FIELD MEASUREMENTS OF THE RHEOLOGICAL PROPERTIES OF BASALTIC LAVAS
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Summary
The rheological properties of lavas erupted on the east rift zone eruption on Kilauea, Hawaii during September, 1994 have been measured using a new field rotating shear vane viscometer. The viscosities are lower than any previous field measurements on basalts, and the lowest measured viscosity is compatible with laboratory measurements on bubble-free tholeiites from Makaopuhi lava lake at similar temperatures. The higher measured apparent viscosities of some of the lavas and their departure from Newtonian behaviour are attributed to the high vesicularities of these lavas. Differences in measured surface cooling rates are also attributed to differences in vesiility.

Introduction
Lava flow emplacement is difficult to model because of the highly temperature-dependent non-Newtonian rheology of crystallising, vesiculating lava [1]; variations in effusion rates during emplacement [2]; the changing topography encountered by the front of an advancing lava flow; and the consequent change in dimensions of different parts of the flow [3]. In view of these complexities, the most useful lava flow models are those based on numerical simulations. Before accurate numerical models can be constructed, however, we require data on the temperature-dependent rheological properties of cooling, vesiculating lavas.

The field viscometer
A new field viscometer system has been developed at Lancaster University based on a prototype rotating shear vane viscometer used to measure the rheological properties of natrocarbonatite lavas of Oldoinyo Lengai, Northern Tanzania [4,5]. Prior to field use, the viscometer was calibrated in the laboratory using newtonian and non-newtonian fluids, and the flow behaviour inside the sensor system was modelled using finite element methods. The viscometer was used successfully to measure the rheological properties of 3 active lava flows on Kilauea, Hawaii during September, 1994. The driving/measuring assembly of the viscometer consists of a 24 volt d.c. variable speed Bosch motor, a 15:1 reduction gearbox, a torque limiter and a torque-rotation rate sensor which measures the torque by optically detecting the torsional deflection of the rod connected to the sensor system that is rotated in the lava. This sensor is connected through a control unit to two Tinytalk data loggers which can store up to 1800 measurements. Data from these loggers are downloaded onto the hard disk of a laptop computer after each viscometer run and analysed using software developed at Lancaster. The cumulative error of the data logging system was comparable with that of the measuring system: 1% of f.s.d.

Two sensor heads, with internal thermocouples have been developed. One incorporates a coaxial cylinder sensor and it is designed to measure the rheological properties of lava in active a'a channels; the other uses a vane as the sensor, and it can measure the properties of lava in smaller pahoehoe flows and lobes. The instrument is supported either by hand or on a turntable attached to a rig which is in turn secured to adjacent cool lava flows using 3 mm diameter stainless steel cable and 15 mm diameter rock bolts. The system permits 70 degrees of vertical movement of the assembly and 120 degrees of horizontal movement and it contains a winch for ensuring the safe withdrawal of the instrument from a'a channels.

The theory of the instrument employed in this experiment, a wide-gap concentric cylinder viscometer, has been developed [6-10]. Edge effects and viscous heating were investigated both in the laboratory and numerically using finite element methods.

Measurements on Kilauea using the field viscometer
Measurements of the rheological properties of the lava flows from the east rift zone eruption on Kilauea, Hawaii were made on 3 occasions during September, 1994. Each measurement was made at the front of small (0.2 to 0.5 m thick) advancing pahoehoe lobes, 250 to 400 m upslope from Paliuli, and each flow had a maximum measured internal temperature of 1146°C. The shear vane version of the instrument was used because of the small size of the flows being erupted at the time when measurements were made. The resulting data were downloaded on to an Apple Macintosh Powerbook and analysed using the methods outlined in Pinkerton & Norton [10].

All lavas had properties that can be approximated by a pseudoplastic power law model (examples of a low and a high viscosity lava are shown in figures 1 and 2). The data in figures 1 and 2 indicate that the lavas had unit strain rate viscosities of 234 Pa s (Run #2) and 548 Pa s (Run #3D) respectively. The apparent viscosity for Run #2 is similar to the value of 250 Pa s we obtain by extrapolating Shaw's [11] laboratory measurements on bubble-free tholeiitic lava from Makaopuhi Lava Lake to a temperature of 1146°C. We attribute the higher apparent viscosities for the other lavas to the higher crystallinities and vesicularities observed in hand specimens of quenched samples from the other localities. The bubble and crystal size distributions and the glass
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compositions of quenched samples collected at the time of each measurement are being determined, and the calculated properties of these lavas [see 1] will be compared with those measured in the field.

Discussion
We have developed equipment that has the potential to measure the rheological properties of moving lavas in the field more accurately than any previously used method. The lowest viscosity measurements are compatible with those for laboratory measurements on degassed lavas of similar compositions and temperatures. Before the results from the present study are used to model the flow behaviour of lavas from Kilauea, it is important to note that three other types of lava were erupted during our 3 week observation period on Kilauea; they had different bubble size distributions and morphological properties and consequently they will have different rheological and thermal properties. Differences in vescularity could also explain the different surface cooling rates of lavas erupted during the 3 week observation period. These complexities will have to be taken into account in any models of the flow behaviour of lavas erupted on Kilauea. The rheological and thermal properties of these and any other types of lava that are erupted will be measured during future visits to Kilauea.

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References