International Partnership to Develop Volcano Monitoring Capacities in Guatemala

GWB Phase I

Silvio De Angelis

4 Brownlow Street
Jane Herdman Laboratories
Liverpool, Merseyside L69 3GP

silvioda@liverpool.ac.uk B
+4407958419795 B +4407958419795

FollowUp Form

Basic Information

Project Name*
Name of Project

International Partnership to Develop Volcano Monitoring Capacities in Guatemala

Project Start Date*
Select the date when your project was started.

09/01/2018

Project End Date*
Select the date when the project ended.

08/31/2021

Report Author(s)*
List the names of the primary author(s) of this final report.

Silvio De Angelis

Executive Summary
The Executive Summary section of the report should succintly, yet comprehensively, summarize the project and its outcomes. Greater detail on the project will be provided as outlined in the additional sections of the report.

Introduction*
Provide a brief, focused introduction to the project and its need.

This project focused on the Santiaguito volcanic complex, where explosions, avalanches, pyroclastic flows and lahars represent a constant threat to the population and farming developments in the area.

Project Goals and Objectives*
Describe the project goal(s) and objectives as they were outlined in the Phase II application or subsequent project revisions approved by the GWB Committee.

The project had three main objectives:

O1. Installation of seismic equipment at Santiaguito with real-time data transmission. The equipment will assist with monitoring operations of activity at the volcano.

O2. Deployment of software for routine analyses of volcano geophysical data.

O3. Training of personnel at INSIVUMEH (Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología) and young Guatemalan scientists in volcano monitoring.

Project Participants*

List all project participants, with title and affiliation.

Silvio De Angelis, Reader, University of Liverpool
Andreas Rietbrock, Professor, Karlsruhe Institute of Technology
Gustavo Chigna, Head of Volcanology, INSIVUMEH
Pablo Roberto Castellano, Technician, INSIVUMEH
Alejandro Diaz-Moreno, PDRA, University of Liverpool
William Carter, PhD, University of Liverpool
Ellen Gottschämmer, Lecturer, Karlsruhe Institute of Technology
Rainer Plokarz, Technician, Karlsruhe Institute of Technology
Amilcar Roca, Head of Geophysics, INSIVUMEH
Carla María Chun Quinillo, Volcanologist, INSIVUMEH

Methods Used*

List all methods used, including application and specific instrumentation.

The project focussed on the installation of three broadband seismic stations streaming data in real-time to INSIVUMEH headquarters in Guatemala City. One additional seismometer recording on-site is installed at the site of the Santiaguito volcano observatory. Two sites are also equipped with acoustic infrasound microphones. The data are used in routine volcano monitoring applications such as RSAM, Spectrograms and earthquake catalogs, and support alerts of elevated activity.

Summary of Results and Key Findings*

Provide a summary of the project's results and key findings.

The project has been completed and all initial objectives were achieved. The initial target of installing two real-time seismo-acoustic stations was exceeded with four installed and currently operational, including three real-time and one recording on-site. The data are routinely used to monitor activity at Santiaguito and have thus far detected numerous lahars (volcanic mud flows), explosions and pyroclastic flows. The data are fully integrated within the INSIVUMEH data processing workflow, including algorithms and software specific to volcano seismic and acoustic data. A workshop was held in Guatemala City in Jan 2021 with 27 local participants aimed at training local scientists to the use of these data for volcano monitoring. The workshop saw the participation of guest instructors Dr. Matt Watson of the University of Bristol and Dr. A. Lockhart of the USGS. Beyond the obvious and immediate benefits to the INSIVUMEH's volcano monitoring programme the project has allowed building the first long-term earthquake catalog of activity at Santiaguito, which will serve as a baseline to implement alerts and define early warning protocols in the near future. Data collected by the new equipment suggests the occurrence seismic tremor and low-frequency signals at Santiaguito in relation to the activity at the vent; data from past short-term temporary deployment had hinted to the presence of such activity but its full classification and characterisation had remained elusive. In a series of studies the team behind this project was able to unravel the dynamics of explosive activity at Santiaguito and presented models of the mechanisms that may govern the transition between effusive and explosive eruption regimes at the volcano. Another interesting aspect that clearly emerged from the investigation of the data collected is their suitability for the future implementation of lahar early warning.

Conclusion and Implications*

List the conclusions that the project team derived and the implications those conclusions have.

The team behind this project has worked on studies that unravel long- and short-term dynamics, and the factors controlling the occurrence of eruptive activity at Santiaguito. These studies provide valuable insights into geophysical signals and their associated processes at Santiaguito; this work has helped to resolve the temporal occurrence of different types of eruptive events during protracted effusive-explosive activity. The scientific output of this project represents a solid foundation for further investigations at Santiaguito and shows promise for furthering our understanding of the processes leading up to major explosive activity at the volcano.

This project was, however, designed with practical objectives at its core. The project has successfully achieved the installation of the first permanent broadband seismic network at Santiaguito, with one of the sites in close proximity of the active Caliente vent. The positive outcomes of this project, even beyond initial expectations, have inspired other organisations to invest in Guattemala in order to build and expand on the work already done. The network installed as part of this project will form the backbone of a new - much larger - monitoring programme at Santiaguito. This new monitoring programme will aim at implementing early warnings and real-time alerts of impending and ongoing activity, in particular with respect to lahars and pyroclastic flows.

Deliverables*

List all deliverables that will be discussed in the final report, including those that were given to the in-country partners and participants.

The deliverables of this project were:

1) Installation of two seismic and acoustic infrasound monitoring stations at the Santiaguito lava dome complex

2) Integration of the real-time data streams from the stations into the INSIVUMEH SeisComp 3 data acquisition system

3) Development and installation at INSIVUMEH of a suite of software tools for data analyses and volcano monitoring

4) Training of local scientists in modern volcano monitoring technologies

Final Report

The final report should be comprehensive and provide enough information for assessment of whether the project has accomplished the technical, humanitarian, educational, and sustainability goals outlined in the Phase II application. You are expected to write the report with the care and attention to detail that a published paper requires. Reports are published (with confidential information removed, including financial data) on the GWB website to help educate the public on the program and its impact. Reports should be proofread to ensure accuracy of language and data.

Figures and pictures should be original, high quality graphics and must include captions and appropriate scales. All maps should be oriented with north at the top. All field data and interpretations should be shown on logs, maps, and sections within the same georeferenced projection system, datum, and scale. All maps and sections are to have distance scales in the same unit system. Include color legends, if appropriate.

If you would like additional guidelines to help you prepare your report, please email us at withoutborders@seg.org and ask for more specific instructions.

Reports that have not been written with the highest attention to detail and accuracy will be returned to draft status for editing and any pending payments will be delayed until an acceptable report is received.

Project Location and Geologic Setting*

In the space below, provide a description of the project's location, including its geologic setting. Using the upload button, attach a Word document, pdf, jpeg or preferrably, a geotiff with a map of the area where the team is working. Include a bounded polygon around the area where studies are being conducted. Include the title "Project Location" at the top of the document.

The project location is the Santa Maria and Santiaguito volcanic complex, located in Guatemala, at the northwest end of the Central American volcanic arc. This complex has produced, for about a century, explosions, collapses and avalanches, pyroclastic flows and lahars. Caliente (14.7358N, 91.5679W), part of the Santiaguito dacitic lava domes, is the presently active vent.

Project Location continued*

Upload a Google Earth kmz file that outlines the boundaries of the project location. This file will be used to display the project location on a master map of GWB projects, including the project map on the GWB website.

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Humanitarian Need and Benefit*

Summarize the reason, need(s) and benefit(s) of the project (humanitarian, community, environmental, etc.)

The Santiaguito lava domes generate recurrent hazards. The land on the slopes of the volcano is used for agriculture, mostly coffee plantations. For large explosive events drifting ash clouds affect towns and cities near the volcano, including the whole municipality of Quetzaltenango with a population of about 220,000. Pyroclastic flows can represent a threat to local communities. Lahars are a recurring hazard in the streams and rivers around the Santiaguito domes, due to the intense summer rainy season. The town of El Palmar was destroyed by lahars in the 1980s, and the newly built town remains under the threat of future mudflows. This project will help developing monitoring capabilities for these hazards.

Project Goals and Objectives*

Describe the project goal(s) and objectives as they were outlined in the Phase II application or subsequent project revisions approved by the GWB Committee and the methods used to accomplish the goal(s).

O1. Installation of seismic and acoustic infrasound equipment at the Santa Maria and Santiaguito volcanic complex with real-time data transmission. The sites were selected from a number previously occupied locations, suitable for their characteristics (proximity, ease of access and safety) and for real-time data transmission using 3G/4G technology.

O2. Deployment of software for routine analyses of volcano geophysical data and integration into automatic systems for detection and monitoring of volcanic unrest. Data from the new sites are received at INSIVUMEH and incorporated into SeisComp 3 and Earthworm systems. These data feed a number of algorithms for near real-time appraisal of the level of volcanic activity.

O3. Training of INSIVUMEH personnel, civil protection officers and young Guatemalan scientists in modern volcano monitoring technology and methods. A training initiative with 27 local participants was held in Guatemala City in January 2020.

Previous Studies in the Project Area*

Provide a summary of the pertinent previous studies by others in the project area. Describe how the current project goals complemented previous work or filled a void.

The Santa Maria and Santiaguito volcanic complex is an international decade volcano located in Guatemala, at the northwest end of the Central American volcanic arc. A number of previous studies at Santiaguito have focussed on reconstructing its eruptive activity in historical times and have put forward conceptual models of its plumbing systems and long-term eruption dynamics [e.g., Harris et al., 2003]. In 1902 Santa Maria erupted 8.5 km3 of dense dacite, producing one of the largest volcanic events in the 20th century. The eruption, which left a 0.5 km3 crater, killed about 8,700 people, and many more died from a consequent outbreak of malaria. In 1922, after about 20 years of dormancy, the ongoing eruption of Santiaguito began with the growth of a lava dome within the crater of the 1902 eruption [Rose, 1972]. In 1929, a 3,000,000 m3 collapse accompanied by a pyroclastic surge occurred. Uncertain estimates suggest that between few hundreds to about 5,000 people were killed by this event. Since then, Santiaguito has produced, for about a century, explosions, collapses and avalanches, pyroclastic flows and lahars, representing a constant threat to a population of several tens of thousands, and to farming developments in the area. Activity at Santiaguito over the past three decades has consisted of small-to-moderate, regular (hourly to every few hours), explosions from the active Caliente vent. The seismic and acoustic fingerprint of such activity has been investigated over the past two decades by various authors that have been able to constraint magma properties and the dynamics within the shallow volcano plumbing that control the timing and style of eruption at Santiaguito [e.g., Johnson et al. 2004; De Angelis et al., 2012; Hornby et al., 2019; Carter et al., 2020; Gottschaemmer et al., 2021].

FIeld Studies*

Using the space below, describe the field studies conducted during the course of the project. Be sure to include the following:

- Approach(es) used, including your rationale for the particular approach(es), the application mode applied, and instrumentation used (manufacturers and models, number of electrodes, etc.);
- Brief description of methods used;
- Who conducted the field work (professors, students, locals, professionals?)? Be sure to clearly indicate who did what;
- Provide maps of data acquisition and acquisition dates;
- Provide evaluation of data quality and usefulness;
- Describe inversions applied and software used;
- Provide field results, including pertinent samples with inversion residual error values)

- Describe any field challenges or problems and the actions taken to mitigate them.

Use the upload button to attach a Word document or pdf appendix with the maps and figures referenced in your summary, including captions. Include the title "Figures for Field Studies" at the top of the document.

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Volcanic activity at the Santa Maria and Santiaguito complex is monitored by the Santiaguito Volcano Observatory (OVSAN), operated by INSIVUMEH, and located about 7 km southwest of the active vent. Local surveillance of Santiaguito, in the form of daytime visual observations from the observatory by a member of OVSAN, complements any monitoring data that are available to INSIVUMEH scientists in real-time. Data from one short-period, vertical-component, seismometer installed at about 2.5 km from the active Caliente vent, have traditionally been available to INSIVUMEH staff in Guatemala City, although with frequent dropouts. The earthquake monitoring group at INSIVUMEH operates the Guatemalan national seismic network with a SeisComp 3 seismic data acquisition system (https://www.seiscomp3.org); this system receives data via the seedlink protocol (http://ds.iris.edu/ds/nodes/dmc/services/seedlink/), and provides a robust platform for the implementation of a real-time, automated data analysis workflow to monitor Santiaguito. However, the system requires equipment, which supports modern digital data transfer protocols.

This project leveraged the modern software infrastructure of the Guatemalan national seismic network to install 4 modern broadband seismic stations equipped with Nanometrics Trillium T120 Compact seismometer (two sites also include broadband IST2018 acostic infrasound microphones). A map of the site locations is included. Data are digitized on-site by Earth Data EDR209 data-loggers and sent to the INSIVUMEH headquarters using INSYS EBW-H100 modems connected to the local 3G/4G network. The 3G signal provides enough bandwidth for up to 6 channels sampled at 50 Hz or three channels sampled at 100 Hz, well within the requirements for seismic monitoring. The field work for the installation of equipment was conducted jointly by all team members of the project, which included local INSIVUMEH scientists (Amilcar Roca, Gustavo Chigna, Carla María Chun Quinillo), University professors (Silvio De Angelis, Andreas Rietbrock, Ellen Gottschämmer) and post-doctoral and PhD researchers (William Carter, Alejandro Diaz-Moreno). Additional students and investigators joined our main team throughout the project and benefitted from the fieldwork and data collected. Data transmission was implemented by INSIVUMEH telecommunication engineer Pablo Castellano with the support of De Angelis, Rietbrock and Rainer Plokarz. All field work was supported by a number of INSIVUMEH technicians and numerous people from the local villages around Santiaguito who offered their kind and constant contribution throughout the duration of project. Many tasks were only possible with the valuable help of local mountaineering guide Armando Pineda who accompanied our team during each trip to Santiaguito.

The quality of the data collected is high, considering the harsh environment of an active volcano, and compared to other volcano-seismic networks. Real-time data retrieval has ranged between 50-90% for different sites, and showed an obvious improvement over time as site installations were finalised. At times data dropouts occurred due to the need for maintenance trips for the solar power system (in particular cleaning of solar panels whose efficiency is reduced by the combination of volcanic ash and heavy rain). The major challenge related to maintenance of equipment is access to some of the sites, which requires adequate planning and effective communication with local communities around Santiaguito; INSIVUMEH has supported this project and continues to date, to independently support the operation of the new network.

Interpretation of Data*

In the space below, describe the interpretation of data for the project. Be sure to include all of the following:

- Describe the interpretation process applied, including data integration, borehole comparisons, 2D surfaces developed, 3D interpretative images, fence diagrams, voxels, etc.;
- Povide examples of representative final interpretations including maps, sections, images, charts, tables, etc.;

- Provide an evaluation of the data quality and usefulness as application to interpretation;
- Include discussion on whether the data support the goals, objectives, and hypotheses and discuss what additional data would be useful.

Use the upload button to attach a Word document or pdf appendix with any figures or pictures referenced in your summary, including captions. Include the title "Figures for Interpretation of Data" at the top of the document.

Over the past two years the new equipment installed at Santiaguito detected numerous explosions, some with associated pyroclastic flows, which have accompanied a phase of renewed lava effusion at Caliente. The data allow tracking background activity at the volcano and any departures from it, which may be indicative of impending eruptive events. Lahars signals were clearly recorded during the regular rainy seasons. The data continue to support monitoring activities at INSIVUMEH.

Preliminary analyses of the data collected over the past two years generally shows seismicity that had not been previously recorded, including volcano-tectonic, long-period volcanic earthquakes, and episodes of harmonic tremor. Earthquake waveforms were extracted from the continuous data via application of automated algorithms. We identified volcano-tectonic earthquakes with rates of 70-250 events/week and low-frequency signals associated with gas and ash emissions with rates of about 100 events/week (e.g., Gottschammer et al., 2021).Seismicity associated to rockfalls associated to the collapse of the extruding lava front were also recognised in the data. Notable examples of harmonic tremor were detected in both seismic and acoustic data, associated sustained gas emission at the Caliente vent.

Analysis and modelling of recorded explosion signals allowed constraining their source mechanisms and location. Explosion at Santiaguito were modelled as a two-stage process comprising the initial opening of a tensile crack at depth of about 600 m below the summit followed by the main explosion phase modelled as a single force mechanisms at a depth of about 200 m below the summit (Rohnacher et al., 2021). These results reveal that explosions at Santiaguito involve an extended source area and complex mechanisms including gas-driven magma migration within the shallow volcano plumbing, and the final explosive fragmentation of magma.

Finally, the analysis of long term seismicity at Santiaguito between 2014-2018 revealed that seismic energy can be an effective discriminant to identify transitions between eruptive regimes at Santiaguito (Carter et al., 2020). We also identified frequency-magnitude relationships for explosion events, which are well described by a power law, similar to the Gutenberg-Richter relation for tectonic earthquakes. We demonstrated that changes in the power law b-value allow identifying transitions between eruptive regimes, and reflects variety of rupture mechanisms, likely controlled by variable magma properties. We concluded that although these relationships allow extrapolating explosive behaviour within a given eruptive phase, a longer-term assessment of future eruptive behaviour at Santiaguito remains challenging.

Human Element*

Describe the involvement of participants. Include all participants, such as college professors, professional consultants, students (either local or from outside the local region), local residents, local governments, and others.

All international and Guatemalan project performers were involved in the project execution. De Angelis, Rietbrock, Chigna, Gottschämmer, Chun Quinillo and Roca, selected the sites for the seismic sites, participated in fieldwork conducted to date, performed preliminary analyses of data. Roca and De Angelis participated in the installation and setup of automatic data analysis software at INSIVUMEH. Castellano set up real-time data transmission from the seismic stations to INSIVUMEH headquarters with assistance from De Angelis and Rietbrock. Diaz-Moreno and Carter assisted during fieldwork and with preliminary data analyses. Plokarz set up software to check the state of health of stations in the field.

Project Sustainability*

It is a goal of GWB that funded projects continue sustainably after their end dates. To receive GWB funding and achieve that goal, funded projects proposed sustainability goals and objectives to achieve them. Describe measures taken to ensure the sustainability of the project beyond the end date. What methods did you use and what objectives were accomplished to ensure project sustainability?

The main challenge with respect to sustainability is maintenance of equipment in the field and of real-time data transmission from the field to INSIVUMEH headquarters. INSIVUMEH personnel has continuously participated in all fieldwork and they are now well-trained in the maintenance and troubleshooting of the new equipment. INSIVUMEH is committed to supporting the new network indefinitely. Data transmission from the field is achieved via established 3G/4G mobile technology and the cost of any associated data plans has been transferred to INSIVUMEH for the past 18 months. Automatic data processing software was installed at INSIVUMEH and is independently managed by INSIVUMEH staff. The present setup insures a robust and future-proof platform for volcano monitoring at Santiaguito.

Education*

What educational institutions within the host country have been involved in the project? What other educational institutions have been involved? Describe any specific educational opportunities that have been provided during the project to any stakeholders (local residents, professionals, students, government officials, etc.) within the host country.

One intern at INSIVUMEH - a final year Physics student at Universidad San Carlos was trained on seismic data analyses (in particular earthquake location and seismic imaging). He has now left INSIVUMEH. One INSIVUMEH staff Carla María Chun Quinillo also participated in the project and received training. She has now left INSIVUMEH to start a teaching and research position at Universidad de San Carlos de Guatemala, Departamento de Física Ingeniería. Amilcar Roca, has travelled to Liverpool in September-Novemeber 2019 to undertake formal training in seismic and acoustic techniques for volcano monitoring with the PI and his team. Amilcar Roca is now Head of volcanology at INSIVUMEH. A training workshop for all INSIVUMEH staff (technical, scientific and management) and for selected staff of the Guatemalan Civil Protection was held in January 2020 in Guatemala City at INSIVUMEH (27 participants).

Lessons Learned*

Describe the positive and negative lessons learned while conducting the project. What you recommend to do and not to do during future projects?

The main challenge encountered was training local young scientists from outside INSIVUMEH. At present there is no formal University program in Geophysics or quantitative Earth Sciences in Guatemala. This poses challenges for the long-term sustainability of any effort related to volcano monitoring in Guatemala. Careful planning involving local stakeholders, mainly INSIVUMEH, is crucial to the success of any training initiative. From the point of view of field logistics, access to field sites can be difficult. In our experience, liaising with our local partners in Guatemala (INSIVUMEH and the local civil protection) has been pivotal in order to establish solid relationships with the local communities around Santiaguito; this has allowed us to perform all work in a safe and supportive environment.

Financials*

Provide a categorical comparison of the actual expenses versus the proposed expenses (as outlined in the project budget submitted for inclusion in the grant agreement).

You may upload a file showing the budget to actuals comparison or use the space below to describe the financials.

Deliverables

Access to Data
As a program of the SEG, a society devoted to advancing an applied science, GWB encourages its project participants to foster transparency and further educational goals of the program by providing access to data collected during the course of the project. In the following question, you will be asked to share the status of the availability of your project's data for others to use for educational purposes.

Access to Data*

Please select the option that describes the status of the availability of your project's data for others to use for educational purposes and type it in the space below:

- Data associated with this project are available and can be accessed via the following URL:____. Note: A digital object identifier (DOI) linking to the data in a general or discipline-specific repository is strongly preferred.
- Data associated with this project are available and can be obtained by contacting the following project participant:_____ at _____.
- Data associated with this project are confidential and cannot be released for the following reason(s): _____. Note: Confidentiality should be limited to 1 to 2 years after project completion. (If you choose to keep it confidential, please describe a way for the GWB Committee to have access to the raw and processed data for three years.
- Your own custom statement of data and materials availability.

All data associated with this project are available from Silvio De Angelis at silvioda@liverpool.ac.uk. All data and derived data products, including a complete catalogue of explosions recorded at Santiaguito between 2014 and present are also publicly available through the archives of the UK National Geoscience Data Centre https://www.bgs.ac.uk/services/ngdc/accessions/index.html? (search for: Santiaguito). All data are also publicly available from INSIVUMEH.

Photos and Videos*

Please provide the GWB office with relevant photos and videos of people, places, and activities to document the project and for later use on the website, social media and other venues for sharing about the GWB program's impact. In the space below, describe how you will make the media available and when the office can expect to receive the items.

Any media material can be requested personally to Silvio De Angelis. Depending on file size the material will be shared either via email or a data transfer service/protocol.

References

Refrences*

List all references to previously published work cited in the report. Provide complete citations, following the SEG guidelines to authors for articles in *Geophysics* and *The Leading Edge*. We encourage use of the digital object identifier (DOI) number for citations, when available.

Carter, W., A. Rietbrock, Y. Lavallee, E. Gottschaemmer, A. Diaz-Moreno, J. Kendrick, and S. De Angelis, 2020, Statistical evidence of transitioning open-vent activity towards a paroxysmal period at Volcan Santiaguito (Guatemala) during 2014-2018: Journal of Volcanology and Geothermal Research, 398, doi:10.1016/j.jvolgeores.2020.106891

De Angelis, S., O. Lamb, A. Lamur, A. Hornby, F. Von Aulock, G. Chigna, and A. Rietbrock, 2016, Characterization of moderate ash-and-gas explosions at Santiaguito volcano, Guatemala, from infrasound waveform inversion and thermal infrared measurements: Geophysical Research Letters, 43(12), 6220-6227, doi:10.1002/2016GL069098

Gottschaemmer, E., A. Rohnacher, W. Carter, A. Nuesse, K. Drach, S. De Angelis, and A. Rietbrock, 2021, Volcanic emission and seismic tremor at Santiaguito, Guatemala: New insights from long-term seismic, infrasound and thermal measurements in 2018-2020: Journal of Volcanology and Geothermal Research, 411, doi:10.1016/j.jvolgeores.2020.107154

Hornby, A., Y. Lavallee, J. Kendrick, S. De Angelis, A. Lamur, O. Lamb, and G. Chigna, 2019, Brittle-Ductile Deformation and Tensile Rupture of Dome Lava During Inflation at Santiaguito, Guatemala: Journal of Geophysical Research Solid Earth, 124(10), 10107-10131, doi:10.1029/2018JB017253

Johnson, J., A. Harris, S. Sahetapy-Engel, R. Wolf, and W. Rose, 2004, Explosion dynamics of pyroclastic eruptions at Santiaguito Volcano: Geophsical Research Letters, 31, L06610, doi:10.1029/2003GL019079.

Rohnacher, A., A. Rietbrock, E. Gottschammer, W. Carter, Y. Lavallee, S. De Angelis, and G. Chigna, 2021, Source Mechanism of Seismic Explosion Signals at Santiaguito Volcano, Guatemala: New Insights From Seismic Analysis and Numerical Modeling: Frontiers in Earth Sciences, 8, doi:10.3389/feart.2020.603441

W. Rose, 1972, Santiaguito volcanic dome, Guatemala: Geological Society of America Bull., 83, 1413–1434

Current and Planned Abstracts, Articles, and Presentations*

List all current and planned abstracts, journal articles, and presentations based on the project.

De Angelis, S., A. Rietbrock, Y. Lavallee, W. Carter, P. Wallace, E. Gottschämmer, and A. Rohnacher, 2019, An International Partnership to Develop Volcano Monitoring Capacities in Guatemala: SEG Technical Program Expanded Abstracts 2019, 4782–85, https://doi.org/doi:10.1190/segam2019-3215154.1.

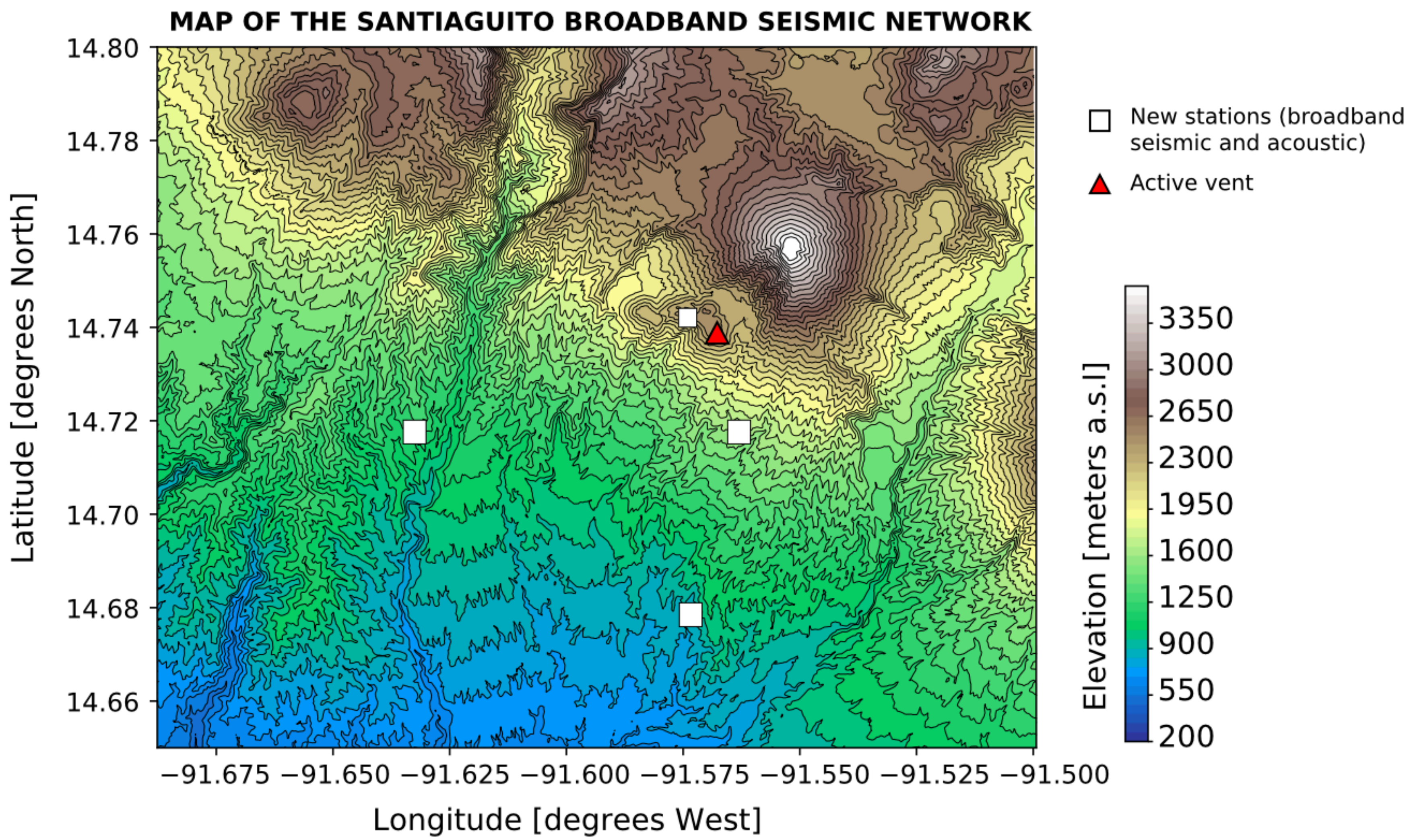
File Attachment Summary

Applicant File Uploads

- f6219366-ee60-4acd-935e-36c53fbf8c4a.kmz
- c004c792-417e-4cb9-977e-c0487efd31df.pdf
- NCR10248 - Figures for financial report Sep 21.xlsx

Supporting Documents

No files were uploaded


MAP OF THE SANTIAGUITO BROADBAND SEISMIC NETWORK
14.80
14.78
14.76
14.74
14.72
14.70
14.68
14.66
Latitude [degrees North]
−91.675 −91.650 −91.625 −91.600 −91.575 −91.550 −91.525 −91.500
Longitude [degrees West]
New stations (broadband seismic and acoustic)
Active vent
3350
3000
2650
2300
1950
1600
1250
900
550
200
Elevation [meters a.s.l]