timescale for the geological column.

Continental flood basalts appear to have been erupted in a subaerial environment, as indicated by the tectonic environment of continental flood basalt provinces and by the characteristics of continental flood basalt lava flows. Such lava flows could not therefore have accumulated while the continents were under water.

Major continental flood basalt provinces occur in the Proterozoic, the ?Early Cambrian, the Late Permian-Early Jurassic, the Late Triassic-Early Jurassic, the Late Jurassic-Early Cretaceous, the Late Cretaceous-Late Eocene, the Palaeocene-Eocene, the Eocene-Miocene, the Eocene/Miocene/ Middle Pleistocene, and the Miocene. The virtual absence of continental flood basalts from the Palaeozoic is puzzling for uniformitarian geologists. Continental flood basalts are thought to originate when a continental rift system coincides with a mantle plume. If this is the case, why did no continental flood basalts form throughout the Palaeozoic? It is suggested that continental flood basalts could not form in the Palaeozoic because they require subaerial conditions and the continents were flooded at that time. However, continental flood basalts in the Mesozoic and Cainozoic are problematic for traditional creationist models which consider these rocks also to have formed during the Flood. The reappearance of continental flood basalts in the Mesozoic and Cainozoic indicates that the continents were above water and forming dry land at this time. The Mesozoic and Cainozoic must therefore be post-Flood in age, and the Floodlpost-Flood boundary must occur much earlier in the geological record than most creationists have assumed.

INTRODUCTION

The volcanic rocks of the Earth's crust are a powerful testimony to the catastrophic events that have dominated our planet's geological history. Some ancient volcanic eruptions were orders of magnitude larger than any historic event, and, according to Ager, *'must leave one doubting the competence of the present as a key to the past'.*[1] The largest known lava flows are the so-called flood lavas, which include both continental flood basalts and mid-ocean ridge basalts.[2] The word 'flood' in this context refers to their lateral extent, and does not necessarily imply subaqueous formation or that geologists consider them to have been erupted during the Noachian Flood. Continental flood basalts, the subject of this study, are widespread, subaerially accumulated lavas erupted from fissures.

My first aim is to show that continental flood basalts provide striking confirmation of rapid and catastrophic geological activity in the past. However, they are important for another reason. There is convincing evidence that continental flood basalts were erupted in a subaerial, terrestrial environment. They were not erupted underwater. As a consequence, they provide us with important evidence for the existence of dry land at certain points in the stratigraphic column. Therefore, knowledge of the stratigraphic distribution of continental flood basalts helps us to locate the Flood/post-Flood boundary in the geological record. Identification of this boundary is of great significance in the development of creationist models, yet there is currently no consensus as to where in the record the 'golden spike'[3] should be driven. It is of the utmost importance for creationist thinking in the earth sciences that this boundary be correctly identified.

THE RAPID, CATASTROPHIC ERUPTION OF CONTINENTAL FLOOD BASALTS

As noted in the introduction, continental flood basalts are some of the largest lava flows known. In a study of the Grande Ronde Basalt of the Columbia River continental flood basalt province,[4] at least 120 major flows, with individual volumes ranging from 90 km^3 to more than 2,500 km^3, produced a total volume of 148,600 km^3. The extent and volume of such units qualifies them as the largest terrestrial lava flows known.[5] One characteristic of continental flood basalts is their extreme lateral extent. Some individual members of the Wanapum Basalt of the Columbia River Plateau may have travelled several hundred kilometres from their sources. The Pomona Member of the Saddle Mountains Basalt has a volume of >600 km^3 and can be traced for a linear distance of some 600 km.[6]

The atmospheric effects of such vast eruptions would have been profound. The 1783 Laki basaltic eruption in Iceland produced extreme cooling over northern Europe and resulted in widespread famine.[7] Yet this eruption — possibly the largest since the close of the Ice Age — is, at 15 km^3 of basalt, two orders of magnitude smaller than many ancient continental flood basalts! Estimates of the sulphur dioxide output for some of the Miocene Columbia River basalt flows are of the order of 1,000 megatons per year — enough to produce conditions similar to those modelled for a nuclear winter.[8] Many geologists have suspected that continental flood basalt eruptions may have been the cause of mass extinction events in earth history.[9] This suspicion has been fuelled by the recognition that the Deccan Traps of India straddle the Cretaceous/Tertiary boundary at which a biotic crisis appears to have taken place.[10]

Remarkable also is the rapidity with which individual continental flood basalt flows were formed. According to Swanson and Wright,[11] all the Columbia River basalt flows, regardless of volume, were emplaced as sheet floods of lava with little cooling during transport. The fact that no shield volcanoes were constructed and only rarely did flows even build low ridges along the fissure systems implies rapid flow and eruption rates. Theoretical consideration of the emplacement mechanisms of voluminous Yakima flows suggests only several days to a few weeks for eruptions involving hundreds of cubic kilometres of lava.[12] Peter Hooper of Washington State University estimated that the Roza Flow moved over 300 km in about seven days at an average speed of about 5 km per hour.[13]

Geologists find it difficult to comprehend the extreme rapidity of continental flood basalt formation within their uniformitarian framework. However, not only were individual flows erupted rapidly, but there is convincing evidence to indicate that, in many instances, whole sequences of flows must have built up rapidly. For instance, ^Ar/^Ar results from an approximately 2,000 m thick sequence of the Deccan continental flood basalt province, Western Ghats, show no significant difference in radiometric age from the stratigraphically oldest rocks to the youngest.[14] However, there is reason to believe that continental flood basalts accumulated even more rapidly than uniformitarian scientists are willing to concede. Take the Deccan for example. The number of eruptive units in the Deccan is probably quite small, perhaps 100-500. If the entire episode lasted for 500,000 years, this would mean that there were, on average, 1,000 to 5,000-year quiescent periods between each eruption.[15] Some geologists suggest that the Deccan continental flood basalts accumulated over even longer periods — perhaps up to four million years,[16] or even longer[17] — which would mean that even greater periods must be represented by hiatuses in the sequence. However, evidence for such long time gaps between flow units is lacking. Sedimentary layers between flows are virtually absent in many of the thickest sections in the western Deccan traps, and in most places erosional profiles between successive eruptions are insignificant or non-existent.[18] West[19] draws attention to two areas in the Deccan province — Igatpuri and Sagar. In the former area there are 15 flows totalling 900 ft (275 m) in thickness, which Kaneoka[20] has estimated were erupted over 20 million years. In Sagar, Alexander[21] believes the first six of the nine flows present in the area were erupted over a period of eight million years. This would mean that well over one million years on average had elapsed between each eruption. However, as West points out:

> *'. . . a million years is a very long time, and one would expect that during such a long period a great deal of erosion would take place, leading to the development*

of a new topography on the top of a flow after eruption. But the field evidence is quite contrary to this.[m]

West points out that the most striking feature of the Deccan Trap topography around Sagar is the flatness of the upper surfaces of the flows:

'To take one of many examples, 3—4 miles to the north of Sagar, the top of the eighth flow on which the village of Shyampura is situated, forms a flat plateau nearly three miles long from south to north and more than a mile wide. The level of this plateau does not vary more than 50 feet over this distance. There is no sign of its having been eroded prior to the eruption of the next flow, though a little laterite has formed in one place.'[23]

West contrasts the modern-day erosion of the scarp slopes of these basalt flows, which produces characteristic conical hills, with the absence of such erosion between the lavas:

'. . . where does one see such features preserved between the flows? The junctions are generally quite flat. In other words, after the eruption of a flow no new topography developed. Evidently there was no time for it.'[7A]

We find a similar situation in certain of the Miocene basalts of the Columbia River Plateau. Take, for instance, the Roza Member of the Wanapum Basalt Formation. Lefebvre says:

'All of the Roza flows (up to three at one locality) *are in direct contact with each other and evidence of weathering, erosion, or deposition has never been found between them.'*[25]

Indeed, even *'delicate surface textures are commonly preserved.'*[26] However, the eruptions appear to have been separated by sufficient time to permit earlier flows to cool, so that they were not disrupted by, nor welded to, the succeeding flow. Calculations based upon the assumption that conductive cooling predominated in the Roza flows indicate a period of 10-30 years between each eruption.[27]

During the eruption of the Columbia River Basalt Group basaltic volcanism was also taking place on the Oregon Plateau. Avent describes a succession of lava flows — collectively called the Steens Basalt — exposed in the escarpment of the Pueblo Mountains. He writes:

'Contacts between flows are irregular and commonly marked by zones of scoria or brecciated scoria. There seems to be no soil between any of the flows, nor is there evidence of erosion. Only one interbed was noted in the entire series and that was a thin layer of ash. It appears that the flows accumulated during a rather brief interval, each flow following the previous one in rapid succession, perhaps in some cases even before complete solidification of the preceding.'[2S]

In a similar vein Walker writes:

'Some flow sequences exposed on high fault scarps, such as at Abert Rim, Poker Jim Ridge on the northeast side of Warner Valley, and Steens Mountain, consist of more than 100 flows stacked one above another with little intervening clastic material . .. Zones of red, iron-stained clinkery and scoriaceous material occur between some flows, and some lenses of baked tuffaceous sediments are present locally, but in many thick sections the flows rest directly upon another, suggesting rapid accumulation.'[29]

Interestingly, the Ethiopian continental flood basalt province, which is thought to have been active for longer than the Columbia River and Deccan Plateau continental flood basalt provinces, may have more abundant evidences of time between individual flows. Mohr and Zanettin[30] mention the common development of lateritic surfaces and palaeosols, some of which are tree-bearing. No supporting references or additional details are given by these authors, so there is some doubt as to the true nature of these tree-bearing horizons. However, if they can be confirmed it would lend weight to my argument that continental flood basalts are post-Flood. There would not have been enough time for the development of genuine tree-bearing palaeosols between flows in any basalt succession formed during the Flood.

EVIDENCES OF SUBAERIAL VOLCANISM

Geologists believe, for a number of reasons, that continental flood basalts were erupted in a subaerial, terrestrial environment. These reasons are outlined below.

(1) Tectonic Environment

Nearly all continental flood basalts are found at the edges of continents.[31] Continental flood basalt eruptions are, in most instances, intimately associated with the initiation and early development of continental rifting[32] — in other words, the breakup of continents. A major review article published recently in **Nature** shows the close association between the stages in the breakup of Gondwanaland (the southern Mesozoic supercontinent) and the extrusion of flood basalt provinces.[33] Macdougall writes:

'The Columbia River basalts of the northwestern United States, for example, appear to have been extruded in a back arc basin like environment to the east of the then-active volcanoes of the Cascades . . . Most of the other large flood basalt provinces seem to be related in some way to the breakup of continents: the North Atlantic Tertiary province to the opening of the North Atlantic .. . the Deccan to the detachment of the Seychelles platform from the western part of the Indian subcontinent. .. and both the Parana and the Karoo to the fragmentation of Gondwanaland.'[34]

(2) Flow Characteristics

Many of the characteristics of lava flows are controlled by the nature of the environment into which they are extruded. Important indicators of subaerial extrusion include widespread flow, columnar jointing, and the absence of pillow structures.[35,36] Continental flood basalts commonly exhibit these features.

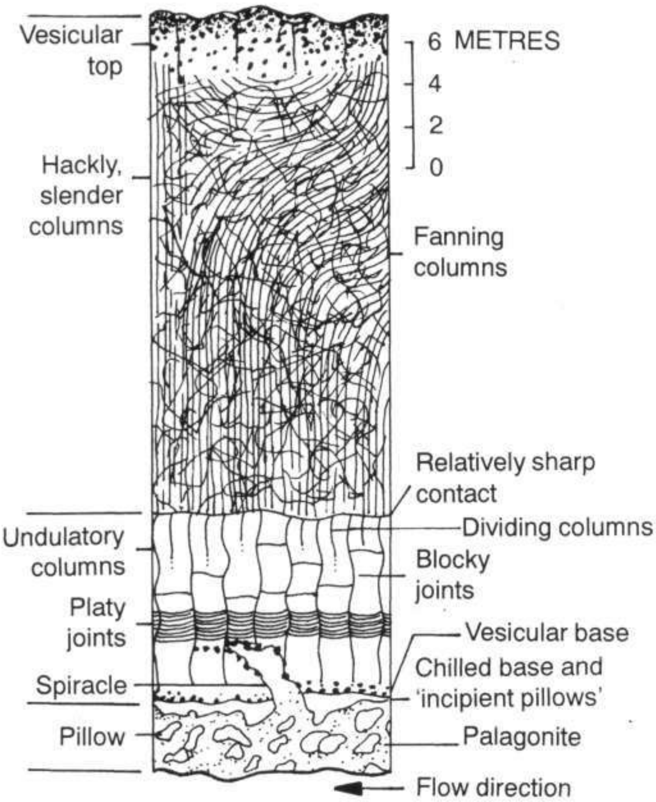

Figure 1. *An idealised cross section of a typical flow in the Yakima Basalt of the Columbia River Basalt Group. From the Basaltic Volcanism Study Project. Drawing by Russell Grief.*

(a) **Widespread Flow**

Subaqueous lava flows tend to cool more rapidly than subaerial lava flows because of the greater thermal conductivity of water compared to air. Thus, subaqueous flows tend to be shorter and thicker than their subaerial counterparts.[37] The vast extent of many continental flood basalt flows, as outlined in the previous section of this paper, is strongly indicative of subaerial extrusion. This is also a key point made by Steven Austin, writing under the pen-name of Stuart Nevins, in his paper on the post-Flood origin of the Cainozoic Mesa basalt.[38]

(b) **Columnar Jointing**

Columnar jointing is characteristic of more slowly cooling flows,[39] in particular those erupted subaerially. Slow cooling leads to contraction and takes place from the cooling surfaces — the top and bottom of the flow — inwards.[40] Contraction sets up tensional stresses and may lead to the formation of regular joints perpendicular to the cooling surfaces. Intersecting joints produce well-defined polygonal columns. Columnar jointing is common in many continental flood basalts (see Figure l).[41]

(c) **Absence of Pillow Structures**

The most distinctive feature of basaltic lava erupted under water is the development of pillow structure.[42] When lava is erupted under water, it chills rapidly to form a glassy but plastic skin around still liquid lava — a rounded mass rather like a balloon full of water. These structures are called pillows and are often found piled up one on top of another (see Figure 2). Although some continental flood basalts developed pillows locally where they flowed into lakes, ponds, and other small, stagnant bodies of water, pillow structure is generally absent from continental flood basalts. For instance, Lefebvre says of the upper Roza flow of the Columbia River Plateau:

> *'Mostpillow developments are sporadic and thin which indicates that the water must have been concentrated in small, widely spaced areas.*[M3]

(3) Interflow Sediments

Interflow sediments associated with continental flood basalt sequences are indicative of fluvial, lacustrine or aeolian conditions. Occasionally palaeosols and weathered surfaces developed between eruptions.[44]

(4) Associated Fauna and Flora

The fauna and flora fossilised in sedimentary beds between the lava flows is typically of a terrestrial nature. For instance, a palynological analysis of interflow sediments of the Columbia River Plateau yielded abundant pollen, spores and freshwater algae.[45] Sometimes terrestrial animals have been preserved as molds even within the lava flows (for example, a *Diceratherium* at Jasper Canyon on the Columbia River Plateau described by Chappell *et* a/.).[46] Austin made this point about associated fauna and flora in his paper on the volcanic sequence of John Day Country, Oregon. Of the Clarno Formation he writes:

> *'The climate was warm and humid as evidenced by the variety of tropical and subtropical plants (palm, breadfruit, cinnamon, sycamore, magnolia, avocado,*

Figure 2. *Pillow lava exposed at Newborough Warren, Anglesey, Wales. The lava flow consists of pillow-like structures with a cuspate base and a rounded top rarely more than one or two metres across. Photograph by Michael Garton.*

walnut, fern, horsetail, etc.). Rare herbivorous mammal fossils are found in the Clarno Formation and include rhinos, giant pig-like creatures, and **Eohippus . . .'**[47]

Similarly, he describes the fauna associated with the lower portion of the John Day Formation:

'These animals include saber-toothed cats, large dogs, camels, llamas, rhinoceroses, oreodonts (giantpig-like mammals having cud-chewing teeth), rabbits, and oppossums [sic]\[48]

Throughout his paper, Austin gives many other examples of terrestrial fossils interbedded with these Cainozoic volcanics.[49] He concludes,

'the fossils of terrestrial animals and plants with absence of marine creatures indicates post-Flood conditions. The occurrence of fossils on specific, widespread horizons (and absence at other levels) along with upright trees (apparently in growth position) can be used to argue for in situ *origin, not transportation from a distant region by the waters of the Flood.'*™

When we take all these features into account — the tectonic environment, flow characteristics, interflow sediments, and associated fauna and flora — we can see that continental flood basalts provide abundant evidence of subaerial accumulation. Continental flood basalts present creationists with crucial evidence of the existence of dry land, and therefore their stratigraphic distribution may help us to solve the problem of where the Flood/post-Flood boundary is located. We would not expect such widespread subaerial volcanism after the continents were completely inundated by the Flood waters (that is, no later than Day 40) and they should only reappear at the time the Flood waters had receded sufficiently to expose large tracts of dry land.

STRATIGRAPHIC DISTRIBUTION OF MAJOR CONTINENTAL FLOOD BASALT PROVINCES

In this section I review each of the major continental flood basalt provinces, starting with the oldest (see Figure 3).[51] I have omitted one or two other less well-known provinces that arguably fall within the scope of my paper (for example, Ontong Java), but since they are Mesozoic in age they do not affect my fundamental thesis that continental flood basalts are virtually absent from the Palaeozoic. The reader should be aware that in referring to radiometric dates I am in no way implying acceptance of these dates in an absolute sense. However, I follow Wise[52] in the reasonable assumption that published radiometric dates provide fairly reliable information about the relative ages of rocks.

(1) Keweenawan Province (Proterozoic)

The Keweenawan province is a Proterozoic accumulation of continental flood basalts in the district of Lake Superior, on the Canadian-American border. The basalts unconformably overlie an older, low-relief crust of Archaean and Lower Proterozoic rocks. The present areal extent of the province is 100,000 km^2, although peripheral dyke swarms, sills, and stratigraphic and structural data indicate an original extent of about 125,000 km^2. Individual flows usually range between 3-30 m thick, with a maximum of 400 m. The maximum total thickness of the volcanic sequence is thought to be between 8,000 and 12,000 m, with an average thickness of 5,000 m. The total volume has been estimated at >400,000 km^3.[53] This continental flood basalt province has been interpreted as an abortive continental rift, since no new ocean basin is considered to have been formed.[54*57] The conventional geologic date assigned to these rocks is 1,100-1,200 Ma.[58] I will not join the debate here about whether the Proterozoic represents Creation Week,

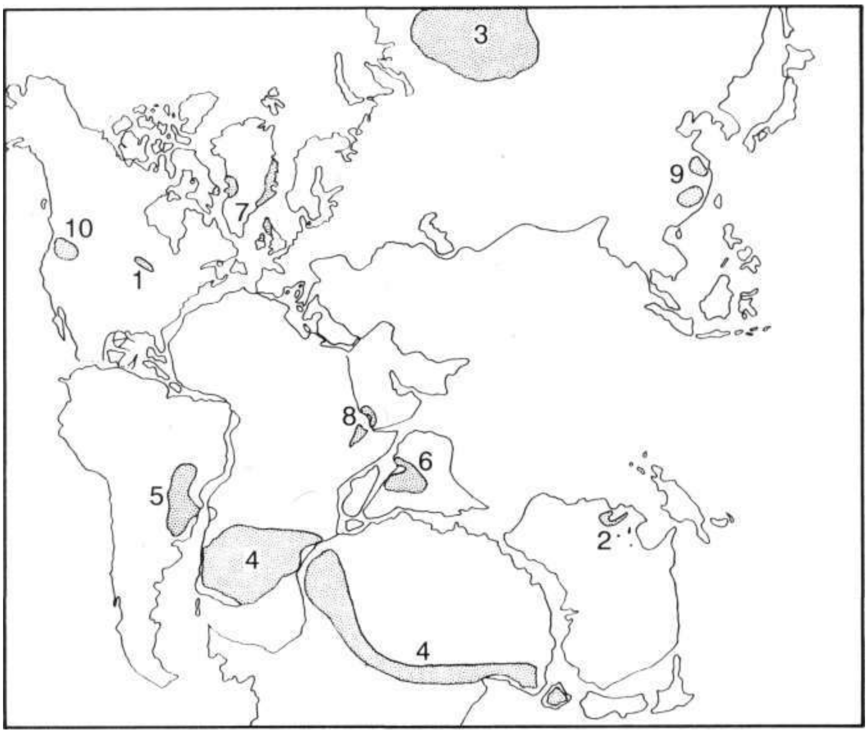

Figure 3. *Map showing the distribution of the major continental flood basalt provinces discussed in the text:*

(1) Keweenawan Province (6) Deccan Province
(2) North Australian Province (7) North Atlantic Tertiary Province
(3) Siberian Province (8) Ethiopian Province
(4) Karoo-Antarctic Province (9) Eastern China Province
(5) Parana-Etendeka Province (10) Columbia River Province.
From Cox.

pre-Flood, or Early Flood activity. Nevertheless, the presence of extensive continental basalts at this point in the geological record indicates that the Flood had yet to inundate all the pre-Flood land surfaces.

(2) North Australian Province (?Early Cambrian)

One of the least well known continental flood basalt terrains is located in northern Australia between the Kimberley region and the Queensland border.[59] The main continuous outcrop in the East Kimberley, Victoria River, and Daly River Basin areas has been given the name the Antrim Plateau Volcanics. A number of other isolated outcrops are also known — the Nutwood Downs, Helen Springs, Peaker Piker, and Colless Volcanics. The northern Australia continental flood basalts occupy an area of about 400,000 km^2.[60] This makes them more extensive than the Columbia River continental flood basalts, but smaller than virtually all the other continental flood basalt provinces. The volcanic sequence is about 1,000 m thick, although in some of the isolated faulted outliers to the west of the main outcrop the volcanics may reach up to 2,000 m. Individual flows are mostly less than 30 m thick.

The sequence is considered to be Early Cambrian in age, although no diagnostic fossils have been recovered from the interbedded sediments and no isotopic dating of the basalts has been undertaken.[61] The volcanics unconformably overlie Precambrian shales which yield a radiometric age of 666 ±56 Ma, and are disconformably overlain in most places by fossiliferous lower Middle Cambrian limestone.[62]

Chemical analyses suggest that the basalts of the Helen Springs outlier may be submarine.[63] However, the Antrim Plateau Volcanics are thought to have been erupted largely in a subaerial environment. Cross-bedded sandstone interbedded with the basalts is interpreted as aeolian, and no pillow lavas or palagonite features have been found.[64] How are creationists to understand these basalts? They are located on a Precambrian craton, and it seems that they were erupted subaerially before the craton was totally inundated in the Flood. Inundation must have been complete by Day 40 according to the biblical account. The stratigraphic position (?Early Cambrian) supports this Early Flood interpretation. Interestingly, stromatolitic chert towards the top of the sequence suggests a marine incursion during the later phases of the eruptive event; this may be the introduction of the transgressing marine waters to this region.

(3) Siberian Platform (Late Permian to Early Jurassic)

The Siberian Platform is a vast terrain between the Enisei and Lena Rivers, consisting of an intensely folded Archaean to Lower Proterozoic basement, overlain by horizontal volcanogenic sediments and intrusive rocks (sills and laccoliths). The oldest of the horizontal cover is thought to be Upper Proterozoic in age. Three distinct episodes of magmatism are recognised: in the Proterozoic, the Middle Palaeozoic, and the widespread development of continental flood basalts at the Palaeozoic-Mesozoic boundary. The continental flood basalts are Late Permian to Early Jurassic in age, and are thought to have been associated with a period of structural rearrangement at the end of the Palaeozoic and during the early Mesozoic. The province can be traced over an area of more than 1,500,000 km^2 and has an approximate volume of 575,000 km^3.[65] Most of the continental flood basalts occur within the Tunguska Basin where they reach a thickness of more than 3 km.[66] Individual flows are usually not more than a few tens of metres thick, and their extent is generally a few tens of kilometres. However, Mezhvilk and Vasilyev[67] have documented some marker flows with thicknesses of 150 m which extend for several hundred kilometres. Interbedded sediments have yielded plant and fish remains.[68]

(4) Karoo Province (Late Triassic to Early Jurassic)

The Karoo continental flood basalt province is a vast and complex terrain, with a probable former extent of 3,000,000 km^2, extending from Barotseland in Zambia to the Suurberg in the Eastern Cape, a distance of 2,000 km.[69] The east-west extent of the province is even greater — 2,800 km from Etendeka in Namibia to Antonio Enes in Mozambique. However, erosion has removed much of the volcanic material, so that outcrops are now scattered and detached from one another. Virtually no information exists on how far individual flows may have travelled.[70] Individual basalt flows in the Lesotho and north-east Cape regions vary in thickness from less than half a metre to over 50 m.[71] The thickest development of the lavas (at least 8,000 m) is in the Nuanetsi-Lebombo area; however, the average thickness is considerably less (about 1,000 m). Because of the discontinuous nature of the Karoo province and because of the unknown amount that lies beneath Cretaceous cover in Mozambique, volumetric estimates are not attempted.[72] Almost everywhere the volcanics rest on the sedimentary rocks of the Karoo Supergroup, an inter-cratonic basinal sequence of Late Carboniferous to Triassic age.[73] Volcanic activity was initiated on a land surface blanketed by continental fluvial and aeolian sediments.[74] Thin sandstone lenses (seldom more than 10 m thick) probably represent transient playa lakes.[75] These continental sediments belong to the Clarens Formation, and in places are interbedded with the lower part of the volcanic succession.

The Karoo continental flood basalt province is one of the earliest manifestations of the volcanic and igneous activity which accompanied the breakup of Gondwanaland in the early Mesozoic. The main peak of activity has been conventionally dated at around 193 Ma,[76] coincident with the initial opening of the Indian Ocean as Antarctica separated from southern Africa. Another peak occurred at around 120 Ma with the opening of the South Atlantic.[77]

(5) Parana Basin (Late Jurassic-Early Cretaceous)

The Parana sedimentary basin of South America consists of Devonian-Triassic deposits thought to represent marine, lacustrine and fluvial environments, overlain by Jurassic-Cretaceous sandstones thought to have originated in an aeolian environment (the Botucatu Formation). Piccirillo *et al* write:

> *'In general, the Devonian-Jurassic evolution of the Parana basin was characterized by a decreasing rate of sedimentation and by a progressive change from marine to continental desert conditions.'*[78]

Overlying these continental sandstones are subaerial continental flood basalts of the Serra Geral Formation. Aeolian sandstones are also found as interbeds between flows. The volcanic succession is capped by non-marine sediments of Upper Cretaceous age. Radiometric dates indicate that volcanic activity persisted from the Late Jurassic to the mid-Cretaceous, with a peak in the Early Cretaceous, coincident with the opening of the South Atlantic Ocean.[79]

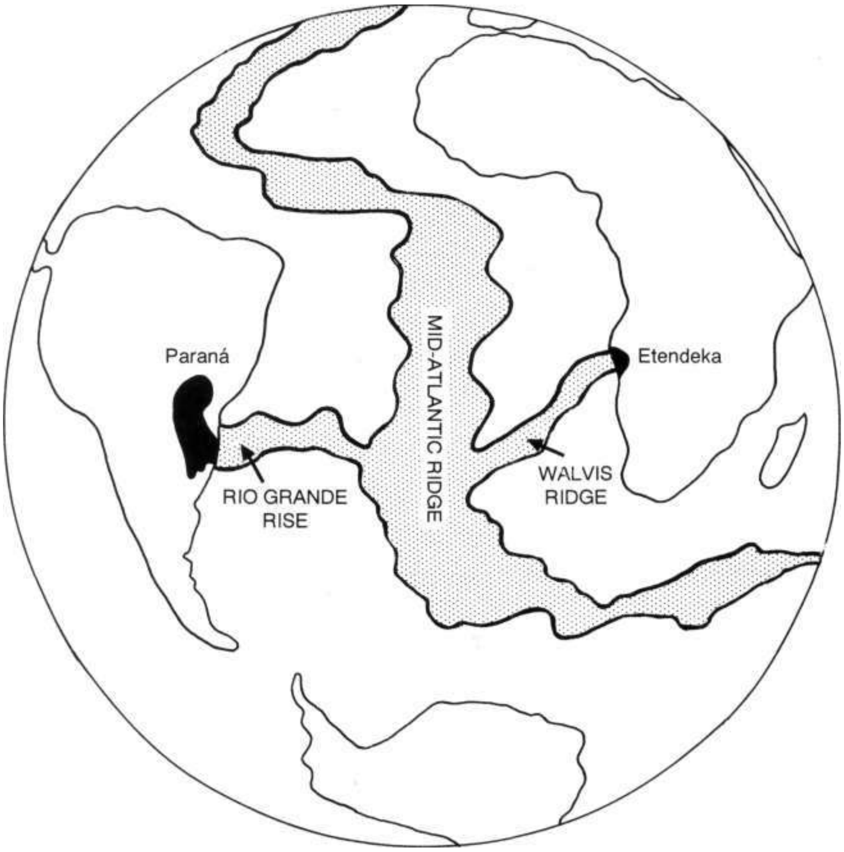

Figure 4. *Map showing the distribution of lavas in the Parana-Etendeka Province, and their relationship to the Walvis Ridge and the Rio Grande Rise. The stippled area represents submarine volcanism that post-dates the subaerial volcanism (in black). From Cox.*

The Parana Basin continental flood basalts are located mostly in Brazil, although they can be traced into Uruguay, Paraguay and Argentina.[80] They extend over an area of 1,200,00 km^2, and may once have covered 2,000,000 km^2.[81] Individual flows average around 50 m thick, but the thickest exceed 100 m. The total thickness of the lavas exceeds 1,000 m, with an average of around 660 m. The total volume has been estimated as 790,000 km^3.[82] Like the continental flood basalts of the Karoo region, the Parana province is associated with the tensional regime accompanying the breakup of Gondwanaland during the Jurassic and Cretaceous.[83] Radiometric, palaeomagnetic, strati graphic, mineralogic and geochemical data show that the Etendeka stratoid volcanics of Namibia, south-west Africa, correspond remarkably closely to the southern Parana volcanics of South America.[84] This impressive convergence indicates that the Etendeka and Parana volcanics were part of the same lava sequence prior to the breakup of Gondwanaland (see Figure 4).[85]

(6) Deccan Plateau (Late Cretaceous-Late Eocene)

The continental flood basalts of the Deccan Plateau currently occupy about 500,000 km^2 of western and central India and southern Pakistan (see Figure 5),[86] although their original extent may have exceeded 1,500,000 km^2. This is indicated by a number of probable Deccan outliers and the presence of sediments up to 400 km away from the main outcrop that have been remagnetised, probably by a now eroded cover of lavas.[87] The Deccan continental flood basalts are underlain by the Indian Shield, a predominantly Archaean terrain.

Over extremely large areas the basalt flows are virtually horizontal, with dips of 1° or less. The succession is thinnest in the east (100-200 m), and thickens westward to more than 2 km along the coastal margin. The thickest individual flows (up to 160 m) and the greatest number of flows occur in the western Deccan.[88] Many of the flows in the east and north-east can be shown to be very extensive, some having been mapped over several thousand square kilometres and having a lateral extent of over 160 km without any signs of thinning out. By contrast, the western Deccan has more flows of restricted extent, although even here there are some that can be traced for over 100 km.[89]

The subaerial nature of the lavas was first propounded by Blanford.[9092] Rare fluvial and lacustrine deposits occur between flows. These are usually limestones, cherts, shales or clays, and occasionally sandstones or grits. They are typically between 1-5 m thick, although some reach only a few centimetres. They rarely exceed 5-6 km in lateral extent.[93] Palaeontological studies of these intertrappean sediments have revealed a fossil fauna and flora

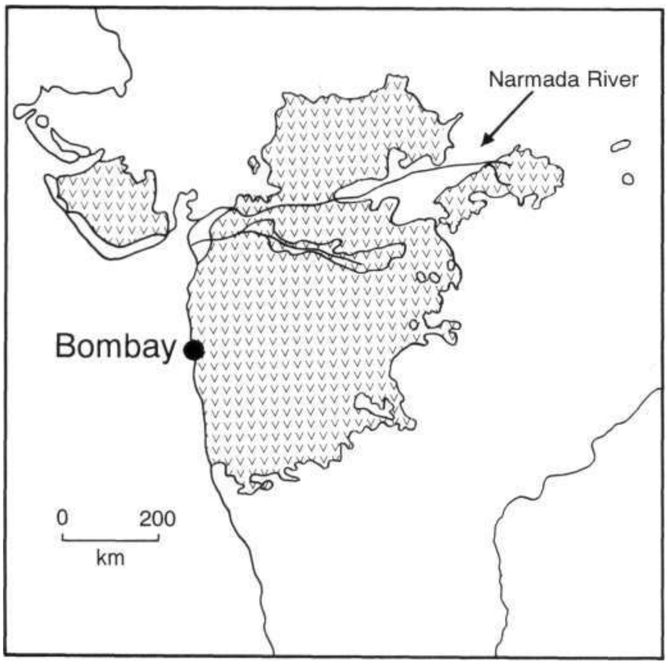

Figure 5. Map showing the distribution of lavas in the Deccan Province of central and north-west India. From the Basaltic Volcanism Study Project

characteristic of a continental environment. Freshwater molluscs, crustaceans, and fishes predominate.[94] Dinosaur remains have been recovered from the intertrappean beds in the Andhra Pradesh region.[95] Fossil frogs and freshwater tortoises are known from Bombay. The flora consist mainly of angiosperms, and rarely gymnopserms.[96]

The age of the Deccan continental flood basalts has been controversial; most now agree that the volcanic episode occurred sometime between the Late Cretaceous and the Late Eocene, with a major peak radiometrically dated around 69-65 Ma.[97] In his review of the geochronological aspects of the Deccan province, Mahoney[98] states that published radiometric dates from the Deccan are *'often sharply contradictory'*, and asserts that *'all approaches to dating the Deccan have inherent—and often serious — shortcomings'*. Nevertheless, the K-Ar ages for the Deccan basalts do tend to cluster around 69-65 Ma, and most geologists now believe that this period saw the formation of an estimated two-thirds or more of all the lavas. Support for such a massive and reasonably continuous outpouring is provided by the small number of magnetic reversals identified throughout the sequence, and the general lack of evidence for periods of quiescence between flows. According to Mahoney:

> *'Intertrappean sedimentary or ash beds, weathering profiles, other unconformities or non-basaltic marker horizons are almost absent in much of the province, and those that exist generally seem to be of restricted extent.'"*

Several major plate tectonic events are thought to have

Figure 6. Well-developed columnar jointing in lavas of the Giant's Causeway, Antrim, Northern Ireland. Photograph by Michael Garton.

coincided with Deccan volcanism, including the separation of the Seychelles Platform from western India (69-65 Ma, conventional geologic date), and the collision of India with southern Asia in the Eocene.[100101]

(7) North Atlantic Tertiary Province (Palaeocene-Eocene)

The North Atlantic Tertiary Province is dominated by plateau basalt sequences, a NW-SE trending swarm of dolerite dykes, and associated central intrusive complexes. It is in the North Atlantic Tertiary Province that we encounter possibly the best developed columnar jointing of any of the continental flood basalt provinces — the spectacular colonnades of the Giant's Causeway, Antrim, which reach heights of over 100 m (see Figures 6 and 7).[102]

The development of the province was associated with the continental rift that led to the opening of the North Atlantic Ocean. It can be subdivided into six main sub-

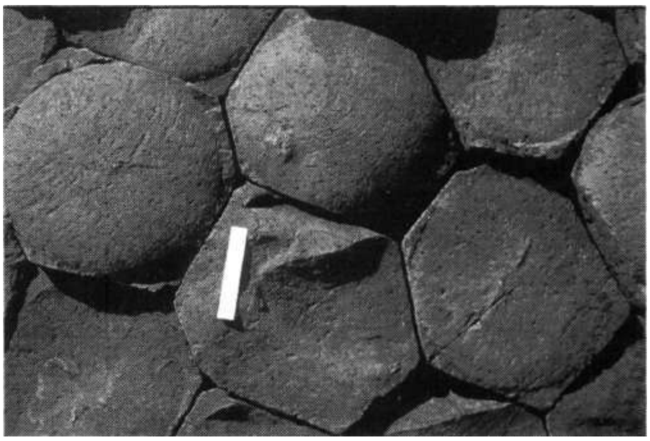

Figure 7. Plan view showing interlocking hexagonal basalt columns defined by cooling joints, Giant's Causeway, Antrim, Northern Ireland. Ruler scale is 15 cm. Photograph by Michael Garton.

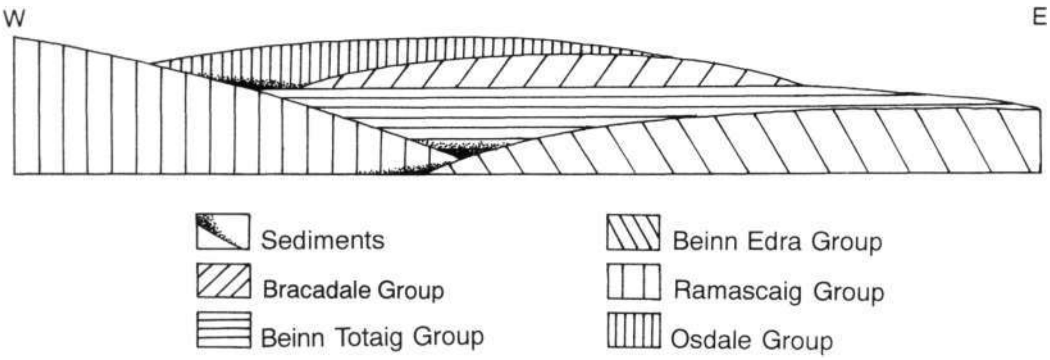

Figure 8. *Cross section through the Skye lava pile of the North Atlantic Tertiary Province showing the overlapping distribution of the five lava groups. From Dickin. Drawing by Russell Grief.*

provinces: the Hebridean/Northern Ireland region, the Faeroe Islands, East Greenland, Baffin Bay/West Greenland, the Rockall Plateau, and the Voring Plateau off north-west Norway.[103] Except where stated, the data in this section on areal extent, thicknesses, and volumes of the North Atlantic Tertiary Province lavas are taken from the paper by Dickin.[104] In the Hebrides continental flood basalts cover an area of around 850 km^2, with a maximum thickness of about 900 m. This sequence is overlain by another 900 m of more silica-rich lavas. On Skye, five lava groups derived from different fissure systems extend over an area of about 1,500 km^2 and reach a total thickness of about 2.3 km (see Figure 8).[105,106] The Antrim Basalts of Northern Ireland cover a total area of around 4,000 km^2, and Preston[107] has argued that the original lava field may have extended for another 50 km beyond its present limits. However, the largest exposed volume of lavas in the North Atlantic Tertiary Province occurs in East Greenland. South of Scoresby Sund the lavas cover an area of at least 80,000 km^2, and reach a thickness of 3.2 km, while north of Scoresby Sund they extend over 16,000 km^2 and attain a thickness of about 700 m. West Greenland has the second largest lava field in the North Atlantic Tertiary Province, with a present-day outcrop of 40,000 km^2. The Faeroe Islands are the exposed remnant of a subaerial lava field that was once much more extensive than its present area of about 1,400 km^2. The basalts around the Faeroe Islands may reach a thickness of up to 5 km.

(8) Ethiopian Province (Eocene-Miocene)

The highlands of Ethiopia and Yemen consist of a volcanic province dominated by continental flood basalts of Cainozoic age.[108] In Ethiopia alone these basalts cover an area of about 600,000 km^2. Before the plateau was uplifted and extensively eroded during the Pleistocene, this area may have been closer to 750,000 km^2.[109,110] The province has had a complicated geological history, with some investigators recognising up to three episodes of continental flood basalt activity.[111] The eruption of these continental flood basalts has been radiometrically dated between 43 Ma and 9 Ma, with a peak at 32-21 Ma (Late Oligocene-Early Miocene).

The subaerial volcanic pile is typically 500-1,500 m thick, although locally it may reach 3,000 m.[112] Individual flows vary between 2 m and 100 m thick, but commonly fall within the range 4-30 m. Columnar jointing is common.[113] The total volume of the preserved Ethiopian volcanics has been estimated at about 350,000 km^3, of which 300,000 km^3 is of basaltic composition.[114] No individual flow has been traced from its source to its termination. However, some flows are thought to be extremely widespread. Basalts of the Aiba Formation extend across at least tens of kilometres and possibly more than one hundred kilometres.[115]

(9) Eastern China Province (Eocene/Miocene/ Middle Pleistocene)

Widespread Cainozoic continental flood basalts have been documented in eastern China. These basalts were erupted in three main tectonic environments: along major continental rift zones, along continental margins, and in the collision zone between the Eurasian and Indian plates. Eruption of these continental flood basalts took place during three main intervals: the Eocene (45-55 Ma), the Miocene (5-20 Ma), and the Middle Pleistocene (<0.6 Ma). Zhou *et al.*[116] review the geochronology, petrology, and tectonic implications of these rocks in five regions of eastern China, and present a histogram of K-Ar ages from these regions (see Figure 9).[117]

(10) Columbia River Province (Miocene)

The Columbia River Plateau is a Miocene continental flood basalt province in north-western USA covering 163,700 km^2 and containing over 174,000 km^3 of tholeiitic basalt (see Figure 10).[118] The basalt flows extend over large parts of the states of Washington, Oregon, and Idaho. Although the Columbia River Province is an order of magnitude smaller than the Karoo or Deccan, it has been more intensively studied, partly because of its accessibility. Canyon erosion has exposed many good cross-sections through the volcanic sequence. Also, the flows are fresh, having been well preserved by the semi-arid climate.

Underlying the Columbia River Basalt Group are rocks ranging in age from the Precambrian to the Mesozoic.[119] The Columbia River Basalt Group has been divided into four main formations, thought to have been erupted between 17.5 to 6 Ma.[120] The earliest lavas of the Columbia River Basalt Group belong to the Imnaha Basalt Formation. These lavas infill the pre-volcanic topography, including the deep canyons of two major drainage systems in the south-east corner of the plateau.[121] Individual flows of the Imnaha Basalt Formation are typically between 20 m and 40 m thick, although they sometimes reach 140 m where they have been ponded due to the underlying topography.[122] Stratigraphically above the Imnaha Basalt is the Grande Ronde Basalt Formation, which accounts for over 85 per cent of the volume of the entire Columbia River Basalt Group (see Figure ll).[123] A hiatus separates the Grande Ronde Basalt from the overlying Wanapum Basalt Formation, and this gap is marked by the Vantage Sandstone in the west and a saprolite horizon in the east.[124] The final one per cent of the volume of the Columbia River Basalt Group is designated the Saddle Mountains Basalt. This formation consists of many, usually small, flows which follow and fill the topographic lows caused by deformation and erosion on the plateau surface.[125]

The volume of some individual flows in the Columbia River Basalt Group is huge, on average exceeding hundreds of cubic kilometres. Several of these large-volume flows were able to travel hundreds of kilometres from their vents, with some known to have travelled more than 750 km.[126] The largest single flows approach 700 km^3 implying flow rates of 0.1 to 1 km^3/day per linear kilometre of vent.[127] This is two to four orders of magnitude greater than the sustained rates observed in present-day Hawaii.[128]

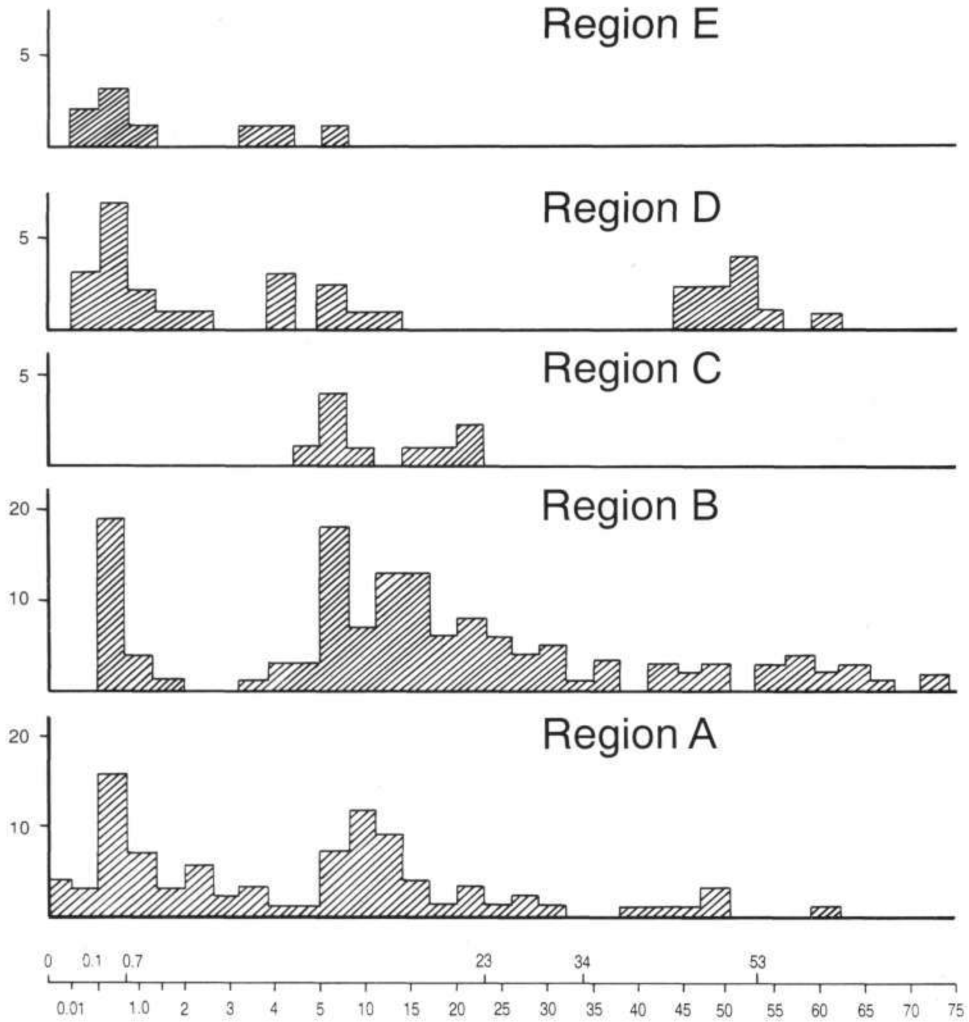

Figure 9. *Histogram of K-Ar ages of Cainozoic volcanic rocks from eastern China (X-axis = millions of years; Y-axis = number of age determinations).*
Region A includes north-east China and Inner Mongolia,
Region B consists of North China including Jiangsu Province,
Region C is an area encompassing Zhejiang, Fujian and Taiwan Provinces,
Region D includes Guangdong and South China Sea Basin, and
Region E the Tengchong area of Yunnan Province.
From Zhou etal.

DISCUSSION AND CONCLUSIONS

Both the large scale and the rapid extrusion of continental flood basalts lend support to catastrophist models of earth history. Continental flood basalts are not forming today, and once again we are confronted with strong evidence that the present is not necessarily the key to the past. However, the stratigraphic distribution of continental flood basalts creates serious difficulties for any young earth model in which the continents are assumed to be flooded with water in the Mesozoic and Cainozoic.

This study of the stratigraphic distribution of continental flood basalts has revealed examples from the Proterozoic and ?Early Cambrian, followed by a long gap in which no continental flood basalts are known, and the subsequent re-occurrence of continental flood basalts from the close of the Palaeozoic onwards. The non-occurrence of continental flood basalts in the Palaeozoic (excepting the ?Early Cambrian instance) is striking and demands an explanation, as geologists have recognised. Members of the Basaltic Volcanism Study Project have written:

'That at least five [continental flood basalts] *have formed during the past 250 m.y. is surely significant for crustal evolution.*[n29]

Attempts by uniformitarians to explain the genesis of continental flood basalts and the clustering of their ages in the Mesozoic and Cainozoic have not been convincing. Duncan and Pyle write:

'The origin of flood basalt volcanism has been problematic and the plate tectonic paradigm has not offered a solution. A strong correlation has been noted, however, between such massive volcanic provinces and the initiation of hotspot activity, usually during continental breakup \[130]

Hotspots are regions where convective plumes of anomalously hot mantle material rise from great depths. It appears that where continental rift systems coincide with mantle plumes, flood basalts are generated. But supposing that this is the case, why did no continental flood basalts form throughout essentially the entire Palaeozoic? There is evidence of plate tectonic activity stretching back well into the Precambrian. According to Park,

(the plate tectonic model is probably applicable, albeit in modified form, for the last 2500Ma.[n31]

If this is the case it is puzzling that no continental flood basalts were formed until the Mesozoic. In the absence of any better explanation, geologists are forced to assume that the stratigraphic distribution of continental flood basalts is simply an artefact of preservation.[132]

A better explanation is, however, possible within a diluvialist framework. Continental flood basalts require subaerial conditions to form. They could not develop during the Flood because the continents were under water at that time. This would explain the almost total absence of continental flood basalts from the Palaeozoic. However, the reappearance of continental basalts at the end of the Palaeozoic indicates that large continental regions were above water and forming dry land throughout the Mesozoic and Cainozoic. It is difficult to see how the data on stratigraphic distribution of continental flood basalts can be accommodated into models in which the Flood does not end until the Cretaceous or Cainozoic. I am led by these data to place the Flood/post-Flood boundary much lower in the stratigraphic record than most creationists have done in the past — towards the end of the Palaeozoic.

As has been established, the eruption of continental flood basalts is intimately related to continental rifting. If continental flood basalts are post-Flood, as I have argued, this must mean that the Mesozoic supercontinents — Pangaea and Gondwanaland — broke up after the Flood, not during it as assumed by Austin *et al.*[133] In the light of the data presented here, further work is needed to develop a creationist model for post-Flood continental division.

Most Flood models, such as that of Whitcomb and Morris,[134] included much of the Cainozoic in the Flood year. However, some creationists have argued that field evidences point to a post-Flood origin for much of the Cainozoic.[135"138] Steven Austin proposed that the basaltic volcanism of north-western USA took place many years after the Flood.[139140] For instance:

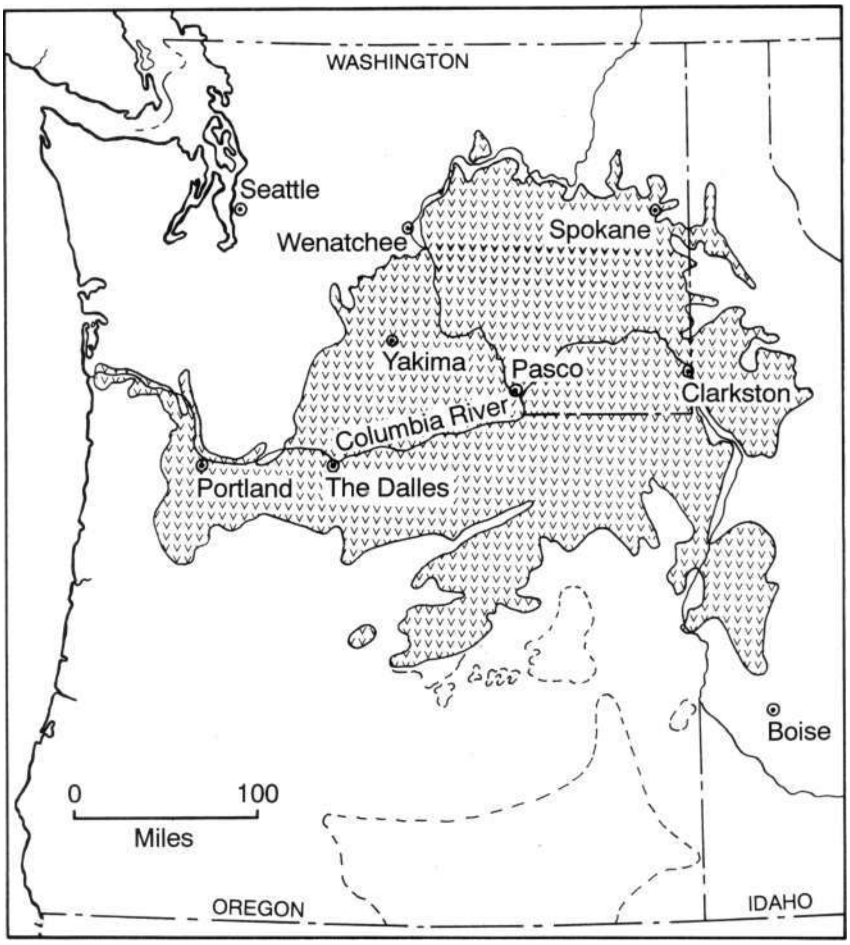

Figure 10. *Map showing the distribution of lavas of the Columbia River Basalt Group of the north-west United States.*

'It is the opinion of the author that the Mesa basalt as well as many other Cenozoic basalts flowed ***after*** *the Noachian Flood. The Mesa basalt could not have flowed during the flood otherwise it would have been "quenched" by the waters and could not have spread so broadly. Other Cenozoic basalts that the author has inspected show various evidences of subaerial accumulation such as widespread flow, development of columnar structures which is an evidence of slower cooling, and lack of rounded masses called pillow structures caused by rapid cooling in water. Included*

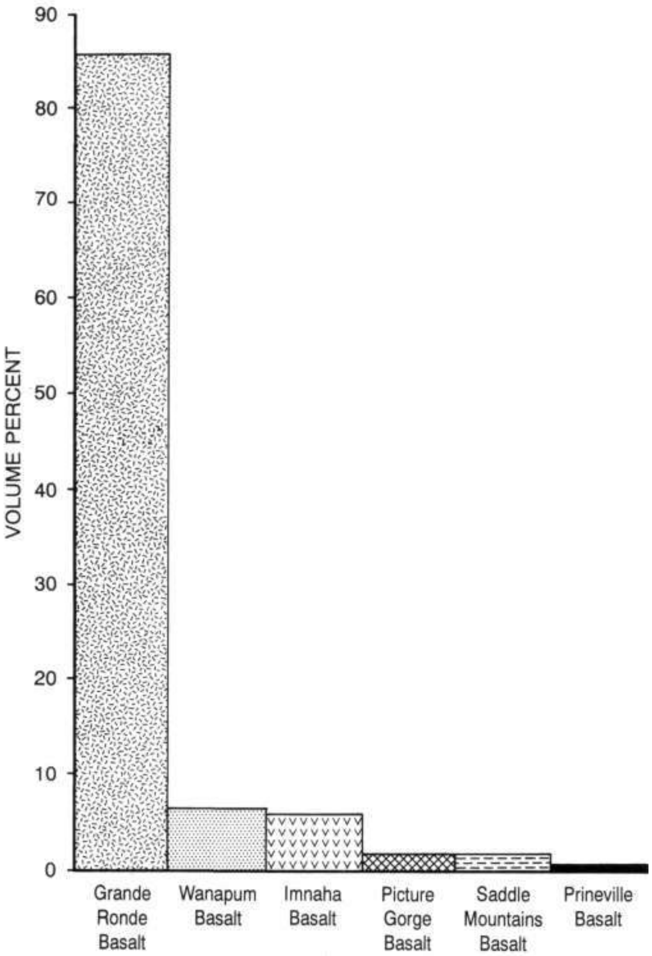

***Figure 11.** Histogram showing the percentage of the total volume of the Columbia River Basalt Group represented by each formation in descending order of importance. The Grande Ronde Basalt comprises over 85 per cent of the entire Columbia River Basalt Group. From Tolan* et al.

in the author's study are the widespread Columbia River basalts (Miocene), the basalts of the John Day formation (Oligo-Miocene) and those of the Clarno formation (Eocene)'.[141]

In a paper published in 1972, Austin went even further than this and argued that similar volcanic sequences elsewhere in the geological record seemed to indicate a post-Flood age for the Mesozoic as well:

'The Mesozoic strata also seem to be post-Flood as subaerial lava flows are well documented.[n42]

The conclusion that much of the Cainozoic is post-Flood in age is now conceded by many creationists. However, there is still a widespread assumption that the Mesozoic was laid down during the Flood, Austin's comments notwithstanding. This review of the stratigraphic distribution of continental flood basalts indicates that Austin was correct when he proposed that the Mesozoic should also be reclassified as post-Flood. The weight of the evidence now supports a Flood/post-Flood boundary somewhere before the end of the Palaeozoic.

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Paul Garner has a B.Sc. (Hons) degree in geology (major) and biology (minor) from the Anglia Polytechnic University, Cambridge (UK) and is currently employed as an information scientist in the pharmaceutical industry. Active as a geologist in European creationist circles, he is on the Editorial Committee of **Origins** (Journal of the Biblical Creation Society).