The significance of observations at active volcanoes: A review and annotated bibliography of studies at Kilauea and Mount St. Helens

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Abstract—Study of active volcanoes yields information of much broader significance than to only the discipline of volcanology. Some applications are 1) interpretation of lava-flow structures, stratigraphic complexities, and petrologic relations in older volcanic units; 2) interpretation of bulk properties of the mantle and constraints on partial melting and deep magma transport; 3) interpretation of geophysical characteristics of potentially active volcanic systems; 4) direct determination of physical properties of molten and solidified basalt, and of intensive variables (e.g., oxygen fugacity and temperature) accompanying cooling and crystallization; 5) quantitative assessment of crystal fractionation and magma mixing, 6) tests of theoretical and experimental geochemical, geophysical, and rheologic models of volcanic behavior; and 7) confirmation in nature of laboratory experiments related to crystallization in igneous systems.

The critical factors that make real-time study of volcanic activity valuable are that the location and timing of events are known, and that molten rock and gases are available for direct observation and sampling for subsequent study. Observations made over a period of time make it possible to calculate rates of magma transport, storage, and crystallization, as well as to quantitatively determine elastic and inelastic deformation and the build up and decay of stress within the active volcanic system.

Discussion of these topics is keyed to an annotated bibliography from which quantitative information on properties and processes may be obtained. Emphasis is on Hawaii’s active basaltic volcanoes for which the most information is available. Additional references are made to research at Mount St. Helens, one of the first real-time studies of an active volcano of dacitic composition.

INTRODUCTION

SCIENTISTS have long been attracted by active volcanoes and have made observations and measurements that have increased our understanding of how volcanic systems behave. Much of this information has been published in the volcanologic literature and disseminated within the small community of volcanologists. The thesis of this paper is that study of active volcanoes provides important constraints on geological processes to disciplines as diverse as geology, seismology, geochemistry, experimental petrology, and rock mechanics.

Continuous monitoring of volcanoes enables quantitative measurement of the rates at which certain volcanic processes take place (5a, b). Such processes range from accumulation and release of strain in rocks to rates of magma transport and their effect on igneous differentiation. We discuss these applications below, beginning with surface observations and progressing to inferences regarding deeper processes. The text is supported by an annotated bibliography for Kilauea with additional references to recent work at Mount St. Helens. We have not attempted to cover studies of other active volcanoes. For Kilauea the reference list includes 1) review articles which themselves contain useful bibliographic coverage, 2) papers that contain quantitative determinations of physical parameters or quantitative demonstrations of specific volcanic processes, and 3) the most recent articles. A primary reference for recent research at Kilauea is U.S. Geological Survey Professional Paper 1350, published on the occasion of the 75th anniversary of the founding of the Hawaiian Volcano Observatory in January of 1987 (4a01). A primary reference for the catastrophic events at Mount St. Helens in 1980 is U.S. Geological Survey Professional Paper 1250 (4a02).

OBSERVATION OF ERUPTIONS

Observation of volcanic eruptions is a key to understanding the origin of volcanic units preserved in the geologic record. A useful distinction here is between catastrophic and milder volcanic events. For catastrophic eruptions (e.g., Crater Lake, the
Bishop tuff, or flood basalts of the Columbia Plateau a nearly complete record of eruption may be preserved in the deposits themselves. Observations of explosive eruptions such as that of Mount St. Helens in 1980 are difficult to make but serve to limit the time frame in which various kinds of deposits—such as surges, pyroclastic flows, and airfall ejecta—are formed (4a02). Eruptions at Kilauea, in contrast, leave a very confused stratigraphic record that is virtually impossible to decipher after the fact (3a01–04; 3b05, 06). Continuous monitoring of eruptions as they take place is the best means of specifying what constitutes a single eruption, or of determining the sequence of events that accompany construction of a large volcanic edifice or lava field that may be preserved in the geologic record. One application of real-time observation of volcanic activity to older rocks involves the origin of thin, dense, streaky layers of basalt exposed locally on the Columbia Plateau. They were identified as collapsed pahoehoe from their similarity to layers that were observed to form during the Mauna Ulu eruption of Kilauea (see Figure 4 in 3b05). The occurrence of collapsed pahoehoe on the Columbia Plateau was then used as evidence for the proximity of source vents. Another example is how observed formation of the debris avalanche at Mount St. Helens on May 18, 1980, elucidated the process and enabled proper reconstruction of similar past events at many volcanoes in the world (6a01).

Volcanic eruptions are also a laboratory for studying the complex behavior of natural silicate melts, consisting of liquid, one or more crystalline phases, and a volatile phase. Laboratory simulations and theoretical study of fountain dynamics and flowing lava can be tested by direct observation. Field observation of the transition from pahoehoe to a’a (3b04) can likewise be used to constrain theoretical or experimental derivation of the rheologic properties of basalt. Finally, deuteric alteration and weathering may be quantified by study of lavas of known age (3a06; last paragraph of following section.)

KILAUEA LAVA LAKES

In contrast to study of eruption dynamics and flowing lava, the filling of circular pit craters at Kilauea by basaltic lava created natural crucibles for study, by core drilling, of the cooling and crystallization of basaltic magma at low pressure and under static conditions (1a–1d). The rates of cooling and crystallization of basaltic magma have been measured, and direct measurements have been made of properties such as density, viscosity, and oxygen fugacity at different stages in the cooling history (1c01b, 1d02, 1d03). These observations combined with estimates of primary volatile contents (2d) can be used in the laboratory to simulate real conditions in basaltic systems under study by experimental petrologists. It is encouraging that the pioneering experimental work of N. L. Bowen, H. S. Yoder, C. E. Tilley, and others at the Geophysical Laboratory on crystallization and differentiation of basaltic magma has found solid confirmation in the observations made on the natural lava lakes (see, for example the temperatures of crystallization of different phases in Kilauea Iki lava lake presented in 1b09).

Several processes of crystal-liquid fractionation have been observed in the lava lakes, and the chemistry of a liquid line of descent has been directly specified. The question of whether high-SiO$_2$ rhyolite can be derived from a crystallizing basalt is answered affirmatively (1b01). Residual glass of rhyolitic composition is present in Alae and Makaopuhi, comprising 6 per cent by weight of the starting basalt. In the larger Kilauea Iki lava lake, liquids of rhyolitic composition were segregated and entered fractures; deep in the lake, however, slower cooling resulted in complete crystallization with no residual glass remaining. Thus we have placed quantitative limits on the possibility of deriving rhyolite from a basaltic liquid that should lead to better understanding of the rhyolite-basalt association in large volcanic fields.

Study of Alae and Makaopuhi revealed differentiation processes that could be directly applied to the origin of differentiated liquids erupted from Kilauea’s rift zones. The deeper and more olivine-rich lake, Kilauea Iki, underwent different differentiation processes, including diapiric transfer of one melt through another without appreciable mixing (1b01, 02), that can be applied to the origin of chemical and mineralogical layering in shallow mafic intrusions.

Another significant benefit from lava lake studies is the geophysical determination of the relative proportions of liquid and solid. Geoelectrical measurements made in Kilauea Iki (1b06) generally agreed with the petrologists’ definition of “melt” and “crust” (see 1a01; 1b01). Seismic measurements generally underestimated the amount of “melt,” presumably due to differences between the seismic attenuation of shear waves expected for passage through a single phase liquid and those observed for a liquid which contained a large population of suspended olivine crystals (1b07). These results have important implications with regard to...
geophysical prospecting for magma, either deep (e.g., hot dry rock) or shallow (e.g., beneath active geothermal systems).

The lava lakes give data on the initial oxidation state of basaltic magma and on the effects of deuteric oxidation during cooling. Minimum weight-percent ratios of ferric to ferrous iron are about 0.12, in equilibrium with directly measured oxygen fugacities slightly above the QFM buffer (1d01, 03). High oxygen fugacities that developed in Makaopuhi lava lake (1d01, 03) resulted only in a streaky hematitic alteration of mafic silicates. No hydrous minerals, such as iddingsite, have been observed. The occurrence of iddingsite in older Hawaiian flows can thus be ascribed to low temperature alteration long after initial cooling and solidification. Kilauea Iki lava lake, whose upper crust has a well developed hydrothermal system at temperatures lower than 100°C, shows increasing deuteric alteration at a given depth in successive drillings of the lake. Eventually we should be able to specify the alteration history, mineralogically and chemically, as a reference for the interpretation of alteration in older ponded basaltic lava flows.

**INTERPRETATION OF SUB-VOLCANIC PROCESSES**

Kilauea is an ideal laboratory for study of subsurface volcanic processes because of its accessibility and frequent activity. Major events—eruptions and earthquakes—occur with a frequency that permits repeated testing of hypotheses of volcanic and seismic behavior. Kilauea’s shallow plumbing system has been intensely studied (2a–e) with the result that we can specify depth and size of a primary magma-storage reservoir (2a01–05; 2b01, 02), measure rates of magma transport from storage to eruption (2a07, 08; 2b17, 18), identify locations of secondary storage (2a05; 2b08, 09; 2e05; 2e04, 05), and evaluate seismicity and ground deformation as they relate to accumulation and release of strain in brittle rocks surrounding the magma reservoir and active rift systems (2a06; 2b14–16; 2e01, 02). The record of the chemistry and petrography of all eruptions since 1952 has resulted in quantitative interpretation of crystal-liquid fractionation and high-temperature magma mixing in the rift zones (2c03–08). These processes are not restricted to Kilauea. Numerous papers on the mid-ocean ridge basalt system and, more recently, on the Krafla system in Iceland, have described processes similar to those first documented for Kilauea.

The concept that volcanic rocks provide a window into the earth’s mantle is not new. Nevertheless most geophysical and geochemical models of mantle processes do not use the constraints and insights gained from study of active volcanic areas. The process of magma generation in the mantle often leads to eruption of lava on the earth’s surface. At Kilauea a key observation connecting shallow and deep processes is the magma supply rate, the rate at which basaltic magma is supplied to shallow storage (2f01, 02; 2b04). Kilauea’s magma supply rate has been estimated at 0.1 km² per year. From storage the magma may either be intruded or extruded; the net result of endogenous and exogenous growth (2f02) and the isostatically controlled subsidence of the volcanic pile into the crust (3a05) is what determines the rate of growth of an Hawaiian volcano above the sea floor.

Several other critical observations constrain melt generation in the Hawaiian hot spot:

1. More than one volcano can be active at a given time.
2. Simultaneously active volcanoes are chemically identifiable (2c01, 02).
3. Deeper storage areas in the mantle have not been identified (2a03).
4. Magma is rapidly resupplied from depth following partial draining of the summit reservoir during summit (2b04) or rift (2b08, 09) activity.

Observations 3 and 4, combined with knowledge of the size of the shallow reservoir and the estimated constant magma-supply rate, require a geologically short time between melting in the mantle and eruption at the surface; current estimates are in the range of a few decades to at most 100 years. Thus each of us is a witness, well within one’s lifetime, to the entire process of melting, magma transfer to shallow storage, and eruption or intrusion of a particular batch of magma. The short times involved make it likely that melting occurs at a relatively shallow depth, but the question of the ultimate depth of the source material brought up to be melted remains unresolved. The fundamental parameters for melting in the mantle, for example, degree and depth of partial melting and the chemistry and mineralogy of the bulk mantle, all may be better addressed in the context of the magma supply rate and the chemistry of erupted lavas associated with an active volcanic system. Again we emphasize the importance of knowing the magma supply rate. To the extent that the supply rate reflects the melting rate within the Hawaiian hot spot, the degree of partial melting is constrained by consideration of the total
volume of mantle available to be melted per unit time, the physical dimensions of magma transport systems in both the asthenosphere and lithosphere, and the rates at which melts can be homogenized to produce a broadly uniform composition. New methodologies in seismology (e.g., tomographic mapping), following on earlier work (2a02, 03), may be important to apply to the roots of volcanic areas (e.g., the Hawaiian hot spot) to elucidate further the distribution of melt in the uppermost mantle. Likewise, theoretical and experimental modeling of magma transport mechanisms (e.g., rates of collection of magma in the asthenosphere from an originally solid crystal framework; fracture mechanisms in a rigid lithosphere) may be constrained by knowledge of magma-supply rates for specific volcanic systems.

A final application of real-time volcanic studies to deeper processes is the determination of volatile contents and rates of outgassing of the earth’s mantle. These are critically dependent on determinations of the concentrations and saturation pressures of volatiles in magmas, as well as quantitative determination of the rates of outgassing of volatiles from an active volcano. Kilauea has provided both kinds of data. Determination of volatile concentrations in rapidly quenched volcanic glasses, both subaerial (glass inclusions in phenocrysts—2d09) and submarine (pillow rinds—2d07, 08), has given estimates of saturation concentrations for CO₂, S, and H₂O). Study of Kilauea gases emitted from fumaroles and active vents (2d04-06) as well as measurement of volcanic plumes both between and during eruptions (2d01-04) yield limiting values for volatile content (2d05) and outgassing rate (2d06, 10) of the mantle.

COMPARISON OF MOUNT ST. HELENS WITH KILAUEA

Volcanic monitoring by the U.S. Geological Survey is currently conducted at two very different active volcanic centers (5a, b). Kilauea is a basaltic volcano in an oceanic intraplate tectonic setting; Mount St. Helens is a dacitic volcano in a continental margin setting. Similar instrumentation for study of seismicity and ground deformation is used on both volcanoes. The contrasts in eruptive style, magma supply rate, shape of volcanic edifice, types of volcanic deposits, and chemistry and petrology of erupted magmas are obvious. What are perhaps more interesting are the similarities in magma storage and the constancy of magma supply rate as inferred from instrumental monitoring.

Seismic evidence obtained prior to and during the eruption of May 18, 1980 suggests the presence of a magma reservoir 7–8 km below the surface (4a05). This depth correlates exactly with the depth of storage and crystallization inferred on the basis of experimental work on pumice erupted on May 18 (4a04). Seismic studies since 1980, however, have failed to detect a magma body beneath Mount St. Helens, although the volcano has been in episodic eruption during this time. This failure might relate to the resolution scale of existing techniques, but by analogy with the Kilauea Iki experiment (1b07) the absence of a clear seismic definition of magma might also reflect a high crystal content in the reservoir that feeds the 50-percent-crystalline dacite into the dome.

The magma supply rate at Mount St. Helens is estimated from study of post-1980 dome growth to be about one order of magnitude less than that estimated for Kilauea. It is, like Kilauea, remarkably constant over the short period of time in which measurements have been made (4a06).

Acknowledgements—This paper grew out of an afternoon workshop moderated by one of us (TLW) entitled “Study of Active Volcanism: Constraints on Petrologic and Geophysical Models of Dynamic Earth Processes” held at the symposium honoring Hat Yoder. We are grateful to the following persons who also participated in the workshop: Fred Anderson, Rosalind Helz, Peter Lipman, Christina Neal, Michael Ryan, and George Ulrich. The present paper covers the overview and not the substance of the workshop. We appreciate the cooperation of Bjorn Mysen in offering a forum in Hawaii and in this volume to present some of our thoughts on the importance of studies at active volcanoes.

Finally, it is appropriate to recognize the contribution that the Geophysical Laboratory and Hatten S. Yoder himself have made to understanding Hawaiian volcanic processes. From the earliest visits of Day, Allen, and Shepard to collect gas at Halemaumau to the weighty synthesis of basalt genesis by Yoder and Tilley, based in part on experiments using Kilauea tholeiite, there has been an important scientific interchange between the Carnegie Institution’s Geophysical Laboratory and the U.S. Geological Survey’s Hawaiian Volcano Observatory. We dedicate this paper to that continued association and hope that a similar association can be established between the Geophysical Laboratory and the fledgling Cascades Volcano Observatory.

The manuscript was reviewed and improved by Paul Greenland, Charlie Bacon, Peter Lipman, and Bjorn Mysen. Fred Anderson provided additional insight into the significance of volatile studies at Kilauea.

ANNOTATED REFERENCES

1. KILAUEA LAVA LAKES

a. Overviews of lava lake studies

1a WRIGHT T. L., PECK D. L. and SHAW H. R. (1976) Kilauea lava lakes, natural laboratories for the study of the cool-

A summary of data and interpretations from earlier studies of Kilauea lava lakes.


Gives an updated summary of differentiation processes observed in the Kilauea lava lakes.

b. Kilauea Iki.


A valuable reference to geophysical and petrological studies of the largest, and only extant, Kilauea lava lake.


Chapter B contains a wealth of information on igneous processes of potential importance to the crystallization of olivine-rich basaltic intrusions.


These papers provide insight into the unusual character of the 1959 eruption (see also 2c04). They document the appearance of new magma during the early part of the eruption, and Helz presents evidence that this magma came directly from the mantle. The 1959–60 eruption of Kilauea Volcano, Hawaii.


Chapter B gives (1) important measured and derived physical data for Hawaiian basalt, including density of solidified and molten basalt, vesiculity and conductivity, and (2) cooling history, with an evaluation of additional physical properties by fitting theoretical cooling models to the observed data.


Chapter C contains a direct determination of the liquid line of descent for tholeiitic basalt, the order and temperature of crystallization of different phases, and the process in which low-temperature basaltic liquids are segregated.


Identification of the temperature of formation, composition, and mineralogy of primary sulfide segregations. These may become altered and disseminated with further cooling or lava movement, thus obscuring their origin in older lava.

d. Makaopuhi.


Reports all results of the four-year study of cooling, crystallization, and differentiation. Processes of convection-driven high temperature fractionation and differentiation by filter-pressing at low temperatures also apply to olivine-poor magma bodies stored in the Kilauea rift zones.


First direct measurement of viscosity in a cooling lava pond. Demonstrated the non-newtonian behavior of the melt.

First direct measurement of oxygen fugacity-temperature profiles through the upper crust of a cooling basalt flow. Updated in 1981.

2. REAL-TIME STUDY OF MAGMA TRANSPORT AND STORAGE

a. Seismic


First detailed seismic portrait of summit reservoir, using distribution pattern of shallow earthquakes.


A different seismic definition of summit reservoir using inversion of local earthquake P-wave arrival times.

ELLSWORTH W. L. and KOYANAGI R. Y. (1977) Three-dimensional crust and mantle structure of Kilauea Volcano, Hawaii. J. Geophys. Res. 82, 5379–5394. 2a03


These papers apply 3-dimensional seismic methods to the subvolcanic structure. Paper 2a03 gives evidence for the absence of deep areas of magma storage.


Presents seismic data in three dimensions to illustrate the plumbing system of Kilauea.


Continuation of the work above, adding finite-element modeling of summit and rift-zone responses to intrusion of magma.


A comprehensive study of the relationship between seismic activity and magmatic intrusion. Data are given on both lateral and vertical rates of intrusion.


Additional definition of dike propagation using analysis of earthquake focal mechanisms.


A comprehensive summary of the occurrence of volcanic tremor and its relationship to magma transport. Assessment of the relative importance of aseismic magma transport and the identification of common source regions for different active Hawaiian volcanoes.


A fundamental study of seismicity associated with a long-lived eruption of Kilauea. 2a07, 2a09, and this paper form a basic reference for study of volcanic seismicity.

b. Ground deformation


Classic papers defining the Kilauea summit reservoir from the modeling of ground deformation during inflation-deflation cycles.


These companion papers illustrate the complex structure of the Kilauea summit reservoir during a long inflation cycle and the response of the volcano to a major summit eruption.


These papers establish the similarity of Mauna Loa’s magma reservoir and feeding system to that of Kilauea, in the first fully documented account of a Mauna Loa eruption cycle.


These two papers are the most complete summaries of typical short rift eruptions that combine extrusive and intrusive processes, the latter revealed largely by measurement of ground deformation.


The first documentation of intrusion above the Kilauea summit reservoir. This activity resulted in the eruption at a later time (1974—see 2c07) of slightly fractionated lava at Kilauea summit, the first documented occurrence in historic time.


First modeling of surface deformation using a dike rather than a point source geometry.


Presents a novel approach to modeling the ground deformation over the reservoir using emplacement of sill-like bodies instead of a point source (2b01, 02) or vertical dikes (2b11).
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Models deformation data for a variety of source geometries, concluding that a point-source is adequate. Documents inelastic deformation at Kilauea summit (See also 2e03).


Shows geometry of deformation related to diiking, as determined by geodetic surveys throughout the century. Documents that deformation follows and is probably caused by intrusion.


Details nature of deformation event resulting from diiking in east rift zone and documents how this deformation increased the storage capacity of the rift zone for several years.


Further investigation of the relationship between intrusive activity and seismicity and ground movement on Kilauea’s south flank.


The first quantitative modeling of diike emplacement at Kilauea using data from continuously recording electronic tiltmeters.


A novel approach to estimating magma-transport rates from ground deformation and seismic measurements. Comparison with observed extrusion rates permits an estimate of the ratio of material erupted to that left underground as intrusions.

c. Petrology 2c


Summarizes high-quality major-oxide analyses for all olivine-controlled historical eruptions of Kilauea through 1968, all historical eruptions of Mauna Loa through 1950, and selected prehistorical eruptions from both volcanoes. Interpretations made in this paper are largely superseded by later work (e.g., 2e02, 09, 10).


A sequel to 2e01, presenting trace-element data for the same samples, and showing that both Kilauea and Mauna Loa show long-term chemical trends.


Demonstrates the homogeneity of different Mauna Loa eruptions after correcting for olivine-controlled chemical variation.


A well-documented example of an eruption fed from two sources.


These three papers constitute a comprehensive treatment of crystal-liquid fractionation and high-temperature mixing of Kilauean magmas, derived by analysis of the complex record of eruption chemistry from 1952–1974.


Provides alternative interpretations to those in 2e05–07 to explain the chemical variation in Kilauea’s most recent eruption.


Provides critical data obtained from real time study of recent Kilauea activity that constrain geochemical and geophysical models of magma generation.


Precise determinations of incompatible trace elements and Sr isotopes for part of the data set for which major-oxide chemistry is present in 2e06. Model for origin of Kilauea magma differs substantially from that presented in 2e09. The importance of working with samples documented as to time and place of eruption is acknowledged in both papers.

d. Geochemistry of magmatic volatiles 2d


Together these papers address the chemical composition of volcanic gas in equilibrium with Kilauea magma 1) as it arises from the mantle, 2) after degassing in shallow storage at pressures of 1–2 kbar, and 3) in solidified lava after degassing during eruption. Oxygen fugacities derived from gas collections are similar to those directly measured in the Kilauea lava lake.


Uses data from real-time gas collections to estimate volatile contents of the magma source.

This paper extends studies of gas chemistry to address subjects such as lava fountain dynamics, dimensions of eruptive conduits, size of immediate source areas, and magma supply rates.


First determination of water saturation values in naturally quenched basaltic glass.


First determination of sulfur saturation values in naturally quenched basaltic glass, and an estimate of sulfur loss during eruption.


Analyses of volatiles in glass inclusions from olivines from the 1959 eruption of Kilauea agree with saturation values determined from pillow glasses (2207) and the estimates of restored equilibrium compositions of Kilauea glasses (2203).


Quantitative modeling of the equilibrium pressures at which different volatile species are exolved.

e. Other geophysical studies


This study combines laboratory measurements and theory related to rock mechanics, and real-time deformation and seismic data, to derive a model showing that magma reservoirs bear a fixed relationship to the surface altitude and size of the summit caldera on Hawaiian shield volcanoes.


A comprehensive treatment of the relationship between the location of magma storage reservoirs and the mechanical properties of the surrounding basaltic shield.


Applies gravity data obtained during the period of episodic east rift eruption to refine interpretations of the summit reservoir to reconcile vertical and horizontal displacement data. The analysis complements those obtained by modeling deformation data with conventional source geometries.


These papers document the electrical structure of Kilauea and discuss dike impoundment of high-standing water tables and aseismic magmatic intrusion without accompanying ground deformation.


Derives the physical state of basaltic magma from modeling flow in active volcanic conduits using real-time monitoring data.


A generalized rheologic model for the subsolidus portions of basaltic lava lakes, and a general model for the origin and development of columnar jointing in basalt, based on the combination of in-situ field measurements and laboratory measurements at high temperature.

f. Estimates of magma supply rate


First documentation of constant magma supply rate (about $9 \times 10^8$ m³/mo) during long-lived eruptions of Kilauea.


Attempts to calculate minimum supply rates on the basis of tilt changes, and to partition the magma into that erupted and that stored in the two rift zones.

3. REAL-TIME STUDY OF VOLCANIC ERUPTIONS: APPLICATION TO OLDER VOLCANIC ROCKS

a. Construction of volcanic edifices and lava fields


A detailed account of the growth of a satellite lava shield formed of dominantly pahoehoe lava.


Completes the study of the growth of the Mauna Ulu shield.

A detailed narrative account of the growth of the Pu‘u O‘o cone and associated a‘a lava flows.


A synthesis of geological observations made during the first half of the current Kilauea east rift eruption.


Emphasizes the high rates of subsidence of Hawaiian volcanoes and the implications of this for volume and growth rates of Hawaiian shields.


Shows that vesicularity of flows can provide information on depth of cooling of ancient lava.

b. Lava flow dynamics


These two papers analyze behavior of lava flows during a typical Mauna Loa eruption. Data on “aging” of the feeding channel, undercooling, and volatile loss.


A comprehensive treatment of the pahoehoe to aa transition in terms of the combined effects of viscosity and rate of shear strain. Chemical composition, temperature, and volatile content, considered independently, are found to be unimportant in determining whether lava is a‘a or pahoehoe.


Describes different kinds of pahoehoe flows and their preservation in sections of the lava pile exposed by collapse. First explanation of the origin of dense pahoehoe far from the vent as being supplied in lava being degassed during flow in tubes.


Discuss the difficulties in deriving eruptive history from stratigraphic sections of older volcanic rocks.


Points out the use of analyses of volatiles in cooled lava to indicate distance from and direction to vent.


These two papers given an account of the formation of basaltic pillows from direct observation of lava flowing into the ocean, the first such observations ever made.


The first real-time study of joint formation, including determination of maximum temperature at which joints propagate (1,000°C), the direction of propagation, and the effects of rainfall.


A fascinating paper which treats an active lava lake surface as a scaled analogue of mantle-crust processes occurring at much higher viscosities and much slower rates.

4. SELECTED BIBLIOGRAPHY TO ENABLE COMPARISON OF MECHANICAL BEHAVIOR OF MOUNT ST. HELENS WITH THAT OF KILAUEA


A modern reference to studies of active Hawaiian volcanoes. Individual chapters are annotated throughout this reference list.


A comprehensive summary of the May, 1980 catastrophic eruption of Mount St. Helens. Articles include eyewitness accounts, geophysical monitoring before, during, and after, detailed accounts of the volcanic deposits formed, and environmental effects of the 1980 eruption.


Challenging model relating eruption dynamics to decompression and vesiculation at a depth of about 4.5 km.


Provides experimental evidence consistent with seismic evidence (4a03) for a magma reservoir at 7–8 km depth.


Provocative discussion of effects of varying supply and discharge rates on nature of eruptions. Presents seismic evidence for existence of magma reservoir whose top is about 7.8 km deep.


Provides volume data documenting relatively constant rate of magma supply during eruption.

Includes good discussion of development of bulge resulting from intrusion of magma into the cone.


These three papers discuss the relative roles of magmatic volatiles and vaporized groundwater in driving the lethal blast. Eichelberger and Hayes favor magmatic gas as the driving agent, whereas Kieffer stresses the role of flashing water in the hydrothermal system. These papers demonstrate how even with close observation, transient events can have controversial origins.

5. GENERAL REFERENCES ON THE MONITORING OF ACTIVE VOLCANOES


Comprehensive summaries of visual and instrumental monitoring of two currently active volcanic areas.

6. OTHER REFERENCES