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A historical overview of Moroccan magmatic events along northwest edge of the West African Craton

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ABSTRACT

Located along the northwestern edge of the West African Craton, Morocco exhibits a wide variety of magmatic events from Archean to Quaternary. The oldest magmatic rocks belong to the Archean Reguibat Shield outcrops in the Moroccan Sahara. Paleoproterozoic magmatism, known as the Anti-Atlas granitoids, is related to the Eburnean orogeny and initial cratonization of the WAC. Mesoproterozoic magmatism is represented by a small number of mafic dykes known henceforth as the Taghdout mafic volcanism. Massive Neoproterozoic magmatic activity, related to the Pan-African cycle, consists of rift-related Tonian magmatism associated with the Rodinia breakup, an Early Cryogenian convergent margin event (760–700 Ma), syn-collisional Bou-Azzer magmatism (680–640 Ma), followed by widespread Ediacaran magmatism (620–555 Ma). Each magmatic episode corresponded to a different geodynamic environment and produced different types of magma.

Phanerozoic magmatism began with Early Cambrian basaltic (rift?) volcanism, which persisted during the Middle Cambrian, and into the Early Ordovician. This was succeeded by massive Late Devonian and Carboniferous, pre-Variscan tholeiitic and calc-alkaline (Central Morocco) volcanic flows in basins of the Moroccan Meseta. North of the Atlas Paleozoic Transform Zone, the Late Carboniferous Variscan event was accompanied by the emplacement of 330–300 Ma calc-alkaline granitoids in upper crustal shear zones. Post-Variscan alkaline magmatism was associated with the opening of the Permian basins.

Mesozoic magmatism began with the huge volumes of magma emplaced around 200 Ma in the Central Atlantic Magmatic Province (CAMP) which was associated with the fragmentation of Pangea and the subsequent rifting of Central Atlantic. CAMP volcanism occurs in all structural domains of Morocco, from the Anti-Atlas to the External Rif domain with a peak activity around 199 Ma. A second Mesozoic magmatic event is represented by mafic lava flows and gabbroic intrusions in the Internal Maghrebian flysch nappes as well as in the external Mesorif. This event consists of Middle-Upper Jurassic MORB tholeiites emplaced during opening of the Alpine Tethys ocean. The Central High Atlas also records Early Cretaceous alpine Tethys magmatism associated with the aborted Atlas rift, or perhaps linked to plume activity on the edge of the WAC.

Cenozoic magmatism is associated with Tertiary and Quaternary circum-Mediterranean alkaline provinces, and is characterized by an intermittent activity over 50 Ma from the Anti-Atlas to the Rif Mountain along a SW–NE volcanic lineament which underlines a thinned continental lithosphere.

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1. Introduction

Northwestern Africa recorded a wide variety of geologic events through geological time beginning with an Archean shield, about the Paleoproterozoic West African Craton (WAC) developed in a series of orogenic cycles in the Neoproterozoic. Although the Mesoproterozoic was long considered a quiescent time in

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northwest Africa, recent studies (Kouyaté et al., 2013; Youbi et al., 2013; El Bahat et al., 2013) document previously unknown Mesoproterozoic events in the northern WAC, filling in a missing chapter in northwestern African geology. With continued cycles of collisions, rifting events and continental growth through time, the WAC became surrounded by Neoproterozoic, Paleozoic and Cenozoic orogenic belts each characterized by a large variety of magmatic events. Thus, Northwestern Africa recorded disparate geologic events related to the successive amalgamation and breakup of the supercontinents over the past 3.5 Ga which are reviewed in this paper.

In the northern part of the West African Craton (WAC), the Reguibat shield consists of two parts: an Archean shield in the west and a Paleoproterozoic shield in the east. These two domains have been juxtaposed and cratonized during the Eburnean orogeny at ca. 2 Ga (Schofield et al., 2006). Further north, the Anti-Atlas is a polycyclic belt that records Eburnean and Pan-African events in several erosional inliers within a Paleozoic fold belt. The tectonic structures of the Eburnean orogeny are often overshadowed by the Pan-African structures, but both orogenies are well marked by an intense and polyphased magmatic activity (Hassenforder, 1987; Villeneuve and Cornée, 1994; Ikenne et al., 1997a,b; Thomas et al., 2002; Gasquet et al., 2004, 2008; Blein et al., 2014). The western part of North Africa (Morocco and western Algeria), has been involved in Variscan events that resulted in the construction of Pangea, following the consolidation and collision of the supercontinent Gondwana, and Laurussia and a microcontinent called Armorica.

While the Variscan events are limited to the western part of North Africa, the Alpine orogeny extends from Morocco to Algeria and Tunisia and continues along the Mediterranean to the Middle East. The breakup of Gondwana around 200 Ma marked the beginning of the interactions between North Africa and Eurasia, and the detachment of India, Africa, Antarctica and Australia (Zitellini et al., 2009). The closure of the Tethyan Ocean on the North African transect occurred through subduction of the oceanic lithosphere beneath the Eurasian Plate, and ended with the collision between the African and Eurasian plates between 65 and 2.5 Ma. The global, counterclockwise N-S trending compression was coeval with an E-W striking movement responsible for the Atlantic Ocean opening.

In this note, we present an overview of the magmatic events documented in Morocco, from the Archean nucleus, to the Paleoproterozoic-Eburnean shield, Neoproterozoic Pan African cycle, Paleozoic orogen (Variscan or Hercynian belt), followed by the Mesozoic-Cenozoic uplift of the Atlantic-Tethyan eastern and southern shoulders.

2. Precambrian

2.1. The Archean

The oldest rocks in northwest Africa occur in the West African craton (Fig. 1) which is composed of two Achaean shields, the Reguibat and the Leo shields, separated by the Taoudenni Meso- to Neoproterozoic and Phanerozoic basin in the center. The Reguibat shield is bordered to the north and east by the Paleozoic-Cenozoic Tindouf and Reggane basins, respectively (Fabre, 2005), and the Tindouf basin in the north (Rooney et al., 2010).

The Reguibat Shield is subdivided into two distinct areas: an eastern part related to the Birimian orogeny (Peucat et al., 2004) and a western section of Lower Siderian to Mesoarchean age (Bessoles, 1977; Schofield et al., 2011; Bea et al., 2013). The western Reguibat shield contains metamorphic rocks with plutonic intrusive bodies (Bea et al., 2013), and is subdivided into several lithostratigraphic domains: the Tasiast–Tijirit Terrane in the south and the Tiris Complex in the north (Rocci et al., 1991).

The oldest Reguibat shield rocks consist of orthogneisses from the Amsaga Complex (Southern part of the Reguibat Shield - Mauritania), dated at 3.52 to 3.42 Ga (Potrel et al., 1996). The 3.5–3.42 Ga age is interpreted to date the time of intrusion, whereas ages of around 2.70 Ga reflect ametamorphic overprint (Potrel et al., 1996). Other migmatitic gneisses and granitic intrusions in the Tiris Complex (Schofield et al., 2011) and Tasiast–Tijirit Terrane (Chardon, 1997; Key et al., 2008) have been dated between 2.97 Ga and 2.88 Ga. Subsequent granitic magmatism (2.69–2.65 Ga) has been documented in the Tiris Complex (Schofield et al., 2011). Archean-Paleoproterozoic granitic intrusions (2.52–2.46 Ga) are also documented in syenites in the Awsard (Aoucerd) pluton and anassociated framework of dykes (Bea et al., 2013).

Recently, Montero et al. (2014) recognized three units, the Tichla greenstone belt, the Tonalite –Trondjehmirte – Granodiorite (TTG) Aghaylas Suite and the Awserd syenites. On the basis of radiometric, geochemistry and isotopic data, these authors argue that the Tichla greenstone belt was formed between 3.03 ± 0.01 Ga and 3.01 ± 0.01 Ga. The TTG crystallized at 3.04 ± 0.01 Ga and 2.92 ± 0.10 Ma; they are not juvenile but generated from a crustal melting of previous juvenile TTGs. The syenites are dated at 2.46 ± 0.01 Ga and display particularly high K_2O contents (Haissen et al., 2015).

2.2. The Paleoproterozoic

The Paleoproterozoic basement outcrops in different inliers of the western and central parts of the Anti-Atlas belt (Fig. 1). Paleoproterozoic basement consists of siliciclastic banded sedimentary sequences recrystallized under low-grade metamorphic conditions (Biotite-bearing, green-schist facies), in which bedding has been well preserved in locations such as Bas Drâa, Tagragra of Akka and Kerdous (Zenaga and Drâa Groups). Locally, the Paleoproterozoic syn- to late kinematic granitoids induced a thermal metamorphic grade reaching the sillimanite to K-feldspar zone (Ikenne et al., 1997a,b). This metamorphic event, related to the Eburnean orogenic cycle, is coeval with the emplacement of silicic to intermediate intrusions documented from several inliers of the Anti-Atlas. Their radiometric ages attest to an important magmatic episode in the waning stages of the Eburnean cycle, ranging from 2187 to 1700 Ma (Aït Malek et al., 1998; Thomas et al., 2002; Gasquet et al., 2004; Soulaimani et al., 2013; Blein et al., 2014). The oldest Eburnean rocks, granitic in composition, have been noted in Kerdous where a two-micatrondhjemite was dated at 2187 ± 33 Ma (Unpublished map of Anezi, BSG, 2001; Blein et al., 2014), and a tonalite was dated at 2110 ± 17 Ma (SHRIMP U-Pb zircon) with inherited zircons at ca. 2180 Ma (sheet of Tlatat Ida Gougmar, Roger et al., 2006). Ebernian acidic intrusion events has been documented in many Anti-Atlas inliers including Tata (Walsh et al., 2002), Tagragra of Akka, Igherm, Bas Drâa (Aït Malek et al., 1998), Zenaga (Thomas et al., 2002), Iguerda and Agadir Melloul (Blein et al., 2014).

On the basis of geochemical data, two Paleoproterozoic plutonic units have been recognized (Fig. 1): the first one is calc-alkaline and the second corresponds to peraluminous rocks. In Bas Drâa and Tagragra of Akka Inliers (Ikenne, 1997; Mortaji et al., 2000) the calc-alkaline unit consists of diorites, monzogabbrodiorites, granodiorites and granites. Their chemical features are of calc-alkaline I-type and suggest a lower crustal, or mantle, origin with variable contamination by crustal material. In Zenaga, Iguerda and Agadir Melloul (Thomas et al., 2002; Blein et al., 2014), medium-K, calc-alkaline intrusions are qualified as “Azegmerzi Type”, consisting of

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