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Reconnaissance paleomagnetic studies of Mesoproterozoic alkaline igneous complexes in the Kaapvaal craton, South Africa

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ABSTRACT

We report paleomagnetic data from three different parts of a diffuse Mesoproterozoic alkaline igneous province in the eastern part of the Kaapvaal craton in South Africa. Except for the ~1.3 Ga Pilanesberg dikes, these rocks have not previously been studied paleomagnetically. Isotopic dates from igneous rocks in the province generally indicate emplacement between 1.4 and 1.35 Ga, which falls in a time frame where the apparent polar wander path (APWP) for the Kaapvaal craton is poorly known. In order to help address this problem, we report paleomagnetic data for syenitic rocks in the large Pilanesberg Complex near the western limit of the alkaline province, two separate syenitic intrusions in the Pienaars River Complexes near Pretoria, and the Spitskop ijolite–nepheline syenite–carbonatite complex near the eastern limit of the province. These intrusive units yield poles that allow a tentative extension of the Mesoproterozoic Kaapvaal APWP back to 1.4 Ga. The data suggest a pronounced bend or cusp in the APWP at 1.1 Ga, which may record a major change in plate motion occurring at the same time as emplacement of the Umkondo large igneous province in southern Africa.

1. Introduction

Paleomagnetism is widely used in helping to constrain tectonic and paleogeographic relations between Earth's ancient cratons during proposed supercontinent cycles in the Precambrian (e.g., Buchan et al., 2001; Meert, 2002; Pesonen et al., 2003, 2012; Pisarevsky et al., 2003; Li et al., 2008; Evans and Pisarevsky, 2008; Evans and Mitchell, 2011; Pradhan et al., 2012; Zhang et al., 2012). Rigorous testing of Precambrian paleogeographic models generally requires comparison of apparent polar wander paths (APWPs) for individual cratons in the appropriate time frames. In many cases, this approach is limited by insufficient paleomagnetic data and/or inadequate age constraints on poles used to define the APWPs.

The Kalahari craton in southern Africa represents one of the main continental blocks of interest in understanding shifting Meso- and Neoproterozoic supercontinent configurations. The core of the craton, termed the "proto-Kalahari craton" by Jacobs et al. (2008), comprises the smaller, Archean Kaapvaal and Zimbabwe cratonic nuclei and associated Paleoproterozoic orogenic belts. Paleomagnetic evidence suggests that these two cratonic nuclei may have undergone significant relative motion between ~1.9 and 1.1 Ga (Hanson et al., 2011). It may, therefore, be more appropriate to consider the Kaapvaal and Zimbabwe cratons separately when discussing paleomagnetic data for time frames >1.1 Ga. Following that line of reasoning, the new paleomagnetic data we present here rigorously apply only to the Kaapvaal craton, although the data are also relevant for the larger and younger Kalahari craton assuming that any relative motion between the Kaapvaal and Zimbabwe cratons ceased prior to the time period of concern in this paper.

There are a number of gaps in published Precambrian APWPs for the Kaapvaal craton, particularly with regard to poles that are well dated (e.g., Evans et al., 2002; de Kock et al., 2006; Tohver et al., 2006; Lubnina et al., 2010; Letts et al., 2011). For the Mesoproterozoic part of this path, several poles are available in the time frame 1.2–1.0 Ga, as discussed later in this paper. A published pole for the ~1.3 Ga Pilanesberg dike swarm (Gough, 1956) also provides a useful data point in helping to constrain part of the APWP, but the age of that pole is not well known. In general, there is a lack of well-dated poles between 1.2 and 1.9 Ga that could be used to help place the Kaapvaal craton (and by extension the larger Kalahari craton) into a global paleogeographic framework for that time period. Here we report the results of reconnaissance paleomagnetic studies of 1.4–1.35 Ga alkaline and carbonatite complexes within the Kaapvaal craton, which are excellent targets for helping

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to generate a more complete Mesoproterozoic Kaapvaal APWP. Precambrian alkaline igneous complexes in other cratons have often yielded good paleomagnetic results (e.g., Lewchuk and Symons, 1990; Symons et al., 1994), which provided an incentive for the present study. The time frame of concern in this paper is of interest because it falls in an interval of major plate reorganization, between breakup of the Columbia (Nuna) supercontinent beginning at ~1.6 Ga and final assembly of the Rodinia supercontinent at ~1.0 Ga. Also, the most precisely dated of the Kaapvaal Mesoproterozoic alkaline complexes have U–Pb zircon SHRIMP ages of 1385 ± 5 to 1374 ± 10 Ma (Harmer and Armstrong, cited in Hanson et al., 2006). As noted by Ernst et al. (2008), intraplate magmatic events with ages of ~1380 Ma occur in several other cratons around the world and may hold important clues for reconstructing the Columbia supercontinent.

2. Geological background

The Kaapvaal craton contains a number of Mesoproterozoic alkaline igneous complexes, which are grouped together as the Pilanesberg alkaline province (Ferguson, 1973) and are either exposed at the surface or known from subsurface studies (Fig. 1). The entire suite, which also includes the extensive Pilanesberg dike swarm, has been reviewed by Verwoerd (1967, 1993, 2006), Woolley (2001) and Hanson et al. (2006); information provided below on the geological framework of our sample sites comes from these sources, unless otherwise indicated. Trachytic to phonolitic volcanic deposits are preserved in some of the complexes, which also contain a variety of intrusive rocks including ijolite, syenite, nepheline syenite and carbonatite. Several of the complexes have yielded U–Pb zircon or titanite SHRIMP dates or Rb–Sr isochron dates of 1.4–1.35 Ga (reviewed in Hanson et al., 2006), and the other complexes shown in Fig. 1 are likely to have been emplaced in a similar time frame, representing a diffuse intraplate igneous province scattered over a significant part of the eastern Kaapvaal craton.

3. Paleomagnetic methods and site descriptions

We carried out paleomagnetic sampling in the Pilanesberg and Spitskop Complexes, near the western and eastern limits of the Pilanesberg alkaline province, and in the Pienaars River Complexes in the central part of the province (Fig. 1). Samples were collected with a gasoline-powered drill and oriented using a sun compass. Between 11 and 17 core samples were collected per site and were distributed over relatively large outcrop areas in order to minimize lightning effects. Analyses were carried out in the Paleomagnetism Laboratory at the University of Texas at Austin. Cores were trimmed to a length of 2.2 cm and measured with a cryogenic magnetometer. Samples were kept in a magnetically shielded room during the demagnetization procedure. All samples were subjected to detailed thermal demagnetization and, in some cases, AF demagnetization, in 8–15 steps. The data were analyzed by the principal component method (Kirschvink, 1980).

3.1. Pilanesberg Complex

The Pilanesberg Complex is the largest member of the Pilanesberg alkaline province, occupying an area of over 500 km^2. It contains several different phases of syenite and nepheline syenite that form concentric rings and intrude a cogenetic trachytic–phonolitic volcanic pile (Fig. 2). Dikes belonging to the Pilanesberg dike swarm cut parts of the complex. White nepheline syenite within the complex has yielded a U–Pb SHRIMP titanite date of

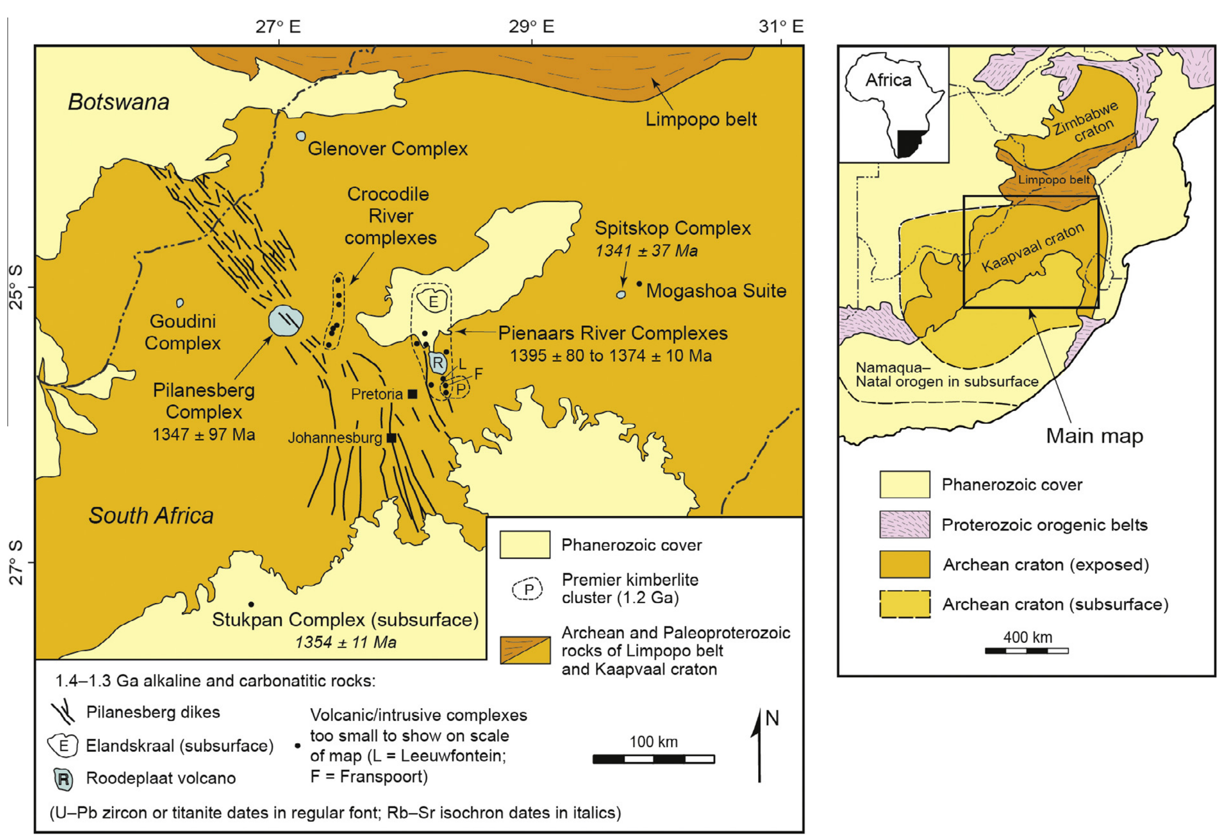

Fig. 1. Various members of the Pilanesberg alkaline province in the Kaapvaal craton, modified from Keyser (1997) and Verwoerd (2006); isotopic dates are from Verwoerd et al. (1993), Harmer (1999) and Harmer and Armstrong (cited in Hanson et al., 2006). Smaller map to right shows location of study area within the Kaapvaal craton.