Submarine Volcanism
Part I — Subaqueous Basalt Eruptions and Lava Flows

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Abstract

For many years significant differences were thought to exist in the form of basaltic lavas generated in subaerial and subaqueous environments. Only with the advent of modern oceanography and marine geology toward the middle the 20th century have uniformitarian geologists begun to understand the significance of subaqueous volcanic settings. Young-earth creationists have generally been unaware that high-volume lava flows and explosive-erupted basaltic volcanic rocks extruded in a subaqueous setting are practically identical to those formed in a subaerial environment. This knowledge opens new possibilities within the young-earth Flood framework in the interpretation of basaltic volcanic strata found in the terrestrial stratigraphic record. While not all continental-based basaltic strata originated in a underwater setting, a more careful examination is now warranted.

Introduction

Basalt is identified as a dark-colored extrusive igneous rock, composed of calcium plagioclase and pyroxene. It contains little to no silica, and high levels of magnesium and iron. It is the most common volcanic rock on the earth occurring across the continents and flooring the world's oceanic basins. Differences were once thought to exist between subaerial and subaqueous basaltic lava in both eruptive style and resulting morphology. Until recently, little has been known of its subaqueous eruptive style or emplacement conditions due to its remote location from direct human observation (Cashman and Fiske, 1991; Griffiths and Fink, 1992a; Tazieff, 1972; Walker, 1992). Modern scientific knowledge of the processes by which basaltic lava erupts and behaves in an underwater setting has increased considerably within the past 45 years (Menard, 1964; Williams and McBirney, 1979). Only since the advent of deep-sea exploration, using the deep-sea submersible, has man finally been able to examine first-hand the processes and products of various subaqueous volcanic environments (Ballard, Bryan, Heirtzler, Keller, Moore, van Andel, 1975; Lonsdale and Batiza, 1980; Renard, Hekinian, Francheteau, Ballard and Backer, 1985; Smith and Batiza, 1989). Other important deep-sea volcanism research tools used are geophysics and side-scan sonar coupled with dredged rock samples for characterization and confirmation (Batiza, Fornari, Vanko, and Lonsdale, 1984; Lipman, Clague, Moore, and Holcomb, 1989). Research continues into how basaltic lava erupts and behaves subaqueously.

Historically, continental silicic volcanism (e.g., non-basaltic) is typically viewed by uniformitarians as having occurred within a subaerial setting. The models used to study volcanic strata are compared to modern subaerial volcanic eruptions such as have occurred at Mount St. Helens, Mount Pinatubo, and El Chichon. Similarly, finding basaltic lava flows on the continents also typically invokes a subaerial setting (Ragland and Rogers, 1984). For example, the majority of the Columbia River Basalt Group flows are interpreted by most uniformitarians as having occurred over the course of millions of years within a subaerial setting (Hooper, 1982, 1997; Reidel and Hooper, 1989), and basalt lava flows in Big Bend National Park are also believed to have been erupted and emplaced in this same manner (Maxwell, 1968; Maxwell, Lonsdale, Hazzard, and Wilson, 1967).

Within both types of historic volcanic settings (i.e., subaerial and subaqueous) young-earth creationists do not have the same liberties with regard to time and energy as do the uniformitarians. We generally regard the majority of the Earth's stratigraphic record as having formed during the global Flood of Genesis (Froede, 1995, 1998a; Froede and Reed, 1999; Reed and Froede, 1997; Reed, Froede, and Bennett, 1996). One can immediately note the impossibility of young-earth creationists invoking the same millions of years of continental subaerial volcanism as do the uniformitarians within their model of Earth history. We must look for other means in which to explain and define Earth history within our Biblical framework. Submarine

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volcanism is both a relevant and important component of our model.

Subaerial to Subaqueous Basaltic Lava Flows and Products

For many years geologists have known of changes in basalt lava morphology as it flowed from the subaerial environment into the subaqueous. This change is expressed by the formation of hyaloclastites, vitric breccia, and where flow is sufficient to continue underwater, basalt pillows (Furnes and Sturt, 1976; Jones and Nelson, 1970). In many instances this interaction with water is violent and results in four primary processes that generate volcaniclastic materials (Kokelaar, 1986):

> ...(1) magmatic explosivity, including accelerated extrusion resulting from rapid vesiculation; (2) explosive expansion and collapse of steam formed at magma-water contact surfaces... (3) steam explosivity resulting from enclosure of water in magma, or entrapment of water close to magma... (4) cooling-contraction granulation. These processes commonly occur together, and many enhance one another.

Where water is involved in terrestrial eruptions the resulting violent volcanic products differ slightly from those produced under subaqueous eruptions (Kokelaar, 1986; Ricketts, Ware, and Donaldson, 1982).

Basaltic eruptions which occur in relatively shallow water form hyalotuffs (Cousineau, 1994; Dimroth, Cousineau, Leduc, and Sanschagrin, 1978), and hyaloclastites (Honnorez and Kirst, 1975). The welding of erupted volcanic fragments is thought to more likely occur in a submarine rather than subaerial setting because dispersal is less rapid and fragments can be convectively reentrained while still hot, even though they have been quenched (Gill, et al., 1990; Orton, 1996).

Where violent subaqueous reactions with water do not occur hyaloclastite formation is minimized and basaltic lava typically flows along the submerged sloped surface (Moore, Phillips, Grigg, Peterson, and Swanson, 1973). Eventually these underwater flows terminate and the resulting exposed basalt surfaces are subject to both chemical and mechanical weathering.

Subaqueous Basaltic Lava Flow Pillows

Probably the most common form of basalt erupted underwater occurs in the form of pillows (Figure 1). These features occur where the rate of effusion is considered to be of low volume. Underwater photography of an ongoing basalt lava flow reveals a lava tube which lengthens as it flows until it finally appears to run out of energy (see photographs in Moore, et al., 1973; Moore, 1975). The final form of these basaltic lava flows are pillows. Formal studies of these structures have been undertaken by Lewis (1914), Moore et al. (1973), Moore (1975) and Ballard and Moore (1977) where they found that lava pillows formed by the spreading cracks on the surface of propagating, branching, and curving lava tubes. The identification of basalt lava pillows is considered a definitive indicator that the lava originally formed within a subaqueous environment. According to Fisher (1984, p. 8) pillowed lava flows and hyaloclastites are:

Figure 1. A block of basalt lava in pillow form taken from Copper Chief mine in Arizona. This basalt is associated with hydrothermal-produced mineral deposits and likely reflects events and processes associated with the Flood (See Froede, Howe, Reed, and Meyer, 1998). Jerome State Historic Park Museum.

> ...prime evidence of subaqueous environments. In areas where fossils or other evidence (e.g., turbidites, carbonates, and facies associations such as shelf, slope or submarine fan) are absent, pillow lavas are commonly the only evidence of a subaqueous environment.

Subaqueously erupted basaltic lava is not limited to the oceanic seafloor. Submarine eruptions and flows have also been documented on the continents having formed beneath glaciers and lakes. The resulting lavas which occur within these unique settings have been studied to determine if certain features in pillow lavas could be used as depth indicators (Jones, 1969). Some researchers have proposed that the multiple-rind structure in pillow lavas can serve as an indicator of shallow water eruption (Kawachi and Pringle, 1988). Basaltic magma chemistry is also believed to constrain the dimensions of basaltic lava pillows extruded in shallow water (Fridleifsson, Furnes, and Atkins, 1982). Interestingly, these subglacial and sublacustrine extruded basalts exhibit morphological features comparable to those which form in the oceans.

Studies on pillow morphology have been undertaken over the past decades to determine what forces, processes, and components affect and alter their form. Yamagishi (1985) found a direct relationship between pillow form and lava flow direction. Walker (1992) investigated pillow size variation and found that pillows have linear dimensions five times greater in one direction as a function of the angle of slope. The relationship between ophiolite complexes and three styles of pillow lava has been investigated and reported from southern Chile (deWit and Stern, 1978). They identified one type of pillow formed by non-explosive submarine effusion, another by magmatic intrusion into a preexisting aquagene tuff which resulted in explosive eruption, and the third pillow form occurred within dikes (p. 55).

Unfortunately, many scientists are unaware of the fact that subaqueously extruded basalt lava flows can occur in forms other than just pillows. However, this information has only recently become widely known.

Other Forms of Subaqueously Extruded Basalt

Extruded submarine basalt flows are not limited to pillow form. Where basaltic lava has erupted underwater it derives its shape from many factors such as the rate of eruption, crystalline content of the melt, slope surface, and temperature. This results in basaltic lava morphology variation from pillow lava to sheet flows to channel flows to brecciated blocks derived from the destruction of the individual pillow lobes (Carlisle, 1963; Cousineau and Dimroth, 1982; Goldie, 1983; Hargreaves and Ayres, 1979; Jackson, 1980; Ricketts, Ware and Donaldson, 1982; Yamagishi, 1991a; 1991b).

Figure 2. Basalt lava flows along channels across the surface of older flows. The chilled lavas are all pahoehoe lava flows. From Kilauea, Hawaii.

Interesting features such as basalt pillars (some up to 45 feet high) form in the deep-sea where the top surface of a lava lake chills, only later to collapse due to the withdrawal of the subterranean molten lava (Ballard, Holcomb, and van Andel, 1979; Francheteau, Juteau, and Rangan, 1979; Gregg and Chadwick, 1996). These features reflect active magmatic activity. Extensive plumbing must be available in the subsurface to allow for the large volumes of lava to be extruded and later withdrawn to form lava pillars.

Basaltic lava domes are considered unique features within the submarine environment. They are believed to be the product of low effusion temperature and rapid convective heat loss which directly affect the magma rheology and influence the final dome-like structure (Smellie, Millar, Rex, and Butterworth, 1998). These features are formed as basaltic lava is pulse-injected into the overlying mass of volcanic rock and hyaloclastites (McPhie, Doyle, and Allen, 1993). Basaltic lava dome-shaped seamounts are also believed to be common on the seafloor (Bridges, 1995).

Subaqueously extruded basaltic lava morphology varies considerably. In a recent paper, Kennish and Lutz (1998, p. 63) identified five different forms of submarine lava flows along mid-oceanic ridges: 1) Pillows, 2) lobates, 3) lineated sheets, 4) folded sheets, and 5) jumbled sheets. Their article is the most thorough review of subaqueous basaltic lava processes and features to date, and should be carefully reviewed when investigating basaltic lava flows as candidates for subaqueous emplacement. Bonatti and Harrison (1988) noted that variations in basaltic lava morphology are linked to eruptive style (see Table I).

Table I. Summary of deep-sea eruptive styles (from Bonatti and Harrison, 1988, p. 2968).

Quiet Eruptions	Lava Lakes (Pillars)	
	Sheet Lavas	Smooth Lobated Corrugated
	Pillow Lavas	Spherical Elongated Broken
Reactive Eruptions	Pavingstone Lavas	
	Hyaloclastites	

Figure 3. This set of complex basalt lava flows exhibit the smooth surface of pahoehoe style lavas. This style is believed to reflect a high volatile content, rapid rate of flow, and high lava temperature. From Kilauea, Hawaii.

Figure 4. A massive aa lava flow (Bonito lava flow) found at the base of Sunset Crater in Arizona. This style lava has a rough and sharp surface which is believed to reflect low volatile content, slow flow rate, and low lava temperature.

Submarine Basalt Lava Flows and Their Similarity to Subaerial Lava Flows

Where large volumes of basaltic lava is erupted into a subaqueous setting, it flows away from the vent in a manner similar to what occurs in a subaerial environment (Figure 2). These submarine extruded lavas typically occur as either pahoehoe or aa style flows (Figures 3 and 4). According to the Basaltic Volcanism Study Project (BVSP) the subaqueously extruded basalt in many cases resembles its subaerial counterpart:

> This is suggested by gross similarities between forms observed in widely separated locations, and by their similarity to many subaerial volcanic features. ... *Overall, submarine lava surfaces bear a strong resemblance to subaerial pahoehoe lava* (1981, p. 732). [italics mine]

This is no isolated comparison as numerous investigators have documented the similarities between the physical features of subaqueous flows and subaerially emplaced pahoehoe (Hon, Kauahikaua, Denlinger, and Mackay, 1994; Jones, 1968; Wells, Bryan, and Pearce, 1979). Lonsdale (1977) discovered abyssal pahoehoe lava coils 1.5 miles beneath the ocean surface at the Galapagos rift which remarkably resemble subaerial flows.

Submarine basaltic aa lava flows also closely resemble its subaerial counterpart (Kennish and Lutz, 1998; van Andel and Ballard, 1979). Differences between the subaqueous and subaerial forms are in the strength of the rock, the subaqueous variety appears to be less competent (Ballard, Holcomb, and van Andel, 1979).

Scoriaceous and Vesiculated Basalts in Shallow and Deep-Water Settings

Shallow submarine eruptions can be quite violent (Macdonald, 1972; Thorarinsson, 1967). Explosive subaqueous eruptions generate scoriaceous breccia lavas resembling their counterparts in subaerial environments (Kano, Orton, and Kano, 1994)[Figures 5 and 6]. This is not surprising for shallow water eruptions, but is not expected in a deep water setting due to the confining pressure of the overlying water (Kokelaar, 1986). However, scoriaceous breccia is believed to have formed in water almost 6000 feet deep (Gill et al., 1990, p. 1214). This finding runs contrary to what has been predicted and described by Honnorez and Kirst (1975). They suggested a simple scheme in which to differentiate deep water basaltic eruptions from those which likely occur in shallow water by proposing to identify deep water erupted basalts as hyaloclastics (non-explosive granulated volcanic glass) and shallow water basalts as hyalotuffs (pyroclastic fine-grained matrix with accompanying scoriaceous breccia formed by explosive phreatomagmatic and phreatic eruptions).

Lackschewitz, Dehn, and Wallrabe-Adams (1994) invoked a complex eruptive style to explain scoriaceous and highly vesiculated basalts which they found on the submerged and active Kolbeinsey Ridge north of Iceland. Their model remains to be throughly tested as it requires a more explosive deep-water eruptive setting than documented in modern times. According to Sparks, Bursik, Carey, Gilbert, Glaze, Sigurdsson, and Woods (1997, p. 232) deep-sea eruptions of basaltic magma create:

Figure 5. Massive (3 to 5 foot diameter) scoriaceous blocks of basaltic lava associated with the Merriam Crater lava flows which created the Grand Falls on the Little Colorado River.

Figure 6. Smaller size (1 to 3 feet in diameter) scoriaceous blocks of lava from the SP lava flow in Arizona.

> ... a slurry of glass shards, seawater and possibly steam. However, because of the generally low volatile contents of most basaltic magmas and the great water depth (>1200 m) [>3960 ft], it is likely that the eruption fountains are denser than the surrounding seawater and will rise primarily as a result of their initial momentum. Collapse of these fountains cause shard-rich (hyaloclastite) gravity flows that move away from the source and deposit bedded hyaloclastite layers. (Brackets mine)

Explosive submarine eruptions are tied to three components (1) The depth (and corresponding hydrostatic water pressure) of the water column, (2) the composition of the magma (especially the amount of volatiles), and (3) the extent of interaction between magma and overlying water (Fisher, 1984). However, an important and commonly predefined component within the uniformitarian model of subaqueous volcanism is their understanding and application of the energy involved in a subaqueous eruption. Their model takes present eruptive rates and projects them back in time, with the foregone conclusion being low-volume and low-energy subaqueous eruptions occurring throughout most of earth's long history. Violent large-scale eruptions are only expected and predicted in shallow water settings. I believe this to be a serious failing of the uniformitarian model. This uniformitarian model deficiency is borne out in the relationship of volcanic fragmentation and explosivity as relate to water depth which is explained below.

The volcanic fragmentation depth (VFD; Fisher and Schmincke, 1984) or the pressure compensation level (PCL; Fisher, 1984) is the maximum depth at which explosive eruption fragmentation can occur. Originally, McBirney (1963) predicted that explosive eruption of basaltic magma would not likely occur below 1500 feet beneath the water surface. According to Fisher (1984, p. 8), the PCL depth for most mafic basaltic magmas is less than 1650 ft. However, subsequent studies have shown the VFD/PCL to range from 660 to >3300 feet as a function of magmatic composition, volatile content, and temperature (Kokelaar, 1986; Lackschewitz et al., 1994). This wide range implies that fragmented shards and breccia of basaltic lava can occur at greater depth than is presently realized or generally acknowledged by many submarine volcanologists. It appears that violent basaltic eruptions occur within the deep sea sufficient to create pyroclastic rocks not predicted as typical to that depth range. Further study is warranted in this area of submarine volcanology.

Flow and Joints Features in Submarine Lavas

For several decades geologists have been interested in basalt flow direction primarily in an effort to identify the source vent which in many cases was buried by the lava flow. Waters (1960) studied several subaqueous flows along margins of the Columbia River Basalt Group where he identified features which could be used to determine the original flow direction. The transition of basalt lava flowing from air into water is also believed to have a structural expression, one which can help decipher both the environment and the flow direction in which it was emplaced (Jones and Nelson, 1970). Additional research into lava flow direction indicators is still required as at present there is no single means by which flow direction can clearly be established.

The rapid cooling of subaqueous basaltic lava is believed to result in the formation of columnar jointing similar to subaerial flows, as well as "cube jointing" which closely resembles the entablature structure of the Colombia River Basalt Group flows (Bergh and Sigvaldason,

Figure 7. Columnar basalt showing the entablature structure. Located near the Coberg Hills, north of Eugene, Oregon. Photograph by Fred A. Brauer.

Figure 8. An active vent expelling volatiles from basalt lavas flowing beneath this structure. With sufficient volumes of basalt lava this vent could erupt and produce lava. Note the small volume of lava around the base of this vent which flowed toward the left side of the photograph.

1991; Long and Wood, 1986)[Figure 7]. Also see Snelling and Woodmorappe, 1998, p. 539. Jointing along with other tensional features which form within basalt flows (both subaerial and subaqueous) can help the researcher attempt to determine whether water played a significant role in the cooling of the basaltic lava flow (DeGraff, Long and Aydin, 1989).

Rate of Extrusion

Originally, scientists postulated that submarine basaltic lava only extruded into pillow forms. However, all of this changed when oceanographers and marine geologists began to examine both slow and fast-spreading oceanic ridges on the deep-sea floor:

> The smooth-surfaced lava plains constitute the principle difference in volcanic morphology between these faster-spreading ridges and a slower-spreading ridge. These lava plains may be 0.5 km or more in width and may extend 2–3 km along the length of the valley. These plains have been provisionally called "sheet flows" by Ballard *et al.* (1979). Surfaces of some flows commonly consist of flattened pillows, giving a low, hummocky relief; other surfaces are flat, featureless, and divided into polygonal plates 2–10 m in diameter. This flat skin may be deformed and wrinkled to various degrees. This may produce intense crumpling and fracturing of the surface, or may result in whorls and ropy coils. *The resulting flow-forms strongly resemble the various forms observed on smooth-surfaced subaerial pahoehoe lava and lava lakes*. The various flow-forms do not necessarily delineate distinct flows, but may grade one into another on the surface of a single flow, and evidently result from different degrees of deformation of an initially smooth skin during progress of the flow. *The formation of these sheet flows is attributed to relatively high rates of extrusion compared to that required to form pillowed flows*. (Basaltic Volcanism Study Project, 1981, p. 740) [italics mine]

A large-scale eruption of basalt from an active vent can produce tremendous volumes of lava (Figure 8). According to Cousineau and Dimroth (1982, p. 98), subaqueous basaltic lava can flow from the source vent in different ways:

> Whereas sheet-flood flows advance simultaneously over their whole front, channelized flows advance by the budding and ramification of small flow lobes. Thus, principal channels divide into major distributories which by bifurcation and ramification deliver the lava to the flow front. Only part of the flow front is active at any time and only the lava in channels and distributories delivering lava to the active part of the flow front is in movement at the same time. A channelized flow then takes the form of an outward growing delta. As the delta advances and the gradient decreases, the existing channel system may not be able to contain the lava flow. In that case, break-out takes place, new channels form, and a new lava delta overlaps the old one.

This is the same style of flow behavior exhibited by subaerial flows, with the differences being in the shape of the lava and its moving frontal lobe (also see Swanson, 1972). Griffiths and Fink (1992a; 1992b) and Gregg and Fink (1995) experimented with polyethylene glycol wax in an effort to understand the relationship between the extrusion rates and flow patterns of subaqueous basalt. They found that the faster the hot wax was extruded the more

Figure 9. A lava tube in volcanic strata at the San Francisco Peaks in Arizona.

Figure 10. Basalt blocks with varying degrees of vesicles. The upper scale is in centimeters and the lower scale is in inches. These gas bubbles reflect the amount of volatiles present within the melt at the time the lava cooled.

likely that sheet-flow would occur. With the highest levels of flow wax pools formed which they believed would directly correspond to the formation of lava lakes. According to Orton (1996), the final morphology and facies of low-viscosity basaltic lavas are determined by the viscosity and volumetric flow rate.

Lava Tubes and Channels

In subaqueous eruptions resulting in the generation of lava, as well as subaerial eruptions which flow into the sea, lava tubes (Figure 9) and channels are considered to be important in distributing lavas around the seafloor (Fornari, 1986; Greeley, 1987). These features are also believed to be characteristic of high-volume and large-scale submarine eruptions. According to Fornari (1986, p. 296), lava tubes may enhance the length of a subaqueous lava flow:

> ... because the confining hydrostatic pressure limits a submarine tube's cross-sectional area and hence for a given eruption volume the flows may be longer because they were forced to move through a narrow tube.

Lava channels form where a high volume submarine eruption continuously breaks its rapidly chilled outer skin and continues to flow along a preexisting channel (Fornari, 1986, p. 297). This interesting flow style has been documented by underwater observation from lava flows originating subaerially from Kilauea volcano, Hawaii (Tribble, 1991).

Factors Affecting Flow Length and Vesicle Size in Submarine Lava Flows

Large-scale basaltic lava flows extending up to 69 miles have been recorded on the deep seafloor in water depths greater than 4950 feet, in areas near Hawaii and the East Pacific Rise (Gregg and Fornari, 1998). It is believed that the confining pressure of the overlying water prevents the exsolution of the dissolved gases within the flow allowing it to travel great distances. The degassing of a subaqueous basaltic lava is believed to increase the viscosity and solidify the flow regardless of the lava temperature (Dixon, Clague, Wallace, and Poreda, 1997; Sparks and Pinkerton, 1978). It is important to note that this water-pressure containment of the dissolved gases within a basaltic lava is not limited to extreme depths of water. Moore, Fornari, and Clague (1985) reported on this same hydrostatic pressure containment of lava gases in basalt flows from a relatively shallow submarine eruption of Mauna Loa, Hawaii.

However, not everyone agrees that exsolved volatiles are the primary issue in the formation of long basaltic lava flows. Fornari (1986, p. 297) suggested that lava tubes played the most significant role in long lava flows. Crisp and Baloga (1994, p. 11,828) and Griffiths and Fink (1992b, 1993) believe that surface temperature cooling and crystallization of the melt slow and solidify basaltic lava flows. Other investigations into the dynamics of cooling melt crystallization have been performed by Stasiuk, Jaupart, and Sparks (1993) and Cashman (1993). They also suggested a causal relationship between temperature and crystallization of the lava. Bonatti and Harrison (1988, p. 2974) proposed that the crystal/liquid ratio at eruption, lava ascent rate, and temperature are the three key components in defining how subaqueous basaltic lavas might flow and solidify. With regard to volatile content, Bonatti and Harrison (1988, p. 2977) stated that:

> ... the volatile content of the melt is not important in determining whether lava lakes, sheet, or pillow morphologies will be produced...

While they proposed that volatile content did not appear to play a role in lava morphology, they did detect a trend toward decreasing eruption temperatures from lava lakes to sheet flows to pillow basalts (1988, p. 2976). According to Byers, Garcia, and Muenow (1986, p. 9) sheet flows and pillow basalts contain identical volatile contents:

> Thus, volatile abundance is not a factor controlling flow morphology. Extrusion rate and/or surface topography are probably the most important factors influencing flow morphology on submarine basalts.

However, they did admit that dissolved water content within the lava did relate to the length of the resulting basaltic flow (p. 9). The loss of H_2O has been proposed by Bridges (1995; 1997) as the means by which basaltic lava flows solidify. He believed that subaqueous flows would lose less water and would be less viscous than terrestrial counterparts.

Williams and McBirney (1979) reported on the relationship between the formation of vesicles and dissolved volatile content within the basalt lava flows (Figure 10). They determined that the greater the water depth and the higher the hydrostatic water pressure, the smaller the vesicle size. Basalt lava samples taken from depths of 2640 feet had vesicles averaging greater than 0.5 mm, while basalt lavas retrieved from depths of 2.5 miles had vesicles which averaged less than 0.1 mm (Moore, 1965, p. 43). Moore, Batchelder, and Cunningham (1977) identified CO_2 as the gas primarily responsible for the formation of vesicles in deep-sea basalt flows. Additional research conducted by Macpherson (1984) on vesicles in submarine basalts from various depths found a relationship between ratios of dissolved H_2O, CO_2 and SO_2 in basaltic melts. He determined that vesicles in submarine lavas are mostly due to the release of CO_2 at ocean depths greater than 1.25 miles, CO_2 and H_2O at depths between 1.25 miles and 660 feet, and CO_2, H_2O and SO_2 in water depths less than 660 feet (Macpherson, 1984, p. 74).

Geological Record of Subaqueous Basalt Lava Flows

According to uniformitarians, probably the greatest period of subaqueous basaltic volcanic activity occurred early in the history of earth — during the Archean Eon (Wells, Bryan, and Pearce, 1979). Most of the evidence used in support of this interpretation comes from the Precambrian volcanic strata found in Canada (Baragar, Coleman, and Hall, 1977). Many of these outcrops of Archean basaltic rocks exhibit only two-dimensions of the former pillows because the outer surface of these submarine flows has been sheared off exposing only a flat surface. These Archean basalt lava flows are believed to be completely analogous to modern day subaqueous basaltic lava flows (Dimroth and Lichtblau, 1979). According to Wells, Bryan, and Pearce (1979, pp. 438–439), the Archean subaqueous pillows were:

> ...compressed together while still very hot and plastic, implying rapid accumulation, compression, and outward spreading flow.
>
> Our preferred model of Archean volcanism resembles that of the abyssal regions of the mid-oceanic ridges, but with *a minimum water depth of less than a kilometer*. The rate of lava production was likely greater than at present day ridges but relatively rapid subsidence for the rate of magma production maintained most volcanic edifices below sea level. (italics mine)

This scenario requires a high-energy high-volume large-scale eruption—one which presently has no modern analogue, and is also unique to the earliest periods of earth history. It should be noted that according to Plate Tectonic theory *all* of the earth's oceanic basins, composed of basalt rock which was extruded under subaqueous conditions, were created within the past 180 million years. Yet none of this subaqueous volcanic activity is viewed as being equal to or exceeding the size or volume that occurred during the Archean. This uniformitarian interpretation is based solely on the basaltic lava volume and morphology of flows found in Canada. Clearly in this instance the uniformitarian model drives the interpretation. It should be noted that more recently submarine volcanologists are starting to examine other submerged igneous provinces in an attempt to define the levels of energy necessary to form these large lava flow areas within the uniformitarian model (Mahoney and Coffin, 1997). Some of these areas required basaltic lava extrusion rates higher than has been measured in recorded history (Self, Thordarson, and Keszthelyi, 1997).

Age-Dating Lava Flows

The relative dating of subaqueous eruptive flows is complex as the flow contacts in many cases do not allow for clear superpositional relationships to be established (Chadwick and Embley, 1994). Additionally, the outer surfaces of many of the flows weather at varying rates, preventing any accurate age determination (Kennish and Lutz, 1998). Age-dating basalt flows using rock weathering can yield incorrect dates by one or more orders of magnitude (Chadwick and Embley, 1994, p. 4773). Using sedimentary cover to age-date submarine lava flows can also provide an incorrect age (Ballard, Holcomb, and van Andel, 1979). Presently, the age dating of subaqueous basaltic lava flows by using weathering rates has not been resolved.

A Young-Earth Flood Model Perspective

When investigating volcanic strata exposed across the continents, the young-earth Flood modeler must first examine the local stratigraphic column in an effort to reconstruct how changing-energy levels (which operated during and following the global Flood) affected what is observed at the outcrop (or well core). Creationists neither have nor need vast periods of time of slowly changing paleoenvironments to explain how volcanic strata formed, in fact we often reconstruct the stratigraphic column within a catastrophic framework. Another important perspective within our short-term catastrophic framework is the likelihood that *the majority of the global stratigraphic column was formed underwater during the global Flood of Genesis*. Hence, our approach is radically different from that invoked by uniformitarians who use subaerial settings spanning millions of years to explain the majority of the strata found on the continents. While I am *not* identifying every volcanic layer (basalt or otherwise) as having formed subaqueously (that determination must be made on a site-by-site basis), much of the volcanic strata found on the continents and interpreted within the global stratigraphic column was likely formed within a submarine paleoenvironment. We must interpret extrusive basaltic strata in a manner which conforms to our Biblical framework. Creationists are now just beginning to examine and interpret volcanic strata in this manner (Froede, 1996a; 1996b; Oard 1996; Williams, 1998; Williams, Howe, and Meyer, 1999). Clearly, additional research should be conducted on basaltic strata found on the continents to determine whether they were extruded in a subaqueous or subaerial environment.

While basalt lava flows occur in similar forms whether extruded within a subaqueous or subaerial environment, other qualifiers are clearly necessary to determine the paleoenvironment in which basalt flows originated. For example, the type of strata which over and underlie the solidified basalt flow might provide some ideas about the previous depositional environment. Likewise, the presence of freshwater or marine fossils might also shed some light on the original setting. *The sole reliance upon the form (i.e., morphology) of a basalt lava flow to determine the original historic setting can no longer be considered the only source for paleoenvironmental reconstruction.*

Many creationists identify links between the high-energy volcanism associated with the Precambrian (specifically in strata identified as the Archean) and the onset of the global Flood of Genesis (Froede, Howe, Reed, and Meyer, 1998; Hunter, 1992; Reed, in press; Snelling, 1991; Woodmorappe, 1999). Understanding the various factors which affect the morphology of basaltic lavas can lead to a better comprehension of the high-energy geological processes that were in operation with the onset and throughout the Flood. Massive subaqueously outpourings of basaltic lava likely occurred on the continents within very short periods of time during the global Flood. Most of this terrestrial volcanism would begin in a subaerial antediluvian environment only to be eventually inundated by rising Floodwater. Subaqueous volcanism along the continental margins and within the deep-sea floor during the Flood would have occurred in a manner greater than what is experienced today within those same types of settings. It should also be noted that subaerial outpourings of basaltic lava likely occurred following the withdrawal of Floodwater. Hence, only through a careful examination of the specific stratigraphic setting can the examiner gain a clear understanding of the possible original paleoenvironment(s). However, the creationist proposal that all the basaltic oceanic basins of the earth formed during the Flood (Baumgardner, 1986; 1990; 1994a; 1994b; Austin, Baumgardner, Humphreys, Snelling, Vardiman, and Wise, 1994) remains unacceptable to this author and several other young-earth creationists (Froede, 1998b; Froede, 1999; Reed, Bennett, Froede, Oard, and Woodmorappe, 1997).

Knowledge of the similarity in form and behavior between subaqueous and subaerial basaltic lava flows provides interesting alternative interpretation possibilities to the young-earth Flood modeler. We no longer have to restrict our interpretation of basalt lava flows found on the continents to a subaerial setting.

Conclusion

Volcanic processes and products are important in reconstructing the depositional history of the local stratigraphic column. Explaining how volcanic materials became a part of the stratigraphic section follows the interpretative framework in which they are defined. Uniformitarians relate volcanic events occurring at time-discrete intervals over the course of millions of years. Continent-based eruptions are typically viewed as occurring within a subaerial environment. Basaltic lava within this same setting is viewed as flowing out and away from a rift or vent until it degasses and cools. In many instances this subaerial interpretation is based on the lack of any obvious subaqueous indicators (i.e., pillows).

Basalt is today extruded at various rates across portions of the seafloor. Oceanographers and marine geologists are just now starting to realize the processes in which this eruptive style occurs. Long gone are the days of subaqueously extruded basalt interpreted as only occurring as pillows. Today, submarine basaltic lava morphology is known to resemble its terrestrial counterpart. The processes responsible for erupting and shaping the basaltic lava flows in a subaerial setting are the same that affect the shape, width, and length in an underwater setting.

Young-earth creationists must take a different approach to understanding Earth history, one based on the Biblical record of a global Flood, along with its corresponding link to high-energy geologic processes. Continent-based subaerial volcanism has a place in our model, but only after emergent conditions were established after the global Flood. Most of the high-energy volcanism we see exhibited within the global stratigraphic record probably occurred in a subaqueous setting during the Flood. Problems with interpreting basaltic lava flows as having occurred underwater has been in identifying features linked solely to subaqueous emplacement, such as basalt pillows. Many hold to the idea that without basalt pillows one cannot argue for subaqueous deposition. This is no longer the case.

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Book Review

Refuting Evolution by Jonathan Sarfati
Master Books, Green Forrest, AZ. 1999, 144 pages, $10.99

Jonathan Sarfati says that recently the National Academy of Sciences (NAS)

> made available to public schools and other institutions a book (*Teaching About Evolution and the Nature of Science*) that supposedly presents the latest information on evolution. . . It is designed to persuade and assist teachers to further indoctrinate their students in favor of evolution, with specific advice on countering anti— evolutionist students" (p. 10).

Sarfati thoroughly investigated the claims of the NAS book and found that some typically outdated and discarded ideas were still being presented as fact.

Refuting Evolution responds to many of the arguments in *Teaching About Evolution and the Nature of Science* so that a general critique of evolution can be made available to challenge educators, students and parents" (p. 14).

Sarfati, who received honors in physical and inorganic chemistry and in condensed matter physics and nuclear physics at Victoria University in Wellington, New Zealand, begins by stating some facts and biases for both evolutionists and creation scientists. He states, "It is a fallacy to believe that facts speak for themselves—they are always *interpreted* according to a framework" (p. 15).

In Chapter 2 the author calls attention to a common evolutionary concept in Teaching About Evolution and the Nature of Science in which *all* changes in organisms are called "evolution" and that this enables the book to "claim that evolution is happening today" (p. 31). An example would be Sarfati's quote from *Teaching About Evolution*, "Many strains of bacteria have become increasingly resistant to antibiotics as natural selection has amplified resistant strains. . ." (p. 39). To this Sarfati asks, "However, what has this to do with the evolution of *new kinds* with *new genetic information?* Precisely nothing" (p. 40).

Another quote from *Teaching About Evolution* used by Sarfati is:

> A particularly interesting example of contemporary evolution involves the 13 species of finches studied by Darwin on the Galapagos Islands, now known as Darwin's finches...

To this, Sarfati retorts,

> However, again, an original population of finches had a wide variety of beak sizes... Again, no new information has arisen, so this does not support molecules-to-man evolution (p.42).

For each point given by the authors of *Teaching About Evolution*, Sarfati points out how the NAS has failed to prove that evolution should be the only origins theory to be taught in the secular schools system. Also, Sarfati in this book gives as much positive information as he can to defend the creationist position. Although a short book, *Refuting Evolution* provides a valuable summary for the layman of the whole evolution/creation controversy.

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