Grand Challenges in U.S. Volcano Seismology

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Background

This white paper arises from a one-day discussion workshop held in Anchorage, Alaska, on April 29, 2014, and co-sponsored by the National Science Foundation, the USGS Volcano Hazards Program, and the Carnegie Institution of Washington. This workshop, attended by 37 scientists (see participant list in Appendix A) was a first step towards developing a relationship among members of the academic community and government agencies, focused around a shared, long-term vision for volcano seismology in the United States. A shared, long-term vision for the field of volcano seismology in the U.S. will provide guidance to scientific funding agencies and organizations responsible for hazard mitigation and disaster response, will facilitate multidisciplinary research on fundamental Earth processes and links between basic and applied volcano seismology, and will enable partnerships with international colleagues.

Observations of volcanically induced seismicity are essential for eruption forecasting and for real-time and near-real-time warnings of hazardous volcanic activity. Studies of volcanic seismicity and of seismic wave propagation also provide critical understanding of subsurface magmatic systems and the physical processes associated with magma genesis, transport, and eruption. However, our ability to successfully forecast volcanic eruptions and to understand fully subsurface volcanic processes is limited by our current understanding of the source processes of volcano-seismic events, the effects on seismic wave propagation within volcanic structures, limited data, and even the non-standardized terminology used to describe seismic waveforms. Progress in volcano seismology is further hampered by inconsistent data formats and standards, lack of state-of-the-art hardware and professional technical staff, and a lack of widely adopted analysis techniques and software. Addressing these challenges will not only advance scientific understanding of volcanism, but also will lead to more accurate forecasts and warnings of hazardous volcanic eruptions that would ultimately save lives and property within the United States and world-wide.

Grand challenges in volcano seismology

Challenges in scientific understanding

Workshop participants identified several key unresolved scientific issues, including the identification and understanding of seismic source versus wave propagation effects, and a fully-developed understanding of the source processes of the various commonly observed volcano-seismic event types. Additional scientific challenges include limitations in our ability to distinguish between precursory and non-eruptive seismic activity, to accurately forecast the time of eruption from seismic unrest, to determine the likelihood of a future eruption based on background seismicity, and to image and understand the processes that ultimately drive magma generation, accumulation, rise and eruption within and through Earth's crust.

Technical challenges

Several key technical obstacles were also identified as impeding scientific progress in volcano seismology. These include A) numerous data sets from past episodes of volcanic unrest or eruptions that

are not consistently archived with appropriate meta-data, B) software and analysis tools that are not standardized or consistently maintained, and C) seismic instrumentation that is expensive and difficult to operate and maintain, especially on active volcanoes that are often in remote areas, at high altitude, and that are frequently exposed to corrosive gases and other destructive volcanic processes.

Situational analysis

Strengths and Opportunities

A major strength of U.S. volcano seismology is the existence of numerous high-quality continuous/long-term seismic data sets collected by the U.S. volcano observatories in Alaska, the Cascades, Hawai'i, Yellowstone, and California, as well as campaign data sets collected by researchers at volcanoes worldwide. Other key strengths of U.S. volcano seismology include the ability to take advantage of IRIS open-source infrastructure, including the PASSCAL instrument pool and the IRIS DMC, and to adopt and apply seismological methods and codes that are commonly initially developed in other fields of seismology. Furthermore, both fundamental and applied research in volcano seismology benefit strongly from clues from related fields of inquiry, including volcano geodesy, acoustics, gas geochemistry, hazards, and petrology; and members of the U.S. volcano seismology community have close ties to academic researchers and agency scientists in these allied fields.

Significant opportunity lies in the fact that most existing data sets have not been fully analyzed using modern seismological processing tools and software, even those from key well-studied eruptions at volcanoes like Mount St. Helens and Kilauea. A related opportunity is the existence of numerous continuously or long-term active 'laboratory' volcanoes either in U.S. territory or from U.S. overseas facilities (e.g., Kilauea, Mount St. Helens, Augustine, Erebus), or in other parts of the world (e.g., Santiaguito, Guatemala; Telica, Nicaragua; Soufriere Hills; Montserrat; Popocatepetl and Colima, Mexico; Stromboli, Italy, Bezymianny, Russia) where various members of the U.S. volcano seismology community have fruitful working relationships with scientists and scientific agencies. Additional major opportunities include the ongoing IRIS 'Wavefields' initiative, and the current burst of development of techniques and codes focused on location and analysis of subduction zone tremor (ETS).

Weaknesses and Limitations

Many problems in volcano seismology are unique and not easily approached with 'standard' seismological tools, e.g., non-double-couple source mechanisms, imaging of complex structures, the existence of surficial events such as rockfalls, explosions, and icequakes (which are significant but generally not cataloged). Furthermore, barriers to short- or long-term entry into the field by seismologists from other subfields may exist in terms of understanding current paradigms, what work is being done, and what data are available for analysis. In the current AGU and NSF structures, volcano seismology exists between programs (Seismology and VGP in AGU; Geophysics, Geochemistry/Petrology, and GeoPRISMS in NSF), limiting the field's ability to attract resources, attain recognition for early-career volcano seismologists, and otherwise reach its full potential. Tool/code development efforts happen largely independently and in a variety of languages/formats, resulting in frequent duplication of effort and difficulties in porting data through workflows made up of colleagues' codes. Finally, as in all fields of

volcano geophysics, there is an inherent dependence on serendipity: Seismic networks must be in place before an eruption occurs, and it is thus difficult to plan hypothesis-driven experiments, especially from a comparative perspective.

Recommendations

Our recommendations for major community-wide efforts in U.S. volcano seismology to address the challenges described above fall under five categories: 1) Ongoing and enhanced community-wide discussions, 2) data and code curation and dissemination, 3) code development, 4) development of resources for more comprehensive data mining, and 5) enhanced strategic data collection. As presented sequentially below, the following specific recommendations can be regarded as a road map for galvanizing and strengthening the volcano seismological community to drive new scientific and application accomplishment over the next 5-10 years.

1. Ongoing and enhanced community-wide discussions:
    - Organize a standalone, multi-day planning workshop to discuss and build on ideas from the one-day planning workshop, and to further define major outstanding scientific questions.
    - Develop a formal mechanism to oversee these recommendations along with an online home for the community.
    - Increase hosting of volcano seismology sessions at SSA, IAVCEI, and AGU, and convene a regular follow-up community meeting/forum.
    - Develop and make available educational resources or student-based analysis tools.

2. Data and code curation
    - Develop a list of key digital volcano-seismic data sets.
    - Archive key, presently unavailable digital data sets (continuous data if available) in modern data formats and with complete meta-data in a universally-accessible location (e.g., the IRIS DMC, WOVOdat).
    - Older data sets that are recorded only on paper records or photographic film should be considered a secondary priority, but efforts should eventually be made for proper archiving of these data.
    - Develop a meta-data archive listing all volcano-seismic data sets in existence and information on how/where they can be obtained.
    - Develop an archive of legacy data format documentation and conversion tools.
    - Develop an archive of codes for the analysis of volcano-seismic data.

3. Code development
    - Assess code/tool development needs to determine priorities for future work.
    - Develop a common 'wrapper' for existing codes to facilitate workflows and porting/visualization of analysis results between existing codes.

4. Data mining
    - Perform a standardized reanalysis of key existing data sets with modern tools/techniques.
    - Develop an (online) waveform almanac, and/or set of tests for volcano-seismic event classification.

5. Enhanced data collection
    - Develop a plan/proposal for a community-driven 'Large N' experiment(s) on one or more lab volcanoes, possibly in conjunction with the IRIS Wavefields initiative, so as to more fully characterize volcano edifice structure at frequencies required to address the “path versus source” question. Ideally such a study would be supplemented with multiparameter instrumentation (e.g., geodetic, gas, etc.), for open community access.
    - Develop a plan/proposal for a Transportable Volcanic Array to assess volcano structure, background activity, etc. at significant U.S. volcanoes.
    - Develop a program that is poised for rapid deployment/collection of research-grade, multiparameter data from critical/opportunistic targets during the next major eruption within the USA, or possibly overseas with appropriate collaborators.

Appendix A: List of participants in the 2014 U.S. Volcano Seismology workshop

Name	Position	Affiliation
Aster, Rick	Professor	Colorado State University
Bennington, Ninfa	Assistant Scientist	University of Wisconsin, Madison
Bowman, Daniel	Graduate Student	University of North Carolina, Chapel Hill
Braunmiller, Jochen	Research Asst. Prof.	University of South Florida
Buurman, Helena	Postdoctoral Fellow	University of Alaska, Fairbanks
Caplan-Auerbach, Jackie	Associate Professor	Western Washington University
De Angelis, Silvio	Lecturer	University of Liverpool (United Kingdom)
Dixon, Jim	Geophysicist	USGS/Alaska Volcano Observatory
Fee, David	Research Asst. Prof.	University of Alaska, Fairbanks
Haney, Matt	Geophysicist	USGS/Alaska Volcano Observatory
Hotovec-Ellis, Alicia	Graduate Student	University of Washington
Ketner, Dane	Geophysicist	USGS/Alaska Volcano Observatory
Keyson, Laura	Graduate Student	University of Alaska, Fairbanks
Lees, Jonathan	Professor	University of North Carolina, Chapel Hill
Lyons, John	Postdoctoral Fellow	USGS/Alaska Volcano Observatory
McCausland, Wendy	Geophysicist	USGS/Volcano Disaster Assistance Program
McFarlin, Heather	Graduate Student	University of South Florida
McKee, Kathleen	Graduate Student	University of Alaska, Fairbanks
McNutt, Stephen	Professor	University of South Florida
Montgomery-Brown, Emily	Geophysicist	USGS
Moran, Seth	Geophysicist	USGS/Cascades Volcano Observatory
Ortiz, Hugo	Graduate Student	Instituto Geofisico, EPN (Ecuador)
Parker, Tom	Geophysicist	USGS/Alaska Volcano Observatory
Paskievitch, John	Geophysicist	USGS/Alaska Volcano Observatory
Power, John	Scientist-in-Charge	USGS/Alaska Volcano Observatory
Prejean, Stephanie	Geophysicist	USGS/Alaska Volcano Observatory
Read, Cyrus	Geophysicist	USGS/Alaska Volcano Observatory
Roman, Diana	Staff Scientist	Carnegie Institution of Washington
Searcy, Cheryl	Geophysicist	USGS/Alaska Volcano Observatory
Smith, Cassandra	Graduate student	University of South Florida
Thelen, Weston	Geophysicist	USGS/Hawaiian Volcano Observatory
Thompson, Glenn	Research. Assist. Prof.	University of South Florida
Thurber, Cliff	Professor	University of Wisconsin, Madison
Waite, Greg	Assoc. Professor	Michigan Technological University
Wech, Aaron	Postdoctoral Fellow	USGS/Alaska Volcano Observatory
Wellik, Jay	Graduate student	Michigan Technological University
White, Randy	Geophysicist	USGS/Volcano Disaster Assistance Program