# White Paper

## Advanced Workshop on Evaluating, Monitoring, and Communicating Volcanic and Seismic Hazards in East Africa

**International Centre for Theoretical Physics Trieste, August 17- 28, 2009**

Co-sponsors: NSF, USAID, UNAVCO, IASPEI, IAVCEI

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## 1. Introduction

Continental rift zones are the surface expression of lithospheric stretching and heating that may culminate in plate rupture and the formation of a new ocean basin. The stretching and heating processes are accompanied by punctuated episodes of faulting and/or volcanism, and longer-term changes in surface elevation that disrupt river drainage and climate. The rise of magma through the thick continental plates may be accompanied by earthquake activity, volcanism or be triggered by large earthquakes. The steep-sided rift valleys, as well as the faulted calderas, increase the risk of fumigation by deadly volcanic gas in the fertile rift valleys.

The Global Volcanism Program at the Smithsonian summarizes the abundant active volcanoes, and paucity of knowledge concerning volcanic activity. "Africa has the highest percentage of volcanoes that are undated but known to be Holocene, reflecting the early stage of detailed geologic studies. Africa leads the world in lava lake production, with 9% of its eruptions—all at Nyiragongo and Erta Ale—having exhibited this uncommon characteristic." (http://www.volcano.si.edu). Increasing pressures of growing populations, famine, and civil unrest have led to migration into new areas, including the flanks of active and dormant volcanoes. In 2002, a volcanic eruption in the Congo destroyed 25% of the city of Goma and forced the evacuation of 500,000 people; a series of damaging earthquakes and multiple volcanic eruptions in the Afar region of Ethiopia have been ongoing since September 2005; a magnitude 7.0 earthquake struck Mozambique in 2006; a rifting event with associated volcanic eruption of Oldoinyo Lengai occurred in the Natron area of northern Tanzania in July 2007, causing an ash plume to rise several km into the sky. The plumes from the 2006 Nyamulagira (Congo) eruption and the 2007 Jebel al-Tair (Yemen) eruption both reached the Pacific ocean, creating hazards to aviation. High alkaline contents of African magmas lead to low-viscosity, fast-moving lavas (e.g., Nyamulagira, Oldoinyo Lengai). Mantle volatiles (mainly $CO_2$) lead to catastrophic degassing events at Lakes (e.g Lake Kivu) high and continuous gas emissions at active volcanoes (e.g. Nyiragongo and Oldoinyo Lengai) and dry cold $CO_2$ vents in regions of historic volcanism (e.g., Rungwe). High $CO_2$ and $CH_4$ concentrations in the crust also leads to seismic hazards possibly facilitating brittle failure in the crust and possibly, upper mantle. These events and observations highlight the need for basic research into past and present volcanism and rifting processes in East Africa. Such efforts will form the framework in which to develop and support capacity-building, regional networks and observatories in East Africa for the evaluation, monitoring and communication of volcanic and seismic hazards.

In response to these growing concerns, the International Centre for Theoretical Physics in Trieste, Italy hosted a two-week long workshop that brought 83 scientists from 34 countries together to prioritize and coordinate research goals, to facilitate infrastructure and capacity-building in East Africa, and to develop strategies to communicate geohazards. These discussions were embedded within a 2-week long research and training workshop that included computer-based training in geophysical data processing and analyses supported by ICTP.

This White Paper outlines common goals and priorities to guide discussions with funding agencies, planners, and the global scientific community. The aims were developed through candid, open discussions focused around sustainable linkages between international research and infrastructure development, and science communication. These discussions were preceded by scientific presentations of experts working the in the East African Rift and/or in research fields relevant to the objectives of the workshop. Consensus was achieved on the following research, infrastructure and capacity-building, and geohazard communication priorities.

## 2. East African Rift and Cameroon Volcanic Line Research Aims

Presentations from African, US, and European scientists spanning geodesy, seismology, volcanology, structural geology and geochemistry highlighted cutting-edge themes, as well as gaps in our understanding of rifting processes, and their implications for geohazards in sub-Saharan Africa. The > 3000 km-long and 45 My to current East African rift system encompasses incipient rift basins and continental rupture, and its seismic and volcanic activity levels uniquely positions this region for studies of the time and length scales of continental rifting processes. The following research themes span the scale of continent to individual volcanoes, and range from basic research to applied, pragmatic solutions: 1) Continental breakup processes; 2) Strain and magmatism along the length of the rift system, and in time; 3) Rift fault propagation, diking, and volcanism; and 4) Implications of rifting on geohazards and natural resources.

### *2.1 Continental Breakup*

The East African rift system is a unique site worldwide to witness the breakup of a continent. As outlined in the Introduction, the system is seismically and volcanically active, and much of the rift system lies above or near the youngest continental flood basalt province worldwide. Finally, the entire rift system lies above the largest thermal anomaly within the mantle: the African Superplume province. The interactions between the deep mantle and continental lithosphere also can be addressed within this zone. The US MARGINS thematic program and international equivalents have identified a number of key rifting, magmatism, and continental rupture themes, many of which can be addressed through case studies of the East African rift system. Specific priorities which can be addressed by multi-disciplinary programs in East Africa are:

- Cause and timing of continental break-up
- Role and origin of magmas and volatiles from rift and/or plume inception to breakup, and their role in creating and modifying continental lithosphere
- Relationship of rifting processes to chemical and physical properties and heterogeneities of the mantle and lithosphere
- Large-scale kinematics of rifting cratonic lithosphere: block-like behavior versus distributed deformation.
- Cycles of supercontinent formation and breakup

### *2.2 Strain and Magmatism in Space and Time*

A second priority in terms of thematic research is the distribution of strain along and across the uplifted plateaus of Africa, reaching from the Afar triple junction southwest into Botswana (Okavango rift), and southeast into southern Mozambique. The zones of seismicity and faulting vary in orientation and distribution along the length of the rift system, from a single rift in Ethiopia to sub-parallel rift zones on either side of the deeply rooted Tanzania craton, to possibly three strands south of 10S (Mweru-Okavango; Malawi-Urema; Davie ridge). The rift zones of northeastern Africa (Ethiopian rift, western Gulf of Aden rift, and southern Red Sea rift) developed within a flood basalt province, yet it remains unclear whether zones of incipient rifting in central Tanzania and Okavango (Botswana) are influenced by magmatism. The Western and Eastern rifts fringe the deeply-rooted Archean Tanzania craton and formed at roughly the same time, yet magmatism has been more voluminous and widespread in the Eastern rift zone. Many of these patterns are also seen in the Cameroon volcanic line, linking this area more closely with the East African rift zone.

Specific questions that provide a framework for investigating strain and magmatism in the rift are:

- Are the along-axis variations in the distribution of extensional strain related to pre-rift lithospheric structure, to mantle heterogeneities, or the geometry of the mantle upwelling beneath Africa?
- What is the relationship of strain and magmatic evolution and along-axis propagation?
- What causes the profound topographic, structural, and magmatic differences between rift branches and within the individual rifts ?

### *2.3 Rift fault propagation, diking, and volcanism*

As seismic and geodetic instrumentation and satellite data increase spatial and temporal coverage of the East African rift, we see increasing evidence for active deformation in highly evolved and incipient rift sectors. Coupled with the geological record of faulting and magmatism from the rift basin sedimentary and volcanic sequences, the East African rift system provides unparalleled insights into the rise of magma through the continental lithosphere, and the deformation of the crust and mantle during various stages of the rifting process. For example, the 2005-present tectono-magmatic events in Afar mirror the time and length scales of faulting and magmatism in the oceanic spreading centers of Iceland (e.g., Wright et al., 2006). Fault patterns in the less than 100 Ka Okavango rift show that normal faults grow and link to form border faults very early in rift evolution (e.g., Kinabo et al., 2008). Paleoseismology studies show 6 ground-breaking earthquakes in the Subukia fault zone, Kenya during the late Quaternary (Zielke and Strecker, 2008), yet little is known of recurrence rates elsewhere along the 3000 km-long East African rift zone. Radar interferometry demonstrates inflation and deflation episodes of duration of months at 4 of 10 volcanoes within Kenya, pointing to much higher levels of volcanic activity than had previously been inferred from historical records alone.The following research questions can be addressed by multi-disciplinary field mapping and dating of rocks and faults:

- What is the strength of the lithosphere and how does it vary with depth and the presence or absence of magma and fluids in the crust and upper mantle?
- How do faults grow and link, and how do they evolve during rift basin evolution?
- •What is the temporal evolution of faulting and magmatism, and how does it relate to the large-scale stretching of the lithosphere?
- What are the rates of faulting/rifting and magma production, and are these two processes linked in time ?
- How is strain partitioned between faults and dikes during and between discrete rifting events, and what is the time-averaged strain in youthful and mature rift sectors?
- What is the proportion of strain accommodated seismically ?

### 2.4 Implications for Geohazards, Geothermal Energy, and Mineral Resources

Pressing needs in Africa require close linkages between research and infrastructure development. Research initiatives in East Africa inform government agencies on a range of issues including mineral resources, geothermal energy, groundwater flow and aquifers, and the protection of these resources from geohazards. The following questions concern geohazards in the East African Rift:

- What are the recurrence times of volcanic eruptions, dike intrusions, and catastrophic $CO_2$ release from lakes?
- Where are shallow magma chambers, what are their recharge rates?
- How do groundwaters interact with magma reservoirs, and how can these systems be tapped for geothermal energy?
- How does the eruption style change in space and time?
- What are geochemical and geophysical baselines for activity, and which volcanoes have active hydrothermal systems and/or magma chambers?
- What and where are historic and ancient landslide, pyroclastic, lahar and tsunami products ?
- Which faults are active, what are their slip rates, and what are the earthquake recurrence intervals on them?
- What are potential earthquake magnitudes given a knowledge of crustal thickness, lithospheric rheology, and the manner in which strain is partitioned between faults

Answers to questions in 2.1 to 2.4 require ground-truthing of remote sensing, detailed geo- and thermo-chronology, petrology, geochemistry, seismicity, and geodesy (InSAR, gravity, and GPS) studies to identify active faults, to discriminate between magmatic and hydrothermal causes for the inflation of volcanoes, and to establish geochemical and geophysical baselines. Theoretical studies of the rise of magma through the plate, evolution of extensional fault arrays, and fault-volcano interactions. These integrated data acquisition and modeling studies are important for predictive approaches to hazards analysis as well as for developing a basic understanding of fault kinematics and evolution in the contemporary stress field. Lithospheric-scale modeling efforts are, of course, crucial for understanding the longer timescale development of continental rift zones.

All participants agreed that implementation strategies required integrated data sets and close partnerships between international and local investigators, and with regional planners. Future programs should consider focus sites for intensive, integrated studies, as well as a continental-scale approach. The value of rapid response by local and international teams to current or anticipated crises (earthquake, volcanic eruption, $CO_2$ degassing, deformation) was recognized.

**3. Linking Research with Infrastructure and Capacity Building**

Successful implementation of the above research aims requires a close partnership between US and African colleagues. Discussions focused on effective strategies to enhance and augment research while also building the capacity of the host African institutions. The meeting participants applauded the newly developed partnership between NSF international programs (OISE) and USAID, which should increase funding for the participation of African partners in data analyses and interpretation.

The following are prioritized recommendations for sustainable hazard mitigation programs, and strategies for their implementation. The group recommended a three-pronged approach to leverage ‘blue-skies’ research funding opportunities to assist with East African rift (including Cameroon volcanic line) capacity-building. These recommendations are all linked to blue-skies research aims, but would also require local support, and draw on funding from international initiatives.

### 3.1 Evaluation of needs

In addition to the limited monitoring of volcanoes, and the sparse seismic and geodetic networks in much of the East African rift system, there even less information on the perception and support of geohazard mitigation programs. For example, Africa is the continent with the lowest density of continuous GPS stations, with less than 100 stations currently available. The distribution of GPS stations in Africa is only marginally driven by geohazards considerations, resulting in a paucity of observations.

A first step is to evaluate the level of support and dialogue within each country, and the level of financial and political support from regional and local Institutions. A compilation of these results from all of the countries transected by the East African rift system can then be used to reassess geohazard models for sectors of the East African rift system

### 3.2 Education, Training, and Networks

Sustainable strategies require support and further enhancement of existing centers of excellence in Africa. African universities with vibrant research teams enable cross-political sharing of expertise without the need for non-African consultants. The development of education and research networks will facilitate inter-African scientific exchange, as well as regional data sharing initiatives. One example is the ICTP support for an African PhD program in geo-hazard to be based at Addis Ababa University, a successful outcome of the workshop (see www.ictp.it and http://agenda.ictp.it/smr.php?2053). The objectives of the PhD program are to provide specialized high-level doctoral training to African candidates and others interested in the program with international standard in the fields of seismology, volcanology and geochemistry.

In light of concerns for incentives to retain younger researchers in African institutions, the group recommended visiting scholar and sabbatical leave programs. With the growth of PhD programs in many African geoscience departments, sandwich courses for PhD/Masters Students from African institutions could provide training opportunities, as well as access to specialist hardware and software yet to become available in sub-Saharan Africa.

Regional networks serve to counter the isolation issues of many African partner institutions. For example, US researchers benefit from the extensive support of UNAVCO, IRIS-PASSCAL, and other national and international geoscience facilities. Participants self-organized to prepare proposals for a consortium of equipment-sharing Institutions in sub-Saharan Africa that could provide hardware, software, and technical support to train end-users of equipment (e.g., seismic, GPS, volcanic gas monitoring, etc.). A recommendation was put forward to ICTP for support of a new regional network at the University of Dar-es-Salaam, and headed by Dr Richard Ferdinand-Wambura (see www.ictp.it).

### 3.3 Proposal preparation

Best practice in proposal preparation involves a clear statement of constraints on both sides, and follow-through on initial promises. For large field programs, US researchers should consider the involvement of students from other African universities. For example, the EAGLE project could have involved EAR community students in the field project. US researchers need to discuss needs during research proposal preparation, and, wherever possible, weave aspects into proposal.

### *3.4 Regional Workshops in Africa, and Education and Outreach initiatives outlined.*

Many of the attendees had participated in earlier East African rift meetings, and they highlighted the importance of speaking with a collective voice to politicians, planners, and funding agencies. Participants were urged to contact national science coordinators to ensure geohazard mitigation becomes a priority for the Organization for African Unity. Education and outreach are important, yet remain under-utilized aspects. For example, US partners can share geohazards public information materials, and assist with translation and modification for local audiences, as in the recent Oldoinyo Lengai example.

## 4. Geohazard Communication

Effective implementation requires demonstration of the benefits to society of these hazard mitigation efforts. Recommendations were organized in terms of risk and scale of dissemination required. At all stages, scientists and planners need to identify and characterize the audience, and speak with one voice.

Minimum risk situations may be regional in scale and relate to historic earthquake or volcanic activity. Interviews, documentaries can be used to disseminate information through primary and secondary schools, through market places and health centers, *Religious gatherings*, *Village council meetings,* r*adio and TV stations – remote, rural, urban. Mobile phones provide a means of feedback between geoscientists and public.*

Medium and high risk situations involve visible signs of potential hazards, as in seismic swarms or increased gas emission from volcanoes. Rapid response teams should be identified in advance of these situations. These teams can then initiate technical meetings between experts to outline potential outcomes and strategies for information dissemination. Implementation of programs first involves an appraisal of outcomes achievable with available resources, and should include media and outreach programs. Suggested programs include sensitization of potential victims via brochures, television documentaries, and posters.

### *4.1 Establish permanent observatory station*

The following is an outline recommendation for African Centers for Volcano Observation and Research (ACVOR), which was discussed as a framework for future regional proposals to international funding agencies and African national government agencies.

The African Center for Volcano Observation and Research (ACVOR) will be a joint program of the East African countries and other partners. (ACVOR) will use resources from member and partner institutions to monitor and study East African and Cameroonian hazardous volcanoes, to predict and record eruptive activity, and to mitigate volcanic hazards to life and property.

*Objectives*

ACVOR will have three primary objectives:

- To conduct monitoring and other scientific investigations in order to assess the nature, timing, and likelihood of volcanic activity;
- To assess volcanic hazards associated with anticipated activity, including kinds of events, their effects, and areas at risk
- To provide timely and accurate information on volcanic hazards, and warnings of impending dangerous activity to local, state, and federal officials and the public.

African active volcanoes offer excellent opportunities for basic scientific investigations of volcanic processes. An important component of ACVOR's program will therefore be to conduct research at selected volcanic centers. The scope of this research includes:

- Basic geological mapping to determine eruptive histories of active volcanoes,
- Geochemical characterization and modeling of diverse magmatic systems,
- Documentation and analysis of eruptive processes, and
- Geophysical exploration of the interiors of volcanoes and mechanisms of eruption

***Appendix 1 outlines a 'strawman' strategy for development of ACVOR.***

## 5. Summary

The **Evaluating, Monitoring, and Communicating Volcanic and Seismic Hazards in East Africa Workshop** highlighted the need for basic research into past and present volcanism and rifting processes in East Africa and the Cameroon volcanic line.  Such efforts will form the framework in which to develop and support capacity-building, and regional networks and observatories in East Africa for the evaluation, monitoring and communication of volcanic and seismic hazards. Results of ongoing and planned research studies will contribute significantly to accurate completion of volcanic hazard assessments, the development and implementation of regional earthquake and volcanic monitoring activities, and to geo-hazard mitigation efforts.

**Appendix 1**

**Recommendation – Discussion Document**

**African Center for Volcano Observation and Research (ACVOR)**
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***Organization***

ACVOR offices will be established in------------. The Main Office will be responsible to coordinate all activities and will serve as the primary point of information dissemination during crises. Other offices will be established to serve as data collection points for most of the seismic and satellite data. ACVOR will be staffed by the necessary number of full-time scientists, technicians, and administrators.

***Volcano Hazard Assessments***

ACVOR will be responsible for assessing the full range of potential hazards at specific volcanic centers, iIn support of public land-use planning, development of emergency response plans, and general public awareness of the nature of volcanic activity in Africa,. This effort involves studying a volcano to determine the style and frequency of past eruptions, and potential impacts of future activity.

***Volcano Research Program***

African active volcanoes offer excellent opportunities for basic scientific investigations of volcanic processes. An important component of ACVOR's program will therefore be to conduct research at selected volcanic centers. The scope of this research includes:
- Basic geological mapping to determine eruptive histories of active volcanoes,
- Geochemical characterization and modeling of diverse magmatic systems,

- Documentation and analysis of eruptive processes, and
- Geophysical exploration of the interiors of volcanoes and mechanisms of eruption.

Results of these studies will contribute significantly to accurate completion of volcanic hazards assessments and to the continual improvement ACVOR's monitoring and predictive capabilities.

### *Volcano Monitoring Program*

ACVOR's volcano monitoring program will consist of networks of continuously recording seismometers installed at selected volcanoes. Seismic data will be relayed to ACVOR facilities where they will be analyzed both automatically and by analysts. Satellite imagery provides information which complements seismic monitoring at those volcanoes with seismic networks, and is the only source of routine monitoring information at those without. Space-based deformation monitoring is an emerging technique. ACVOR will operate a network of telemetered GPS receivers at selected volcanoes that provide a continuous record of ground deformation. ACVOR will also conduct periodic field-based GPS surveys as well as measuring deformation with satellite radar interferometry (InSAR) techniques. These techniques are providing important information about inflation and deflation of volcanoes.

### *Response to Activity*

ACVOR will establish a volcano crisis center, a seismic data collection and archiving center at the Main Office, and other offices responsible for various tasks.

### *Information Dissemination and Outreach*

During eruptions and under conditions of heightened concern, the crisis center at the ACVOR Main Office will be directly responsible for all activities concerning the emergency. ACVOR will be the principal point of contact for information on volcanic activity and hazards assessment for government agencies, the media, and the public. At all times and especially during volcanic emergencies, ACVOR will maintain close communication links with critical international agencies such as the African Union and the UN.

### *Staff*

Several institutions will contribute personnel at several locations. A wide variety of disciplines will be represented, including geophysics, geology, geochemistry, remote sensing, computing, electronics, and administration.

**Appendix 2**

## SUMMARY OF GPS DISCUSSIONS

Africa is the continent with the lowest density of continuous GPS stations, with less than 100 stations currently available. Surface-wise the African continent is however equivalent to China, USA, Europe, Central America, and Japan which together represent more than 8,000 continuous GPS stations with openly available data. In addition, the distribution of GPS stations in Africa is only marginally driven by geohazards considerations, resulting in a paucity of observations in the East African Rift and the Cameroon volcanic line in regards to the challenges at hand.

Current efforts to equip Africa with GPS stations involve efforts from individual research projects and national mapping agencies. These efforts are coordinated, to some extent, under AFREF (AFrica REFerence frame), an initiative that promotes the creation of a uniform coordinate system for Africa by establishing a framework of permanent GPS stations and tying national geodetic system in a common, space-based, reference system. Publicly available data is key to the success of such initiatives but a number of organizations or project PIs are still reluctant to share their data. It is important to establish a culture of open geodetic data in Africa in order to optimize the use of the scarce resources available and avoid duplicating efforts.

Together with other geophysical sensors, satellite observations, and field data, GPS measurements can provide several of the observables required to address the science and geohazard questions listed above. In addition, GPS instruments can serve other science applications in disciplines such as meteorology, hydrology, and climate, as well as practical applications for surveying and mapping. African geoscientists interested in developing GPS networks should try and partner with other agencies (e.g., national weather bureau, national mapping agency, etc.) to spread the cost and maintenance of the instruments.

The collocation of GPS with seismic stations or other types of permanent geophysical instrumentation is a good way to reduce the efforts and costs to maintain observations in the long term, although technical requirements may sometimes be incompatible between various instruments.

A fundamental condition to the success of geodetic networks in Africa is the training of a modern science workforce in tectonic/seismic geodesy. Geodesy is typically taught in civil engineering departments, it is important to break that barriers and make sure that geology and geophysics departments also provide access to the science advances made possible thanks to the latest geodetic tools such as GPS and InSAR. The graduate program to be established in Addis Ababa will play a key role in that regard. Additional specialized sessions should be organized in Africa to train geoscientists to using the latest data analysis software and become independent in the processing of the data of their choice.

It was suggested that the upcoming regional network for East Africa headed by Dr Richard Ferdinand-Wambura becomes an associate member of UNAVCO. It is important that this network shares information about upcoming station installations and acts to facilitate instrument collocation and data sharing.