HYDRAULIC FRACTURING

Fracking and earthquakes: Taking stock of seismic risks in the Karoo

What does seismic risks and hydraulic fracturing have in common? The latest research in Leeu-Gamka in the Karoo provides some interesting results that should inform local shale gas development plans and practices, according to the scientist involved. Jorisna Bonthuys reports.

Efforts to extract shale gas resources in South Africa have been under intense public scrutiny in recent years.

The government has been looking into hydraulic fracturing or 'fracking' in the Karoo as a way to broaden South Africa's energy mix. This has been met with push-back from lobby groups and environmental organisations that are concerned about its impact on agricultural water resources and long-term socio-economic prospects in the region.

There are also concerns about the impact of such plans on the country's already high per capita carbon footprint in the context of the current climate crisis and South Africa's international obligations to reduce its fossil fuel dependency.

Government and energy companies are reportedly still contemplating their next moves in this regard. At the moment no applications for shale gas rights can proceed until the necessary technical regulations are promulgated by the Minister of Environmental Affairs, Janse Rabie, Agri SA's Head of Natural Resources, indicated.

And while legal battles were underway in 2019 about the Department of Mineral Resources' fracking regulations, a Cape

Town researcher generated new knowledge about seismic risk and geohazards in the southern Karoo.

Melody Finn believes these results should be taken into consideration when future fracking plans are considered. Not only is the debate about fracking about the potential risks of groundwater contamination and the use of fossil fuels: there are seismic risks involved too.

Fynn received her Masters Degree in the Department of Geological Sciences at the University of Cape Town on this subject. Her study, titled ***Micro-seismic Observations in Leeu Gamka, Karoo, South Africa,*** has provided new insights into our understanding of microseismic activity in the interior of the country.

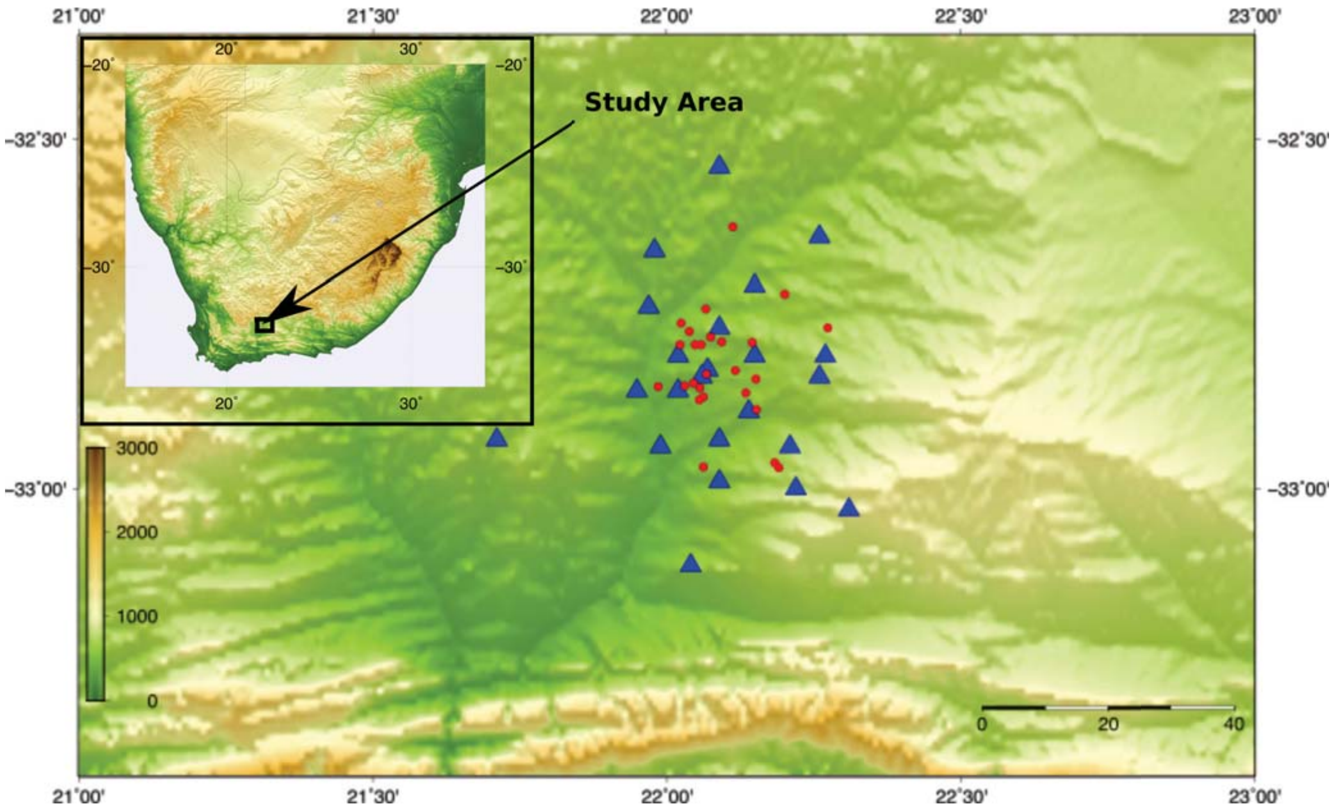
This study is important because the area she focused on is of economic interest to those interested in shale gas exploration.

Tectonic setting

The International Seismological Centre catalogue reported 27 localised anomalous seismicity in the Leeu-Gamka region between 2007 and 2013, with local magnitudes up to ML4.5. These small quakes occurred in a region that is considered as tectonically stable, and far from major tectonic plates. Leeu-Gamka's "seismic swarms" occur in a region which shows little evidence for previous earthquake activity or a fault segment that reaches the surface.

Fynn wanted to understand what caused these swarms. She also wanted to investigate the depth of the earthquake, the orientation of the structure along which the earthquakes are occurring and its source mechanism.

She deployed an array of seismometers in Leeu-Gamka, covering an area of 60 km x 65 km on private farm land based on the previous seismicity recorded in the region.



Melody Fynn

An illustration of the study area with the station locations as blue triangles .

These instruments were installed by digging a 30-50cm deep hole. After three months, the instruments were collected from the field. The data, which had been logged with GPS signals for accurate timing, were analysed.

Seismic swarms differ from earthquakes that are followed by a series of aftershocks in that there is no obvious mainshock in the sequence.

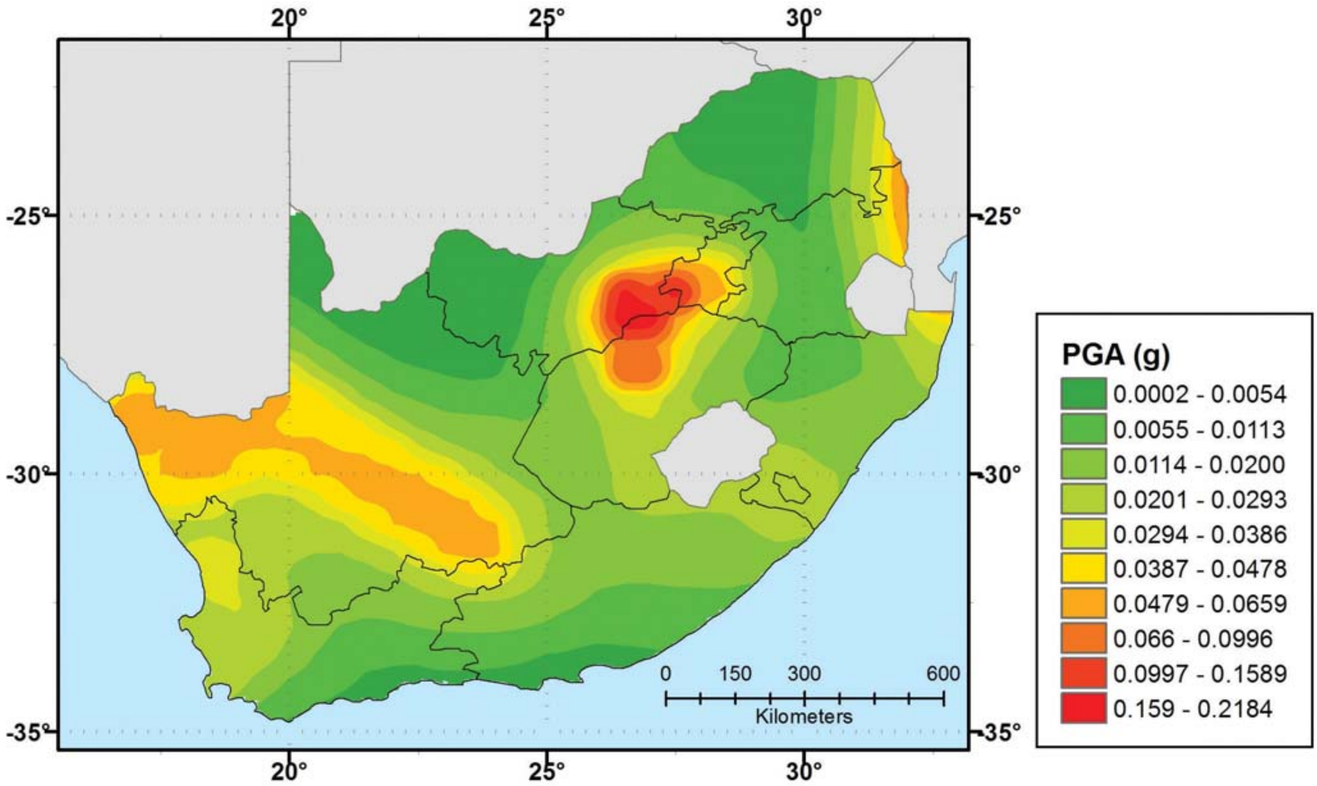
Fynn identified a total of 106 earthquakes from March-June 2015 in the Leeu-Gamka area. Interestingly, almost all of these events happened in the same small area (75% of the epicentres fall within a one square kilometre block).

She then calculated an average hypocentral depth of approximately 6km for the earthquakes, assuming a depth to the base of the Karoo of 5 km. This places the earthquakes just below the base of the Karoo, in the Cape Supergroup. The magnitudes of the earthquakes recorded range from -1.5<ML<0.4.

Fynn's work showed there is an active NW-SE strike-slip fault in this area, consistent with the distribution of the earthquakes. The presence of such a structure has implications for shale gas exploration in that wastewater pumping in an area with active faults could trigger larger and more frequent earthquakes, as seen in case studies in the central states of America, in particular, Oklahoma.

To understand this risk, we have to consider seismicity in the region.

Council for Geoscience)



Seismic hazard map of South Africa.

Spotlight on seismicity

Seismic stresses produced by relative tectonic plate motions result in frequent earthquakes at plate boundaries, where more than 90% of natural seismicity occurs. These are the most widely studied earthquakes and are relatively well-understood, Fynn points out.

"By contrast, large earthquakes in the interior of continents, known as intraplate seismicity, occur far from plate boundaries, are rare and are poorly understood. Surface evidence of ruptures is also generally absent during these quakes in the study area and makes them harder to study. South Africa falls within this region type."

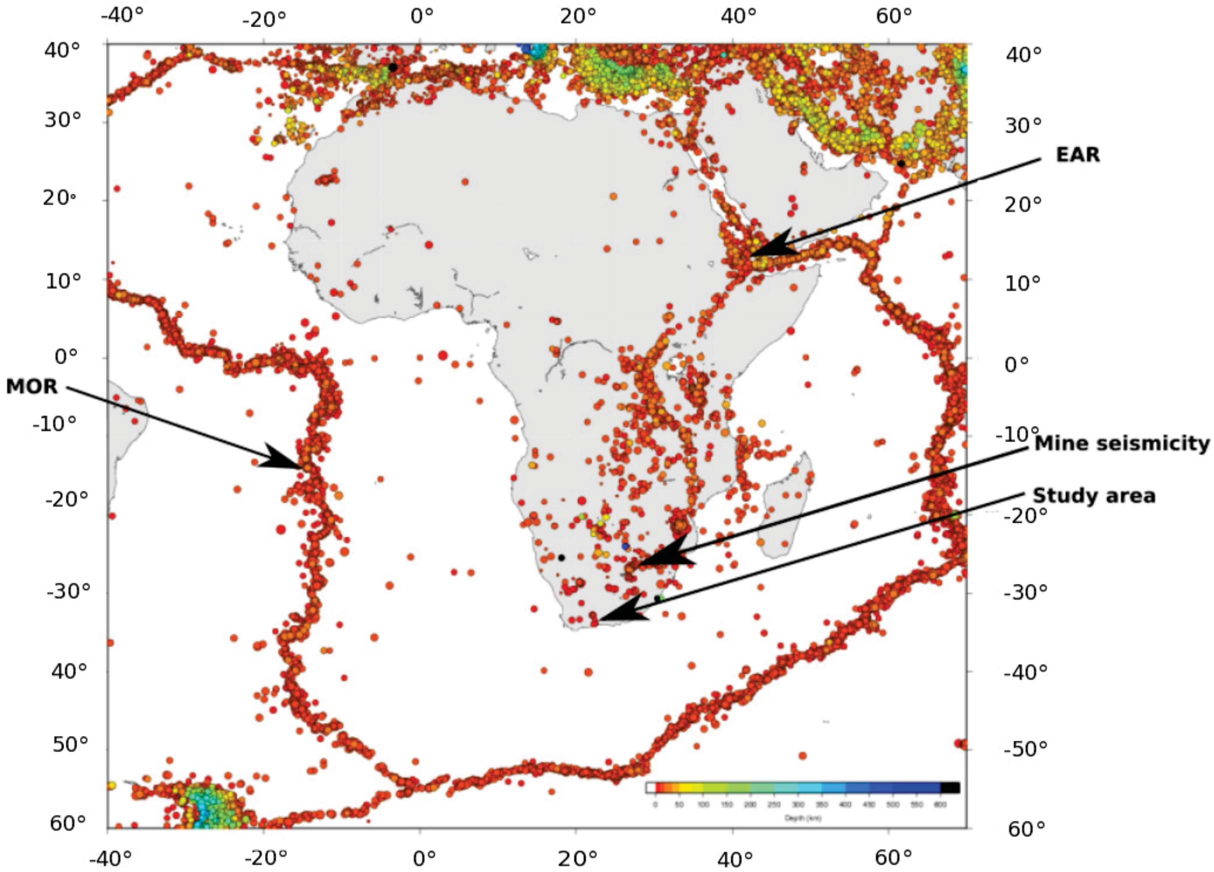
Although far less common, earthquakes located far from plate boundaries are still capable of releasing large amounts of seismic energy and are often located on pre-existing structures. The potential energy that can be released on intraplate structures should not be underestimated, Fynn says.

"The essential concept of plate tectonics is that stress builds up on faults over time until the frictional strength of the clamping forces holding the fault together is exceeded, releasing energy in the form of an earthquake," Fynn explains. "It is, therefore, important to understand the conditions in which intraplate earthquakes might occur, especially those areas whose inherent stress conditions may be affected by human-induced activities."

Sporadic earthquakes sometimes occur as a single seismic event on an old fault that has not recently been active, she says. "This seems to be a characteristic that most stable continental regions share." This means that intraplate earthquakes can occur in regions where seismicity was not recorded before and no surface evidence for strain accumulation is observed.

The ML6.3 earthquake in Ceres-Tulbagh that occurred on 29 September 1969 is such an example. This event resulted in at least 12 deaths and considerable damage to infrastructure in the northern Boland. Interestingly, the towns of Ceres and Tulbagh have continued to experience regular seismicity after the quake and its aftershocks.

Southern Africa is generally classified as a stable continent region, bounded to the northeast by the East African Rift System (This is an active continental rift zone where the African plate is in the process of separating into two separate plates: The Nubian plate which is moving towards the west relative to the Somali plate, which is moving towards the east). Although this structure is not well defined, it is linked to much of the seismicity in Mozambique, Zambia, Zimbabwe, Namibia, Botswana and South Africa according to a recent article in the ***Journal of African Earth Sciences***.



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Map illustrating the plate boundaries.

Although massive earthquakes do not happen often in South Africa, it has happened according to geological evidence. The largest recorded earthquake in southern Africa is located at the southernmost extent of this system, in south-western Mozambique. The MW7 earthquake was recorded on 22 February 2006 and was unusually large considering that the earthquake occured at a divergent plate boundary, which typically produces events with smaller magnitudes.

"There are many, many smaller quakes and examples of rumblings underground – you just have to listen in the right place," according to Fynn. A total number of 22 089 earthquakes were recorded by the South African Network between 1996–2016.

Most of the seismicity recorded in South Africa is mining-related, but occasionally, clusters like the Augrabies cluster in the Northern Cape, the Drakensberg, Ceres-Tulbagh and quite unexpectedly in Leeu-Gamka, are observed and are of tectonic origin.

The stress region of the study region is according to Fynn influenced by the southern extension of the East African Rift System and the so-called Wegner Stress anomaly along the western coast of Southern Africa. These regimes are largely responsible for earthquakes of a tectonic source in South Africa and are mainly observed in the western regions of the country, including Ceres-Tulbagh and Augrabies.

Until the Tulbagh quake occurred, intraplate regions such as the Western Cape were conceived as effectively rigid and subject to no tectonic loading, except at distant boundaries.

The recurrence time for large earthquakes in individual parts of an intraplate seismic zone may be very long, measured on a scale of millennia rather than centuries, Hartnady says. "Consequently, the historical and instrumental seismic record yields an inaccurate view of the long-term seismicity, and seismic hazard analysis requires additional, scientific tools."

In the early understanding of the African plate, the Western Cape is far from an active plate boundary, explains Dr Chris Hartnady from Umvoto Africa. Hartnady, a former professor at the University of Cape Town, is involved in efforts to improve early warning systems for earthquake hazards in South Africa.

"It is, however, located close to the rifted ocean-continent margins that formed during the break-up of the Gondwanaland supercontinent, between 180 million and 135 billion years ago," he says. "So the western and southern parts of the province are riddled with major faults related to this episode of the supercontinent breakup."

In South Africa, the map of seismicity is dominated by mining regions due to two factors. "Firstly, natural or tectonic earthquakes are relatively rare in South Africa due to its location far from the plate boundary zones," Fynn says. "Secondly, seismic monitoring is concentrated around the mines due to the potential risk of earthquakes to mining." This means that more smaller earthquakes are recorded around the mines than elsewhere and this leads to an artificially high density of seismicity if all events are considered, she says. Fynn plotted all ML>4 earthquakes in southern Africa.

The largest mining-related earthquake to be recorded in South Africa was a ML5.5 and occurred near Orkney on 5 August 2014 in the KOSH ((including Klerksdorp, Orkney, Stilfontein and Hartbeesfontein) mining district. The region is quite active with more than 8 000 events recorded between 1971 and 2014 as well as about 150 events of magnitude greater than or equal to MW4.

Lessons from Oklahoma

Since the 1960s, the link between wastewater injection and seismicity has been documented.

This has been seen extensively in Oklahoma, also a previously seismically quiet region, where large earthquakes (>ML5) have been linked to the disposal of wastewater injection with the source locating within a few hundred meters of wastewater injection wells. In 2014, Oklahoma recorded more earthquakes than California, situated on a major active fault and known for its geohazards and seismic risks.

A relationship between increased seismicity and injection of wastewater has also been widely reported in Colorado, Ohio, Arkansas, Texas, New Mexico and China and seems to lead to larger magnitude earthquakes than those said to be related to fracking.

The pumping of wastewater, associated with the process of hydraulic fracturing, into a seismically active region can reactivate dormant faults, increase the seismicity on active faults or induce larger earthquakes than previously experienced or expected.

Research shows an increase in seismicity due to wastewater injection can happen because the pumped fluid causes an increase in pore-pressure which reduces the effective normal stress (or clamping forces) on the fault.

Seismicity can be triggered by changing the pore-fluid pressure at depth. "Faults usually remain locked by the pressure of an overlying column of rock and injecting fluids can counteract the pressure, making the frictional failure of rocks more likely," Fynn says.

A precautionary approach

Hartnady believes a prudent approach to groundwater-resource development requires micro-seismic monitoring in areas that undergo low levels of natural earthquake activity or if wellfield development has the potential to trigger induced seismicity.

Temporary deployments of seismic monitoring arrays have recently been undertaken in the Western Cape to demonstrate ongoing micro-earthquake activity following the 1969-1970 Tulbah-Ceres seismicity and the 2009-2011 Leeu-Gamka earthquake swarm.

Perturbations of stress may be a result of an increase in pore-pressure at earthquake source depths, or from local changes in secondary stresses, for example, surface loading and unloading. In the Karoo, these secondary stresses could originate from unloading caused by excessive borehole water extraction or in the case of possible fracking activities, the pore-pressure could be increased by waste-water injection.

It is also possible that natural seismic swarms can be attributed to fluid overpressure, Fynn points out. Some researchers argued that fluid pressure at depth plays a key role in earthquakes occurring by lowering effective stress on highly stressed fault segments close to shear failure.

Earthquakes can also be triggered by loading and unloading of the crust by surface or groundwater. Research showed that changing the local stress by extracting water from a shallow aquifer likely caused the ML5.1 earthquake near Lorca, Spain in 2011.

This is important for an area like Leeu-Gamka Fynn says. "Earthquakes greater than >ML3 associated with fluid injection are almost always associated with the injection of large volumes of wastewater, and not necessarily the deliberate, controlled formation of fractures to liberate the gas during the fracking process."

The depths of the earthquakes was a key research outcome, Fynn says. The location of the seismicity will prove to be important if fracking should start in the region, particularly if the wastewater produced is re-injected into the subsurface to a similar depth of the active fault.

Providing a baseline study of seismicity and identifying active faults in a region being considered for shale gas extraction is vital.

What this study has revealed, is that there is an active fault in the region with a NW-SE striking surface, capable of generating an earthquake of ML4.5, the largest observed within the period between 2007–2013. "I can say with some degree of confidence that the earthquakes in the Leeu-Gamka region are a consequence of reactivation along a pre-existing fault," Fynn says.

The active part of the fault identified starts at a depth of approximately 6 km, a critically stressed zone within the Cape Supergroup, and could further be exacerbated by wastewater injection near this depth if this method is adopted for disposal.

The disposal of wastewater produced by fracking merits further study, Fynn adds. Studies are also needed to examine earthquake swarm processes and their potential for reactivating inactive faults or unidentified faults in a particular region, she concludes.