



# Characteristics of Hawaiian Volcanoes

Professional Paper 1801

U.S. Department of the Interior  
U.S. Geological Survey



Halema'uma'u lava lake and Kilauea Caldera, with a snowcapped Mauna Loa in the background. Untitled painting by D. Howard Hitchcock, 1894. Image courtesy of the National Park Service, Hawai'i Volcanoes National Park, HAVO catalog number 452.

#### COVER

Summit eruptive vent of Kilauea Volcano and the southwest flank of Mauna Loa, as seen from Waldron Ledge. The small cluster of lights on the right side of the image is the Hawaiian Volcano Observatory and the Jaggar Museum. USGS photograph by M.P. Poland, February 4, 2011.

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Michael P. Poland, Taeko Jane Takahashi, and Claire M. Landowski, editors

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**U.S. Geological Survey**  
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## Foreword

The Hawaiian Islands and their volcanoes have featured prominently in the history of the United States Geological Survey (USGS) nearly back to the 1879 founding of the organization. In 1882, USGS Director John Wesley Powell sent Captain Clarence E. Dutton, an officer in the United States Army who was detailed to the USGS, to Hawai'i—then still an independent kingdom—to study its volcanic geology in preparation for mapping in the Cascade Range. Dutton was an inspired choice for the assignment. He was already well known for his explorations in the western United States, thanks in large part to his vivid written accounts of the Grand Canyon region, and his observations of the volcanoes, land, and people of Hawai'i after 4 months of field work (published as part of the “4th Annual Report of the U.S. Geological Survey” in 1884) are no less engaging. Dutton’s experience in Hawai'i was a great aid to his subsequent assignment as the head of the USGS Division of Volcanic Geology, which mapped volcanoes throughout California, Oregon, Washington, Utah, Arizona, and New Mexico.

USGS work in Hawai'i subsequently shifted toward water resources, especially as related to agricultural development. In 1909, USGS geologist Walter Mendenhall toured the islands and established a framework for systematic observations that were eventually assumed by what had become the Territory of Hawaii. In 1919, the Territory requested a comprehensive assessment of the geology and water resources of the entire island chain. One of the main participants in this work was USGS geologist Harold T. Stearns. Over the ensuing 30 years, Stearns published 12 comprehensive reports (Hawaii Division of Hydrography Bulletins) covering the characteristics of every major Hawaiian island (except Kauai, which was covered in 1960 in volume 13 by another longtime USGS geologist, Gordon Macdonald). The work of Stearns and his colleagues has stood the test of time and is still an important resource for geologists working throughout the State.

In 1924, the USGS took over operation of the Hawaiian Volcano Observatory (HVO), renewing its commitment to the study of Hawaiian geology. Founded in 1912 at the edge of the caldera of Kīlauea Volcano, HVO was the vision of Thomas A. Jaggar, Jr., a geologist from the Massachusetts Institute of Technology, whose studies of natural disasters around the world had convinced him that systematic, continuous observations of seismic and volcanic activity were needed to better understand—and potentially predict—earthquakes and volcanic eruptions. Jaggar summarized the aim of HVO by stating that “the work should be humanitarian” and have the goals of developing “prediction and methods of protecting life and property on the basis of sound scientific achievement.” These goals align well with those of the USGS, whose mission is to serve the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage natural resources; and enhance and protect our quality of life. In fact, Jaggar and the USGS expanded volcano monitoring in the 1920s, establishing an observatory at Lassen Peak, California, and a seismic monitoring station at Dutch Harbor, Alaska. These efforts and a planned expansion of nationwide volcano monitoring, with HVO at its hub, were derailed by the Great Depression and World War II, and the National Park Service took over operation of HVO during 1935–47. The USGS returned to administer HVO in 1947, continuing to oversee the observatory’s evolution from humble beginnings as a largely one-person operation into a world-class laboratory for volcano and earthquake research and a critical facility for natural hazards assessment and mitigation in Hawai'i.

In 2012, HVO celebrated the centennial of its founding. In the more than 100 years since Jaggard began making systematic observations of Hawaiian volcanism, HVO has been responsible for numerous innovations and scientific insights into natural hazards and Earth processes. For example, in the 1920s and 1930s, HVO scientists made the first forecasts of tsunami arrival times from distant earthquakes. The development of modern seismic networks was started, in large part, by the work of HVO scientist Jerry P. Eaton during the 1950s. HVO has also served as a training ground for volcanologists from the United States and around the world, following the example of Dutton's visit to Hawai'i as a means of preparing him for mapping volcanoes elsewhere in the country. As awareness of volcanic hazards in the United States grew—especially following the reawakening and eruption of Mount St. Helens in 1980—four new observatories were established to monitor volcanic activity in Alaska, California, Yellowstone, and the Cascade Range of Washington and Oregon. HVO's legacy as a training ground for volcanologists continues even to this day, with the observatory participating in the development of scientists from other countries as part of an international volcano-monitoring education program run by the Center for the Study of Active Volcanoes (a cooperative effort of HVO, the University of Hawai'i at Hilo, and the University of Hawai'i at Mānoa and founded by former HVO Scientist-in-Charge Robert Decker).

The legacy of USGS scientists in Hawai'i goes far beyond scientific accomplishments. In fact, USGS employees who spent time in Hawai'i have helped to shape the organization on a national level, and many have gone on to assume high-level positions within the USGS. This long history of symbiosis has been mutually beneficial—studies of Hawai'i and its volcanoes have had a strong impact on the direction of USGS science, and USGS practices have shaped HVO's evolution into the international center it is today.

The chapters in this volume were written by scientists with strong ties to the USGS, including many who spent portions of their careers at HVO studying how Hawaiian volcanoes work. "Characteristics of Hawaiian Volcanoes" establishes a benchmark for the current understanding of volcanism in Hawai'i, and the articles herein build upon the elegant and pioneering work of Dutton, Jaggard, Stearns, and many other USGS and academic scientists. Each chapter synthesizes the lessons learned about a specific aspect of volcanism in Hawai'i, based largely on continuous observation of eruptive activity (like that occurring now at Kīlauea Volcano) and on systematic research into volcanic and earthquake processes during HVO's first 100 years. Researchers and students interested in basaltic volcanism should find the volume to be a valuable starting point for future investigations of Hawaiian volcanoes and an important reference for decades to come, as well as an informative and entertaining read.

Suzette M. Kimball  
**Acting Director**  
**U.S. Geological Survey**

## Preface

“The history of these volcanoes is such as has been supplied by no other volcanic region”

“The records of such a region, whoever the reporter, are of great importance to science”

—*James Dwight Dana, 1890*

The Hawaiian Islands have long been recognized as an exceptional natural laboratory for volcanology. Indeed, American geologist James Dana emphasized as much with the words quoted above from his 1890 treatise on volcanology, “Characteristics of Volcanoes.” Dana visited the Hawaiian Islands twice, in 1840 and 1887, and in the interim was kept apprised of the activity at Kīlauea and Mauna Loa through letters from local observers, such as Reverend Titus Coan (whose interpretations Dana famously, and sometimes erroneously, questioned in the pages of the *American Journal of Science*). In fact, having seen volcanoes around the world (especially those in Italy, which were at the time the focus of the volcanological community), Dana states with authority that “the two active craters of Hawaii [Kīlauea and Mauna Loa] should share equally with Vesuvius and Etna in the attention of investigators.” Much of Dana’s book is dedicated to describing Hawaiian volcanoes, and in the preface he provides a surprisingly long list of volcano “facts” that were determined from investigations in Hawai‘i rather than at other volcanoes. He also laid out a number of “points requiring elucidation,” which are listed in table 1 of the first chapter of this volume (by Tilling and others). “The geologist who is capable of investigating these subjects,” Dana writes, “will find other inquiries rising as his work goes forward.”

Looking back at the first century of the Hawaiian Volcano Observatory (HVO), it is difficult to dispute Dana’s wisdom. Many of the issues he cited have since been thoroughly explored, and the answers are now well known. For example, “the temperature of the liquid lava” and “the kinds of vapors or gases escaping from the vents or lakes” (two of Dana’s “points”) were some of the first problems addressed by Frank A. Perret, Thomas A. Jaggar, and their colleagues when HVO was established during 1911–12. Some of Dana’s questions, however, are still just as relevant today as they were in 1890. The “differences between the lavas of the five Hawaiian volcanoes,” and “the movement of the lavas in the great lava-columns, and the source or sources of the ascensive movement” remain compelling issues for modern volcanologists studying Hawai‘i.

In the current volume, “Characteristics of Hawaiian Volcanoes,” we describe the present state of the art in understanding how Hawaiian volcanoes work, building on Dana’s initial comprehensive examinations of volcanism in Hawai‘i and the studies of many others that have followed. As was true in Dana’s time, “much remains to be learned from the further study of the Hawaiian volcanoes.” Today, for example, major problems include:

- The composition (including volatiles) and depth of the magma source region and its variability over space and time
- The mechanism for distribution of magma among individual active volcanoes
- The connectivity or communication between adjacent volcanoes
- The characteristics of magma supply to individual volcanoes over time
- The compositional evolution and volume history of individual volcanoes over time, including the source and mechanism of rejuvenated-stage volcanism
- The inception and initial evolution (both structural and compositional) of Hawaiian volcanoes, especially with regard to the still-submerged Lō‘ihi

- The cause of the paired Loa and Kea compositional trends
- The geometries and volumes of the magma plumbing systems at Kīlauea and Mauna Loa
- The mechanisms for volcanic flank instability, and the forecasting of huge landslides
- The causes of great earthquakes and the interactions between tectonic and magmatic activity
- The causes of both eruption onset and eruption termination
- The physics of lava flows, especially with regard to forecasting flow behavior
- The influence of bubble nucleation and coalescence, and of degassing and eventual outgassing, on magma convection and eruption style
- The characteristics of three-phase (liquid magma, exsolved gas, and crystals) fluid flow, and the manifestations of such flow in geophysical and geochemical time series
- The mechanisms of explosive basaltic eruptions (including the importance of magma-water interactions), caldera collapse, and possible cyclicity in explosive and effusive behavior
- The quantification of diverse hazards associated with Hawaiian volcanoes, and the best methods for communicating these hazards with the public

Many of these questions are relevant far beyond the confines of the Hawaiian Islands. For example, dual compositional trends, like the “Loa Range” and “Kea Range” recognized by Dana, are apparent at several Pacific hotspot chains, and the question of how (or if) adjacent, closely spaced volcanoes are connected and interact is relevant around the world. As the Hawaiian Volcano Observatory enters its second century, continued research making use of Hawai‘i as a natural laboratory for volcanology promises insights that will not just contribute to local knowledge, but advance the field as a whole.

The 10 chapters that make up this volume treat in detail various aspects of Hawaiian volcanism, from the evolution of the volcanoes that make up the island chain to the dynamics of effusive and explosive eruptions. This book is not intended to supersede “Volcanism in Hawaii”—the magnificent 62-chapter dual-volume USGS Professional Paper 1350, which was produced in conjunction with HVO’s 75th anniversary in 1987. Instead, “Characteristics of Hawaiian Volcanoes” provides new perspectives on important aspects of basaltic volcanism by synthesizing past studies with insights from recent data and modeling, with the ultimate goal of developing new models of basaltic volcanism in Hawai‘i and elsewhere. Our hope is that these contributions will update the foundation of understanding for Hawaiian volcanism, serving as a starting point for researchers as well as providing ideas and stimuli for new avenues of scientific investigation.

Hawai‘i offers an unparalleled opportunity for students of volcanology to study a vast range of problems and processes, and the first 100 years of the Hawaiian Volcano Observatory have been an exceptional period of investigation, discovery, and understanding. The outstanding eruptive and intrusive activity at multiple volcanoes, long record of volcanism, and relatively easy access will ensure that Hawai‘i remains one of the world’s foremost volcano laboratories for the next 100 years and beyond. In Dana’s words, “There is terrible sublimity in the quiet work of the mighty forces, and also something alluring in the free ticket offered to all comers.”

Michael Poland  
July 28, 2014  
Hawai‘i Volcanoes National Park, Hawai‘i

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The Hawaiian Volcano Observatory Technology Station (left) and Instrument House (center) at the rim of Halema'uma'u Crater in 1913. USGS photograph, July 6, 1913 (photographer unknown).