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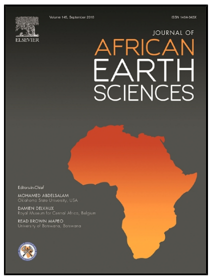


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# Seismotectonics of South Africa

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## Abstract

Assessment of seismic hazard is challenging especially for low seismicity regions like southern Africa. There is very little knowledge in terms of the coupling between the seismicity and active faults leading to an incomplete dataset in terms of recurrence times and seismic zonation. Concerted efforts have been made to compile a seismotectonic map of South Africa that will assist in delineating seismic hotspots in order to carry out a proper seismic hazard assessment using state of the art methodologies. In preparing the map, a homogeneous earthquake catalogue was compiled from local, regional and international databases. Fault plane solutions and stress information were obtained from publications, reports and international organisations such as the ISC, USGS and Harvard CMT. Though few such data are available for South Africa, all collected information is vital in the effort to understand the tectonics and stress modelling of the region. Several faults have been identified as possibly active, though some of them have no significant seismicity associated with them. Through these efforts, a seismotectonic map of South Africa has now been prepared. It is hoped that the information in the seismotectonic map will contribute to the preparation of more accurate hazard assessments for South Africa. However, efforts continue to collect and improve collection methods of historical and instrumental seismicity data, as well as geological information to improve the available seismotectonic data for this region.

Keywords: Seismotectonics, South Africa, Faults, Fault Plane Solutions, Seismicity

## Introduction

Assessment of seismic hazards for Stable Continental Regions (SCR) like South Africa is challenging due to the poorly understood seismotectonic models. The seismotectonic context of South Africa is characterized by a low rate of crustal deformation as well as temporally and spatially diffusely distributed seismicity. Due to the low seismicity and surface deformation, there is a lack of information regarding the coupling between the seismicity and active faults. This underlines the importance of seismotectonic studies to improve seismic hazard assessment studies.

The Global Seismic Hazard Assessment Program (GSHAP) divided the African continent into broad seismotectonic zones based on an analysis of the major tectonic structures and a correlation with present-day seismicity (Midzi et al., 1999). Due to the large scale of the GSHAP project, only regional structures were accounted for in the preparation of the source zones. Several other studies have also been conducted to try and understand better the seismotectonics of different parts of southern Africa (e.g. Singh et al., 2009; Hlatywayo, 2001; Mangongolo and Hutchins, 2008; Malephane, 2007; Bertil et al., 1998). Hlatywayo (2001) compiled a seismotectonic map of central southern Africa centred mostly on Zimbabwe. He assessed the energy released by earthquakes that occurred in the period 1910 to 1991. A common factor between his study and that of Singh et al. (2009) is that though they were able to identify provinces of tectonic activity, not enough information existed to characterise these provinces or determine the activity of nearby faults. Mangongolo and Hutchins (2008) indicate that seismicity of Namibia is mainly associated with the Wegener stress anomaly which is assumed to run from southern Angola into South Africa. Singh et al. (2009) attempted to derive a seismotectonic model for South Africa by synthesising different geoscientific information together in order to explain earthquake clusters in South Africa. Similarly, in this study, different but updated geoscientific information compiled mainly from available published information that can be used to understand better the seismotectonics of southern Africa. The main purpose behind this effort was to obtain information that can be used to develop a seismic source model that can then be used to conduct a reliable seismic hazard assessment of South Africa.

**Geological Setting**

The basement geology of southern Africa is dominated by Archean cratons and Mobile belts (Figure 1). The three major cratons are the Kaapvaal, Zimbabwe and the Congo. Of these, the Kaapvaal Craton is the oldest, formed between 2.7 and 3.7 Ga and covering an area of about 1.2 million $km^2$ (Johnston et al., 1994; Adams and Nyblade, 2011). The Kaapvaal Craton collided with the Zimbabwe Craton along the Limpopo Mobile Belt during late Archean, which caused dominant foliation in the Zimbabwe Craton (de Wit and Ransome, 1992). The southern margin of the Kaapvaal Craton is bound by the Neoproterozoic Namaqua-Natal Belt whilst the north-western margin is bound by the Proterozoic Damara-Lufilia domain (Johnston et al., 1994).

The Namaqua sector of the Namaqua-Natal Belt is separated on its north-eastern boundary from the Kaapvaal Craton by the Paleoproterozoic Kheis Mobile belt (Adams and Nyblade, 2011), which was described as a thin-skinned region with east-verging thrust belt characteristics (Cornell et al., 2011). The Namaqua Mobile belt extends north-west into Namibia where it forms a ‘triple junction’ with the Damara and Kaoko Mobile belts. The Damara belt itself appears to be part of a westward extension of the East African Rift System (EARS) through the Zambezi valley and the Okavango delta, both of which are associated with some of the major earthquakes in the region. Along the eastern edge of the Kaapvaal Craton is the Pongola rift, which is believed to have reactivated in the late Proterozoic as a compressional zone (Johnston et al., 1994).

Another prominent structure on the sub-continent is the Cape Fold Belt, which is a dominant structural domain along the southern coast and is assumed to have been caused by late Palaeozoic compression associated with the assemblage of Pangea (Hälbich, 1983). According to Tucholke et al. (1981), the belt extends southwards offshore as far as the Agulhas Bank along the strike slip margin of south-eastern Africa (Figure 1). Along the eastern part of the Cape Fold Belt is a large duplex structure, formed along the southern margin of Gondwana (Booth et al., 2004). This duplex structure, formed during the Late Palaeozoic, contains typical patterns of numerous and north-verging thrust faults and associated folds.

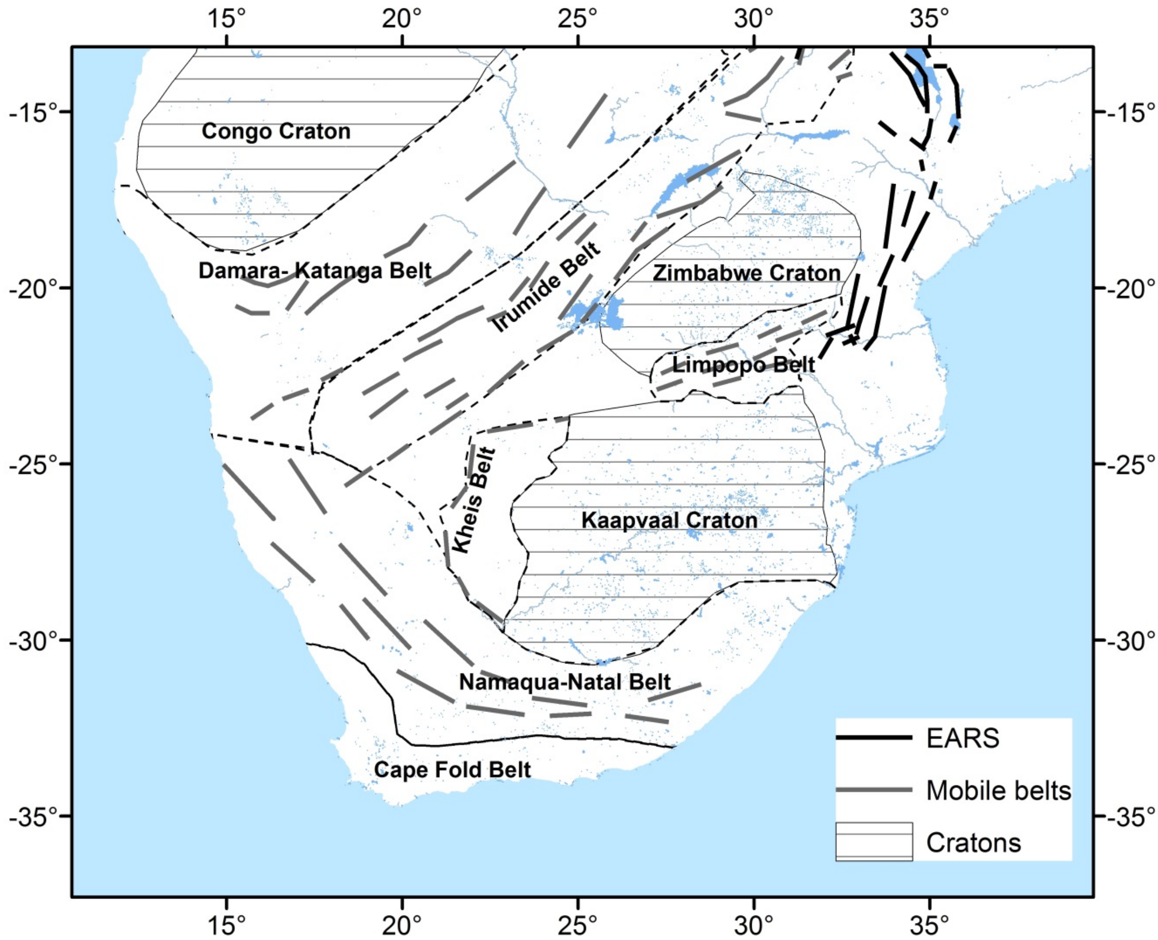


**Figure 1:** Basement geology of southern Africa showing the major structural units of the region. (Prepared using information from James et al., 2001; Nguuri et al., 2001; James and Fouch, 2002; James et al., 2003; Gore et al., 2009; Vinnik et al., 2009; Adams and Nyblade, 2011; Cornell et al., 2011). Dotted lines represent uncertain positions of unit boundaries.

## Seismicity of South Africa

The seismicity of South Africa has been documented by several authors (Gane, 1939: Gane and Oliver, 1953; Fernandez and Guzman, 1979; Singh et al., 2009; Brandt et al., 2005). It can be traced back as far as 1620 with instrumental monitoring dating back to 1899 (Brandt et al., 2005). In their study, Brandt et al. (2005) clearly observed that the seismicity is dominated by events in the gold and platinum mining regions (Figure 2). A significant amount is also related to blasting activities in quarries and coal mining regions (Saunders et al., 2010). However, Singh et al. (2009) identified the existence of several clusters of tectonic events, the majority of which are shown in Figure 2. A low level of seismic activity characterises the region with a pattern typical of intra-plate regions. The north-eastern part of the region just outside South Africa has a higher occurrence of seismicity, which may be attributed to the southern extension of the EARS. According to Saunders et al. (2010), correlating seismicity to geological structures should be done with care since uncertainties in earthquake location in South Africa are large. However, as shown by Singh et al. (2009), it is possible to clearly identify clusters of events with various tectonic and mining regions. Some of the main clusters are (Figure 2):

*Witwatersrand Basin Cluster* –Located within the Witwatersrand basin are some of the deepest gold mines in the world, where induced and triggered events occur on a daily basis at a rate much higher than observed in the tectonic regions of South Africa. Clusters are identified within the Basin in the Welkom, Klerksdorp, Carletonville, West Rand, Central Rand and East Rand gold fields (Figure 2). The largest event in this region occurred on 5 August 2014 with a magnitude of ML = 5.5 (Midzi et al., 2015a). The event resulted in the death of one person and extensive damage to houses on the surface in the area.

*Ceres Cluster* –A prominent cluster of events has been recorded and located in the Ceres / Tulbagh region about 100km northeast of Cape Town (Figure 2). Within this cluster is the largest recorded and most damaging earthquake in South Africa, the 29 September 1969 ML=6.3 event (Green and Bloch, 1971). Though clearly active, unambiguous association of earthquake epicentres in this region with the many faults in the region has proved to be a challenge. One of the reasons is that no recent surface displacement has been observed along any of the faults. However, the earthquakes are observed to be located at the western termination of the Kango – Bavianskloof - Worcester fault system where it converges against NW – SE trending faults (Figure 3). In their study, Smit et al. (2015) obtained a good agreement between, the strike of the surface trace of the 1969 aftershock plane and the strike on the surface on the microseismic events they analysed. The microsesmic events showed a sub vertical fault zone to a depth of 15 km.

*Cape Town Cluster* —A cluster of historical earthquakes is located at Cape Town. The events were compiled using information obtained mainly from diaries, journals, and newspapers written from 1620 to 1902. However, no earthquakes have been recorded in the area since instrumental recording began in 1899. It could be that the earthquakes were only located in Cape Town because that is where they were felt. However, the area is considered at risk due to the existence of the Milnerton fault that runs approximately eight kilometres offshore of Milnerton, and then cuts almost directly through the Cape Flats. Two large earthquakes that are said to have occurred in this cluster are located very close to the city along the fault.

Evidence of earthquake related rupture was reported during the 1809 earthquake around the Cape Town area when an earthquake of magnitude ML = 6.3 was said to have occurred on this fault, just 10 km from the present Cape Town central business district (Von Buchenroder, 1830).

*Koffiefontein Cluster* – Seismicity within the Koffiefontein region is located within a region of radius of about 50km. It is one of the most active tectonic regions with a relatively large number of moderate to large earthquakes (Strasser et al., 2015). The largest of the events include the Mw 6.2 event of 20 February 1912 and an Mw 5.8 event of 1 July 1976. The cluster of events is coincident with an observed gravity high anomaly, which forms a ring with a diameter of about 100km (Brandt, 2008).

Several other smaller clusters are scattered around the country including the Lesotho / Cedarville fault cluster (Figure 2), which is made up of epicentres in the southeastern part of Lesotho and in the districts of Matatiele and Cedarville. The Grootvloer cluster of events in the northwestern part of Namaqualand comprises of epicentres that nearly complete a full circular arc and appear to have a relationship with a number of geophysical, geological and geomorphological features (Brandt, 2008). The Augrabies cluster (Figure 2) is a location of a swarm of events that occurred in the area around 2010. In 2006, an earthquake of magnitude Mw7.0 ruptured along the Machaze fault in Mozambique. Fenton and Bommer (2006) surveyed three segments of the fault rupture with a combined length of some 15 km (the total rupture length is expected to be in the order of 30-40 km). They observed an average vertical displacement of 1.0-1.5 m, and observed in one segment left-lateral offsets of 0.7 m. They also observed spectacular liquefaction features, such as sand blows with diameters of 5-8 m, and a 318-m-long fissure. Fenton and Bommer (2006) were unable to decide if the earthquake source was on an ‘old, slow fault’, similar to those usually found in intraplate regions, or a new structure related to the southward propagation of the East African Rift. Satellite radar interferometry allowed both the co-seismic and post-seismic displacement along the entire surface rupture to be measured (Raucoules et al., 2010).

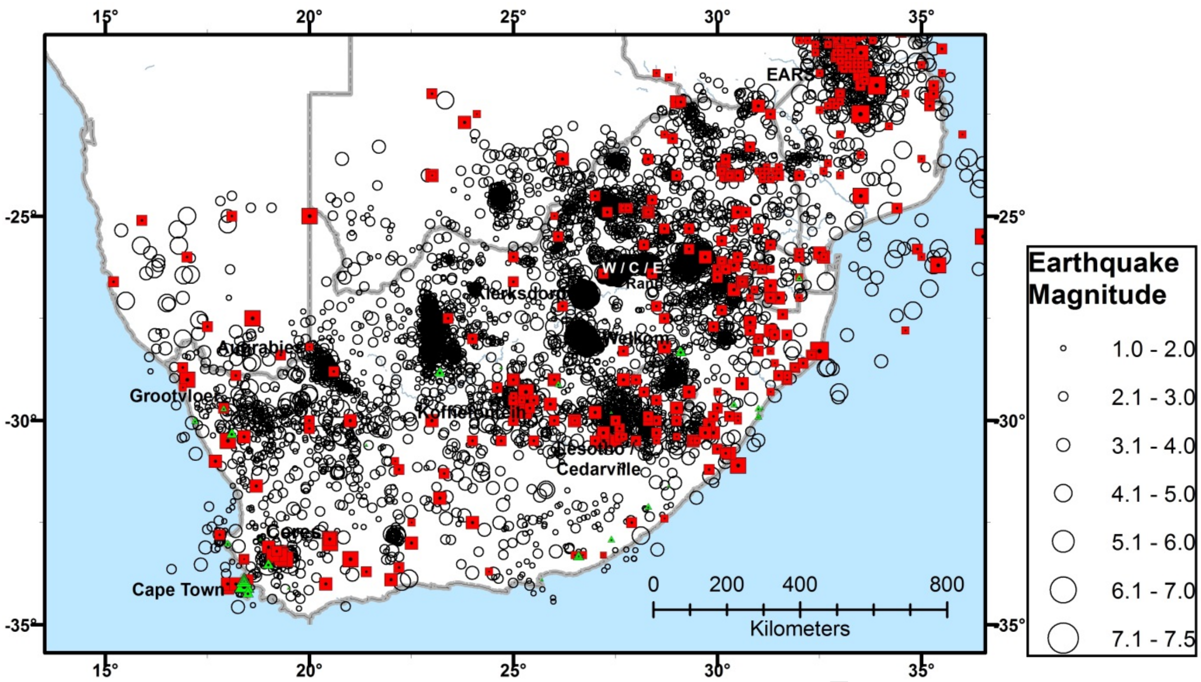


Figure 2. Seismicity of South Africa. Green filled triangles with a black dot in the middle represent historical events (Pre-1900), whilst red filled squares with a dot in the middle stand for early instrumental events (1900 – 1970) and open black circles are modern instrumental events (Post 1970). W – West Rand, C – Central Rand and E – East Rand. The earthquake magnitude scale in the legend equally represents the sizes of all symbols in the three time periods.

**Major Faults**

The digitisation of already mapped major faulting and folding is an important step in the effort to understand the seismotectonics of any region. Using data and information obtained from books (e.g. SA Geology by Johnson et al., 2006), maps (e.g. tectonic map of Africa, by Milesi et al., 2010; Simplified Geology of South Africa by Johnson and Wolmarans, 2008), articles (e.g. Brandt et al., 2005; Singh et al., 2011; Goedhart, 2016; Meghraoui et al., 2016), a map of potentially active Quaternary faults was prepared (Figure 3).  In regions where no specific mapping or studies on late Quaternary and/or active faults are present, the background mapping of the recently published Tectonic Map of Africa (Milesi et al., 2010) was used. Google Earth, ArcGIS and the SRTM DEM were used as a basis for digitizing and geo-referencing the mapped faults. Most major faults in South Africa appear to be located either within or at the boundaries of Mobile belts with cratons (Figure 3). Fault orientations vary from region to region with the central part of South Africa characterised by E - W oriented faults, N-S and

NE-SW trending faults in the eastern and northeastern part South Africa, whilst the western and southwestern part of the country is populated also by N-S and NW-SE oriented faults.

One of the major Quaternary faults that have been studied in South Africa is the Kango fault (Hill, 1988; Partridge, 1995; Goedhart, 2006). It is part of the east-west-striking extensional Ceres-Kango-Baviaanskloof-Coega (CKBC) fault system that extends from near Cape Town to Port Elizabeth (Figure 2). Paleoseismic investigations by Goedhart (2006, 2016) provided information regarding the size, timing, and extent of the most recent surface-faulting event on the Kango fault. Evidence of repeated normal-slip surface-faulting events during the Quaternary was found, clearly demonstrating late Pleistocene and Holocene activity (Goedhart, 2006, 2007, 2016; McCalpin, 2009). In their site specific seismic hazard study of a proposed nuclear power station site at Thyspunt, South Africa, Bommer et al. (2015) concluded that available evidence confirms Quaternary reactivation of the Kango fault but none for the other faults (e.g. Bavianskloof fault) that make up the CKBC fault system. However, characterisation used for the Kango fault was used in their study to infer characteristics ($M_{char}$ and recurrence) of the other faults in the fault systems, which were then used in the seismic hazard assessment.

Available geological and paleoseismic evidence (White et al., 2009) shows activity in Quaternary times along the Dreylingen and Hebron faults in Namibia (Figure 3). A clear fresh-looking fault scarp is observed along the faults with Quaternary sediments displaced up to 65 m. The Hebron fault is characterized by a 4 to 9.6 m high fault scarp that can be traced for at least 40 km along the eastern Namib Desert in a roughly NW-SE direction. However, the Dreylingen fault is not as pronounced on the ground as the Hebron fault. On examining the morphology of the Hebron fault scarps, White et al. (2009) identified three types of scarp profiles corresponding to different levels of scarp maturity. The youngest scarps were 4 to 6 m in height. They also argue that Proterozoic basement and middle to late Pliocene crystalline conglomerates are displaced as well as Aeolian dunes post-dating the Middle Stone Age, suggesting that fault displacements occurred during the late Pleistocene to recent, whilst the Dreylingen fault shows neotectonic activity since the early mid-Pleistocene. The main section of the Dreylingen fault strikes 320-325 degrees with a total length of 100 km and displaces the sedimentary rocks of the middle and upper Nama Group (Schwarzrand and Fish River Subgroups) laterally by several kilometres. According to Viola et al. (2005), both the Hebron and Dreylingen faults are transtensional faults.

Nixon et al. (1983) were the first researchers to recognise the Cedarville fault, which is located in the eastern part of the Namaqua-Natal belt, south of Lesotho (Figure 3). However, there was no neotectonic analysis carried out in the area. The cluster of seismicity in the area shows that the Cedarville fault is active and may signal the development of the southward and westward propagation of the rift fractures from the EARS into South Africa (Brandt, 2008). Development of zone rifting may be represented by the Cedarville fault axis, which has thermal springs in Kwazulu-Natal and Mpumalanga occurring along it (Singh et al., 2011).

Major subsidence within the Bushveld Basin during the Pliocene, is said to have caused the development or reactivation of major marginal faults (e.g. the Thabazimbi and Zebediela faults) with downthrows to the south. The latter fault is associated with a number of thermal springs (Singh et al., 2009). Of interest is the fact that almost the entire depressed area of the Bushveld Basin is associated with a fairly high level of recorded seismicity, which cannot be explained as resulting from the sporadic mining activity in the area. There seems to be a prima facie case, therefore, for continuing movements within the area of basining. The area is mainly located on the Archean Kaapvaal Craton and most of the natural seismicity appears along a lineament defined by the Murchison Greenstone Belt, the Zebediela fault and the Thabazimbi fault. Partridge (1995) indicated these faults as “potentially capable”.

Major faults in the Central Zone of the Limpopo Mobile belt include the Tshipise and Bosbokpoort faults. These faults, downthrow to the south and cross sediments of the Upper Cretaceous Malvernia Formation, which are, in turn, overlain by now-vegetated red aeolian sands blown from the nearby Limpopo during arid phases, the youngest of which terminated some 16 000 years ago. Both the Malvernia rocks and the aeolian sands are displaced along fault scarps ranging from 2 m to 10 m in height (Brandl, 1995). Reactivation of these faults therefore took place during the latest Pleistocene or Holocene. No neotectonic analysis has been undertaken, but considerable recent seismic activity has been located in the area. The association of the fault with recorded hot springs in the area also provides evidence of current activity along the fault (Singh et al., 2011). Further to the west is the ENE–WSW trending Zoetfontein fault, which is a high-angle fault zone that marks the northern edge of the Kaapvaal Craton. It has a history of repeated reactivation since the late Archean and continuing to the present and controlled deposition of both the Mesoproterozoic Waterberg and Carboniferous–Jurassic Karoo sediments and basalts (Hutchins and Reeves, 1980; Smith, 1984). A seismic survey interpretation of the Karoo Supergroup, reflects reactivation of the Zoetfontein fault during Karoo sedimentation and its development as a growth fault (Modie, 2007). Smith (1984) also reported on the existence of the down-throw of Karoo rocks on the northern side of the Zoetfontein fault of up to 300 m along with several hundred metres throw on other post-Karoo NNW-SSE oriented faults intersecting the Zoetfontein fault. A major earthquake (Mw 6.5) that occurred on 3 April 2017 in Central Botswana (Midzi et al., 2018), appears to indicate the existence and capability of the NNW-SSE orientated faults.

In Gauteng, the Rietfontein fault system runs in an east – west direction across Johannesburg. Stewart et al. (2004) recognised normal faulting associated with uplift of the hinterland. Through Central Rand Group times, the Rietfontein and West Rand faults controlled sediment distribution in the west, central and east rand areas (Myers et al. 1990). During this period the Witwatersrand Basin was under northeast/southwest compression (Myers et al.. 1990). According to Charlesworth and McCarthy (1990) the Rietfontein fault also underwent oblique reverse movement, associated with left-lateral strike-slip faulting resulting in northwest/southeast oriented fold axes. However, there is no direct evidence linking the fault to any recent major faulting though it is said to probably be the centre of low-level seismic events (Singh et al. 2009).

Major mapped faults in the KwaZulu-Natal Province are mostly oriented parallel to the coast in a NE-SW direction with some perpendicular to the coast in a NW-SE direction. According to Singh et al. (2013), seismicity in the region appears to correlate well with the faults, despite the significant errors in earthquake locations. A prominent E-W fault line (Tugela fault) is also observed (Figure 3) and coincides with a boundary described in interpreted aero-magnetic data of the region. The boundary is assumed to separate the Namaqua-Natal Mobile belt from the Kaapvaal Craton (Singh et al., 2013). Studies by Hughes (2008) and King and Maud (1964) showed displacements of a few centimetres to tens of metres along faults in the Durban area, which indicated predominant normal faulting. A detailed description of the tectonics of the KwaZulu-Natal was given by Singh (2016).

From the information summarised above as well as the seismicity of the region (Figure 2), it was possible to identify and characterise some of the major identified faults as active (Figure 3).

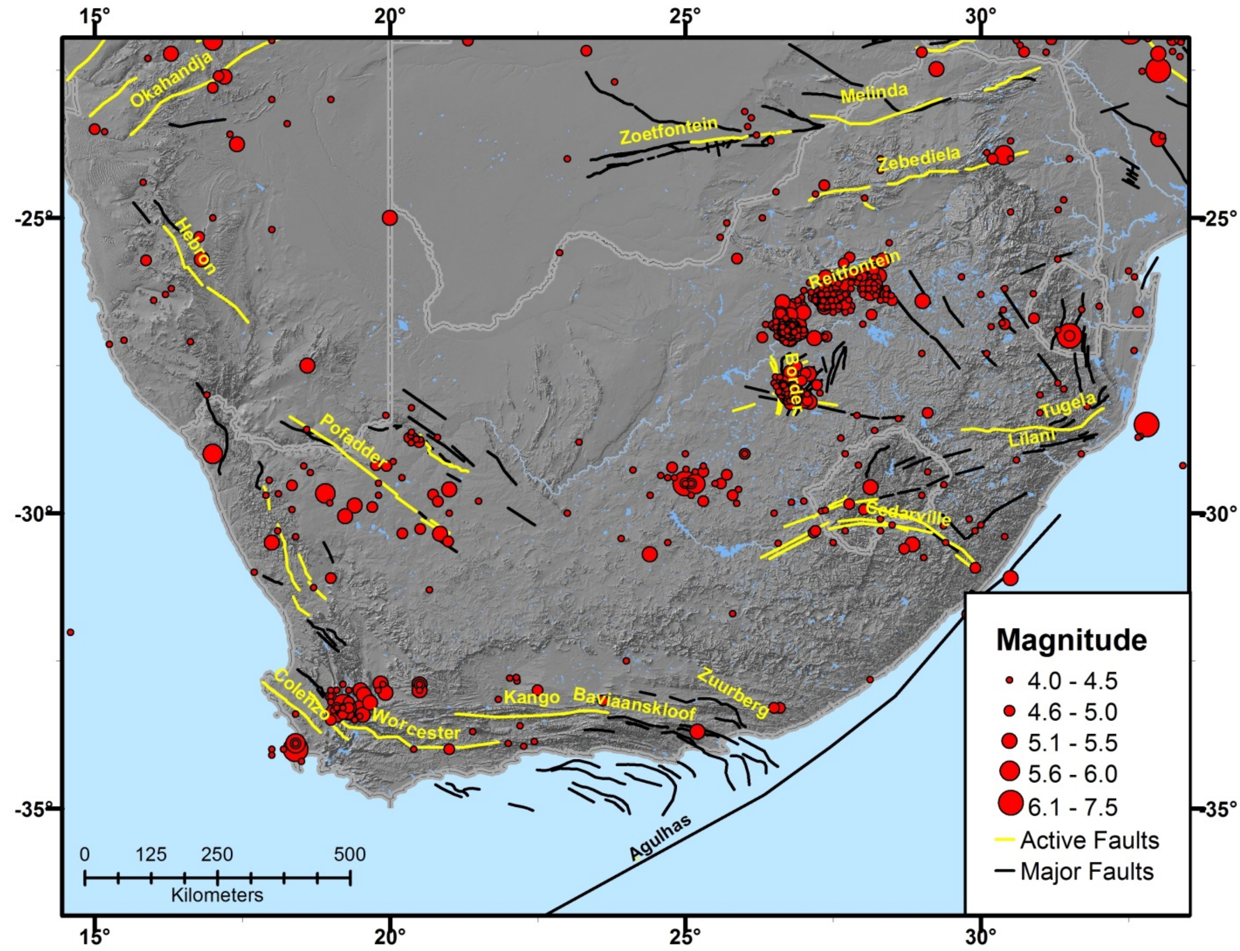


Figure 3: Major faults within South Africa with active faults marked in yellow. Also included are earthquakes of magnitude greater than or equal to 4.

**Focal Mechanism Solutions and Regional Stress Field**

The few previously determined focal mechanisms that are available in literature (e.g. Brandt and Saunders, 2011) as well as some determined in this study (Figure 4), together with other stress data as that recently published by Meghraoui et al. (2016) (Figure 5), provide information on the state of stress and faulting in the country. The faulting regime changes from normal faulting in the northeast of the country, possibly related to the influence of the nearby EARS, to strike-slip along the western and south-western part of the country (Brandt and Saunders, 2011). The change to strike-slip faulting can be explained through the dominating stresses becoming horizontal through ridge push from the Mid-Atlantic Ridge against the African plate (Singh et al., 2009).

Tremors resulting from deep mine operations in the South African gold fields form the bulk of the seismic events recorded by the SANSN (Saunders et al., 2008). The largest principal stresses in Savuka mine, Far West Rand gold-mining area, are compressive oriented near vertically, and are relaxed through a mix of volume closure and normal faulting for earthquakes with $0.5 < Mw < 2.6$ (Julià et al., 2009). Evidence indicates that mining-induced seismicity is characterised by normal faulting due to stope closure (Dennison and Van Aswegen, 1993; Wong, 1993). However, solution 24 (Figure 4), obtained from the 2014 ML5.5 Orkney earthquake (Midzi et al., 2015a) shows strike-slip faulting in a mining region. The event occurred at a depth of 4.7km, which is deeper than is normally observed in the region implying that it might not be directly linked to mining activities in the region (Manzunzu et al., 2017).

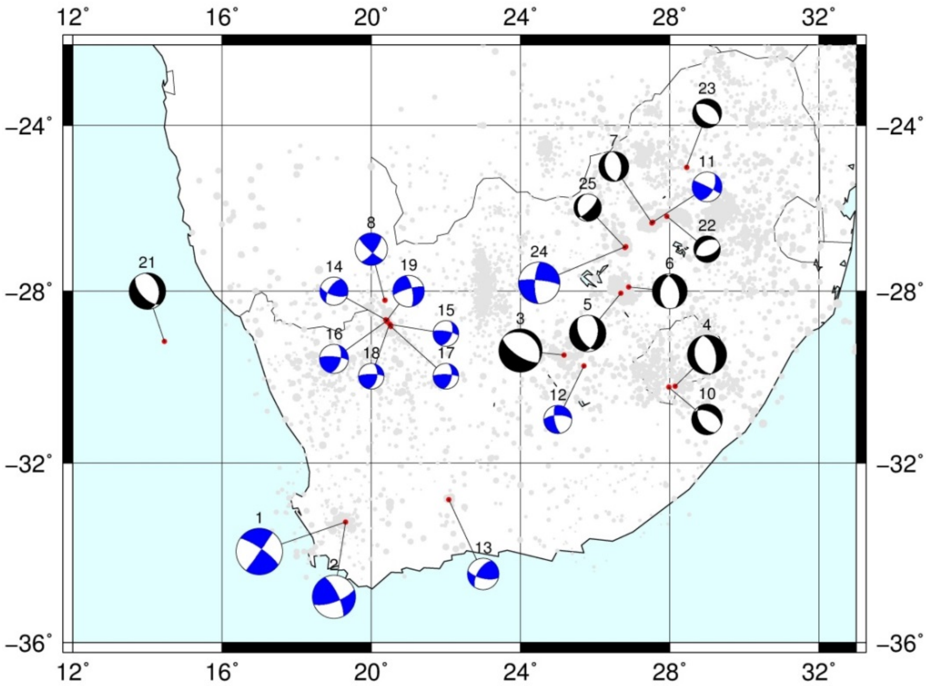


**Figure 4:** Fault Plane solutions obtained for the South Africa region with "beach ball" sizes proportional to magnitude. Black and white beach balls represent normal faulting, blue and white strike-slip faulting. Grey dots represent background seismicity. A table of the solutions is included as Table 1 with numbering of events as shown in the figure.

The seismicity in southern Africa is driven by regional stresses originating from large-scale features that include intra-continental rifts, large-scale topographic elevations, and the network of surrounding mid-oceanic ridges. More specifically, the stress pattern in southern Africa appears to be dominated by two main fields: (1) a predominant NNE to ENE oriented trend corresponding to the EARS; (2) a NW/NNW trend that affects a very broad region, which includes the central and north-eastern portion of South Africa (Figure 5). Whereas the NNE – orientation trend roughly parallels the direction of the plate's motion, the NW-trending stress field is less easily explained and was referred to as the Wegener Stress Anomaly (Andreoli et al., 1996; Viola et al., 2005).

The determination of strain distribution using the present-day GNSS velocity field of Africa under Trignet, provides little information to characterize the seismotectonics of South Africa (Meghraoui et al., 2016). The first findings were published by Malservisi et al., (2013), using the stations with at least a thousand days of recording by June 2011. The results show that the South African region behaves rigidly, with deformation in the order of one nanostrain/year or less. On comparing the Trignet data to that obtained from the Nubian plate it was found that the South African block is rotating in a clockwise direction with respect to the African continent, which is consistent with the propagation of the EARS along the Okavango region. Analysis of GPS data shows that the South African plate is slowly deforming and the vector directions confirms the effects of the spreading EARS and the occurrence of seismicity in the mines (Malservisi et al., 2013).

Table 1. South African fault plane solutions as shown in Figure 4. Magnitude of events quoted as moment magnitude (MW) unless stated otherwise, ML – Local magnitude and Ms- Surface wave magnitude. ISC MT – International Seismology Centre Moment tensor, GCMT – Global Centroid Moment Tensor catalogue.

| Index | Year | Month | Day | Latitude | Longitude | Dep | Mag | Strike | Dip | Rake | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1969 | 09 | 29 | -33.342 | 19.311 | 15 | 6.2 | 305 | 78 | -1.2 | Krüger et al. (2011), Foster & Jackson (1998), Shudofsky (1985) |
| 2 | 1970 | 04 | 14 | -33.342 | 19.311 | 10 | 5.8 | 334 | 74 | 160 | Green & Bloch (1971), inversion & modeling |
| 3 | 1976 | 07 | 01 | -29.508 | 25.166 | 5.5 | 5.8 | 308 | 22 | -86 | Jensen (1991), Shudofsky (1985) |
| 4 | 1986 | 10 | 05 | -30.240 | 28.140 | 15 | 5.3 | 168<br>348 | 37<br>53 | -90<br>-90 | Dziewonski et al., (1987) |
| 5 | 1990 | 09 | 26 | -28.050 | 26.690 | 28.3 | 5.0 | 11<br>153 | 45<br>52 | -61<br>-115 | Dziewonski et al., (1991) |
| 6 | 1994 | 10 | 30 | -27.900 | 26.900 | 2.3 | 4.7Ms | 190 | 45 | -70 | Bowers (1997), Fan & Wallace (1995) |
| 7 | 1997 | 09 | 25 | -26.370 | 27.520 | 2 | 4.1 | 354<br>167 | 49<br>41 | -86<br>-95 | Brandt & Saunders (2011) |
| 8 | 1998 | 04 | 24 | -28.214 | 20.367 | 6.8 | 4.3ML | 138<br>132 | 90<br>80 | 38<br>18 | Unpublished |

| Index | Year | Month | Day | Latitude | Longitude | Dep | Mag | Strike | Dip | Rake | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 1998 | 09 | 06 | -30.255 | 27.976 | 5 | 4.1 | 148 | 48 | -67 | Unpublished |
| 11 | 1998 | 12 | 05 | -26.348 | 27.540 | 1 | 4.1 | 296<br>28 | 88<br>54 | 144<br>3 | Brandt & Saunders (2011) |
| 12 | 1999 | 02 | 04 | -29.760 | 25.700 | 11 | 3.8 | 170<br>269 | 70<br>66 | -25<br>-165 | Brandt & Saunders (2011) |
| 13 | 2007 | 03 | 11 | -32.834 | 22.081 | | 4.3 | 103<br>212 | 68<br>61 | 151<br>28 | Unpublished |
| 14 | 2010 | 11 | 21 | -28.684 | 20.393 | | 3.8 | 21<br>212 | 52<br>61 | 18<br>28 | Unpublished |
| 15 | 2010 | 12 | 25 | -28.795 | 20.507 | | 3.4 | 16<br>21 | 53<br>52 | 17<br>18 | Unpublished |
| 16 | 2010 | 12 | 25 | -28.718 | 20.414 | 1 | 3.9 | 10<br>16 | 53<br>53 | 14<br>17 | Unpublished |
| 17 | 2010 | 12 | 28 | -28.833 | 20.519 | | 3.4 | 10<br>26 | 53<br>56 | 14<br>23 | Unpublished |
| 18 | 2011 | 01 | 04 | -28.781 | 20.491 | | 3.4 | 22<br>10 | 58<br>52 | 20<br>16 | Unpublished |
| 19 | 2011 | 12 | 18 | -28.687 | 20.423 | 10 | 4.3 | 254<br>349 | 78<br>70 | -21<br>167 | ISC MT solution |
| 20 | 2011 | 10 | 09 | -26.890 | 38.880 | 30.8 | 4.9 | 219<br>44 | 50<br>40 | -93<br>-86 | GCMT |
| 21 | 2012 | 03 | 24 | -29.190 | 14.460 | 17.2 | 4.9 | 138<br>351 | 58<br>37 | -109<br>-62 | GCMT |
| 22 | 2013 | 11 | 18 | -26.212 | 27.920 | | 3.6ML | 72 | 51 | -77 | Midzi et al. (2015b) |
| 23 | 2013 | 12 | 02 | -25.020 | 28.456 | | 3.9ML | 135 | 45 | -82 | Midzi et al. (2015b) |
| 24 | 2014 | 08 | 05 | -26.942 | 26.818 | 4.7 | 5.5ML | 182.6 | 72.77 | -10 | Midzi et al. (2015a), Manzunzu et al. (2017) |
| 25 | 2014 | 08 | 27 | -26.965 | 26.801 | 2.0 | 3.7ML | 44.15 | 71.25 | -68 | Unpublished |

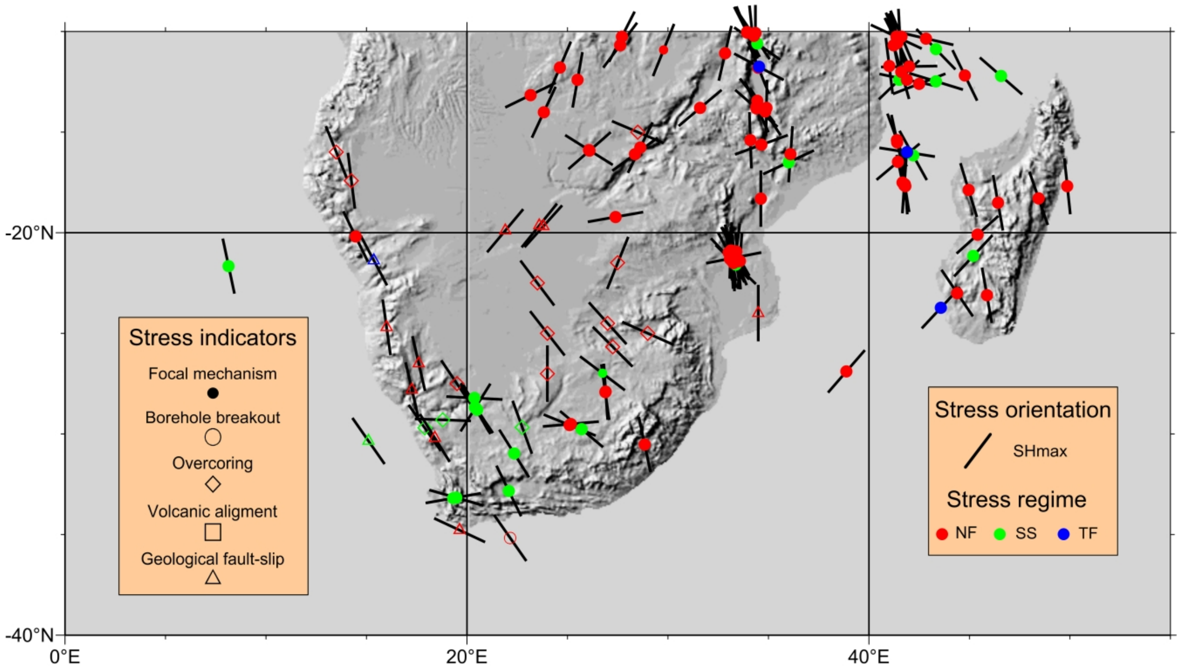


**Figure 5.** Stress orientation data for Southern Africa. Extracted from the seismotectonic map of Africa (Meghraoui et al., 2016).

## Discussion and conclusion

The seismological, geological as well as tectonic data compiled were synthesized to identify potential seismic sources within South Africa. A seismotectonic map (Figure 6) was derived through the analysis of structural, neotectonic and seismological data to establish links between seismicity and current deformation mechanisms with the ultimate goal to individualize and delimit the different seismotectonic units. A major task of this project was to associate the seismicity to some geological phenomena. Though this was possible in general, the scatter in seismicity associated with poor locations especially of small events, makes this a difficult task. Many of the events were observed to occur within the Mobile belts as well as in the mining regions of South Africa. Several seismic clusters were observed which were identified as possible seismic hot spots.

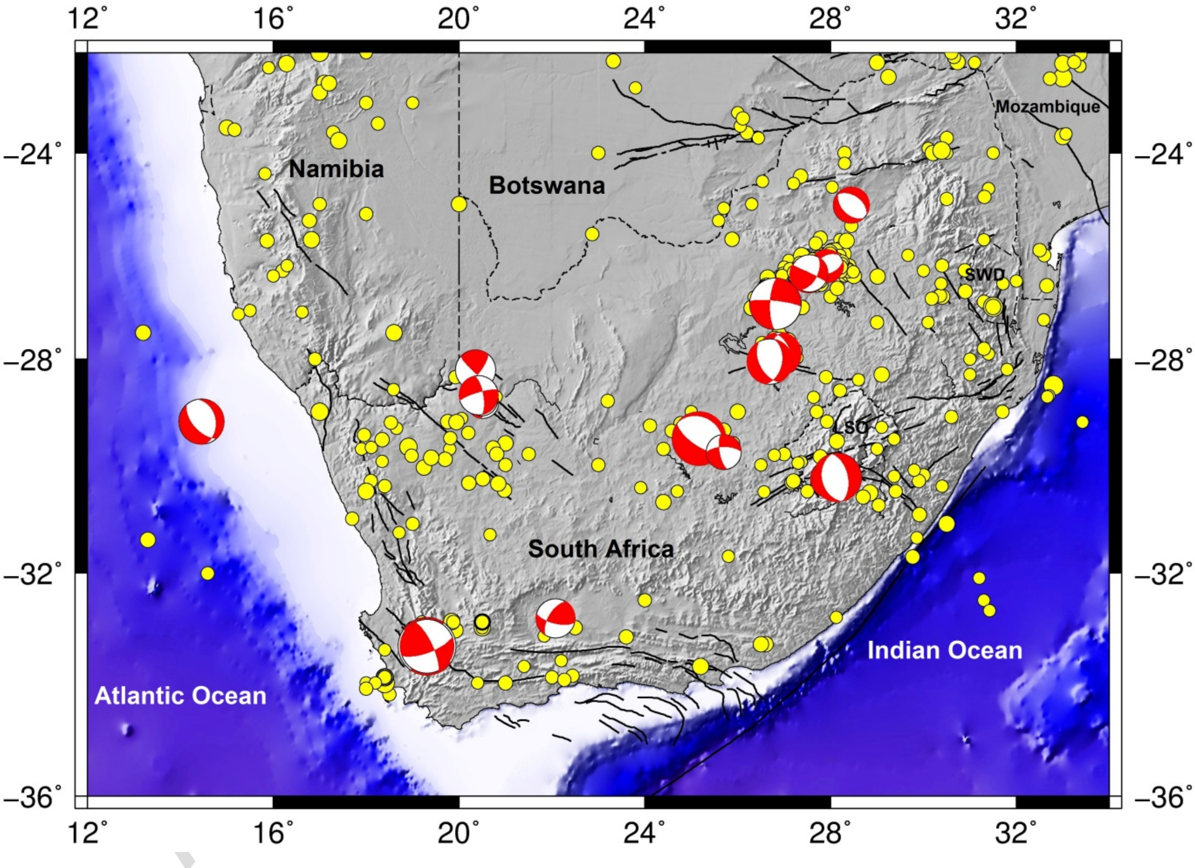


**Figure 6:** Synthesized data of the Seismotectonic model for South Africa. Extracted from the seismotectonic map of Africa (Meghraoui et al., 2016).

Focal mechanism solutions were used in studying and understanding the stress field in the South African sub-continent as well as in confirming the orientation of identified major faults. The derived composite focal mechanisms and fault orientations with mainly normal faulting indicate a remarkably consistent regional stress pattern with maximum extension in the NE-SW and NW–SE directions. A major problem with SCR regions is to associate seismicity with active faults as the fault movement and deformation rates are very slow. Paleoseismic studies are needed to understand the recurrence rates for some of the faults assumed to be active.

New studies as well as revisions to present data are needed to determine heat flow conditions beneath southern Africa, and to examine earthquake swarm processes and their potential for reactivating inactive large faults, particularly in the Mobile belts and the EARS branches. To complete such studies, the dimensions of major faults, i.e., those capable of producing damaging earthquakes, should be re-established from existing records, as well as from new field studies. Some of the faults that need to be reassessed are the Thabazimbi, Zebediela, Zoetfontein, Dreyling, Hebron, Reitfontein and the Cedarville fault to determine if they are still active and assess their activity rate. Spatial clustering tendencies as inferred from Figure 6 for the Koffiefontein, Ceres, and Augrabies, should be examined further to get more insight into the occurrence of the events in these areas.

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# Seismotectonics of South Africa

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**Highlights**

- Analysis of different geoscientific information.
- Map of potentially active faults in South Africa.
- A Seismotectonic map for South Africa.