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Early Neoproterozoic rift-related magmatism in the Anti-Atlas margin of the West African craton, Morocco

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ABSTRACT

The Moroccan Anti-Atlas contains the relics of a Tonian(?)-early Cryogenian rift developed along the northern margin of the West African craton. A distinct tholeiitic volcanic suite of lava flows, sills and dikes is encased in the Jbel Lkest Group (Kerdous inlier), the Taghdout Group (Zenaga inlier), the U1–U4 units of the Bleida-Tachdamt Group (Bouazzer Elgraara inlier), and the Lower Sedimentary Ensemble and Middle Volcanic Unit of the Tizi n'Taghatine Group (Siroua, Zenaga and Bouazzer Elgraara inliers). Two magmatic groups are distinguished that originated from a spinel–garnet transition zone ranging from zero garnet content to moderately enriched residual garnet content in the source, and partial melting degrees decreasing from 10% to 3%. Incompatible element patterns indicate contribution of both asthenospheric and lithospheric components suggesting an initial rifting geotectonic context, with lithosphere thinning and asthenosphere upwelling, similar to other complex systems of rifts that dissected Rodinia during the Early Neoproterozoic.

1. Introduction

The West African craton (WAC) consists of two Archaean–Palaeoproterozoic metamorphic and magmatic shields separated by two intracratonic sedimentary basins. The WAC was constructed during the Archaean and the ~2 Ga Palaeoproterozoic Eburnean Orogeny. After a long Mesoproterozoic interval of quiescence (ca. 1.7–1.0 Ga), except emplacement of some mafic dikes (1.41 Ga; El Bahat et al., 2013; Söderlund et al., 2013), the margins of the WAC were affected by several Early-Neoproterozoic rifting events reflecting continental break-up. Finally, at the end of the Neoproterozoic, the WAC was subjected to various stages of convergence on all of its margins, to the North along the Anti-Atlas, to the East along the Trans-Saharan belt, to the South along the Rockelides and Bassarides, and to the West along the Mauritanides (Hefferan et al., 2000; Ennih and Liégeois, 2008; Gasquet et al., 2008; Villeneuve, 2008).

One of these Early Neoproterozoic rifts, preserved in the Anti-Atlas, encompasses a ~400 km long domain that forms a roughly ENE–WSW-trending belt of disconnected inliers. In the central Anti-Atlas, remnants of the rift are exposed in the inliers of Kerdous, Tagrara de Tata, Agadir Melloul, Zenaga, Siroua and Bouazzer Elgraara (Fig. 1), which contain evidence of its entire history, from birth (ca. 900–700 Ma) to senescence and final Pan-African closure and suturing (ca. 660–605 Ma). Rifting on the Eburnean basement took place by the development of fault-controlled troughs into which the volcanosedimentary succession of the Tizi n'Taghatine Group (Bouougri and Saquaque, 2004) was deposited associated with hydrothermal activity (Leblanc and Billaud, 1978, 1990; Leblanc and Lancelot, 1980; Leblanc and Moussine-Pouchkine, 1994; Fekkak et al., 2003; Thomas et al., 2004). The aim of this paper is to characterize the nature and evolution of the Early Neoproterozoic rift recorded in the Anti-Atlas margin of the WAC, based on (1) the stratigraphic relationships of the rift-related mixed (carbonate–siliciclastic) sediments and igneous rocks; and (2) the petrological and geochemical features of mafic rocks.

2. Geological setting and stratigraphy

The Anti-Atlas Mountains are structurally divided by the Anti-Atlas Major Fault (AAMF in Fig. 1) into two major

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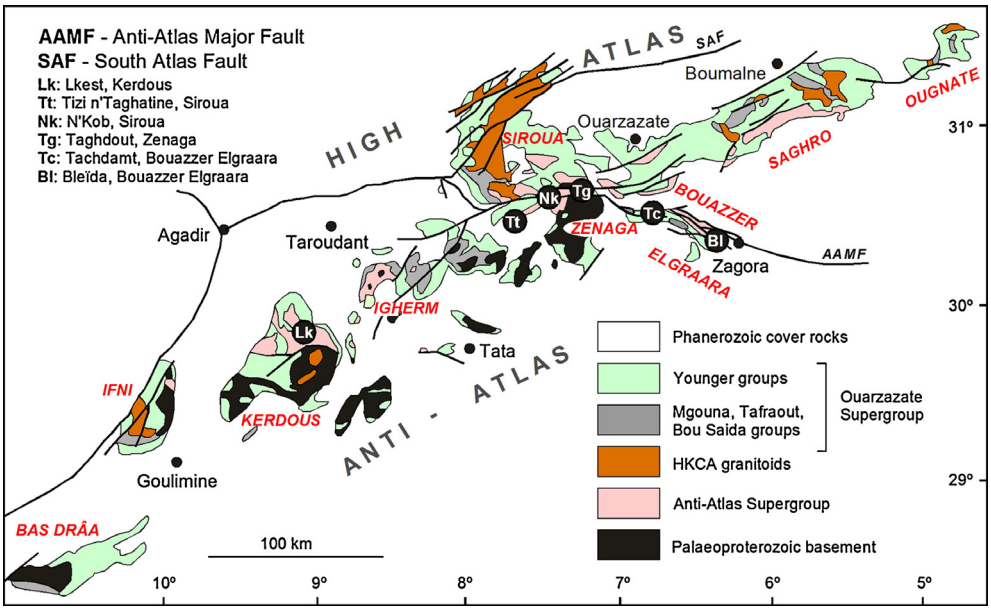

Fig. 1. Geological sketch of the Precambrian outcrops of the High Atlas and Anti-Atlas, Morocco. Modified from Gasquet et al. (2005).

tectonostratigraphic domains: (1) the western and central Anti-Atlas, SW and along the AAMF; and (2) the eastern Anti-Atlas, situated NE of the AAMF to the SAF (South Atlas Fault). Palaeoproterozoic rocks of the western Anti-Atlas are not exposed in the eastern Anti-Atlas and their absence has direct implications for the northern limit of the WAC (Ennih and Liégeois, 2001, 2008; Bouougri, 2003; Gasquet et al., 2005). Ophiolitic rocks found in the central Anti-Atlas along the AAMF mark the location of obducted Neoproterozoic oceanic lithosphere relics onto the northern margin of the WAC, and broadly coincide with the northern limit of exposed Palaeoproterozoic basement (Walsh et al., 2012). Whereas the AAMF represents a significant Neoproterozoic suture zone, the SAF played key roles in (1) Cambrian palaeogeographic reconstructions (marking the limit between the Ediacaran–Cambrian rifted platform and its basinal counterpart; Destombes et al., 1985; Álvaro et al., 2008); and (2) Variscan models (marking a sharp contact in the style of Variscan deformation; Soulaimani and Burkhard, 2008; Michard et al., 2010). Our paper offers no arguments to the debate of the northern boundary of the WAC as the shallower marine sediments simply point to the setting of the WAC coastline, in a rifting context, receiving sediments from a southern source area (Bouougri and Saquaque, 2004).

The traditional lithostratigraphic subdivision of the Precambrian of the Atlas Mountains into three broad "lithosomes" (e.g., Choubert, 1963), the so-called P-I (Archaean or Palaeoproterozoic), P-II (Lower and Middle Neoproterozoic) and P-III (Upper Neoproterozoic), was widely followed until ~2000 (Thomas et al., 2002). Recent mapping and the increase of available radiometric ages have generated a proliferation of lithostratigraphic nomenclature due to the abundance of Precambrian inliers, each of which has commonly received its own terminology. The P-II lithosome analyzed in this paper is bounded by two major unconformities, a lower angular discordance covering Palaeoproterozoic rocks and the Pan-African angular discordance. The lower P-II or Anti-Atlas Supergroup (Thomas et al., 2004) comprises three discrete sequences related to (1) rifting and break-up of the northern margin of the WAC (on which this paper is focused), (2) production of oceanic crust (preserved as metamorphic ophiolitic remnants), and (3) island-arc formation (thrust sheets of calk-alkaline metavolcanic and plutonic rocks).

The lower part of the Anti-Atlas Supergroup shows a progressive change of sedimentary facies from SW to NE representing a broad proximal–distal trend in a rifting context: conglomerates and sandstones dominate in the Ifni and Kerdous inliers; and quartzites, carbonates and shales (Choubert's "Série des Calcaires et Quartzites") in the Igherm, Siroua, Zenaga and Bouazzer Elgraara inliers (Bouougri and Saquaque, 2004; Thomas et al., 2004) (Fig. 1). This lithological arrangement has led to a proliferation of lithostratigraphic terminology: e.g., the Jbel Lkest Group in the Kerdous inlier (Hassenforder, 1987), the Bleida-Tachdamt Group in the Bouazzer Elgraara inlier (Leblanc and Moussine-Pouchkine, 1994) and the Taghdout Group in the northern edge of the Zenaga Complex and in highly deformed and metamorphosed tectonic slices of the AAMF (Thomas et al., 2004). Correlation between these groups (recently included in the Lkest-Taghdout Group; Gasquet et al., 2005, 2008; Álvaro et al., 2014) is both lithostratigraphic and structural. The Jbel Lkest, Bleida-Tachdamt and Taghdout groups are post-Palaeoproterozoic volcanosedimentary packages predating the main Pan-African tectonic event. The only lithostratigraphic correlation linking the Siroua-Zenaga and Bouazzer Elgraara inliers was proposed by Bouougri and Saquaque (2004), which is in need of revision (Fig. 2).

The oldest sampled sills are embedded in the mixed (carbonate–siliciclastic) Jbel Lkest Group (Hassenforder, 1987) of the Kerdous inlier, and in the Agouny Formation (Taghdout Group; Thomas et al., 2004) or Taghdout Formation (Tizi n'Taghatine Group; Bouougri and Saquaque, 2004) of the Zenaga inlier. Their metamorphic and structural patterns allow differentiation from a swarm of doleritic dikes, named Ifzwane Suite by Thomas et al. (2004), which include dolerites ranging in age from Palaeoproterozoic to Neoproterozoic (Walsh et al., 2002; Kouyaté et al., 2013). The latter is also recognized in the U1 unit of the Bleida-Tachdamt Group (Leblanc and Moussine-Pouchkine, 1994) or Ifarkhs-n-Tirsal Formation (Bouougri and Saquaque, 2004) at Tachdamt (Bouazzer Elgraara inlier). Younger sampled lava flows are interbedded in the U2–U4 units of the Bleida-Tachdamt Group (Leblanc and Moussine-Pouchkine, 1994) and in the Middle Volcanic Unit and Upper Sedimentary Ensemble (Bouougri and Saquaque, 2004) of the Siroua and Bouazzer Elgraara inliers.

Mafic sills and doleritic dikes are also known in the Igherm inlier (Hafid et al., 1998; El Aouli et al., 2001). Doleritic dike