

# **Major-Element, Sulfur, and Chlorine Compositions of Glasses from the Submarine Flank of Kilauea Volcano, Hawaii, Collected During 1998-2002 Japan Marine Science and Technology Center (JAMSTEC) Cruises**

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## Introduction

From 1998 to 2002, four cruises by Japan Marine Science and Technology Center (JAMSTEC) research vessels explored the submarine flanks of the Hawaiian Islands (Naka and others, 2002; Takahashi and others, 2002). This collaborative Japan-USA research program resulted in new multibeam mapping of the seafloor around Hawai'i (Eakins and others, 2003), and seafloor observation and sample collection during 53 manned submersible and 25 remotely-operated vehicle (ROV) dives. In this report, we present major element, S, and Cl compositions of volcanic glasses collected from the submarine flanks of Kīlauea Volcano during the JAMSTEC research program. The compositions were determined by electron probe microanalysis (EPMA) at the USGS in Menlo Park, California.

The submarine portion of Kīlauea, Hawai'i's most active volcano, was a main target during the JAMSTEC program (Figure 1), with 15 manned submersible dives and seven ROV dives. Dive observations revealed that much of the volcano's south flank, manifested as the midslope bench, consists of volcanoclastic debris, shed from the volcano as turbidites and debris flows (Lipman and others, 2002). Debris exposed in the outer scarp of the midslope bench spans a large compositional range and records the pre-shield, alkalic phase for this volcano (Lipman and others, 2002; Sisson and others, 2002). Coarser debris (breccia clasts) is almost certainly from Kīlauea, as are most alkalic sands. For low-S, tholeiitic sand grains, the source volcanoes are probably Mauna Loa and perhaps Mauna Kea (Lipman and others, 2002; Sisson and others, 2002).

Dives on the upper slope of Kīlauea's south flank and along Puna Ridge, the submarine extension of the volcano's east rift zone, encountered in-place tholeiitic, transitional, and mildly alkalic pillow lavas of the primary volcanic edifice (Johnson and others, 2002; Lipman and others, 2002; Sisson and others, 2002). All sampled pillow lavas are unequivocally from Kīlauea.

In addition to the outer scarp of the midslope bench and the primary volcanic edifice, JAMSTEC dives sampled several other surrounding features (Figure 1). Punalu'u slump clasts are likely derived from Mauna Loa Volcano (Lipman and others, 2002). A ridge southeast of Lo'ihi Seamount probably contains material from Lo'ihi and other sources. Breccia clast rinds from Papa'u Seamount are likely derived from Mauna Loa

Volcano (Kimura and others, 2002). Supra-bench breccias contain material from Kīlauea, Mauna Loa and maybe Mauna Kea (Coombs and others, 2004).

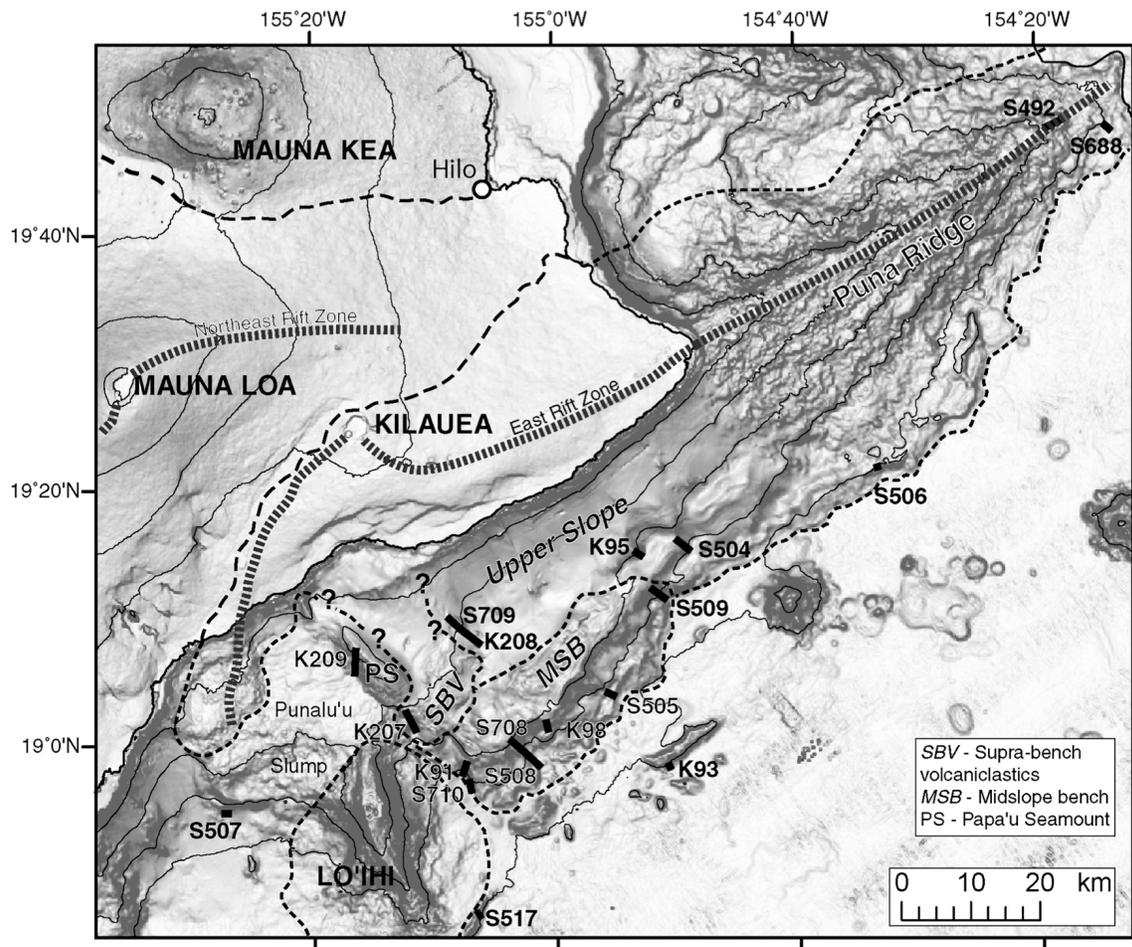


Figure 1. Shaded slope map of southern Hawai'i Island and surrounding sea floor. Shoreline, solid bold black line; 1000 m contours, thin black lines. Subaerial volcano boundaries and rift zones adapted from Wolfe and Morris (1996). Dive sites, thick black lines: *Shinkai 6500* (S-prefix), *Kaiko* (K-prefix). South flank domains include the upper slope, midslope bench, and supra-bench volcaniclastics.

Dives were conducted by two JAMSTEC vehicles: the ROV *Kaiko* in 1998 and 2001, and the manned submersible *Shinkai 6500* in 1999 and 2002. The vehicles are operated from the R/Vs *Kairei* and *Yokosuka*, respectively. Both vehicles have depth limits well beyond the depths encountered around Hawaii and thus provided the first access to the deepest portions of Kīlauea and other areas. Regardless of the vehicle, efforts were made to sample rocks directly from outcrop when possible, although some talus was collected where outcrops were not available. Kīlauea-area dive details, including exact location,

depth, and outcrop descriptions for 1998 and 1999 dives are presented in Lipman and others (2002).

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## **Analytical Techniques**

The glass data in this report include four main sample types: glassy rinds of in-place pillow lavas, glass rinds on clasts from debris-flow breccias, glass sand grains adhered to breccia clasts, and glass grains from lithified volcanoclastic sandstones (hyaloclastite). Reported glass compositions are the averages of 10-15 spot analyses for pillow and breccia clast rinds, and three spot analyses for sand grains; background intensities were determined 1-3 times for each grain.

Analyses were conducted using wavelength dispersive techniques with a 5-spectrometer JEOL 8900R electron microprobe at the USGS in Menlo Park, California. All analyses used a 20  $\mu\text{m}$  diameter beam with 25 nA current and 15 kV accelerating potential. Count times were 15-20 seconds for Na, which was analyzed first to reduce Na-loss, 40 seconds for most elements, and 40-80 seconds for S and Cl. Concentrations were determined with the CIT-ZAF reduction scheme (Armstrong, 1995). During analysis, sets of 5-10 replicate analyses of USNM glass standards VG2 and A99 (Jarosewich and others, 1979) were performed to monitor instrument drift.

Natural glass and mineral standards were used for calibration: glass A99 for Si; glass VG2 for Na, Mg, Fe, Al, and Ca;  $\text{Mn}_2\text{O}_3$  for Mn;  $\text{TiO}_2$  for Ti; glass GSC for K; Sodalite for Cl; Wilberforce apatite for P; and Barite for S. These are the same standards used for several studies of Hawaiian basaltic glasses (for example, Clague and others, 1995; Thornber and others, 2002), with the exception of Si, for which VG2 has typically been used. During the course of this study, however, we recognized that using VG2

produces SiO<sub>2</sub> values for other glass working standards (A99, JB-2) that are generally high by several tenths of a weight percent. This prompted us to retroactively adjust our older glass analyses to correct for this deficiency. This was done by multiplying original SiO<sub>2</sub> values for unknowns by 0.991 (average *analyzed* A99 SiO<sub>2</sub> value divided by *accepted* A99 SiO<sub>2</sub> value). Relative precision, as estimated from averages and standard deviations of repeated analyses of A-99 and VG-2, is ~0.5 % for SiO<sub>2</sub>, <2 % for Al<sub>2</sub>O<sub>3</sub>, FeO, MgO, and CaO, <5 % for TiO<sub>2</sub>, Na<sub>2</sub>O, and K<sub>2</sub>O, and <10 % for MnO and P<sub>2</sub>O<sub>5</sub>. Relative precision for S is <10 % for higher abundances (as represented by VG2; 1200 ppm), but ~30% for lower S concentrations (A99, 100 ppm S). Relative precision for Cl is less than ~20% for measured standards. We have reported values of <100 ppm for both elements, but the detection limit for both may be around this value (Thorner et al., 2002). Published values for these standards are generally within one standard deviation of our analyzed values (except SiO<sub>2</sub> for A99, as discussed above). Standard deviations of averages of multiple spot analyses for single unknown samples are generally within those listed above for working standards.

Some of the data presented here were previously published (Coombs and others, 2004; Sisson, 2003; Sisson and others, 2002). For sample compositions presented in Sisson et al. (2002), we have adjusted the SiO<sub>2</sub> values to be consistent with the new A99 standardization; this results in slight differences in SiO<sub>2</sub> values and totals for the two datasets.

## **Explanation of the Data File**

The data are presented in an Excel workbook format. The first worksheet contains average standard compositions, as analyzed during the course of this study (1998-2003). Following is a series of eight worksheets that contain the glass data. These are organized geographically, generally from the southwest to the northeast. Each glass data worksheet is organized in the same fashion. The sample number prefix (for example, "S506-") indicates the dive during which each sample was collected. Prefixes beginning with an S indicate *Shinkai* dives, prefixes beginning with a K indicate *Kaiko* dives. The number immediately following the S or K shows the dive number. The prefix is followed by the sample number. For rock samples that contain many glass grains (such as the indurated sandstones), the sample number is then followed by a number (usually 1-25 for each sandstone sample; 50 grains were analyzed for particularly diverse sandstones) indicating the individual glass

grains analyzed within each sandstone. Oxides are presented in weight percent, and Cl and S are presented in parts per million (ppm).

The last worksheet, "sample locations," lists the dives in chronological order, and gives latitude and longitude (in decimal degrees) and collection depth (in meters below sea level) for each sample location. Also shown for each sample are rock type, location description, and the best estimate for whether a sample was collected from outcrop or talus.

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