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14. Classification of the Mafic Lava Flows from ODP Leg 183[1]

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ABSTRACT

Ocean Drilling Program Leg 183 (Kerguelen Plateau) produced some of the most systematic and detailed descriptions of lava flows ever compiled. A wide variety of lava types in various states of preservation were recovered. An initial attempt to make the identification of mafic lava flow types more systematic using only macroscopic observations made on the drill core is presented here. This technique successfully categorizes pahoehoe, aa, slab pahoehoe, and rubbly pahoehoe flows and provides an estimate of the certainty of each categorization. However, the technique needs to be improved in the future by increasing the list of diagnostic characteristics for slab and rubbly pahoehoe. Because of poor recovery and/or extreme alteration and weathering of the units, 12 of the 42 units (29%) could not be classified. Of the remaining 30 units, 7% were classified as slab pahoehoe, 13% as aa, 27% as pahoehoe, and 53% as rubbly pahoehoe. Pahoehoe and rubbly pahoehoe flows were found in Holes 1136A, 1137A, 1138A, and 1139A, whereas aa and slab pahoehoe flows were confined to the latter two holes.

INTRODUCTION

Basaltic lava flows have been traditionally classified according to their surface morphology and style of emplacement (e.g., Dutton, 1884; Macdonald 1953; Wentworth and Macdonald, 1953). However, in drill core, it can be difficult to observe those distinguishing characteristics. The main objective of this paper is to present a flow chart to systematically determine the lava flow type based only on macroscopic observations that can be made in drill core. The technique presented here also

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assigns a level of certainty to the determination. In cases when a unique lava type cannot be determined, the technique is still able to rule out some lava types. This procedure has wide potential application and with minimal modification can be applied to any cross-sectional view of a lava flow.

LEG 183 OBSERVATIONS

Eight holes (1135A–1142A) were drilled on the Kerguelen Plateau and Broken Ridge during Leg 183. Hole 1135A did not reach basaltic basement, Hole 1140A encountered pillow basalts, and the lavas in Holes 1141A and 1142A were exceptionally altered. Thus, this chapter only considers Holes 1136A–1139A. Table T1 briefly summarizes the basement units encountered in those holes. In addition to mafic lava flows, sedimentary, volcaniclastic, and evolved lava flows were encountered. This chapter only examines the mafic (basaltic-trachybasaltic) lava flows.

T1. Summary of basement units, p. 22.

The drill core recovered during Leg 183 is 6–7 cm in diameter and cut in half longitudinally on board the *JOIDES Resolution*. Both the exterior and the cut surfaces of the core were used for making the observations, but most quantitative measurements were made on the flat, sawed surfaces. Usually, the bit advanced 9.6 m between cores. Recovery was generally good (>50%) in the lavas but was highly dependent on the structure of the rock. Only in Hole 1137A were downhole logging measurements available to compare with recovered mafic subaerial lava flows, providing a direct measure of core recovery (Coffin, Frey, Wallace, et al., 1999). Massive portions of the flows often had 92%–100% recovery, but vesicular lavas had 27%–91% recovery. The worst recovery was in sections where the vesicle diameters approached the core diameter. Breccias had 62%–87% recovery but were sometimes significantly disturbed by the drilling and sawing processes.

The difficulty in recovering the vesicular and brecciated portions of the lava flows was exacerbated by alteration and weathering processes. The more permeable vesicular portions of the flows were often significantly more altered than the dense interiors. Breccias were even more intensely altered, and there was evidence for postemplacement mechanical weathering of some of the breccias. In the most severe examples, the alteration and weathering could completely mask the original shapes of the clasts. Both alteration and weathering preferentially attacked the most angular protrusions on the breccia clasts, making them seem rounder than they originally were. Interestingly, vesicle shapes were often still recognizable because of resistant secondary mineral fillings. There was also significant sediment fill within a number of the breccias (e.g., Fig. F2A). Whereas it is possible that some of the sediment-breccia mixtures are peperites, the preferred interpretation is that these are sediments that were deposited onto (and into) the breccia after lava flow emplacement.

Before the detailed examination of the lava could begin, the core had to be divided into units. Although a strong effort was made to have unit boundaries reflect individual lava packages, the term "unit" cannot be considered synonymous with "lava flow" for a number of reasons. The first problem was that the unit boundaries were usually fixed before the complete investigation of the core. Only rarely were changes made to the unit boundary locations, even when the initial justification for placing the unit boundaries was lost as the understanding of the site improved. Also, some unit boundaries reflect major physical changes in the core (e.g., brecciated vs. massive) that were visible in the physical properties and downhole measurements. These units may be parts of the same lava flow. Finally, when the precise location of the boundary could not be determined in the initial examination, an arbitrary decision was required for the core description to proceed. This was a common problem in areas with extreme alteration.

The observations recorded during Leg 183 are some of the most detailed and systematic macroscopic data ever collected from lava flows. Specific observations were made of (1) lava surface morphology, (2) vertical vesicle distribution, and (3) sedimentological characteristics of the breccias.

Observation of the surface morphology of the lava was often not possible because flow surfaces are rarely recovered and are most affected by alteration, weathering, and erosion. When visible, the key attributes of the flow surfaces that were recorded were (a) smooth pahoehoe vs. autobreccia, (b) glassy vs. microcrystalline, and (c) evidence for time between successive lava flows (e.g., weathering and sediments).

Vesicle distribution has been shown to be a key indicator of the style of emplacement of lava flows (e.g., Aubele et al., 1988; Cashman and Kauahikaua, 1997; Self et al., 1998). The systematic description of vertical vesicle distribution was made by documenting (1) volume percentage of vesicles, (2) size range (maximum, minimum, and mean diameters), (3) number density, (4) shape (sphericity and angularity), and (5) grading (fining up or coarsening up). The measurements were made over intervals appropriate for the variability shown in the core (typically every 1–30 cm). During these measurements, notes were also taken on the presence of mesostasis blebs, orientation of elongated vesicles, changes in groundmass texture, and other macroscopically visible petrographic features.

The detailed description of the volcanic breccias relied on the techniques used to describe sedimentary breccias. Specifically, clast sizes, sorting, grading, roundness, and lithology were documented. The porosity of the breccia was measured, and evidence for cementing and welding was noted. Of special interest were breccia clasts that showed evidence for deformation while hot and plastic (i.e., that the breccia was an "autobreccia" formed during flow emplacement). The clearest evidence that a breccia formed while the lava was hot came from clasts that had enveloped earlier clasts. The nature of the interface between the breccia and the coherent interior of the flow was also of special interest.

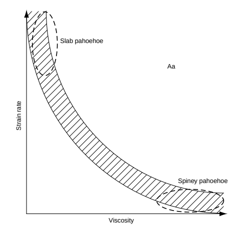
LAVA FLOW TYPES

Mafic lava flows have been classically divided into two categories: pahoehoe and aa (e.g., Dutton, 1884; Macdonald, 1953). Pahoehoe is characterized by having a smooth surface, and aa has a spinose autobreccia surface. In more recent years, some transitional types of basaltic lava have been noted, including slab pahoehoe and spiny pahoehoe (also called "toothpaste" or "sharkskin" pahoehoe). Spiny pahoehoe has the same centimeter-scale morphology as classical pahoehoe but has a spinose surface (e.g., Rowland and Walker, 1987). Slab pahoehoe has the same meter-scale morphology as an aa flow, but the autobreccia is dominated by slabs of broken pahoehoe surfaces (e.g., Macdonald, 1972). There are also many subvarieties of classic pahoehoe in Hawaii, such as S- and P-type pahoehoe (Walker, 1989), dense blue glassy pahoehoe (Hon et al., 1994), and shelly pahoehoe (Swanson, 1973). Most recently, another type of intermediate lava flow has been recognized. This flow type, dubbed "rubbly pahoehoe," is characterized by a flow-top autobreccia comprised primarily of broken pahoehoe lobes (Keszthelyi, 2000; Keszthelyi and Thordarson, 2000).

Pahoehoe and Aa

The transition between aa and pahoehoe is controlled by two factors, viscosity and strain rate (Fig. **F1**) (Peterson and Tilling, 1980). However, each of these factors is controlled by a vast array of parameters, including crystallinity, dissolved gas content, temperature, bubble content, slope, eruption rate, and lava composition. Studies suggesting that a single parameter controls the pahoehoe to aa transition have not considered a wide enough region in parameter space. For example, Rowland and Walker (1990) found that in Hawaii all eruptions >5–10 m^3/s form aa and those <5–10 m^3/s form pahoehoe. This is only true for viscosities and slopes typical in Hawaii. In the Columbia River Basalt Group, classic pahoehoe flows have formed despite eruption rates on the order of 4000 m^3/s (Thordarson and Self, 1998). Cashman et al. (1999) found that the transition from pahoehoe to aa took place in a Kilauea lava channel as the lava crystallinity increased past ~50%. Clearly, pahoehoe flows that crystallize after they have stopped do not transform to aa. Instead, the observations of Cashman et al. (1999) show that both high crystallinity and significant motion of the lava are needed to form aa. Since lava viscosity is proportional to crystallinity, this further supports the Peterson and Tilling (1980) hypothesis that both high viscosity and strain rate are necessary to form aa lava.

F1. Controls on the formation of pahoehoe, aa, and transitional lava types, p. 16.



Watching the transition from pahoehoe to aa in active lava flows allows one to see how both strain rate and viscosity control the transition. On an active pahoehoe flow, the surface is a plastic fluid. It is able to stretch, and the lobes advance much like a rubber balloon filling with water (Keszthelyi and Denlinger, 1996). If the lava becomes more viscous (i.e., due to crystallization) or if it is subjected to increased strain rate (i.e., by advancing over a steeper cliff), the lava is no longer able to stretch in a ductile manner. Instead, the hot plastic lava is ripped apart. Chunks of lava that are torn off of the main flow are tumbled into irregular, angular shapes. The torn surfaces are the spinose protrusions that are characteristic of aa clinker. The breccia rides on top of the flow and is dumped at the flow front. The flow then advances over this breccia, looking much like the advance of bulldozer treads (Macdonald, 1953).

Hawaiian Transitional Lavas

Slab pahoehoe flows form when the strain rates are high enough to form aa but the lava is too fluid to tear in a brittle manner. Spiny pahoehoe forms under very low strain rates but when the lava is too crystalline and viscous to form a smooth glassy surface (Rowland and Walker, 1987). These observations are shown in graphical form in Figure **F1**, using the plot first proposed by Peterson and Tilling (1980). Spiny pahoehoe flows were not encountered during Leg 183 and are therefore not discussed further in this chapter.

Slab pahoehoe involves the emplacement of relatively low-viscosity lava under very high strain rates. The name is derived from the abundance of slabs of pahoehoe in the disrupted upper crust. These slabs form when a flow initially forms a flat pahoehoe surface that is later disrupted from within. The individual slabs usually demonstrate the full range of brittle to ductile deformation; the upper chilled portion cracks while the lower hot portion deforms plastically (Macdonald, 1972). Such disruption is most often caused by high strain rates associated with surges of lava, most common in larger, sheetlike lobes. In Hawaii, slab pahoehoe lavas rarely extend for more than a kilometer before transitioning to classic aa (as the lava becomes more viscous) or pahoehoe (if the flow rate diminishes).

Rubbly Pahoehoe

Although the pahoehoe vs. aa classification scheme is applicable to the vast majority of the Hawaiian basaltic lava flows, it fails to describe many lava flows seen in Iceland, the Columbia River Basalt Group, or Leg 183 drill sites on the Kerguelen Plateau. The descriptive name "rubbly pahoehoe" has been suggested for a lava type that has a flow top composed of broken pieces of smaller pahoehoe lobes rather than spinose aa clinker (Keszthelyi, 2000; Keszthelyi and Thordarson, 2000). These breccia clasts are also distinct from pahoehoe slabs in that they have glassy chills on both sides—indicating that the lobe was broken by external forces rather than being torn apart from within. In cross section, rubbly pahoehoe flows have a four-part structure, passing from autobreccia top to coherent vesicular upper crust to dense core to lower vesicular crust. These flows often have a smooth pahoehoe base.

At this time, it is unclear where a rubbly pahoehoe flow would plot on Figure F1. Rubbly pahoehoe autobreccias lack aa clasts, implying relatively lower strain rates or viscosities. The examples of rubbly pahoehoe seen in the Columbia River Basalts have relatively high silica contents, suggesting that low viscosity is unlikely. Although this indicates that strain rates should have been quite low in the liquid portion of these flows, the breaking of pahoehoe lobes indicates high stresses.

It is clear that rubbly pahoehoe flow top autobreccias form over an extended period of time because younger clasts that engulf older cooled clasts can be found. Some lobes appear to have been broken after they were completely solidified, whereas others underwent some plastic deformation. As in aa flows, there is evidence of partially resorbed breccia clasts in the interior of the flows and there are "arms" or "lobes" of the core material pushing up into the breccia. Although these flows have many characteristics of aa flows, they have many of the internal features indicating inflation and a pahoehoe flow base.

SYSTEMATIC LAVA FLOW IDENTIFICATION

During Leg 183, we encountered clear examples of aa, pahoehoe, slab pahoehoe, and rubbly pahoehoe lava flows (Coffin, Frey, Wallace, et al., 1999). Table T2 details the characteristics that were used on board the ship to define each lava type. However, a more systematic methodology for interpreting these data is desirable in many cases. The procedure described in this chapter can readily be incorporated into a spreadsheet program to provide a very simple "expert system" for lava flow identification. The concept is to list the key macroscopic attributes that allow one to distinguish the different lava flow types. Each attribute is given a weighting factor depending on its importance in identifying that spe-

T2. Attributes of pahoehoe, aa, slab pahoehoe, and rubbly pahoehoe, p. 23.

cific lava type. Then for each lava flow, the presence, absence, or nondetection of that attribute is noted. The sum of the observed attributes gives a quick estimate of how closely that lava flow matches a given lava type. Ideally, one and only one lava type will have a high sum, providing a definitive identification of the type of lava flow. In the absence of sufficient data to make a definitive identification, the process should provide some estimate of the level of confidence in assigning a type to the flow and eliminate as many lava types as possible.

The attributes and weights used in this paper are shown in Table T3. Characteristics that are listed as "required" in Table T2 for a specific lava type are given a weight of 10. Characteristics that are "common" are given a weight of 1. Similarly, characteristics that are commonly absent and required to be absent were given weights of –1 and –10, respectively. The negative weights are what allow one to rule out a given lava type for the flow being studied.

T3. Weights assigned to characteristics used to distinguish lava types, p. 24.

Upon examining Table T3, one immediately can see that this scheme needs to be improved upon by adding more diagnostic characteristics for the transitional lava types. In particular, it is important to note that the total number of distinguishing characteristics for slab pahoehoe is only about half of that for the other three lava types. This means that we have a shortage of attributes with which to identify slab pahoehoe. This can lead to problems. For example, if the only observation we have is that a lava flow has a autobrecciated flow top, this has 19% of the attributes of an aa flow, 17% of the attributes of a rubbly pahoehoe flow, and 34% of the available attributes of slab pahoehoe.

One additional step is required before this technique can be used. In reality, not all the important observations can be made. For example, the base of a lava flow might not be exposed or recovered. Thus a level of confidence in the presence (or absence) of each attribute is required. Table T4 summarizes the values used here: confident detection and nondetection are assigned a value of 1 and –1, respectively, whereas a value of 0.5 or –0.5 is used when the detection or nondetection is questionable (e.g., because of extreme weathering of the core). A value of zero is used when the feature is not observable at all.

T4. Values given each characteristic, p. 25.

The weighting factor of each attribute is multiplied by the confidence in determining the presence (or absence) of that attribute. Note that this scheme provides a positive value when an attribute the lava should not have is determined to be absent. For example, the tentative nondetection of an attribute a flow must not possess results in $-0.5 \times -10 = 5$. These products are summed, then normalized by the maximum possible total, to provide a score (in percent) for that flow being a specific lava type. This entire procedure was incorporated into a spreadsheet program that is available in the volume supplementary material (see the **"Supplementary Materials"** contents list).

Even in this preliminary state, this system is able to adequately distinguish the four different lava types and provides good results when applied to four actual Hawaiian flows (see Tables T5, T6; also see **"Appendix A,"** p. 10). Table T5 shows that the an ideal pahoehoe flow shares significant similarity to a rubbly pahoehoe flow but is clearly distinguished from aa and slab pahoehoe flows. The similarity between pahoehoe and rubbly pahoehoe is primarily because both flow types are commonly inflated. Aa flows share some characteristics with slab pahoehoe flows but are very different from both pahoehoe and rubbly pahoehoe flows. An ideal slab pahoehoe flow is clearly distinguished from both pahoehoe and rubbly pahoehoe but is difficult to distinguish from an aa flow. This is not just because of the shortage of identifying charac-

T5. Discrimination of idealized lava types, p. 26.

T6. Discrimination of actual Hawaiian lava flows, p. 27.

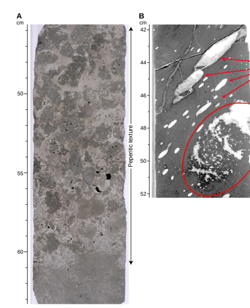
teristics for slab pahoehoe flows; it is also a reflection of the great similarity in the way both lava types form. An ideal rubbly pahoehoe flow is clearly separated from aa flows and is significantly different from pahoehoe. However, the ideal rubbly pahoehoe flow also scores highly as a slab pahoehoe flow. Again, this reflects inherent similarities between rubbly and slab pahoehoe as well as our limited list of characteristics with which to identify slab pahoehoe.

Applying this technique to Hawaiian lava flows shows that this "expert system" does work on real lava flows. Two classic aa flows, a transitional aa flow, and a classic pahoehoe flow are shown in Table **T6** and **"Appendix B,"** p. 11. The aa and pahoehoe flows are unambiguously identified. The transitional lava flow scores high on both the aa and slab pahoehoe categories, accurately reflecting the transitional aa nature of this flow. None of these Hawaiian examples could be confused with rubbly pahoehoe.

Application to Leg 183 Lavas

The detailed observations of all the lava units encountered during Leg 183 are described in Coffin, Frey, Wallace, et al. (1999). These observations were converted into tables, noting the presence or absence of each of the attributes listed in Table **T2** for every unit containing mafic lava flows in Holes 1136A–1139A. These tables are reproduced in **"Appendix C,"** p. 12, **"Appendix D,"** p. 13, **"Appendix E,"** p. 14, and **"Appendix F,"** p. 15. Figure **F2** shows examples of the sections of drill core used to confidently determine the presence of some of the attributes listed in these tables.

F2. Examples of lava attributes as seen in Leg 183 samples, p. 17.



A spreadsheet program uses these tabulated data to compute a score (in percent) for each unit for its similarity to aa, pahoehoe, slab pahoehoe, and rubbly pahoehoe. The unit was confidently interpreted as a given flow type only if it scored above 1 σ (68.26%) and the score was at least 20 percentage points higher than any other lava type. The unit was tentatively identified as a lava flow of a given type if it scored >34% for that lava type and the score was >10 percentage points higher than for any other lava type. The remaining units were considered unclassifiable. However, for half of the unclassifiable units, the allowable flow types were limited by the classification process (i.e., one or more flow types scored much poorer than the rest of the flow types).

The resulting classifications of lava type (including unclassifiable) are largely consistent with those made on board the ship. The discrepancies were reviewed, and in each case, the new interpretations are actually found to be preferable. In particular, the tables in Coffin, Frey, Wallace, et al. (1999) often did not adequately convey the degree of uncertainty in the classification.

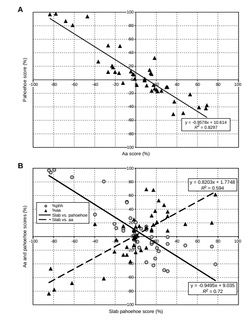
Table **T7** summarizes the results. Overall, 12 of the 42 units (29%) could not be classified. This was the result of poor recovery and/or extreme alteration and weathering of those units. In fact, in many of those cases the original interpretation of those units questioned whether they represented a single lava flow (Coffin, Frey, Wallace, et al., 1999). Of the remaining 30 units, 7% were classified as slab pahoehoe, 13% as aa, 27% as pahoehoe, and 53% as rubbly pahoehoe. Whereas aa and slab pahoehoe flows were confined to Holes 1138A and 1139A, pahoehoe and rubbly pahoehoe flows were found in all four holes. As discussed in Coffin, Frey, Wallace, et al. (1999), these and other observations suggest that Holes 1138A and 1139A penetrated lavas emplaced on steeper slopes closer to the vent than Holes 1136A and 1137A.

T7. Summary of characterization of lava flows drilled, p. 28.

A large enough number of lava flows were sampled during Leg 183 to see some of the relationships between the different lava types. Figure F3 plots the score of different lava types against each other. Figure F3A shows how pahoehoe and aa are very clearly anticorrelated; the best fit line has a large R^2, has a slope close to –1, and passes very close to the origin. This is a striking demonstration of the fact that pahoehoe and aa flows are fundamentally different and that those differences are very well characterized. Figure F3B shows that slab pahoehoe is anticorrelated with pahoehoe and is correlated with aa. However, the best-fit lines do not have as high R^2 as the pahoehoe vs. aa trend. As noted earlier, this is the result of a combination of the inherent similarities between slab pahoehoe flows and aa flows as well as the relatively limited number of identifying characteristics developed for slab pahoehoe flows.

Figure F3C shows a remarkable noncorrelation between rubbly pahoehoe and any of the other lava types. R^2 values range from 0.02 to 0.005. Several conclusions can be drawn from this. First, this noncorrelation is clear confirmation that rubbly pahoehoe is unlike any of the common Hawaiian lava types. Second, it shows that the technique here does clearly distinguish rubbly pahoehoe from other lava types—there are no units that score high as rubbly pahoehoe flows and as another flow type. This is despite the fact that the ideal rubbly pahoehoe flow was similar to an ideal slab pahoehoe (Table T5). Finally, this figure also shows that the characterization of rubbly pahoehoe is incomplete. No lava unit scored less than –10% for rubbly pahoehoe. In other words, the characteristics that define rubbly pahoehoe are well described but the features which rubbly pahoehoe flows lack have yet to be identified. Only after more rubbly pahoehoe flows have been scrutinized will it be possible to make strong statements as to what features are *never* found in rubbly pahoehoe flows.

F3. Leg 183 lava flow classification system results, p. 20.



CONCLUSIONS

Leg 183 provided an exceptional opportunity to examine a wide variety of mafic lava flows in unprecedented detail. This allowed the development and application of a systematic lava flow characterization scheme. Although this technique needs additional work, especially for the identification of slab pahoehoe, it is more than adequate to identify the types of lavas found during Leg 183 and to assign confidence values to the identifications. Whereas about half the lava flows were similar to lava flows found in Hawaii, just over 50% were of a different morphology. This lava type has been named "rubbly pahoehoe" and shares characteristics with both aa and pahoehoe lava flows.

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REFERENCES

Aubele, J.C., Crumpler, L.S., and Elston, W.E., 1988. Vesicle zonation and vertical structure of basalt flows. *J. Volcanol. Geotherm. Res.,* 35:349–374.

Cashman, K.V., and Kauahikaua, J.P., 1997. Reevaluation of vesicle distributions in basaltic lava flows. *Geology,* 25:419–422.

Cashman K.V., Thornber, C.T., Kauahikaua, J.P., 1999. Cooling and crystallization of lava in open channels, and the transition of Pahoehoe lava to a'a. *Bull. Volcanol. (Heidelberg),* 61:306–323.

Coffin, M.F., Frey, F.A., Wallace, P.J., et al., 1999. *Proc. ODP, Init. Repts.,* 183 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station, TX 77845-9547, U.S.A.

Dutton, C.E., 1884. Hawaiian volcanoes, *U.S. Geol. Surv. Annu. Rep.*, 4:75–219.

Hon, K., Kauahikaua, J.P., Denlinger, R., and Mackay, K., 1994. Emplacement and inflation of pahoehoe sheet flows: observations and measurements of active lava flows on Kilauea, Hawaii. *Geol. Soc. Am. Bull.,* 106:351–370.

Keszthelyi, L., 2000. The brecciated lava flows of the Kerguelen Plateau: what are they? *Eos, Trans. Am. Geophys. Union*, 8:S431 (Abstract).

Keszthelyi L., and Denlinger, R.,1996. The initial cooling of pahoehoe flow lobes. *Bull. Volcanol.,* 58:5–18.

Keszthelyi, L., and Thordarson, T., 2000. Rubbly pahoehoe: a previously undescribed but widespread lava type transitional between a'a and pahoehoe. *Geol. Soc. Am. Abstr. Progr.,* 32:7. (Abstract).

Keszthelyi, L., Thordarson, T., and Self, S., 2001. Rubbly pahoehoe: implications for flood basalt eruptions and their atmospheric effects. *Eos, Trans. Am. Geophys. Union,* 82:F1407.

Macdonald, G.A., 1953. Pahoehoe, a'a, and block lava. *Am. J. Sci.,* 251:169–191.

————, 1972. *Volcanoes:* Englewood Cliffs (Prentice-Hall).

Peterson, D.W., and Tilling, R. I., 1980. Transition of basaltic lava from pahoehoe to aa, Kilauea Volcano, Hawaii: field observations and key factors. *J. Volcanol. Geotherm. Res.* 7:271–293.

Rowland, S.K., and Walker, G.P.L., 1987. Toothpaste lava: characteristics and origin of a lava structural type transitional between pahoehoe and aa. *Bull. Volcanol.,* 49:631–641.

————, 1990. Pahoehoe and aa in Hawaii: volumetric flow rate controls the lava structure. *Bull. Volcanol.,* 52:615–628.

Self, S., Keszthelyi, L., and Thordarson, T., 1998. The importance of pahoehoe. *Annu. Rev. Earth Planet. Sci,* 26:81–110.

Swanson, D.A., 1973. Pahoehoe flows from 1969–1971 Mauna Ulu eruption, Kilauea Volcano, Hawaii. *Geol. Soc. Am. Bull.,* 84:615–626.

Thordarson, T., and Self, S., 1998. The Roza Member, Columbia River Basalt Group: a gigantic pahoehoe lava flow field formed by endogenous processes? *J. Geophys. Res.,* 103: 27,411–27,445.

Walker, G.P.L., 1989. Spongy pahoehoe in Hawai'i: a study of vesicle-distribution patterns in basalt and their significance. *Bull. Volcanol.,* 51:199–209.

Wentworth, C.K., and Macdonald, G.A., 1953. *Structures and forms of basaltic rocks in Hawaii.* U.S. Geol. Surv. Bull.

APPENDIX A

Idealized Lava Classification

Unit	phh	aa	slphh	rphh
Characteristic:				
Breccia flow top	–1	1	1	1
Breccia flow base	–1	1	1	0
Spinose aa clinker	–1	1	1	–1
Angular vesicles	–1	1	0	1
Entrained clasts	–1	1	1	1
Core pushing into breccia	0	1	1	1
Slabs in breccia	0	–1	1	1
Welding in basal breccia	0	–1	0	0
Intact pahoehoe lobes in breccia	0	–1	–1	1
Fragmented pahoehoe lobes	0	–1	–1	1
Jigsaw-fit clasts in breccia	0	–1	0	0
Sediment infill in breccia	0	0	0	0
Pseudopeperite texture	0	0	0	0
Pahoehoe flow top	0	0	0	0
Pahoehoe flow base	0	0	0	0
Pahoehoe lobes (intact)	1	–1	0	1
Glassy chill crust	1	–1	1	1
Coherent upper vesicular crust	1	–1	–1	1
Coherent lower vesicular crust	1	–1	–1	1
Round vesicles	1	–1	0	1
HVS	1	0	0	0
%aa	–88.46	100.00	65.38	–26.92
%phh	100.00	–98.46	–90.77	18.46
%slphh	–48.28	24.14	100.00	62.07
%rphh	36.21	–55.17	–46.55	100.00

Note: phh = pahoehoe, slphh = slab pahoehoe, rphh = rubbly pahoehoe.
HVS = horizontal vesicle sheet (Self et al., 1998).

APPENDIX B

Hawaiian Examples

Unit	1	2	3	4
Characteristic:				
Breccia flow top	1	1	1	–1
Breccia flow base	0	1	1	–1
Spinose aa clinker	1	1	1	–1
Angular vesicles	1	1	1	0.5
Entrained clasts	1	1	1	–1
Core pushing into breccia	1	1	1	–1
Slabs in breccia	0.5	–1	–1	–1
Welding in basal breccia	0	–1	–1	–1
Intact pahoehoe lobes in breccia	–1	–1	–1	–1
Fragmented pahoehoe lobes	–1	–1	–1	–1
Jigsaw-fit clasts in breccia	–1	–1	–1	–1
Sediment infill in breccia	–1	0.5	–1	–1
Pseudopeperite texture	–1	–1	–1	–1
Pahoehoe flow top	–1	–1	–1	1
Pahoehoe flow base	–1	–1	–1	1
Pahoehoe lobes (intact)	–1	–1	–1	1
Glassy chill crust	–1	–1	–1	1
Coherent upper vesicular crust	0.5	–1	–1	1
Coherent lower vesicular crust	–1	–1	–1	1
Round vesicles	0.5	–1	–1	1
HVS	–0.5	–1	–1	1
%aa	70.19	100.00	100.00	–77.88
%phh	–58.46	–100.00	–100.00	97.69
%slphh	67.24	24.14	24.14	–79.31
%rphh	–24.14	–55.17	–55.17	16.38

Note: phh = pahoehoe, slphh = slab pahoehoe, rphh = rubbly pahoehoe. HVS = horizontal vesicle sheet (Self et al., 1998).

APPENDIX C

Hole 1136A Lava Classification

Unit	1	2	3
Characteristic:			
Breccia flow top	0	0	1
Breccia flow base	–1	–1	0
Spinose aa clinker	0	0	–0.5
Angular vesicles (outside of segregation features)	–0.5	–0.5	0.5
Entrained clasts	–1	–1	0
Core pushing into breccia	0	0	0
Slabs in breccia	0	0	–0.5
Welding in basal breccia	0	–1	0
Intact pahoehoe lobes in breccia	0	0	–0.5
Fragmented pahoehoe lobes	0	0	0.5
Jigsaw-fit clasts in breccia	0	0	1
Sediment infill in breccia	0	0	1
Pseudopeperite texture	0	0	0.5
Pahoehoe flow top	0	0	–1
Pahoehoe flow base	0.5	0.5	0
Pahoehoe lobes (intact)	0	–0.5	–0.5
Glassy chill crust	0.5	0.5	0.5
Coherent upper vesicular crust	0	0	0
Coherent lower vesicular crust	1	1	0
Round vesicles	1	1	0.5
HVS	1	1	0
%aa	–26.92	–15.38	17.31
%phh	*50.77*	*50.00*	–7.69
%slphh	–8.62	–8.62	17.24
%rphh	17.24	16.38	*34.48*

Notes: phh = pahoehoe, slphh = slab pahoehoe, rphh = rubbly pahoehoe. HVS = horizontal vesicle sheet (Self et al., 1998). Italics = tentative identification.

APPENDIX D

Hole 1137A Lava Classification

Unit	1	2	3	4	7	8	10
Characteristic:							
Breccia flow top	0.5	1	0	–1	1	–1	1
Breccia flow base	–0.5	0	0.5	–1	1	–1	0
Spinose aa clinker	0	–1	0.5	–1	–1	–1	–1
Angular vesicles	–0.5	0.5	0.5	0.5	0.5	0.5	–0.5
Entrained clasts	–0.5	0.5	–1	–1	0.5	–1	0
Core pushing into breccia	0	–1	–0.5	–1	–1	–1	–1
Slabs in breccia	–1	–1	–1	–1	–1	–1	–1
Welding in basal breccia	0	0	–1	–1	–0.5	–1	0
Intact pahoehoe lobes in breccia	0	1	–0.5	–1	–0.5	–1	–0.5
Fragmented pahoehoe lobes	0.5	1	–0.5	–1	1	–1	1
Jigsaw-fit clasts in breccia	0	0.5	–0.5	–1	1	–1	0.5
Sediment infill in breccia	0	–0.5	0.5	–1	1	0.5	1
Pseudopeperite texture	0	–1	–0.5	–1	–0.5	–1	0.5
Pahoehoe flow top	0	–1	0	1	–1	0	–1
Pahoehoe flow base	0.5	0	0.5	1	–1	0	0
Pahoehoe lobes (intact)	0	1	0	1	–0.5	–0.5	–1
Glassy chill crust	1	1	0	1	1	0	–0.5
Coherent upper vesicular crust	0	1	1	1	–0.5	1	0.5
Coherent lower vesicular crust	0	0	1	1	1	1	0
Round vesicles	1	0.5	1	1	0.5	1	0.5
HVS	0.5	0.5	0.5	1	–1	1	1
%aa	–4.81	–26.92	18.27	–77.88	25.00	–47.12	15.38
%phh	12.31	11.54	*32.31*	**97.69**	–16.15	**93.85**	8.46
%slphh	–18.97	–12.07	–39.66	–79.31	–1.72	–82.76	–12.07
%rphh	17.24	**73.28**	14.66	16.38	*59.48*	12.07	*53.45*

Notes: phh = pahoehoe, slphh = slab pahoehoe, rphh = rubbly pahoehoe. HVS = horizontal vesicle sheet (Self et al., 1998). Bold = confident identification, italics = tentative identification.

APPENDIX E

Hole 1138A Lava Classification

Unit	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Characteristic:																				
Breccia flow top	0	1	1	–1	1	1	1	1	0.5	–0.5	1	1	1	0	1	1	1	0	1	1
Breccia flow base	0.5	0	0	–1	0	0.5	0	1	0.5	–1	0.5	1	0	0	0	0	1	–1	0	0
Spinose aa clinker	0	0.5	0	–1	0.5	–0.5	–0.5	0.5	–1	–1	1	0.5	–0.5	0	–1	–0.5	–1	0	–1	–1
Angular vesicles	0.5	1	1	–1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0	0.5	0	–1	–1	0.5	–1
Entrained clasts	0	1	1	–1	1	1	1	1	1	–1	1	1	0.5	0	0	0	0.5	1	1	0.5
Core pushing into breccia	0	0	0	–1	–1	0.5	1	1	–1	–1	1	–0.5	0	0	–1	0	1	0	1	–0.5
Slabs in breccia	0	–0.5	–0.5	–1	–0.5	–0.5	1	–0.5	–1	–1	1	–0.5	0	0	–0.5	–0.5	–1	0	–1	–0.5
Welding in basal breccia	–1	0	0	–1	0	0.5	0	1	0.5	–1	1	1	0	0	0	0	0.5	–1	0	0
Intact pahoehoe lobes in breccia	0	–0.5	–0.5	–1	–0.5	–0.5	–0.5	–0.5	–1	–1	–0.5	–0.5	–0.5	0	–1	–1	–0.5	0	1	1
Fragmented pahoehoe lobes	0.5	–0.5	0	0.5	0.5	–0.5	0.5	1	0.5	–1	1	0.5	0.5	0	1	0.5	1	0	1	1
Jigsaw-fit clasts in breccia	0	–0.5	0	–1	0.5	1	–0.5	1	–1	–1	1	–0.5	0	0	0.5	0.5	–0.5	0	0.5	0.5
Sediment infill in breccia	0	0	0	–1	1	1	0.5	0.5	–1	–1	0.5	–0.5	–0.5	–0.5	–1	–1	0.5	0	–1	–1
Pseudopeperite texture	0	–0.5	0	–1	0.5	–1	0.5	–1	–1	–1	–1	–0.5	–0.5	0	–1	–1	–1	0	–1	–1
Pahoehoe flow top	0	–1	–1	1	–1	–1	–1	–1	0.5	0.5	–1	–1	–1	0	–1	–1	–1	0	–1	–1
Pahoehoe flow base	0	–0.5	0	1	0	–0.5	–0.5	–1	0	1	–1	–1	–1	0	0	0	–1	1	0	0
Pahoehoe lobes (intact)	0	–0.5	0	1	–0.5	–0.5	–0.5	–0.5	1	1	–1	–1	–1	0	–1	–1	0	0	0.5	0.5
Glassy chill crust	0	0	0.5	1	0.5	0.5	0.5	0.5	1	1	0.5	–1	–0.5	0	1	–0.5	1	1	1	0.5
Coherent upper vesicular crust	0.5	–1	0.5	1	0.5	–1	0.5	1	1	1	0.5	0.5	0.5	0	1	0	1	0	0.5	1
Coherent lower vesicular crust	0	0.5	0.5	1	0	0	0	1	1	1	0.5	0.5	0	0.5	0	0	1	1	0	0
Round vesicles	1	0.5	0.5	1	0.5	–1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0	0.5	1	1	1
HVS	0.5	–1	–1	–1	–0.5	–1	0.5	1	–0.5	–1	–1	–0.5	–0.5	–0.5	–0.5	–0.5	–1	0.5	0	–0.5
%aa	8.65	*46.15*	21.15	–83.65	*37.50*	36.54	20.19	52.88	–22.12	–68.27	61.54	**68.27**	29.81	–1.92	13.46	30.77	14.42	–23.08	–12.50	–20.19
%phh	1.54	–49.23	–16.92	**96.92**	–32.31	–50.77	–14.62	–21.54	18.46	**86.92**	–40.77	–42.31	–10.77	7.69	14.62	–10.77	10.00	20.77	–4.62	11.54
%slphh	–1.72	27.59	20.69	–84.48	18.97	31.03	**74.14**	22.41	–20.69	–62.07	*77.59*	17.24	31.03	–1.72	10.34	15.52	0.00	0.00	–1.72	5.17
%rphh	19.83	–6.90	*37.93*	39.66	26.72	0.86	50.86	*65.52*	**71.55**	25.00	39.66	31.90	*42.24*	9.48	*66.38*	29.31	**87.07**	20.69	**68.97**	**71.55**

Notes: phh = pahoehoe, slphh = slab pahoehoe, rphh = rubbly pahoehoe. HVS = horizontal vesicle sheet (Self et al., 1998). Bold = confident identification, italics = tentative identification.

APPENDIX F

Hole 1139A Lava Classification

Unit:	6	7	8	9	10	11	12	13	14	15	16	17
Characteristic:												
Breccia flow top	0	0.5	0	0.5	0	0.5	1	1	1	0	1	1
Breccia flow base	0	0	0	0	–1	0.5	–1	0	1	0	0	0
Spinose aa clinker	0	–0.5	0	0	–1	1	–1	–0.5	–1	0	–1	–0.5
Angular vesicles	–0.5	0.5	0.5	0.5	0.5	1	0.5	0.5	–1	0.5	–0.5	0.5
Entrained clasts	–0.5	0.5	0.5	0	–1	1	1	0.5	1	0	1	0
Core pushing into breccia	0	–0.5	0	0	–1	0.5	–0.5	0.5	–0.5	0	1	0
Slabs in breccia	0	–0.5	0	0	–0.5	–0.5	–1	–0.5	0.5	0	–0.5	0
Welding in basal breccia	0	–0.5	0	0	–1	–0.5	–1	0	1	0	0	0
Intact pahoehoe lobes in breccia	0	–0.5	0	0	–0.5	–1	–1	0	0.5	0	1	0
Fragmented pahoehoe lobes	0	–0.5	0	0	–0.5	–0.5	0.5	0.5	1	0	1	0
Jigsaw-fit clasts in breccia	0	–0.5	0	0	–0.5	–0.5	–0.5	0	–0.5	0	1	0
Sediment infill in breccia	0	0.5	0	0	–0.5	–1	–1	0	0	0	0	0
Pseudopeperite texture	0	0.5	0	0	–0.5	–1	–1	0	–0.5	0	–0.5	0
Pahoehoe flow top	0	–1	0	0	0	–1	–1	–1	–1	0	–1	0
Pahoehoe flow base	0	0	0	0	1	–1	1	0	–1	0	0	0
Pahoehoe lobes (intact)	0	–0.5	0	0	1	–1	1	0	–0.5	0	0.5	0
Glassy chill crust	0	0	0	0	1	–0.5	1	0	1	0	0.5	0
Coherent upper vesicular crust	0	–0.5	0	0.5	1	0.5	0.5	0.5	0.5	0	1	0.5
Coherent lower vesicular crust	0	0	0	0	1	0.5	1	0	0.5	0	0.5	0
Round vesicles	0.5	0.5	0.5	0.5	0.5	–1	0.5	0.5	0.5	1	0.5	0.5
HVS	–0.5	0	0	–0.5	0.5	–1	0.5	–0.5	–0.5	0.5	–0.5	–0.5
%aa	–2.88	15.38	0.96	8.65	–61.54	**69.23**	–36.54	10.58	18.27	–0.96	–16.35	8.65
%phh	8.46	–16.15	–7.69	–0.77	**80.77**	–37.69	26.92	–8.46	–13.08	1.54	10.00	–0.77
%slphh	–1.72	3.45	1.72	15.52	–31.03	10.34	–5.17	15.52	48.28	0.00	10.34	31.03
%rphh	–0.86	–0.86	2.59	18.97	43.10	–2.59	**71.55**	*45.69*	**71.55**	2.59	**83.62**	36.21

Notes: phh = pahoehoe, slphh = slab pahoehoe, rphh = rubbly pahoehoe. HVS = horizontal vesicle sheet (Self et al., 1998). Bold = confident identification, italics = tentative identification.

Figure F1. Controls on the formation of pahoehoe, aa, and transitional lava types, after Peterson and Tilling (1980). Pahoehoe forms when fluid lava is subjected to low strain rates. Aa forms when viscous lava is subjected to high strain rates. Slab pahoehoe is the result of fluid lava subjected to high strain rates, and spiny pahoehoe comes from viscous lava and low strain rates. It is currently unclear where rubbly pahoehoe would plot on this graph.

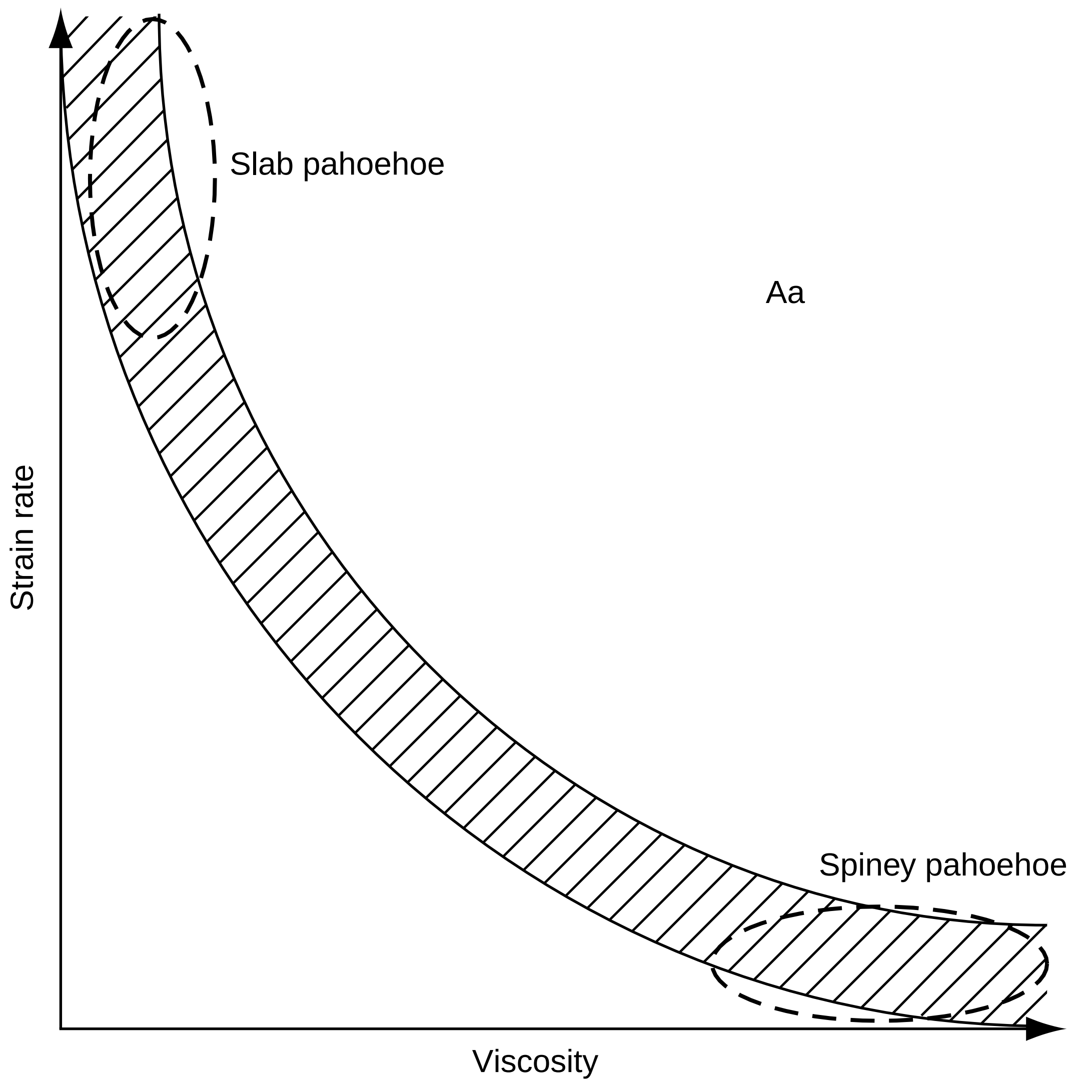


Figure F2. Examples of lava attributes as seen in drill core from Leg 183. **A.** Peperitic texture from Unit 9 (interval 183-1138A-82R-3, 46–63 cm). The lava could have been fragmented by explosive mixing of hot lava with wet sediments to produce this texture, but it is also possible that this is simply the product of a loose volcanic breccia being filled by later sediments percolating down from the surface. **B.** Entrained clasts from Unit 11 (interval 183-1139A-65R-5, 42–52 cm). The margins of this clast have been largely assimilated back into the core of the flow, but the gas that was entrained with the clast has left a distinctive patch of vesicles within the flow. Vesicles in the core of the flow appear to have been deformed around the entrained clast but vesicles within the clast are undeformed. (Continued on next two pages.)

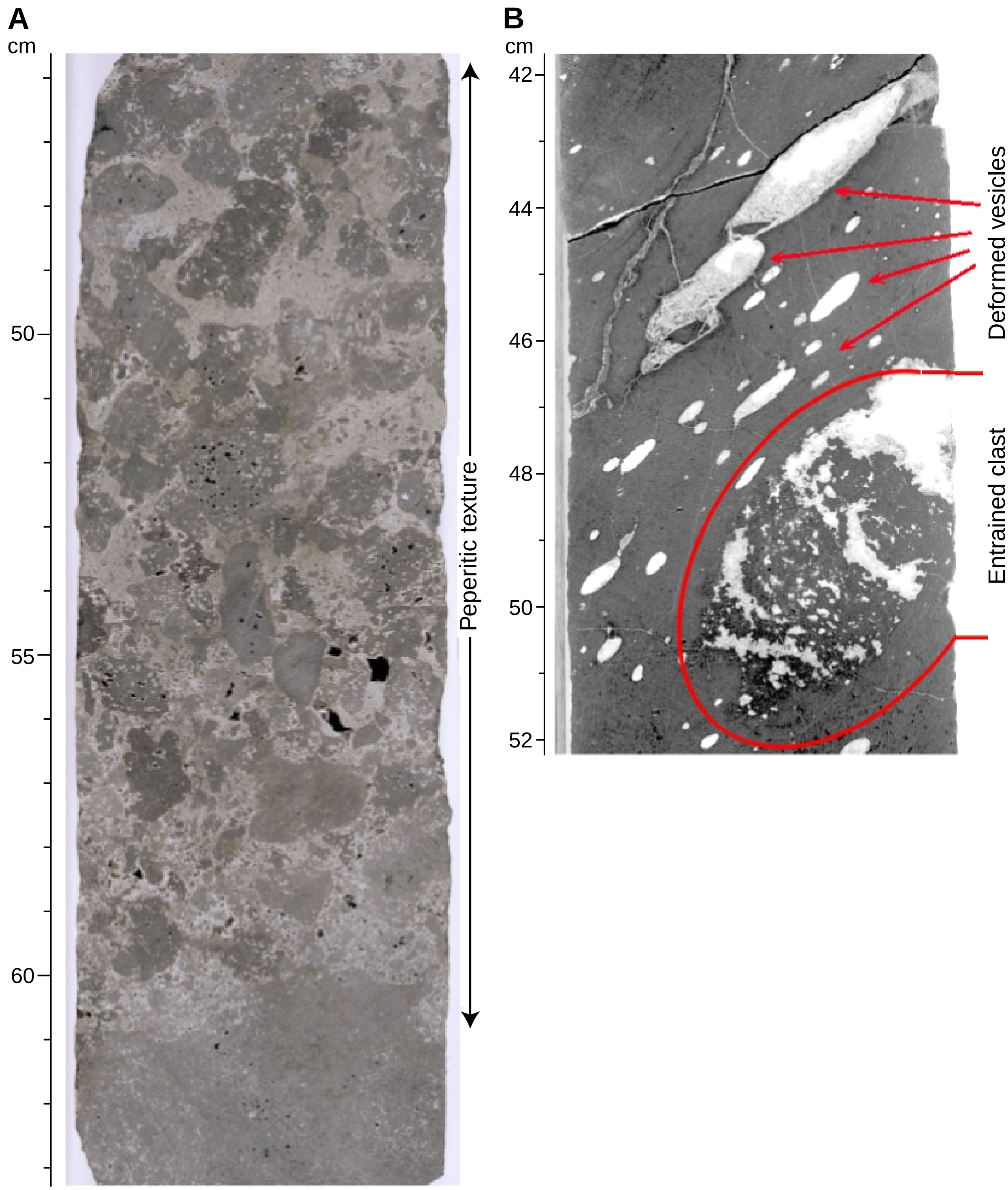


Figure F2 (continued). **C.** Slabs in flow-top breccia from Unit 9 (interval 183-1138A-82R-2, 98–114 cm). Note the ropy chilled glassy margin on one side (arrows) and that the entire clast appears to have been ductily deformed (instead of torn with ragged margins like an aa clast). **D.** Pahoehoe flow top from Unit 4 (interval 183-1137A-29R-2, 69–81 cm). Note the glassy rind on the smooth pahoehoe surface.

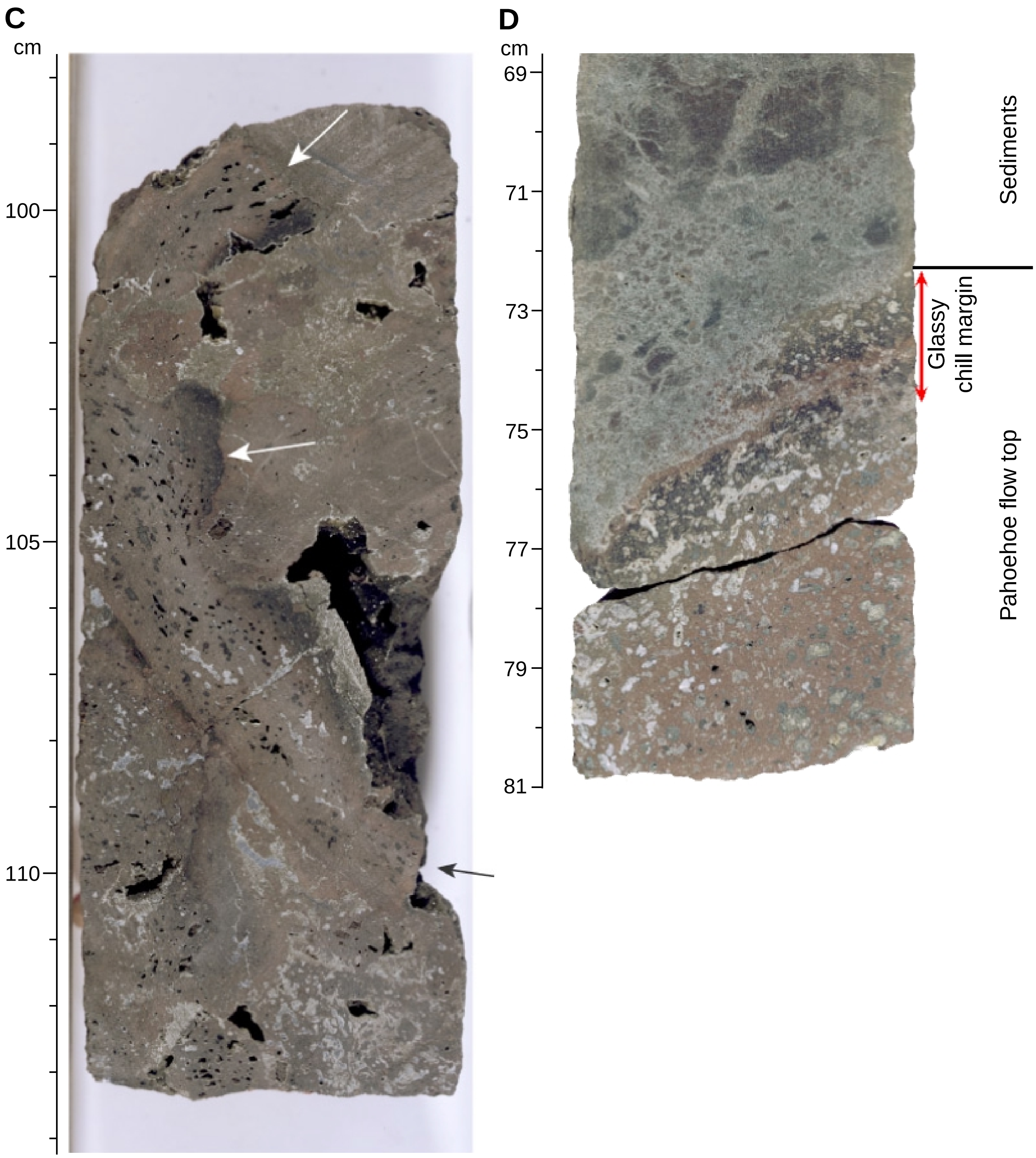


Figure F2 (continued). E. Intact and fragmented pahoehoe lobes in flow-top breccia from Unit 2 (interval 183-1137A-25R-4, 44–91 cm). Note the glassy margins and rounded vesicles diagnostic of pahoehoe lobes on the breccia clasts.

E

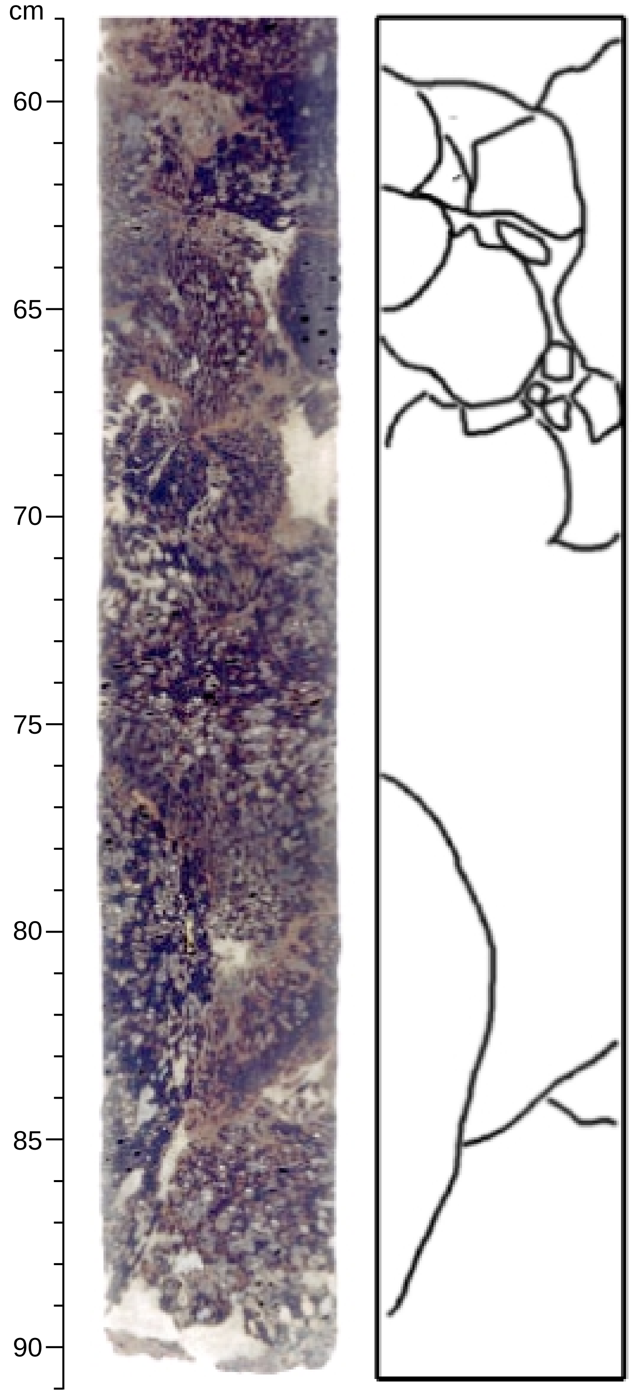
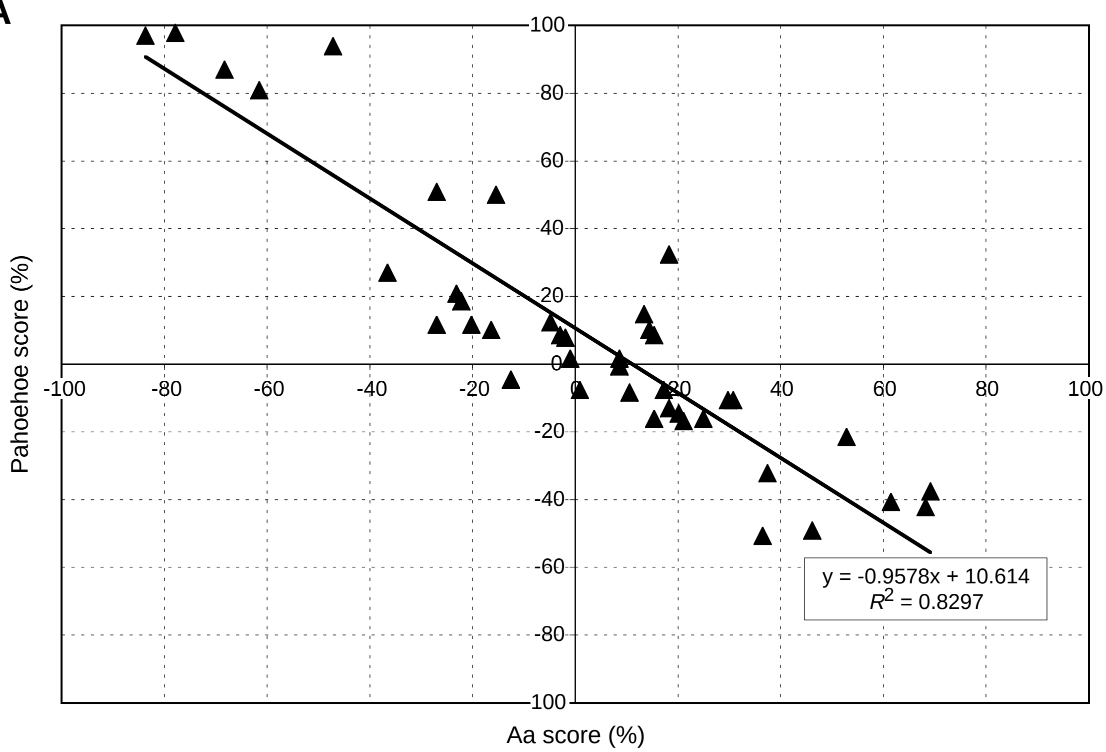


Figure F3. Results from application of the automated flow classification system to Leg 183 subaerial lava flows. **A.** Plot of aa vs. pahoehoe. The excellent anticorrelation demonstrates how clearly aa and pahoehoe are distinguished by this method. **B.** Plot of slab pahoehoe vs. aa and pahoehoe. This shows that slab pahoehoe is very similar to aa and is clearly distinguished from regular pahoehoe. (Continued on next page.)

A



B

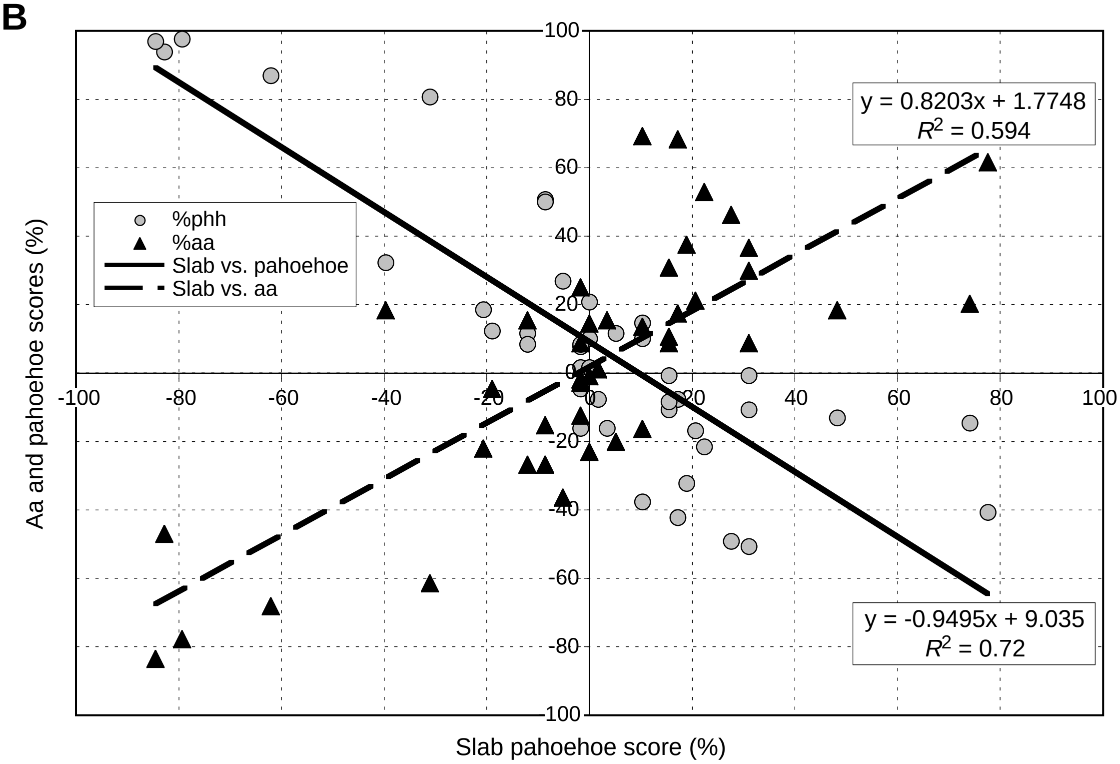


Figure F3 (continued). C. Plot of rubbly pahoehoe vs. other types of lava flows. The complete lack of correlation between rubbly pahoehoe and any of the common Hawaiian lava types indicates that it is an entirely different type of lava flow. slphh = slab pahoehoe, phh = pahoehoe.

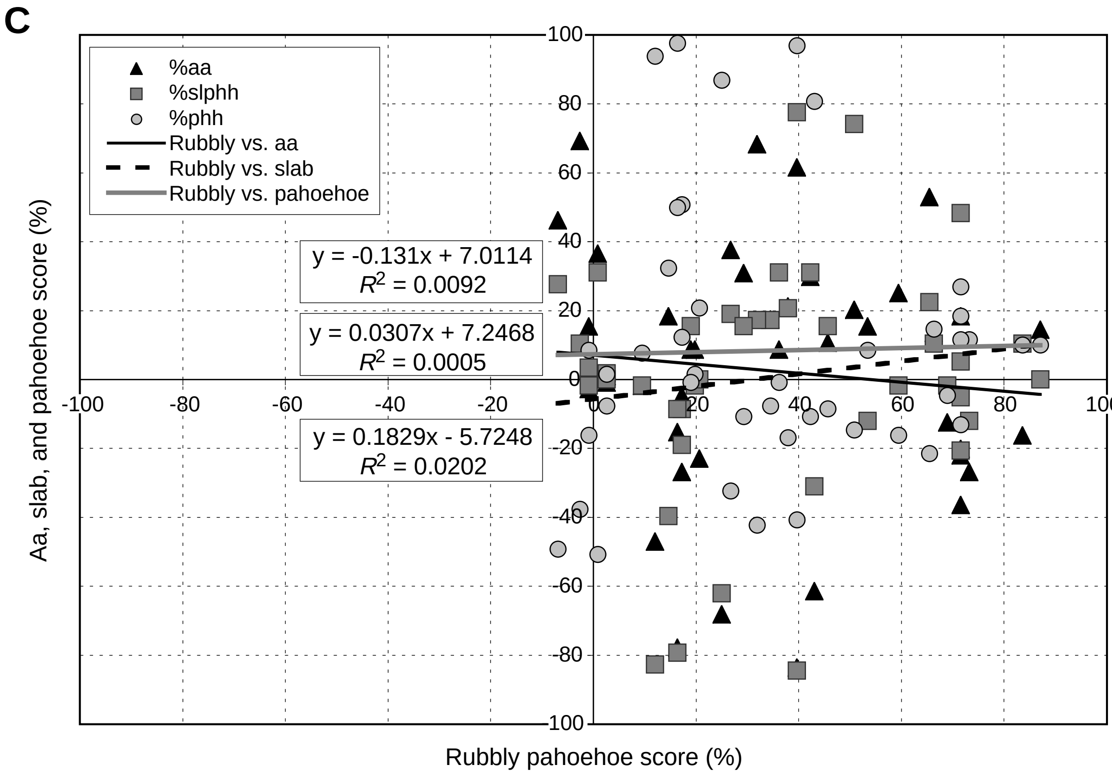


Table T1. Summary of basement units from Holes 1136A–1139A.

Unit	Hole 1136A	Hole 1137A	Hole 1138A	Hole 1139A
1	Tholeiitic basalt	Tholeiitic basalt	Dacite cobbles	Volcaniclastics
2	Tholeiitic basalt	Tholeiitic basalt	Tuffs	Rhyolite
3	Tholeiitic basalt	Tholeiitic basalt	Tholeiitic basalt	Tuff
4		Tholeiitic basalt	Tholeiitic basalt	Rhyolite
5		Sandstone	Tholeiitic basalt	Trachyte
6		Conglomerate	Tholeiitic basalt	Trachybasalt
7		Tholeiitic basalt	Tholeiitic basalt	Basaltic trachyandesite
8		Tholeiitic basalt	Tholeiitic basalt	Trachybasalt
9		Tuff	Tholeiitic basalt	Trachybasalt
10		Tholeiitic basalt	Tholeiitic basalt	Trachybasalt
11			Tholeiitic basalt	Trachybasalt
12			Tholeiitic basalt	Trachybasalt
13			Tholeiitic basalt	Trachybasalt
14			Tholeiitic basalt	Basaltic trachyandesite
15			Tholeiitic basalt	Basaltic trachyandesite
16			Tholeiitic basalt	Basaltic trachyandesite
17			Tholeiitic basalt	Basaltic trachyandesite
18			Tholeiitic basalt	Trachyandesite
19			Tholeiitic basalt	Trachyandesite
20			Tholeiitic basalt	
21			Tholeiitic basalt	
22			Tholeiitic basalt	
Recovery (%):	55	69	48	27

Table T2. Distinguishing macroscopic attributes of pahoehoe, aa, slab pahoehoe, and rubbly pahoehoe.

Lava type	MUST have	Commonly has	Commonly lacks	MUST NOT have
Pahoehoe	Smooth (piece-wise continuous) flow top and base Glassy upper chill crust (0.2–1.5 cm thick) Vesicular upper crust (15%–50% vesicles) Lower vesicular crust (10%–30% vesicles)	0.3- to 80-m flow thicknesses Inflation features (e.g., tumuli) Thick dense core (0%–5% vesicles) Compound flow lobes Internal differentiation features (e.g., vesicle cylinders)	Angular vesicles	Autobrecciation
Aa	Autobrecciated flow top and base Breccia clasts gnarled and spinose Subangular, microcrystalline lava Dense core Angular vesicles	2- to 5-m flow thicknesses Clasts entrained within the core Core pushing into the flow-top breccia 5%–20% vesicularity of clasts and core Minor eolian sediment infill	Round vesicles Inflation features Internal differentiation	Pahoehoe surfaces
Slab pahoehoe	Autobrecciated flow top Slabs of broken pahoehoe surfaces	Aa and pahoehoe clasts in breccia Thin basal breccia		
Rubbly pahoehoe	Autobrecciated flow top Broken and intact pahoehoe lobes Coherent vesicular crust below breccia Lower vesicular crust	Dense core Distorted but rounded vesicles Smooth pahoehoe base	Basal breccia	Aa clasts

Notes: Pahoehoe and aa characteristics from Macdonald (1953). Rubbly pahoehoe characteristics from Keszthelyi et al. (2001).

Table T3. Weights assigned to observable characteristics used to distinguish lava types.

Characteristic	Pahoehoe	Aa	Slab pahoehoe	Rubbly pahoehoe
Autobreccia flow top	–10	10	10	10
Breccia flow base	–10	10	1	0
Spinose aa clinker	–10	10	1	–10
Angular vesicles	–1	1	0	1
Entrained clasts	–10	1	1	1
Core pushing into breccia	0	1	1	1
Slabs in breccia	0	–1	10	1
Welding in basal breccia	0	–1	0	0
Intact pahoehoe lobes in breccia	0	–1	–1	1
Fragmented pahoehoe lobes	0	–1	–1	10
Jigsaw-fit clasts in breccia	0	–1	0	0
Pahoehoe lobes (intact)	1	–10	0	1
Glassy chill crust	1	–1	1	1
Coherent upper vesicular crust	10	–1	–1	10
Coherent lower vesicular crust	10	–1	–1	10
Round vesicles	1	–1	0	1
Horizontal vesicle sheet	1	0	0	0
Maximum possible score	65	52	29	58

Table T4. Values given to each observable characteristic.

Value	Characteristic
1	Confident detection
0.5	Debatable detection or very rare
0	Unable to observe
–0.5	Debatable nondetection
–1	Confident nondetection

Table T5. Discrimination of idealized lava types.

Score	Pahoehoe	Aa	Slab pahoehoe	Rubbly pahoehoe
%pahoehoe	**100.00**	–98.46	–90.77	18.46
%aa	88.46	**100.00**	65.38	–26.92
%slab pahoehoe	–48.28	24.14	**100.00**	62.07
%rubbly pahoehoe	36.21	–55.17	–46.55	**100.00**

Table T6. Discrimination of actual Hawaiian lava flows.

Score	1972 Mauna Ulu Transitional	1972 Mauna Ulu Aa	1907 Mauna Loa Aa	1990 Kupaianaha Pahoehoe
%aa	*70.19*	**100.00**	**100.00**	–77.88
%pahoehoe	–58.46	–100.00	–100.00	**97.69**
%slab pahoehoe	*67.24*	24.14	24.14	–79.31
%rubbly pahoehoe	–24.14	–55.17	–55.17	16.38

Note: Bold = confident lava type identification, italics = tentative lava type identification.

Table T7. Summary of characterization of lava flows drilled on Leg 183.

Unit	Hole 1136A					Hole 1137A					Hole 1138A					Hole 1139A				
		%aa	%phh	%slab	%rbb		%aa	%phh	%slab	%rbb		%aa	%phh	%slab	%rbb		%aa	%phh	%slab	%rbb
1	*phh*	–27	51	–9	17	**unk**	–5	12	–19	17										
2	*phh*	–15	50	–9	16	**rbb**	–27	12	–12	73										
3	*rbb*	17	–8	17	34	*phh*	18	32	–40	15	**unk**	9	2	–2	20					
4						**phh**	–78	98	–79	16	*aa*	46	–49	28	–7					
5											*rbb*	21	–17	21	38					
6											**phh**	–84	97	–84	40	**unk**	–3	9	–2	–1
7						*rbb*	25	–16	–2	59	*aa*	38	–32	19	27	**unk**	15	–16	3	–1
8						**phh**	–47	94	83	12	*unk*	37	–51	31	1	**unk**	1	–8	2	3
9											**slab**	20	–15	74	51	**unk**	9	–1	16	19
10						*rbb*	15	8	12	53	*rbb*	53	–22	22	66	**phh**	–62	81	31	43
11											**rbb**	–22	19	–21	72	**aa**	69	–38	10	–3
12											**phh**	–68	87	–62	25	**rbb**	–37	27	–5	72
13											*slab*	62	–41	78	40	*rbb*	11	–8	16	46
14											**aa**	68	–42	17	32	**rbb**	18	–13	48	72
15											*rbb*	30	–11	31	42	**unk**	–1	2	0	3
16											**unk**	–2	8	–2	9	**rbb**	–16	10	10	84
17											*rbb*	13	15	10	66	*unk*	9	–1	31	36
18											*unk*	31	–11	16	29					
19											**rbb**	14	10	0	87					
20											*unk*	–23	21	0	21					
21											**rbb**	–12	–5	–2	69					
22											**rbb**	–20	12	5	72					

Notes: Scores for each lava type are given in percent, followed by assigned lava type. Bold indicates confident determinations, italics indicate tentative assignments. phh = pahoehoe, rbb = rubbly pahoehoe, unk = unclassifiable. Note that negative values indicate the confidence that the unit is *not* of that lava type. Also note that in several cases even when the exact flow type cannot be identified, some flow types can be excluded. For example, Unit 8, Hole 1138A, may be an aa or slab pahoehoe flow but cannot be a pahoehoe flow.