The 2006 Earthquake Swarm in the Sulu Range, Central New Britain, Papua New Guinea

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Summary

In July 2006, unusual earthquake activity commenced in the Sulu Range area, Central New Britain, Papua New Guinea, accompanied by vigorous activity in neighbouring hot springs. This region has not been active in historic times, so these events caused alarm and resulted in evacuation of the area because of the possibility of volcanic eruption. Digital seismographs were installed by Rabaul Volcanological Observatory and Geoscience Australia at five sites and approximately 2000 events were recorded per day during the peak of the activity. The majority of the events of the earthquake swarm are concentrated in a cylindrical cluster about 2 km wide, extending southwest from the Sulu Range for a distance of about 13 km at a depth between about 4 and 9 km. They are confined to the northeast of a plane passing through the location of a magnitude 6.4 earthquake which occurred prior to the deployment. It is inferred that this demarcation marks the location of a major strike-slip fault trending northwest-southeast. Detailed analysis of the swarm, together with USGS InSar radar data and ground levelling will constrain the location of an inferred magma intrusion below the Sulu Range.

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Abstract

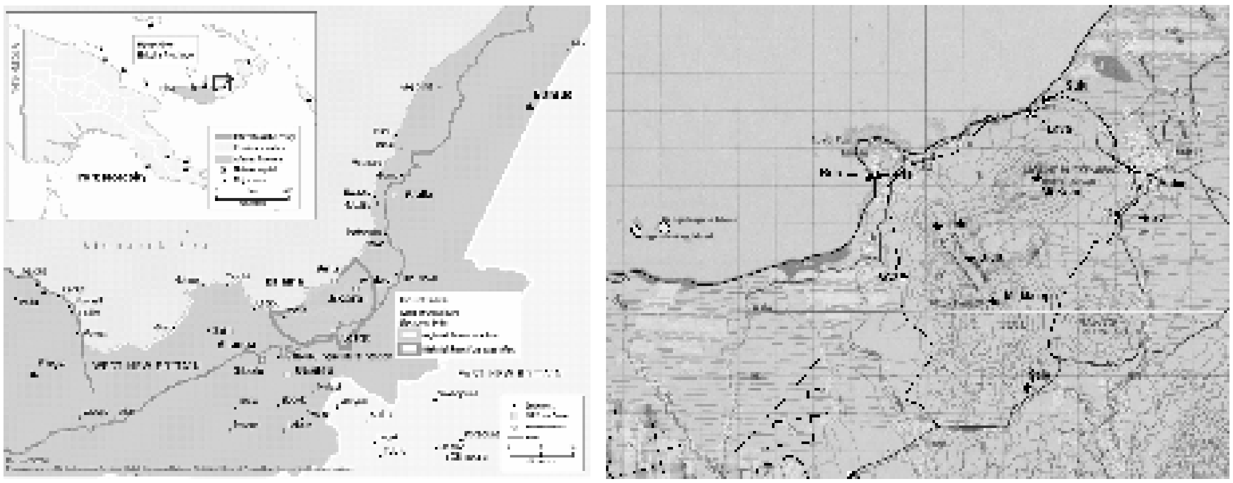
In July 2006, very considerable and unusual earthquake activity commenced in the Sulu Range area, Central New Britain, Papua New Guinea, accompanied by vigorous activity in neighbouring hot springs. This region has not been active in historic times. Fearing the possibility of volcanic eruption and the potential for tsunamis, the residents of villages in the Sulu Range area were evacuated. To locate these earthquakes more precisely, portable digital seismographs were installed by Rabaul Volcanological Observatory and Geoscience Australia at five sites in the area. Approximately 2000 events were recorded per day during the peak of the activity. Prior to the deployment, several larger events were recorded by regional stations, culminating in a magnitude 6.4 event northwest of the swarm area. The majority of the events of the earthquake swarm are concentrated in a cylindrical cluster about 2 km wide, extending southwest from the Sulu Range for a distance of about 13 km, and at a depth between about 4 and 9 km. They are confined to the northeast of a plane passing through the location of the magnitude 6.4 event. It is inferred that this demarcation marks the location of a major strike-slip fault trending northwest-southeast. A detailed analysis of the swarm is being undertaken to understand the tectonics of this event, and to constrain the location of a possible magma intrusion below the Sulu Range which was inferred from US Geological Survey regional earthquake and radar interferometry data, repeat leveling data and observations of coastal subsidence.

Introduction

On 6th July 2006, an intense swarm of earthquake activity began in the Sulu Range, Central New Britain, Papua New Guinea. There were reports of continuous shaking accompanied by booming noises and ash emissions originating from the Sulu Range, unusual vigorous activity in the hot springs, clear river systems turning milky and disturbances in the sea. The earthquakes were felt locally with modified Mercalli intensities of MM1 to MM4, almost every one to two minutes, 24 hours a day for the first two weeks or so since the onset of activity. Fearing a possible eruption, and possibly tsunami, about 1000 locals within the Sulu Range area were evacuated from their villages and oil palm blocks.

A single smoked-paper seismograph was deployed about 25km northeast of the Sulu Range by the Rabaul Volcanological Observatory (RVO) to monitor the earthquakes, but was insufficient to locate them accurately. RVO made a request for assistance to Geoscience Australia (GA) through AusAID, and five digital seismographs from GA were deployed in the area. Just prior to deployment of the digital seismographs, a magnitude 6.4 earthquake occurred about 40km northwest of the Sulu Range, causing damage to houses and cracks in the ground surface at Tarobi near the epicenter (Fig. 1).

Following the commencement of seismic activity, aerial and ground inspection did not confirm any ash emissions or new venting in the Sulu Ranges. However, the vigorous activity in the hot springs southwest of the Sulu Range was confirmed. This activity increased in intensity prior to the M6.4 earthquake, and about the same time more hot steam spots were observed for the first time in this vast geothermal area. Following the inspection, and the deployment of the GA instruments, RVO was able to issue more informative situation reports of the activity to the appropriate provincial and national authorities.



a) b)

Figure 1. Locality Map. (a) Areas which were likely to be affected by an eruption of Mt Karai are shown, as well as the evacuation centres. (b) Detailed map of the Sulu Range

Geological and Tectonic Setting

The Sulu Range consists of a cluster of five small partially overlapping volcanoes; the highest of these is Mt Karai (also called Mt Ruckenberg). They are part of the Bismarck Volcanic Arc which has formed as a result of the subduction of the Solomon Sea plate beneath the South Bismarck plate (see for eg. Johnson, 1971; Wiebenga, 1973; Woodhead and others, 1998). There are no known eruptions in recent history in the Sulu Range; however, recent geological mapping which is nearing completion may provide a clearer picture of the eruptive history.

The last documented swarm of earthquake activity in Central New Britain within the vicinity of Sulu Ranges occurred in 1979. According to Almond (1981), the earthquakes were high-frequency (HF) volcano-tectonic (VT) in nature, associated with rock breaking beneath the volcano. However, he only deployed a single broadband seismograph about 25km northeast of the Sulu Ranges at Bialla (Fig. 1), and attributed these HF events to the nearby Galleseullo (Hargy Lake) volcano.

Instrument Deployment and Data Analysis

Initially, a single smoked-paper seismograph was deployed at Bialla to monitor the activity. Later, the seismograph was moved several times a day to record at different locations, in an attempt to derive a composite epicenter location for the earthquakes. However, this was not successful due to very emergent phases being recorded at some locations. Following a request from RVO, digital seismographs from GA were deployed in the area and detailed monitoring of the swarm began on 21st July.

Five Kelunji Echo digital seismographs were deployed, equipped with 3-component seismometers of which four were short-period and one was broadband (Fig 2). Accelerometers within the Echos were also used briefly at the start of the deployment. The sampling rate was set at 100 samples per second. Each seismograph was powered by a 12V car battery which was recharged every second or third day; a replaceable 2Gb Compact Flash Card was installed and stored about 3 days worth of data. The sites were located within and around the area of earthquake activity and were selected by RVO based on the approximate epicenters of prior large events recorded on the permanent Kimbe and RVO network stations.

Data retrieval and processing was undertaken daily during the first two weeks, and later every second or third day, depending on the decline in the number of earthquakes recorded per day. Data collected from 21st July to 7th August were re-processed at GA using Antelope software to automatically pick and associate arrivals. This process identified some 8000 events.

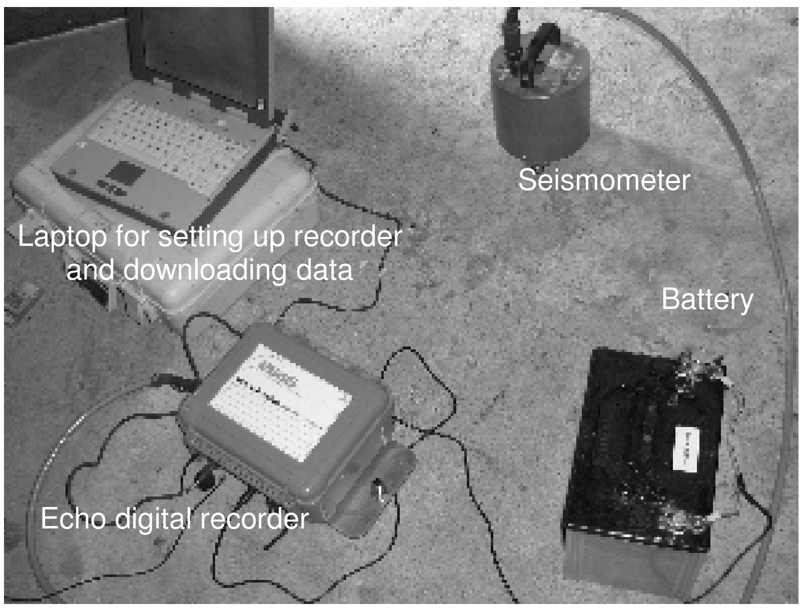


Figure 2. Setup of a temporary recording site

Daily Earthquake Occurrences

More than 2000 earthquakes per day were recorded by station KAI at Kaiamu during the first 3 days of the installation. Thereafter, the earthquakes declined steeply, but were occurring in hundreds, with above 1000 events for the next 9 days. By 6th August 2006, the daily number of earthquakes was declining at a steady rate of less than 500 events per day to less than 200 events per day for the next 13 days (Fig. 3).

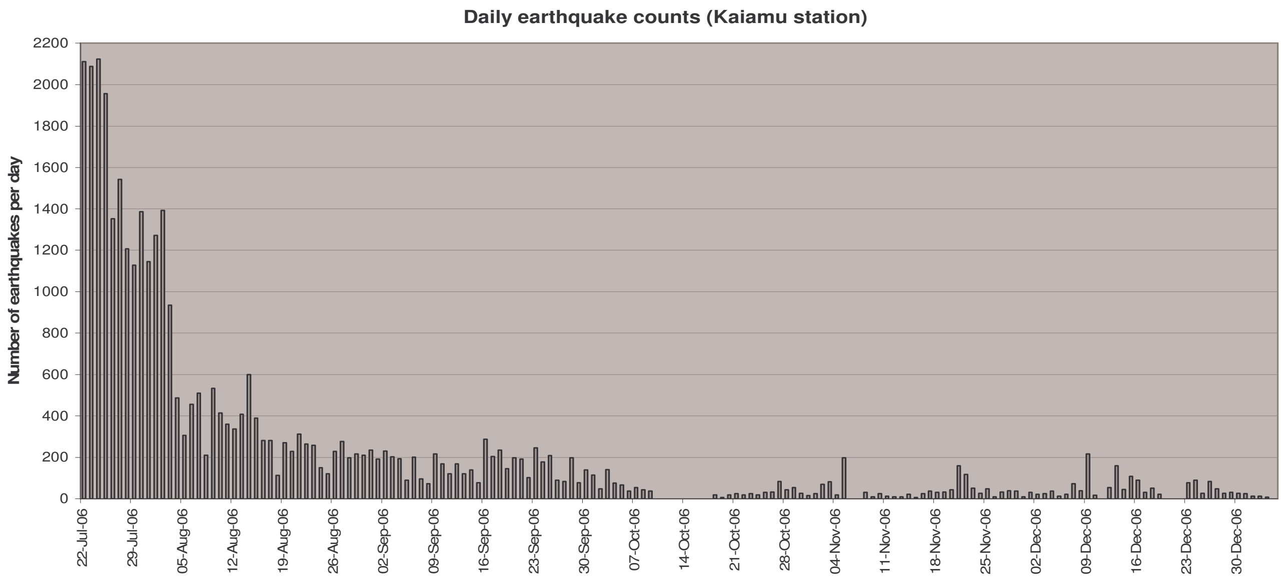


Figure 3. Daily earthquake counts at Kaiamu

The Magnitude 6.4 Earthquake of 19th July 2006

On the 19th July 2006, an earthquake measuring 6.4 on the Richter scale occurred about 40km northwest of the Sulu Range, and was followed by a magnitude 5.9 a few hours later. These earthquakes caused damage to houses in the Tarobi area and ground-surface cracks extending more than a kilometer from the shoreline along a northwest-southeast direction, parallel to the inferred strike-slip fault of the earthquake.

Violent mud expulsions from the hot springs occurred 3-4 days prior to this earthquake, and an increased number of hot steam spots were observed for the first time in the geothermal field to the southwest of the Sulu Range. This added to the fear of the locals close to the epicenters around the Tarobi area, who evacuated to higher grounds in fear of a tsunami, and thus increased the number of displaced people that were already in the Care Centers.

Observations and Results

The locations and magnitudes of a representative sample of events computed by the automatic Antelope event detection and association process were manually reviewed and displayed in a three-dimensional volume using GoCad. The majority of the events of the earthquake swarm are concentrated in a cylindrical cluster about 2 km wide, extending southwest from the Sulu Range for a distance of about 13 km, and at a depth between about 4 and 9 km (Fig. 4). They are shallowest beneath the Sulu Range cones of Ubia to the north and Malopu to the south.

The earthquakes are confined to the northeast of a plane passing through the location of the magnitude 6.4 event. This plane is also evident in a second, deeper and more diffuse cluster of earthquakes which lies below the main swarm and extends northwestwards as far as the coastline. It is inferred that this demarcation marks the location of a major strike-slip fault trending northwest-southeast.

These observations are consistent with an intrusion of magma inferred from US Geological Survey regional earthquake data and InSar radar interferometry (Wicks and others, 2007). Evidence of deformation due to intrusion is apparent in the InSar data (Fig. 5), and in the results of repeat leveling by RVO. Photographs taken in October 2007 show evidence of subsidence along the coastline north of the Sulu Range and the geothermal area (Fig. 6).

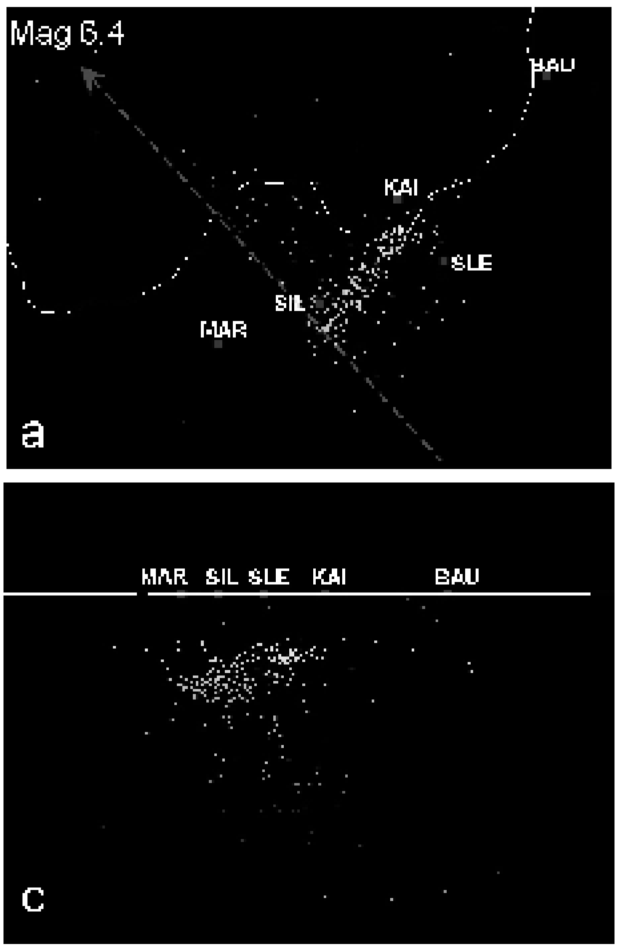


Figure 4. 3D views of the earthquake swarm. Earthquakes are shaded by depth. a) Viewed from the top, with seismic recording stations; dashed line passes through location of magnitude 6.4 earthquake and edge of swarm activity; b) From the southeast, looking along the northwest-southeast vertical plane through the magnitude 6.4 earthquake; c) From the east; d) Elevated view from the northeast, looking down the axis of the earthquake swarm.

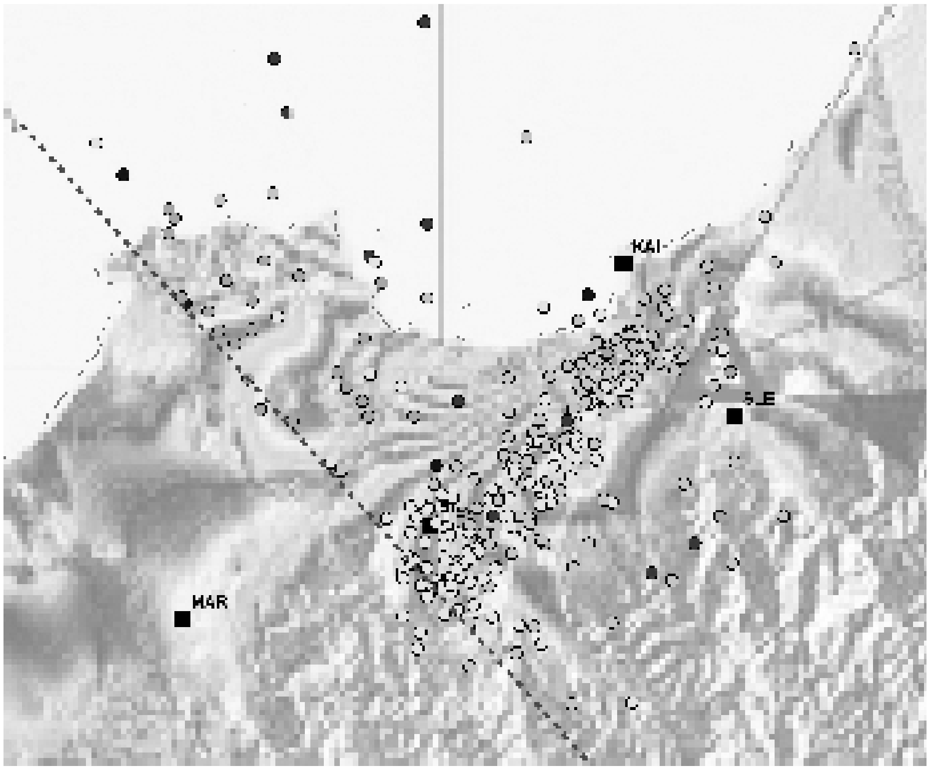


Figure 5. Radar interferometery (InSar) image and earthquakes overlain on the topography. Earthquakes are shaded by depth. Dashed line passes through location of magnitude 6.4 earthquake and edge of swarm activity. InSar Image is adapted from Wicks and others (2007).

a) b)

Figure 6. Vegetation killed by inundation of the sea along the coastline, west of Kaiamu and north of the geothermal field, where the Insar radar interferometry indicates deformation. a) Note the trees in the water; b) Kaiamu village with dying vegetation to the left (east) and far right (west). (*Photographs by John Bosco*).

Discussion

Volcanic earthquakes are commonly classified into four main categories according to source processes. The first group known as volcano-tectonic (VT) earthquakes are characterised by high-frequency (HF) spectra and clear P and S phases. They are related to shear failure within the volcano (McNutt, 2005, Caplan-Auerbach & Duennebier, 2001) and are indistinguishable from other tectonic earthquakes. The second group is low-frequency (LF) earthquakes, also called long-period or LP events that are thought to be associated with fluid processes (McNutt 2005, Caplan-Auerbach & Duennebier, 2001). They are characterised by a very emergent onset and do not have clear P and S phases. The third group is caused by volcanic explosions, and is associated with the degassing processes at the vent. They have clear P phases and a strong air-wave. The fourth group is volcanic tremor, which is the most distinctive seismic signal observed at volcanoes. Volcanic tremor is generally marked by its narrow frequency range and its long duration compared with earthquakes (McNutt, 2005).

Only volcano-tectonic (VT) events were observed during the entire duration of the Sulu Range swarm, and their waveforms appeared to be similar at all five recording sites. However, two groups of waveforms of these VT events could be distinguished. The first group, whose waveforms contain multiple phases, was observed during the initial intense period of activity and persisted towards the end of the swarm. The second group, whose waveforms consisted only of the two P and S phases, occurred later and was observed increasingly as the swarm declined.

The occurrence of volcanic earthquake swarms commonly precedes an eruption, but this did not eventuate in the case of the Sulu Range. Coupled with its unknown history of recent eruptive activity, a challenging but interesting phenomenon is presented. However, an indicative scenario is inferred from the progression of the earthquake depth ranges becoming shallower from the southwest to the northeast, indicating that any eruption would be likely to occur between Ubia, Ululu and Malopu cones (see fig 1). Determining the most probable depth at which the magma stalled is an objective of the current work. The vast geothermal area southwest of Sulu Range, which lies directly above the earthquake swarm, may have influenced the progression of the magma intrusion and resulted in the decline of the activity.

Further work will be undertaken to investigate the location and development of any intrusion during this event and its relationship to the regional tectonics. A number of different approaches will be used to reveal the presence of fluids and volatiles, including b-value spatial mapping (McNutt, 2005); spatial and temporal variations in the spectral characteristics of the earthquakes; relative amplitudes of shear-wave arrivals of both local and teleseismic events; composite focal mechanism solutions and further analysis of the seismic data set for additional and improved hypocenters.

One outcome of this research will be a better understanding of the causes and behaviour of any future earthquake swarms in the Sulu Range, so that appropriate emergency management measures can be emplaced. The findings may also be applicable to other volcanic regions in Papua New Guinea, and other areas with a similar tectonic setting.

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