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Inflation and cooling data from pahoehoe sheet flows on Kilauea volcano.

by

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Table of Contents

Appendices

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Introduction

Here we present both cooling and uplift data acquired during 1987-1990 from active pahoehoe sheet flows on Kilauea volcano, Hawaii. This report provides the data that was used by Hon and others (in press) to model formation of inflated sheet flows. Our study interval represents only a small segment of the overall eruption, which began in January of 1983 and continues as of this writing. Although inflation of sheet flows is relatively easy to document qualitatively, the task of collecting quantitative information is much more complicated. The dearth of such data in the literature is directly related to the infrequency of historic tube-fed pahoehoe eruptions and the difficulty in making quantitative measurements on active lava flows.

The data sets included within this report include those from experiments that ran for days or weeks and are relatively complete as well as several partial data sets from lava flows that stagnated within a matter of minutes or a few hours after the experiment began.

The report is available in both printed (OF93-342A) and 3.5" IBM-compatible diskette (OF-93-342B) forms. The contents of both reports are identical.

Collection of Data

The largest problems we encountered involved the implantation of thermocouples into active flows and lava over running observation sites. For sheet flows, we attempted to choose sites so that either natural topographic barriers or rock walls would halt flow advance and induce inflation. These also served as heat protection while recording thermal data. Even so, we generally had to move our observation sites 3-4 times during the course of an experiment. Most of the data were collected from flows advancing through the town of Kalapana during the spring of 1990, as the abundant road network allowed easy repeated access for people and equipment.

By definition, all of our experiment sites were originally on the margin of flows. This allowed us to place thermocouples in the molten lava front and measure initial flow thickness. Potential target sites were painted on the pre-existing ground surface prior to emplacement of the flow. Flow thickness was monitored continuously by placing a painted target rock on the flow just after it covered the designated spot. With time, the lava flows continued to advance and target sites were eventually 10-30 m from the flow edge. Multiple target sites were monitored during each experiment, and all target sites record uniform uplift of the sheet flow surface not tumescence over developing tube systems.

Complete Data Sets

Our best set of thermal data was acquired from a sheet flow emplaced on 17-Apr-90. Surface temperatures were measured with a Minolta Cyclops 330 radiometer using an emissivity setting of 1. Temperatures were measured on a single spot of non-incandescent crust, approximately 5 cm in diameter. Relative precision of repeated measurements on the same spot were within 2-3°C, but absolute accuracy is unknown. Temperatures from within the crust were obtained using chromel-alumel thermocouples accurate to 1-2°C. The thermocouples placed at 0.005, 0.02, 0.06, and 0.10 m depth were all 1/16 inch diameter, whereas the thermocouple placed at 0.20 m depth was 1/8 inch diameter. The shallow thermocouples (0.02, 0.06 m) were wrapped around a 2 m length of pipe so that the tips

extended perpendicular to the long axis of the pipe (Figure 1A). The thermocouples were emplaced into a molten pahoehoe toe just as it formed, and the pipe was held parallel to the lava surface until the crust cooled sufficiently to hold the thermocouples in place. The 0.005 m thermocouple was implanted at a site about 10 m away from the main site; times were corrected to match the other data. The deeper thermocouples could not be emplaced until the flow inflated from its original 0.10 m thickness. These thermocouples were each inserted through a hole pierced in 0.02-m-thick, plastic crust using a rock hammer (Figure 1B). The depth placement of the thermocouples is estimated to be better than 0.002 m. The relative distances between the thermocouples remained fixed throughout the experiment. Data collection was terminated after 18 hours on the 0.005 m thermocouple due to flow stagnation at this site. All of the other cooling profiles were all disrupted after about 60 hours, when a new surface flow over ran the main thermocouple site.

Inflation data for sheet flows were easier to obtain than cooling profiles, and good curves were acquired on three separate occasions. Initial measurements were done by leveling on 23-Jan-88 (Table 1) in conjunction with mapping of the advancing lobes (Hon and others, in press). Loss of lava supply to the flow terminated this experiment after 55 hours. Later uplift data, taken on 13-Apr-90 and 17-Apr-90, were calculated from transit angles and horizontal distances measured with a steel tape. The use of the transit allowed more continuous data collection than leveling, particularly when the flows were very young and hot. Measurement errors are less than ± 0.01 m for both techniques. Both inflation and cooling data were collected from the same flow on 17-Apr-90 over a period of 113 hours, until the site was covered by another flow. The most complete set of inflation data was acquired over a 400 hour interval beginning on 13-Apr-90. In this case, the flow quit inflating at about 300 hours (12 days), which is in agreement with our observational inferences regarding stagnation of the liquid lava core and the initiation of tube formation.

Partial Data Sets

In addition to the three well constrained data sets discussed above, cooling and some inflation data were collected on 3 other occasions (13-Mar-90, 24-Apr-90, 3-May-90). The longest of these data sets was collected over an interval of less than 4 hours, whereas collection times on the other experiments varied from about 0.3-1.5 hours in duration. These partial data sets yield some interesting information about the early cooling history of pahoehoe toes, but had insufficient data to be useful in modeling sheet flow formation. All of these flows were vesiculated pahoehoe in contrast to the dense, vesicle-poor flow of 17-Apr-90.

Cooling, inflation, and crack depth data were collected from three sites within several meters of each other on 13-Mar-90. This site was about 2 km to the northwest of the site of Kalapana. Inflation and crack depth data were recorded at three sites (1, 2, and 3); inflation was measured by leveling from a fixed reference point on an older flow. Cooling data were collected only at site 2; readings were taken using the Minolta Cyclops radiometer (described above) and a 1/16 inch thermocouple planted within 0.002 m of the surface of the flow. This flow inflated unevenly (final thicknesses varied from about 0.6-1 m) and inflation effectively ceased after only 1.5-2 hours due to loss of lava supply to the flow lobe. These circumstances limit the usefulness of the data collected at this site.

Limited cooling data were also collected from a vesicular pahoehoe toe on 24-Apr-90. Temperatures were measured using the radiometer on the surface and a 1/16 inch thermocouple imbedded at a depth of about 0.002 m in the crust. This toe ceased inflating almost immediately after it formed (0.3 m thick) and hence the data represent simple static cooling of this body with no further replenishment of lava.

Cooling data were collected on two separate runs on 3-May-90. On both runs data were collected using the radiometer and 1/16 inch thermocouples embedded at 0.002 m, 0.01 m, and 0.02 m in the crust. On the first run, the toe we were measuring inflated slowly over 6-7 minutes before stagnating and represents a situation similar to the 24-Apr-90 flow. The second lobe we measured inflated rapidly to 0.25 m within 2 minutes and then became inactive. This flow yielded a very consistent set of data for cooling without continued lava replenishment.

Discussion and Comparison of the Data Sets

The inflation and cooling data from the 23-Jan-88, 13-Apr-90, and 17-Apr-90 lava flows have been discussed in detail and modeled by Hon and others (in press). There are, however, some significant differences between the cooling data collected on 17-Apr-90 and some of partial data sets that require discussion.

The radiometer data from all of the field experiments plot in narrow interval and display nearly identical slopes after 0.1 hour on a plot of temperature versus the log of time (see Figure 10, Hon and others, in press). Prior to 0.1 hour, the surface cooling is generally more rapid than after 0.1 hr due to the onset of exothermic crystallization within the lava crust. The transition from rapid formation of glass to partial crystallization of the flow interior appears to take place between 0.05 and 0.1 hours. However, surface radiometer data from the pahoehoe toes that ceased to inflate (24-Apr-90 and run 1 of 3-May-90) suggests that cooling was very slow prior to 0.1 hours and increased to rates comparable to those of other flows after 0.1 hours. In fact, this apparent behavior is an artifact of the very low supply rates to these toes that caused them to grow very slowly. The slow growth and stretching of the skin kept hotter material near the surface for a longer time; once the toe stopped growing the cooling profiles returned to a relatively normal pattern.

The very shallow thermocouples (0.002 m) display a range of data that may be attributed to problems with accurately locating their true depth within the crust. Slight variations of only 0.001 m (the estimated placement error) between the depth of the thermocouples could cause significant shifts in the plots of the cooling data. The lack of precise locations of the shallow thermocouples within the crust may account for the variability of this data. However, the form of the 13-Mar-90 and run 2 of 3-May-90 curves are very similar to the radiometer profiles and also appear to record the glassy/crystalline transition at about 0.1 hour. Particularly encouraging is the close correspondence between the radiometer and 0.002 m thermocouple data collected from run 2 on 3-May-90. Again, however, the 0.002 m data from the 24-Apr-90 flow do not show the rapid early cooling of the glassy outer crust and , like the radiometer data from this flow, may be attributed to the very slow growth of the pahoehoe toe.

Data from the 0.01 and 0.02 m thermocouples were only taken on 3-May-90 during both run 1 and 2. There is a very close agreement between the two data sets, although temperatures at times less than 0.1 hour from run 1 are slightly hotter (10-20 °C) than those from run 2. More importantly, the 3-May-90 0.01 and 0.02 m data shows much more rapid cooling than the equivalent data from the 17-Apr-90 flow. In fact, temperatures from 0.01 m in the 3-May-90 flow are consistently lower than those measure at a depth of 0.005 m in the 17-Apr-90 flow. We suggest that the more rapid cooling of the 3-May-90 flow is a direct result of stagnation of the flows. In contrast, the 17-Apr-90 flow was long-lived and had a continual influx of new, hot lava at the base of the crust that apparently retarded cooling of this flow. Even though the curves from the 3-May-90 flow are shifted to lower temperatures, they are still parallel to curves from the 17-Apr-90 flow. This suggests that the thermal properties of the

crust remained relatively constant and that the amount of input of heat from below was primarily responsible for differences in the observed cooling rates.

However, differences between dense, vesicle-poor and vesicular crusts may have some effect on the surface cooling profiles we measured using the radiometer. The 17-Apr-90 flow had a dense, vesicle-poor glassy skin in contrast to the vesicular glassy crust of the 3-May-90 flows. It is possible that some of the near-surface cooling in the 3-May-90 flows is attributable to radiation of heat across vesicles. This may be supported by slightly lower surface temperatures (measured by radiometer) in the 17-Apr-90 flow than the other flows, which were all more vesicular. The shifts in the position of the radiometer data are relatively small in comparison to those from the 0.01 m and 0.02 m thermocouples suggesting that radiation losses are not responsible for most of the differences in cooling rates.

The more rapid cooling of the short-lived lava flows is also seen in the crustal growth data taken on the 13-Mar-90 flow. Initially, crustal growth rates are indistinguishable from those measured from the 17-Apr-90 flow. However, the crustal growth rates for the 13-Mar-90 flow increased significantly after about 2 hours or roughly at the same time active inflation of the flow ceased. Unfortunately, there is no 0.01-0.02 m thermocouple data from this flow to directly compare with the crack depth measurements, and the data from 3-May-90 flows are not directly comparable as inflation ceased after no more than 0.2 hours.

Our observations suggest that cooling profiles differ significantly between static, non-inflating pahoehoe (such as the 3-May-90 flows) and inflating pahoehoe flows (such as the 17-Apr-90 flow) that are constantly being replenished with an influx of new, hot lava. As would be expected, static flows cool more rapidly than inflating flows. Similarly, the one-dimensional cooling models of Carslaw and Jaeger (1959) predict much more rapid cooling than we measured from inflating flows. Clearly much more work needs to be done to quantify the cooling of pahoehoe flows. However, even our limited data suggest that real pahoehoe flows are dynamic and that cooling within these flows may not be adequately modeled by simple cooling equations.

Acknowledgments

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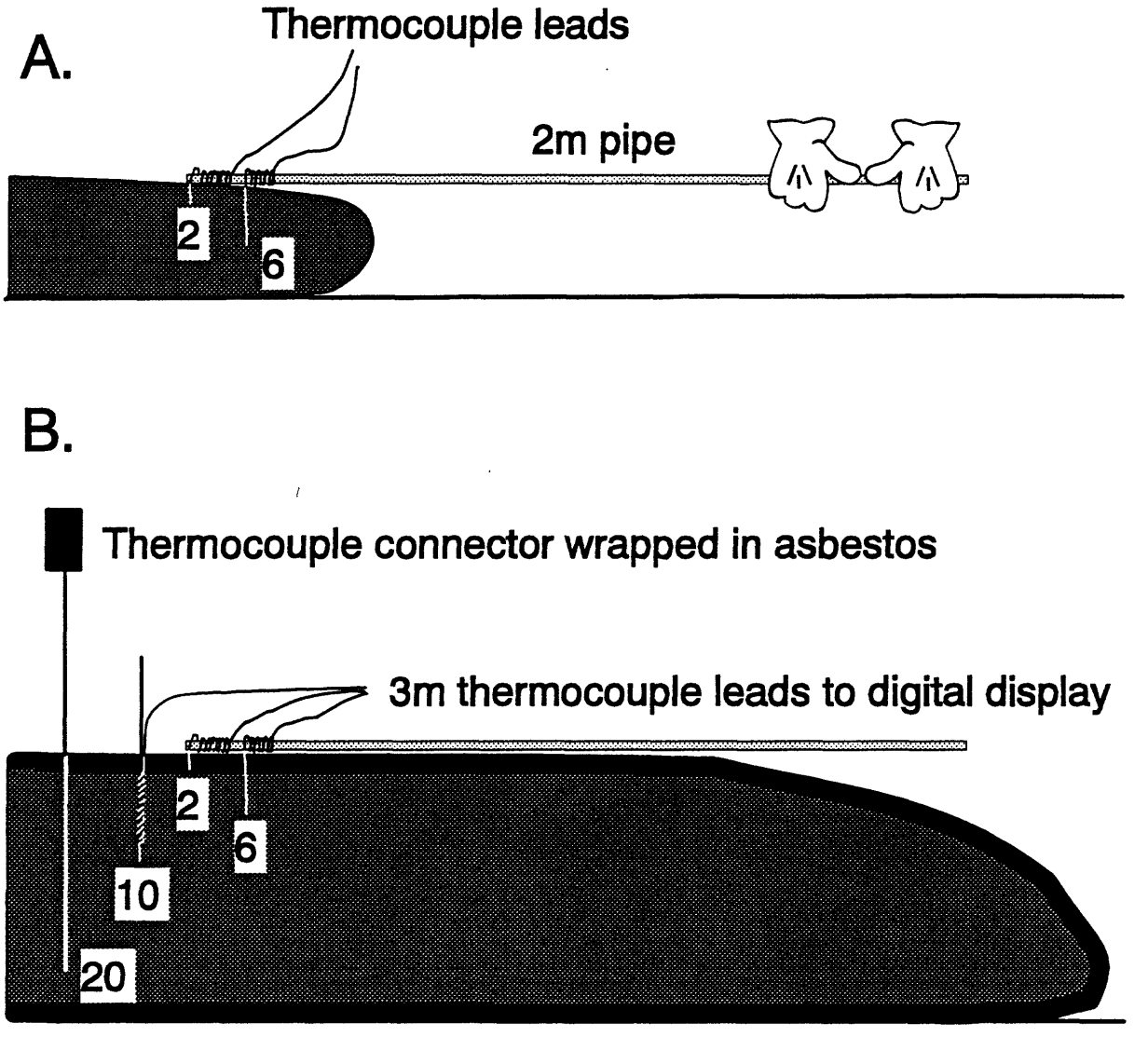

Figure 1. Sketch of thermocouple placement within the 4/17/90 sheet flow.

A) Initial emplacement of the 2-cm (0.02m)- and 6-cm (0.06m)-depth thermocouples within a 10 cm thick molten pahoehoe toe at the front of the advancing flow. The thermocouples were wrapped around and wired to the end of a 2-m-long pipe that was held horizontally until the sufficient crust formed to hold the thermocouples in place. Leads from the thermocouples were about 3 m long and were draped over a rock wall along the flow margin.

B) Emplacement of 10-cm (0.10m)- and 20-cm (0.20 m)-depth thermocouples within the sheet flow 12-13 minutes after formation. By this time the flow had inflated to about 23 cm, which was thick enough to emplace the 20 cm thermocouple. The crust at this time was 1-2 cm thick and had to be pierced with a rock hammer to insert the thermocouples. The 10-cm-depth thermocouple was 1/16" diameter and was wrapped around and wired to a rigid steel rod in order to be inserted to the proper depth. About 1 cm of the thermocouple was left protruding past the end of the rod to avoid thermal perturbations. The 20-cm-depth thermocouple was 1/8" diameter and was rigid enough to be inserted without additional support.

APPENDIX A: U.S. Geological Survey Open-File Report 93-342A

Data from thermocouples implanted at various depths in the crust of the 17-Apr-90 sheet flow

Time is in decimal hours from 14:48:19 Hawaiian Standard Time

Depths of the thermocouples within the crust are listed for each data set

Temperatures taken after 55.69 hours do not accurately reflect normal cooling as the site was overrun by a new lava flow

Radiometer measurements were made using a Minolta Cyclops 330 radiometer with an emissivity setting of 1.

	Radiometer		Thermocouple		Thermocouple		Thermocouple		Thermocouple		Thermocouple
Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature
(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)
	surface		0.005-m-depth		0.02-m-depth		0.06-m-depth		0.10-m-depth		0.20-m-depth
0.017	700	0.017	1017	0.019	1116	0.019	1135	0.206	1142	1.000	1142
0.036	576	0.018	1009	0.021	1119	0.021	1135	0.211	1141	1.492	1139
0.042	573	0.021	1004	0.022	1121	0.022	1136	0.217	1139	2.817	1135
0.053	550	0.024	1001	0.024	1119	0.024	1135	0.222	1142	3.450	1129
0.057	498	0.025	1000	0.025	1114	0.025	1135	0.228	1140	4.661	1123
0.060	512	0.026	998	0.026	1117	0.026	1136	0.233	1139	6.145	1104
0.061	496	0.028	997	0.028	1119	0.028	1135	0.239	1142	6.795	1093
0.064	496	0.029	995	0.029	1120	0.029	1136	0.244	1141	7.161	1086
0.065	488	0.031	994	0.031	1121	0.031	1136	0.250	1137	7.745	1073
0.069	488	0.032	993	0.032	1122	0.032	1136	0.256	1139	9.078	1044
0.072	474	0.033	992	0.033	1121	0.033	1136	0.261	1137	10.19	1018
0.075	473	0.035	991	0.035	1120	0.035	1136	0.267	1137	11.91	983
0.078	458	0.036	990	0.036	1120	0.036	1136	0.272	1137	15.36	922
0.079	456	0.038	989	0.038	1119	0.038	1135	0.278	1137	16.69	900
0.081	455	0.039	988	0.039	1119	0.039	1135	0.283	1137	18.19	877
0.082	454	0.040	987	0.040	1119	0.040	1135	0.289	1137	18.93	867
0.083	453	0.042	987	0.042	1119	0.042	1136	0.294	1138	20.19	849
0.086	450	0.043	986	0.043	1119	0.043	1136	0.300	1136	24.19	807
0.088	454	0.044	985	0.044	1119	0.044	1136	0.306	1137	24.81	802
0.089	450	0.046	984	0.046	1119	0.046	1136	0.311	1142	31.19	746
0.092	448	0.047	983	0.047	1112	0.047	1136	0.317	1142	34.44	719
0.094	455	0.049	982	0.049	1113	0.049	1136	0.322	1136	37.86	690
0.096	446	0.051	981	0.050	1113	0.050	1136	0.328	1135	40.51	677
0.097	441	0.054	979	0.051	1114	0.051	1136	0.333	1139	44.94	664
0.100	443	0.057	978	0.053	1113	0.053	1136	0.339	1142	48.94	654
0.103	440	0.060	976	0.054	1112	0.054	1136	0.344	1137	55.69	637
0.106	439	0.063	974	0.056	1111	0.056	1136	0.350	1142	xxxxxx	xxxxxxxxxxx
0.108	440	0.065	972	0.057	1110	0.057	1136	0.356	1142	64.81	631
0.111	440	0.068	969	0.058	1108	0.058	1136	0.361	1141	71.44	679
0.113	445	0.071	967	0.060	1109	0.060	1136	0.367	1138	81.03	690
0.115	434	0.074	965	0.061	1107	0.061	1136	0.372	1135	89.11	684
0.118	436	0.076	961	0.063	1106	0.063	1136	0.378	1136	93.44	678
0.119	436	0.079	960	0.064	1105	0.064	1136	0.383	1136	99.78	693
0.122	441	0.082	957	0.065	1105	0.065	1136	0.389	1139	112.8	752
0.126	443	0.085	954	0.067	1104	0.067	1136	0.394	1135		
0.128	438	0.088	952	0.068	1104	0.068	1136	0.400	1134		
0.132	429	0.090	949	0.069	1104	0.069	1136	0.406	1134		
0.133	431	0.093	946	0.071	1104	0.071	1136	0.411	1136		
0.136	430	0.096	943	0.072	1103	0.072	1136	0.417	1138		
0.140	427	0.099	941	0.074	1103	0.074	1137	0.422	1132		
0.146	427	0.101	939	0.075	1103	0.075	1136	0.428	1134		
0.151	426	0.110	931	0.076	1102	0.076	1136	0.433	1131		
0.154	425	0.113	928	0.078	1101	0.078	1136	0.439	1136		
0.157	422	0.115	925	0.079	1100	0.079	1136	0.444	1138		
0.161	426	0.126	916	0.081	1099	0.081	1136	0.450	1139		
0.165	422	0.132	911	0.082	1098	0.082	1136	0.456	1133		
0.168	420	0.146	900	0.083	1097	0.083	1136	0.461	1138		
0.174	423	0.150	897	0.085	1095	0.085	1136	0.467	1132		
0.178	424	0.158	890	0.086	1095	0.086	1136	0.472	1131		
0.182	414	0.163	888	0.088	1094	0.088	1136	0.478	1135		

	Radiometer		Thermocouple		Thermocouple		Thermocouple		Thermocouple	
Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature	
(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	
	surface		0.005-m-depth		0.02-m-depth		0.06-m-depth		0.10-m-depth	
0.186	414	0.167	884	0.089	1094	0.089	1136	0.483	1135	
0.190	418	0.171	881	0.090	1094	0.090	1136	0.489	1135	
0.194	411	0.175	877	0.092	1093	0.092	1136	0.494	1131	
0.200	418	0.179	875	0.093	1093	0.093	1136	0.500	1135	
0.207	398	0.185	871	0.094	1093	0.094	1136	0.506	1134	
0.213	404	0.190	868	0.096	1092	0.096	1136	0.511	1134	
0.218	396	0.196	865	0.097	1092	0.097	1136	0.517	1136	
0.236	388	0.201	861	0.099	1091	0.099	1136	0.522	1136	
0.243	385	0.207	858	0.100	1091	0.100	1136	0.528	1135	
0.254	380	0.211	855	0.101	1089	0.101	1136	0.533	1134	
0.261	382	0.215	853	0.103	1088	0.103	1136	0.539	1135	
0.264	380	0.221	850	0.104	1088	0.104	1136	0.544	1136	
0.271	385	0.226	847	0.106	1087	0.106	1136	0.550	1133	
0.275	378	0.232	844	0.107	1086	0.107	1136	0.556	1133	
0.281	378	0.238	841	0.108	1086	0.108	1136	0.561	1133	
0.288	376	0.243	838	0.110	1085	0.110	1136	0.572	1127	
0.292	371	0.249	835	0.111	1085	0.111	1136	0.578	1125	
0.294	368	0.258	831	0.113	1084	0.113	1136	0.583	1129	
0.300	365	0.265	827	0.114	1085	0.114	1135	0.589	1128	
0.308	366	0.271	825	0.115	1083	0.115	1135	0.594	1130	
0.313	365	0.276	821	0.117	1083	0.117	1135	0.600	1131	
0.321	366	0.283	819	0.118	1082	0.118	1135	0.606	1130	
0.333	362	0.288	817	0.119	1082	0.119	1135	0.611	1127	
0.344	358	0.296	813	0.121	1081	0.121	1135	0.617	1125	
0.351	359	0.301	810	0.122	1080	0.122	1134	0.622	1125	
0.358	369	0.311	807	0.124	1080	0.124	1134	0.628	1125	
0.363	366	0.317	804	0.125	1080	0.125	1134	0.633	1129	
0.372	355	0.324	802	0.126	1080	0.126	1134	0.639	1129	
0.382	351	0.329	799	0.128	1079	0.128	1135	0.644	1125	
0.390	362	0.338	797	0.129	1079	0.129	1135	0.661	1124	
0.403	355	0.351	791	0.131	1079	0.131	1135	0.667	1125	
0.417	352	0.360	788	0.132	1079	0.132	1135	0.672	1124	
0.428	352	0.365	785	0.133	1079	0.133	1135	0.678	1122	
0.435	351	0.374	783	0.135	1078	0.135	1135	0.683	1123	
0.443	353	0.382	781	0.136	1079	0.136	1135	0.689	1123	
0.447	346	0.385	778	0.138	1078	0.138	1135	0.694	1124	
0.458	344	0.392	777	0.139	1078	0.139	1135	0.700	1128	
0.468	343	0.400	774	0.140	1078	0.140	1135	0.706	1125	
0.478	340	0.407	772	0.142	1078	0.142	1135	0.711	1126	
0.488	342	0.413	770	0.143	1077	0.143	1135	0.717	1126	
0.500	330	0.421	767	0.144	1077	0.144	1135	0.722	1125	
0.508	336	0.429	765	0.146	1077	0.146	1135	0.728	1123	
0.519	327	0.438	762	0.147	1076	0.147	1134	0.733	1124	
0.533	328	0.446	759	0.149	1075	0.149	1134	0.739	1124	
0.550	334	0.454	757	0.150	1075	0.150	1135	0.744	1122	
0.560	327	0.463	754	0.151	1075	0.151	1135	0.750	1122	
0.571	323	0.471	752	0.153	1074	0.153	1135	0.756	1121	
0.582	332	0.479	750	0.154	1074	0.154	1135	0.761	1122	
0.593	326	0.488	748	0.156	1073	0.156	1135	0.767	1122	
0.604	323	0.496	746	0.157	1073	0.157	1135	0.772	1122	
0.614	316	0.504	744	0.158	1072	0.158	1135	0.778	1122	
0.632	328	0.513	742	0.160	1072	0.160	1135	0.783	1123	
0.644	325	0.521	740	0.161	1072	0.161	1134	0.789	1121	
0.660	313	0.529	737	0.163	1071	0.163	1134	0.800	1122	
0.674	311	0.538	735	0.164	1071	0.164	1134	0.806	1123	
0.686	304	0.546	733	0.165	1070	0.165	1134	0.811	1123	
0.696	306	0.554	730	0.167	1070	0.167	1134	0.817	1122	

	Radiometer		Thermocouple		Thermocouple		Thermocouple		Thermocouple	
Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature	
(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	
	surface		0.005-m-depth		0.02-m-depth		0.06-m-depth		0.10-m-depth	
0.708	310	0.563	729	0.168	1069	0.168	1134	0.822	1121	
0.718	306	0.571	727	0.169	1069	0.169	1134	0.828	1122	
0.729	306	0.579	725	0.171	1068	0.171	1134	0.833	1122	
0.740	305	0.588	723	0.172	1068	0.172	1134	0.839	1121	
0.758	303	0.604	719	0.174	1067	0.174	1134	0.844	1120	
0.769	296	0.621	716	0.175	1067	0.175	1134	0.850	1120	
0.782	308	0.729	694	0.176	1067	0.176	1134	0.856	1121	
0.799	296	0.829	675	0.178	1067	0.178	1134	0.861	1123	
0.810	306	1.113	641	0.179	1066	0.179	1133	0.867	1120	
0.818	301	1.292	621	0.181	1066	0.181	1134	0.872	1120	
0.831	298	1.875	575	0.182	1065	0.182	1134	0.878	1122	
0.842	306	2.367	544	0.183	1065	0.183	1134	0.883	1120	
0.851	295	4.050	461	0.188	1064	0.185	1134	0.889	1119	
0.868	307	4.628	442	0.189	1063	0.186	1134	0.894	1119	
0.882	298	5.111	428	0.190	1062	0.188	1133	0.900	1120	
0.899	292	5.628	414	0.192	1063	0.189	1134	0.906	1117	
0.915	290	6.828	374	0.193	1063	0.190	1134	0.911	1118	
0.935	297	7.945	345	0.194	1063	0.192	1134	0.917	1118	
0.950	288	10.19	306	0.196	1063	0.193	1134	0.922	1120	
0.968	283	15.28	260	0.197	1062	0.194	1133	0.933	1117	
0.983	285	15.36	247	0.199	1062	0.196	1134	0.939	1130	
0.994	285	16.69	230	0.200	1061	0.197	1134	0.944	1132	
1.008	289	17.01	218	0.206	1059	0.199	1134	0.950	1125	
1.021	281	18.19	206	0.211	1061	0.200	1133	0.956	1122	
1.029	282			0.217	1059	0.206	1133	0.961	1118	
1.046	277			0.222	1056	0.211	1133	0.967	1117	
1.063	287			0.228	1052	0.217	1133	0.978	1115	
1.079	276			0.233	1054	0.222	1133	0.989	1115	
1.088	278			0.239	1048	0.228	1132	0.994	1118	
1.100	282			0.244	1046	0.233	1133	1.000	1115	
1.108	294			0.250	1044	0.239	1132	1.008	1115	
1.121	292			0.256	1042	0.244	1132	1.017	1114	
1.129	288			0.261	1040	0.250	1132	1.025	1113	
1.150	276			0.267	1038	0.256	1132	1.033	1112	
1.158	283			0.272	1040	0.261	1132	1.042	1112	
1.175	284			0.278	1034	0.267	1132	1.050	1112	
1.183	277			0.283	1032	0.272	1131	1.058	1114	
1.192	286			0.289	1029	0.278	1131	1.067	1112	
1.200	279			0.294	1027	0.283	1131	1.075	1112	
1.208	281			0.300	1027	0.289	1131	1.083	1112	
1.217	281			0.306	1023	0.294	1130	1.092	1112	
1.233	278			0.311	1025	0.300	1130	1.100	1114	
1.250	273			0.317	1018	0.306	1129	1.108	1113	
1.275	278			0.322	1017	0.311	1129	1.117	1112	
1.292	272			0.328	1020	0.317	1128	1.125	1111	
1.333	267			0.333	1018	0.322	1128	1.383	1103	
1.367	268			0.339	1012	0.328	1129	1.408	1100	
1.400	283			0.344	1009	0.333	1128	1.442	1099	
1.433	264			0.350	1007	0.339	1127	1.492	1096	
1.450	274			0.356	1005	0.344	1127	1.550	1092	
1.483	260			0.361	1003	0.350	1126	1.592	1091	
1.517	271			0.367	1005	0.356	1126	1.650	1089	
1.550	261			0.372	999	0.361	1125	1.767	1081	
1.683	254			0.378	997	0.367	1125	1.850	1075	
1.700	257			0.383	995	0.372	1125	1.933	1069	
1.742	263			0.389	993	0.378	1124	2.267	1044	
1.783	250			0.394	991	0.383	1124	2.367	1035	

	Radiometer			Thermocouple		Thermocouple		Thermocouple	
Time	Temperature		Time	Temperature	Time	Temperature	Time	Temperature	
(hours)	(Centigrade)		(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	
	surface			0.02-m-depth		0.06-m-depth		0.10-m-depth	
1.817	251		0.400	989	0.389	1124	2.450	1028	
1.867	241		0.406	987	0.394	1124	2.733	1006	
2.033	234		0.411	986	0.400	1123	3.450	954	
2.183	231		0.417	983	0.406	1123	3.983	918	
2.267	231		0.422	982	0.411	1123	4.461	890	
2.383	225		0.428	979	0.417	1122	6.145	813	
2.483	219		0.433	980	0.422	1121	6.711	793	
2.700	218		0.439	976	0.428	1121	7.111	780	
3.383	212		0.444	973	0.433	1120	7.745	761	
4.628	208		0.450	973	0.439	1120	9.078	729	
6.145	241		0.456	976	0.444	1119	10.19	701	
6.711	212		0.461	974	0.450	1118	11.91	669	
7.111	200		0.467	972	0.456	1117	15.36	615	
7.745	200		0.472	969	0.461	1117	16.69	599	
9.078	195		0.478	962	0.467	1117	18.19	583	
10.19	197		0.483	962	0.472	1117	18.93	574	
11.91	170		0.489	961	0.478	1117	20.19	564	
15.68	160		0.494	963	0.483	1116	24.19	537	
16.69	165		0.500	961	0.489	1115	24.81	533	
18.19	165		0.506	954	0.494	1115	31.19	502	
18.93	168		0.511	957	0.500	1114	34.44	483	
20.19	157		0.517	955	0.506	1115	37.86	466	
42.11	149		0.522	955	0.511	1114	40.51	443	
64.81	148		0.528	952	0.517	1115	44.94	417	
89.11	145		0.533	951	0.522	1115	48.94	408	
			0.539	944	0.528	1115	55.69	391	
			0.544	948	0.533	1114	xxxxxx	xxxxxxxxxxxx	
			0.550	941	0.539	1113	64.81	510	
			0.556	937	0.544	1112	71.44	563	
			0.561	942	0.550	1111	81.03	568	
			0.572	932	0.556	1111	89.11	557	
			0.578	936	0.561	1111			
			0.583	929	0.572	1110			
			0.589	934	0.578	1110			
			0.594	932	0.583	1110			
			0.600	924	0.589	1110			
			0.606	923	0.594	1110			
			0.611	927	0.600	1110			
			0.617	921	0.606	1111			
			0.622	924	0.611	1110			
			0.628	917	0.617	1109			
			0.633	915	0.622	1109			
			0.639	918	0.628	1108			
			0.644	913	0.633	1107			
			0.656	909	0.639	1106			
			0.661	907	0.644	1106			
			0.667	909	0.700	1103			
			0.672	905	0.706	1103			
			0.678	906	0.711	1102			
			0.683	902	0.717	1102			
			0.689	902	0.722	1102			
			0.694	902	0.728	1101			
			0.700	903	0.733	1101			
			0.706	900	0.739	1100			
			0.711	902	0.744	1100			
			0.717	898	0.750	1100			
			0.722	894	0.756	1099			

	Thermocouple		Thermocouple	
Time	Temperature	Time	Temperature	
(hours)	(Centigrade)	(hours)	(Centigrade)	
	0.02-m-depth		0.06-m-depth	
0.728	894	0.761	1099	
0.733	893	0.767	1098	
0.739	890	0.772	1098	
0.744	890	0.778	1098	
0.750	887	0.783	1097	
0.756	887	0.789	1097	
0.761	884	0.800	1096	
0.767	885	0.806	1096	
0.772	881	0.811	1096	
0.778	880	0.817	1095	
0.783	881	0.822	1095	
0.789	877	0.828	1094	
0.800	875	0.833	1094	
0.806	874	0.839	1094	
0.811	873	0.844	1093	
0.817	873	0.850	1093	
0.822	870	0.856	1092	
0.828	869	0.861	1092	
0.833	869	0.867	1091	
0.839	867	0.872	1091	
0.844	868	0.878	1091	
0.850	865	0.883	1090	
0.856	865	0.889	1090	
0.861	864	0.894	1089	
0.867	862	0.900	1089	
0.872	863	0.906	1089	
0.878	859	0.911	1088	
0.883	861	0.917	1088	
0.889	860	0.922	1087	
0.894	859	0.933	1086	
0.900	858	0.939	1086	
0.906	852	0.944	1085	
0.911	854	0.950	1085	
0.917	850	0.956	1085	
0.922	849	0.961	1084	
0.933	849	0.967	1083	
0.939	855	0.978	1083	
0.944	856	0.989	1082	
0.950	850	0.994	1081	
0.956	850	1.000	1081	
0.961	845	1.008	1080	
0.967	842	1.017	1080	
0.978	840	1.025	1079	
0.989	835	1.033	1078	
0.994	836	1.042	1078	
1.000	834	1.050	1077	
1.008	832	1.058	1077	
1.017	831	1.067	1075	
1.025	833	1.075	1074	
1.033	828	1.083	1074	
1.042	826	1.092	1073	
1.050	825	1.100	1072	
1.058	827	1.108	1071	
1.067	825	1.117	1070	
1.075	821	1.125	1070	
1.083	823	1.383	1041	
1.092	820	1.408	1040	

	Thermocouple		Thermocouple
Time	Temperature	Time	Temperature
(hours)	(Centigrade)	(hours)	(Centigrade)
	0.02-m-depth		0.06-m-depth
1.100	819	1.442	1036
1.108	813	1.492	1030
1.117	815	1.550	1024
1.125	813	1.592	1020
1.383	774	1.650	1013
1.408	772	1.767	1001
1.442	768	1.850	992
1.492	762	1.933	983
1.550	754	2.267	950
1.592	751	2.367	941
1.650	745	2.450	933
1.767	732	2.733	913
1.850	721	3.450	855
1.933	712	3.983	833
2.267	685	4.461	808
2.367	678	6.145	741
2.450	672	6.711	724
2.733	656	7.111	713
3.450	620	7.745	695
3.983	596	9.078	665
4.461	576	10.19	644
6.145	527	11.91	614
6.711	515	15.36	567
7.111	506	16.69	553
7.745	494	18.19	537
9.078	474	18.93	529
10.19	457	20.19	520
11.91	440	24.19	496
15.36	404	24.81	492
16.69	394	31.19	449
18.19	384	34.44	425
18.93	381	37.86	404
20.19	376	40.51	389
24.19	363	44.94	368
24.81	362	48.94	356
31.19	327	55.69	333
34.44	305	xxxxx	xxxxxxxxxxx
37.86	294	64.81	318
40.51	281	71.44	323
44.94	269	81.03	318
48.94	262	89.11	311
55.69	244	93.44	312
xxxxx	xxxxxxxxxxx	99.78	803
64.81	239		
71.44	245		
81.03	339		
89.11	233		
93.44	237		
99.78	961		
112.8	958		

APPENDIX B: U.S. Geological Survey Open-File Report 93-342A									
Surface heights of inflating sheet flows. Measured on flows that began on 23-Jan-88, 13-Apr-90, and 17-Apr-90.									
Time is in decimal hours from the beginning of the experiment.									
Start times (Hawaiian Standard Time) are (~12:00 PM, 23-Jan-88), (18:25, 13-Apr-90), and (14:48:19, 17-Apr-90)									
13-Apr-90	**Site 2**	**13-Apr-90**	**Site 3**	**17-Apr-90**	**Sites 1+3**	**17-Apr-90**	**Site 1**	**17-Apr-90**	**Site 3**
Time	**Thickness**	**Time**	**Thickness**	**Time**	**Thickness**	**Time**	**Thickness**	**Time**	**Thickness**
(hours)	**(meters)**	**(hours)**	**(meters)**	**(hours)**	**(meters)**	**(hours)**	**(meters)**	**(hours)**	**(meters)**
0.042	0.120	0.044	0.280	0.024	0.097	0.024	0.097	20.195	1.431
0.100	0.250	0.126	0.380	0.029	0.103	0.029	0.103	41.211	1.851
0.200	0.290	0.411	0.610	0.039	0.103	0.039	0.103	66.478	2.139
0.317	0.310	1.142	0.820	0.049	0.108	0.049	0.108	89.695	2.416
0.417	0.300	1.904	0.940	0.054	0.114	0.054	0.114	113.695	2.469
0.553	0.470	2.510	1.030	0.061	0.114	0.061	0.114		
0.686	0.550	3.146	1.040	0.067	0.120	0.067	0.120		
0.968	0.710	3.772	1.130	0.072	0.125	0.072	0.125		
1.661	0.920	4.210	1.160	0.092	0.137	0.092	0.137		
2.317	1.030	5.003	1.260	0.100	0.142	0.100	0.142		
3.056	1.150	5.157	1.410	0.113	0.154	0.113	0.154		
3.692	1.220	7.439	1.600	0.124	0.159	0.124	0.159		
4.315	1.260	9.494	1.720	0.129	0.165	0.129	0.165		
4.757	1.300	11.038	1.820	0.136	0.171	0.136	0.171		
5.558	1.410	11.592	1.860	0.144	0.177	0.144	0.177		
5.883	1.410	14.467	1.870	0.150	0.188	0.150	0.188		
7.958	1.570	14.750	1.930	0.154	0.194	0.154	0.194		
10.044	1.690	15.000	1.950	0.163	0.199	0.163	0.199		
11.594	1.780	15.267	1.950	0.171	0.205	0.171	0.205		
12.163	1.810	15.567	1.970	0.178	0.211	0.178	0.211		
15.033	1.950	16.017	1.990	0.188	0.216	0.188	0.216		
15.333	1.970	16.483	2.010	0.196	0.216	0.196	0.216		
15.583	1.980	17.017	2.030	0.204	0.222	0.204	0.222		
15.850	1.990	18.100	2.050	0.217	0.233	0.217	0.233		
16.167	2.010	19.067	2.080	0.228	0.233	0.228	0.233		
16.583	2.030	19.300	2.120	0.239	0.245	0.239	0.245		
17.067	2.050	19.983	2.120	0.251	0.251	0.251	0.251		
17.583	2.070	21.100	2.140	0.265	0.256	0.265	0.256		
18.667	2.100	21.983	2.160	0.278	0.262	0.278	0.262		
19.650	2.190	23.733	2.160	0.288	0.268	0.288	0.268		
19.650	2.110	26.400	2.250	0.296	0.273	0.296	0.273		
19.833	2.070	42.000	2.470	0.308	0.279	0.308	0.279		
20.567	2.090	42.500	2.450	0.322	0.285	0.322	0.285		
21.683	2.110	44.833	2.410	0.335	0.296	0.335	0.296		
22.567	2.130	47.000	2.390	0.344	0.296	0.344	0.296		
24.200	2.130	62.750	2.490	0.356	0.302	0.356	0.302		
26.917	2.250	67.000	2.580	0.369	0.313	0.369	0.313		
32.417	2.380	70.000	2.600	0.385	0.324	0.385	0.324		
42.583	2.440	85.917	2.760	0.400	0.330	0.400	0.330		
43.083	2.460	88.050	2.800	0.418	0.336	0.418	0.336		
45.417	2.400	91.050	2.860	0.438	0.347	0.438	0.347		

13-Apr-90	Site 2	13-Apr-90	Site 3	17-Apr-90	Sites 1+3	17-Apr-90	Site 1		
Time	Thickness	Time	Thickness	Time	Thickness	Time	Thickness		
(hours)	(meters)	(hours)	(meters)	(hours)	(meters)	(hours)	(meters)		
47.583	2.400	113.250	3.060	0.456	0.353	0.456	0.353		
63.333	2.470	134.267	3.200	0.478	0.359	0.478	0.359		
67.583	2.590	157.633	3.410	0.492	0.364	0.492	0.364		
70.583	2.610	182.000	3.630	0.511	0.370	0.511	0.370		
86.500	2.780	205.633	3.740	0.528	0.381	0.528	0.381		
88.633	2.820	252.900	3.870	0.544	0.387	0.544	0.387		
91.633	2.880	300.233	3.940	0.597	0.404	0.597	0.404		
113.833	3.070	324.500	3.960	0.614	0.410	0.614	0.410		
134.850	3.230	373.067	3.960	0.640	0.415	0.640	0.415		
158.217	3.460	397.000	3.940	0.663	0.421	0.663	0.421		
182.583	3.660			0.681	0.427	0.681	0.427		
206.217	3.700			0.708	0.438	0.708	0.438		
253.483	3.750			0.738	0.444	0.738	0.444		
301.083	3.810			0.763	0.455	0.763	0.455		
				0.789	0.467	0.789	0.467		
				0.818	0.478	0.818	0.478		
				0.842	0.489	0.842	0.489		
				0.868	0.501	0.868	0.501		
				0.890	0.506	0.890	0.506		
				0.918	0.518	0.918	0.518		
				0.950	0.523	0.950	0.523		
				1.117	0.552	1.117	0.552		
				1.150	0.552	1.150	0.552		
				1.167	0.552	1.167	0.552		
				1.038	0.557	1.038	0.557		
				1.088	0.557	1.088	0.557		
				1.208	0.557	1.208	0.557		
				1.258	0.557	1.258	0.557		
				1.275	0.558	1.275	0.558		
				1.350	0.569	1.350	0.569		
				1.417	0.569	1.417	0.569		
				1.642	0.586	1.642	0.586		
				1.792	0.609	1.792	0.609		
				1.942	0.620	1.942	0.620		
				2.167	0.637	2.167	0.637		
				2.550	0.671	2.550	0.671		
				3.117	0.734	3.117	0.734		
				3.450	0.779	3.450	0.779		
				3.833	0.830	3.833	0.830		
				4.050	0.847	4.050	0.847		
				4.811	0.915	4.811	0.915		
				5.378	0.921	5.378	0.921		
				5.628	0.932	5.628	0.932		
				6.011	0.960	6.011	0.960		
				20.195	1.431	6.828	1.000		
				41.211	1.851	7.228	1.005		

				17-Apr-90	Sites 1+3	17-Apr-90	Site 1		
				Time	Thickness	Time	Thickness		
				(hours)	(meters)	(hours)	(meters)		
				66.478	2.139	7.861	1.011		
				89.695	2.416	8.995	1.028		
				113.695	2.469	12.178	1.068		
						15.278	1.096		
						17.011	1.107		
						18.678	1.158		
						20.345	1.187		
						41.211	1.472		

23-Jan-88	Sites A+C+D	23-Jan-88	Site A	23-Jan-88	Site B	23-Jan-88	Site C	23-Jan-88	Site D
Time	Thickness	Time	Thickness	Time	Thickness	Time	Thickness	Time	Thickness
(hours)	(meters)	(hours)	(meters)	(hours)	(meters)	(hours)	(meters)	(hours)	(meters)
0.880	0.240	0.880	0.24	0.930	0.430	0.970	0.64	23.580	1.23
0.970	0.640	1.530	0.58	1.570	0.520	1.580	0.65	24.420	1.25
1.530	0.580	2.080	0.85	2.070	0.620	2.030	0.65	25.030	1.3
1.580	0.650	2.530	0.86	2.600	1.000	2.470	0.89	25.570	1.32
2.030	0.650			4.800	1.210	4.830	0.9	26.080	1.35
2.080	0.850			6.170	1.220	6.170	0.92	26.530	1.37
2.470	0.890			23.520	1.450	23.550	1.29	27.130	1.38
2.530	0.860			24.470	1.470	24.430	1.3	51.170	1.42
4.830	0.900			25.080	1.490	25.070	1.31		
6.170	0.920			25.620	1.490	25.600	1.32		
23.550	1.290			26.130	1.490	26.170	1.33		
23.580	1.230			26.600	1.500	26.570	1.34		
24.420	1.250			27.180	1.510	27.150	1.36		
24.430	1.300					51.230	1.55		
25.030	1.300								
25.070	1.310								
25.570	1.320								
25.600	1.320								
26.080	1.350								
26.170	1.330								
26.530	1.370								
26.570	1.340								
27.130	1.380								
27.150	1.360								
51.170	1.420								
51.230	1.550								

APPENDIX C: U.S. Geological Survey Open-File Report 93-342A

Crack depth meaurements taken on 17-Apr-90 flow, start time 14:48:19

Time is in decimal hours from start

Crack depths measured near site 1 until 20.111 hours, then measured near site 3

Depth was measured on a crack system with no vertical displacement

Crack temperature was recorded at bottom of crack using a chromel-alumel thermocouple

Time (hours)	Crack depth (meters)	Crack Temperature (Centigrade)
.200	0.01	
.283	0.02	
.567	0.07	
1.433	0.09	
1.833	0.10	
3.450	0.12	
6.645	0.14	
5.111	0.14	
7.945	0.19	>900
11.911	0.22	
15.678	0.26	943
19.195	0.28	984
20.111	0.29	975
24.195	0.35	921
40.695	0.42	955
89.111	0.65	770
99.778	0.76	860
99.945	0.84	820

APPENDIX D: U.S. Geological Survey Open-File Report 93-342A

Cooling, thickness, and crack depth data for pahoehoe flow above Keone jeep trail, 3/14/90

Time is in decimal hours from 12:28:25 PM on 14-Mar-90

Depths of the thermocouples within the crust are listed for each data set

Radiometer measurements were made using a Minolta Cyclops 330 radiometer with an emissivity setting of 1.

Crack temperature was recorded at bottom of crack using a chromel-alumel thermocouple

Cooling data from Site 2

Time (hours)	Radiometer Temperature (Centigrade) surface	Time (hours)	Thermocouple Temperature (Centigrade) 0.002-m-depth
0.017	733	0.022	1034
0.022	690	0.024	1019
0.025	651	0.025	1027
0.035	643	0.026	1008
0.029	634	0.028	974
0.032	634	0.029	959
0.038	618	0.031	950
0.040	608	0.032	942
0.053	592	0.035	881
0.056	577	0.036	860
0.058	566	0.038	843
0.063	566	0.039	825
0.071	547	0.040	815
0.075	546	0.042	803
0.088	537	0.043	790
0.079	536	0.044	780
0.082	532	0.046	770
0.085	528	0.047	761
0.090	518	0.049	751
0.093	517	0.050	741
0.097	512	0.051	736
0.106	507	0.053	730
0.112	493	0.054	723
0.110	492	0.056	717
0.115	491	0.057	711
0.118	490	0.058	706
0.121	487	0.060	698
0.124	487	0.061	692
0.143	487	0.063	687
0.146	486	0.064	682
0.132	484	0.065	678
0.135	483	0.067	673
0.137	483	0.068	667
0.140	482	0.069	664
0.151	481	0.071	661
0.154	478	0.072	657
0.157	476	0.074	653
0.160	476	0.075	649
0.162	476	0.076	644
0.165	474	0.078	639
0.168	468	0.081	635
0.171	468	0.083	629
0.182	468	0.085	625
0.174	467	0.086	621
0.193	467	0.088	619
0.176	466	0.089	617
0.179	466	0.090	615
0.185	465	0.092	615
0.187	462	0.093	608

Thickness and crack depth data from Site 1

Time (hours)	Thickness (meters)	Time (hours)	Crack depth (meters)	Crack Temperature (Centigrade)
0.000	0.00	0.000	0.00	
1.560	0.70	0.772	0.09	790
2.421	0.88	1.424	0.13	884
3.382	0.89	2.316	0.21	990
5.419	0.96	3.479	0.23	887
		5.537	0.22	687
		5.605	0.20	1003

Thickness and crack depth data from Site 2

Time (hours)	Thickness (meters)	Time (hours)	Crack depth (meters)	Crack Temperature (Centigrade)
0.000	0.00	0.000	0.00	
0.017	0.20	0.301	0.03	
0.115	0.30	1.374	0.10	1001
0.229	0.37	1.630	0.12	994
0.662	0.43	2.288	0.19	1048
1.529	0.49	3.439	0.18	956
2.403	0.57			
3.351	0.58			
5.383	0.58			

Thickness and crack depth data from Site 3

Time (hours)	Thickness (meters)	Time (hours)	Crack depth (meters)	Crack Temperature (Centigrade)
0.000	0.00	0.000	0.00	
1.569	0.50	1.483	0.14	930
2.429	0.53	2.351	0.18	849
3.393	0.54	3.508	0.19	800

Cooling data from Site 2										
Time	Radiometer	Time	Thermocouple							
(hours)	Temperature	(hours)	Temperature							
	(Centigrade)		(Centigrade)							
	surface		0.002-m-depth							
0.199	461	0.094	606							
0.196	460	0.096	605							
0.190	457	0.097	603							
0.226	456	0.132	569							
0.204	452	0.135	567							
0.201	451	0.137	565							
0.207	448	0.140	563							
0.229	448	0.143	562							
0.218	447	0.146	559							
0.210	446	0.149	559							
0.215	446	0.151	560							
0.221	446	0.154	559							
0.212	445	0.157	557							
0.232	445	0.160	555							
0.240	443	0.162	552							
0.235	442	0.165	550							
0.237	441	0.168	548							
0.265	441	0.171	546							
0.243	440	0.174	542							
0.246	440	0.176	540							
0.249	439	0.179	538							
0.268	439	0.182	537							
0.251	438	0.185	536							
0.254	438	0.187	534							
0.257	437	0.190	532							
0.301	437	0.193	529							
0.262	436	0.196	528							
0.260	435	0.199	526							
0.271	435	0.201	524							
0.274	433	0.204	521							
0.296	431	0.207	518							
0.293	427	0.210	515							
0.299	427	0.215	512							
0.304	426	0.265	499							
0.310	423	0.268	498							
0.307	422	0.271	497							
0.312	420	0.274	497							
0.326	417	0.276	496							
0.443	410	0.279	496							
0.390	406	0.282	495							
0.399	405	0.340	469							
0.401	405	0.343	468							
0.404	405	0.346	467							
0.407	405	0.349	466							
0.424	405	0.351	465							
0.376	403	0.354	464							
0.379	403	0.357	462							
0.387	403	0.360	463							
0.410	403	0.362	462							
0.382	402	0.365	463							
0.385	401	0.371	463							
0.412	401									
0.415	401									
0.418	401									
0.421	401									
0.426	401									

Cooling data from Site 2	
Time	Radiometer
(hours)	Temperature
	(Centigrade)
	surface
0.440	401
0.429	400
0.432	398
0.435	398
0.446	397
0.437	396
0.451	396
0.449	395
0.454	395
0.465	395
0.468	395
0.457	393
0.462	393
0.460	392
0.653	373
0.674	370
0.685	368
0.690	368
0.676	367
0.679	367
0.687	367
0.682	366
1.312	332
1.318	332
1.382	332
1.254	331
1.290	331
1.299	331
1.301	331
1.304	331
1.307	331
1.310	331
1.324	331
1.235	330
1.240	330
1.243	330
1.249	330
1.274	330
1.296	330
1.315	330
1.321	330
1.349	330
1.365	330
1.371	330
1.379	330
1.229	329
1.238	329
1.246	329
1.257	329
1.287	329
1.376	329
1.226	328
1.251	328
1.262	328
1.265	328
1.276	328

Cooling data from Site 2	
Time	Radiometer
(hours)	Temperature
	(Centigrade)
	surface
1.293	328
1.326	328
1.329	328
1.332	328
1.362	328
1.368	328
1.435	328
1.232	327
1.260	327
1.268	327
1.354	327
1.357	327
1.374	327
1.385	327
1.399	327
1.271	326
1.279	326
1.282	326
1.335	326
1.337	326
1.346	326
1.360	326
1.387	326
1.393	326
1.343	325
1.390	325
1.396	325
1.401	325
1.404	325
1.407	325
1.340	324
1.351	324
1.426	324
1.410	323
1.460	323
1.412	322
1.415	322
1.418	322
1.424	321
1.446	321
1.457	321
1.421	320
1.437	320
1.443	320
1.451	320
1.454	318
1.462	318
1.440	317
1.449	317
2.329	291
2.338	291
2.346	291
2.351	291
2.321	290
2.326	290
2.332	290

Cooling data from Site 2										
Time	Radiometer									
(hours)	Temperature									
	(Centigrade)									
	surface									
2.335	290									
2.343	290									
2.349	289									
2.318	288									
2.324	288									
3.552	270									
3.526	267									
3.544	267									
3.563	267									
3.539	265									
3.574	263									
3.566	261									
3.558	258									
3.569	257									

APPENDIX E: U.S. Geological Survey Open-File Report 93-342A

Cooling data for pahoehoe flow on Lokelani just below Highway, 24-Apr-90

Pahoehoe toe inflated very slow during the initial 6-8 minutes, then ceased inflating

Run begins at 14:00

Time (hours)	Radiometer Temperature (Centigrade) surface	Time (hours)	Thermocouple Temperature (Centigrade) 0.002-m-depth
0.008	712	0.004	986
0.013	733	0.008	954
0.021	717	0.013	900
0.025	710	0.021	839
0.033	704	0.025	817
0.038	717	0.033	785
0.042	702	0.038	768
0.046	674	0.042	756
0.050	628	0.046	743
0.054	622	0.050	731
0.058	610	0.054	721
0.063	562	0.058	710
0.067	578	0.063	701
0.071	566	0.067	692
0.075	558	0.071	685
0.088	530	0.075	677
0.092	520	0.079	670
0.100	518	0.083	663
0.104	514	0.088	656
0.108	512	0.092	645
0.113	506	0.100	640
0.117	497	0.104	636
0.121	477	0.108	631
0.125	487	0.113	627
0.129	517	0.117	621
0.133	477	0.121	617
0.138	481	0.125	613
0.142	477	0.129	609
0.146	477	0.133	606
0.154	465	0.138	602
0.158	461	0.142	597
0.163	465	0.146	594
0.175	450	0.154	589
0.183	451	0.158	587
0.188	438	0.163	584
0.250	426	0.175	577
0.254	425	0.183	571
0.258	418	0.188	569
0.263	426	0.192	567
0.267	411	0.200	564
0.271	422	0.204	561
0.275	418	0.208	561
0.279	411	0.221	558
0.283	406	0.229	556
0.288	405	0.233	554
0.292	404	0.242	552
0.296	401	0.250	548
0.300	401	0.254	547
0.304	401	0.258	546
0.308	394	0.263	545
0.313	397	0.267	543
0.317	394	0.271	539

Time	Radiometer	Time	Thermocouple				
(hours)	Temperature	(hours)	Temperature				
	(Centigrade)		(Centigrade)				
	surface		0.002-m-depth				
0.321	390	0.275	538				
0.325	388	0.279	536				
0.329	387	0.283	533				
0.333	382	0.288	533				
		0.292	532				
		0.296	531				
		0.300	529				
		0.304	527				
		0.308	526				
		0.313	524				
		0.317	523				
		0.321	521				
		0.325	518				
		0.329	515				
		0.333	515				

APPENDIX F: U.S. Geological Survey Open-File Report 93-342A							
Cooling data for pahoehoe flow on Lokelani just below Highway, 3-May-90							
Pahoehoe toe inflated rapidly to 0.25 m in about 2 minutes then ceased inflating							
Time for run 2 is in decimal hours from 13:15 (Hawaiian Standard Time)							
Cooling data from run 2							
	Radiometer		**Thermocouple**		**Thermocouple**		**Thermocouple**
Time	**Temperature**	**Time**	**Temperature**	**Time**	**Temperature**	**Time**	**Temperature**
(hours)	**(Centigrade)**	**(hours)**	**(Centigrade)**	**(hours)**	**(Centigrade)**	**(hours)**	**(Centigrade)**
	surface		**0.002-m-depth**		**0.01-m-depth**		**0.02-m-depth**
0.013	875	0.017	863	0.013	1053	0.017	1108
0.017	782	0.025	760	0.017	990	0.025	1097
0.025	648	0.033	695	0.025	973	0.067	1053
0.042	588	0.042	638	0.033	934	0.071	1048
0.046	580	0.046	622	0.042	913	0.075	1046
0.050	572	0.050	619	0.046	902	0.079	1046
0.054	556	0.054	605	0.054	879	0.083	1043
0.058	547	0.058	594	0.058	872	0.088	1042
0.063	538	0.063	584	0.063	865	0.092	1040
0.067	535	0.067	568	0.067	856	0.096	1037
0.071	527	0.071	568	0.071	852	0.100	1033
0.075	518	0.075	568	0.075	846	0.104	1025
0.079	513	0.079	550	0.079	841	0.108	1021
0.083	513	0.083	548	0.083	837	0.113	1025
0.088	511	0.088	544	0.088	833	0.117	1022
0.092	503	0.092	542	0.092	828	0.121	1019
0.096	497	0.096	531	0.096	823	0.125	1018
0.100	498	0.100	537	0.100	816	0.129	1006
0.104	496	0.104	534	0.104	812	0.133	1003
0.108	492	0.108	530	0.108	807	0.138	1005
0.113	486	0.113	521	0.113	800	0.142	1001
0.117	487	0.117	520	0.117	795	0.146	997
0.121	479	0.121	511	0.121	788	0.150	993
0.125	478	0.125	516	0.125	784	0.154	991
0.129	480	0.129	518	0.129	780	0.163	980
0.138	470	0.133	511	0.133	775	0.171	973
0.142	474	0.138	506	0.138	769	0.175	970
0.146	467	0.142	510	0.142	766	0.179	966
0.150	467	0.146	504	0.146	761	0.183	963
0.154	465	0.150	506	0.150	756	0.188	960
0.163	456	0.154	499	0.154	753	0.192	956
0.171	454	0.163	499	0.163	739	0.196	953
0.175	452	0.171	485	0.171	732	0.200	950
0.179	451	0.175	485	0.175	735	0.204	947
0.183	446	0.179	491	0.179	733	0.208	944
0.188	445	0.183	489	0.183	726	0.213	941
0.192	446	0.188	483	0.188	719	0.217	938
0.196	446	0.192	479	0.192	722	0.221	935
0.200	447	0.196	482	0.196	719	0.225	932
0.204	441	0.200	481	0.200	716	0.229	930
0.208	437	0.204	474	0.204	714	0.233	927
0.213	432	0.208	471	0.208	710	0.238	924
0.217	434	0.213	468	0.213	706	0.242	921
0.221	432	0.217	469	0.217	705	0.246	919
0.225	433	0.221	470	0.221	701	0.250	916
0.250	426	0.225	470	0.225	698	0.254	914
0.254	423	0.229	471	0.229	696	0.258	911
0.258	421	0.233	464	0.233	694	0.263	908
0.263	417	0.238	465	0.238	691	0.267	905
0.267	416	0.242	464	0.242	689	0.275	902
0.271	413	0.246	465	0.246	687	0.279	899

Cooling data from run 2							
	Radiometer		Thermocouple		Thermocouple		Thermocouple
Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature
(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)
	surface		0.002-m-depth		0.01-m-depth		0.02-m-depth
0.275	415	0.250	466	0.250	685	0.283	896
0.279	416	0.254	461	0.254	683	0.292	892
0.283	407	0.258	460	0.258	682	0.300	888
0.292	405	0.263	455	0.263	673	0.308	884
0.300	407	0.267	448	0.267	675	0.317	879
0.308	402	0.271	451	0.271	673	0.325	875
0.317	401	0.275	452	0.275	672	0.333	871
0.325	402	0.279	454	0.279	665	0.342	867
0.333	398	0.283	445	0.283	667	0.350	863
0.342	401	0.292	437	0.292	662	0.358	859
0.350	399	0.300	434	0.300	658	0.367	856
0.358	400	0.308	424	0.308	653	0.375	852
0.367	397	0.317	427	0.317	650	0.383	849
0.375	395	0.325	427	0.325	646	0.392	846
0.383	393	0.333	432	0.333	644	0.400	843
0.392	381	0.342	433	0.342	640	0.404	840
0.400	380	0.350	430	0.350	638	0.408	837
0.467	377	0.358	433	0.358	636	0.417	829
0.475	372	0.367	427	0.367	633	0.425	827
0.483	373	0.375	426	0.375	631	0.433	824
0.492	368	0.383	428	0.383	628	0.442	821
0.500	371	0.392	424	0.392	623	0.450	818
0.508	372	0.400	419	0.400	620	0.458	815
0.517	375	0.404	414	0.404	616	0.467	813
0.525	370	0.408	416	0.408	616	0.475	811
0.533	368	0.417	409	0.417	608	0.483	808
0.592	366	0.425	410	0.425	604	0.492	805
0.600	366	0.433	413	0.433	602	0.500	803
0.608	368	0.442	405	0.442	601	0.508	801
0.625	342	0.450	411	0.450	600	0.517	798
0.633	352	0.458	408	0.458	598	0.525	796
0.642	345	0.467	408	0.467	597	0.533	794
0.650	359	0.475	401	0.475	595	0.542	791
0.667	351	0.483	403	0.483	593	0.558	787
0.675	349	0.492	391	0.492	591	0.567	785
0.683	351	0.500	394	0.500	589	0.575	782
0.950	327	0.508	399	0.508	588	0.592	778
0.958	327	0.517	404	0.517	586	0.600	777
0.967	326	0.525	403	0.525	585	0.608	774
1.067	305	0.533	397	0.533	583	0.617	773
1.183	305	0.542	398	0.542	582	0.625	771
1.333	305	0.558	396	0.558	580	0.633	769
1.450	309	0.567	392	0.567	578	0.642	766
		0.575	392	0.575	576	0.650	764
		0.592	381	0.592	572	0.667	761
		0.600	382	0.600	570	0.675	759
		0.608	383	0.608	569	0.683	757
		0.617	379	0.617	567	0.733	750
		0.625	384	0.625	566	0.742	748
		0.633	375	0.633	564	0.750	746
		0.642	381	0.642	563	0.758	745
		0.650	377	0.650	562	0.767	743
		0.667	371	0.667	558	0.775	741
		0.675	366	0.675	556	0.783	739
		0.683	364	0.683	554	0.792	738
		0.733	360	0.733	549	0.800	737

Cooling data from run 2							
			Thermocouple		Thermocouple		Thermocouple
		Time	Temperature	Time	Temperature	Time	Temperature
		(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)
			0.002-m-depth		0.01-m-depth		0.02-m-depth
		0.742	364	0.742	548	0.808	735
		0.750	366	0.750	546	0.817	733
		0.758	363	0.758	545	0.825	732
		0.767	362	0.767	544	0.833	731
		0.775	368	0.775	543	0.842	729
		0.783	368	0.783	543	0.850	728
		0.792	361	0.792	543	0.858	726
				0.800	542	0.867	725
				0.808	541	0.875	723
				0.817	540	0.883	721
				0.825	540	0.892	719
				0.833	540	0.900	717
				0.842	539	0.908	716
				0.850	536	0.917	714
				0.858	533	0.925	713
				0.867	531	0.933	711
				0.875	528	0.942	710
				0.883	525	0.950	708
				0.892	524	0.958	706
				0.900	524	0.967	705
				0.908	523	0.975	704
				0.917	521	0.983	703
				0.925	519	0.992	703
				0.933	518	1.000	702
				0.942	516	1.042	699
				0.950	516	1.050	698
				0.958	516	1.058	698
				0.967	516	1.067	697
				0.975	518	1.083	695
				0.983	521	1.100	693
				0.992	522	1.117	691
				1.042	523	1.133	689
				1.050	522	1.150	687
				1.058	522	1.167	685
				1.067	521	1.183	683
				1.083	518	1.200	682
				1.100	516	1.217	680
				1.117	515	1.233	678
				1.133	514	1.250	677
				1.150	512	1.267	675
				1.167	511	1.283	673
				1.183	512	1.317	671
				1.200	509	1.333	667
				1.217	509	1.367	665
				1.233	508	1.450	658
				1.250	506		
				1.267	506		
				1.283	502		
				1.317	506		
				1.333	499		
				1.367	497		
				1.450	494		

Cooling data for pahoehoe flow on Keone Drive just above Highway 130, 3-May-90

Pahoehoe toe inflated slowly for about 6-7 minutes then ceased inflating

Time for run 1 is in decimal hours from 11:30 AM (Hawaiian Standard Time)

Cooling data from run 1

	Radiometer		Thermocouple		Thermocouple		Thermocouple
Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature
(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)	(hours)	(Centigrade)
	surface		0.002-m-depth		0.01-m-depth		0.02-m-depth
0.004	631	0.063	687	0.008	1050	0.008	1130
0.008	603	0.067	680	0.025	1002	0.025	1121
0.013	586	0.071	673	0.033	980	0.033	1112
0.017	541	0.075	668	0.042	942	0.042	1094
0.042	525	0.079	663	0.050	914	0.050	1081
0.046	511	0.083	660	0.054	902	0.054	1074
0.058	510	0.088	649	0.058	892	0.058	1068
0.063	498	0.096	643	0.063	882	0.063	1065
0.067	482	0.100	635	0.067	873	0.067	1060
0.083	466	0.108	631	0.071	866	0.071	1058
0.088	462	0.113	624	0.075	860	0.075	1054
0.092	457	0.117	624	0.079	859	0.079	1051
0.096	456	0.125	622	0.083	845	0.083	1047
0.100	452	0.133	614	0.088	843	0.088	1046
0.104	460	0.138	603	0.096	835	0.096	1043
0.108	455	0.142	599	0.100	829	0.100	1041
0.113	450	0.150	589	0.108	819	0.108	1037
		0.175	574	0.113	812	0.113	1035
		0.183	575	0.117	805	0.117	1033
		0.192	571	0.125	800	0.125	1028
		0.204	560	0.129	795	0.129	1025
		0.213	558	0.133	790	0.133	1023
		0.217	557	0.138	785	0.138	1019
		0.221	554	0.142	778	0.142	1016
		0.229	553	0.150	767	0.150	1010
		0.233	551	0.175	732	0.175	989
		0.238	547	0.183	727	0.183	982
		0.246	547	0.192	721	0.192	975
		0.250	543	0.204	709	0.204	968
		0.254	543	0.213	705	0.213	960
		0.258	538	0.217	702	0.217	956
		0.263	536	0.221	698	0.221	952
		0.267	533	0.229	693	0.229	947
		0.271	530	0.233	689	0.233	944
		0.275	530	0.238	685	0.238	941
		0.279	529	0.246	681	0.246	937
		0.283	527	0.250	679	0.250	932
				0.254	677	0.254	930
				0.258	675	0.258	929
				0.263	673	0.263	925
				0.267	669	0.267	923
				0.271	664	0.271	920
				0.275	662	0.275	917
				0.279	660	0.279	915
				0.283	659	0.283	912