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12th Annual AfricaArray Workshop

School of Geosciences
University of the Witwatersrand
Johannesburg, South Africa

27 June - 1 July 2017

Programme

12th Annual AfricaArray Workshop

27 June - 1 July 2017

University of the Witwatersrand, Johannesburg, South Africa

Tuesday 27 June and Wednesday 28June	*08h30-17h00*	***Course:*** Experiment Design and Implementation Using GNSS/GPS Data *Sarah Stamps, Virginia Tech, USA*
Tuesday 27 June & Wednesday 28 June	*08h30-17h00 & 08h30-12h00*	***Course:*** Techniques in palaeoseismology *Marc Goedhart, KainosSA & Marco Andreoli, Wits University*
Wednesday 28June	*14h00-17h00*	***Course:*** Joint inversion of receiver functions and surface waves *Eldridge Kgaswane, Council for Geoscience*
Wednesday 28 June	*14h00-17h00*	***Course:*** Natural and Human-Induced Hazards and Disasters in Africa *Ray Durrheim, Wits University*
Thursday 29 June & Friday 30 June	*8h00-19h00 & 8h00-17h00*	***AfricaArray Scientific Meeting***
Saturday 1 July	*9h30-16h00*	***AfricaArray station operator course*** *Andy Nyblade, Ranto Raveloson, Fenitra Andriampenomanana*
Saturday 1 July to Friday 21 July		***AfricaArray International Field School***
Sunday 2 July to Saturday 22 July		***AfricaArray Research Experience for Undergraduates*** ***Field Trip to the Bushveld Complex***

GLT Lecture Theatre, Geosciences Building, Wits **Thursday 29 June 2017**

***Abstract appended**

08:00 - 08:30	**REGISTRATION**
08:30 - 08:40	Welcome **Professor Ebrahim Momoniat** (*Dean, Faculty of Science, University of the Witwatersrand*)
08:40 - 09:00	AfricaArray status report - network activities and development plan **Andy NYBLADE** (*Penn State University USA*)
09:00 - 09:15	Training and complementary activities **Ray DURRHEIM** (*University of the Witwatersrand & CSIR, SOUTH AFRICA*)
09:15 - 09:30	Building Geophysics Talent and Opportunity in Africa: Experience from the AfricaArray/Wits Geophysics Field School **Susan Webb** (*University of the Witwatersrand SOUTH AFRICA*)

Theme: Reflection Seismology, Mineral & Energy Resources

09:30 - 10:00	***New seismic technology drives trends in land and offshore exploration **Musa MANZI** (*University of the Witwatersrand, SOUTH AFRICA*)
10:00 – 10:30	***TEA BREAK***
10:30 – 10:45	***Using 3D reflection seismics to map loss-of-ground structures in the western Bushveld Complex: Faults zones, dykes, IRUPS, potholes and diapirs **Stephanie SCHEIBER-ENSLIN** (*University of the Witwatersrand SOUTH AFRICA*)
10:45 - 11:00	***Use of the seismic reflection method to optimize safety and extraction: A case study from a South African platinum mine **Seeiso MOSHOESHOE** (*MSc candidate, University of the Witwatersrand SOUTH AFRICA*)
11:00 - 11:15	***Structural interpretation using seismic attributes: a case study from offshore Orange Basin, South Africa. **Buhle DONGA** (*MSc candidate, University of the Witwatersrand SOUTH AFRICA*)
11:15 - 11:30	Seismic constraints on the Neoarchaean-Palaeoproterozoic crustal-scale tectonics, Witwatersrand Basin (South Africa) **Marcello MOLEZZI** (*MSc candidate, University of the Witwatersrand SOUTH AFRICA*)
11:30 - 11:45	***Theoretical overview of complex seismic attributes and applications to soft and hard rock environments in South Africa **Michael WESTGATE** (*MSc candidate, University of the Witwatersrand SOUTH AFRICA*)
11:45 - 12:00	***Physical property measurements for hydrocarbon exploration in the Main Karoo Basin, South Africa **Jonise COETZEE** (*MSc candidate, University of the Witwatersrand, SOUTH AFRICA*)
12:00 - 12:15	***Multi - Component Anisotropic Seismic Borehole Tomography **Julius VON KETELHODT** (*PhD candidate, University of the Witwatersrand SOUTH AFRICA*)
12:15	***GROUP PHOTO***
12:30 - 13:45	***LUNCH BREAK***
12:30 - 13:45	**PATRON'S PROGRAMME: TOUR OF REFLECTION SEISMICS LAB & SNACK LUNCH**

Theme: Structure, tectonics and resources of Africa

13:45 - 14:15	*Invited keynote address: Continental rift initiation: the results of the PRIDE experiment **Estella ATEKWANA** (*Oklahoma State University USA*)
14:15 - 14:35	*Extending the Rift Zone: evidence from central Botswana **Mark VAN DER MEIJDE** (*University of Twente, THE NETHERLANDS*)
14:35 - 14:55	Comparison of surface wave studies of the Central East African Rift System **Aubreya ADAMS** (Colgate University, USA)
14:55 - 15:10	*East African basins from S-wave receiver functions **Helio INGUANE** (*University of the Witwatersrand SOUTH AFRICA & Department of Mine MOZAMBIQUE*)
15:10 - 15:45	***Tea Break***
15:45 - 16:00	*On the origin of the Cenozoic alkaline volcanism of Madagascar: evidence from Pn Tomography and Receiver Function Imaging **Fenitra ANDRIAMPENOMANANA** (*PhD candidate, University of the Witwatersrand, SOUTH AFRICA*)
16:00 - 16:15	Seismic structure of the southern part of Madagascar as revealed by waveform modelling **Ranto RAVELOSON (***University of the Witwatersrand, SOUTH AFRICA*)
16:15 - 16:30	*The subsurface structure of the Congo Basin **Etienne KADIMA** (*University of Lumbumbashi DRC*)
16:30 - 16:45	*The economic potential of the frontier Volta Basin: geophysical constraints on the basin structure **Abigail ENYONAM AYIKWEI** (*PhD candidate, University of the Witwatersrand, SOUTH AFRICA*)
16:45 - 17:00	*Modelling of Basement and Basin Structure in the Zululand Basin using Potential Fields **Tamara MAKHATENG** (*MSc candidate, University of the Witwatersrand SOUTH AFRICA*)
17:00 - 17:15	*The crustal structure of Egypt and the northern Red Sea region **Ahmed HOSNY** (*National Research Institute of Astronomy and Geophysics, EGYPT*)
17:15 – 17:30	Introduction to a discussion **"The Future of the AfricaArray Observatory Network"**
17:30 - 19:30	**POSTERS & SNACKS IN THE BLELOCH MUSEUM** **Visit to the Wits University Reflection Seismology Research Centre**

GLT Lecture Theatre, Geosciences Building, Wits **Friday 30 June 2017**

Theme: Geodesy and space science

08:30 – 09:00 *****Invited keynote address: Advances in the kinematics and geodynamics of Africa
Sarah STAMPS (*Virginia Tech USA*)

09:00-09:15 *****Velocity field of the Nigerian Permanent GNSS stations
Joseph DODO (*National Space Research and Development Agency (NASRDA), NIGERIA*)

09:15 - 09:30 *****The role of time and frequency in geodesy: an example from GNSS positioning
Cilence MUNGHEMEZULU (*University of Pretoria, SOUTH AFRICA*)

Theme: Seismic monitoring and hazard assessment

09:30-09:45 *****The 2017 Botswana M6.5 Earthquake: Scientific Rapid Response
Vunganai MIDZI (*Council for Geoscience, SOUTH AFRICA*)

09:45-10:00 *****Learning from earthquake disaster in Tanzania: lessons from the Kagera earthquake event (M_w5.9) of 10th September 2016
Michael MSABI (*University of Dodoma, TANZANIA*)

10:00- 10:15 *****Seismic risk for cities around the Lake Kivu Basin, Western Branch of the East African Rift System
Mifunda Dieudonne WAFULA (*Goma Volcanic Observatory DRC*)

10:15 – 10:45 ***TEA BREAK***

10:45 – 11:00 *****Assessing seismic hazard of the East African Rift using seismic and geodetic tools
Georges MAVONGA TULUKA (*Goma Volcanic Observatory DRC*)

11:00 - 11:15 *****Recently felt earthquakes in Ethiopia
Atalay AYELE (*University of Addis Ababa, ETHIOPIA*)

11:15 - 11:30 *****Waveform inversion for minor and moderate local earthquakes in Egypt
Hazem BADR EL-DIN (*National Research Institute of Astronomy & Geophysics, EGYPT*)

11:30 - 11:45 *****Seismicity of Madagascar
Tsitsi RAKOTONDRAIBE (*PhD candidate, University of the Witwatersrand, SOUTH AFRICA*)

11:45 - 12:00 *****Determination of a local magnitude scale for Uganda
Joseph NYAGO (*Directorate of Geological Survey, UGANDA*)

Theme: Mining-related seismicity

12:00 - 12:15 *****Drilling into seismogenic zones of M2.0–M5.5 earthquakes in deep South African gold mines (DSeis)
Ray DURRHEIM (*University of the Witwatersrand SOUTH AFRICA*)

12:15 - 12:30 *****Uncertainty associated with the earthquake catalogue: impacts on seismic hazard assessment for Johannesburg
Brassnavy MANZUNZU (*PhD candidate, University of the Witwatersrand & Council for Geoscience, SOUTH AFRICA*)

12:30 - 12:45 *****An integrated approach to understanding different geotechnical zones using high resolution microseismicity in underground mines
Siyanda MNGADI (*MSc candidate, University of the Witwatersrand SOUTH AFRICA*)

12:45 - 14:00 ***LUNCH***

14:00 - 14:15 *****The macroseismic survey of the 3 April 2017 Stilfontein M4.2 earthquake
Tebogo PULE (Council for Geoscience, SOUTH AFRICA)

14:15 - 14:30 *****Time-dependent seismic hazard
Brian Sibunelo ZULU (*MSc candidate, University of the Witwatersrand & Council for Geoscience, SOUTH AFRICA*)

Theme: Near-surface & groundwater

14:30 - 14:45 *****Case study: deep groundwater exploration using geophysics
Charles OSANGO OCHALO (*Kenya Society of Geophysicists, KENYA*)

14:45 - 15:00 *****Assessment of site effect at the seismological stations in South Africa using the HVSR technique
Emmanuel ONYEBUEKE (*PhD candidate, University of the Witwatersrand, SOUTH AFRICA*)

15:00 - 15:15 *Geophysical methods to locate potential underground voids at Springlake Colliery, SA
Lebogang SEHOOLE (*MSc candidate, University of the Witwatersrand, SOUTH AFRICA*)

15:15 - 15:30 *****Method refinement of the DC Resistivity Method for near surface exploration
Wesley HARRISON (*MSc candidate, University of the Witwatersrand, SOUTH AFRICA*)

15:30 - 16:00 ***TEA BREAK***

Theme: Initiatives allied to AfricaArray

16:00 - 16:15 IASPEI & the African Seismological Commission
Atalay AYELE (*University of Addis Ababa, ETHIOPIA*)

16:15 – 16:30 IUGS Resourcing Future Generations initiative
Ray DURRHEIM (CSIR & *University of the Witwatersrand, SOUTH AFRICA*)

16:30 – 16:45 ICSU Regional Office for Africa: Science Plans
Richard GLOVER (*ICSU Regional Office for Africa*)

16:45 – 17:00 American Geophysical Union (AGU) & Society of Exploration Geophysicists (SEG)
Susan WEBB (*University of the Witwatersrand SOUTH AFRICA*)

17:00 – 17:30 Continuation of the discussion **"The Future of the AfricaArray Observatory Network"**

17:30 - 19:00 **POSTERS & SNACKS IN THE BLELOCH MUSEUM**

Posters on display in the Bleloch Museum, 29-30 June 2017

Earth Structure & Mineral Resources

Acquisition of a unique onshore/offshore geophysical dataset in the Northern Malawi Rift
Patrick CHINDANDALI (*Geological Survey of Malawi, MALAWI*)

*Crustal structure beneath Mount Cameroon region derived from new gravity measurements
Evariste NGATCHOU HEUTCHI (*University of Younde 1, CAMEROON*)

Geodesy and space science

*Mapping GPS Total Electron Content in mid-latitude regions: the importance f the Trignet Network of South Africa
Colette DE VILLIERS (*BSc Hons candidate, University of Pretoria, SOUTH AFRICA*)

*Analysis of GPS position time series in Africa
Sikelela GOMO (*MSc candidate, University of the Witwatersrand, SOUTH AFRICA*)

Tectonics, Earthquakes, Volcanoes & Geohazards

*Probabilistic Seismic Hazard Assessment along the Cameroon Volcanic Line: preliminary results
Bekoa ATEBA (*Institute of Geological & Mining Research, CAMEROON*)

*Seismic Catalogue for Ghana
Sylvanus Tetteh AHULU (*Geological Survey Department, GHANA*)

*Focal mechanism of the southeastern part of Madagascar using data from the temporary and Malagasy seismic stations
Rijatiane BARIMALALA (*IOGA, MADAGASCAR*)

The kinematic model of the Malawi Rift from GNSS/GPS data
Harvey CHILEMBWE (University of *Malawi, MALAWI*)

*M5.9 Kaputa earthquake
Mirriam Mwango CHILESHE (Geological Survey Department, ZAMBIA)

Active fault mapping in Mozambique
Vladimiro MANHICA (*National Institute of Mines, MOZAMBIQUE*)

*Status of AfricaArray stations in Zambia
Annie MULOWEZI (Geological Survey Department, ZAMBIA)

*The status of ICDP DSeis drilling into The 2014 Orkney M5.5 fault: location of initial and main ruptures, and aftershocks
Hiroyuki OGASAWARA (*Ritsumeikan University, JAPAN*)

*Assessing active tectonics pf the south-central part of Madagascar: Ihorombe Region, Ihosy District
Herimitsinjo RAJAOALISOBN (*IOGA, MADAGASCAR*)

*Statistical and clustering properties of the Alboran Sea seismic sequence following the 25 January 2016 earthquake
Mohamed ROUAI (Meknes University, MOROCCO)

ABSTRACTS

Comparison of Surface Wave Studies of the Central East African Rift System

Aubreya ADAMS

Colgate University, USA

This study uses the Automated Generalized Seismological Data Function (AGSDF) method to develop a Rayleigh wave velocity model of the central and southern portions of East African Rift System (EARS). Derived phase velocity models give insight into the lithospheric structures associated with surficial features, include rift segments, volcanic activity, and pre-rift structures. A large dataset of 740 earthquakes is used, and is comprised of Mw=6.0+ events that occurred between the years 1995 and 2016. These events were recorded by a composite station array of 176 stations from twelve different non-current seismic networks, each with a distinctive array geometry and station spacing. In this study, data from these events were used to determine Rayleigh wave phase velocities at periods ranging from 20 to 100 seconds. Several first-order features are resolved in this phase velocity model. (1) Low velocities are observed in isolated regions along the Western Rift Branch and across the Eastern Rift Branch, corresponding to areas of active volcanism. (2) Two linear low velocity zones are imaged trending southeast and southwest from the Eastern Rift Branch in Tanzania, corresponding with areas of seismic activity and indicating possible incipient rifting. (3) High velocity regions are observed beneath both the Tanzania Craton and Bangweulu Block, with faster velocities found beneath the Bangweulu Block at the longest periods studied.

Velocity models derived using the AGSDF method are compared to previous models generated using the two plane-wave (TPW) methodology. Primary geologic features, as well as the shapes and sizes of velocity anomalies are similar in both models. At most periods, velocities in the AGSDF models display greater variability than those generated using the TPW method, which may be attributed to lateral smoothing applied following the TPW method. Two regions display significant differences between models, which may be attributed to the inclusion of additional recent data. The comparability of results from these two tomographic methods indicate that the AGSDF method may be used to generate rapid insights into velocity structure even using compound dataset that lack an ideally spaced station distribution.

Seismic Catalogue for Ghana

S. AHULU[1] and R.M.W. Musson[2]

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The earthquake catalogue for Ghana has been provided. The study used all available data based on earthquakes between latitudes 4ºN-8ºN and longitudes -4ºW-2ºE. The earthquake data covers the period 1615 – 2009 and was compiled from different catalogue sources; USG-United States Geological Survey, AKO-Akoto and Anum (1992), BER- Bertil (1991), BGS-British Geological Survey, GSA-Geological Survey Authority, ISC-International Seismological Centre, NNA-Ambraseys and Adams (1986). Expressing the data in moment magnitude, Mw, was not straight forward since values were expressed in a mixture of scales, and are generally rather approximate, and there are no true local Mw values for comparison. As a rough solution, it was assumed that macroseismic magnitude values quoted by Ambraseys and Adams (1986) and body-wave magnitudes quoted by ISC can be taken as roughly equivalent to Mw, while local magnitude values were converted to Mw using a conversion formula proposed recently by Grünthal et al. (2009). Hence approximately 200 events of the earthquake magnitude values were unified to the moment magnitude (Mw), which is a direct indicator of the co-seismic deformation (Boore and Joyner, 1984; Joyner, (1984).

Keywords: Earthquake catalogue, Ghana, Unified movement magnitude.

On the Origin of the Cenozoic Alkaline Volcanism of Madagascar: Evidence from *Pn* Tomography

Fenitra ANDRIAMPENOMANANA[1,4], Andrew Nyblade[2], Raymond Durrheim[1] and Michael Wysession[3]

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2. Penn State University, Pennsylvania, USA
3. Washington University in St. Louis, Missouri, USA
4. Université d'Antananarivo, Madagascar

Even though Madagascar was tectonically stable for the past 85 Myr and remote from tectonic plate boundaries, volcanic eruptions anomalously occurred in several parts of the island during the Cenozoic (*ca*. 50-0.5 Ma). To investigate the origin of the Cenozoic volcanism in Madagascar, we use the travel-time of *Pn* waves to tomographically image the lateral variations of seismic velocity and seismic anisotropy of the uppermost mantle. Results show an average uppermost mantle *Pn*-velocity of 8.1 km/s. However, significant low-*Pn*-velocity zones (~7.9 km/s) are found beneath the Cenozoic volcanic provinces in the northern, central, and southwestern region of the island. These low-*Pn*-velocity zones are attributed to thermal anomalies that are associated with upwelling of hot mantle materials and gave rise to the Cenozoic volcanism. The direction of *Pn* anisotropy shows a dominant NW-SE direction of fast-polarization in the northern region, suggesting mantle flow from a region northwest of Madagascar and supporting the hypothesis that links the Cenozoic volcanism in Madagascar to the Comoros hotspot. A low magnitude of *Pn* and *SKS* anisotropy, which was observed only in the low-*Pn*-velocity zone beneath the central volcanic province, suggests the vertical flow in the mantle associated with the upwelling of hot materials beneath the region. The station static delays reflect the significant variation in the Moho depth beneath the island.

Probabilistic Seismic Hazard Assessment Along the Cameroon Volcanic Line: Preliminary Results

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The Cameroon Volcanic Line (CVL) extends from the Gulf of Guinea to Lake Chad. Many types of volcanic hazards are linked to its eruptive manifestations. These include lava flows, dust and ash projections from Strombolian activity, earthquakes, landslides and gas emissions. The hazards have significant consequences on the population and their property, the environment and its biodiversity and therefore on the economy of the country. In this preliminary study, we use a probabilistic approach to investigate the seismic hazard of the CVL. The most active seismic region is around Mount Cameroon which is an active volcano. The seismicity is also recorded in west Cameroon where gas explosions have been recorded in two crater lakes. The tectonics are characterised by faults mostly covered by lava flow and the Central Cameroon Shear zone whose extension is recognised as Pernambuco fault in Brazil. Accordingly, four seismic source zones are considered: two area sources (seismicity) and two line sources (faults). A seismic catalogue is built from bulletins of our observatory, and from external sources: historical reports, ISC, NEIC, USGS etc. Magnitudes are harmonised to M_w. Seismic source parameters are determined and seismic hazards are computed using CRISIS 2012 software on sites supposed to be located on bedrocks. The preliminary results show that the chance of exceeding a PGA of 0.10 g is less than 10% in 100 years. This low value contrasts with damages observed in particular around Mt Cameroon region, and shows the importance to investigate seismic site effects along the CVL.

Keywords: Cameroon Volcanic Line, Mt Cameroon, probabilistic seismic hazard

Continental Rift Initiation: the Results of the PRIDE Experiment

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Significant advances have been made in our understanding of the evolution of continental rifts. Nonetheless, our understanding of the dynamic processes occurring within the Earth's crust and upper mantle that drive the development of amagmatic and magma-poor rifts remain limited largely because of the lack of geological and geophysical data from these rift systems. For example, we do not know how strain is localized in the lithosphere and the relative roles that magma and fluids play in driving magma-poor rifting. In addition, although pre-existing structures within the Proterozoic mobile belts are suggested to exert a major influence on the localization of the rifts, the exact manner in which these structures reactivate and modulate rift structures remains poorly understood. The multidisciplinary Project for Rift Initiation, Development and Evolution (PRIDE) was funded to address this long standing problem and focused on amagmatic rift segments of the East African Rifts System (EARS) at different stages of their evolution including the Okavango, Luangwa, and Malawi rifts. The PRIDE experiment included passive and active source seismology, potential fields, magnetotelluric, hot spring geochemistry and geological surveys. Our results show surface geomorphic features characteristic of rifts (long narrow, grabens bounded by faults) but no consistent along axis thinning of the crust beneath the rifts. A thin crust is observed beneath the Okavango rift and is associated with elevated heat flow compared to the surrounding Proterozoic basement. However, beneath the Luangwa and Malawi rifts, a thin crust is only observed in their northern segments in the vicinity of the Rungwe Volcanic Province. The southern segments of the Luangwa and Malawi Rifts are underlain by thick crust. Our results also show no thermally perturbed mantle transition zone beneath all three rift segments suggesting absence of lower mantle influence on rifting. We infer from these observations that the variability in crustal and lithospheric thickness beneath the rifts may not be related to rifting but is probably inherited from the older (prerift) lithospheric accretion terranes. This finding demonstrates a previously unknown role of pre-rift structures during rifting processes. Strain localization at continental rift initiation is dominantly controlled by the strength of the pre-rift lithosphere and its tectonic history (pre-existing inherited lithospheric heterogeneity/accretionary terranes). We advocate for a three end-member model that incorporates pre-rift lithospheric heterogeneity and tectonic history.

Recently Felt Earthquakes in Ethiopia

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The East African Rift is one of the most classic examples of active continental rifts that we witness to date. Active tectonics manifests itself through moderate magnitude seismicity and volcanism in the region. Major cities and towns in Ethiopia are located either within the active rift floor or the nearby margins where small farming villages got highly urbanized over the years which is unintended overlap that exacerbated earthquake risk in the area.

The January 24, 2016 earthquake of magnitude 4.4 M_w occurred nearby the highly populated Awasa town at 18:34:32 UTC which was widely felt all over the town with minor damage on buildings. The Awasa University students staying in dormitories of high rise buildings panicked and minor injuries were reported. Another earthquake of magnitude 4.6 Ml occurred on December 4, 2016 at 01:56:15 UTC at the rift margin 40 km south of Ankober town and about 90 km NNE of Addis Ababa. It was widely felt in Addis Ababa where a number of residents from different part of the city reported their feeling to the media. On January 27, 2017 an earthquake of magnitude 5.3 M_w ruptured at 16:29:23 UTC, 160 km south of Addis Ababa just beneath Lake Langano. This earthquake was widely felt in most of rift valley towns in Ethiopia as far as Addis Ababa and it has been a subject of discussion both in the public and mainstream media in the country.

Addis Ababa being one of the fastest growing cities in sub-Saharan Africa and as the capital of Africa, there is a risk due to potential earthquake hazard which has never got due attention by the concerned stakeholders. The Ethiopian

Seismic Station Network (ESSN) is beaming real-time data, though there is a constraint due to frequent power failure and poor internet connectivity. On the other hand, awareness in the society and all the concerned is still low which demands a coordinated effort in the years ahead so as to mitigate possible earthquake risk.

Keywords: Felt earthquakes, Seismicity of Ethiopia.

Waveform Inversion for Minor and Moderate Local Earthquakes in Egypt

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The waveform inversion technique, which uses waveform data from near-source seismic stations of the Egyptian National Seismic Network (ENSN), is applied to estimate focal mechanism and moment magnitude of minor - moderate local earthquakes that occurred after 2010 in and around Egypt. Fifty eight earthquakes with local magnitude ranges from 3.5 to 5.5 are analyzed. The earthquake focal mechanism obtained by waveform inversion was fundamentally validated by means of using the first onset polarities technique. Based on the obtained results, we have identified several seismic sources in and around Egypt. Combining the estimated earthquake focal mechanisms and the previously published focal mechanisms of earthquakes occurred before 2010 are used for determining the stress field in each relevant seismic source. A new scaling relation, between local magnitude Ml and the estimated moment magnitude Mw, was developed using a nonlinear regression. The results of this study can be used to improve the ENSN's stations configuration and the efficiency to record teleseismic and regional events.

Keywords: waveform inversion, Focal mechanism, stress field.

Focal Mechanism of the Southeastern Part of Madagascar.

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The high number of earthquakes recorded in the southeastern part of Madagascar requires a seismological study in order to investigate the characteristics of the existing fault system. Five hundred and thirty earthquakes, with magnitude greater than 3 Richter, were recorded in the area by the seismic network Malagasy for the period of 1988 – 2014 ; while forty-six earthquakes were recorded by temporary seismic stations deployed between 2011 and 2013.
In this study, the focal mechanism of the southeastern part of Madagascar is investigated by using seismic data from temporary stations, given that the permanent stations do not cover the whole area of study.
The first motion method was used and 25 focal mechanisms are identified. We found that the majority of earthquakes in the area are caused by strike-slips and normal faults. The strike-slip faults correspond well to the known shear zones tectonic settings in the area. Moreover, the presence of normal faults confirm the East-West extension in the southern part of Madagascar, which was found in some previous studies.

Keywords: Southeast Madagascar, Focal mechanism.

M 5.9 Kaputa Earthquake

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This abstract highlights the findings on ground in Kaputa district of Northern Province of Zambia that was hit by an earthquake (locally called Makumba) and mitigation measures that ought to be taken before and after occurrence from such a calamity. An earthquake of magnitude 5.9 and depth of 27km from the hypocenter to the epicentre that lasted for about 2 minutes on the 24th February 2017 at around 02:30 hit kaputa district of the northern province of Zambia and it was felt in many places surrounding kaputa district and as far as those in the neighbouring democratic republic of Congo. The location of affected villages is near the dambo (marshlands) surrounding Lake Mweru Wantipa where the water table is not expected to be so deep.

Keywords: Earthquake, epicenter and magnitude.

Physical Property Measurements for Hydrocarbon Exploration in the Main Karoo Basin, South Africa

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The seismic velocities (P- and S-wave velocities) and bulk densities of sandstone, shale and dolerite core samples from borehole KWV in the southeast Main Karoo Basin were investigated to establish the effect they may have on surface reflection seismic exploration of hydrocarbon reservoirs in the basin.

The bulk density of the borehole samples was obtained using Archimedes' principle and the P- and S-wave velocities were calculated using the ultrasonic pulse transmission technique. The densities of the shale (2.75 g/cm3) and sandstone (2.71 g/cm3) samples were similar, while the dolerite (2.96 g/cm3) sample had a higher density. The seismic velocity of the shale sample was lower than expected (P-wave = 1541 m/s; S-wave = 795 m/s) and can be explained by vibrations in the lab affecting the signal, and thus the position where the P- and S-wave was interpreted to be. The seismic velocity of the sandstone (P-wave = 5462 m/s; S-wave = 2867 m/s) and the dolerite (P-wave = 6033 m/s; S-wave = 3156 m/s) samples were what we expected it to be, based on bulk density calculations and previous studies in the area. In order to mimic the in situ conditions of the rocks, and to investigate the stress at which pores close, the samples were put under stress, up to 50 MPa. All the samples reached their terminal velocity at 15 MPa, although the shale showed the fastest initial increase, and the dolerite the slowest initial increase.

Lastly, micro x-ray tomography was used to investigate the presence and orientation of micro-fractures in the samples. The micro-fractures in the shale were found to be parallel to the wave propagation direction, and the micro-fractures in the sandstone perpendicular to the wave propagation direction. Anisotropy studies still need to be conducted to determine the effect that the orientation of these fractures will have on the seismic velocities of the samples. The dolerite sample has no visible micro-fractures, and pore spaces should be in the nano-range, since there are no pores identified from micro x-ray tomography. Once stress is applied to the dolerite, no increase in seismic velocity is initially observed, which corroborates the absence of pores. The seismic velocity only increases between 5 MPa and 15 MPa, which can be attributed to the closure of nano pores.

Keywords: Karoo, hydrocarbon, seismic velocity, bulk density, x-ray tomography.

Mapping GPS Total Electron Content in mid-latitude regions: the importance of the Trignet Network of South Africa

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The Global Positioning System (GPS) solutions such as positioning are affected by the delay introduced by the free electrons in the ionosphere. The electron densities are increased during geomagnetic storms that are caused by solar activity. The GPS data measurements can be used to monitor solar activity by estimating Total Electron Content (TEC) from the dual-frequency receivers. Therefore, ionospheric TEC can be computed along the satellite-receiver signal path by combining dual-frequency carrier phase and code-delay GPS measurements. South Africa currently operates one of the largest GPS networks in Africa i.e., Trignet network. It has 67 GPS stations that are well distributed throughout South Africa. This network provides an opportunity to study geophysical and space weather processes with high spatial and temporal resolutions in the mid-latitudinal ionosphere. There are very few studies in South Africa that have studied the changes of TEC in regards to seasonal variability. The availability of TEC data is essential for corrections of GPS positioning and timing caused by variability in solar activity and ionospheric TEC. The ground-based receivers from Trignet provide users with daily GPS data in the Receiver Independent Exchange Format (RINEX) sampled at 30 second intervals. The For the comparison of seasonal variability of TEC, GPS data from the 1st of June (winter) and 1st of December (summer) of 2016, were chosen. The RINEX observables (L1 = 1575.42 MHz and L2 = 1227.6 MHz) obtained from Trignet were then used to estimate absolute TEC from the group and phase TEC values. The GPS_TEC analysis application was used to calculate the TEC values. The software also requires the satellite differential code bias (DCB) files and navigation files, which were retrieved from the International GNSS Service (IGS) site. The obtained TEC values for available stations in South Africa was used to derive a vertical TEC map to represent the change of TEC throughout South Africa for the specified dates. The preliminary results indicate that the TEC values start increasing from 04h30 and reach maximum values at 12h00. The TEC values are higher during summer period compared to winter period. The spatial distribution of TEC values recorded by the Trignet network indicates higher values from the stations towards the North and low values are depicted towards the South. Trignet network can play an important role in space weather monitoring in South Africa. We therefore, propose an automated TEC retrieval system that can improve space weather monitoring in South Africa using Trignet Network.

Keywords: Total Electron Content, Trignet Network, Seasonal variability, Mid-latitudinal ionosphere

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The Place of Space Geodesy in Global Earth Observation at the Centre for Geodesy and Geodynamics (CGG) Toro

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Space Geodesy received a boost in 2012 with the approval of Centre for Geodesy and Geodynamics (CGG) Toro as a "Candidate Site" by the Bureau of Network Communication of the Global Geodetic Observing System Committee. This approval followed a response to GGOS "Call for Participation (CforP) for the development, implementation, and maintenance of the Global Geodetic Core Network. The Global Geodetic Observing System (GGOS) is established by the International Association of Geodesy to integrate the three fundamental areas of geodesy (Earth's shape, gravity field, and rotation), to monitor geodetic parameters and their temporal variations in a global reference frame; to provide products and services with the geodetic accuracy necessary to address important geophysical questions and societal needs, and to provide the robustness and continuity of service which will be required of this system in order to meet future needs and make intelligent decisions. The Global Geodetic Observing System (GGOS) integrates different space geodetic techniques such as Global Navigation Satellite Systems (GNSS), Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Interferometric Synthetic Aperture Radar (InSAR) and Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), models and analysis techniques for the purpose of ensuring long-term, precise monitoring of geodetic observables vital for monitoring Earth system processes. This paper highlights the position of CGG Toro in filling a large geographic gap in the international space geodesy network.

Keywords: Space geodesy, Global Earth Observation, GNSS, geo-hazards, geodynamics

Velocity Field of the Nigerian Permanent GNSS Stations

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Today there are several permanent and continuously operating GNSS network stations around the world, some in dense regional arrays and others widely scattered to help define the International Terrestrial Reference Frame and to support global and regional geodetic studies. In Nigeria, a continuously operating GNSS Network known as NIGerian Reference GNSS NETwork (NIGNET) is established under the AFREF Project and to serve primarily as the fudicial network for Nigeria, the network consists of 15 continuously operating reference stations (CORS). To improve the understanding of the kinematic behaviour of Nigeria, a velocity field based on the analysis of time series from 2 to 6 years of data from about 13 GNSS stations constituting the network (NIGNET), is carried out relative to the stable Nubia plate. The north component of the network has an average velocity of 18.491 mm/yr while the east component has 22.283 mm/yr. The NIGNET shows an average network horizontal velocity of 20.514 mm/yr in the NE direction, with RMS network uncertainty of about 0.73 mm/yr. Maximum horizontal velocities are observed at stations CLBR, ULAG and RUST. This could be attributed to the fact that these stations are located at the costal areas. In general, the pattern of the velocity field for GNSS stations in Nigeria is quite consistent with the directions of present-day tectonic stress of the Nubia plate, thus presenting Nigeria moving dependently of the Nubia plate.

Keywords: NIGNET, velocity field, Nubian plate, plate tectonic.

Structural Interpretation using Seismic Attributes: a Case Study from offshore Orange Basin, South Africa

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The western offshore area of South Africa is an extensional margin which originated during Gondwana break-up. Just like many other extensional margins, the area in which the current survey was undertaken is riddled with structural features which are necessary to study based on their effect on geo-hazards, marine life proliferation and possibly, climate change. In this study, a 3D seismic volume from the AK99 3D survey was analyzed via the computation of seismic attributes. The aims were to illuminate and further improve the understanding of the structural complexities that exist in the Orange Basin by explicitly delineating faults and sub-faults, analyzing the relationships between the structures and determining seismic resolution for thin bed characterization. The methods used are: (1) manual and auto-picking of the strong seismic reflectors from the seismic data, (2) seismic data conditioning of horizons and the seismic amplitude volume by using mean and median based filters, (3) computation of horizon attributes such as dip-magnitude, dip-amplitude and edge detection attributes and (4) computation of volumetric attributes which include instantaneous attributes, variance, chaos and ant-tracking. Seismic resolution comprises vertical and horizontal resolution. The vertical resolution has been determined to be 22m, below this, the individual beds cannot be resolved and the throw of the fault cannot be determined if less than 22m. The horizontal resolution is 378m and 812m for a shallow and deep event, respectively. Seismic attributes have played an important role in highlighting the structural complexities in the study area. The results confirm the existence of structures such as seabed depressions (occurring mostly in the northern parts of the survey area), seabed mounds, a NNW-SSE trending normal listric fault and accompanying rollover anticline, polygonal faults, fluid pipes and a fluid chimney, all of which are features mentioned in previous works. The results demonstrate that the seabed depressions may be linked to the dense network of polygonal faults in the subsurface

or the fluid pipes which terminate underneath them. The fluid chimney follows a path of weakness along the regional normal listric fault therefore the fluid chimney appears to be controlled by this regional fault.

Keywords: Orange Basin, South Africa, 3D seismic data, seismic attributes, horizons, amplitude, resolution, structural analysis, faults.

Drilling into Seismogenic Zones of M2.0 – M5.5 Earthquakes from Deep South African Gold Mines (DSeis): Establishment of Research Sites

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While mining-induced earthquakes in the deep gold mines of South Africa pose a risk to mines, mineworkers and the public, they also provide an unusual opportunity to study the physics of earthquakes. The source zone of a M5.5 earthquake that occurred near Orkney, South Africa on 5 August 2014 was well-defined by tens of thousands of aftershocks recorded by instruments deployed as part of a Japanese - South African research project. The upper edge of the M5.5 rupture is located hundreds of meters below the mining horizon. A proposal to drill into the M5.5 source zone, as well as several other active faults in other deep mines, was approved by the International Continental scientific Drilling Programme (ICDP) in August 2016. Here we describe the scope and objectives of the project, and the selection and preparation of the principal drilling sites. In addition to the studies of earthquake phenomena, some of the holes will be used by geomicrobiologists to investigate deep microbiological activity fueled by H_2 released by seismic rupture to address questions about early life on planet Earth.

Keywords: ICDP, DSeis, active faults, deep gold mines

The Economic Potential of the Frontier Volta Basin: Geophysical Constraints on the Basin Structure

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West Africa is rich in mineral resources, with the majority of deposits being linked to Birimian basement rocks (2.2 - 2.0 Ga) that have significant cover of younger sediments such as the Volta Basin in Ghana. The possibility of extensive hydrocarbon and mineral resources (gold, diamond) in the Volta Basin has motivated for a renewed focus on the basin. However, the structural complexity of the basin and its thick sedimentary sequences require an integrated geophysical approach, incorporating electromagnetics, gravity, magnetics and seismic data to aid in targeting. This approach can be used to interpret basement and near surface structures, and will thus highlight their possible importance in the formation of stratigraphic and structural traps in the hosting of hydrocarbons and other important economic resources. The Volta Basin's structural and lithostratigraphic linkage to the much larger Taoudeni Basin of the West African Craton, as well

as its age equivalence to the Pan African Dahomeyide Orogeny (~ 600 Ma), are not yet resolved. This is due to the lack of field information, as well as lack of harmonization of available datasets. We expect to gain a better insight into the spatial and temporal relationships between Birimian basement structures and those found in the basin in order to better understand its structural evolution and possible linkage to the Taoudeni and Dahomeyides.

Keywords: Volta Basin, Birimian, West African Craton, Structural Evolution, Geophysical Techniques.

Analysis of GPS Position Time Series in Africa

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Data collected using continuous GPS stations located on the African continent were evaluated to study the geodynamic processes of the African Plate and quantitatively describe the displacements observed in GPS time series. The results of the investigation show that with every passing time, the African plate comprising of the Somalian and Nubian plates, is undergoing continued rifting along the East African Rift System. Both the Somalian and Nubian plates are moving in a north easterly direction at almost the same speed. However, their direction of motion differs by approximately 5.9 degrees. The difference in the direction of motion of the Somalian and Nubian plates enlightens the apparent rifting of the African plate.

Decomposing the GPS time series using the Fast Fourier transform revealed that, the displacements are present in the horizontal component of motion, of the GPS stations, even though they are not apparent in the time domain as in the vertical component of motion of the stations. The displacements in the vertical component of motion of the GPS stations were determined to be two orders of magnitude greater than those in the horizontal component. The density power spectra of the time series revealed that the displacements are characterized by a dominant frequency of 1 cycles/year, that is, a signal with a period of 1 year, which is thought to be associated with the yearly repetitive weather cycle. The displacements in the horizontal component were observed to be embedded in noise, hence they are not apparent in the time domain and, in some cases, in the frequency domain as well. The magnitude of the power spectra of the time series differed from station to station, signifying that the geophysical processes affecting the GPS stations do not have the same power at every GPS station site on the African continent.

Keywords: Fast Fourier Transform, displacement, rifting of the African plate, East African Rift System

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DC Resistivity Noise Reduction Methods within Mining Environments

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The direct current resistivity method is widely used in near surface (<50 m) geophysical exploration and resource monitoring. Unfortunately in electrically noisy environments, such as mines, where current is likely to be leaking into the ground, the resistivity model can be severely compromised by electrical noise. Three main methodologies for electrical noise removal was identified during a number of direct current resistivity field surveys conducted on mining property. These methodologies encompass the noise removal and compromised data recovery practice within mining environments. The three methodologies are, identifying sources of electrical noise and their effects, preparing electrically noisy data for processing and processing the prepared data. The electrical noise identification phase is crucially important, since this will govern the noise removal tactics that follow within the data preparation and processing phases. Types of electrical noise sources, which can induce spikes within the data, include mining machinery, local conducting bodies and cultural features. Once a noise source is identified the data preparation phase can commence. During data collection phase, spontaneous potential, average resistivity and borehole core resistivity measurements should be made. During the data preparation phase, the background spontaneous potential can be

subtracted from apparent resistivity measurements in order to enhance finer details within the apparent resistivity cross-sections. Also average resistivity measurements can be used to identify electrode errors, usually above average resistivity values (>20 000 Ω·m) due to poor soil contact, throughout the survey period. Borehole core resistivity measurements are also incorporated within the data preparation phase, since a general understanding of the underling geology will assist in allocating the upper and lower apparent resistivity boundaries. Taking an average of repeat measurements of direct current resistivity data has been shown to improve the data quality within electrically noisy environments and is particularly useful within the mining context. It has been shown that by preparing electrically noisy data with the previously mentioned methods, the root mean square error of apparent resistivity inversion models can be reduced by up to 20 % and unusable data sets can be recovered to a certain extent (unfortunately some data will still be lost but the less noisy data set can be inverted and not lost completely). During the processing stage, the removal of spikes caused by electrical noise sources or electrode malfunctions has improved the produced apparent resistivity models, when compared to borehole and borehole core sample resistivity measurements, during inversions. Once all the above mentioned methodologies have been completed, the produced geological models are compared to borehole core resistivity measurements and borehole logs for quality control and evaluation.

Keywords: Near surface, resistivity, electrical mining noise.

The Crustal Structure of Egypt and the Northern Red Sea Region

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P-wave receiver functions from 26 stations in the Egyptian National Seismic Network (ENSN) have been modeled using the H-k stacking method and in a joint inversion method with Rayleigh wave group velocities to investigate crustal structure across Egypt and the northern Red Sea region. The new estimates of crustal structure, when combined with previous results, show that the rifted margins along the Red Sea, Gulf of Suez and Gulf of Aqaba crustal thickness ranges from 25-30 km, the average crustal Vp/Vs ratio is 1.77, and the average crustal shearwave velocity is 3.6 km/s. Beneath northern and central Egypt, including the Sinai Peninsula, crustal thickness ranges from 32 to 38 km, the average crustal Vp/Vs ratio is 1.79, and the average crustal shear-wave velocity is 3.5 km/sec. Beneath southern Egypt, crustal thickness ranges from 35-40 km, the average crustal Vp/Vs ratio is 1.76, and the average crustal shearwave velocity is 3.7 km/s. In southern Egypt, the crust is also characterized by a 10-20 km thick mafic lower crust. These findings indicate that crust along the rifted margins of the northern Red Sea, and Gulfs of Suez and Aqaba have been thinned by about 5 to 10 km. The thick mafic lower crust in southern Egypt can be attributed to suturing during the Neoproterozoic collision of east Gondwana against the Sahara metacraton. Overall, the structure of the crust in Egypt away from the northern Red Sea region is similar to the structure of Precambrian crust in many other parts of Africa.

S-wave Receiver Function studies in African Sedimentary Basins

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Sedimentary basins are the result of prolonged subsidence of the Earth's surface. They occupy almost half of the African surface. The S-wave Receiver Functions (SRF) relies on the conversion of S-waves to P-waves produced by teleseismic earthquakes at the Moho discontinuity. The travel time between the direct S-wave and the Ss phase is used to deduce the thickness and the average velocity of the crust. This method can constrains the crustal thickness in regions where the P-wave Receiver Functions (PRF) fails due to strong intracrustal layering such as in sedimentary basins. Using the SRF in the sedimentary basins were possible to image the crust because in SRF methods the Sp phase arrives before any reverberation produced by the intracrustal layers in the crust. The earthquakes used to generate the SRFs were selected at epicentral distances between 60 and 82 degrees with magnitude ≥ 5.5 from data acquired between 2007 and 2013 in thee rift basins (Lake Albert, Lake Edward and Rukwa) and four pull-apart basins (Mozambique, Madawa, Rovuma and Ruvu). A moveout correction was made to align the SRFs obtained from different events, enabling them to

be stacked to reduce random noise, enhance the signal-to-noise ratio of the Sp phase and accuracy of the pick of the Sp arrival time. The Sp arrival time uncertainties, typically 0.05s of time error, were estimated for each station using bootstrapping method. The surface wave group velocity models for each station, at 10, 15, 20, 25 and 30s periods, were used to constrain the depth-velocity models. The grid search modeling was performed using the DISPER80 package. The fallowing crustal thickness (H) and average crustal velocities (Vs) were obtained: H of 38.8 ± 2.4 km and 33.83 ± 0.9 km, and Vs of 3.72 km/s and 3.73 km/s respectively for Lake Albert and Lake Edward rift basins within Mesoproterozoic Ruwenzori Orogenic belt; H of 32.73 ± 1.8 km, 37.79 ± 2.2 km and 39.63 ± 2.2 km, and Vs of 3.68 km/s, 3.76 km/s and 3.79 km/s respectively for Rovuma, Madawa and Ruvu pull-apart basins within Neopreoterozoic Mozambique Mobile Belt; H of 36.9 ± 2.1 km/s and Vs of 3.7 km/s for Phanerozoic Mozambique pull-apart basin. The results obtained from this study were compared with previous regional and global studies, and found thinner crust (H) and slower shear velocity (Vs) than previous studies.

Keywords: Sedimentary basins, S-wave receiver functions, Moho discontinuity, crustal thickness, shear velocity

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The Subsurface Structure of the Congo basin: Gravity Signatures, Isostatic Anomaly and Seismic Constraints

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The Congo Basin (CB) is a remarkable large sub-circular long-term sedimentation area defined in Central African. It contains more than 9 km of mostly detrital and very few organic types of sediment. Surrounded by known and explored cratonic blocks, its thick sedimentary column overlain a less constrained shield structure. The loaded sediment hided the connection between known and unknown cratonic blocks forming the largest African amalgamation of crustal blocks defined as "Congo shields" [3]. This complex structure was been supported by global-scale seismic tomography and gravity constraint models.

Tick (~ 200 km) rigid and faster velocities lithosphere had been defined beneath much of the basin contrasted with a thin and slower velocities one observed somewhere [6]. Otherwise, pronounced and low free-air gravity anomaly dominated the CB area had been associated even to the effect of a thick but low-density sediments overlying a thick lithosphere rifted during NeoProterozoic age or to that of a high-density body within a deeper lithosphere[2, 4]. Though global-scale tomography models and gravity constraints attest the existence of a complex lithosphere structure beneath the basin, today more scientific evidences are needed to well defining cratonic block limits.

Choosing an Airy scheme land area, we obtain an isostatic anomaly map of the CB area. The correspondent map shows that the CB is dominated by large undercompensated zones separated by thin zones isostatically overcompensated. This indicates that the isostatic correction (IC) agrees with deep crustal gravity effects beneath large area of the basin and shallow crustal gravity effects somewhere. On the residual gravity map obtained after removing sediment attraction effect |1, 5], overcompensated areas can be correlated with high residual gravity anomaly zones and undercompensated areas with other zones of low residual gravity (under 30 Mgal).

To the southwestern area of the basin, we perform a combined geophysical interpretation including gravity and seismic (reflection and refraction) modeling. The models highlighted a plausible suture zone between the known Archean Cuango-Kasai craton block to the south and a hided unknown craton block to the north. The North unknown craton could be limited by a thin and NW-SE elongated overcompensated area suture zone early defined [3]. This result supports the complex nature of the Congo basin's subsurface structure and provides some clarification on the cratonic block limits.

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Modelling of Basement and Basin Structure in the Zululand Basin using Potential Fields

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Due to the heavy dependence on fossil fuels for South Africa's primary energy, has resulted in the country being the highest emitter of carbon dioxide (CO_2) in Africa. South Africa has pledged to reduce their CO_2 emission by 34% by 2020 and 42% by 2025 through the help of first world countries and their technologies. These objectives will be facilitated through the Carbon Capture and Storage (CCS) project. The Zululand Basin has been proposed as a suitable CO_2 storage site for the project due to the porous sandstone lithologies within the basin. As part of the overall initiative we will be using geophysical methods to delineate the basement Lebombo volcanic lithologies underlying the Zululand Basin, and determine the structural relationships between these units. We will be using aeromagnetic, gravity, and seismic data to calculate the depth of these volcanic lithologies and form a 3D model of the Zululand Basin.

Keywords: CCS, Lebombo, Zululand Basin, depth estimates, aeromagnetic.

New Seismic Technology Drives Trends in Land and Offshore Exploration

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For over a decade we have seen the proliferation of broadband seismic solutions for offshore and onshore exploration (i.e., state-of-the art equipment and acquisition designs) as well as standalone broadband processing and interpretation treatments which can be applied to a variety of situations. In particular, marine broadband seismic has provided the industry access to seismic data with a significant increase of seismic frequency bandwidth on both the low side and high side of the frequency spectra, thus providing better resolution for interpretation. This paper demonstrates the benefits of using broadband seismic technology, over conventional seismics, to image geological features such as thin beds, subtle sedimentary traps, deep-water pre-salt plays and shallow drilling hazards. We present case studies from onshore (e.g., Witwatersrand Basin, South Africa; Dukhan Oil Field, Qatar) and offshore (e.g., Orange Basin; Durban and Zululand Basins (South Africa); Gabon and Angola Basins; Brazil Compos Basin) environments.

Keywords: Broadband, seismics, exploration, hydrocarbons, minerals.

Uncertainty Associated with the Earthquake Catalogue: Impacts on Seismic Hazard Assessment for Johannesburg

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A critical input in all seismic hazard assessments is a reliable and accurate catalogue of earthquakes. This is usually of use in several aspects of the assessment process (*e.g.* source delineation, recurrence parameter calculations and maximum expected magnitude (M_{max}) determination). It has been observed that parameters for seismic hazard analysis are sensitive to uncertainties associated with catalogues they are derived from. Uncertainties are usually introduced during the process of compiling and homogenising the earthquake catalogue. Therefore it is necessary that such errors be assessed and their impact on recurrence parameters, thus seismic hazard, be investigated and accounted for. A critical issue to be addressed before any scientific analysis is to assess the quality, consistency and homogeneity of the data.

In compiling the earthquake catalogue used in the seismic hazard assessment for Johannesburg, an effort was made to incorporate uncertainties introduced in the catalogue compilation process. Several sources of earthquake information were consulted and the reliability of each source was assessed during the compilation of the seismic catalogue. Different catalogues often provide different locations, magnitudes, focal mechanisms, and error estimates for the same event. The problem of combining these earthquake data in one catalogue was addressed by establishing a list of priorities for each parameter and reporting the highest priority estimate as the favoured one. The accuracy of the location of an earthquake depends critically on the number of stations, their distance to the source, as well as their azimuthal distribution. The best-constrained solutions are obtained from dense, close-in networks surrounding the source. The evolution of the seismic network in southern Africa has shown some improvements in the earthquake location for last few decades. Events that have been located using macroseismic information only have shown some bias to the human settlement behaviour. It is clear that large errors in earthquake locations contribute massively to the identification and characterisation of earthquake sources, especially fault sources. The sparsity of the South African National Seismograph Network (SANSN) resulted in such large errors (about 10km). Magnitude uncertainties associated with the homogenisation process were assessed. By far the greatest number of earthquakes with magnitudes values that require conversion were those expressed in terms of local magnitude, Ml, which is the magnitude routinely reported by CGS. However, several versions of the Ml magnitude scale have been used in the current catalogue. Results have shown that these Ml scales are not equal and hence, as was suggested by previous authors, converting them to the moment magnitude using a single global regression equation will introduce errors. Due to the fact that South Africa is in the stable continental region, very few large events have been recorded with more than one magnitude scale. This has hindered the development of regression equations for the conversion of local data. Hence, adopted global regression equations were compared with the local data. Large variations were observed and these have increased the uncertainty associated with the homogenisation process. Though the lack of well-constrained earthquakes with Mw values that can be used to constrain conversions is likely to affect the reliability of the catalogue, efforts are underway to improve the dataset of events with Mw values to help optimise the regression equations.

Keywords: Uncertainty, seismic hazard, catalogue, homogenisation, Johannesburg

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Assessing Seismic Hazard in the Kivu Rift Segment using Seismic and Geodetic Tools

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The major problem to assess seismic hazard in the Kivu Rift, located in Sub-Saharan Africa, is the lack of basic information to construct ground motion model. Moreover, the historical earthquake record is largely incomplete, while

instrumental catalogue is complete down to magnitude 4.5 only for a relatively short time span. To compensate this lack of information, we are experimenting the use of strain rate model developed by Stamp et al. (2015). We use the inferred geodetic strain rates to derive estimates of total scalar moment release, subsequently needed to constrain earthquake recurrence relationships for both area (as distributed seismicity) and fault source models. The activity rates obtained indirectly from strain rates and more classically derived from the available seismic catalogues is compared and combined into a unique single value and used as the base for seismic hazard calculations. Using Openquake software developed by GEM, this method was applied to the Kivu Rift segment. Higher ground acceleration values as high as 0.5g have been found , for spectral periods of 0.1 sec and 0.2 sec, in the rift axis and vary laterally in function of tectonic setting of the region(Active Shallow Crust and/or Stable Continental Crust

Keywords: seismic hazard, geodetic strain rate, earthquake recurrence.

The 2017 Botswana M6.5 Earthquake: Scientific Rapid Response

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An earthquake of magnitude M6.5 occurred in the evening of 3 April 2017 in Central Botswana. The event was well recorded by the regional network and located by both the Council for Geoscience (CGS) and United States Geological Survey (USGS). Its effects were felt widely in southern Africa and were especially pronounced for residence of Gauteng and the North West Province as these regions were earlier on the same day shaken by a magnitude ML4.6 earthquake that was located in the Stilfontein area. In response to these events, the CGS, together with the Botswana Geoscience Institute (BGI), embarked on two scientific projects. The first involved the quick installation of a temporary network of five seismograph stations in and around the location of the main Botswana event with the purpose of detecting and recording its aftershocks. Initially the intention had been to record the events for a period of one month, but on realizing just how active the area was it was decided to extend the period to three months. A sixth station was then installed on a 2nd expedition to the epicentral area after about a month to try and optimize the station configuration. Data recorded in the first month by the five initial stations were collected during this 2nd expedition and delivered to both the CGS and BGI for processing. Currently, the first week of data has been analysed and a total of 270 located aftershocks identified. All are located at the eastern edge of the Central Kalahari Park near the USGS location of the main event. The second scientific project involved a macroseismic survey to study the extent and nature of the effects of the event in southern Africa. This involved CGS and BGI scientists conducting interviews of members of the public to extract as much information as possible. Other data were collected from questionnaires submitted online by the public. In total 180 questionnaires were obtained through interviews and 141 online from South Africa, Zimbabwe and Namibia. All collected data have been analysed to produce 76 intensity data points located all over the region, with maximum intensity values of VI (according to the Modified Mercalli Intensity scale) observed near the epicenter. These are quite low values of intensity for such a large event, but are to be expected given that the epicentral region is in a National Park and is sparsely populated. Analysis of both waveform data from the temporary network of stations and collected macroseismic data is continuing.

Keywords: Botswana, earthquake, seismograph stations, waveforms, intensity, macroseismic.

An Integrated Approach to Understanding Different Geotechnical Zones using High-Resolution Microseismicity in Underground Mines

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Mining-induced seismicity and rockbursts pose a risk to mine infrastructure, ore extraction operations and workers in deep and highly stressed mines such as the Cooke 4 shaft in South Africa. The shaft pillar is prone to large seismic events and rockbursts, which may cause fatalities and loss of production. Seismicity and rockbursts result from high levels of stresses, which exceed rock strength and lead to rock failure, which is often violent and emit elastic waves.
This makes the rock composition very important when taking decisions of the preferred pillar composition in underground mines. The composition of the shaft pillar, observed through underground mapping and core sample analysis, was found to be quartzite, pebbly quartzite, argillaceous quartzite and conglomerate. Forming the roof of the hangingwall is the Ventersdorp Contact Reef (VCR) and Ventersdorp soft lavas.

All rock samples (excluding lavas) that were tested failed in a brittle manner, especially the quartzite and pebbly quartzite. This suggests that seismic activities could be highly anticipated. The laboratory tests showed that quartzite has the strongest uniaxial compressive strength (UCS), followed by pebbly quartzite, argillaceous quartzite and lastly conglomerate.

Different lithologies exhibited specific rockmass mechanical behaviour, and this was expressed by rock-specific mining-induced fracturing patterns in the hangingwall, mainly due to the presence of the interbedded weak Ventersdorp lavas. Using high-resolution acoustic emission sensors deployed underground, rock-specific mining-induced fracturing patterns in the hangingwall were delineated, with moment magnitudes down to M_w -5. These fracture patterns correlate positively with fracture models proposed by Roberts and Schweitzer (1999) for different geotechnical zones defined by footwall/hangingwall rock assemblages.

Majority of these acoustic emissions were found to be associated with the mining stope faces. These acoustic emission clusters delineated Ortlepp shears forming ahead of the stope caused by the excavation-induced stress field. This interpretation is supported by underground damage observations, core sample analysis which showed ubiquitous discing, and local stress measurements of 127 MPa made by Ogasawara et al. (2014).

Key words: acoustic emissions, microseismicity, rock mechanics, petrology, fractures, geotechnical zones

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Use of the Seismic Reflection Method to Optimize Safety and Extraction: A Case Study from a South African Platinum Mine

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Mining operations in the Bushveld Complex face challenges associated with increases in mining depth and geological complexity. The higher thermal gradient, compared to the Witwatersrand gold mines, means more investment in ventilation and cooling. The less well-defined zones of reef depression (potholes) and varying dip and strike along the reefs also need to be better understood to define a clear mine plan that will enable efficient mining. Mining depth is the central factor in determining the optimum extraction plan of an ore reserve. Mining for platinum group metals in the Bushveld Complex has been mostly restricted to the well-understood shallow depths, but is migrating to medium depths. It is the characteristics of these conditions; the local geology, prevailing rock mass conditions, thickness and dip of the orebody that influence the mining procedures and standards. The study was investigating the structural complexity of the remaining part of the lease area of a platinum mine located in the western Bushveld Complex. This area is earmarked for future operations, and thus the impact and effect these complexities have on current mine planning is studied to understand what future mine planning and ore valuation will entail. The objectives were: (i) to identify the economically mineralised horizons hosting the platinum group elements, chromite and vanadium, (ii) to check for possible geological structures cross-cutting them on the 3D reflection seismic data, and also (iii) analyse the occurrence of seismicity and its correlation with mining. Preliminary results suggest that the region where the Merensky and UG2 reefs are mined is structurally complex, i.e., the reefs are warped and displaced by faults. The mining-induced seismicity correlates with mining operations. Faults and dykes that intersect and displace reefs are likely to prove problematic during mining and these should be taken into account in planning mining layouts.

Key words: 3D reflection seismic, mining induced seismicity, Merensky, UG2 reef, mine planning.

Learning from Earthquake Disaster in Tanzania: Lessons Learnt from the Kagera Earthquake Event (Mw 5.9) of 10th September 2016

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The Kagera Earthquake event of moment magnitude (M_w) 5.9 which occurred at 15:27:33.11 on 10th September 2016, caused unprecedented devastation in Tanzania, Kagera Region and its Districts in particular, with 17 people officially confirmed dead and leaving others with minor to major permanent injuries. Furthermore, the earthquake led into the destruction of the residential buildings, public buildings such as schools, religious buildings, hospitals and lifelines utilities such as roads, powerlines and water supplies and the environments in general. A disaster of this extent has never before been experienced by Kagera residents and the Nation as a whole. The Kagera earthquake event has saved as a 'National wakeup call' to look within and introspect again on the state of disaster preparedness, policy, legal and institutional framework of the country. This event can be considered as a learning opportunity. There should be a national learning to take appropriate or specific measures towards disaster reduction, mitigation, prevention, preparedness, recovery and rehabilitation. In this paper an attempt has been made to highlight the lessons learnt from recent devastating Kagera earthquake event and a plan must be designed for the areas located within the earthquake prone areas to mitigate the impacts of future earthquake events if are to occur.

Keywords: Kagera Earthquake Event, Preparedness, Impact, Lessons Learnt

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Zambia's AfricaArray Seismic Stations and its Challenges and Experiences

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The Government of the Republic of Zambia, through Geological Survey under the Ministry of Mines and Minerals Development, operates and maintains a network of Nine Seismic stations four are Africa Array seismic stations. These stations were established from 1983 to 1985 with help of Finland. And in 2006 Africa array brought on board four broadband seismic stations and these comprises of Kasama (KASM), Itezhi-tezhi (TEZI), Mongu (MONG) and Kitwe (KTWE). All these stations are located in remote stations some good kilometers away from the City. They are all not on real time hence needs travelling every after two to some months to go and retrieve data.

The Role of Time and Frequency in Geodesy: An Example from GNSS Applications

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Time and frequency standards play a crucial role in geodesy to ensure millimeter accuracy in geodetic data products is maintained. This level of accuracy from geodetic techniques ensures that International Terrestrial Reference Frames are

well maintained and that other products such as plate tectonic velocities derived from these reference frames have millimeter accuracy. We evaluate the performance of Leica GR10 receiver on three scenarios, (1) the first receiver was locked to a 5 MHz sine wave from the hydrogen maser (2) the second receiver was locked to 5 MHz sine wave from the rubidium 4380a clock (3) the third receiver was on free-running mode i.e., using its own internal clock. The Leica AR25 antenna was used, the Global Navigation Satellite Systems (GNSS) signal slitter was used to provide identical signals to the three receivers. Data was processed using GAMIT/GLOBK software. The positioning and Integrated Precipitable Water Vapor (IPWV) results showed no significant level of sensitivity to the use of different timing systems, suggesting that the Leica GR10 can provide millimeter accuracy data products without external reference frequency. However, the vertical component of the positioning solution was sensitive to changes in mapping functions during processing. The VMF1 model proved to reduce the noise levels in the vertical component by 5% compared to the GPT2 model. These results suggest that more accurate results that are better than millimeter accuracy can be achieved by better understanding the atmosphere, as this contributes large part of the error budget in the GNSS solutions. The free-running Leica GR10 receiver was found to have higher variable receiver clock-offsets, making it difficult to predict the behavior of the internal clock. In contrary, the receivers locked to the rubidium 4380a and hydrogen maser produced clock-offsets that are predictable over a short period and less noisy by a factor of 10^{-1} and 10^{-2} for rubidium 4380a and hydrogen maser respectively when compare to the free-running receiver clock-offsets. The highly stable clocks utilized in this study showed no clear improvement on GNSS solutions, the next improvement in GNSS solutions relies on better understanding the interaction of the radio frequencies from the GNSS satellites with the atmosphere. However, these stable clocks continue to play an important role in other geodetic techniques such as lunar laser ranging and very long baseline interferometry.

Keywords: International Terrestrial Reference Frame, GNSS, IPWV, Clock-offsets.

Crustal Structure beneath Mount Cameroon Region derived from New Gravity Measurements

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In the present study, gravity information is available for improving the understanding of the crustal structure and its relationship to regional tectonics environment beneath the large volcanic system called Mt Cameroon. The multi-scale wavelet analysis method is applied to separate the gravity fields. The logarithmic power spectrum method is used to estimate different depths of the gravity field source. The results show that the crustal structure is very complicated beneath Mt Cameroon area with the crustal density exhibiting lateral inhomogeneity. The lateral discontinuities of density structure causes undulations of the gravity anomaly field whose complexity can be an indicator of past crustal instability. The Buea-Tiko region appears to be the most tectonic active zone in the Mt Cameroon area. The upper and middle crusts consist of many small-scale faults, uplifts and depressions. In the lower crust, these small-scale tectonic units disappear gradually, and replaced by large-scale units. The gravity anomalies in upper and middle crusts are correlated with geological and topographic features on the surface. Compared with the crust, the structure is relatively simple in uppermost mantle. The earthquakes occurred predominantly in upper and middle crusts, their epicenters are limited in transitional regions between high gravity anomaly and low gravity anomaly. The earthquake occurrence as well as complicated gravity behavior may be related to the Upwelling of high density magmatic materials and asthenosphere heat flow materials beneath Mt Cameroon. The overall results, in a good agreement with previous findings, show the performance of the wavelet-based filter in the possibility of getting a multi-resolution analysis and the study of structures using gravity data.

Determination of Local Magnitude Scale for Uganda

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We derived a local magnitude *M*L scale for Uganda using waveform data recorded by AfricaArray temporary broadband seismic network deployed in Uganda and a permanent IRIS-GSN broadband station. We used 54 earthquakes recorded between July 2007 and November 2008. First, we determined hypocenters of these earthquakes using P and S phase arrivals. Most of their locations are associated with the western rift of the East African Rift System. We compared the hypocenters of seven earthquakes determined by this study to those reported by NEIC's PDE catalog and IDC bulletins. They do not differ much, and they are roughly consistent with each other. To develop the *M*L scale, we removed instrument responses in the waveforms and then applied the frequency response of the standard Wood-Anderson torsion seismograph for amplitude measurements. We obtained 529 amplitude data from horizontal components of 52 earthquakes whose focal depths are up to 34 km. We performed simultaneous linear inversion to determine the coefficients of distance correction function and local magnitudes to obtain the formula $M_L = \log A + 0.848 \log(r/100) + 0.00116\,(r-100) + 3.0$, where A is the maximum peak amplitude (mm) observed on the horizontal component seismogram, and r is the hypocentral distance (km). The coefficients of the above formula are smaller than those obtained for Southern California, and closer to those obtained for Tanzania. The result of this study and its application to data from the existing local seismic network will be useful for improving earthquake monitoring and seismicity study in Uganda.

Keywords: M_L, amplitude, hypocenter, linear inversion, maximum peak amplitude, distance correction.

The status of ICDP DSeis drilling into the 2014 Orkney M5.5 fault: location of initial and main ruptures, and aftershocks

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In August 2014, a *M* 5.5 seismic event took place near Orkney in Klerksdorp. The upper edge of this fault was several hundred meters below the deepest level of Moab Khotsong gold mine. So we can drill into the seismogenic zone of the M5.5 event and would like to elucidate the M5.5 rupture. Seismograms both on surface and underground were characterized by an initial weak phases lasting about 1 second, followed by much stronger phases lasting a few seconds. The P- and S- arrival piking algorithm of Horiuchi et al. (2011) is used for the aftershocks. Okubo et al. (2015 and 2016) re-located the hypocenters with hypoDD and 3 dimensionally back-projected CGS strong motion data. Ishida et al (2016 JpGU and IGC) constrained the slip extent by comparing the observed and calculated difference in co-seismic strain changes of the strainmeters. The origins of the M5.5 initial and main phases were located by introducing station corrections, which was calculated by some major aftershocks located by in-mine dense seismic.

ICDP approved drilling into M2.0-5.5 seismogenic zones (DSeis) from deep South African gold mines. The ICDP 1st NQ hole from Site 1 is now 186m long with ~100% core recovery. First borehole logging is planned this week, followed by extension of drilling to intersect the M5.5 rupture. These accurately locate and elucidate the M5.5 rupture, geology, material, and environment. The ICDP 2nd NQ 600m hole from Site 2 also intersects the rupture precisely located, followed by deploying hydrological and geomicro-biological monitoring system funded by US NSF (PI: Onstott, Princeton Univ.). If JSPS approves a fund, geophones are installed in the 1st hole. The 3rd or more drilling (>900m) traverses both denser and sparser aftershock areas.

Case Study Deep Groundwater Exploration with Geophysics Methods, Katito Area, Kisumu County

Charles OSANGO

Kenya Society of Geophysicists

The most favorable geophysical investigation for depths on the order of 200 feet or less, the electrical resistivity profiling are general successfully and useful for economic, groundwater is an essential resource in this area and his important increases in the light of the rapid increase human population, industrial expansion, and agricultural activities. The geology of the area is comprised of tertiary volcanic rocks, which include phonolites and basalts. These are overlain by recent alluvial deposit and soil composed of sand, clays and gravel. The influence of faults, joints and others fractures on groundwater in the study area is twofold; The survey's purpose is twofold (a) to study the geophysical response of faults in the study area, (b) to characterize electrical resistivities of subsurface strata in the area to try to relate the geophysical response to groundwater depth. Katito area, administratively, it is within the Sub-County of Nyando in Kisumu County in republic of Kenya is a water scarce area whose residents have to travel long distances to get water for their domestic use. There are no surface water sources in the area. To alleviate the water problem the Kenya Society of Geophysicists proposes to conduct a groundwater exploration in papondit area.

The proposed project to successfully carry out the groundwater exploration the Society plans to use magnetic and electromagnetic methods. Magnetic method will be used to identify potential water-holding structures in the area. The electromagnetic method will outline subsurface resistivity variations which will be used to delineate potential water holding zones. To achieve the objective is to determine the depth to the groundwater in the study area and to reach these objectives the FQA how can the aquifer be represented by its geophysical response.

Since the Society does not have equipment of its own, equipment to be used in the survey will be hired from organizations that are in possession of the required equipment. To implement the project, the Society expects to recruit two (2) geophysicists, six (6) field assistants and twelve (12) casual workers for this exercise. The Society will also need to hire two (2) suitable vehicles to carry the equipment and personnel.

The output will be a geophysical report with recommendations for drilling depending on the results of the survey. The survey work is expected to last four (4) months which includes two months of field operations and two months of compilation of the geophysical report. Including exploratory drilling, the project is expected to cost about US$ 100,000. The project is expected to commence as from October, 2017.

Keywords: Kenya, groundwater, economic, Magnetic method, development.

High-Resolution Shallow Seismic Imaging for Hydrogeological Investigation in an Area Characterized by High Source-Generated Noise

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Shallow reflection and refraction seismic surveys were employed in the Nyl River Floodplain within the Nylsvley Nature Reserve, South Africa. The main objectives of the surveys were to map the depth to the bedrock and to investigate the hydrogeological characteristic in the area. Four seismic profiles were acquired along two straight lines perpendicular to each other using 1-2 m and 2 m receiver and source spacing, respectively. We deployed 14 and 48 Hz resonant frequency geophone on each line for comparisons. The study area was characterised by low-frequency, high-amplitude source generated noise (surface and guided wave). To enhance the seismic signal, an extensive seismic processing was deployed; these involve pre-processing (geometry check and trace edit), amplitude scaling, careful manual first arrival picking, spiking deconvolution, bandpass frequency filtering, F-K filtering, careful direct and refracted arrival top mute, interactive NMO and stacking velocity analysis, and surface-consistence static correction.

The processing procedure was the same for the four acquired seismic profiles. Bedrock is poorly reflective in most raw shot gathers from the seismic profiles. However its reflectivity is more evident in the stacked sections following the detailed processing of the data. Tomographic models generated from the refraction seismic data greatly complement the reflection seismic data in locating the bedrock-overburden contact at 10-16.5 m depth. In addition, bedrock undulation and weak zones associated with fracture systems are inferred from the reflection characteristics and tomographic models, and this information is confirmed by the borehole information. We interpret these characteristics to be associated with groundwater storage related to the fractured/weathered zone within the bedrock. The integrated data also show delineation of the second layer (representing the gravel at the base of the Alluvium deposit) interpreted as the hydrogeological unit, which exhibits P-wave velocities between 1293-2673 m/s and thickness of 4.2-9.5 m. This study demonstrates that joint application of shallow reflection seismic and refraction tomography is a good approach for near-surface investigations.

Keywords: Reflection seismic, refraction seismic, hydrogeological, bedrock undulation, NMO.

Macroseismic Survey of the M4.6, 2017 Stilfontein Earthquake

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On 3 April 2017 an earthquake of local magnitude ML = 4.6 occurred in the Stilfontein area in the North West Province, South Africa. Using the cluster network of strong motion seismograph stations located in the Klerksdorp-Orkney-Stilfontein-Hartbeesfontein (KOSH) area, the event records were analyzed and location distributed by the Council for Geoscience (CGS). A total of 213 aftershocks of the event were also recorded and are found to plot in a NE-SW line, which follows the orientation of shallow faults in the region. The earthquake shaking was felt in the closest provinces of South Africa, but no damage has been reported. In response to the earthquake, the CGS sent out a team of scientists to further assess the effects of the event in the community by interviewing members of the public and completing questionnaires. A total of 177 questionnaires were collected. Analysis of the collected macroseismic data produced 35 intensity data points which showed that a maximum intensity of VI according to the Modified Mercalli Intensity scale was experienced in communities located close to the epicentral area.

Keywords: Stilfontein, questionnaire, macroseismic, epicentral area, intensity.

Assessing Active Tectonics of the South-Central Part of Madagascar: Ihorombe Region, Ihosy District

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The abnormal movement (anomaly) found by the temporary GPS station named AMBI, placed in the village of Ambia, district of Ihosy brought us to make these retailed studies concerning this zone. It was about assessment and investigating of the active tectonics of the region concerned. The assessment of active tectonics of the south-central part of Madagascar was made from the data recorded by the Malagasy Seismic Stations, as well as the PASSCAL Project Stations, and the investigation of the characteristics geomorphologic created by types of active faults, also the structural characteristics with Quaternary ages in our study zone. We have found that the south-central part of Madagascar is tectonically active. It is acting by a regime of E-W extension (in the Western and Central part of our study zone) and EES-WWN extension (in the Eastern part of our study zone). There is slightly rotation of the extension E-W to EES-WWN in the Eastern part of our study zone. Based on the geological data and geomorphologies, the Ihosy district is acting by Horst and Graben system.

Keywords: active tectonics, geomorphology, fault, dike, shear zone, stress, extension, horst, graben.

Preliminary study on Probabilistic Seismic Hazard for Madagascar

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Central part of Madagascar occurs on a major extensional faulting. Moderate seismic activity is seen in the whole area with local magnitudes not exceeding 6.0. Most of the events are presented in the central part of the island. Some damaging earthquakes have been reported from historical seismic data but the information about the major seismogenic lineaments are not enough to evaluate the damage caused by the earthquake. Insufficient kinematic information about the tectonic features is one of the disadvantages from this study.

In this present work, we attempt to evaluate the seismic hazard of Madagascar using the probabilistic seismic hazard analysis (PSHA) following Cornell-McGuire approach (1962, 1971, 2004) and the parametric-historic developed by Kijko and Sellevoll (1989, 1992), after selecting and filtering earthquakes from the combined catalogues from NDC and MACOMO stations. All of the data are recorded from short period and broadband temporary and permanent seismometer networks that are deployed in the whole part of Madagascar during the time period of 84 years (1932-2016). In order to unify magnitude values from the combined catalogue, moment magnitude M_w. was estimated using 10 local events and local magnitude scale was calibrated from the recorded MACOMO data (2011-2013). Probabilistic seismic hazard for Madagascar was processed using a grid of 0.5° x 0.5°and characterized by seven source zones. Ground motion and alternative seismogenic relations were inserted for the calculation. Seismic hazard parameters are estimated following the two approaches such as the activity rate λ, the maximum regional magnitude and the b-values from each areal zone. Seismic hazard maps were created based on weighting procedure and using 2% and 10% probabilities of exceedance for 50 years, following logic tree. Models developed by Boore and Atkinson, and Akkar and Bommer were used to evaluate the hazard for Madagascar after using CRISIS software.

New relation between local magnitude M_L and moment magnitude M_W was obtained and a new magnitude scale for Madagascar was evaluated. For seismic hazard, spatial values of the peak ground acceleration (PGA) were determined in the central part of Madagascar and average values of approximately 0.01 to 0.5 gals were obtained. Use of the classic method developed by Cornel and McGuire (1962, 1971, 2004) and the use of parametric-historic by Kijko and Sellevoll (1989, 1992) give results that reflect the delineated pattern of seismic zones.

Keywords: Probabilistic seismic hazard analysis, Cornell-McGuire, Kijko and Sellevoll, magnitude, peak ground acceleration (PGA), areal zone

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Statistical and Clustering Properties of the Alboran Sea Seismic Sequence Following the 25 January 2016 Earthquake

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An important earthquake of magnitude Mw=6.3 struck in Alboran Sea, North of Morocco, on January 25, 2016. The epicenter was located about 50 km NNE of Al Hoceima, the most seismically active region of Morocco. The hypocenter was estimated around 10 km. fortunately, no reports of injuries or fatalities, although some slight construction damage in Moroccan Mediterranean coastal zone. This earthquake is the strongest one since the Agadir event of February 29, 1960 (M~5.9, 12 000 victims). The aftershocks sequence following the main shock (552 events with M≥3 during 15 days) has been investigated by non-linear tools. The inter-event time between successive aftershocks is analyzed to

study the temporal structure and clustering properties by means of: Omori and Korçak laws, Hurst analysis, and the autocorrelation function. From the Gutenberg-Richter law, the b value is found to be around 0.69. The Omori law exponent is high (1.95) for a period of 7 days and not relevant for the whole period. Korçak fractal exponent is around 1.75. The autocorrelation function shows a high degree of correlation and persistence memory only during the first week, after that another temporal structure organization began. This latest observation is not in agreement with Hurst analysis which indicated a continuous and nearly uniform aftershock activity with high persistence behavior (H~0.81). A comparison with Al Hoceima aftershocks inter-event time of February 24, 2006 (with similar magnitude) have been made showing some similarities but also and above all important differences related to their scaling properties and continuity although similar focal mechanisms and geodynamic context. Further analysis should be implemented to explore the origin and the causes of discrepancies, and also to criticize the relevance and usefulness of some popular tools like Hurst analysis.

Keywords: earthquake, seismic sequence, Alboran Sea, clustering properties, Al Hoceima, Morocco.

Using 3D Reflection Seismics to Map Loss-of-Ground Structures in the Western Bushveld Complex: Faults Zones, Dykes, IRUPs, Potholes and Diapirs

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The Bushveld Complex in South Africa hosts the largest reserves of platinum in the world. One of the important economic horizons is the UG-2 chromitite seam at the top of the Critical Zone. The layering of the complex, including the UG-2, was disrupted by several structural features post formation. These structural features include dykes, faults and iron-rich ultra-mafic pegmatoids (IRUPs) that cross-cut the layering of the complex; diapirism and flow features that uplift layering; and potholes or slump structures that result in horizons transgressing into the hanging wall. These structures are imaged by integrating high resolution aeromagnetic data and 3D seismic data. These seismic data are able to resolve faults with throws as small as ~10 m. These data reveal oval potholes as slump structures bounded by faults and IRUPs. These slump structures are up to 2.5 km in length, causing up to 1 km of vertical displacement. Other features that are better defined on the seismic data include a large-scale fault mapped on surface, which is mapped on seismic data as complex multiple fault networks and regions of material flow. Seismic data also show good mapping resolution of dykes due to their close association with faults, which cause displacements on economic horizons. The seismic data are also characterized by disrupted seismic amplitude zones associated with a diapir (~ 6 km in diameter), which is linked with the upwelling of basement rocks during the emplacement of the complex. This diapir displaces the economic UG-2 horizon at the mining levels. This information could be used for future mining planning and designs to assess and mitigate the risks posed by these features during mining activities.

Keywords: Bushveld Complex, seismic, aeromagnetic, fault, dyke, IRUP, pothole, diapir.

Geophysical Methods to Locate Potential Underground Voids at Springlake Colliery, South Africa

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Mining is a large source of South Africa's economic growth, therefore understanding the subsurface structure of the Earth is vital. Various geophysical methods have been used to investigate the subsurface of the Earth one of these methods is reflection seismic that is often used to maximise the subsurface mapping resolution of the Earth. This paper reports the results from integrating shallow reflection and refraction seismic surveys with electrical resistivity surveys to detect voids at the Springlake Colliery mine near the town of Dundee in KwaZulu-Natal, South Africa. Reflection and refraction seismic methods are ideal for locating voids due to a contrast in acoustic impedance between the target and host rock. Voids are empty spaces within the subsurface. The voids may be caused by previous mining activities,

natural phenomena such as expanding soils and dissolution of carbonate rocks by acidic underground water. This information is important because voids can lead to subsidence and collapse of the ground. Dundee is stratigraphically in the Ecca Group within the Karoo Supergroup. The Group consists of sedimentary geological formations that are predominantly made up of inland sea shale, sandstone, and coal sedimentary deposits. Results from the reflection seismic method and resistivity pseudo-section correlated well and suggest that the longwall mining method was previously used for mining and has caused subsidence in the mine roof. Both the high resistivity values (603 – 1041 Ω/m) high amplitude reflections were observed as a dolerite layer. Voids were identified in both the seismic section and resistivity pseudo-section.

Keywords: seismic reflection, seismic refraction, tomography, resistivity, voids.

Advances in the Kinematics and Geodynamics of Africa

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Africa hosts the East African Rift System, the Earth's largest sub-areal continental rift system, which actively breaks apart the Nubian and Somalian tectonic plates. Unraveling the kinematics and major forces driving African surface motions hinges on our understanding of the East African Rift System. Over the past decade, the number of Global Positioning System (GPS) instruments available to measure surface motions in Africa has increased by an order of magnitude allowing us to develop an improved picture of deformation along the East African Rift System. In concert, our ability to test the physics of African deformation advances with each new kinematic solution and with evolving computational capabilities. In our work, we employ block kinematic modeling constrained by GPS velocities, bi-cubic spline interpolation of kinematic solutions and GPS, 2D geodynamic thin-sheet modeling, and 3D regional computational geodynamic modeling. We find (1) the EARS is comprised of three microplates between Nubia and Somalia (Victoria, Rovuma, and Lwandle), consist with earlier studies, (2) the EARS diverges 1 mm/yr slower that previous predictions, (3) zones of relatively higher strain rates, (4) internal lithospheric buoyancy from the highlands along the EARS dominate the force balance driving continental divergence in Africa, (5) shallow edge-driven convection can explain the distribution of volcanism, and (6) in some locations, dislocation creep rheology extends below the lithosphere into the asthenospheric mantle. Overall, these results provide an improved foundation from which future scientific investigations can be launched.

Keywords: geodesy, kinematics, geodynamics, Africa, East African Rift System

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Extending the Rift Zone: Evidence from Central Botswana

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The 3D crustal and upper mantle structure of Botswana is a major gap in our knowledge about the tectonic evolution of Africa. We will present a new model for crust and upper mantle structure and velocity in which we indicate very strong indications for active rifting in north and central Botswana. Our model is based on data from the NARS Botswana and AfricaArray networks, broadband temporary networks in southern Africa (Botswana, Namibia, South Africa and Zambia).

The NARS-Botswana seismic network was established to provide broadband recordings in Botswana, covering one of the least studied regions in the world. It is an area that is for a large part covered by the Kalahari sands but also covers the southwestern most branch of the African Rift under the Okavango delta. The goal is to understand how the rifting process and cratonic provinces influence crustal thickness and couple to the underlying mantle.

Crust and upper mantle structure, down to the bottom of the mantle transition zone, will be based on receiver function analysis. We observe crustal thicknesses between 35 and 46 km, strongly linked to basins and cratons in the region. The

central Kalahari part, which has been previously unstudied, showed some anomalous structure, possibly suggesting melt in the lower crust. This lower crustal anomaly is also visible in seismic tomography models and coincides with the present Botswana earthquake which also suggest an extensional stress regime in central Botswana. Going deeper we see that the mantle transition zone varies in thickness, and sharpness of the bounding discontinuities, suggesting active dynamical processes underneath Botswana.

Keywords: Rifting, Botswana, receiver functions, ambient noise tomography

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Anisotropy Parameters from Shear and Compressional Wave Borehole Tomographic Measurements

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Anisotropic parameters were derived from cross-borehole tomographic measurements in a layered environment with previously glaciated Tertiary and Quaternary sedimentary deposits. Three different seismic wave types, namely P-waves, horizontally polarised S-waves and vertically polarised S-waves were generated and the signals were recorded with a multi-station three-component receiver array. This allowed the computation of three co-located tomograms. Due to the presence of prominent X-shaped artefacts in the horizontally and vertically polarised S-wave tomograms, we plotted straight-ray velocities as a function of ray path angle and the results indicate the presence of anisotropy. The vertical transverse isotropy (VTI) anisotropic parameters were fitted to the velocities versus ray path angle plots for two distinct velocity zones. These parameters were subsequently incorporated in an anisotropic tomographic inversion, with the resulting anisotropic tomograms showing lower root-mean-square errors compared to their isotropic counterparts. In addition, the velocity structures are more differentiated and offer an alternative, more detailed interpretation. The anisotropic parameters were also fitted based on three-layer, and geologically subdivided models, yielding velocity images with a higher resolution compared to the isotropic models. The survey shows the potential of routinely carrying out co-located P-, SH- and SV-wave tomographic surveys, thereby offering more detailed interpretations and the ability to derive complete anisotropic parameters for a VTI-medium in-situ.

Keywords: Shear wave, Seismic tomography, Anisotropy, Borehole geophysics.

Seismic risk for Cities around the Lake Kivu basin, Western Branch of the East-African Rifts System

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The Lake Kivu Basin is located in the Western Branch of the East African Rifts System consisting of two branches. This Western Branch includes the several great lakes namely: Albert, Edward, Kivu, Tanganyika, Rukwa and Malawi. All these are presently very active. The tectonic conditions of the dome uplift, faulting, volcanism and shallow seismicity around the Lake Kivu (the highest 1462 m) are believed to be the indications of actual rifting and may represent a nascent stage in the development of plate boundary. Since 1997, it was observed in the Lake Kivu Basin the recrudescence of seismic activity. This seismic activity is mostly concentrated in the South-Western part of the Basin where earthquakes are regularly felt. Three large earthquakes associated with foreshocks and long duration aftershocks mostly confined around the epicenter areas were already recorded in the Basin: The October 24th event with magnitude mb (6.1), the February event with magnitude mb (6,0) and the August 7, 2015 event with magnitude mb (5,8). Three events occurred at shallow depth around 10 km. It was observed small Tsunamis during these earthquakes reaching 5 m high and landslides on the shorelines near the epicenters. Many damages are regularly recorded in the villages and towns mostly near the epicenters area. Most of damages are correlated with the secondary faults which move when

large earthquake occurred. More than 50 persons are already killed since 2002, by the earthquakes. The maximum intensity observed near the epicenter area is usually more than 8. According to the actual development of seismic activity, more large event is expected. The occurrence of such large earthquake may be catastrophe for the dense cities around the Lake Kivu basin in D.R. Congo and Rwanda side. The situation may be more catastrophe if it occurs inside the lake containing dissolved gas; carbon dioxide (CO_2) and methane (CH_4) in the deep water, with the possibility of gas explosion. This assertion is supported by the existence of active faults in this lake.

Keywords: Lake Kivu Basin, seismic, risk, faults, catastrophe.

Theoretical Overview of Complex Seismic Attributes and Applications to Soft and Hard Rock Environments in South Africa

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Since their inception in the 1970s, seismic attributes have grown in both number and theoretical complexity and have played a significant role in (reflection) seismic data interpretation and in seismic attribute analysis. The most common method of calculating these attributes is by means of the complex trace, a notion that also came forth in the 1970s which incorporates the analytic signal into seismic processing. The introduction of the complex trace into reflection seismology brought about the concepts of instantaneous frequency and phase and the trace envelope, each of which notably contrast the then conventionally used Fourier analysis approach. Examples of other fundamental attributes that can be computed using complex trace analysis include apparent polarity, bandwidth, Q-factor, dip and azimuth. Included in this study is the verification of the effectiveness of several attributes. The instantaneous phase proves useful at singling out strata truncations and toplap features and bedding is accentuated by the instantaneous amplitude. Apparent dip and semblance can be used to locate vertically anomalous structures such as gas escape features.

Key words: analytic, signal, reflection, seismology, attributes.

Impact of Temporal Seismicity Variation on Seismic Hazard due to Mining-Induced Earthquakes in Gauteng, South Africa

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A time-dependent probabilistic assessment of the seismic hazard along the densely populated northern rim of the Witwatersrand Basin of the Gauteng Province, South Africa, is described. Seismicity in this region is mainly induced by deep gold mining and the flooding of worked-out mines. Seismic hazard assessment in the gold mining regions has not been incorporated in global projects such as the GSHAP, although the seismicity related to the gold mining activities accounts for about 90 % of the seismicity of South Africa. Time-dependent seismic hazard estimates are given in terms of peak ground acceleration and 5 % damped response spectra at periods, 0.1 s, 0.5, 1.0 and 2.0 s for 10 % probability of exceedance in 50 years (475 year return period) for two different periods named Period A (1970 - 2004) and Period B (2005 - 2015). Seismic hazard estimates are higher in Period A owing to higher activity rates than in Period B. The highest estimated PGA value was approximately 0.250 g for a return period of 475 years in the western part of the region in Period A while the corresponding estimated PGA value was 0.206 g for a return period of 475 years in the same region in Period B. The spectral acceleration values also decreased from Period A to Period B. It was observed that the Far West Rand seismic zone contributes more hazard in the study region, followed by the West Rand seismic zone and then the East Rand seismic zone. The Central Rand seismic zone is the least active seismic zone and contributes least to the hazard of the study region. The hazard estimates are higher in the western parts of Johannesburg than in the eastern parts of Johannesburg.
