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Submarine Lava Flows: Possible Mechanism of Thick Glassy Crust Formation

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Submarine pillow basalt lavas with and without glassy crusts are known to differ in structure. A possible cause of thick glassy crust formation is the presence of large amounts of fluids (water) dissolved in the lava, which had remained in this relatively closed system. The contents of fluids in lavas were estimated using the contents of constitutional water (H_2O^+) determined by the chemical analyses of rock samples. The minimum contents of dissolved H_2O^+ in lavas were found to range from 2.3–2.5% (sodic basalts) to 3.3–3.5% (sodic–potassic basaltoids).

INTRODUCTION

As lava flows into the sea, a thin (1–2 cm) quenching glassy crust develops on the surface of the flow. This glassy crust has a very low thermal conductivity: the temperature of water in contact with the basalt lava that flowed into the sea from the Hawaiian coast rose merely by 2.5° [8]. Under the glass the lava remains liquid and capable of flowing for a long time. This leads to the formation on the lava flow surface of secondary lava streams and to the bifurcation of tubular flows that run down the slopes of the newly formed lava bodies [5]. The low viscosity of basalt lava favors crystallization and gravitational differentiation in the flow, the redistribution of the gas–liquid constituent in the lava, liquid immiscibility, layering, and other processes [4], [5], [6].

Of particular interest are lava flows with a glassy crust as thick as 10–20 cm. Such crusts are often observed on tubular (pillow) basalt lava flows. They form on the lavas that flow on the floor of deep-sea basins, and also on the bottoms of fresh-water rivers and lakes and under the bottoms of continental glaciers [5]. Consequently, there are no grounds to associate the formation of thick glassy crusts on lava flows with the salinity or pressure of the surrounding water. Moreover, members of such glassy lavas are known to alternate with lava flows that have usual (thin) glassy crusts. This fact alone prohibits the explanation of the formation of compositionally similar glassy crusts of different thicknesses by the habitual mechanism of liquid lava quenching and instantaneous vitrification.

STRUCTURE AND SPECIFIC COMPOSITION OF GLASSY LAVA FLOWS

Lava flows with very thin glassy crusts usually do not have a distinct variolitic zone (Fig. 1, *a*). At the same time they often have an amygdaloidal structure and numerous concentric and radial cleavage fractures. The tubular flows with thick glassy crusts usually have a variolitic zone under the crust and rarely show an amygdaloidal structure (Fig. 1, *b*). Glassy crusts are thicker on thick lava flows, even though seemingly a thin lava flow should have solidified as glass throughout its whole volume, but this has never been observed.

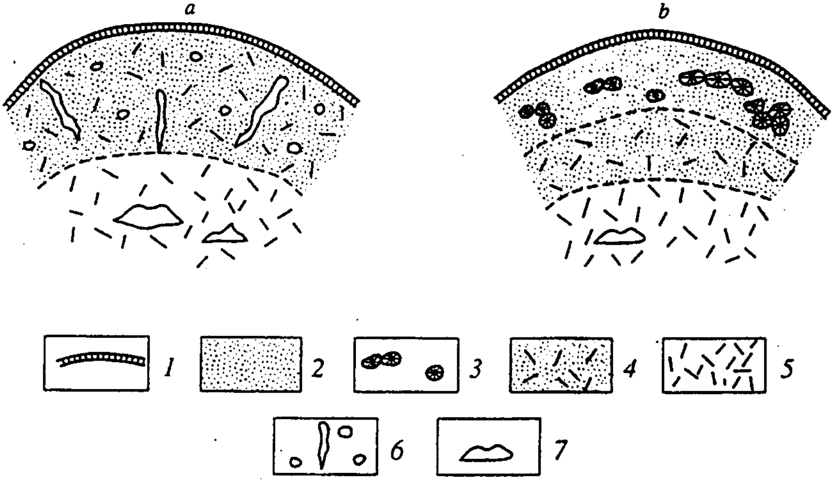

Figure 1 Sections across pillow lava flows of polyzonal structure (*a*) and relatively homogeneous (*b*): *1* – primary glassy crust, *2* – secondary glass zone, *3* – variolites, *4* – fine-grained rock, *5* – internal crystallized part of the flow, *6* – round and tubular amygdules, *7* – gas voids.

In view of the fact that the contents of major petrogenic oxides are similar in zoned and unzoned lava flows, it is conceivable that the composition of lava does not play any role in the formation of a glassy crust on the lava flow. The more so as zoned and unzoned lava flows are known from volcanic rocks belonging to series of different alkalinities [5]. However, there is geological evidence that isolated magma portions may produce glassy lava flows. Observations in the South Urals [5] revealed that a complex of dolerite dikes that had channeled magma for pillow basalt flows contained, along with the predominant dolerites, uncommon dikes of a variolitic, glassy rock. At the same time the pillow lava sequence produced by these dikes does not contain any significant glassy lava flows with variolitic zones. This fact suggests that some specific lava, which produced flows with glassy zones, had been channeled from time to time by these feeders. The specific composition of this lava is confirmed by the fact that whenever a new mini-flow issued to the surface from the liquid core of the parental flow through fissures in its crust, its structure always repeated the structure of the parental flow: the tongue of the secondary mini-flow produced by the zoned flow is usually wholly vitrified or transformed to hyaloclastite, whereas the secondary flow of the unzoned lava flow is merely covered by a thin glassy crust.

Apparently, the compositional specifics of different lava portions should be sought in the components which are poorly recorded in the results of the chemical analysis. It is obvious that these are volatiles: their amount, composition, and ability to dissolve in lava. The occurrence of volatiles in the lava can be proved by degassing traces: amygdules or voids of an irregular form. Gases are not completely dissolved in lavas and accumulate in voids, often communicating with the surrounding water. Where the solubility of volatiles in lava is not high enough, few voids are formed in it. It follows from this assumption that lava that produced flows with glassy and variolitic zones and did not generally include amygdules contained a significant volume of dissolved volatiles. This is what specifies the composition of lava portions which make up glassy lava flows. Lava flows without glassy crusts, often having an amygdaloidal structure, are relatively depleted in volatiles.

POSSIBLE FACTORS CAUSING LAVA VITRIFICATION

According to A. V. Gorokh [2], gas-saturated magma begins to crystallize only upon the growth of the system's specific volume, which can take place through the removal of volatiles. Where the system is closed, and its volatiles do not leave it, magma must be transformed to a solid amorphous state, that is, become vitrified, on further cooling. This process can occur in tubular lava flows, whose upper portions were initially enriched in volatiles (Fig. 2). The presence of the latter prevents the formation of spontaneous crystallization centers. Volatiles are retained in the flow volume by the sturdy primary chilling glassy crust and by the high hydrostatic pressure of the surrounding water. Where the hermetic state of the system is violated by cracks, or where the water pressure is low, volatiles liberate easily, and the liquid begins to crystallize spontaneously without the formation of a thick glassy zone. Various combinations of the primary gas content of the liquid, chill crust thickness, and water pressure result in the fact that glassy zones arise in lava flows with different depths of their issue, the phenomenon which is observed in nature [5].

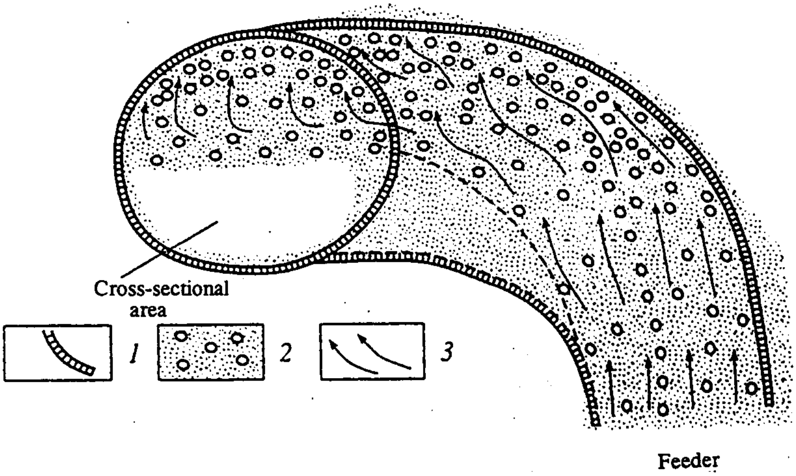

Figure 2 Diagram showing the movement and distribution of volatiles in the body of a tubular lava flow: *1* – primary glassy crust, *2* – gas-saturated volume of the flow, *3* – direction of fluid movement in the lava.

Based on the above considerations and on the observations of submarine lava flows, the following model is proposed for the formation of thick glassy crusts. The primary thin chill glassy crust keeps the lava to be fluid, capable to flow, for a long enough time, especially long in flows of gas-saturated lava portions. The migration of gasses to the roof portion of the flow makes its gas saturation more complete, which often results in liquid immiscibility and in the formation of bands and isolated varioles. Despite the quenching effect of the surrounding water, the melting temperature of the lava flow in its roof portion, where volatiles are concentrated, declines notably. As a result, this lava portion remains to be liquid, its crystallization centers are suppressed by the dissolved water, and the internal zones of the flow, where the volatile content is notably lower, begin to crystallize. It follows that on this assumption we have a paradoxical situation: the lava flow begins to crystallize from the core to the margins. The thickness of the uncrystallized marginal rim is the larger, the greater is the heat reserve in the cooling flow and the larger is the amount of volatiles dissolved in it. All of these parameters must be directly controlled by the volume of the lava flow. The elevated alkalinity of the lava is another factor decreasing the melting temperature of the liquid. On the attainment of solidus, which is controlled by the sum of volatiles in the lava, by the content of alkalis, and by the surrounding temperature, the previously liquid envelope of the lava flow, which now

Table 1 Average H_2O^+ contents (wt.%) in submarine basaltoid lava flows from different rock sequences.

Zoned pillow lava flows			Unzoned flows			
			pillow flows		stratal flows	
1	2	3	3	4	5	6
Sodic basalts of Mugodzhary sequence						
4.36 (8)	3.47 (3)	2.51 (5)	2.29 (6)	2.33 (12)	2.27 (5)	2.31 -
Sodic–potassic basaltoids (chacharites) of Chanchara sequence						
9.55 (6)	5.18 (16)	3.55 (20)	3.35 (5)	2.89 (11)	- -	- -

Note. Data for this table were derived from the chemical analyses reported by V. G. Korinevsky, V. K. Zaravnyaeva, G. E. Narvait, and A. A. Chumakova [1], [3] and by N. A. Rumyantseva and E. L. Rozinova [6]. The figure in parentheses is the number of analyses. 1 – glass from pillow crusts, 2 – pillow variolitic zone, 3 – pillow internal zone, 4 – pillow margins, 5 – chill crust of stratal flows, 6 – internal part of a stratal flow.

has a solidified core, having a significantly smaller volume than the core, cools off rapidly becoming vitrified.

This model explains the above mentioned structural peculiarities of glassy tubular lava flows: the great glass thickness in large flows, the occurrence of variolitic zones in their near-roof parts, the thicker glassy crusts in potassic basaltoids (chancharites), and the absence of notable amounts of gas voids in them.

ESTIMATION OF RELATIVE AMOUNTS OF VOLATILES IN LAVA

I attempted to estimate the relative contents of volatiles dissolved in basalt lavas using the weight per cent contents of constitutional water (H_2O^+) in the rocks from the results of chemical analyses. I examined the H_2O^+ distribution in different parts of basalt flows from two sequences in the South Urals: the Mugodzhary sequence of sodic basalts and the Chanchara sequence of sodic–potassic basalts [1], [3], [4], [5], [6]. I compared the H_2O^+ contents in the lava flows with glassy and variolitic zones and in the lava flows of similar composition where such zones were absent. The results are given in Table 1. One can see a considerably higher H_2O^+ content in the potassic basaltoids (chancharites) compared to the sodic basalts. It is important that the chancharites contain thicker glassy zones than do the Mugodzhary sodic basalts. It is important also that in the unzoned flows of both petrochemical groups of basaltoids, the inner and outer portions of the stratal and pillow lava flows showed little difference in this parameter. In the zoned lava flows, the H_2O^+

content increases drastically from the cores to the margins, where this content attains its maximum value in the glassy crusts of the pillows. This was caused to a great extent by the post-magmatic low-temperature hydration of glass through the use of the surrounding water [1]. It should be recognized that this process occurred in a limited range: according to J. G. Moore [7], the isotopic composition of hydrogen from the water contained in the surficial layer of a basalt pillow was 6% lower in deuterium compared to the average oceanic water, which excludes the possibility of large amounts of water absorbed by the lava. Of principal importance is the fact that the inner portions of the zoned and unzoned lava flows contain roughly equal amounts of H_2O^+. This observation concerns both groups of the examined basaltoids. I used these values (2.3–2.5 and 3.3–3.5%, respectively) to evaluate the minimum quantities of H_2O^+ dissolved in the lavas. The resulting values were 3.5–4.4% in the sodic basalts and 5.2–9.5% in the chancharites in the near-roof portions of the pillows, from which the glassy zones had been formed later. Therefore the real H_2O^+ distribution in the rocks from different zones of pillow basalt lava flows confirms the idea of the significant role of volatiles (water) dissolved in the lava during the formation of glassy crusts.

REFERENCES

1. V. N. Bykov, V. G. Korinevsky, V. E. Eremyashev, and V. N. Anfilogov, *Mineral. Sb.* N6: 122–134 (1996).
2. A. V. Gorokh, in: *Minerals and Mineral Resources of the Urals* (in Russian) (Ekaterinburg: UrO RAN, 1992): 142–145.
3. B. P. Zolotarev, M. N. Iliinskaya, and V. G. Korinevsky, *Izv. AN SSSR. Ser. Geol.* N1: 136–149 (1975).
4. V. G. Korinevsky, in: *Volcanism in the South Urals* (in Russian) (Sverdlovsk: UNTs AN SSSR, 1974): 43–59.
5. V. G. Korinevsky, *Volcanic Rocks of the Urals* (in Russian) (Sverdlovsk: Izd-vo Ural. Un-ta, 1987).
6. N. A. Rumyantseva and E. L. Rozinova, in: *Petrology of Uralian Volcanic Rocks* (in Russian) (Sverdlovsk: UNTs AN SSSR, 1975): 100–110.
7. J. G. Moore, *Contrib. Mineral. Petrol.* **28**, N4: 272–279.
8. J. G. Moore, *Bull. Geol. Soc. Amer.* **84**, N2: 537–546 (1973).