Dissecting hearts of the continent in southern Africa using first *P*-wave tomography based on local, regional, and mining-induced earthquakes

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Introduction

Seismic tomography is one of the most fascinating subjects of modern seismology. The purpose of the present work is to use *P*-wave tomography to investigate the anatomy of the uppermost subcontinental lithosphere (USCL) beneath the Kalahari (or Kgalagadi) craton covering much of southern Africa (**Figure 1**). The Kgalagadi craton comprises the Archaean Kaapvaal and Zimbabwe cratons and their abutting circum-cratonic mobile belts that constitute the Precambrian hearts of the continent around which southern Africa was formed (**Figure 1**).

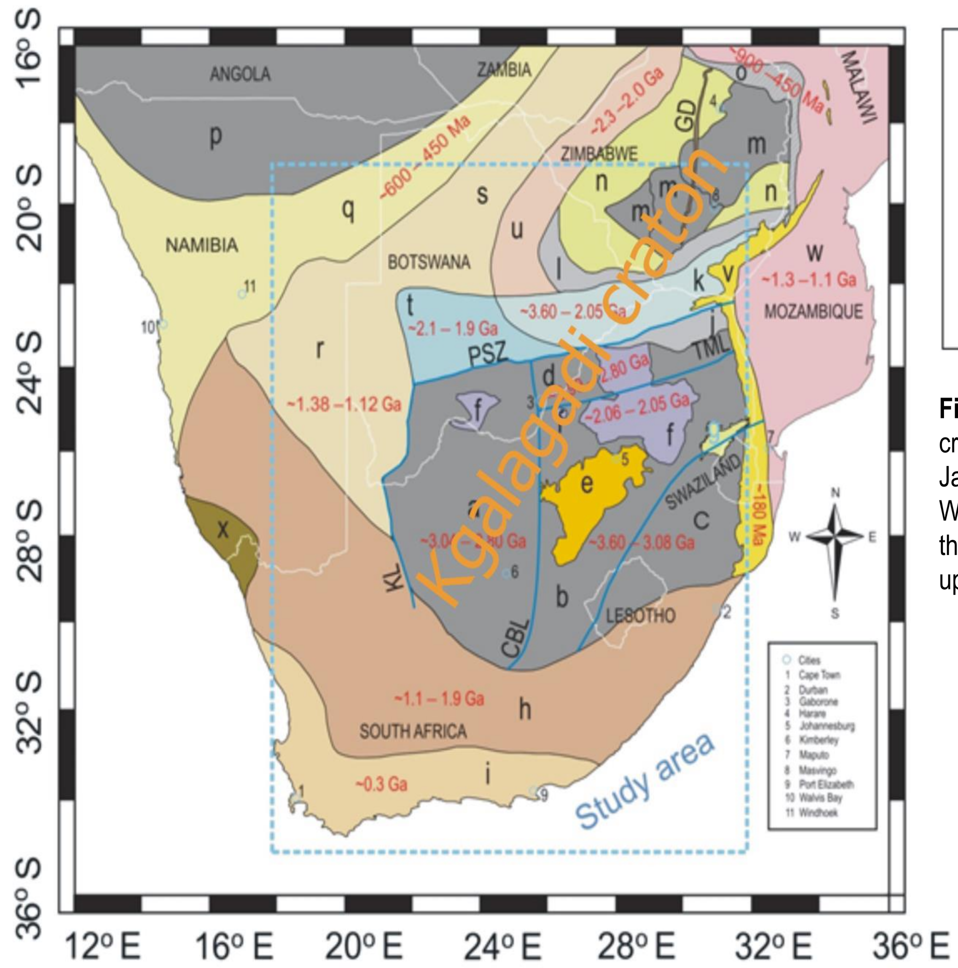
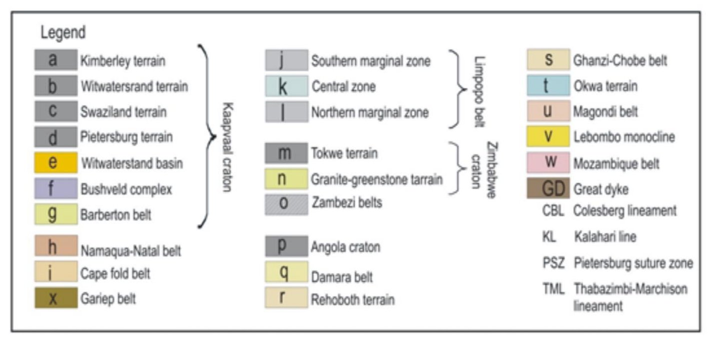

Figure 1: Map showing a generalized distribution of the major crustal blocks in southern Africa (After Durrheim, 1989, 1998a,b; James *et al*., 2001; Nguuri *et al*., 2001; Kwadiba *et al*., 2003; Wright *et al*. 2003). The dashed blue rectangular overlay denotes the target region for a tomographic study of the crust and uppermost mantle undertaken by Kwadiba (2018).

The *P*-wave arrivaltimes are based on high-quality seismograms from local, regional and mining-induced earthquakes recorded during the April 1997–July 1999 southern Africa seismic experiment (SASE), which involved deployment of a network of 54 broadband seismic instruments that were installed at 84 different sites distributed across southern Africa (**Figure 2**). SASE was carried out as the geophysical component of the international and multidisciplinary Kaapvaal Craton Project, which investigated the structure and composition of the Kgalagadi craton for a better understanding of the origin, modification, and preservation of continents on Earth (Carlson et al., 1996, 2000; James *et al*., 2001; Wright et al. 2002, 2003). Events used in the present study are shown in **Figure 3.**

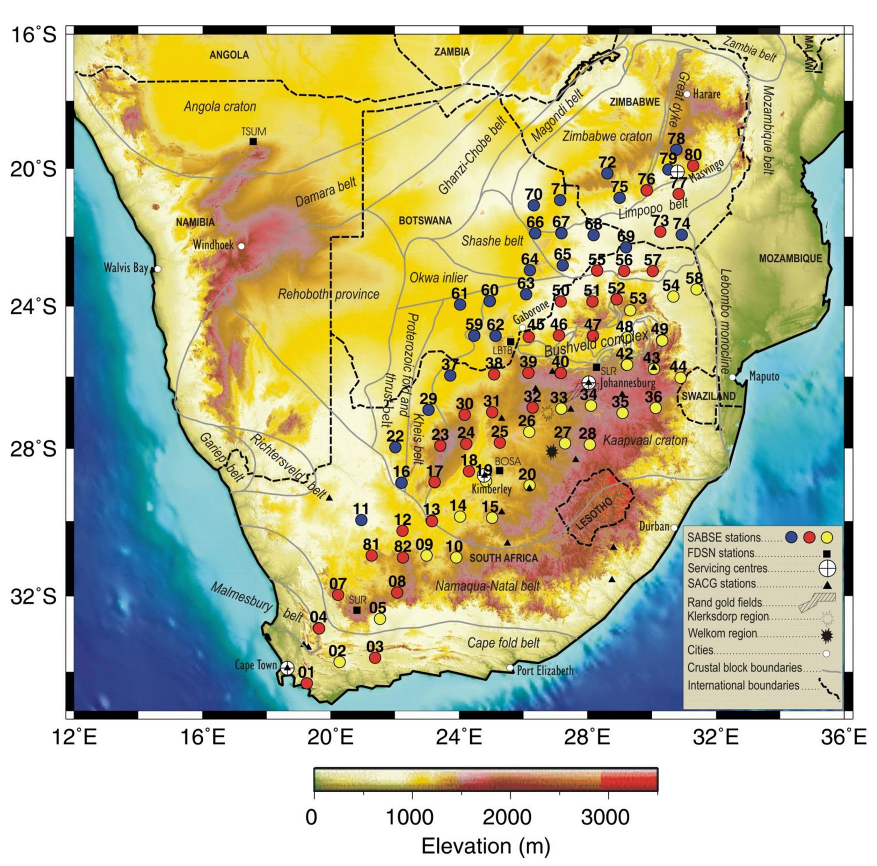

Figure 2: Map of southern Africa showing distribution of stations of the April 1997 - April 1999 Southern Africa Broadband Seismic Experiment (SABSE) superimposed on the major crustal blocks constituting the subcontinent (James et al., 2001; Nguuri et al., 2001; Wright et al., 2003). The blue circles, red circles and yellow circles denote stations deployed during the period April 1997-April 1998, April 1997-April 1999 and April 1998-April 1999, respectively. The black squares symbolize IMS stations located in the study area. Locations of the Klerksdorp and Welkom mining regions are shown as open and closed pentagons, respectively.

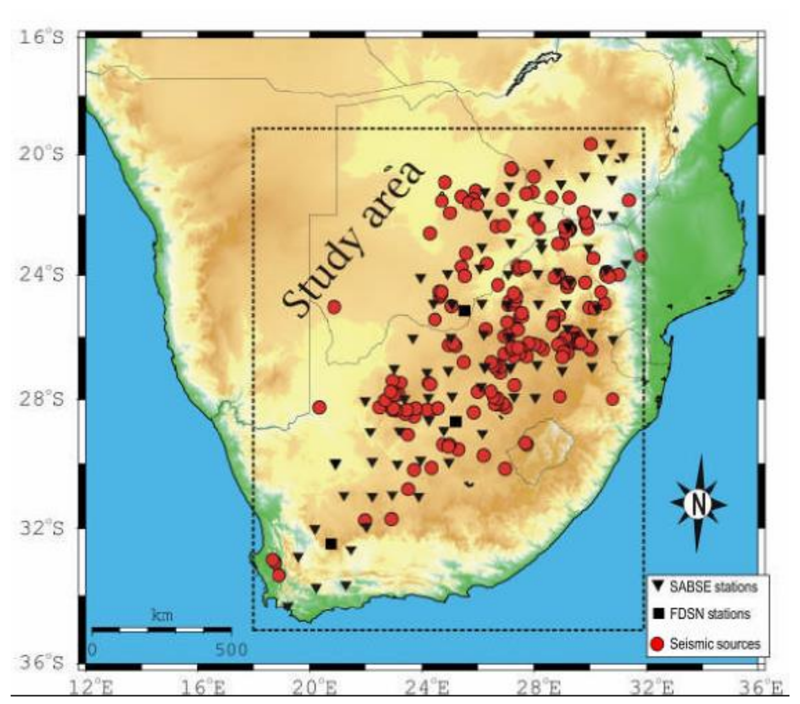

Figure 3: Map showing distribution of epicentres for the 496 events (red circles) used as seismic energy sources in this study. Inverted triangles and squares denote the 82 temporary SASE stations and 3 permanent IMS stations located in the study area, respectively (Figure 2). Dashed rectangle outlines the study area.

Methodology

- ❑ In this study, the three-dimensional (3D) *P*-wave velocity structure beneath the Kgalagadi craton of southern Africa was imaged by the tomographic inversion method and computer code developed by Zhao (1991) and subsequently improved by Zhao *et al.* (1992, 1994).
- ❑ The basic principles of the ZTI method, entailing theoretical formulation and formal expression of the solution, are well established and have been described by many authors including Zhao (1991, 2001a), Zhao *et al.* (1992, 1994), Hirahara (1993), Lei *et al.* (2002), and Zhao and Lei (2004).

Results

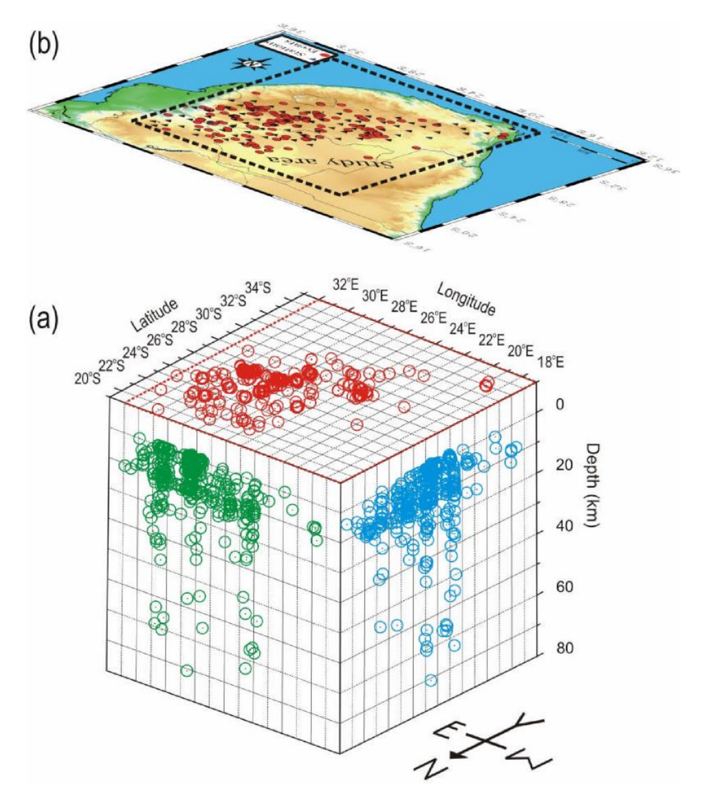

Figure 4: (a) Orthographic projection diagram showing the hypocentral distribution of the 496 events used in this study. The dotted rectangle on the top face outlines the study area as delimited in Figures 1 and 3. (b) A supernatant reference basemap relating the 3-D block diagram to the study area. The overhead askew map is based on the transformation of the map shown in Figure 2b.

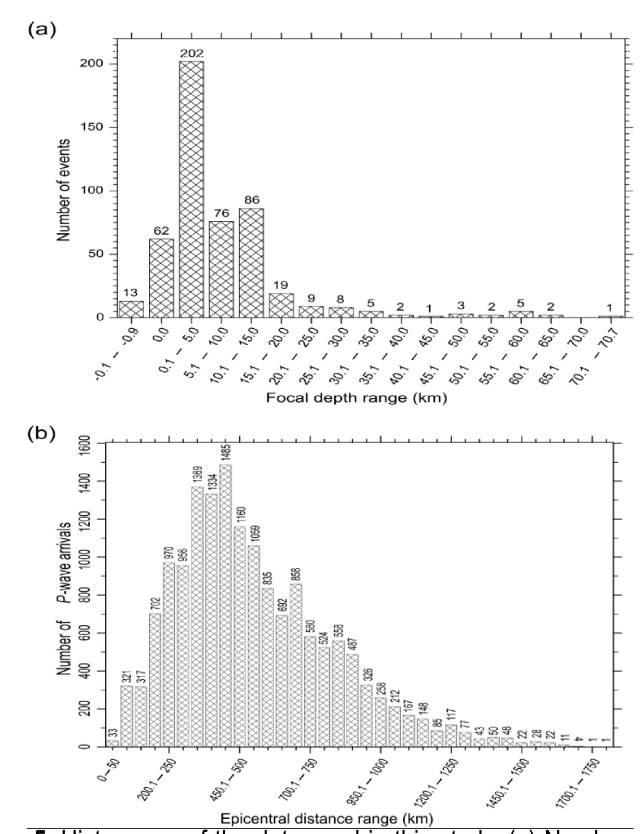

Figure 5: Histograms of the data used in this study. (a) Number of events as a function of focal depth range. Most of the events (89%) occurred at depths shallower than 15 km. (b) Number of P arrivaltimes versus epicentral distance range for the 15860 data points used in this study. Most arrivaltimes (~98%) come from events at epicentral distances smaller than 1250 km, though a few arrivals (~2%) came from distance ranges between 1250 and 1754 km.

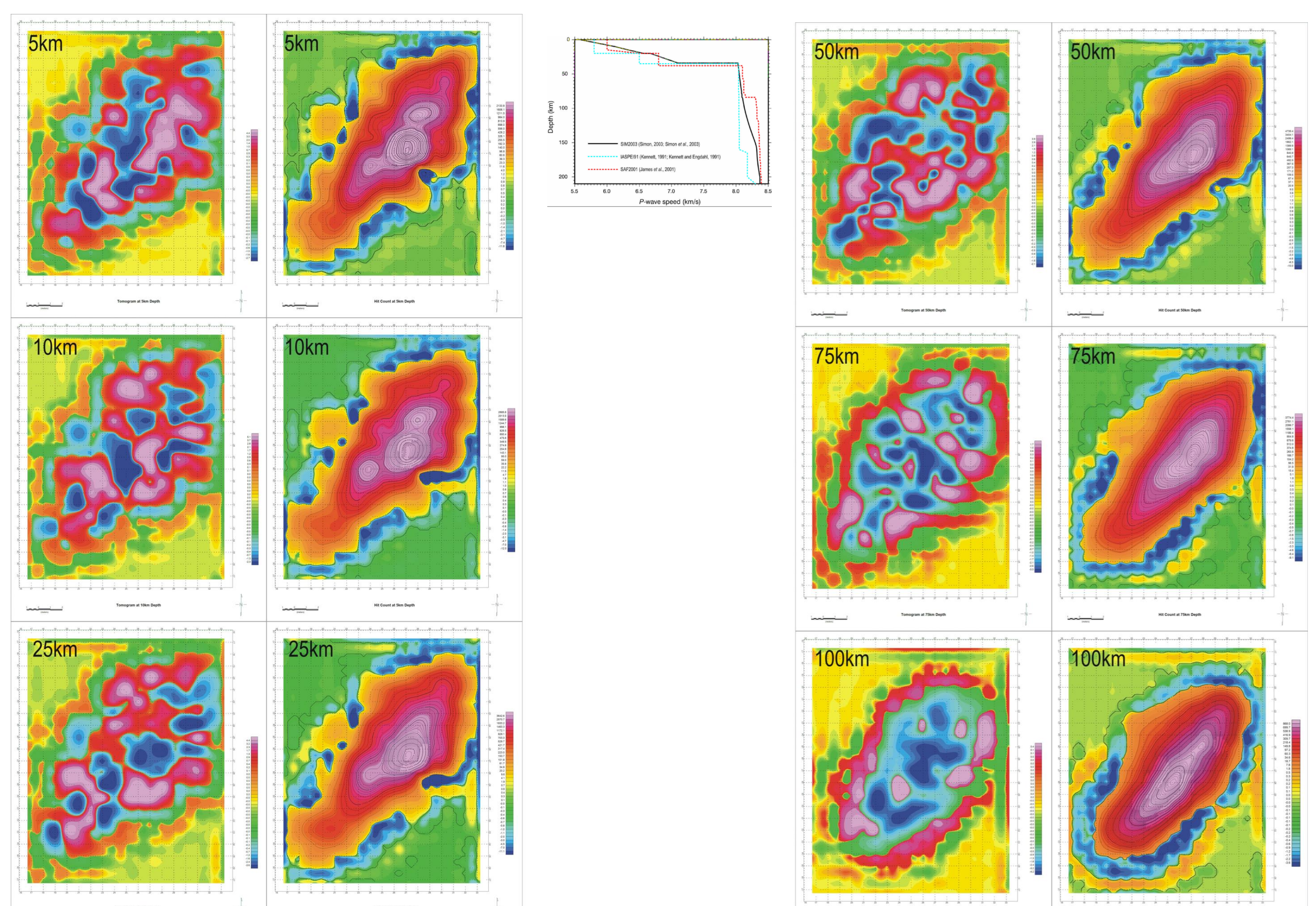

Figure 6: Tomograms of fractional P wavespeed perturbations (in percent) for horizontal slices through the 3D model of P-wave velocity cut at 5, 10, 25, 50, 75 and 100 km depths. The corresponding images on the right display hit count maps reflecting ray density through the model space. The starting 1-D model used for various tomographic inversions performed in this study is shown at the top center. The depth of each layer is shown in the upper left corner of the images. Fractional P wavespeed perturbations range between -5 and 5% relative to the seed model. Red, blue and green colors correspond to low (slow), high (fast) and normal wavespeeds, respectively. The wavespeed perturbation scales in percent are shown on the right sides of the corresponding images.

Conclusions

- ❑ The tomographic inversion method and computer code of Zhao (1991) and Zhao *et al.* (1992, 1994) have been used successfully to map the 3D *P*-wave velocity structure of the USCL of the Precambrian Kgalagadi craton and its adjoining circum-cratonic mobile belts down to a depth of about 100 km beneath southern Africa
- ❑ The tomograms obtained in the present work indicate that the *P*-wave velocity structure of the crust and uppermost mantle of the Kgalagadi craton is heterogeneous
- ❑ The delineated wavespeed variations reflect a superposition of various effects, including changes in composition, thermal structure and other perturbations imprinted during the complex modification history of southern Africa

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