THE UNIVERSITY OF THE WEST INDIES
THE SEISMIC RESEARCH CENTRE

Report on the 2015 unrest activity at Kick-'em-Jenny submarine volcano, Grenada

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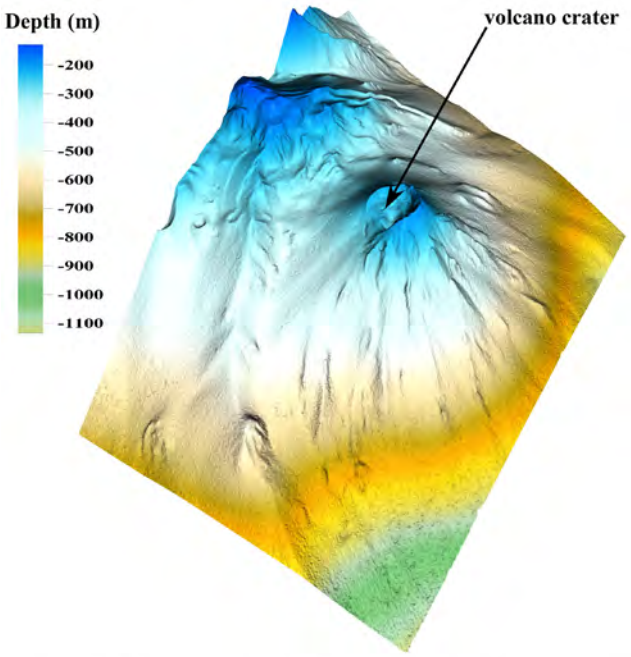

Kick 'em Jenny Submarine Volcano

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INTRODUCTION

On 23rd July, 2015 at 01:42 a.m. (local time) a strong, continuous signal was recorded on the GCMP and GRGR seismic stations, which are located at Mt. Pleasant, Carriacou and Meribu, Grenada respectively, that lasted until about 02:58 a.m. local time. Based on the strong T-phase signals that were recorded at seismic stations in Montserrat, the signal was interpreted to be an eruption from the Kick-'em-Jenny volcano. A second eruption, which lasted about an hour, was recorded the following morning, 24th July, from 00:02 a.m. These eruptions were the culmination of volcanic unrest at the volcano that began on 11th July 2015 with two earthquakes of volcanic origin and steadily increased. Following the eruptions, volcanic seismicity rapidly subsided to background.

BACKGROUND ON THE VOLCANO

Kick-'em-Jenny (KeJ) is a submarine volcano located just 7.5 km north-west of Grenada in the Eastern Caribbean, at about 12.18°N latitude and 61.38°W longitude (Figure 1). The volcano first demonstrated its presence in 1939, when numerous earthquakes were felt, and high waves affected Grenada, the Grenadines, and as far east as Barbados (Lindsay and Shepherd, 2005, Lindsay, et. al. 2005), when an explosive eruption broke the surface of the sea and produced sub-areal ash-laden columns that reached a height of 300 m above sea level [Devas, 1974]. Other historical eruptions have breached the surface producing steam and ash-laden plumes and minor waves.

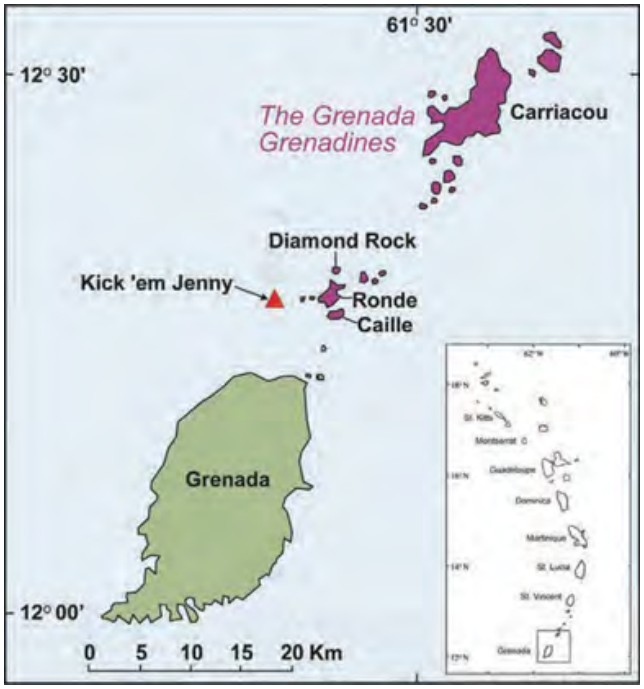

Figure 1: Location of Kick-'em-Jenny in the Grenada Grenadines.

KeJ has erupted at least 12 times since 1939 and is one of the most active volcanoes in the West Indies [Lindsay et al., 2005]; the last eruption episode occurred during the period 4th to 6th December 2001 (Table 1). The average repose period has been about six years, although during the past several decades it has erupted about once every 10 years. Some of the eruptions produce surface disturbances and minor tsunamis, whereas most have been detected only by T-phase seismic signals (acoustic waves generated from an earthquake or underwater explosion that travel through the ocean), recorded by the local seismic network [Shepherd and Robson, 1967; Lindsay et al., 2005]. The distinctive seismic signals have been interpreted to be steam bubble collapse associated with submarine eruptions [Shepherd and Robson, 1967; Lindsay et al., 2005]. Rock samples recovered from KeJ by dredging in 1972, were found to be basaltic in composition and unusually rich in amphibole megacrysts [Sigurdsson and Shepherd, 1974; Devine and Sigurdsson, 1995].

In March 2003, the crater area of KeJ was explored using a remotely operated vehicle [ROV] during cruise RB-03-03 of the NOAA research vessel R/V Brown (Figure 2). An extensive area of hydrothermal venting with gas release was discovered in the crater area of the volcano [Sigurdsson and Carey, 2003]. A water column survey of the Lesser Antilles arc found the strongest evidence for hydrothermal activity on the flanks of KeJ [Koschinsky et al., 2007], it should be noted, however, that the survey did not include the crater area due to operational restrictions. More recently (during cruises NA039 in 2013 and NA054 in 2014), the E/V Nautilus conducted detailed ROV explorations, high-resolution multibeam mapping, and sampling of KeJ hydrothermal system (Figure 3 & 4). These more recent data are still being analysed.

Date (GMT)	Description	Evidence for eruption	Ref.
July 24, 1939	Eruption cloud up to 270 m above sea level; local felt earthquakes; largest known historical eruption	Witnessed	1
Oct. 5-6, 1943	Submarine eruption; local felt earthquakes	T-phase recorded in Martinique	6
Oct. 30, 1953	Submarine eruption; earthquakes felt in north Grenada	T-phase recorded throughout Eastern Caribbean	8
Oct. 24, 1965	Submarine eruption; earthquakes of intensity V felt on Île de Ronde	T-phase recorded throughout Eastern Caribbean (and traced to KeJ)	2
May 5-7, 1966	Submarine eruptions; earthquakes in north Grenada	T-phase recorded throughout Eastern Caribbean (and traced to KeJ)	8
Aug. 3-6, 1966	Submarine eruption, 168 free T-phase recorded, shocks with intensities ≤ IV felt in Grenada	T-phase recorded throughout Eastern Caribbean	8
July 5, 1972	Submarine eruption about 5 hours long	T-phase recorded throughout Eastern Caribbean	8
Sept. 6, 1974	Material ejected into the air; sea above the volcano bubbling turbulently and spouting steam	Witnessed; T-phase recorded throughout Eastern Caribbean	8
Jan. 14, 1977	Submarine eruption. *Formation of dome*	T-phase recorded throughout Eastern Caribbean	5
Dec. 29-30, 1988	Submarine eruption; turbulent discoloured water; earthquakes felt in north Grenada. *Destruction of dome*	Witnessed; T-phase recorded throughout Eastern Caribbean	4,7
March 26 to April 5, 1990	Earthquakes felt in north Grenada	T-phase recorded throughout Eastern Caribbean	3
Dec. 4-6, 2001	Submarine eruption, earthquakes felt in north Grenada	T-phase recorded throughout Eastern Caribbean (and traced to KeJ). 600 volcanic earthquakes recorded on proximal stations	9

References: 1 = Devas (1974); 2 = Shepherd and Robson (1967); 3 = McClelland et al. (1990); 4 = Sigurdsson (1989); 5 = McClelland et al. (1989a); 6 = Molard (1947); 7 = Shepherd (1988); 8 = Seismic Research Unit, unpublished data; 9 = Lindsay et al. (2005).

Table 1: Historical activity at Kick-'em-Jenny volcano (Lindsay & Shepherd, 2005).

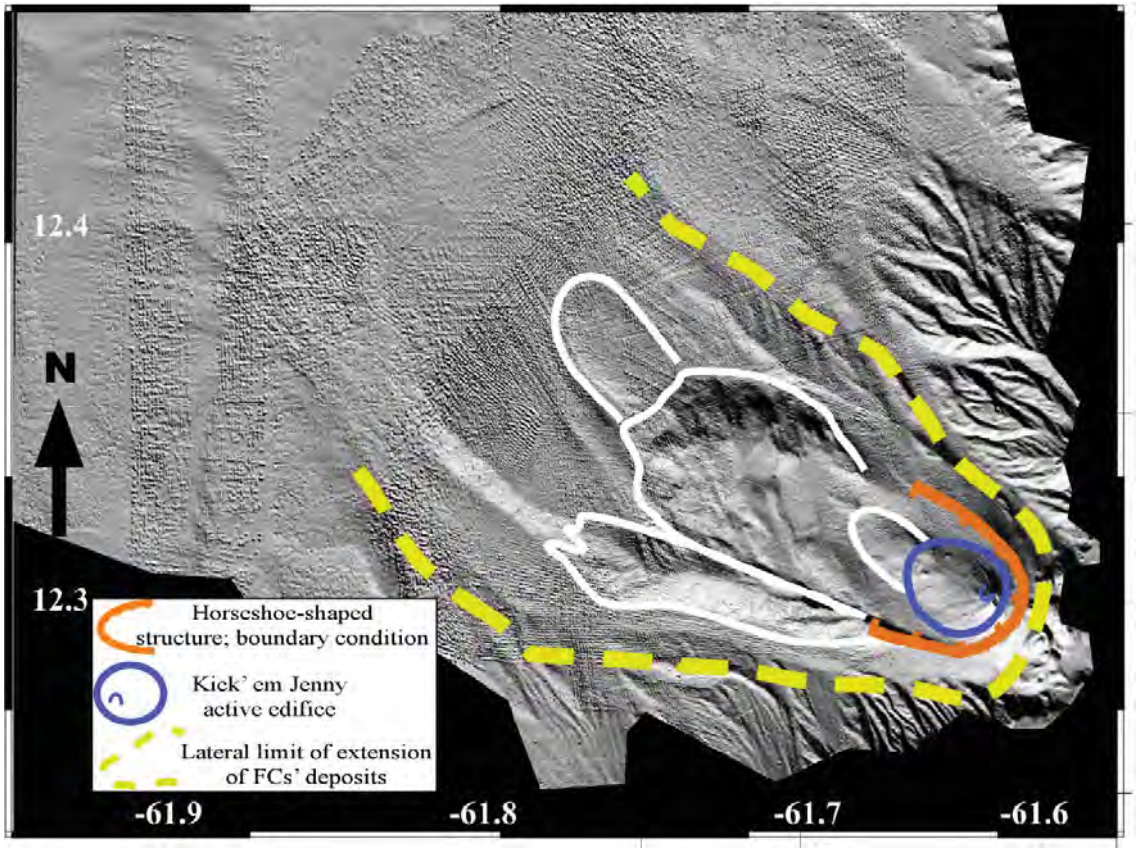

Figure 2: Map of the Kick-'em-Jenny volcano and its associated submarine landslide deposits from Lindsay and Shepherd (2005). White lines are limits of the deposits indentified by Lindsay and Shepherd (2005).

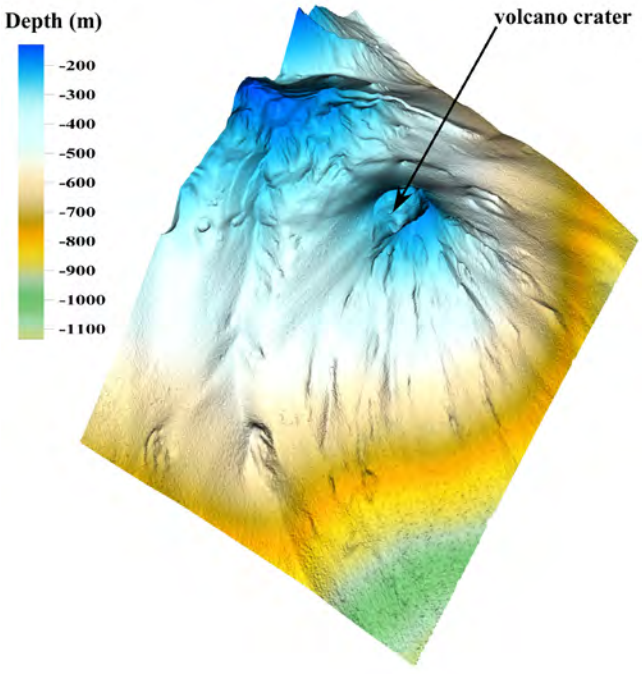

Figure 3: 5 m lateral resolution digital terrain model (DTM) of the Kick-'em-Jenny (KeJ) current edifice obtained from multibeam data collected during the November 2013 NA039 E/V Nautilus Cruise at KeJ (OET-URI-SRC).

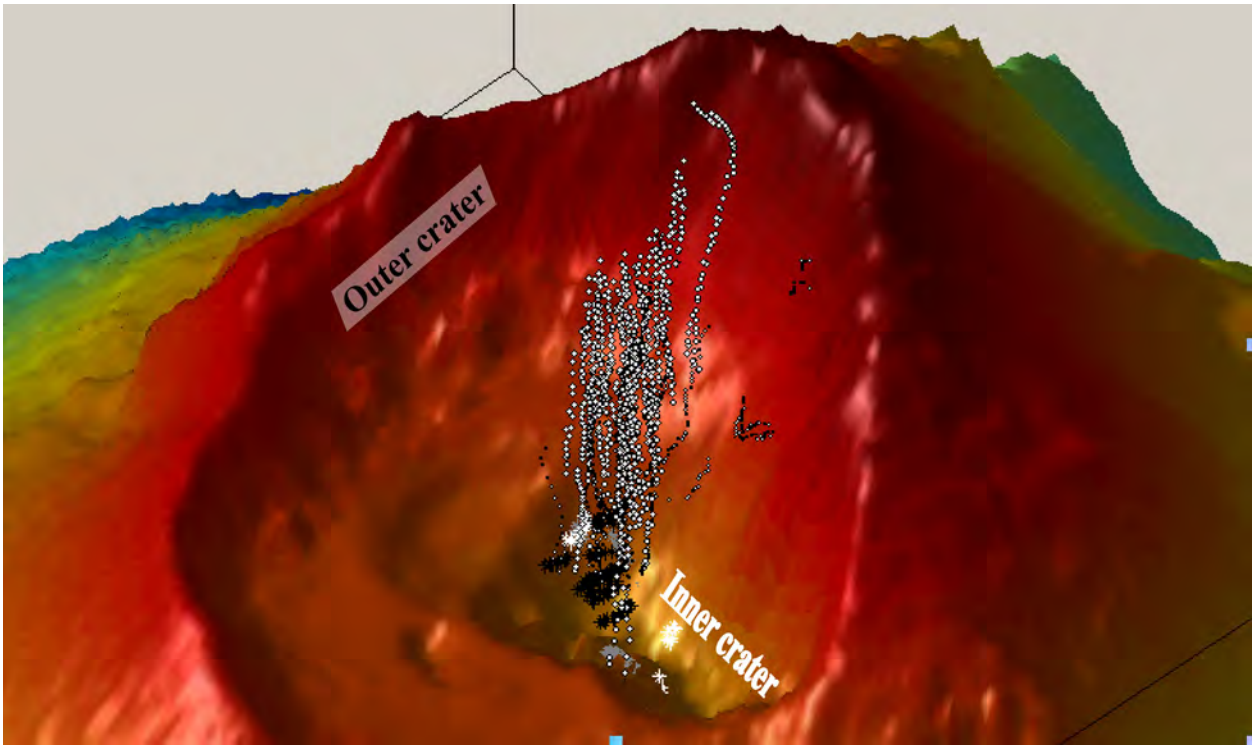

Figure 4: Active venting evidences at Kick-'em-Jenny submarine volcano: bubble streams rising up in the water column; view from the NNE side of the edifice. Image taken from Dondin and Robertson, 2015; data used with courtesy of Ocean Exploration Trust.

TSUNAMI HAZARD

Tsunami hazard evaluation at Kick-'em-Jenny were first undertaken by Smith and Shepherd (1993). In this paper the authors focused on the hazard related to potential eruption scenarios based on the Volcanic Eruption Index (Newhall and Self, 1982) and applying Le Mehaute's underwater explosion generated water waves (Le Mehaute, 1971). For the more realistic eruption scenario (VEI = 3) they showed that the highest hazards would be confined to the closest coasts from the tsunami source and to the eastern coasts of Isla Marguarita and La Blanquilla Island; though the tsunami would have hit the entire Lesser Antilles island arc. The highest run-up estimate, as high as ca. 8 meters, would be generated at the northern coast of Grenada island. In the case of a less realistic case (VEI 6) the regional tsunami would generate the highest run-up on the northern coast of Grenada (ca. 46 m) and in the Grenadines (10-30 m).

The same authors re-investigated this topic by applying a Cauchy-Poisson-Lamb model in both two and three dimensions (2D & 3D) (Unoki and Nakano, 1953a, b) for the generation of tsunami waves at the volcano considering a submarine explosion scenario disturbing the water surface. Taking into account an eruption of maximum energy ca. 2.8 x 10^{14} J and therefore a tsunami of maximum energy of 2.8 × 10^{12} J (Smith and Shepherd (1995) their 3D results showed that a regional tsunami would be generated with wave height predictions of about 4 and 0.14 m at distances of 10 and 100 km, respectively. Highest run-up, above 1 m and up to 8 m, would occur along the northern coast of Grenada and the southern Grenadines while

run-up values below 1 m would occur in the northern Grenadines and beyond. Therefore, the hazard would not extend beyond 100 km. Within the 15 minutes following the event the entire coast of Grenada and the southern Grenadines up to Canouan would be inundated (Smith and Shepherd, 1995).

Smith and Shepherd (1996) were also the first to investigate the potential tsunami hazard related to a landslide event scenario at the Kick-'em-Jenny edifice. They implemented the Striem and Miloh (1975) quantitative evaluation of tsunami wave height, which considers that the energy transmitted, is contained in a single solitary wave. For the most realistic case implying an estimated landslide volume of 0.01 km^3, this event would generate a tsunami wave of 4.5 m at 10 km distance from the source. Therefore such an event would be significantly hazardous for the northern and southern coasts of Grenada while the hazard would be low at the coast of Guadeloupe with run-up of ca. 0.6 m.

Gisler et al. (2006) reassessed the potential tsunami hazard related to an explosion scenario at KeJ. The authors used three explosion scenarios based on the Volcanic Explosion Index (VEI) with values equal to 3.7, 4.5 and 5.5, respectively. For these three scenarios they showed that the wave height would diminish rapidly due to poor coupling between the explosion energy and the wave energy. Their extrapolated wave heights at 10 km distance from the volcano are significantly less than those reported by Smith and Shepherd (1993). On the contrary Gisler et al. (2006) showed that tsunami hazard related to a potential landslide episode at KeJ would be more hazardous due to a more efficient coupling between landslide energy and wave energy.

Dondin (2010) presented results from numerical simulations of a tsunami triggered by the collapse of a proto-KeJ edifice. The initial volume of the collapse was 5.2 km^3 (Dondin et al., 2012). The tsunami generated was capable of impacting the entire Eastern Caribbean as well as Puerto Rico. The highest hazard zone was limited to Grenada, the Grenadines and the southern coast of St Vincent with the highest waves recorded ~1 km offshore of the north coast of Grenada (26 m). However along the coasts of neighbouring islands there are no deposits to support the occurrence of such a tsunami episode in the past.

Harbitz et al. (2012) presented results of tsunami exposure assessment based on first order maximum shoreline water levels taking into account wave amplification effect in the shallow bathymetry environment. Among the scenarios investigated was the collapse of 0.6 km^3 of material from the current KeJ edifice. Their results suggest that such an event could generate a regional tsunami capable of impacting not only the Eastern Caribbean, but as far as the southern coast of the Dominican Republic, as well as well a large portion of the Caribbean coast of Venezuela. Offshore, recorded maximum wave heights would range between a few tens of centimetres to ca. 5 meters. The entire Eastern Caribbean would be affected in 0-1 hr (ca. 30 min) whereas the travel time to Hispaniola would be ca. 2 h 20 min after the tsunami onset. The authors suggest that for such a scenario the highest percentages of population exposure would be in Antigua and St Lucia, at 51 % and 45% respectively. Venezuela had the highest number of people (50,000) in areas of vulnerability.

Monitoring Network

Of necessity, seismic networks operate within the constraint of an acceptable percentage of station down time. This means that rapid onset events may find some sub-networks under full capacity. Such was the case during the recent unrest at the Kick-'em-Jenny (KeJ) volcano when only two of the sub-network of five stations were operational in the days leading up to the eruption. The two stations in operation were GRGR located near the Mirabeau primary school (19 km from the volcano) and GCMP at Mt. Pleasant, Carriacou (31 km from the volcano). These two stations are equipped with state-of-the-art broadband and strong motion sensors and make use of photovoltaic (solar panel) power systems. Data are transmitted via satellite telemetry to multiple processing centres, including the Seismic Research Centre. The other three stations in the network: GRIC (located at Ille de Caille, The Grenadines), GRSS (located at the Sisters, The Grenadines) and GRHS (located at the KeJ Observatory at Sauteurs, Grenada), make use of analogue technologies, which are susceptible to frequent breakdowns due to:

a. Unreliable utilities (Internet connectivity and power) at the Observatory;
b. Deteriorated state of the physical facilities (perimeter fence and building) at the Observatory; and
c. Age, hence reliability of the instrumentation.

In March 2014, a full suite of equipment to upgrade station GRHS located at the KeJ Observatory in Sauteurs, with modern sensors and satellite communications systems was shipped to Grenada. However, the state of disrepair of this facility, made it necessary to delay installation until building rehabilitation was completed. Several metres of copper cable used for grounding the antenna systems at the Observatory had previously been stolen, possibly due to the absence of a gate. By the middle of December 2014, continuous streaming of data out of Sauteurs for periods longer than days to a few weeks became challenging. It was equally or more time consuming to have the services restored when broken. Therefore, priority was given to getting the facility repaired. Inspector Wilson obtained an estimate for the repairs and Dr. Robertson, Director of the SRC, followed up verbally and in writing with officials at the National Disaster Management Agency (NaDMA), Grenada. Repair of the badly leaking roof of the building, which posed a threat to the integrity of the monitoring equipment and the electrical installation (for example, none of the roof lighting fixtures was working), was of urgent importance. The deficiencies of the KeJ network as well as challenges to network restoration were discussed and pursued at the last two quarterly monitoring meetings of SRC. Tentative plans were made to visit Grenada in the second week of July, but this was postponed after it was discovered that any repairs to the building were very unlikely before the middle of August.

During the week of 13th July 2015, increased local seismicity was observed on the network and a local Grenada official (Inspector Wilson) was contacted and asked to try to get one or other of the two acquisition computers at the facility repaired locally. On Wednesday 23rd July 2015, it became evident that the seismic activity recorded on seismic stations GCMP

and GRGR was intensifying and that an eruption appeared imminent. Instrumentation Engineer, Lloyd Lynch therefore booked a flight to Grenada for the following day and prepared a consignment of portable digital sensors to rapidly enhance monitoring capability with three additional, temporary sites. Mr Ian Juman, Senior Engineering Technician prepared and followed with the necessary spares to restore the aging legacy equipment.

By midday on Saturday 25th, July the computer system at the Observatory in Sauteurs was restored, making two additional stations available: GRSS at Sisters and GRHS at Sauteurs. On Sunday 26th July GRSS was upgraded with a broadband seismometer and a 220-Watt photovoltaic power system. The necessary infrastructure (thermally insulated seismic vault and a digital radio link) was installed to make the operations sustainable. On Tuesday 28th July and Wednesday 29th July a temporary broadband sensor was added at Sauteurs, a strong motion sensor GRFF at NaDMA (Fort Frederick) was restored, and the analogue station site at Mt. St. Catherine (GRW) was visited to assess the feasibility of establishing a digital sensor and a digital radio link from this site to the Police Training Centre at Pearls. The SRC team deployed to Grenada returned to Trinidad on Wednesday night, 29th July. Despite all efforts expended in restoring the Sauteurs installation, the Internet connection was lost on the evening of Tuesday 28th July and did not return until two weeks later.

REVIEW OF UNREST ACTIVITY

Changes in seismicity and evolution of crisis

Unusual seismicity occurring in the vicinity of the Kick-'em-Jenny (KeJ) volcano was first observed on 11th July. This consisted of an elevated number of micro and small events recorded on station GCMP (located in Carriacou) and on GRGR station (a USGS station in Grenada). The daily counts remained low until 16th July after which it increased to 23 on 20th July 2015. Limited network capability prevented the accurate location and magnitude determination of these events, but the pattern of arrival times at GCMP and GRGR enabled SRC scientists to determine that they were most likely occurring in the area north of Grenada, possibly in the vicinity of KeJ submarine volcano.

On Wednesday, 22nd July seismic activity continued to increase such that at 18:07 UTC 170 events were recorded (cumulative counts; Figure 5). The daily count had by then increased to 105 events. These events were estimated to be of magnitude less than 3.0. At 9:15 PM local time, 48 additional events were recorded giving a total of 218 events.

On Thursday, 23rd July from about midnight to 4:00 p.m. local time, the SRC recorded more than 400 events. The largest was of magnitude 3.3 and occurred at 14:39 UTC. At 01:42 a.m. local time a strong, continuous signal was recorded that lasted until about 02:58 a.m. local time. After consultation with Roderick Stewart and Dr. Patrick Smith, SRC staff based at the Montserrat Volcano Observatory, this signal was interpreted to have been caused by an eruption, which had generated strong T-phase signals that were recorded at seismic stations in

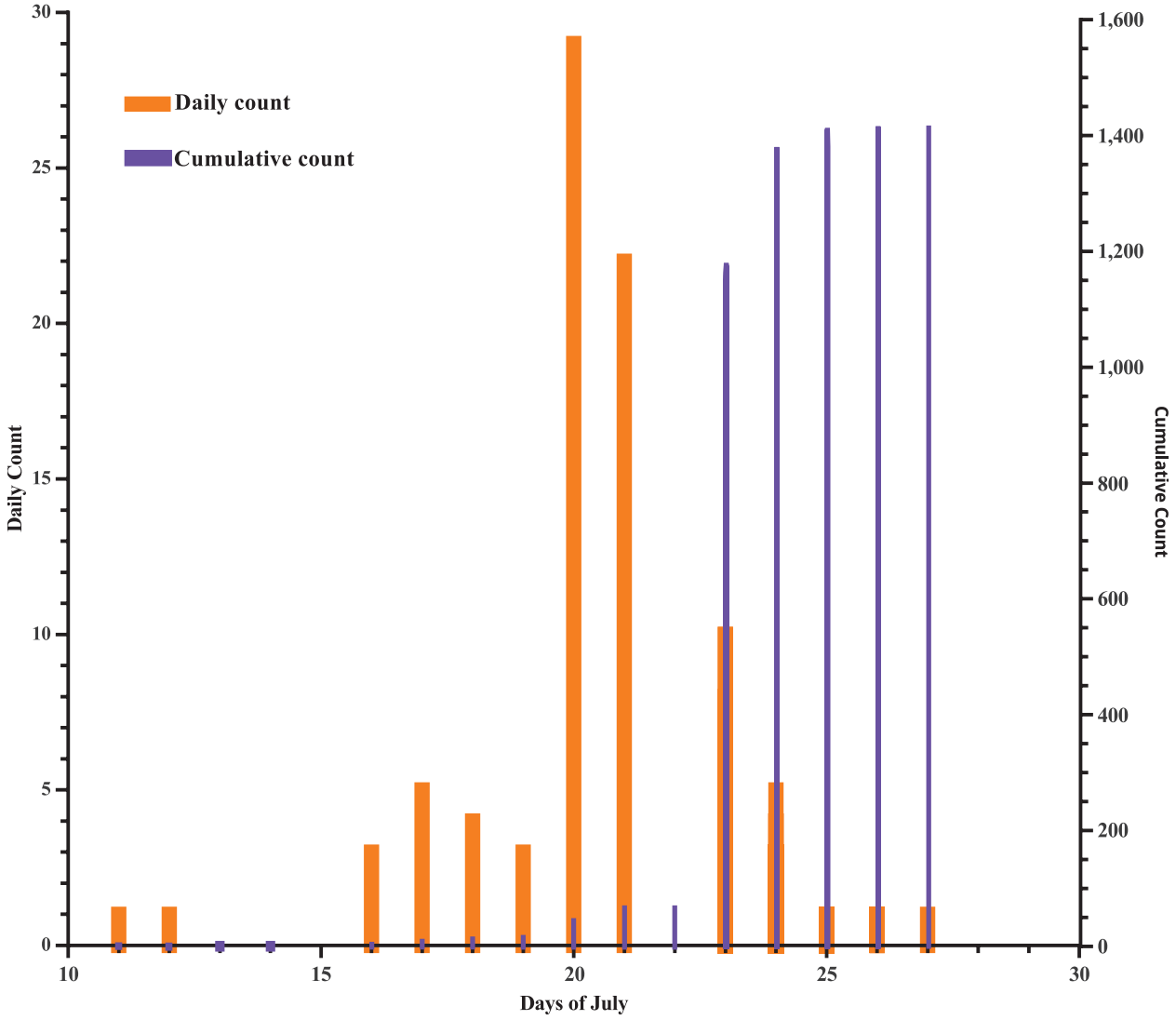

Figure 5: Daily and cumulative number of earthquakes associated with Kick-'em-Jenny unrest activity that were recorded on seismic station GCMP located in Carriacou.

Montserrat. Just prior to the eruption signal, more than 300 earthquakes had been recorded. Following the eruption, approximately100 more events were recorded, with some larger than magnitude 3.0. Local authorities confirmed to the SRC that associated with this increase in magnitude was the receipt of felt reports from northern Grenada. Based on this level of activity and given the specifications of the Alert Level System used in managing activity at the volcano the SRC suggested to the local authorities that they should consider raising the alert level. The SRC recommended that the 5 km exclusion zone perimeter be strictly enforced and that maritime interests should be vigilant in the area.

From 1:30 p.m. to 5:30 p.m. the activity level declined with about 40 events recorded during the period. The SRC informed the local authorities that it would be premature, given the pattern of multiple eruptions during past eruptive episodes, to take the decline as an indication

that the eruption episode was over. Between 5:30 p.m. to 7:30 p.m. 50 additional events were recorded and a further 90 events up to 11:30 p.m. (all at local time).

At about 00:02 a.m. on Friday 24th July 2015 the seismic network recorded another hour-long explosion signal. A T-phase signal from this event was also recorded in Montserrat confirming the nature of the activity. Following the explosion signal there were at least 70 volcanic earthquakes recorded up to 6:30 a.m. A further 19 events were recorded to 4:00 p.m. (all local time). From 4:00 p.m. on 24th July to 6:30 a.m. 25th July (all local time) less than 20 earthquakes associated with the KeJ volcano were recorded. With this decrease of activity the SRC suggested to the local authorities that they might want to reconsider the alert level.

From 6:30 am until 8:00 p.m. (local time) on Saturday, 25th July 2015, 10 events of magnitude less than 2.0 were recorded. During that afternoon an observation flight of the waters above KeJ was undertaken and no surface activity or relic of surface activity was observed. No further earthquakes associated with the KeJ system were recorded after this period and based on the absence of seismicity and any other evidence of continued activity, it was concluded that the present eruptive episode was at an end.

Satellite Imagery

The SRC, with the assistance of the Director Montserrat Volcano Observatory, Roderick Stewart, obtained satellite images under the International Charter, which provides for access to satellite imagery when it can help mitigate the effects of disasters on human life and property. Optical and radar images of the area were provided by US, German, Canadian and Russian space agencies for the period 26th – 28th July. None of these images showed any evidence of a disturbance near KEJ or of a pumice raft floating on the waters in the area. These observations supported the conclusion that no eruptive material broke the surface of the sea and no eruptive activity continued after the seismic activity ended on 24th July.

Scientific Management of Crisis

Following traditional protocols SRC staff on duty during the rapid build-up in seismicity during the afternoon and evening of Wednesday 22nd July discussed amongst themselves and quickly concluded that there were clear signs of possible eruption within the next few days. Measures were implemented to ensure continued data analysis throughout the night. A field team was deployed to improve the network and brief local authorities on the prognosis. Throughout the entire period of elevated activity the scientific group who at various times were based in Grenada, St. Vincent, Montserrat and Trinidad, discussed the data using telephone, email and Skype videoconferencing. The following paragraphs outline the key elements of the scientific and other interventions, which occurred during the crisis.

Official advisories and updates to stakeholders

The first scientific advisory on elevated activity associated with Kick 'em Jenny

submarine volcano was sent to Mr Terrence Walters, National Disaster Coordinator of Grenada at 5:30pm on 21st July 2015. After the second advisory at 3:05 pm on 22nd July, at least two updates were circulated daily until the last update at 5:36pm on 26th July 2015. With each subsequent update, the circulation list was expanded to include more and more of the regional stakeholders as an eruption episode appeared imminent (Table 2). On 23rd July, in response to a request from Mr. Walters at 12:18 a.m., the following prognosis was provided, at 12:40 a.m. "At this time, the most likely candidate as the source of the activity is the Kick-'em-Jenny volcano. Should the activity continue to escalate (since 09:15 pm to midnight there have been a further 60 events) with increasing numbers and magnitude, then the next stage would in all likelihood be an eruption episode, which can consist of a series of eruption events. Should we get to the stage of increasing magnitudes, there may be felt reports coming from northern Grenada". Dr Latchman, Seismologist, sent the updates from the SRC headquarters in St. Augustine, Trinidad. Dr Latchman was the scientist in charge of day-to-day operations in Trinidad during most of the period of unrest at KeJ.

Date	Time	Distribution
21st July 2015	5:30pm	NaDMA
22nd July 2015	3:05pm	NaDMA, NEMO
23rd July 2015	12:09am	NaDMA, NEMO, DEM
23rd July 2015	12:40am	NaDMA
23rd July 2015	1:58pm	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU,
23rd July 2015	6:53pm	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU
24th July 2015	5:43am	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU
24th July 2015	5:42pm	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU, CTIC, PTWC
25th July 2015	6:52am	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU, CTIC, PTWC, PRSN
25th July 2015	8:42pm	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU, CTIC, PTWC, PRSN
26th July 2015	9:06am	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU, CTIC, PTWC, PRSN, CWC
26th July 2015	5:36pm	NaDMA, NEMO, DEM, MVO, IPGP, NDCs, SMU, CTIC, PTWC, PRSN, CWC

Table 2: Circulation list for advisories sent out during the period 21st to 26th July.

In addition to the advisories, SRC staff deployed in Grenada and St Vincent directly briefed disaster management officials. Mr Lynch, an experienced first responder to several volcanic crises, who arrived in Grenada at about 1:00 pm on 24th July, travelled directly to NaDMA headquarters where he addressed the National Emergency Management Committee on the situation, providing insights on risk to the population and likely outcome. Dr Robertson, Director of SRC, who at the time of the unrest was visiting St. Vincent briefed disaster management officials on the ongoing situation during the entire period of his visit from 22nd-24th July.

Review of Outreach efforts

During the unrest period, the small Education and Outreach Team (E&O Team), consisting of three members of staff, was expanded to include other staff members, who engaged with the public via phone calls, media interviews, the website and social media platforms Facebook (FB) and Twitter. The eruption coincided with ongoing earthquakes NE of Barbados and the media attention from this event (particularly in Barbados) merged with that generated from the unrest at KeJ. The entire unrest period was one of intense activity for the E&O Team and the following paragraphs detail the interaction with the traditional and social media.

Press Releases

During the unrest period, five releases were prepared and disseminated to all relevant stakeholders and other authorities. Four were distributed on the website under 'Scientific Advisories' and the last one was posted under' News Articles'. The timeline of the releases can be found below:

23rd July:	Release 1: Changed Alert Level at Kick 'em Jenny Submarine Volcano
	Release 2: No Tsunami Warning Issued
25th July	Release 3: Kick 'em Jenny Update 1
	Release 4: Kick 'em Jenny Update 2
26th July	Release 5: NADMA Press Release - Kick-'em-Jenny Alert Lowered to Yellow

Regular Media

International Media

Associated Press

Regional representatives from the international press agency, Associated Press (AP) contacted the SRC and spoke to Mr Ash, Head of the E&O Team. Using the first statement released, an article was generated. This article was then picked up by news agencies (television, radio and online news) throughout the world, some of which are listed below. Our last count of agencies using the AP article was 43.

List of agencies that carried the AP article: Daily Mail (UK), Yahoo (US & UK websites), NY Times, Japan Times, International Business Times, Huffington Post, New Zealand Herald, Miami, Herald, Florida National, The Indian Express, Time Union, Star Tribune, ABC News, Fox News- was carried on 5 or more local FOX stations, Las Vegas Sun, Houston Chronicle, New Europe, NewsTime, The Gazette, Washington Top News, ZEETV

CNN

CNN World Edition created both a video and article using the first release. Several local American stations (local CBS and NBC) and news agencies re-used this on their websites. The article was also shared on CNN Wire Service and affiliate sites such as GantDaily.com.

Several agencies in various parts of the USA (e.g. Texas, San Francisco and Kansas) used the article. Over 20 stations used the CNN article and/or video.

BBC Newsday

A BBC Newsday team conducted two interviews with Dr Robertson, Director of the SRC on the 26th July.

Other agencies

Canadian Network dedicated to Caribbean News (CEEN) conducted an interview with Dr Robertson on the 27th July. Several Science news websites and blogs also used the releases as posts on the respective pages e.g. Phys.org, e-sciencenews.com, Global Rumblings, Dailykos.com, Source.com, Volcano Discovery, Old Salt Blog. A post was also sent on Reliefweb.com based on a note sent to them from CDEMA.

Regional & Local

Several television, radio or online news agencies in the Caribbean Region shared the press releases distributed by the SRC. Table 3 summarizes the area of coverage and name of agencies involved.

Area of Coverage	Name of Agency
Regional	CARICOM Today, Times Caribbean, Antillean Media Group, CDEMA.org
Barbados	Barbados Nation and Nation news, Barbados Advocate, Barbados Today, GIS Barbados, Caribbean Digital Network, CBC, CMC, StarCom Network
Jamaica	Jamaica Gleaner, Jamaica Observer and Radio Jamaica
Puerto Rico	Puerto Rico EFE Agency
Anguilla	Anguillan News
Bahamas	Bahamas Local
British Virgin Islands	British Virgin Islands Disaster Management Agency
St. Marteen	St. Marteen Daily Herald, Voice of St. Martin
St. Croix	St. Croix Source
St. Kitts & Nevis	ZIZ Broadcasting Corporation St. Kitts, Online and Winn FM
Dominica	Dominica News Online
St. Lucia	St. Lucia Times and News Online, Hitz1037.com
Venezuela	TeleSur TV
Colombian	FM Radio Station
Trinidad	IETV, TV6, CNC3, CNMG/CTV, GISL, Trinidad Express, Trinidad Guardian, Newsday, Radio 103 FM, I95.5, Power 102, Trinidad Broadcasting Network-primarily SKY 99.5 FM
Interviews with SRC staff members were also conducted by the following agencies: Jamaica Observer and Radio Jamaica, EFE Agency, ZIZ St Kitts, CBC, CMC, StarCom Network, IETV, TV6, CNC3, CNMG/CTV, GISL, Trinidad Express, Trinidad Guardian, Newsday, Radio 103 FM, I95.5, Power 102	

Table 3: Agencies to which press releases were distributed and their areas of coverage.

In addition to these interventions the National Emergency Management Organization of St. Vincent arranged for Dr. Robertson, who was in St. Vincent at the time, to give a live statement on the National Broadcasting Corporation (NBC 705 radio) on Thursday 23rd July, which was broadcast simultaneously by SVG TV, IWN, Agency for Public Information and nine other radio stations. This statement was shared subsequently on stations/frequencies that broadcasted the press conference as well as shared the releases on their websites/frequencies and/or stations.

In Grenada where a team of SRC staff members was based from Wednesday 22nd July 2015, all agencies covered press conferences held and also disseminated any news bulletin sent out by NADMA. These included: NOW Grenada, Barnacle Grenada, Government of Grenada official website, City Sound 975FM, NBC 105.7 FM, Voice Grenada, SKY FM Grenada, and Grenada Informer. Most of these broadcasts had information from interviews with SRC staff present in Grenada: Mr. Lynch and Dr. Dondin. Mr. Lynch participated in a press conference organised by NaDMA at 4:00 p.m. on 24th July. On the morning of the 25th July, he was interviewed regarding the significance of the second prolonged seismic signal. He participated in a GIS interview on Monday 27th July and a 2-hour television program the night of Tuesday 27th July. Dr. Dondin participated in an interview with local media immediately following his observation flight.

Social Media

All press releases and information updates on the activity were shared on the SRC's FB page and a link was tweeted to our followers. The following numbers detail the interaction that occurred with the online public during the unrest period.

Facebook

Post	Date	Time	People Reached	Likes	Shares	Comments
Changed alert level at KeJ	23rd	11:20am	126,912	278	1236	101
No Tsunami Warning	23rd	6:33 pm	41,792	317	347	34
Update Post	24th	10:46 am	27,232	281	226	24
YouTube video of RR's interview	24th	4:25 pm	19,964	118	170	11
Photo post- taken from BVI DDM	24th	8:28 pm	10,192	20	0	7
KeJ FAQs	24th	10:56 pm	23,944	176	160	15
Cover Photo change	25th	3:33 pm	6,256	151	65	17
Update post	25th	10:23 pm	34,672	240	184	19
Update post	26th	8:17 am	5,586	145	54	12
NADMA Press Release	26th	11:02 am	46,880	288	449	13

Table 4: Statistics on the distribution and response to updates and releases on the SRC Facebook site.

Overall page interaction and engagement

Over twenty (20) persons posted to the SRC FB wall and over twenty (20) messages regarding the event were dealt with. At one point comments were received, which suggested that our replies were being automated because similar responses were given for similar queries. This misconception was addressed. The main questions asked or issues raised were:

- Whether the alert level was for specific islands (these came in particular for Trinidad and Barbados);
- If there was a threat of a tsunami;
- The question of whether there was any association with earthquake activity off the NE of Barbados;
- The constant need for updates; and
- The threat of a massive eruption with lava and hot gases.

'***Likes***' of the page spiked from 11.5 to 12.8 thousand over a week with 1700 likes on the 23rd July. External visits to the page came from Google searches (google.com, .tt, .co, .ve) and the website.

Due to the increasing demands from our social media audience, arrangements were made early in the crisis to have near 24-hour monitoring of the site throughout the unrest period. All comments with any questions or queries were addressed resulting in a 95% response rate and at the peak of activity a 15-minute response time. Comments were responded to as late as 12:38 a.m. on Friday 24th July and as early as 4:10 a.m. that same morning.

The peak time of views was at 8:00 pm but the page reach was about 4000 between 7:00 am-midnight.

Spatial Distribution of Interaction (People Reached)

Location	**Number of persons**
Trinidad and Tobago	106,848
USA	71,809
Barbados	57,274
UK	20,743
Canada	18,973
SVG	18,491
France	9,171
Grenada	8,610
Martinique	7,987
St. Lucia	7,962
Cities Distribution: 1. Bridgetown, 2. POS, 3.San Fernando	

People Engaged (people who liked, shared or commented)

Location	Number of persons
Trinidad and Tobago	3,238
Barbados	2,840
USA	1,235
SVG	543
Martinique	414
Grenada	316

Twitter

The Table below summarizes the tweets made during the unrest period and the number of times these were re-tweeted.

Tweet	Number of times re-tweeed
Increased activity	42
Details on increased activity	54
Change in alert level	112
No tsunami warning	86
YouTube video link	26
KeJ FAQs	14
Update	27
NADMA press release	49

The number of persons following the SRC tweet feed increased by over fifty (50) following the first tweet made regarding the unrest. Local, regional and international agencies re-tweeted, followed or highlighted the unrest tweets along with scientists, agencies and the regular public.

DISCUSSION

Social Media: Servicing the needs of the community utilizing social media was a significant factor in response to the unrest. The immediate and instant increase in traffic on this forum required an adaptation of our routine procedure for its management. It was recognised early in the crisis that the demands of followers of our Facebook page and twitter feed required a more continuous monitoring of these interactions. The social media public demanded information in near real-time and a lot of time was spent both releasing updates and also correcting misinformation that was circulating. The same questions or queries along the similar line continued to be posed. This resulted in the use of 'standardized' responses. This in turn led to comments of automated responses and lack of forthcoming information. In media interviews, it was indicated that eruptions and not just elevated activity were observed.

This led to some confusion, as we did not explicitly state that we had observed eruptions on the page. Persons again accused us of withholding information and a response was drafted to respond to this. The needs of this community and the requirement to respond are matters that must be catered for in any future periods of unrest or elevated activity in the region. Social Media has clearly changed the dynamic that existed in 2001 during the last eruption of KeJ and while people would go to their respective NDO's for information, the SRC has been steadily increasing its interactive user base over the years and people have come to depend on our updates.

Status of network: The poor state of the network, caused mainly by the disrepair of the facilities at the observatory, made clear identification and characterization of the source of the activity challenging. There was, therefore, a delay in reporting the observations at the onset of the activity to the Disaster Coordinator, because the reduced number of seismic stations in operation did not allow for the accurate location of the earthquakes being seen. The reduced state of the network, resulting in the absence of location capability for small, local earthquakes, is a direct reflection of the lack of adequate support provided to the SRC by the Government of Grenada prior to the onset of the crisis. In addition continued non-payment of annual contributions to the SRC by several island governments has undermined the SRC's capacity to maintain, let alone modernise the regional monitoring network. In a letter sent by the Director of the SRC to all Prime Ministers of contributing territories in January 2015, it was noted that "***If the current situation regarding contributions to the Seismic Research Centre does not change in the ensuing year, the impact of the short-fall will begin to affect our normal operations at a time when we are seeing unusual levels of earthquake activity in some areas and should have our networks at appropriate strength***."

Timing of KeJ event and Barbados sequence: The occurrence of the KeJ unrest simultaneous with the ongoing sequence of tectonic earthquakes NE of Barbados complicated the management of information. A popular and recurring perception was that the two events were causatively linked and despite a significant amount of effort to dispel this idea, the linkage continued to be made. The perception varied from persons believing that the earthquakes caused the unrest sequence to their belief that continuation of the earthquakes after the unrest period had ended, clearly indicated that things had not yet died down at KeJ.

Public perception of KeJ and tsunami hazard: Comments received on FB along with questions asked during media interactions suggest that the public perception of KeJ is that it posed a major tsunami threat to the region. Despite ongoing efforts to dispel this perception over the past decade, the general high concern and panicked reaction of communities in Barbados, Grenada and St. Vincent suggests that people generally still believe that KeJ eruptions are very likely to produce tsunamis that can cause damage to all of these countries. A number of deliberate responses were given to address this perception via FB and the regular media.

Impact of having staff in three locations: It proved highly useful to have staff located in two of the islands (Grenada and St. Vincent) with greatest vulnerability during the crisis. They were able to provide timely information and advice to disaster management officials and even the general public. This helped with dispelling rumours and informing communities in each territory about the situation.

SRC response: The benefits to the region of having a resident team of scientists to respond and provide advice to civil authorities and the public was clearly demonstrated during the crisis. The SRC was able to mobilize support from its staff based in Montserrat and also to rapidly deploy a field team to improve the surveillance network and also provide direct and timely advice on the situation to disaster management officials. Such a response would not have been possible if this team had to be mobilized from elsewhere. The familiarity with the volcanic system obtained from several decades of ongoing research also helped in terms of providing the best scientific advice on the developing crisis within the prevailing constraints. All of this would not be possible without the existence of such an organization.

Benefits of research collaborations: The SRC input to the management of the crisis benefited significantly from collaborations within and outside the region. These have resulted in improved knowledge and better understanding of hazardous tectonic features and processes in the region and upgrades in instrumentation used for their surveillance. In the case of KeJ, the SRC benefited from its participation in two research cruises undertaken by the EV Nautilus operated by Ocean Exploration Trust. In addition, the two seismic stations, which were used to identify the source of the events, were both funded from extra-regional sources.

Alert level system: The crisis demonstrated the usefulness of having an established system for managing the evolving unrest at a submarine volcano and the attendant threat it poses. The Alert Level Table used for KeJ volcano proved useful for conveying information about the state of activity, nature of the threat to delimited zones, the expected future trend and appropriate responses from the major parties involved. However, it was apparent that the system, while clearly understood by the SRC was not similarly understood by the public or more particularly, some members of the disaster management community. This was became apparent early in the crisis when the first press release issued by the SRC informing of the change in the alert level was released prior to NaDMA releasing their official notice of a change in the alert level. This press release was the first public notification of a change in the alert level resulting in the public perception being that the SRC had responsibility for setting the alert levels.

Disruption of telecommunications: It has been reported that the hour-long seismic disturbance recorded at the KeJ on 23rd July from about 01:42 a.m. was responsible for the disruption in the telecommunications services that occurred from about that time. The cause has been attributed to damage to the undersea cables between Grenada and the Grenadines. We have been unable to verify whether this was the case since we were unable to obtain full details of the disruption.

Disruption in telecommunications severely affected the communication between the SRC and NaDMA for about 8-9 hours. No voice nor data contact were made between the two offices during this period. In anticipation of this kind of eventuality the SRC had purchased a satellite phone in 2013. However due to the cost of its recurrent operation and our ongoing challenges with securing our full recurrent budget from contributing territories we did not renew the annual subscription when it lapsed in 2014.

RECOMMENDATIONS

1. There needs to be a regular program of continuing education for disaster management professionals in the region to disseminate new research findings, update and/or review protocols, procedures and responsibilities as well as to address staff volatility.

2. The volcano alert level system should be reviewed and adapted to reflect the existing situation regarding the disaster management community in the region. Some of this work is already underway as part of an MPhil research project being undertaken by a post-graduate student at the SRC. We will work with CDEMA and other stakeholders in the region to ensure that existing knowledge and understanding of the system is improved.

3. Governments of the Eastern Caribbean, who currently owe contributions to the Seismic Research Centre, should move expeditiously to make contributions due for the 2014-2015 financial year and begin discussions with The University Bursary regarding payment of arrears.

4. The SRC should review its own internal mechanisms for interaction with the public, particularly regarding the servicing of its social media sites. We need to become more strategic with social media posts e.g. utilizing Facebook's targeting capabilities where posts can be sent to persons from a particular location/demographic first then others updated after.

5. A clear framework for the dissemination of Press Releases and other information needs to be established particularly as regards responsibility for the issuing of releases.

6. There is a clear need for redundant communication systems such as HF radio or satellite telephones during such crises.

7. There is an urgent need for shallow bathymetry data (between 0-50m below sea level), to enable accurate modelling of tsunami wave run-up along the shoreline. Such data is crucial for risk assessment and will better inform emergency plans and mitigation measures.

8. A full and comprehensive upgrade of the Kick-'em-Jenny monitoring network is urgently needed. The core component of the existing monitoring network was

established through a grant from the Caribbean Development Bank in 1999. The SRC would normally undertake such upgrade incrementally through its recurrent budget but recent shortfalls in contributions has prevented this from being done. The upgrade will therefore require a specific injection of funds to enable it to occur; it cannot be done from within our recurrent budget.

BIBLIOGRAPHY

Antonopoulos J (1992) The great Minoan eruption of Thera volcano and the ensuing tsunami in the Greek archipelago. Natural Hazards 5:153-168

Beget JE (2000) Volcanic Tsunamis. In Sigurdsson H (ed.) Encyclopaedia of Volcanoes. Academic Press, San Diego, California, pp. 1005-1013 Bouysse P, Mascle A, Mauffret

Carey, S., Ballard, N., Bell, K. L. C., Bell, R. J., Connally, P., Dondin, F., Fuller, S., Gobin, J., Miloslavich, P., Phillips, B., Roman, C., Seibel, B., Siu, N., and Smart, C. (2014a). Cold Seeps Associated with a Submarine Debris avalanche Deposit at Kick 'em Jenny Volcano, Grenada (Lesser Antilles). Deep-Sea Research I, 93:156–160.

Carey, S., Bell, K., Ballard, R., Roman, C., Dondin, F., Miloslavich, P., Gobin, J., Seibel, B., Smart, C., Fuller, S., Siu, N., Connally, P., Blake, R., Wishner, K., and Phillips, B. (2014b). Fluid/gas venting and biological communities at Kick' em Jenny submarine volcano, Grenada (West Indies). Oceanography, 27(1):38–41.

Dondin, F., Simulations numériques et impact tsunamogène d'une déstabilisatio de flanc au volcan sous-marin Kick 'em Jenny, Petites Antilles. PhD thesis, Université des Antilles et de la Guyane, 2010, pp. 1–256.

Dondin, F., Lebrun, J.-F., Kelfoun, K., Fournier, N., and Randrianasolo, A. (2012). Sector collapse at Kick 'em Jenny submarine volcano (Lesser Antilles) – Numerical simulation and mass flow behaviour implications. Bulletin of Volcanology, 74:595–607.

Dondin, F. and Robertson, R. E. A. (2015). Report on E/V Nautilus Cruise NA054 at Kick 'em Jenny Volcano, Grenada and at the submarine mud volcanoes offshore of Trinidad and Tobago islands September 21st to October 9th, 2014, pp. 1-47.

Gisler, G., Weaver, R. and Gittings, M. (2006). Two-dimensional simulations of explosive eruptions of Kick 'em Jenny and other submarine volcanoes. Science of Tsunami Hazards, 25(1):34-41.

Harbitz, C.B., Glimsdal, S., Bazin, S., Zamora, N., Løvholt, F., Bungum, H., Smebye, H., Gauer, P. and Kjekstad, O. (2012). Tsunami hazard in the Caribbean: Regional exposure derived from credible worst case scenario. Continental Shelf Research, 38:1-23.

Koschinsky, A., Siefert, R., Knappe, A., Schmidt, K., and Halbach, P. (2007). Hydrothermal fluid emanation from submarine Kick 'em Jenny volcano, Lesser Antilles island arc. Marine Geology, 244:129–141.

Latter J (1982) Tsunamis of volcanic origin: summary of causes, with particular reference to Krakatoa 1883. Bull Volcanol 44(3):467-490

Le Mehaute, B. (1971). Theory of explosion-generated water waves. Advances in hydroscience, 7, 1-79.

Lindsay, J. M. and Shepherd, J. B. (2005). Kick' em Jenny and Ile de Caille. In: Lindsay, J. M. and Robertson, R. E. A. and Shepherd, J. B. and Ali, S. (Eds). Volcanic Hazard Atlas of the Lesser Antilles. Seismic Research Unit, The University of the West Indies, Trinidad and Tobago, W. I., pp. 105-125.

Lindsay, J. M., Shepherd, J. B., and Wilson, D. (2005). Volcanic and scientific activity at Kick' em Jenny submarine volcano 2001-2002: Implications for volcanic hazards in the Southern Grenadines, Lesser Antilles. Natural Hazards, 34:1–24.

Mirchina, N. R., & Pelinovsky, E. N. (1988). Estimation of underwater eruption energy based on tsunami wave data. Natural Hazards, 1(3), 277-283.

Olsen (2011). Hydrothermal mineralization at a submarine island arc volcano, Kick 'em Jenny, Lesser Antilles Island Arc. Master's thesis, The University of Rhode Island.

Roman, C., Inglis, G., Vaughn, I., Smart, C., Dansereau, D., Bongiorno, D., Johnson-Roberson, M., and Bryson, M. (2013). New Tools and Methods for Precision Seafloor Mapping. Oceanography, 26(1):10–15.

Smith, M. S., & Shepherd, J. B. (1993). Preliminary investigations of the tsunami hazard of Kick'em Jenny submarine volcano. Natural hazards, 7(3), 257-277.

Smith, M. S., & Shepherd, J. B. (1995). Potential Cauchy-Poisson waves generated by submarine eruptions of Kick'em Jenny volcano. Natural Hazards, 11(1), 75-94.

Smith, M. S., & Shepherd, J. B. (1996). Tsunami waves generated by volcanic landslides: an assessment of the hazard associated with Kick'em Jenny. Geological Society, London, Special Publications, 110(1), 115-123.

Striem, H., & Miloh, T. (1975). Tsunamis induced by submarine slumpings off the coast of Israel. Israel Atomic Energy Commission, Tel Aviv. Licensing Div.

Unoki, S., and Nakano, M. (1953a). On the Cauchy-Poisson waves caused by the eruption of a submarine volcano (paper 1). Oceanogr. Mag., 4, 119-141.

Unoki, S., and Nakano, M. (1953b). On the Cauchy-Poisson waves caused by the eruption of a submarine volcano (paper 2). Oceanogr. Mag.