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The geophysical signatures of the West African Craton

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ABSTRACT

This paper examines existing and newly compiled geophysical representations of the West African Craton (WAC) in terms of its large-scale tectonic architecture. In order to build an interpretation with a significant depth extent we draw upon a range of geophysical data, principally seismic tomographic inversions, receiver functions, gravity and magnetics. We present these results as a series of layers providing a series of depth slices though the cratonic lithosphere. The different geophysical methods suggest partitioning of the WAC into two tectonic elements at the largest scale which is observed in both seismic tomographic images, lithosphere–asthenosphere boundary (LAB) models and long wavelength gravity signals. The different models of the Moho, or crust-mantle boundary, based on these gravity or seismic datasets show little or no correlation, either for short or long-wavelength features, and show little correlation with new receiver function inferred crustal thickness estimates. Manual interpretation of low-wavelength gravity and magnetic data suggest a possible continuation of the WAC across the western margin of the modern boundary, and also highlight distinct domains interpreted to be of Birimian age.

1. Introduction

The West African Craton (WAC) extends across western Africa, and consists of two Archean nuclei in the north-western and south-western parts of the craton juxtaposed against an array of Paleoproterozoic domains made up of greenstone belts, sedimentary basins and regions of extensive granitoid-TTG plutons, which are overlain by Neo-Proterozoic and younger sedimentary basins (Fig. 1).

The borders of the WAC are largely defined by a combination of surface geology and gravity signature (Burke and Whiteman, 1973; Lesquer et al., 1984; Roussel and Lesquer, 1991; Ennih and Liégeois, 2008). Debates around the first-order tectonic architecture of the craton have been based on petrographic and structural variations as measured at the surface, with depth interpretations restricted to geometric projections or limited magnetic-gravity inversions. The resulting architectures are effectively two-dimensional and limit a full understanding of crustal scale structure and large regions of metal potential.

The deep structure of the crust and Subcontinental Lithospheric Mantle (SCLM) can play a crucial role in controlling the location of major mineral systems, as has been highlighted by Cassidy and Champion (2004), Begg et al. (2010), Griffin et al. (2013).

This study combines existing analyses with previously unpublished inversions, new P-wave receiver function estimates and manual interpretations of the gravity and magnetic anomaly maps in order to examine the geophysical database for the WAC in terms of its large-scale tectonic architecture. In order to build an interpretation with significant depth extent we draw upon a range of geophysical data, principally seismic tomographic inversions, gravity and magnetics. We present these results as a series of horizontal slices through the crust and upper mantle leading to an integrated 3D model though the lithosphere.

No single dataset is able to unravel the structural architecture alone, and the absolute values of predicted properties probably have only general significance since the variations in petrophysical properties can have a range of causes. Instead, we have taken a multi-data and multi-study approach that attempts to find correlations between different studies attempting to describe the same property, and to look for correlations in the spatial variations between properties. In this we support and generalise to all types of geophysical data the assertion of Foulger et al. (2013):

> “If a feature imaged by tomography is reliable, it should be resolvable in multiple independent studies. Geological

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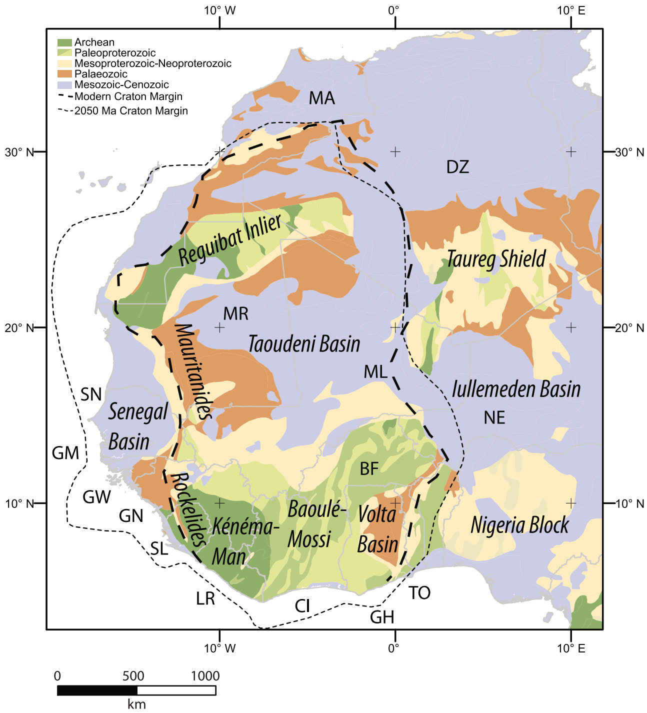

Fig. 1. Map of West Africa showing the ages of the major terranes, modified from the Geological Survey of Canada 1:35 M map of the world (Chorlton, 2007). The approximate limits of West African Craton today are indicated by a thick dashed line (after Ennih and Liégeois, 2008). We also present he interpreted location of the craton margin at 2050 Ma, at or immediately below the Moho (thin dashed line), in an attempt to "see through" later reworking of its margins. Two-letter country codes: BF: Burkina Faso; CI: Côte d'Ivoire; DZ: Algeria; GH: Ghana; GM: The Gambia; GN: Guinea; GW: Guinea Bissau; LR: Liberia; MA: Morocco; ML: Mali; MR: Mauritania; NE: Niger; SL: Sierra Leone; SN: Senegal; and TO: Togo.

> significance should only be attributed to features detected in all reputable studies."

The drawback to taking this approach with multiple datasets is that they do not generally measure the same petrophysical properties, and their observation depth range varies as well, however correlations in features in such datasets make powerful arguments for the presence of fundamental structures, whereas conflicting results from different measurements are not "wrong" but are often harder to interpret. Each individual model that results from inversion have their own absolute error estimates, and limitations due to the spatial coverage and depth smearing, however the we have worked on the principal that significant correlations between two models or datasets attempting to predict the same features are a more robust demonstration of significance than error estimates internal to any one dataset.

The aim of this paper is simply to document the range of geophysical observations that pertain to the WAC, so that we can define those features that can reliably be used as the basis for studies attempting to define the tectonic evolution of the region. This tectonic evolution itself is constrained by the geophysics, but equally by the surface geology, geochemistry and metallogenesis and is thus beyond the scope of this current work.

2. The geology of the West African Craton

2.1. The Baoulé-Mossi Paleoproterozoic domain

The oldest rocks in West Africa are Archean in age (with a major peak at ~2850 Ma) and are found in western Côte d'Ivoire, Liberia, Sierra Leone and southern Guinea in the south and Western Sahara and Mauritania in the north. They consist of felsic and mafic gneisses and migmatites associated with narrow greenstone belts of lower grade rocks. The belts are composed of metamorphosed tholeiitic basalts and metasediments including turbidites, conglomerates and extensive banded iron formation.

The Baoulé-Mossi domain (Fig. 1) is found to the north and east of the Kénéma-Man Archean domain (Bessoles, 1977). The Paleoproterozoic domain is characterised by the Archean-like greenstone-granitoid assemblages that principally consist of volcanic, volcano-sedimentary, and sedimentary sequences separated by extensive tonalite-trondhjemite-granodiorite and granite provinces, or alternatively by slightly younger sedimentary basins whose basement is not exposed. The volcanic and volcano-sedimentary rocks belong to the Birimian Supergroup, which is thought to have formed in the context of volcanic arcs and oceanic plateaus (Abouchami et al., 1990; Béziat et al., 2000; Boher et al., 1992; Leube et al., 1990; Pouclet et al., 1996). Radiometric dating of the volcanic units (Davis et al., 1994; Lüdtke et al., 1998; Ludtke et al., 1999) places the main peak of the Birimian volcanism at around 2190–2160 Ma, while detrital zircons from the sedimentary basins yield ages as young as 2130 Ma (Ludtke et al., 1999) or 2107 Ma (Doumbia et al., 1998). The Birimian volcanic and volcano-sedimentary units are unconformably overlain at several places across the craton by late basins, which are collectively known as the Tarkwaian or Tarkwa-like sediments since their relative ages are poorly constrained (Feybesse et al., 2006; Whitelaw, 1929; Sestini, 1973; Leube et al., 1990; Oberthur et al., 1998). The whole complex of volcanic, volcano-sedimentary and sedimentary units has been intruded by several generations of granitoids, which were emplaced during discrete magmatic pulses from 2180 to 2040 Ma (Agyei Duodu et al., 2009; Castaing et al., 2003; Doumbia et al., 1998; Gasquet et al., 2003; Hirdes et al., 1996; Leube et al., 1990; Naba et al., 2004; Gueye et al., 2008; Pons et al., 1995; Baratoux et al., 2011; Perrouty et al., 2012). The general geochemistry of the granitoids evolves from Na-rich calc-alkaline to K-rich alkaline (Boher et al., 1992) while their shape depends on the tectonic regime during their emplacement, ranging from undeformed circular plutons to elongate and complex interlocking bodies (Pons et al., 1995; Jessell et al., 2012).

The limits of the West African Craton has evolved with time, as craton outlines are diachronous – that is, they vary through time as some fragments of continental lithosphere are either joined to, or separated from, an existing large block of internally stable continental lithosphere (a craton). For instance, the eastern half of the Reguibat craton sutures to the WAC at ca 2070 Ma (Schofield and Gillespie, 2007; Fig. 1). The eastern boundary of WAC, defined by the Late Neoproterozoic (Pan-African) Dahomeyan and Pharusian terranes of the Trans-Saharan orogenic belt (Black et al., 1979; Black and Liégeois, 1993), is identified with reasonable confidence. The other boundaries are either artefacts of later plate movements or less well understood. The northern boundary is obscured beneath the Anti-Atlas Mountains. The southern boundary is an artefact of Atlantic opening (southern WAC terranes appear to correlate with, and were likely once contiguous with, those of the Guiana Shield in South America). The western boundary lies offshore – it is not known precisely how far the craton extended to the west at 2050 Ma. The present study focuses on the interior of the craton, in contrast to its margin, which were the subject of IGCP 485 (Ennih and Liégeois, 2008), which describe the younger (post-Proterozoic) history.

2.2. Tectonic evolution

The Baoulé-Mossi domain developed during the Eburnean orogeny (Bonhomme, 1962), which operated between ~2130 and 2040 Ma (Davis et al., 1994; Feybesse et al., 2006; Oberthur et al.,