Seismic signatures of volcano-tectonic activity in Afar and the main Ethiopian rift

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ABSTRACT

Several volcano-tectonic earthquake sequences have occurred in Afar and the main Ethiopian rift for the last eight years and the corresponding seismic data are recorded by broadband digital seismic stations. The notable sequences are; the May-June, 2000 Gewane sequence; the August 2002 western Ert Ale sequence; the October-November 2003/2004 Melka Sedi/Worer sequence and the September 2005 Dabbahu sequence. A wide range of seismic signals are recorded from high frequency micro fractures to tilt signals during those sequences which all explain the various dynamics underway around the volcanic source regions. The tectonic stress release mechanism in the area is associated with the interplay between crustal deformation and magma emplacement. In all the aforementioned activities, it is quite common to observe hybrid events that commence with a high-frequency onset with long period tail, while typical long-period (LP) events with emergent onset are least common. This kind of volcano seismicity is observed even when there was no eruption observed at all. Except the Ankober area in the western plateau where typical tectonic type earthquakes occur, significant part of seismic energy in the area is released as sequences/swarms with finger prints of diking or magma emplacement. This shows that there are several active volcanic and fissure eruptive centers in the area which need monitoring to study continental rift mechanisms and for mitigating volcano and earthquake hazards.

Key words: volcano-tectonic events, Afar, East African Rift

Dr. Ayele's Biography

Atalay Ayele has obtained his PhD in seismology in 1998 from Uppsala University, Sweden. He joined the Geophysical Observatory of Addis Ababa University in 1999 and strongly involved in running the Ethiopian seismic station network. He has been collaborating with several broadband seismic experiments conducted in Ethiopia. Currently he is the staff of the new Institute of Geophysics Space Science and Astronomy in Addis Ababa University.

POST-COLLAPSE BANDED TREMOR AT THE SOUFRIERE HILLS VOLCANO, MONTSERRAT, WEST INDIES.

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ABSTRACT

A major collapse of the Andesitic lava dome at the Soufrière Hills Volcano occurred on 29 July 2001. This resulted in the loss of approximately 45 million cubic meters of material from the lava dome over a period of 8-9 hours and the creation of a major collapse scar. The collapse was followed by an episode of banded tremor recorded on the seismograph network that continued for over 2 months with the interval between the peaks in the tremor activity varying between 6-30 hours. The duration of the tremor bands is typically 1-3 hours. The tremor bands appear to be composed of small long-period earthquakes that merge together to form tremor, although rockfall activity also increases during these tremor episodes, and are sometimes accompanied by venting of ash. The dominant period of the tremor bands can remain approximately constant or change slowly over an interval of several days. Though at other times the tremor can stop for an interval of a few days before restarting again. We suggest that the occurrence of the tremor bands is controlled by the magma supply rate in the upper conduit and has developed as a result of the collapse, which reduced the overpressure and increased magma ascent rate, allowing gas-rich magma to rise quickly to the surface. Degassing magma at the top of the conduit, results in an increase in pressure below the lava dome and the occurrence of the tremor bands and in the extrusion of fresh material, as indicated by the increase in rockfall activity and gas venting. If this is the case the duration of individual tremor bands should be related to the degassing and extrusion processes.

Key words: Soufrière Hills, tremor, cycles.

PRESENTER'S BIOGRAPHY

Brian Baptie joined the British Geological Survey in 1996 as a member of the multi-disciplinary team monitoring the eruption of the Soufrière Hills Volcano in Montserrat, West Indies. While working on Montserrat he collaborated widely with colleagues both within the UK and overseas on work that has helped to gain key insights into the nature of volcanic earthquakes. Recent research has focused on the use cross-correlation of seismic noise to study temporal variations during volcanic eruptions.

Temporal changes in seismic shear-wave splitting before earthquakes and volcanoes suggest that the behaviour of stress before fault breaks and volcanic vent openings is similar

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ABSTRACT

The temporal changes in the time-delays of shear-wave splitting observed with in retrospect before some 15 earthquakes worldwide (with one successful real-time stress-forecast in SW Iceland) are believed to monitor changes in microcrack geometry caused by the stress-accumulation necessary before the release of energy by all large earthquakes. The logarithms of the duration of stress increases are observed to be proportional (self-similar) to the magnitudes of the impending earthquakes. Earthquakes occur when crack density reaches fracture-criticality, at the percolation threshold, when the microcracks are so closely-spaced there are through going pathways, shear-strength is lost, and the rock necessarily fails in fractures and earthquakes. Immediately before fracturing, and earthquake occurrence, a break of slope is observed in the increase of time-delays. This break is thought to be the start of stress relaxation as the microcracks begin to coalesce onto the eventual fault break. The logarithms of the durations of coalescence are again self-similar to earthquake magnitudes.

Although the number of case studies is small, similar observations of changes in shear-wave splitting in both stress-accumulation and crack-coalescence before volcanoes strongly suggest that the behaviour of stress before fracture-criticality and rock fracture before earthquakes and before fracture-criticality and venting in volcanic eruptions is similar. The similarity is presumably because both earthquakes and volcanic eruptions involve failure of fluid-saturated microcracked rock, by fault slippage in the case of earthquakes, and by 'magma-fracturing' (analogous to hydro-fracturing in hydrocarbon recovery) in the case of volcanic eruptions. This suggests that at least in some respects the behaviour of stress before volcanic eruptions is not "significantly different from conventional tectonic earthquakes" as is claimed by the outline for this session.

The repeatability is believed to be due to the distributions of microcracks being so closely spaced that they verge on fracturing and are critical systems. This leads to a *New Geophysics* where universality applies and phenomena extend to all available space. Almost all complex, heterogeneous, interactive phenomena are critical systems, and it must be expected that the Earth, an archetypal complex, heterogeneous, interactive system, must also be critical, as is typified by the self-similarity/linearity of the Gutenberg-Richter relationship. Critical systems impose new properties on conventional sub-critical behaviour including universality, which accounts for the similarities before earthquakes and volcanic eruptions.

Since monitoring of stress-accumulation before earthquakes can lead to the time, magnitude, and in some circumstances location of the impending earthquake being stress-forecast in real time, the implication is that the approach of volcanic eruptions, when venting occurs, can also be stress-forecast by monitoring shear-wave splitting. . Papers presenting these ideas are available at <www.geos.ed.ac.uk/homes/scrampin/opinion>.

Key words: earthquakes, fluid-rock evolution, shear-wave splitting, the New Geophysics, volcanoes

PRESENTER'S BIOGRAPHY

Stuart Crampin: PhD, ScD, FRAS, FRSE; Conrad Schlumberger Award (EAGE); Virgil Kauffman Gold Medal (SEG); highly cited <http://www.isihighlycited.com/>; h-index 36.

Crampin pioneered theory, observation, computation, interpretation of seismic anisotropy in 260^+ papers.

Crampin founded biennial International Workshops on Seismic Anisotropy (14IWSA will be in Perth, Australia).

Crampin founded Edinburgh Anisotropy Project (EAP) at BGS for processing multi-component seismograms. EAP still continues with ~20 oil company sponsors.

Crampin developed anisotropic poro-elasticity (APE) model of fluid-saturated crack deformation. APE led to the successful calculation (prediction) of oil production operations, and successful prediction of time, magnitude, and fault-break of M=5 earthquake.

Crampin developed prototype Stress-Monitoring Site (SMS) between 500m-deep boreholes which recorded spectacular sensitivity to remote minor seismic activity confirming science/technology/sensitivity.

Crampin is currently promoting the concept of crack-critical crust, where *in situ* cracks are so closely-spaced they are critical-systems. Consequently, low-level deformation can be monitored with shear-wave splitting, modelled/predicted with APE, and in appropriate circumstances, future behaviour controlled by feedback.

Volcano Nyiragongo: Observation of long-period earthquakes and volcanic tremors.

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In a previous study, the authors investigated on the seismic activity associated with the January 17th 2002 Nyiragongo eruption. They stated that volcanic tremors were a noticeable precursor of the eruption and that the eruption coincided with a rifting phenomenon suggesting that the eruption may have been triggered by a rifting process.

This study focuses on the long period earthquakes activity that followed the Nyiragongo eruption in 2002. Real time amplitude of volcanic tremors are interpreted in relation with lava lake activity within the Nyiragongo crater.

It is found that, since the 2002 eruption of volcano Nyiragongo , the long period earthquakes are scattered on the south-Eastern flank of the volcano close to the central crater. However, the February 03,2008 destructive in Bukavu area, about 90Km south of the volcano, has triggered a cluster of such magmatic earthquakes under a populated areas near cities of Gisenyi-Rwanda and Goma-R.D.Congo.

A drastic increase in RSAM volcanic tremor amplitude was observed in the period November-December 2004 .Routine observation of the lava lake level also indicated a dynamic increase of more than 150 m of the lava lake level. This first experience may be of great interest in the future as far as the Nyiragongo lava lake level is concerned.

Key words: Nyiragongo, long-period, earthquakes, volcanic tremors.

PRESENTER'S BIOGRAPHY:

KAVOTHA: Researcher involved in the observation of the seismic activity of the Western Rift valley of Africa and the seismic monitoring of Volcano Nyiragongo and Nyamulagira since 1980.

RECENT SEISMIC ACTIVITY AT VOLCANO NYAMULAGIRA, WESTERN RIFT VALLEY OF AFIRCA.

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Following the catastrophic eruption of Volcano Nyiragongo on January 17, 2002, a great effort has been devoted to the seismic surveillance of volcanoes Nyiragongo and Nyamuragira located at the North of Lake Kivu in the Western branch of the east African rift.

Five years of observations at 6 seismic stations let us derive the following results:

(a) The daily counts of long-period earthquakes indicate a significant increase in the earthquakes occurrence . Similarly, the volcanic eruptions have at volcano Nyamulagira become more frequent following the continuation of the high active stage of eruptive activity which began in 1980.

(b) The authors could locate, with enough accuracy, 10657 long period earthquakes related to deep magma activity of volcano Nyamuragira. The epicenters are spreading mainly along a NNW-SSE direction which coincides with the main fracture zone within the Virunga volcanic complex. The four recent eruption outbursts at this volcano lie within the above epicenter area.

(c) Compared to other eruptions at this volcano, the November 27 Nyamuragira eruption is unique for having been preceded by a swarm of short-period earthquakes that occurred few hours before the lava outburst. The epicenters of those earthquakes correlate well with the location of the eruption site as it also does with the InSAR observations of surface deformation associated with the eruption. InSAR deformation maps indeed indicate a NNW-SSE trending deformation on the southern flank of the volcano extending up to the Nyiragongo southwestern flank.

(d) Hypocenters of the swarm type of Long-period earthquakes that forerunned the May 8, 2004 and the November 27, 2006 eruptions of volcano Nyamuragira were located. From the hypocenter locations, it is inferred that shallow magma chambers that gave rise to the eruptions are within 5 to 10 Km beneath the eruption locations as indicated by aseismic regions within that depth range.

Role of failure by static fatigue (creep) in passive eruptions: integration of laboratory, and field results

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ABSTRACT

There are two models for precursors associated with volcanic eruptions. One involves active forcing of magma to the surface under overpressure, often associated with release of volatiles, and another involves passive failure of the carapace by static fatigue under a relatively constant load from the magma chamber. Here we test a recently-derived model for time-dependent static fatigue in passive eruptions due to stress corrosion cracking, using data from the laboratory on basaltic rocks, and examine its scaling properties to field examples for Kilauea volcano between 1959 and 2000. The model requires only two fundamental processes both to describe the three stages of creep and to predict power-law creep as an emergent process. The model fits laboratory data both on observed strain and acoustic emission event rate, the latter showing a greater degree of fluctuation associated with local failure events. It is also consistent with seismicity data both after and prior to volcanic eruptions, although the three stages of creep are not always seen in the field data. In stacked data sequences a consistent critical point acceleration predicted by the model is seen in the natural data on timescales of 10-15 days prior to eruption. For individual eruptions there is a high false alarm rate that is similar to the ratio of intrusive to extrusive events mapped in presently exposed dyke systems in Iceland. This implies that the physical processes involved are very similar, and that it is impossible from this signal alone to distinguish *a priori* whether an acceleration event will end in intrusion or eruption.

Key words: passive eruptions, creep, prediction, theory, interpretation.

PRESENTER'S BIOGRAPHY

Ian Main works on the fundamental physical, mechanical and hydraulic properties of rocks undergoing brittle deformation, including the nature of the earthquake source, the population dynamics of earthquakes as a complex non-linear system, and their practical applications to seismic and volcanic hazard. In rock physics he has worked on the experimental determination of fluid-rock interactions such as sub-critical crack growth and the effect of fracturing on fluid flow and transport through porous media undergoing deformation. He is currently director of the Edinburgh Collaborative of Subsurface Science and Engineering, and has served as Associate Editor with 'Geology', 'Journal of Geophysical Research', and 'Natural Hazards', as a member of the International Seismological Centre governing council, and on IASPEI sub-commissions on 'Modelling the Earthquake Source' and 'Significant Earthquake Precursors'. He gave the Bullerwell lecture in Geophysics in 1997, and moderated the Nature website debate on earthquake prediction in 1999.

Seismicity on volcanoes – a completely different beast?

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ABSTRACT

Seismic signals on volcanoes are often classified as volcano tectonic events, low-frequency earthquakes and tremor, as well as so-called rockfall events. In this contribution we give an overview about the criteria to distinguish between the different events and discuss the latest models how these events can be interpreted in terms of volcanic processes. Topics that will be discussed include source mechanisms for different types, differences to usual tectonic earthquakes and special emphasis will be given to the potential to forecast volcanic activity through seismicity on volcanoes.

Key words: Low-frequency, volcano tectonic, trigger mechanism, forecasting

PRESENTER'S BIOGRAPHY

Professor of Physical Volcanology at Leeds University, UK; Chaiman of IASPEI/IAVCEI Inter association Commission on Volcano Seismology; working on several aspects of volcano monitoring and modeling, including broadband seismological monitoring tools, numerical simulation of seismic wave propagation in volcanic settings, deformation and magma flow models.

Seismic effect of magmatic and tectonic events on the static and dynamic stress triggering processes driving intra-lake seismicity:
The Lake Van basin, Eastern Anatolia Accretionary Complex (EAAC), E-Turkey

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ABSTRACT

Different types of earthquakes, unusual seismic events and static/dynamic stress exchanges may occur in volcanic areas, particularly in post-orogenic-accretionary plateaus with no mantle lid. The Lake Van-accretionary wedge basin surrounded by an active alkaline volcanic chain is emplaced over the thinned, rheologically weakened crust resulting from asthenospheric upwelling after the slab break-off in the EAAC region. Multi-channel seismic reflection images and structural analysis showed that basin margins of the lake are densely covered by propagating extensional magmatism and domed-like magmatic intrusions. These isolated intrusions are rooted on geometrical discontinuities associated with extensional or transtensional faulting along the S-portion of the lake, supporting that these are related to open tension fractures or crack systems. We suggest that these intrusions may behave mechanically heterogeneous, affecting internal stress field and ground deformation in the lake. These are subjected to underneath volumetric expansion and pressure differentials to form the threshold of static stress triggering, for example, at about 10 kPa and in some cases even an effect of the earth tides (about 1 kPa). Such stress changes may alter fluid flow within the shallow crust and hydrothermal reservoirs. Local stress variations, such as weak-low viscous material-ductile shears or steeply-thrusted-accreted topography, may amplify pressure in seismograms and hence the triggering effect as well as that the gas phase within the magma-hydrothermal system may be significantly affected by the passing seismic waves. Thus, dynamic changes at the shallower depths of the lake may produce small-moderate seismicity and also dense intrusive magmatism within lake as very small changes of the stress field may activate a system that is in a near critical state.

The raising question is if past or present volcanic activity in the lake is influenced by regional tectonic earthquakes in the EAAC (e.g., Çaldıran-Muradiye-1976 earthquake M_w, *7.3*). We aim to understand the mechanism by which magmatic events are triggered and to search for whether they are influenced mainly by transient stress changes (e.g., caused by the passing of seismic waves) or by permanent stress changes (e.g., static displacement). We suggest that the modes of stress transfer between regional earthquakes and intra-lake seismicity are based on a large amount of volcano-magmatic intrusive material of the lake and magma-controlled, deeper mini-basin formations, as shown by multi-channel seismic reflection profiles, in earthquake-producing zones, the SE- delta, Deveboynu peninsula and Çarpanak spur. Previous seismological studies in and around the lake showed that there are considerable spectral differences between earthquake waveforms and Gutenberg-Richter seismic b-values abruptly vary from low to high, even at same location. Hypo-/epicenter distribution of the most seismic activity across the lake is seated in the upper crust. The spectral examination of earthquake waveform patterns, areal distribution of the seismic-b-values and focal mechanisms imply that tectono-magmatic events in and around the lake is influenced by stress changes related to tectonic earthquakes in the region. The possible stress transfer between the earthquakes and the volcanoes shows that dynamic stress changes rather than static are likely responsible for the temporal and spatial proximity of these events extracted from earthquake waveforms.

We propose a model that the lake and surrounding volcanic chain is interacting with tectonic earthquakes in a two-way mode; *In the first*, magma accumulation and pressure perturbation under the volcanic mountains (e.g., Nemrut and Süphan volcanoes) may have triggered small-moderate earthquakes in the lake. *In the second*, stress changes related to the earthquakes may explain the increase in volcano-magmatic activity, particularly at Nemrut volcano and magmatic intrusions

in the lake. For the assessment of the magma chamber dynamics in the lake, this model implies that consideration of a potential extrinsic triggering source is important. We conclude that the upper crustal structure of the lake is differentiated by tectono-magmatic activities and magma chamber dynamics which might be triggered by tectonic earthquakes. Thus, seismic effect of magmatic and tectonic events on the static and dynamic stress triggering processes drives intra-lake seismicity. Although the tectono-magmatic activity/seismicity in the lake can be triggered by tectonic earthquakes, the coupling of magmatism and tectonic earthquakes in and around the lake basin need to be taken into account.

Key words: static/dynamic stress exchanges, tectono-magmatic activities, magma chamber dynamics, seismic-b-values, earthquake waveform patterns, tectonic earthquakes, magma-hydrothermal system.

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- Bacholar degree by Geophysical Engineering department, Yıldız Technical University, Istanbul-Turkey.
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- Research topics; Orogenesis-Collisional Geodynamics, Seismotectonics, Tectonics, Volcano-tectonics, Tectonic and Kinematic modeling, Salt-sediment dynamics, Halokinesis, Basin and delta analysis, Seismic sequence stratigraphy, Continental drilling process and Seismic/seismologic data interpretation.
- Studied areas; the NE-Mediterranean basin, the NW marginal province of the N-Cyprus platform, Eastern Anatolia Contractional Province (E-Turkey) and the N-delta province of the Black Sea.

Some characteristics of seismicity prior to the recent eruptions of volcano Nyamuragira, Western Rift Valley of Africa

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ABSTRACT

The Nyamuragira volcano is situated in the Western Rift Valley of Africa. Virunga Province, at the northern edge of Lake Kivu. The volcano Nyamuragira is characterized by frequent Hawaiian-type eruptions and highly potassic lavas. Most eruptions, with the exception of the summit eruption of 1938, occur on the flanks of the volcano. The most recent flank eruptions occurred on 27 January 2000, 5 February 2001, 25 July 2002, 8 May 2004 and 27 November 2006.

The spatial- temporal variation in the seismicity in the Nyamuragira area was examined for the period 18 August 2002 to 7 May 2004 and 1 July 2004 to 27 November 2006 prior to respectively the Nyamuragira eruption of 8 May 2004 and 27 November 2006.

It is found that seismicity exhibits similar tendencies. Swarm-type seismicity composed mainly of long period earthquakes foreran by 2-4 months these eruptions of Nyamuragira and were probably enhanced by tectonic seismicity related to rifting. Ten or eleven months before eruption, a steady increase in seismicity at a constant rate from a deep magma feeder was observed. In the last stage (1 or 2 months) before the eruptions, the hypocenters of long period earthquakes became shallower.

Key words: Nyamurgira volcano, Long-period earthquakes, Western Rift Valley of Africa

PRESENTER’S BIOGRAPHY

I am from the Goma Volcano Observatory (GVO), which is part of the Department of Geophysics of the “ Centre de Recherche en Sciences Naturelles (CRSN)“ in Democratic Republic of Congo (DRC). I started working in the Seismic Unit of the Department of Geophysics of CRSN in 1988. I completed postgraduate studies in seismology at the International Institute of Seismology and Earthquake Engineering, Tsukuba, Japan in 1991. In 1995, I completed the course “ Assessing Natural Hazards and Monitoring Active volcanoes” at the University of Hawaii, Hilo, USA. My duty at GVO is to monitor tectonic and volcanic earthquakes in order to advise the Governor of the Province on issues related to earthquake and/or volcanic hazards and disasters in the region.
I am currently registered since 2007 at Wits University as PhD student in Geophysics. My present research work is mostly concentrated on Seismic hazard assessment for Democratic Republic of Congo and surrounding areas in the Western Rift Valley of Africa.