Title	Viscous Behavior of Syowa-Sinzan New Lava
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Citation	Journal of the Faculty of Science, Hokkaido University. Series 7, Geophysics, 1(2), 93-101
Issue Date	1958-11-05
Doc URL	https://hdl.handle.net/2115/8623
Type	departmental bulletin paper
File Information	1(2)_p93-101.pdf

[Journal of the Faculty of Science, Hokkaidô University, Japan, Ser. VII, Vol. I, No. 2, 1958]

Viscous Behavior of Syowa-Sinzan New Lava

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(Received June 3, 1958)

Abstract

In order to throw light on the difficult problems concerning the viscosity of lavas which characterizes volcanic activities the present writer investigated the viscosity of Syowa-Sinzan (or Showa shinzan) new lava within the temperature range from 800°C to 1150°C.

In these experiments the lava showed quite extraordinary behavior, that is, the viscosity depends not only on temperature (T), but also on heating rates (dT/dt). Under constant temperature, after the specimen was heated rapidly to the given temperature, viscosity increases with time and approaches an asymptotic value. In explanation of this relation, it is plausible to suppose that the glassy part in groundmass of the lava must begin to crystallize. By application of the results obtained the writer deduced the viscosity of the lava on extrusion.

Also the writer compared the results obtained by present experiment with those concerning Oshima lava.

1. Introduction

The physcial properties of volcanic rocks as ascertained by reheating or remelting in laboratory are of the so-called "dry" state, so geologists and geophysicists avoid considering them in direct relation to the volcanic activities. Indeed there is an enormous difference between the viscosity obtained by experiment in laboratory and that of the actual flow of lava in field. Oshima lava is a case in point1)2). However as the viscosity of rocks at elevated temperatures is an important factor in volcanic activities, many investigators have been engaged in some experiments on viscous properties of some rocks with the purpose of measuring the viscosity as a function of temperature.

Sakuma2) deduced from his experiment the changes in viscosity of Oshima lava cooling under natural conditions.

In the present paper the writer reports the results of experiment of new lava which forms the dome of Syowa-Sinzan3) and makes some discussions on the cooling process of the lava.

2. Method

The method of viscosity measurement applicable to rock is limited by the experimental difficulties resulting from the high temperature. So great is the range of viscosity of rocks that different methods must be used in the various portions of the viscosity-temperature curve.

Kani[4] measured the viscosity of basalt and nepheline basalt by the Margules method, in which two concentric cylinders are separated by the rock samples, and the rate of rotation of the inner cylinder is measured under a given torque, the other one remaining stationary. This method is applicable over the largest temperature range, but was useless for viscosities greater than 10^5 poises.

Sakuma[5] devised a new method by the application of rheology. In the present paper the method of measurement of viscosity is the same as his. The following is a summary of his method.

The ordinary bending or sagging method of measuring elasticity and slow viscous flow was adopted. The deflection of the centre of the beam is measured and it is connected with the formula which is utilized frequently in rheology. The quantity of deflection (X) is expressed by the linear combination of those derived from Maxwell-model and Voigt-model.

$$\begin{aligned} X = (Wl^3 g/4\,bd^3 + 5\,wl^4 g/32\,bd^3)\big[&(1/E_U)\{1+(t/\tau)\} \\ &+\{(1/E_R)-(1/E_U)\}(1-e^{-t/\tau'})\big] \end{aligned}$$

where W : applied load,

w : weight of the specimen per unit length,

b & d : breadth and thickness of specimen,

l : distance between the supporting knife-edges,

E_U : unrelaxed Young's modulus,

E_R : relaxed Young's modulus,

τ & τ' : relaxation times.

Viscosity is derived from the following equation which is based on the assumption that the specimen is an incompressible viscous liquid.

$$\eta = \tau E_U/3\,.$$

The temperature of specimen is raised not step by step but at a constant and definite rate and the load is applied from long before the commencement until the end of heating, to obviate any effects of the thermal history of specimen.

This method has some weak points, viz., (i) possible lag of temperature in the furnace increases with time and is not kept constant, and (ii) lag of deformation due to elastic after-effect occurs. However, the former weak point is negligible and the latter one is also at least at the temperatures higher than 800°C.

3. Specimens

The tested specimens (ca. $8 \times 1 \times 0.3$ cm^3) were cut out of a piece from the new lava of Syowa-Sinzan. Chemical and petrographical studies have already been carried out by Yagi[6]. According to his study, the new lava is hypersthene dacite, with phenocrysts of andesine and hypersthene unevenly scattered in the fine-grained groundmass. The chemical composition of the specimen is given in Table 1 together with that of 1950 lava from Volcano Oshima.

Table 1. Chemical Composition of Specimens (%)

Specimen	Syowa-sinzan new lava	Oshima 1950 lava
SiO_2	69.74	52.02
Al_2O_3	15.59	15.83
Fe_2O_3	1.52	2.28
FeO	2.59	10.80
MgO	0.85	4.47
CaO	3.63	9.48
Na_2O	3.43	1.58
K_2O	1.36	0.29
H_2O_+	0.67	0.99
H_2O_-	0.23	0.24
TiO_2	0.45	1.52
P_2O_5	0.22	n.d.
MnO	0.08	0.09
Total	100.36	99.59
Analyst	K. YAGI	J. OSSAKA

4. Results

Results obtained in the temperature range from 800°C to 1150°C were almost the same as those in the case of 1950 Oshima lava that was investigated by Sakuma[2]. They are summarized as follows:

a) Viscosity coefficient decreases with the rise of temperature and decreases abruptly within the narrow range of 50°C above 1100°C. (Fig. 1).

b) When the specimens were dealt with under various rates of increases of temperature, viz., 600°C/*hour*, 100°C/*h* and 30°C/*h* and the applied stress was kept the same for all experiments, viscosity was observed to depend not only on T, but also on dT/dt and the more rapidly the specimens were brought to high temperature, the more fluidal they became, viz., $\eta^{600} < \eta^{100} < \eta^{30}$ (Fig. 1).

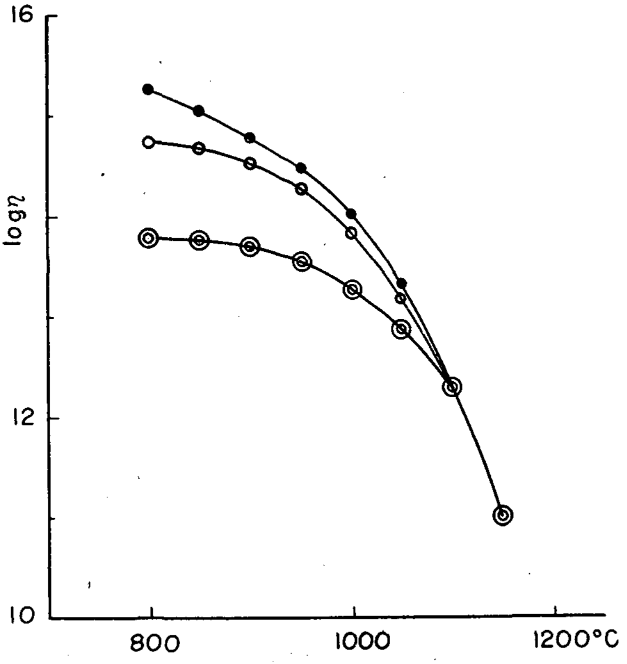

Fig. 1. Viscosity versus temperature with various heating rates for Syowa-Sinzan new lava (in poises).
Closed circles : 30°C/h.
Open circles : 100°C/h.
Double circles : 600°C/h.

c) Experiments under constant temperature, after specimen was rapidly heated to the desired temperature, showed that viscosity increases with time and gradually approaches an asymptotic value. (Fig. 2)

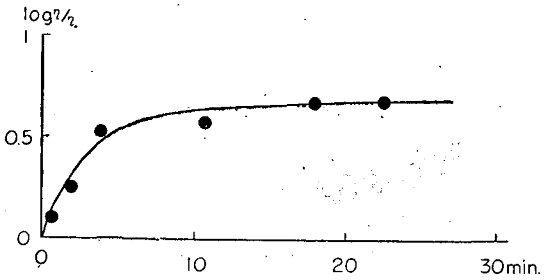

Fig. 2. Viscosity (log η ($t=t$) − log η_0 ($t=0$))-time curves for Syowa-Sinzan new lava at constant high temperatures (1010°C).

5. Discussion

The present experiments show the viscosity of Syowa-Sinzan new lava is a function of T and dT/dt just as in the case of Oshima 1950 lava. These results mean that new lava is not cooling under perfect thermodynamical equilibrium and this fact may complicate the experimental studies of visco-elastic properties of rocks. However, the writer discusses whether there is any significance to be attached to these experimental facts as follows.

First, let the present results be compared with those of Oshima 1950 lava, since accurate knowledge of the relations between chemical composition and viscosity and between temperature and viscosity is a matter of importance to a study of rocks.

a) The results obtained under the same rate of increase of temperature, i.e. 100°C/*hour* are shown in Fig. 3. Though the silica content of Oshima lava is less than that of Syowa-Sinzan new lava by about 18% as shown in Table 1, the viscosity obtained in the laboratory has almost the same as that from Syowa-Sinzan.

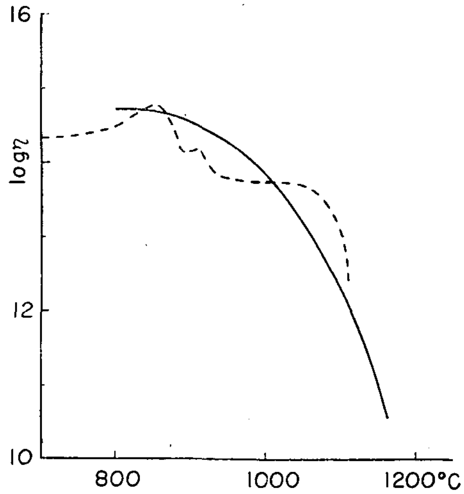

Fig. 3. Comparison of viscosity-coefficients with heating rates 100°C/h for two specimens.
Solid line: Syowa-Sinzan new lava.
Dotted line: 1950 Oshima lava.

Many investigators carried out experiments on the effect of the composition of glasses on viscosity. The results obtained have been fully dealt with by Morey in his book[7]. In the ternary system Na_2O-CaO-SiO_2 at high temperatures the viscosity is largely determined by the SiO_2 content and an increases of 20% in the SiO_2 content increases viscosity by about 10^2 poises.

The viscosity coefficients of some lavas which were estimated in the field in molten state differ considerably according to the silica content, for example, the viscosity of dacite lava such as that from Syowa-Sinzan is more than 10^6 times that of basaltic lava such as that from Oshima.

While the difference between the laboratory value and the field one in basaltic lava is 10^7–10^{10} poises (at about 1000°C). It is generally suspected that this difference may depend on the volatile materials, but this problem has not come to a satisfactory solution.

Thus when the viscosity of rocks is measured in laboratory, the consideration of the chemical composition of the rocks may be unessential for the problem of what petrographical changes correspond to the changes in viscosity. More systematic investigations are required to make sure this conclusion.

b) Comparing the viscosity-time relation under constant temperature provids Fig. 4. The results were obtained at a little different temperature, but Syowa-Sinzan new lava seems to approach an asymptotic value faster than Oshima lava does. The latter was cooled within a very short time in the field, while that of Syowa-Sinzan which was at about 1000°C on extrusion over ten years ago keeps at about 800°C at present as shown in Fig. 5. The difference in cooling time might probably cause the different quantity as well as quality of glass in the groundmass of the rocks. According to Yagi[6], Syowa-Sinzan new lava is of a high crystalinity, that is, it has less glassy content than Oshima lava. Considering these facts it is plasusible to suppose that the glassy parts of reheated rock crystallize to reach perfect thermodynamical equilibrium at the given temperature and the crystallization causes viscosity which becomes constant when the equilibrium is reached.

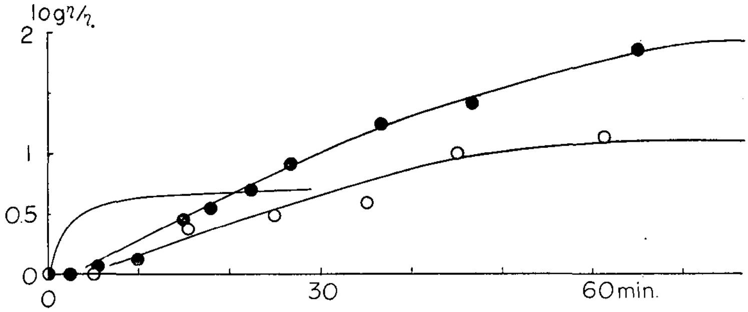

Fig. 4. Comparison of viscosity-time curves for two specimens at constant high temperatures.

Line with closed circles : 1950 Oshima lava at about 1010°C.
Line with open circles : 1950 Oshima lava at about 1000°C.
Line only : Syowa-Sinzan new lava at about 1010°C.

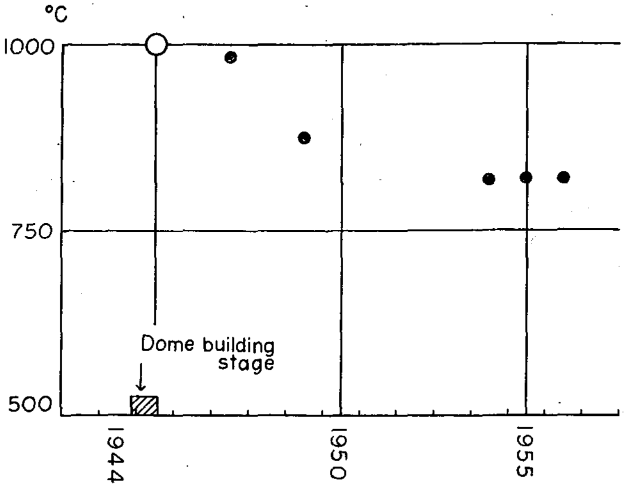

Fig. 5. Variation of temperature of some cleavages on and at the side of the dome of Syowa-Sinzan.

Further, some qualitative discussions lead that the behavior of the curves in Fig. 3 where Syowa-Sinzan curves are smooth, but Oshima's lack smoothness, may correspond to the influence of cooling rates of each lava. The latter which has more glassy part than the former was unevenly strained by cooling under natural conditions and the strain will be release unevenly by reheatment in laboratory.

In the next paragraphs the writer discusses the application of the results obtained.

Fig. 1 shows that $(\eta^{600}-\eta^{100})>(\eta^{100}-\eta^{30})$. The extrapolation of this relation gives viscosity coefficient η^0 which is the viscosity under the heating rate $dT/dt \approx 0$. The result of the extrapolation is graphed in Fig. 6. Though such extrapolation may be a rough one, it may be justified considering that η^0 is in accord with the asymptotic value in Fig. 2 which represents the viscosity-time relation at constant temperature. But this curve is not of the cooling process under natural conditions.

The physical state of the specimen which shows η^0 corresponds to the state in which the unstable part in groundmass is lost or minimum in quantity at the given temperature. Of course in considering the cooling process under natural conditions it is unnecessary to consider the crystallization by reheating in laboratory; then one can concluded that η^0 is the upper limit which Syowa-Sinzan new lava shows at the given temperature.

The viscosity coefficient of Syowa-Sinzan new lava on extrusion was more than 10^{11} poises and its temperature more than 1000°C[3]. These items of information and the experimental results above reported give the range of the viscosity of Syowa-Sinzan new lava on extrusion as shown in Fig. 6. In this figure the viscosity of Oshima lava during cooling process under natural conditions is illustrated too.

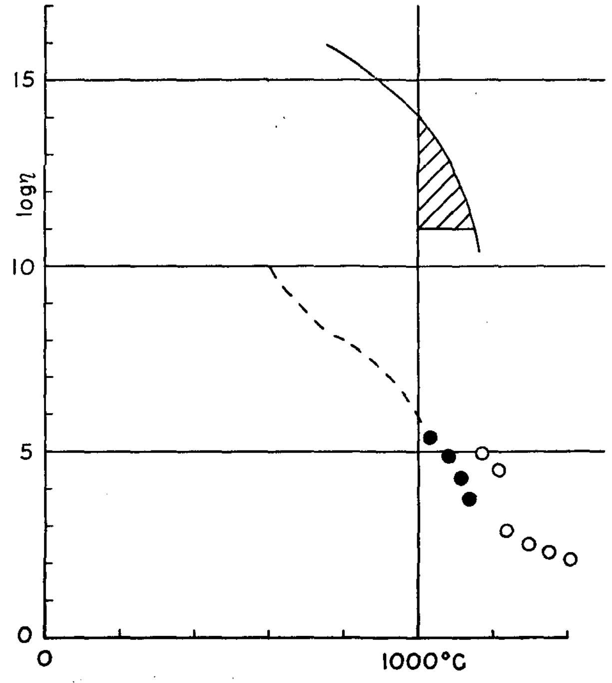

Fig. 6. Comparison of viscosity coefficients obtained in the field and in the laboratory for two specimens.

Hatched area : Range of viscosity of Syowa-Sinzan new lava on extrusion by the present experiment.
Solid line : Viscosity versus temperature with heating rate 0°/h obtained by the extrapolation of Fig. 1.
Open circles : K. Kani's experiment for Oshima lava.
Closed circles : Observed viscosity in the field for Oshima lava (T. Minakami)
Broken line : Calculated viscosity for an assumed cooling rate for Oshima lava (S. Sakuma).

6. Conclusions

In this paper, the writer has explained the viscosity-time relation on the basis of the crystallization of the supercooled glass in groundmass of the rock. However, there remains one essential problem, that is, does the supercooled glass in the groundmass crystallize within a short time such as 10 minutes ?

Similar experiments on obsidian are to be carried out in order to clarify the functional relation of viscosity to crystallization, though obsidian is not the same as the glass in groundmass in physico-chemical natures.

Acknowledgements .— The writer wishes to express his cordial thanks to the late Prof. S. Sakuma, Prof. T. Ishikawa, and Assist. Prof. I. Yokoyama for the facilities and advices accorded to him.

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