Seismic monitoring in Namaqualand/Bushmanland region

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ABSTRACT

The Namaqualand-Bushmanland region has numerous features that make it attractive for the storage of radioactive waste. In the late 1970s a programme to find a suitable site for low- and intermediate-level waste was launched and Vaalputs was identified. Such site has been in operation at Vaalputs, ca. 100 km S of Springbok since 1986, and seismicity is one of several key factors that are monitored as part of the on-going disposal operations. We evaluate the region's seismic history with the aim of assessing its long-term stability and geodynamic setting. The two-station network of short-period seismometers that was installed in 1989 was replaced with a three-station network in 2012, which comprises one broadband and two short period seismometers. Data from these networks, the South African National Seismological Network, and the International Seismological Centre has been used to compile a catalogue of the general seismicity of the region. A previously known cluster of earthquake foci, with M_{Max} = 5.8, termed the "Grootvloer cluster", is found to consist of three distinct seismic source zones, namely: (1) the Springbok area source, which is attributed to mining activities that ended around 2000; (2) the Great Escarpment area source, which could be attributed to continental margin instability, and (3) the Bushmanland Plateau area source, which is not easily understood. However, we believe that such sub-cluster reflects the strain in the upper and middle crust in response to the transpressional force of a robust, horizontally–oriented $\sigma_{1,}$ a vector known in the literature as the Wegener Stress Anomaly. The overall cumulative trend of the number of events displays a significant increase in the rate, from 13 events/year for the period 1989 to 1995 to 25 events/year for the period 2005 to 2009. These changes seem to coincide with periods of increased global seismic moment release.

Key words: Namaqualand, Bushmanland, Seismicity, Radioactive waste

INTRODUCTION

Generally, South Africa is characterized by a low-level intra-plate seismicity which is sparsely distributed and not clearly associated with any known geological features or causes**.** The region covered in this study lies between latitudes 27° and 32° South and longitudes 16° and 22° East. This area is considered tectonically stable, according to world standards; even though, in recent years there has been sporadic seismic activity, with swarms in 1996, 2001, and again in 2010/11 near the Augrabies falls.

The direct motivation for the present project is represented by need to characterize the seismic parameters (maximum expected magnitude, peak ground acceleration, hypocentral location, fault plane solutions, etc) that may be forecast for the next few centuries at the Vaalputs National Radioactive Waste Disposal Facility, located about 100km southwest of Springbok in the Northern Cape Province. The region presented favorable conditions for the establishment of this facility for low and intermediate level waste in the 1980's, as it is situated in the Precambrian Namaqualand tectonic province, whose geology is dominated by large ~1.3–1.6 Ga granite plutons covered by dry, compacted Cenozoic continental sediments (greywacke, sandstone), overlain in turn by a thin veneer of sand, calcrete and other duricrusts, none of them prone to soil liquefaction.

In summary, a good understanding of the geodynamic processes operating across Namaqualand-Bushmanland is expected to improve current seismic hazard assessment, not just for large, nuclear waste engineering projects, but also for the Square Kilometer Array (SKA) project, destined to be the world's largest and most sensitive radio-telescope system with its base stations near Carnarvon.

PREVIOUS STUDIES

Historical records of seismicity in South Africa date back to 1690. Instrumental data was first recorded in 1910, while the South African National Seismological Network (SANSN) was established in 1971. The SANSN has been upgraded and expanded from time-to-time, and in December 2009 consisted of 32 stations. However, the stations are sparsely distributed in the western half of South Africa, hence the sensitivity and accuracy of location is relatively poor and the SANSN catalogue is only complete above about M=3. These studies yielded a seismic distribution that can be seen in Figure 3, where the Grootvloer seismic cluster (Singh, 2010) is indicated, as one of the seismotectonic provinces of South Africa This cluster is of great value to this study as it falls right within our area of interest.

The SANSN was upgraded in 2006. Stations were equipped with extended short-period seismometers (30s) and seven selected stations received broadband (100s) sensors. The largest event in the 2010 Augrabies cluster was a M_L4.1 event that occurred on 26 July 2010.

SEISMOTECTONIC SETTING

Data from these stations indicate that levels of seismicity are typical of a moderately active intraplate region. Our study area is seemingly characterized by a NNW-SSE oriented S_H, referred to in the literature as the Wegener Stress Field, and by earthquake clusters (Viola *et al*., 2005; Bird *et al*., 2006; Andreoli *et al*., 2009). M. Singh (M.Sc., University of the Witwatersrand, 2010) recently constructed a seismotectonic scheme for South Africa and identified several clusters of earthquake foci in the western region, viz. the Cape Town, Ceres, Cape Fold Belt, Grootvloer (Bushmanland), and Koffiefontein clusters. Seismic activity in the Grootvloer cluster is generally less than in Ceres cluster, although events with M>5 have been recorded and earthquake swarms occur sporadically e.g. in 1996, 2001, and again in 2010/11 (near Augrabies).

METHOD

In 2012 the two Vaalputs stations were replaced by three stations that cover Namaqualand-Bushmanland region. This new network comprised a broadband and two short-period seismometers. Data from these stations is being processed. Apart from internal Necsa reports and short accounts presented at local conferences, no full length article has been published on the Grootvloer seismicity.

The catalogue used in this study is compiled from three sources: one from the Council for Geosciences (CGS) catalogue, starting from 1908 to 2010 with a total of 1159 events with a minimum magnitude of M=1.1 for the study area; another from the South African Nuclear Corporation (Necsa) Vaalputs network, which covers the period 1989 to 2010, with a total number of 501 events, some as low as magnitude M=0.4. The Necsa events were recorded within a 150 km radius from the Vaalputs site. A third data source, from the International Seismological Centre (www.isc.ac.uk) is incorporated in the work for comparison for the period 1900 and 2010, with events from magnitudes as low as M=1.0. The ISC data indicates some seismic events that do not exist in the CGS and Necsa data sets and this is attributed to the fact that some events reported to ISC by CGS were located by single stations and excluded from the CGS catalogue. For the Necsa catalogue, it is believed that some events are missing due to the localized nature of the network. M.B.C. Brandt (pers. comm., 2011) reported that the CGS was in the process of re-analysing their bulletins such that only events recorded by three or more stations are submitted to the ISC.

A 120 s broadband sensor (Compact Trillium) was installed at Stofkloof near Vaalputs, while 4.5 Hz Mark Geophones were installed at Aggeneys and Koffiemeul, about 100 km to the north and east, respectively. All stations are equipped with a REFTEK logger, solar panel, Global Positioning System (GPS), battery and voltage regulator. (Figure 1). This deployment is meant to improve the sensitivity and hypocenter location of earthquakes as the South African National Seismological Network (SANSN) is relatively sparse.

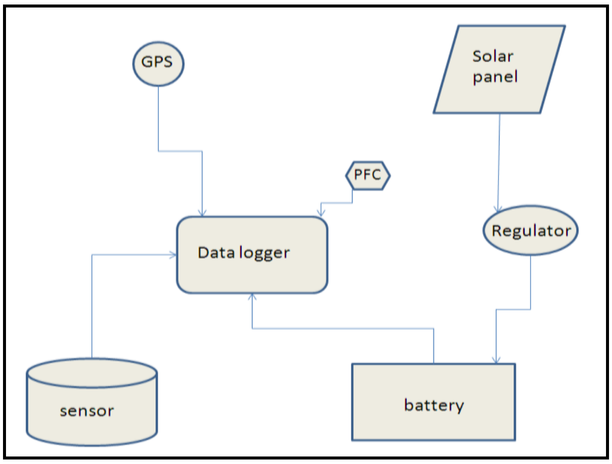

Figure 1: schematic diagram of the seismic stations. (PFC is a hand-held device used to configure settings during installation).

The equipment used is highly specialized and compatible with that which is used for the Africa Array stations deployed by a Wits University, the Council for Geosciences and Penn State University consortium. These stations should supplement the CGS network's coverage of the area, therefore increasing the sensitivity and accuracy of hypocentre location, as well as providing focal mechanism solutions for the events.

Currently data is downloaded manually from a flash disc to computer. The data logger has two flash disc slots and each disc can store up to 4GB of data. Data is analyzed using the SEISAN program (Havskov & Ottemoller, 2005).

A cellular phone modem is installed at two of the three sites; at Stofkloof (STKN) and Aggeneys (AGGN) but are not yet fully functional. These modems will enable data transfer from Vaalputs to Wits, per desired frequency (e.g. daily/weekly), as long as there is enough airtime for connection. However, Koffiemeul (KOFN) has no cellular phone coverage so data will be downloaded manually with the assistance of Vaalputs personnel.

RESULTS

The Necsa data shows that seismic clusters have occurred in 1996 (Bushmanland), 2001 (Gamoep), and again in 2010 and 2011 (near Augrabies). See Figure 3.

All data that was recorded on the Stofkloof station since its installation in March 2012 has been downloaded from the logger to a personal hard-drive disk and processing of this data took rather long as there were just too many files to go through one by one. The files from the disk were then downloaded to laptop, converted into SEISAN format (i.e. the analysis software) and analyzed. Broadband data requires filtering during the analysis process, as waveforms usually do not appear as clearly as those from short period sensors. A total of 279 seismic events were found during the period of March to May 2012 (98 events in March, 69 in April and 112 in May). For this period, 126 events were found to be local events and only 63 of these were locatable with the single-station method. The rest of the events were either regional or teleseismic and even though records of big (M>5) global earthquake were used to compare, some events did not correspond.

13 MARCH 2012 EVENT

The Stofkloof (STKN) station was installed on the 13th March 2012. One event was identified out of 10 signals recorded since installation. This event's recording time is 16:41 GMT. The CGS was contacted for verification of this event and confirmed an event was recorded by four SANSN stations at about the same time (16:38 GMT), but was not located. After seismograms were acquired from CGS, this event was analyzed and located, its origin time was found to be 16:44 GMT; and the epicenter was at 94 km south-east of Vaalputs, at (-30.398, 19.200), with magnitude M_L = 2.8. Figure 2 shows the location on Google Earth. The location errors were found to be 2.7 km in latitude and 4.5 km in longitude

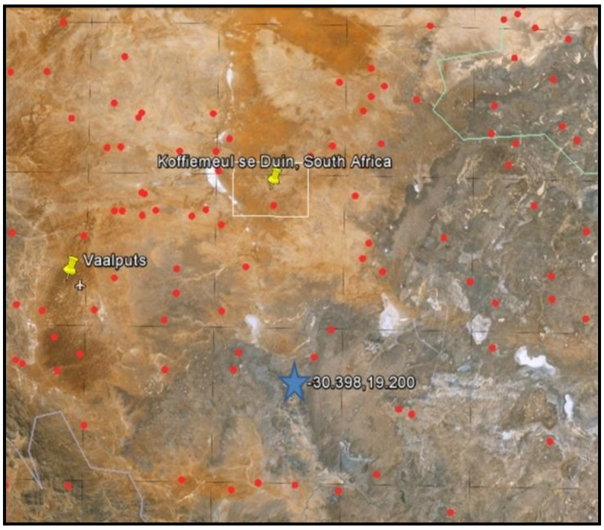

Figure 2: The epicentre of the event recorded by STKN on March 13, 2012 indicated by the blue star. The location error is 2.7km in latitude and 4.2km in longitude.

CONCLUSIONS

From our studies in the area, we draw the following conclusions:

- The Namaqualand-Bushmanland events fall within the Grootvloer "cluster of earthquake foci" (Singh *et al.*, 2011);
- The events are generally of low to intermediate magnitude (M<5.8);
- The geological formations in the area of the Grootvloer cluster comprise granitic basement, locally covered by calcrete and/or dry, compacted Tertiary sediments (greywacke, sandstone), none of them prone to soil liquefaction;
- The Grootvloer cluster consists of several sub-clusters: Springbok (probably mining related), Gamoep (north west of Vaalputs), Riembreek (west of Vaalputs) and Bushmanland (east of Vaalputs). The NNW-SSE orientation of several clusters (e.g. Riembreek) is consistent with reactivation of pre-existing faults under the poorly understood Wegener Stress Field (cf. Andreoli et al., 2009; Viola et al., 2005; Bird et al., 2006).

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FIGURES

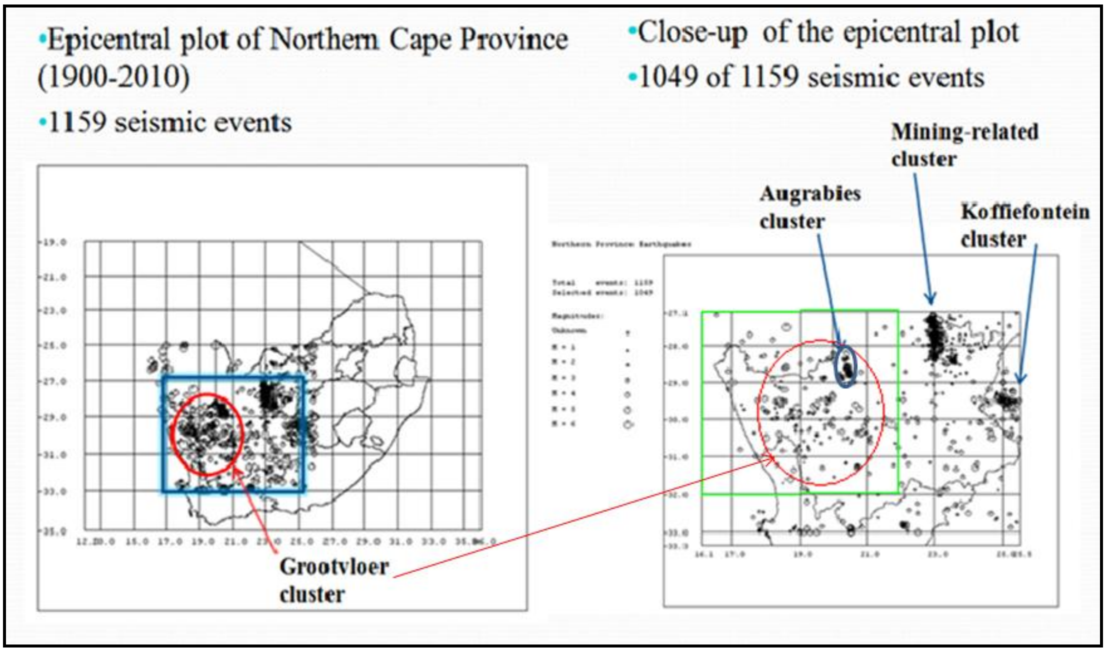

Figure 3: Catalogue containing events from previous studies and current studies. On the left, the blue box encloses all events from the 3 sources; the red circle inside this box indicates the Grootvloer cluster. On the left, the green box delineates the study area, with the Grootvloer cluster as well as the Augrabies swarm.

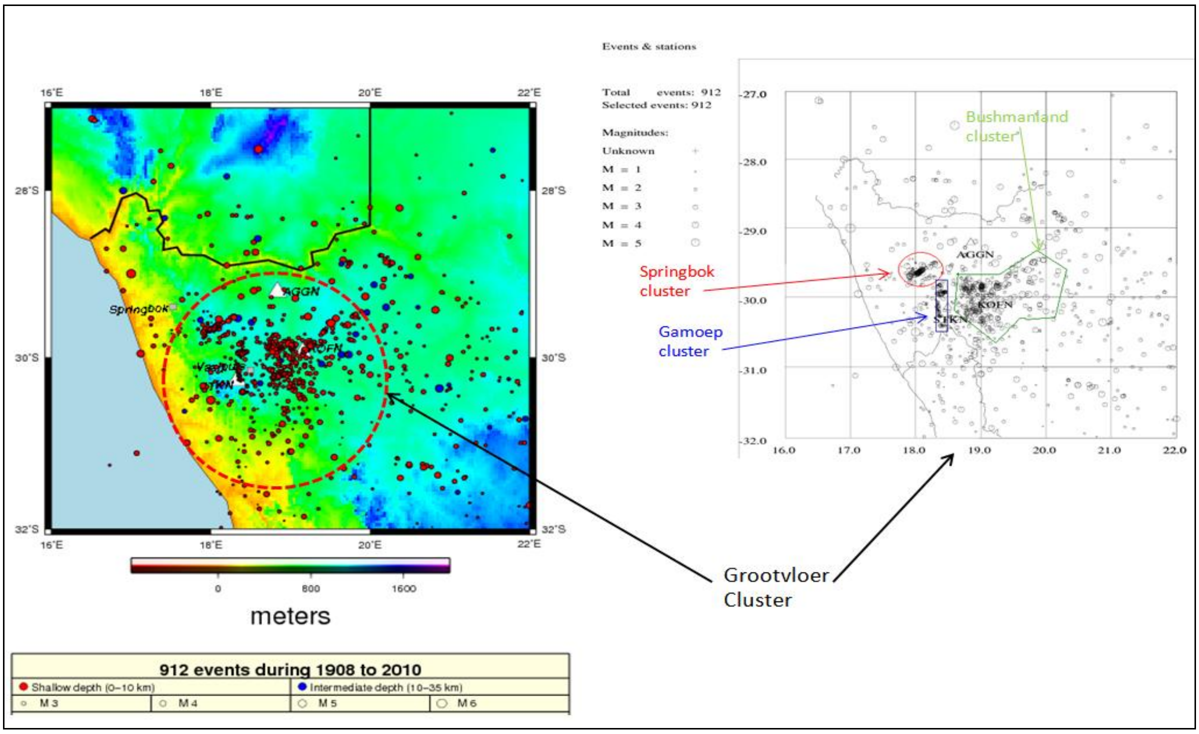

Figure 4: Map of Grootvloer Cluster on the left and its sub-cluster (Springbok, Gamoep and Bushmanland) on the right.

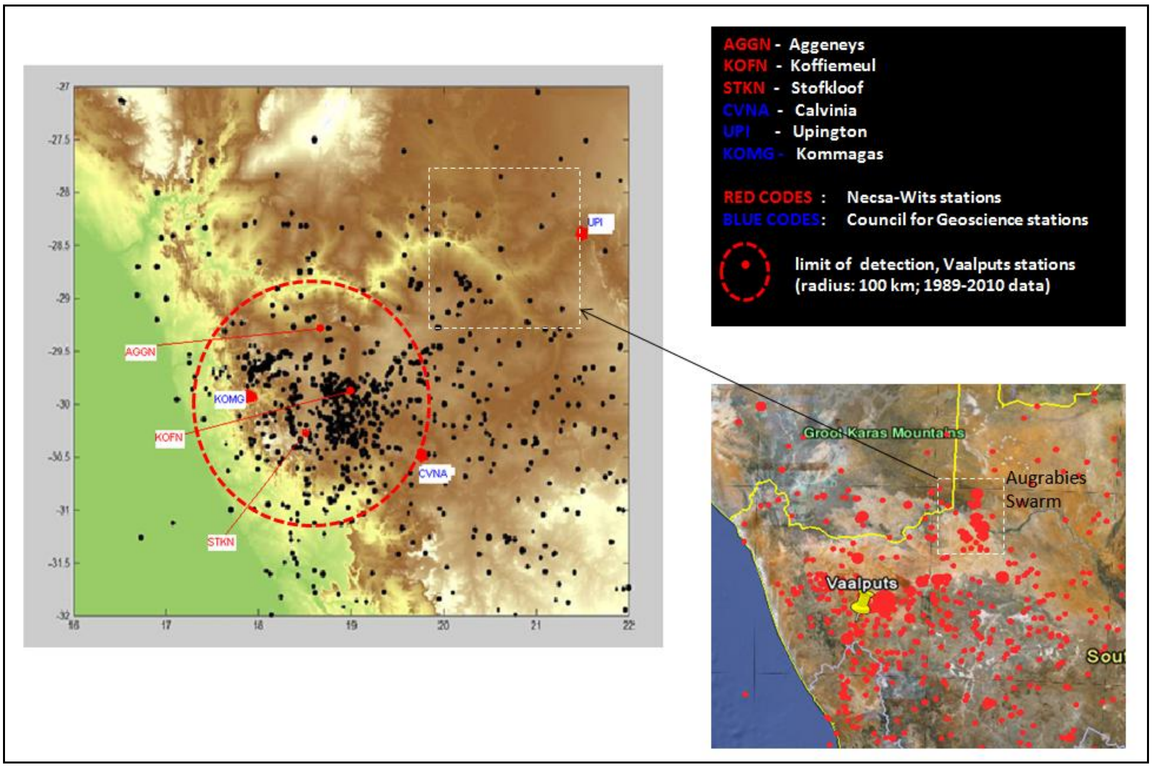

Figure 5: Map of study area showing earthquake distribution and seismic stations, on the left. The small red dots in red codes indicate the new Necsa network while the bigger red dots in blue codes indicate the distribution of the SANSN stations. The right side of this figure shows the Augrabies Falls' swarms, which is depicted by the white dashed box on the left-side picture.