DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2015/7

Volcanic surveillance techniques at Volcán de Colima, Mexico, 2014

Internship at GEUS with volunteer work at Universidad de Colima, Mexico

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

G E U S

Contents

1. Abstract

As part of an internship at the Geological Survey of Denmark and Greenland the author of this report spent 2.5 months (September-November 2014) to carry out volunteer work at Universidad de Colima in Mexico as an office and field assistant on the nearby volcano, Volcán de Colima. The volcano is one of the most active volcanoes in the Americas and is therefore under constant surveillance by University de Colima under the program '*Centro de Intercambio e Investigacíon en Volcanología' (CIIV)*, which is led by Dr. Nick Varley.
One of the main outcomes of this program is to produce a volcanic hazard map, and keep this updated based on the continuous monitoring of the volcano. The actual surveillance work led by the university is to a large extent carried out by geology students and graduates from around the world, thus providing a welcome opportunity to gain practical experience in collecting and analyzing data from an active volcano like Volcán de Colima.

The work consisted mainly in fieldwork, different computer analyses and laboratory work. The field work was carried out from several camp sites distributed around the volcano within a distance of 3-8 km from the volcano summit (Appendix). Usually four persons attended weekly field trips that each lasted for 2-4 days. A variety of methods were implemented during this surveillance study under CIIV; each method is described in detail in this report.

The field work involved collection of infrared data, digital photography and SO_2 measurements. Often equipment for CO_2 measurements was also brought along to measure gas releases from the soil. Samples of volcanic ash and rock samples were collected on a monthly basis to keep updated with the latest pyroclastic flows or big, ash-producing explosions. Similarly water samples were collected at the springs around the volcano every month. Different monitoring stations equipped with radar, infrasound, radon probe and precipitation gauge are located around the volcano; these stations were visited once a month for data tapping.

2. Introduction

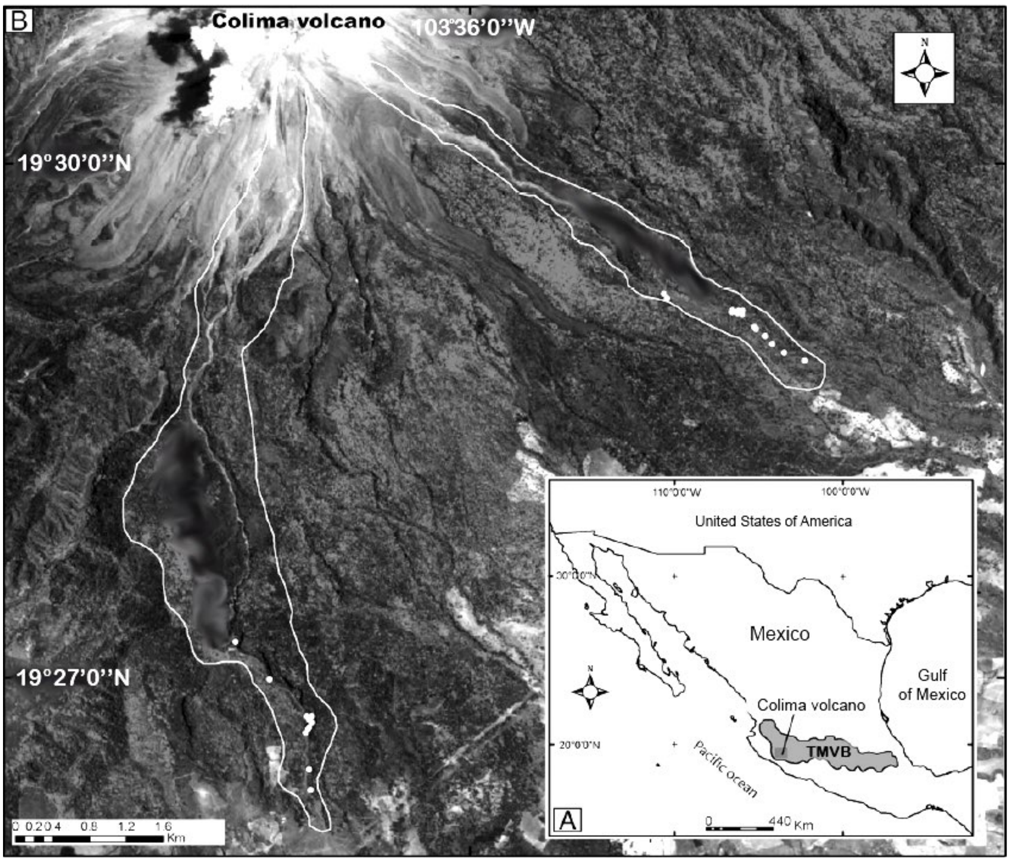

Figure 1. *Location of Volcán de Colima in the volcanic belt in Mexico (TMVB) (A) and an indication of two of the main ravines on the volcano (B)(Franco-Ramos et al., 2013).*

Volcán de Colima is located in the western part of Central Mexico (103°61'W, 19°51'N) (Fig. 1). The volcano is a stratovolcano of andesitic composition and the youngest in the volcanic complex, which consists of two other extinct volcanoes. The volcano has been rather active for the past 300-400 years with both plinian and subplinian eruptions through the 19th and 20th century (González et al., 2002). The volcanic activity has mostly been dominated by low effusion of blocky lava, daily explosions dominated by ash and gas and often also pyroclastic flows. The main risks of danger at the volcano are pyroclastic flows and the possibility of volcanic mudflows (lahars), which mainly occur during the major thunderstorms in the rainy season. Historical data shows that these phenomena have previously traveled over distances of up to 15 km (Franco-Ramos et al., 2013), affecting the nearby villages. The volcanic activity was mainly dominated by rock falls and lava flows during the length of the authors stay in the fall of 2014, and prior to that consisted mostly of explosions. In September 2014 large rock falls would occur within few minutes of each other. This happened from the southwestern flank of the volcano, where a big blocky lava flow was slowly moving down the flank. By the end of October the lava flow reached the end of the flank and therefore met a flat area, bringing an end to the movement and the associated rock falls. As a result of this, the volcano resumed its small gas-ash explosions, which had been the prevalent activity throughout the year until the lava flow eruption started. After a longer field trip to the old volcano peak, Nevado (duration of four days, 17/11 to 20/11 2014), the volcano appeared unusually calm. During this fieldtrip only a handful of rock falls were observed and even fewer explosions. This changed on November 21st when a big explosion from the volcano occurred. An ash column of 5 km height emerged from the volcano summit and the collapse of the column resulted in pyroclastic flows down the flanks (Fig. 2). The explosion was one of the biggest since 2005. Fortunately the pyroclastic flows did not create much damage to the vegetation and equipment stationed on the volcano due to their rather low temperatures.

Figure 2. *The vulcanian explosion on the 21.11.2014 with an ash column of c. 5 km.*

2.1. Personal responsibilities

At the office I was in charge of organizing field trips to the volcano by having the overview of what data needed to be collected and when, as well as what equipment to bring. During the field trips I was responsible for the photographic documentation using a Nikon D90 Digital Single Lens Reflex (DSLR) camera, and for collecting rock and ash samples for various analysis purposes. I performed several other field techniques during the program, which are all described in the following section. I attended all field trips during my stay: 12 trips of 24 days in total. At the office I was in charge of data organization and homepage maintenance. I also aided in seismic and thermal analysis, as well as repairing computers, pH-meters and GPSs.

3. Methods

3.1. Infrasound

Around the volcano there are three infrasound stations installed to observe the volcanic explosions on a semi-continuous basis. Pressure sensors, recording low frequencies emitted when quickly expanding gas escapes the volcano, indicate occurrences of explosions. The infrasound data is used to localize and define the source mechanism of the explosions. The stations are visited monthly to download the data collected by data cubes. The data cube is set up with a solar panel and packed in plastic cans to avoid moisture. This setup allows for uninterrupted data collection for time periods of up to six months.

3.2. Radar

Radar measuring equipment is installed on the volcano collecting data by. Measuring radar is a quite new practice with only few others like it in the world. It is equipped with radio wave receivers, which are highly usefull during ballistic explosions from the volcano, as data collection is independent of visibility and weather conditions. Thus the instrument will measure and calculate volumes of projectiles ejected during explosions in any kind of weather. There has not yet been software developed for processing the data, so the work with the radar station is temporarily just data collection. With the database the software should be able to detect eruptions and estimate ash amount distribution.

3.3. Radon

There is a stainless steel probe installed at Monte Grande continuously measuring the amount of radon emitted from the soil with an alpha scintillation counter. The radon measured is the isotope ^{222}Rn. The isotope is formed during the decay of ^{225}Ra, which derives from the decay of U to Th. The radon leaches out of the soil and a release can indicate degassing or changing locations of the magma, making radon measurements quite valuable in a volcanic survey. The data from the probe can be transferred with a computer and should be collected regularly.

3.4. CO_2

CO_2 is a typical gas being emitted at volcanoes. It is released from the magma and travels up through fractures and faults to the surface and the rate of gas released is therefore related to the volume of magma body. With a soil gas flux meter, *LI-8100A Automated Soil*

CO_2 Flux System (Licor®), the amount of CO_2 gas emitted from the soil can be measured. This is done in varying distances to the volcano to localize potential faults or pathways, where the gases can escape to the surface. The measurements are performed in a round accumulation chamber of metal, which placed on the ground, creates a vacuum around an area of soil, where the gas emitted from the soil is then measured in the connected analyzer for two minutes. The chamber of the probe is set up to a LI-8100A® system (yellow suit case in Fig. 3) from where the chamber is controlled, the gases are analyzed and the data stored. Data is then viewed immediately by a LI-8100A® application on an iPod® device. Upon arrival at the office the CO_2 flux measurements are then transferred to a computer (imported into an Excel® spread sheet), where they are organized and used for later interpretation. Based on these results anomalies are identified and from those a map localizing gas rich areas and gas pathways including faults can be mapped as well as obtaining an image of the fluctuations in CO_2 emission.

Figure 3. *Measuring for CO_2 in the field of La Mesa.*

3.5. Seismic

In another department at the University, *Red Sismológica de Colima* (RESCO), seismic data are collected at different stations around the volcano. The volunteers in the CIIV program also are involved in analyzing these data. This is done by the computer software, *Didger®* (GoldenSoftware), which enables to geo-reference and digitize the data. The software also allows for the different types of seismic signals to be picked manually, which then enables for a statistical evaluation of the frequency of the different events using Matlab®. The events include rock falls, explosions, and degassing and minor tremors.

3.6. SO_2

There are several ultraviolet-spectrometers available in the CIIV program to measure SO_2 gas emission from the volcano. Flyspec® is the main instrument used alongside COSPEC®. The emission rate of gas is measured by this equipment and gives an insight into pressure, temperature and chemical changes around the volcano, with particular peaks during explosions. SO_2 is highly ultraviolet absorbent, and so the spectrum will be influenced in the case of SO_2 gas molecules present. The spectrometer uses scattered sunlight as its light source and scans through the sky comparing the spectrum to calibration cells with standard concentrations of SO_2. From the amount of energy absorbed and the wind speed the Lap-Fly V4® software computes the accurate SO_2 emission rate. Flyspec® is stabilized on a tripod and orientated towards the volcano during periods of clear sky and sunshine (Fig. 4). Different setups of the spectrometer are possible by changing the integration time and mirror range. On the computer the unit shows an instant image of the measured spectrum, calibrations and calculations of the recorded spectral and graphic plots of the measurements correlated with position and timing. A scan should take a minimum of 20 minutes to produce a useful plot for analysis. After the data has been collected in the field it needs to be analyzed in a computer in a MatLab® script created by the USGS Hawaii department. The script aids in the analysis of data and calculations of total amount of gas emitted from the volcano.

Figure 4. *Setup of VarioCAM HD® infrared camera on the left and Flyspec® spectrometer on the right.*

3.7. Infrared

The CIIV program has field equipment for collecting infrared data. Two thermal cameras measure the temperature conditions on the volcano. The newer camera, *VarioCAM HD infrared camera (8-14 microns*)®, records images in high resolution (Fig. 5) and, depending on weather and distance to the volcano, provides a good estimate of the temperatures on the volcano. The images are recorded every 3-4 seconds so that the volcanic activity is observed in great detail. In this way, explosions, fumarole activities, rock falls and lava flows are constantly being monitored and tracked. The temperature variations, heat fluxes and cooling rates are analyzed continuously to track the evolution of crater and lava flows. Changes in these are important and useful precursors of eruption onsets. This is performed in the computer software *Irbis*®*,* which is used to visualize and analyze thermal data.

Figure 5. *Recordings of infrared images on the thermal camera in front of Volcán de Colima. On the screen the progressing lava flow on the southern flank is indicated by the red colour. Location is La Mesa, which can be found on Figure A1 in Appendix.*

3.8. Photography and video

The thermal images are collected in conjunction with simultaneously recorded photographs and video recordings. The photographs are in such high quality that they are also used to calculate the volume of rocks during rock falls. Overnight photographs depend highly on the amount of moon- and artificial light determining the exposure time of the pictures. In cases of high amounts of light the exposure time will be less than a minute and this creates a high amount of pictures that is then used to create time lapses to study the dynamic behavior of the volcano. In case of lower light the exposure time on the camera can be up to 4 minutes, creating long exposure photos (Fig. 6). These recording sequences give a good understanding of both source and extent of the rock falls. Both the DSLR camera and the infrared camera are used on a monthly flight around the volcano to observe the summit close up.

Figure 6. *A four minute exposed photo of the volcano during night, showing the incandescent rocks, descending from the lava lobe and glowing due to their heat. Recorded at La Mesa (see Appendix).*

3.9. Water samples

There are three springs identified in the area of the volcano from which water samples are collected on a monthly basis. The three localities are: La Lumbre (Fig. 7), Cordoban and San Antonio (see Appendix). During water sampling measurements are collected at the springs, including pH, conductivity, temperature, TDS and redox potential of the water. The springs move around in the area, due to the varying amounts of rain fall and vegetation, so often it is necessary to localize different springs in the area and measure them to locate the warmest spring (usually around 30°C with a distance to the volcano of c. 6 km). The warmest spring represents the most unaltered collection of ions collected by the water from gases emitted through the soil around the volcano. Measuring the spring waters therefore gives an idea of acidity and amount of ion in solution in the water affected by the volcano, two features that convey a lot about the volcanic activity as well as the changing quality of drinking water in the villages nearby. When the water samples have been collected, two drops of HNO_3 acid are added. This is performed in the university laboratory and afterwards they are transferred to a different laboratory where measurements for Mg^{2+}, Cl^- and B^{3+} are performed. These chemical elements correlate with volcanic activity. E.g. the amount of boron will increase during periods of eruption and prior to explosions. Chloride will increase during magma degassing.

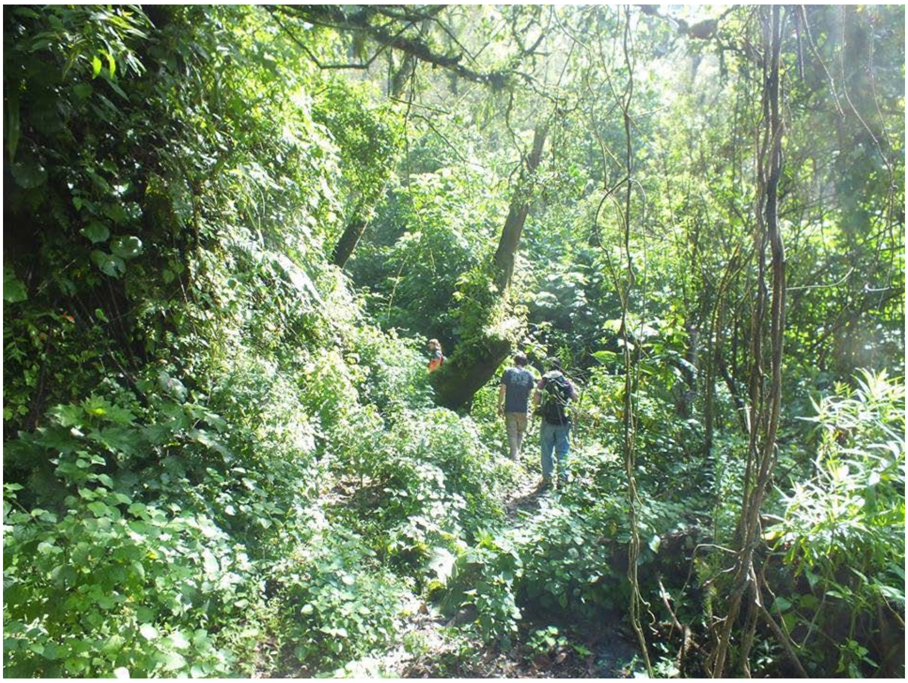

Figure 7. *Hiking through the jungle to collect water samples at the La Lumbre spring.*

3.10. Ash and rock samples

Both ash and rocks are sampled around the volcano. Ash, which is emitted during explosions, is collected in buckets. Six buckets are located within a radius of 1-5 km away from the volcano. The buckets are visited every second month, where the ash is sampled into zip lock bags and brought back to the laboratory. During high activity of rock falls, lava flows and pyroclastic flows, the team will also collect fresh rock samples (Fig. 8, 9). These samples are identified by being the warmest in the area. Collecting these samples can be quite dangerous since they have to be collected up the flank of the volcano and rock falls can frequently occur, with boulders the size of cars tumbling down the flank. At current time the rock and ash samples are put in storage, but not further analyzed.

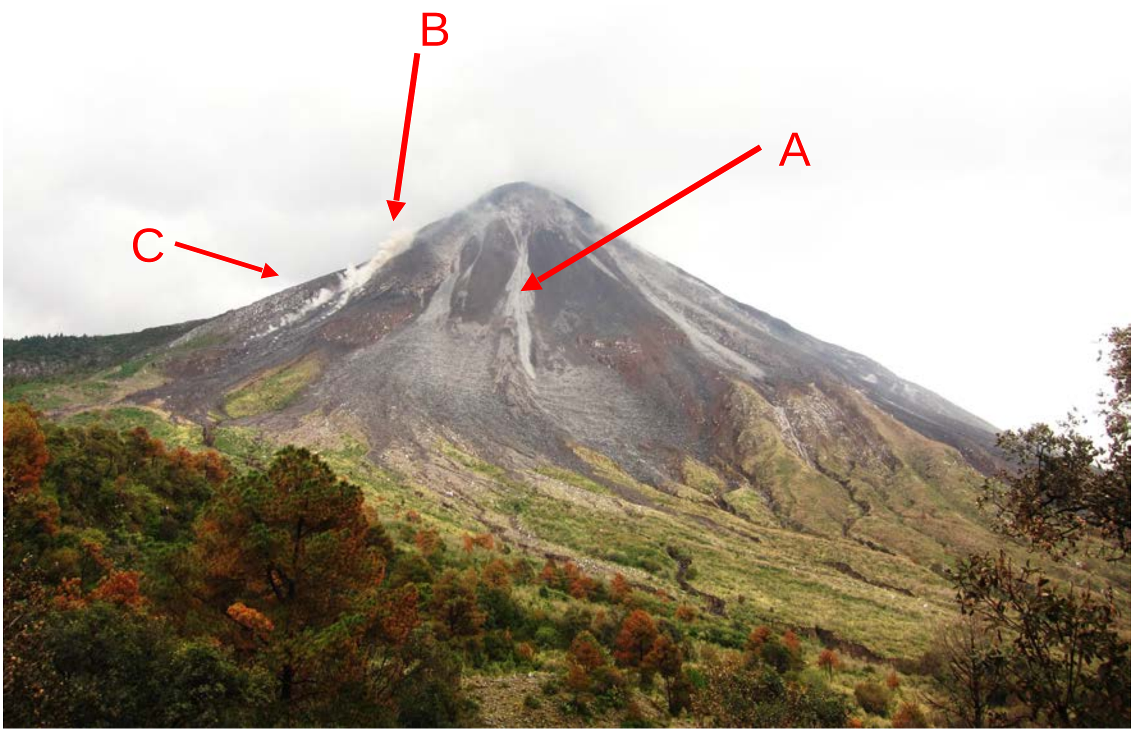

Figure 8. *The volcano seen from Playon (west) with indications of freshly deposited pyroclastic flow (A), an occuring rock fall (B) and where rock samples are collected (C). In the foreground the pine trees have a characteristic yellow-orange colour, which is most likely due to soil gas discharge causing tree mortality.*

Figure 9. *The aftermath of the explosion on the 21st of November (Fig. 2). Note the termination of the pyroclastic flows is clearly seen by the change from gray, ash covered to green non-ash covered vegation.*

4. Conclusion

The different field methods described here all contribute to the continuous surveillance of this extremely active Volcán de Colima. Responsible for the work are the department of '*Centro de Intercambio e Investigacíon en Volcanología' (CIIV)*, *Red Sismológica de Colima* (RESCO) and *Observatorio Vulcanologico* (all institutions affiliated under the University of Colima), in collaboration with the *Protección Civil y Bomberos* of Jalisco and Colima. The main objective of the surveillance program is to attain an enhanced understanding of volcanic systems, improve the quality of monitoring at the volcano, as well as provide early warnings of volcanic activity that might pose a hazard to the local inhabitants, and to advice governmental bodies about evacuation schemes. The CIIV department is currently working on using the high amounts of data collected to produce a hazard map that illuminates the areas in risk of volcanic impact, while the seismic network (RESCO) and the observatory informs the civil population of potential alert situations. Most of the data collected through the CIIV program, and described in this report, are used for later academic research.

The magma emits different chemical components while moving around and several of these are measured both in gaseous and aqueous state. CO_2 is rather insoluble in water and is therefore released from the magma very early on allowing the gas to percolate through the soil on the flanks of the volcano. Radon is also measured in the soil on the flanks. SO_2 is more soluble in water than CO_2 and it therefore separates from the magma at a later stage, which is why it is measured in the gas plume ascending from the volcanic crater. Fluids percolating the soil around the volcano also collect many ions that correlate with the volcanic activity, such as Mg^{2+}, Cl^- and B^{3+}. These chemical variations are likely also observable in the ash and rock deposits. Crater and lava flow evolution, as well as fumarole activity were monitored by the use of an infrared camera. It is important to make notice of the crater shape and size in case of plugging of the vent, which can cause big and catastrophic explosions, as the case of Mount St. Helens in 1980. Data from the infrasound and radar stations offer insights into the origin and size of the balistic projectiles as well as achieving an understanding up the eruption style and eruption frequency. Along with seismic, infrared, gas flux and photographic recordings it is possible to obtain a better understanding of fluid transport pathways and conduit processes (Johnson et al., 2004). Altogether, this provides a basis for better understanding of the dynamics of a volcano and predict future volcanic events.

5. References

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Appendix

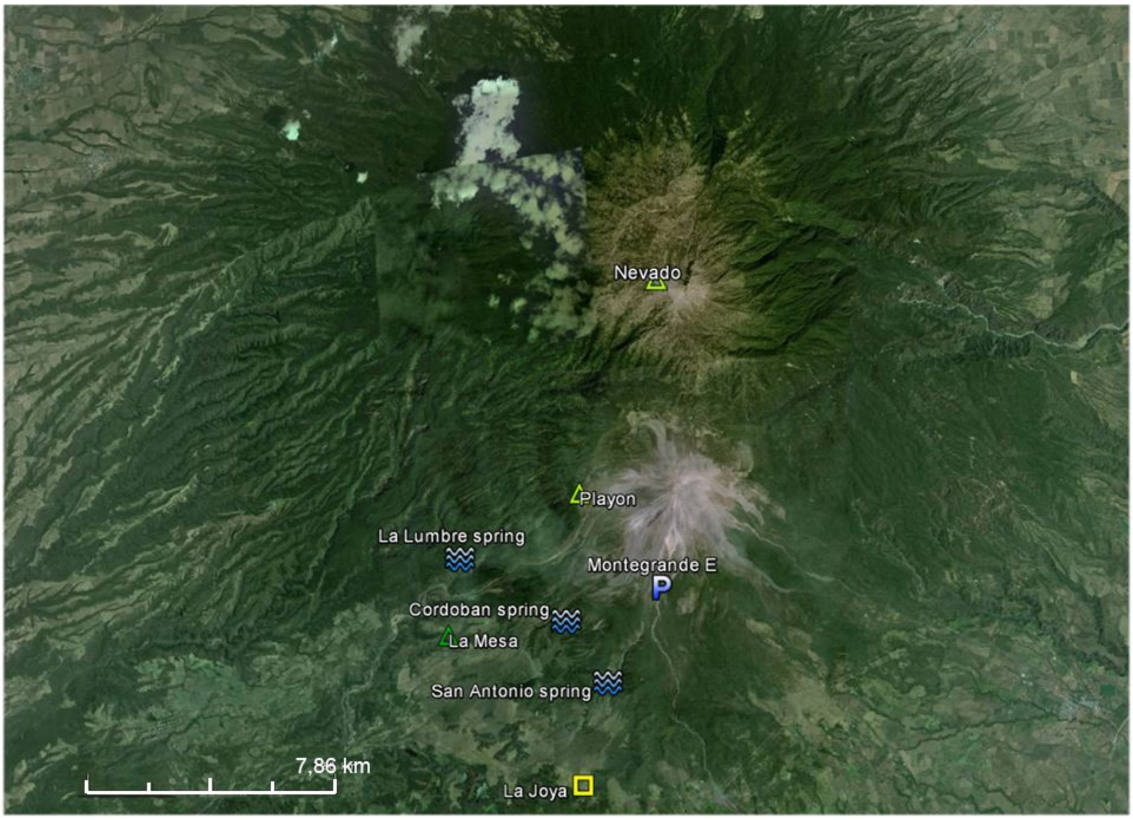

Figure A1. *Map indicating different localities around Volcán de Colima.*

La Mesa

In the fall of 2014 this was the most frequently used camping site since it was located on the southwestern side of the volcano from where a blocky lava flow was moving down the flank. This resulted in frequent rock falls. La Mesa is also an easy accessible location and it is possible to stay at a local avocado farm that offers electricity, toilet and kitchen facilities. From La Mesa it is easy to access La Lumbre, one of the spring locations (Fig. A1).

Monte Grande

Monte Grande is the area that hosts most of the data stations at the volcano. It is located on the southern flank of the volcano (Fig. A1), but as it is situated out of sight of the main lava flow, that progressed during the fall of 2014, it was less relevant for monitoring the main activity in that time period.

Playon

Playon is the camping site located closest to the volcano with a distance to the summit of 3 km (Fig. A1). It is one of the most interesting localities since the close location allows great observations of pyroclastic flows. Unfortunately the location is at times rather difficult to reach by car. The trip easily takes 4-5 hours depending on potential landslides and fallen trees. It is essential to bring shovel and axe for these trips, as well as solar panel and car batteries to keep the equipment running for days.

Nevado

This is the peak of the old volcano in the complex, which is located just north of the active volcano (Fig. A1). Up at 4,000 meters elevation is an observatory, which is staffed by the civil protection force of the area. They keep constant track of the volcanic activity by web-cams around the volcano. This is a good locality to measure temperatures on the fumaroles since most of them occur at similar altitude. Furthermore, the observatory provides a warranted shelter for overnighting as the outdoor temperatures usually tend to be close to freezing at night.

La Joya, Cordoban & San Antonio

La Joya is a farming area approximately 8 km distance from the volcano (Fig. A1). It offers open areas great for observations and access to the localities of Cordoban and San Antonio. These are located in the jungle where two of the springs can be found.