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The New Botswana Seismological Network (BSN): Developments in detection of seismic events in Southern Africa and beyond

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Introduction

Inspired by recommendations from a plethora of previous local and regional seismic studies, the Government of Botswana through the Department of Geological Survey or DGS (now the Botswana Geoscience Institute or BGI) embarked on the implementation of a national development project (NDP) entitled the *"Botswana Seismological Network"* (BSN).

The BSN project was launched during the period between 2000 and 2001, and involved the installation of a network of seven accelerographic stations distributed across the Okavango delta region (ODR) in northwestern Botswana that is the most seismically active area in Botswana.

The network was deployed for long-term monitoring of seismic activity of northwestern Botswana to improve our understanding of the causes of earthquakes in the area and enable better assessment of the distribution, frequency, and severity of seismic-related hazards and risks throughout the northwestern part of Botswana.

These BSN accelerometric stations reached the end of their lifetime of operation around 2015, and were consequently de-installed from the field sites in 2016. The new BSN stations have been revitalized through the deployment of a countrywide state-of-the-art network of 21 autonomously recording broadband, three-component seismographic stations. The network was installed through a collaborative project between the BGI and the Netherlands based University of Twente (UT) and the Utrecht University (UU), called the 2013-2018 Network of Autonomously Recording Seismographs Botswana or NARS-Botswana.

The BSN Stations

- The old BSN stations were operated by the Department of Geological Survey and two of them were by the University of Botswana.
  - The main aim of the stations was to assist in the investigation of processes involved in the on-going incipient rifting across the Okavango rift zone
  - The stations were located in the northwestern part of Botswana around the Okavango delta (figure 1)
  - The station housing were made of steel pipes that made up a rectangular structure and the corrugated iron roofing as shown in figure 2(c).
  - All the station sites were equipped with three-component EpiSensor Kinematrics K-2 accelerometers (figure 2(b) equipped with GPS receiver timing, Altus K2 recorders and removable hard disks
  - The stations were de-installed from the field in 2016 as they became obsolete and costly to replace parts.

- The new BSN stations were initially part of the NARS-Botswana project to map the seismological structure of the crust and mantle beneath Botswana using seismic signals from teleseismic events.
  - The 21 broadband seismic stations was deployed country-wide (figure 1) shown in table 1.
  - The stations housing were mostly made by burying a water tank and placing the sensor and the datalogger at the bottom of the tank in the concrete slab (figure 2 (a) and (b)).
  - In 2018, the BGI started operating the stations and the BSN was revitalized.
  - 18 of these stations are telemetered to transmit near-real time data to the processing center at the BGI offices in Lobatse

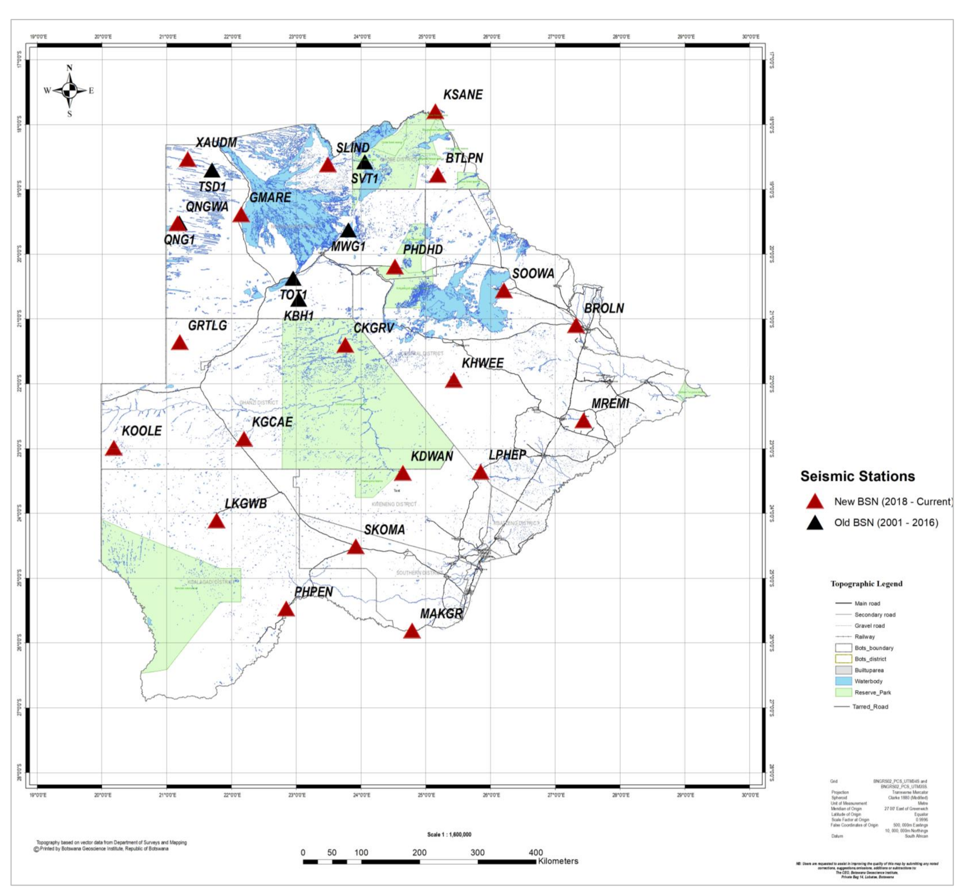

Figure 1: Map showing the distribution of the BSN stations (triangles) across Botswana

Station code	Location name	Sensor	Latitude (Degrees)	Longitude (Degrees)	Altitude (Meters)
SKOMA	Sekoma	Trillium 120p	-24.51535	23.93279	980
LKGWB	Lokgwabe	Trillium 120p	-24.11352	21.78230	1153
KOOLE	Kole	Trillium 120p	-22.99307	20.19555	1313
XAUDM	Xaudum	STS-2	-18.53956	21.33822	1060
SLIND	Selinda	Trillium 120p	-18.62089	23.50048	961
KSANE	Kasane	Trillium 120p	-17.80017	25.16189	1006
QNGWA	Qangwa	Trillium 120p	-19.52957	21.17400	1094
KHWEE	Khwee	Trillium 120p	-21.94641	25.44691	1083
CKGRV	Central Kalahari Game Reserve	Trillium 120p	-21.40355	23.77177	1005
GRTLG	Groot Laagt	STS-2	-21.36192	21.21571	1198
KGCAE	Kacgae	Trillium 120p	22.85382	22.20679	1153
KDWAN	Kaudwane	Trillium 120p	-23.38039	24.66079	1038
PHEPN	Phepeng	Trillium 120p	-25.47553	22.85729	1030
GMARE	Gumare	STS-2	-19.38931	22.16246	985
BTLPN	Bottlepan	STS-2	-18.78417	25.19601	1035
PHDHD	Phuduhudu	STS-2	-20.19568	24.53719	956
BROLN	Borolong	Trillium 120p	-21.09968	27.33424	1047
SOOWA	Sowa	Trillium 120p	-20.56285	26.21785	941
MREMI	Moremi	Trillium 120p	-22.56967	27.44682	911
LPHEP	Lephepe	Trillium 120p	-23.36303	25.85961	1020
MAKGR	Mmakgori	Trillium 120p	-25.81185	24.80085	1158

Table 1: Tabulated specification list of the current BSN stations

Figure 2: The new BSN stations (a) and the old BSN station vaults with recording equipment

BSN – Data Acquisition and Archiving

- Remote connection between the BSN stations and the Server is achieved via the RUT240 network modem
- Data acquisition is facilitated by SeisComp3 software through seedlink protocol installed in both the server PC and the station data loggers
- Stations that are not transmitting real-time data are those which are located in remote areas where there is no network coverage (3 stations)
- Near real-time data archiving of broadband channels is done using SeisComp3 (*slarchive* module)
- Seedlink server is shared with IRIS DMC for data storage and backup
- MSEED data downloaded from telemetered stations (through a secure file transfer protocol or sftp)
- Data from the 3 standalone stations is collected manually using USB stick swap

BSN – Data Quality check

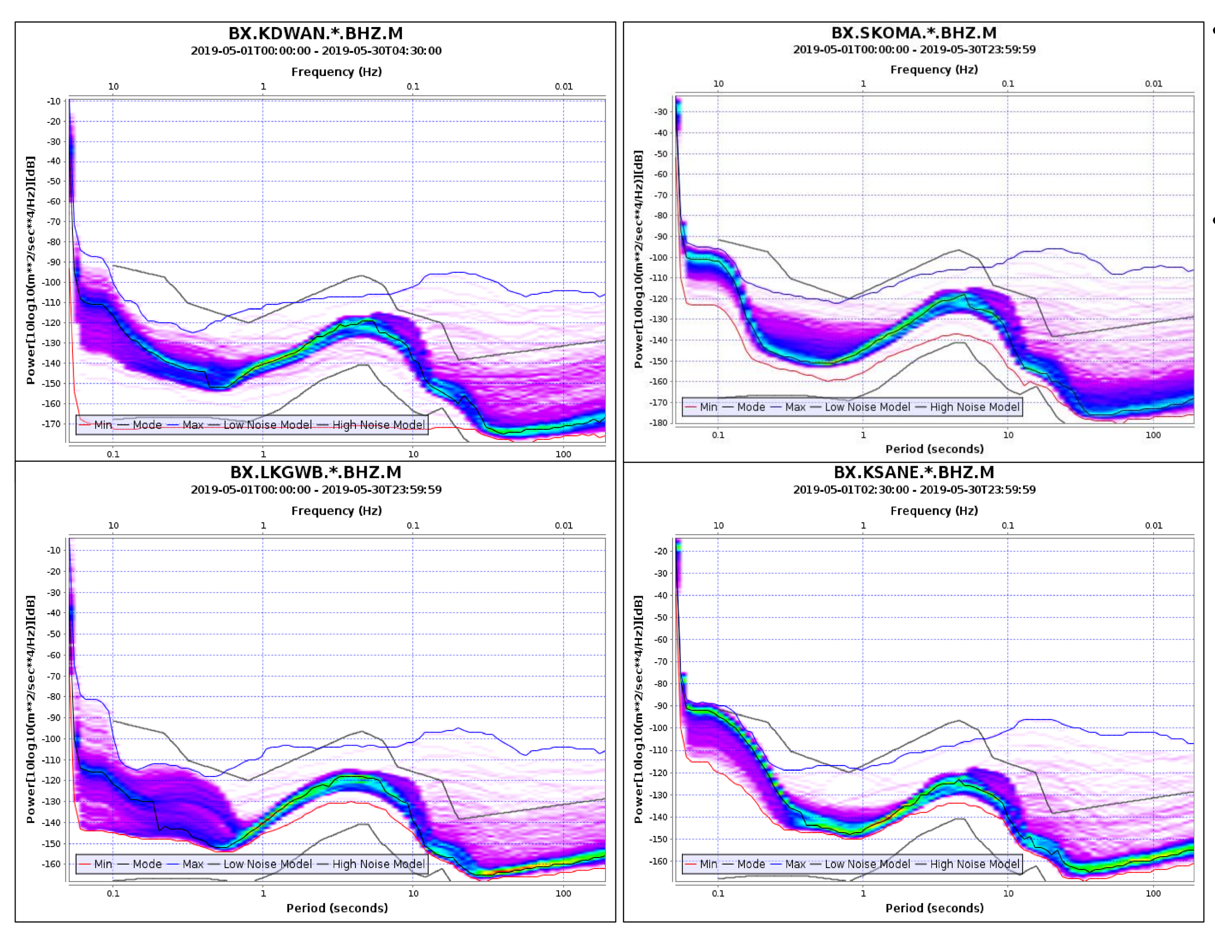

Figure 3: Probability density functions (PDFs) examples for selected BSN stations' BHZ channels in the month of May 2019

- The quality of the BSN data and the stations operations are continually monitored with monthly State of health (SoH) report.
- Recently, the stations data quality assurance resources utilize the Incorporated Research Institutions for Seismology (IRIS) Data Management Center's **M**odular **U**tility for **ST**atistical k**N**owledge **G**athering (MUSTANG).
  - Probability density functions (PDFs) examples for selected BSN stations' BHZ channels in the month of May 2019
  - The Broadband stations display good records in the several frequency domains in relation with their site installation

Analysis and Results

- Seismic waveform analysis is achieved using a number of programs including the following:
  - SEISCOMP3 is utilized to automatically detect and locate events (mostly tele-seismic and regional events)
  - Geo-tool NDC-In-A-Box for IMS station data
  - SEISAN (version 10.3) for sharing phase arrival data with the International Seismological Centre (ISC)
- The map showing location of epicenters and corresponding magnitudes recorded in Southern African region is shown in Figure 4 for the period 2018 –March 2019.
- Significant number of events were recorded in the South African Bushveld and Witwatersrand mining areas suspected to either be explosions or mine-induced earthquakes.
- In Botswana, most events cluster around Orapa-Letlhakane mining areas . The waveforms from nearby BSN stations exhibit an explosion signal and this is supported with the timing of these events.
- Other events in the central part of the country areas associated with the aftershocks from the 6.5 *ML* April 2017 Earthquake in Central Botswana.
- The BSN also clearly records regional events (figure 5(a)) and most of the teleseismic events (figure 5(b))

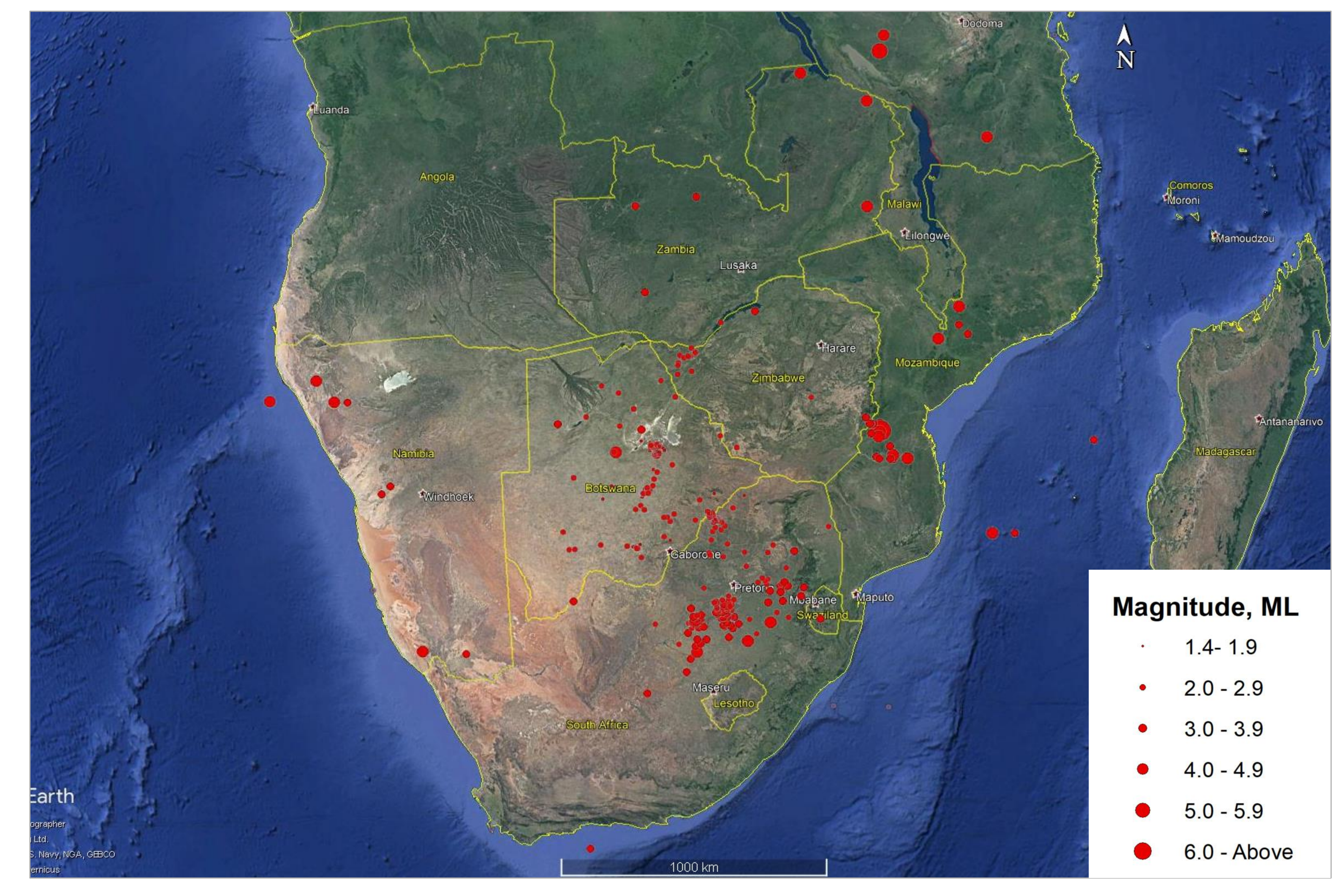

Figure 4: Seismic Events located only by the BSN stations January 2018 – March 2019

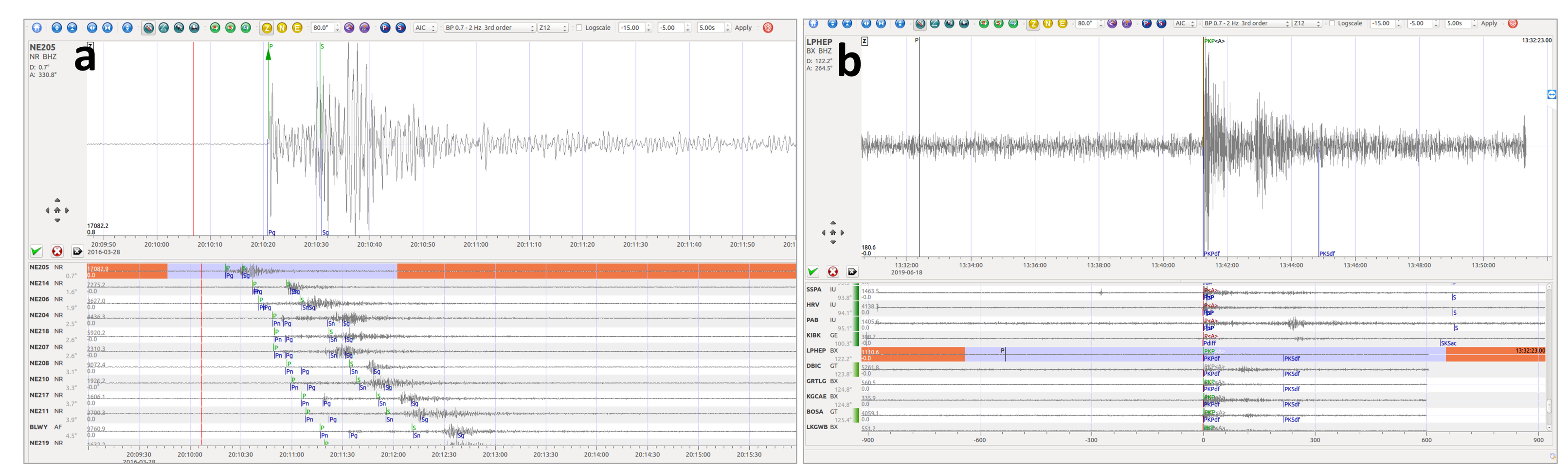

Figure 5:BNS stations showing phase picks from both regional (a) and teleseismic (b) events

Summary

The new BSN is now linked through continuous telemetry to the Botswana Geoscience Institute (BGI) server via the Seiscomp3 acquisition system.

Integration of IMS stations and other regional into the Seiscomp3 enhances detection of local, regional and Teleseismic events.

Data from the BSN stations is shared internationally with the Data Management Center (DMC) of the Incorporated Research Institutions for Seismology (IRIS).

The current operation of the BSN is graded satisfactory since most stations are operating with negligible ranges of downtime mainly due to battery power outages and digitizer errors.

Reference

Assuring the Quality of IRIS Data with MUSTANG, Robert Casey, Mary E. Templeton, Gillian Sharer, Laura Keyson, Bruce R. Weertman, Tim Ahern, Seismological Research Letters (2018) 89 (2A): 630-639., DOI: https://doi.org/10.1785/0220170191