Geoscientific introduction to the seismicity of the Ceres area

Nicolette S. Flint, Coenraad H. de Beer and I. Saunders, Council for Geoscience

One of the most destructive earthquakes in South African history struck the Ceres area of the Southwestern Cape Province at 10:03 p.m. on 29th September 1969. The main shock was preceded by M_L 3.5 and 3.7 events during the day, and was followed by a long sequence of aftershocks, extending until at least April 1970. It is reported that local inhabitants felt light tremors about a month before the main event on 29 September 1969.

The main shock displayed a maximum intensity of VIII on the Mercalli Modified Scale (1956). This scale measures the effects of the earthquake, derived from observations made during and after of the earthquake, with groups of diagnostic criteria being assigned to each scale increment. This scale quantifies the effects of the earthquake on the earth's surface, humans, natural and man-made structures, and it follows that the highest intensities are experienced around the epicentre, i.e. the point on the earth's surface directly above the hypocentre (focus) of the earthquake.

While intensity is an important characteristic of the earthquake, it varies with geographical location and this is why you will seldom hear of earthquakes being described in terms of intensity in the press. The term 'magnitude' is a measure of the energy released by the earthquake and this is measured on a logarithmic scale. For example, an earthquake of magnitude 7.0 releases about 32 times as much energy as one of 6.0 and nearly 1,000 times that of an earthquake of 5.0. Magnitude is expressed by the Council for Geoscience as the local magnitude (M_L), which is calibrated against the original Richter magnitude (developed in California), but modified to suit the geology of southern Africa. This means that the magnitudes of South African earthquakes prior to July 2012 are marginally overestimated.

The magnitude of the main shock was M_L 6.3. By means of comparison, the 29 September 1969 earthquake was roughly equivalent to the energy released in an explosion of approximately 15 kilotons of TNT. The magnitude of main shock was of large enough to be felt as far away as Upington (570 km) and Durban (1,175 km).

South Africa has only experienced one other earthquake of equal magnitude – an earthquake that struck just offshore of St. Lucia on 31 December 1932, which was felt over most of the country. Fortunately, this earthquake resulted in less damage, because the epicentre was some distance offshore.

Severe earthquakes are a relatively rare phenomenon in South Africa, but earthquakes are occasionally felt. Some of these occur in the Witwatersrand area and are linked to mining activities, while others occur infrequently in various places in the country and are usually of moderate magnitude (i.e. M_L<5). The Ceres-Tulbagh-Wolseley area presently has more frequent felt tremors than most other parts of the country. Despite statements published in the press since 1969, the tremors are not due to volcanic activity under the mountains of the area, but to movement along faults. The reason for these movements is the anomalous build-up of stress along faults, thought to be caused primarily by the geological complexity of intersecting folds and faults in the area.

In order to locate the epicentre of an earthquake, the seismic phase arrival times at multiple seismograph stations are used. The seismic phases propagate at different and distinct velocities, as well as frequencies, through the earth. A very simplistic understanding of earthquake location is that the time difference between the primary waves (longitudinal) and secondary waves (transverse) can be used to define the approximate distance of the observation station from the earthquake source. Using this approximate distance, a radius around the station is defined where the wave could have originated. The area where these records overlap indicates the epicentral area, also known as the epicentre, with a margin of uncertainty. Where only one or two stations record an event, the location becomes very unreliable, and in the absence of additional information affirming its status as an earthquake, the event is not included in the earthquake catalogue. The causes of these records may vary from explosions, rock falls, landslides and storm events such as lightning strikes, etc.

In 1969, several geologists initially hypothesised that movement along the large Worcester fault was responsible for the earthquake. Analysis of the main shock and aftershocks in 1969 indicated that this was not the case. The epicentre of the main shock was fixed by the USGS, using a sparse network of seismic stations, at a position 63 km NE of the linear, WNW-ESE trending zone of aftershocks. Two better constrained events on 10 October 1969 and 14 April 1970, recorded by South African seismographs in the area, showed that the presumed epicentre of the 29 September 1969 event was inaccurate and the event was relocated to 33.28˚S and 19.24˚E, approximately 1 km to the north of the zone of aftershocks between Ceres and Prince Alfred Hamlet. The latter zone approximately correlates with the WNW-ESE striking Groenhof fault, which has a mapped length of about 15 km and may be continuous with the Saron and Piketberg faults. It can therefore be concluded that most of the 1969 and 1970 events occurred along a zone of WNW-ESE fractures between Tulbagh and Ceres, at the western termination of the 800 km long, E-W striking, Ceres-Kango-Baviaanskloof-Coega fault zone.

The earthquakes of 29 September 1969 were followed by a series of aftershocks varying between M_L 3.3 and 5.1; two events of M_L 5.1 occurred in the beginning of October and November 1969, almost exactly one month apart from each other and with the first of them occurring one month after the main M_L 6.3 event. Subsequent relatively large events were the M_L 5.7 event on 14 April 1970, and M_L 5.9, 5.6, 5.1, 4.4 events in 1977, 1983, 1991 and 2003, respectively; the spacing between post-1969 larger events was therefore 2, 7, 6, 8 and 11 years. The fact that the M_L 5.7 event occurred some 6 months after the "main shock", means that it should rather be interpreted as a standalone shock, rather than as part of the aftershock sequence. The seismic events in this area from the late 1960's to the early 1970's are therefore viewed as a seismic cluster, rather than a classic main shock - aftershock succession of events.

Brief outline of the seismicity in the area before 1969

Historically, the south-western Cape has a record of intermittent earthquakes dating back as far as 1690. Since the largest concentration of the population was in Cape Town itself for most of the intervening period, the effects of these earthquakes are often reported in more detail from Cape Town, and many which may have been felt inland, for example, perhaps in the area of Ceres (settled around 1699), were not recorded or reported. For this reason, many of the historical earthquakes within the area of Cape Town and the Boland are associated with a level of uncertainty. Seismologists refer to the “Cape cluster”, which includes the Ceres-Tulbagh-Wolseley area.

To date, we have records of 4 earthquakes in the late 1690’s, 3 in the 1700’s, fifteen before 1850 and about fifteen between 1850 and 1900. This is as much a function of the sparsity of population and the resultant lack of historical sources (diaries, journals, etc.) as it is a reflection of the lack of local press in the early years of the Cape Colony. Key events include earthquakes of M_L 3.7 in 1690 in Cape Town, M_L 4.2 on 14 July 1766 in Simonstown, M_L 4.2 in January 1806 at the Griquatown Mission Station, M_L 6.2 on 4th December 1809 in Cape Town, an M_L of 5.0 on the 14th August 1857 that was felt over most of the Swartland, an M_L of 3.0 on 10th May 1885 in Cape Town and an M_L of 5.0 on 15th September 1899 in Cape Town.

The earliest seismic events in the CGS historical catalogue that are shown as having occurred in the Ceres-Tulbagh area were two events at the beginning of the 1920’s: an M_L 5.0 in 1921 and an M_L 3.7 event in 1922. The record then contains no events for this area until the 1950’s, when three events estimated to have been of the order of M_L 4.2 occurred within 2 to 5 years of each other. Events during the 1960’s started off with an M_L 4.8 in 1960, followed by four events between 4.8 and 5 occurring before the 1969 event, all separated by 1 to 3 years from one another.

Brief outline of the seismicity in the area since 1969

The record of instrumentally recorded seismicity obtained in the South African National Seismological Database indicates that 530 seismic events have occurred within an approximate radius of ~180km from Ceres during the September 1969 to September 2017 period. The yearly distribution of earthquakes (Figures 1A and 1B) shows that there is an uneven distribution in seismic activity, most notably a peak in activity during September 1969 when the major earthquake occurred with its related aftershock activity. The apparent high incidence of earthquake activity shown on Figure 1A during the 2006 and 2007 is attributed to an upgrade of the South African National Seismograph Network during 2006 when continuous waveform recording was initiated.

Seismic signals from sources other than earthquakes, such as explosions in quarries, can contaminate the seismic record. Explosions are identified through the proximity of their location to known quarries coupled with the time of day occurrence since South African Law dictates that explosions are limited to daytime hours from 6:00 to 18:00. A total of 167 seismic events in the ~180km radius from Ceres have been flagged as likely explosions from five quarries (see Figure 2). Thus, the remaining 363 seismic events are ‘natural’ (or tectonic) in origin. Figure 1B indicates the yearly distribution of seismic events after removing likely quarry blasts. It is evident that the high incidence of seismic events during the 2006 and 2007 period can be attributed to more explosions being recorded during the respective time period.

Figure 2 shows the distribution of earthquakes in the area of interest. Tectonic earthquakes are shown as filled red circles scaled according to magnitude, whereas the blue diamond symbols indicate likely explosions. The white linear features indicate the faults appearing on geological maps of the area.

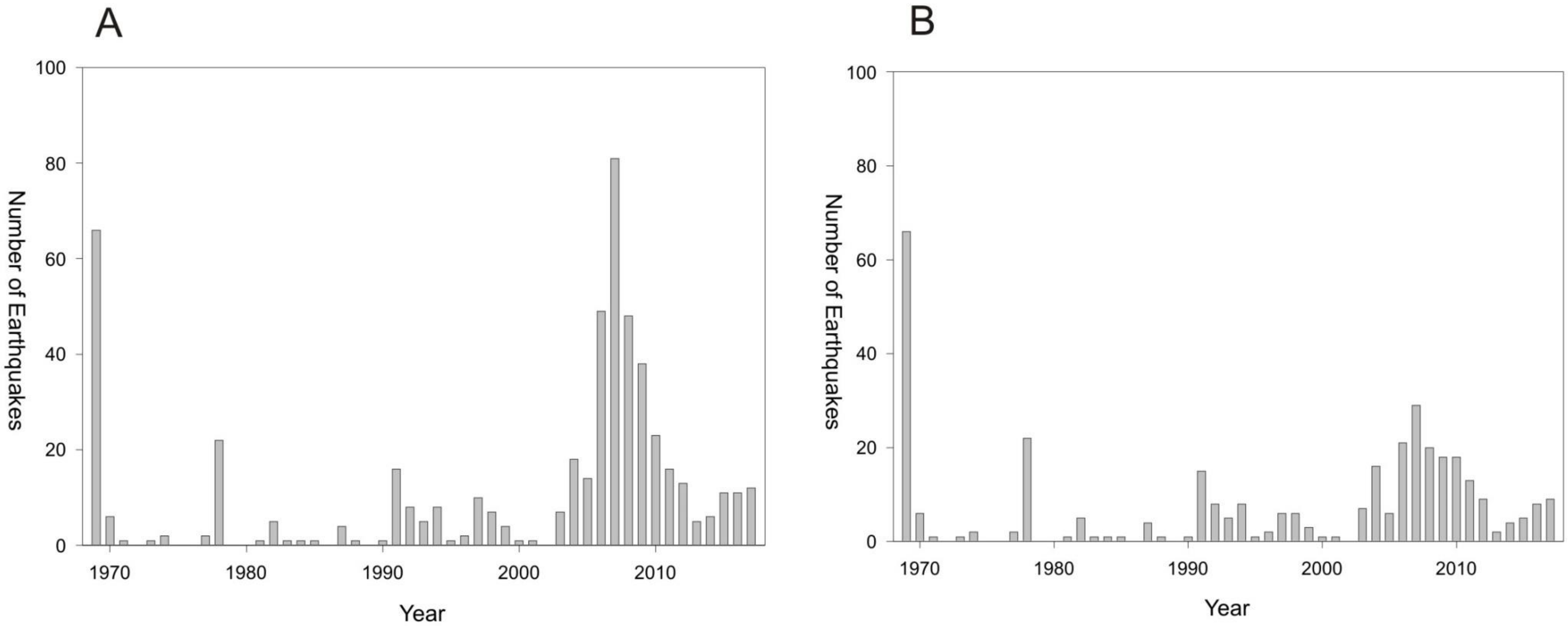

Figure 1: Yearly distribution of seismic activity captured in the south African National Seismological Database. A) All seismic events B) Excluding seismic events identified as likely explosions.

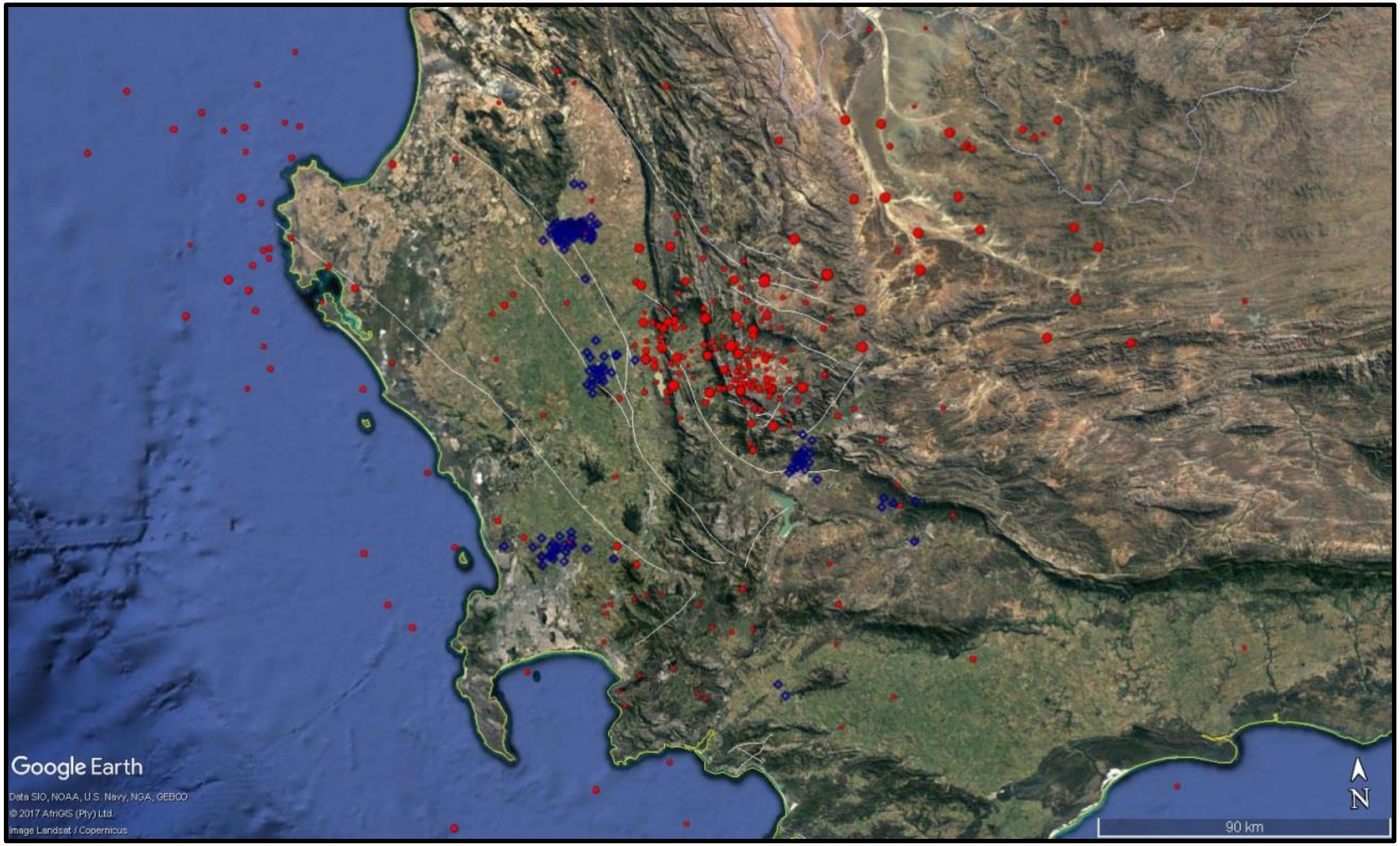

Figure 2: Spatial distribution of earthquakes (red circles) and likely explosions (blue diamonds). The white lines on the figure indicate mapped fault lines.

Figure 3 shows the magnitude distribution of earthquakes in a ~180km radius around Ceres. It is clear from the figure that the majority of earthquakes recorded have magnitudes equal or less than 2. The smallest earthquake recorded had a magnitude of 0.5.

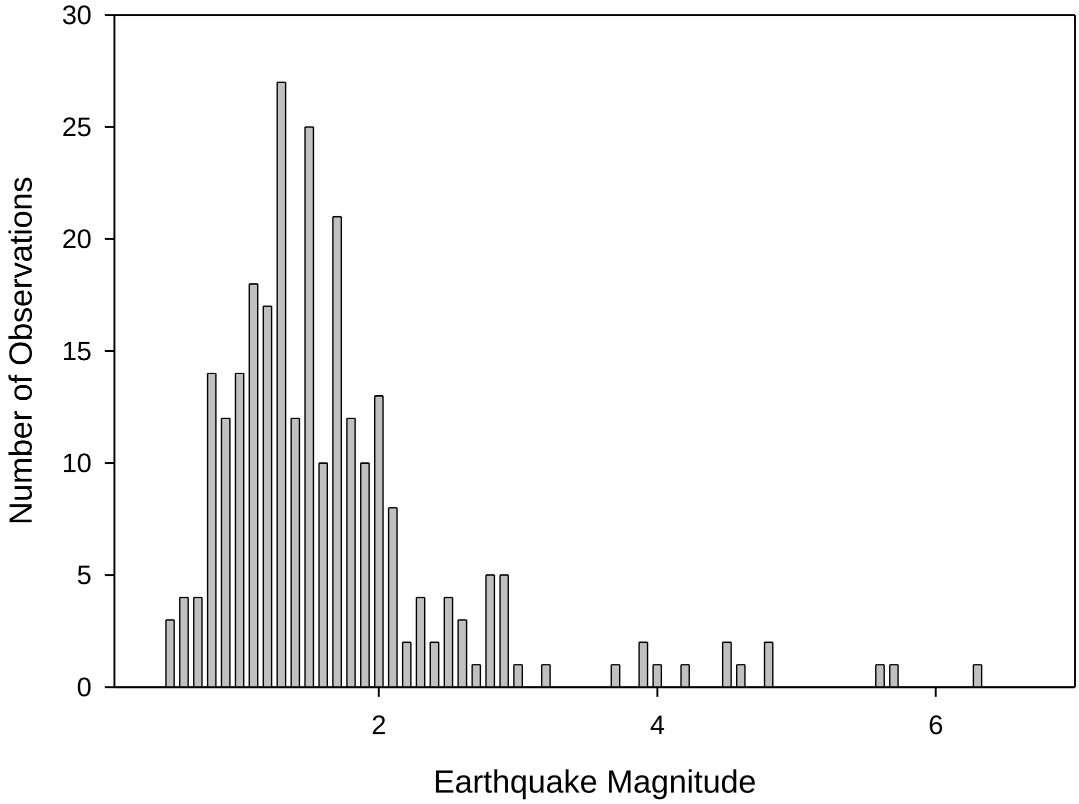

Figure 3: Distribution of magnitudes in a ~180 km radius around Ceres. Note that likely explosions are excluded.

How does the Council for Geoscience monitor seismicity in South Africa

The Council for Geoscience is mandated by the Department of Mineral Resources to operate and maintain the South African National Seismograph Network. Records of seismicity is analysed daily and the results reported through monthly reports compiled by the Council for Geoscience and added to the record of seismicity in the South African National Seismological Database.

Few analogue instruments were deployed in South Africa during the 29 September 1969 earthquake which was recorded at Grahamstown, Gariep Dam, Pretoria and Bloemfontein.

The South African Seismograph Network was substantially expanded between 1970-1990 with the addition of 17 stations, of which four were located in the Western Cape Province, *viz*., Ceres, Tulbagh, Bellville and Beaufort-West. The Ceres station has been in continuous operation since 1970, and used in conjunction with the rest of the network, records and locates seismic events in South Africa.

The South African Seismograph Network remained analogue with selected digital stations until 2000 when all the analogue equipment was replaced with digital broad-band equipment. A complete overhaul of the network was undertaken during 2006 to enable real-time transfer of digital signals. The National Network was further expanded during this time period to 34 stations within the Republic's borders. A total of six seismograph stations are located within the provincial borders of the Western Cape (Figure 4).

Earthquake location is complex because our understanding of the processes that cause earthquakes is limited and there are many factors along the path that affect the propagation of energy from the source to the seismograph station. Therefore there is a statistical uncertainty associated with earthquake locations, including the uncertainty in the depth at which earthquakes occur. Earthquake depths in South Africa are therefore artificially fixed depth of 5km during routine analysis. However, a comprehensive earthquake study by researchers from the University of Cape Town was able to determine earthquake depths in the Western Cape Province using a dedicated small network of seismographs and complex analysis techniques to analyse seismic phases that are sensitive to depth. Their findings showed that earthquakes in the Ceres area were within the upper crustal layer approximately ~5km below surface, whilst earthquakes in the Tulbagh area occur deeper at ~15km.

How can you help?

While the Council for Geoscience uses seismographs to locate and measure earthquakes that occur in South Africa, more information on the effects of the earthquake on the earth's surface, humans and natural and man-made structures are of use in helping us better understand the effects of the earthquake and where they are experienced, which in turn allows us to more accurately measure, locate and record earthquakes. These surveys are used to compile isoseismal (lines of equal shaking) maps that are used to investigate the geological site conditions and can be used to confirm the magnitude and, with further analysis, the approximate depth at which the earthquake occurred.

The seismic catalogues compiled in this way help determine the earthquake hazard/risk in South Africa, and determine the degree to which buildings and critical structures, such as dams, hospitals, power plants, etc. are designed to withstand earthquakes, building a safer South Africa for everyone.

Earthquakes that are widely felt and reported are investigated by the Council for Geoscience by conducting field surveys to understand the effect of the ground vibration on both people and structures. Residents throughout the affected areas are encouraged to check for infrastructural damage and take part in the intensity survey to determine the full effects of the earthquake. This will aid Government Departments to provide assistance where needed and revise action plans for potential future earthquakes.

If you feel an earthquake, please go to our website (http://www.geoscience.org.za/index.php), click on the link "Seismic events", select the correct date and complete the earthquake questionnaire (available in English, Afrikaans, isiZulu, isiXhosa and Sesotho). Please provide as much detail as you can, even if it seems unimportant. Ask you friends, family, schoolmates and neighbours to do the same. All responses will be greatly appreciated.

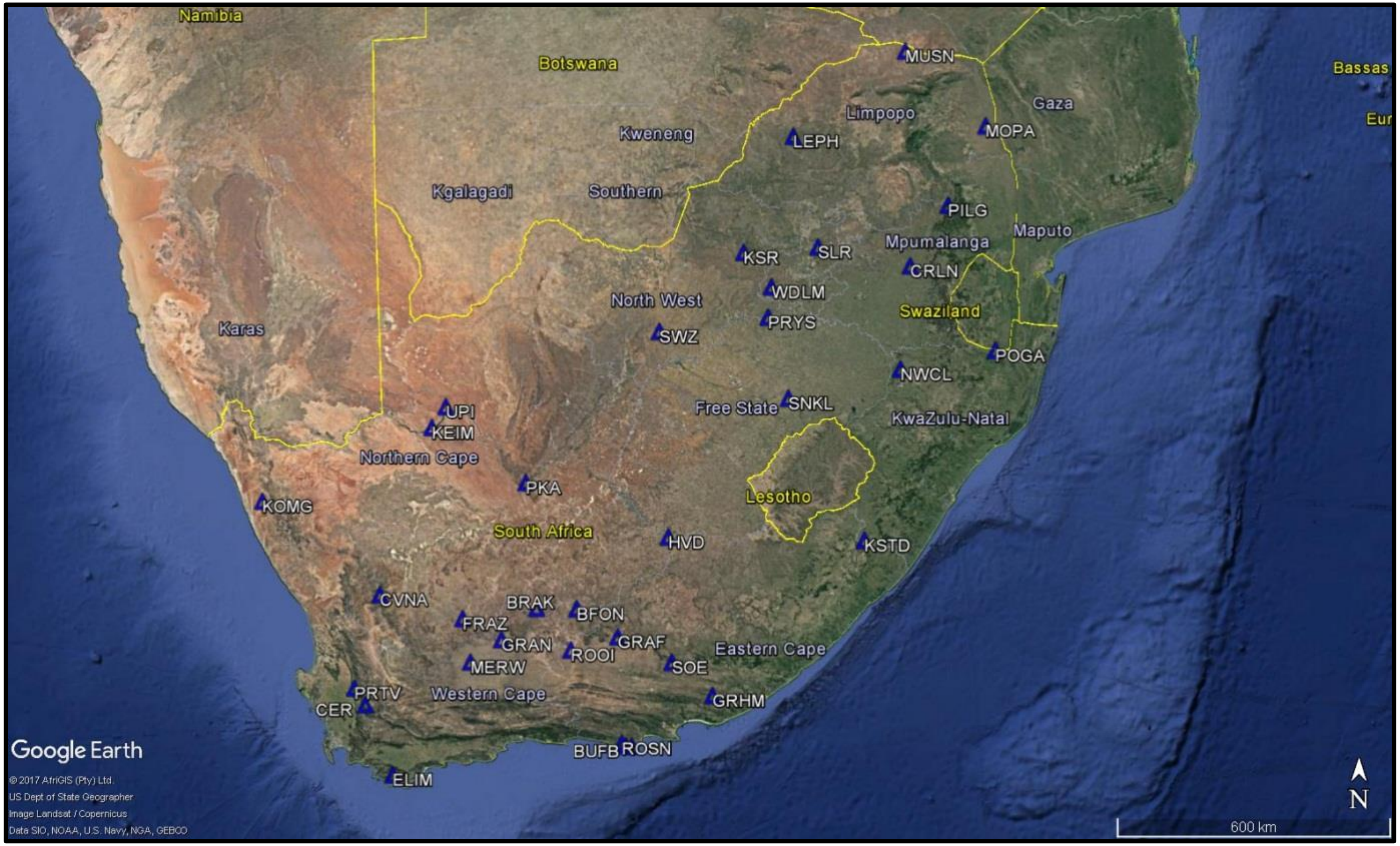

Figure 4: Station distribution map of the South African National seismograph Network.

Please note

To date, there is no means of predicting the occurrence of an earthquake in space or in time. There is no area in the world where such predictions can accurately be made, not even in California, where earthquakes are more frequent and of higher magnitude. While the CGS is constantly monitoring seismic activity in southern African, we cannot say with any certainty when or where an earthquake will happen. Should we note an increase in seismic activity, either in frequency or in magnitude, in a particular area, we inform Disaster Management and they prepare themselves accordingly.

However, please also note that an increase in seismic activity is not always the precursor of an earthquake – sometimes they suddenly strike in areas that have not experienced seismicity before. An example of this is the M_L 6.4 earthquake of 3rd April 2017 in central Botswana.

Also an earthquake may be followed by aftershocks hours, days or weeks after the main earthquake and these may hamper aid efforts, cause further damage to buildings, dislodge debris and injure people.

The Council for Geoscience would caution people against “misleading” and “untrue” messages about earthquakes on social media, some claiming to predict the next earthquake, or promoting untrue facts, such as “it was a volcano!”. While social media provides a valuable communication platform, we encourage the media to aid the dispersion of accurate information that we provide, along with Disaster Management. The members of the public are urged to remain calm and listen to relevant updates through official channels. Please use accurate information from a reputable source for confirmation and decision making.

The public are advised to make themselves aware of precautions that can be taken during an earthquake to prevent injury and loss of life.