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History of the West African Neoproterozoic Ocean: Key to the geotectonic history of circum-Atlantic Peri-Gondwana (Adrar Souttouf Massif, Moroccan Sahara)

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ABSTRACT

Bordered by the Archaean basement of the Reguibat Shield to the E and S, the Adrar Souttouf Massif is located in the southern regions of the Moroccan Sahara and represents the northern part of the Mauritanide belt. The central areas of this massif comprise the Dayet Lawda and Sebkha Matallah units that are mainly composed of mafic rocks. Ten samples taken from these rocks yielded 531 zircon grains that were analysed with respect to their morphology, U-Th-Pb, and Lu-Hf isotope composition. Additionally, 155 apatite grains from six samples were also dated by the U-Th-Pb method. Mostly well rounded zircon grains commonly showed bright cathodoluminescent (CL) overgrowth domains and leaching zones, indicating metamorphic overprint around unaffected oscillatory zoned core areas. All samples but one yielded two significant zircon age populations: ~605 Ma and ~634 Ma with some inherited grains in the range of ~650–740 Ma and very scarcely up to ~1190 Ma. For six samples the Hf isotope composition suggests a major contribution of Neoproterozoic juvenile magmas from depleted mantle source. The zircon Hf data for the remaining samples points to a predominant recycling of older Archaean to Palaeoproterozoic crust. Based on the geochemical composition of the rocks, an island arc setting is assumed at the periphery of the West African Craton close to the Cryogenian-Ediacaran boundary. Subsequent metamorphism during accretion and partial obduction onto the basement rocks took place at about 605 Ma. A minor Variscan overprint could be demonstrated for only one sample. This case study exemplifies the great potential of the widely occurring metamorphosed mafic and ultramafic rocks along the western margin of the West African Craton for palaeogeographic and geodynamic reconstructions including the peri-Gondwanan terranes during the Late Neoproterozoic.

1. Introduction

Several occurrences of mafic and ultramafic rocks are reported along the western margin of Africa. Some of them are interpreted to represent remnants of Neoproterozoic oceanic crust, but yet remain undated. The introduction of a West African Neoproterozoic Ocean by Villeneuve et al. (2010) led to the question how the numerous mafic rocks along the recent Atlantic margin of Africa could be correlated and how this particular ocean may have evolved. One of the largest areas of rocks potentially related to such an oceanic or island arc setting is located in the Adrar Souttouf Massif (Moroccan Sahara). Although there are several maps at large scales and much detail recently published by the Geological Survey of Morocco, wide areas remain unmapped. This applies particularly for major parts of the units, which are mainly composed of mafic rocks related to oceanic crust.

The Adrar Souttouf and the Dhlou Massif are both forming the Souttouffide Belt, which is the northern part of the Carboniferous Mauritanide Belt in the Moroccan Sahara (Dacheux, 1967; Villeneuve et al., 2006; Villeneuve, 2008; Michard et al., 2010). A complex and polyphased geologic history including a thin skin model for nappe tectonics of the four main units of the Adrar Souttouf Massif has already been assumed by several authors (e.g. Sougy, 1962a; Bronner et al., 1983; Marchand et al., 1984; Villeneuve et al., 2006; Michard et al., 2010; Gärtner et al., 2013a). First attempts to reconstruct the complex

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evolution of this massif using several geochronological methods were done by Villeneuve et al. (2006), Gärtner et al. (2013a), while Montero et al. (2014) give valuable information about the adjoining parts of the Reguibat Shield. The following study aims to a precise age determination of the intrusion as well as the metamorphic overprint of several magmatic rocks that are possibly Neoproterozoic in age and related to oceanic and island arc settings (Youbi et al., submitted for publication). This paper presents new U-Pb ages of zircon and apatite combined with zircon Hf isotope analyses and zircon morphology. A regionally limited reconstruction of the West African Neoproterozoic Ocean's evolution is proposed.

2. Geological setting

Situated at the western margin of the Archaean Reguibat Shield of the West African Craton, the Adrar Souttouf Massif represents the northern section of the Mauritanides (Sougy, 1962a). A subdivision of the investigated area into four main structural domains was introduced by Villeneuve et al. (2006, 2010). The geotectonic units are named from west to east as follows: Oued Togba, Sebkha Gezmayet, Dayet Lawda, and Sebkha Matallah. All of them show a NNE-SSW trending strike and are thrusted top-SE onto the western Reguibat basement and / or a thin Ordovician to Devonian sedimentary succession termed as Dhloat Ensour Group (Michard et al., 2010, and references therein). The thin skin model was introduced by Sougy (1962a) and supported by most of the later authors. Polyphased metamorphic overprint of the entire region in the course of Neoproterozoic and Variscan-Alleghanian orogenies can be inferred from the dominant occurrence of rocks showing all stages of metamorphism within the Adrar Souttouf Massif. Geochronologic data corroborates the hypothesis of a complex polyphased geologic history of the entire area (Villeneuve et al., 2006; Gärtner et al., 2013a). Both of the western Oued Togba and Sebkha Gezmayet units are mainly composed of high-grade metamorphic rocks intruded by granitoids and, locally, by mafic and ultra-mafic dykes (Villeneuve et al., 2006; Michard et al., 2008, 2010). Recent radiometric data from the Oued Togba and Sebkha Gezmayet units suggest their peri-Gondwanan origin. The zircon age distribution patterns of the first mentioned unit is interpreted to show Avalonian affinities, while the latter one is highly likely linked to Meguma (Gärtner et al., 2013a). The Dayet Lawda and parts of the Sebkha Matallah units are interpreted to contain rocks potentially derived from oceanic crust, forming an ophiolitic massif of approximately 220 km length and about 45 km width within the Adrar Souttouf Massif (Gasquet et al., 2008; Rjimati and Zemmouri, 2011; Fig. 1).

2.1. Dayet Lawda unit

The Dayet Lawda unit consists mainly of metamorphosed mafic to ultramafic rocks (gabbro, gabbro-diorite, olivine gabbro, anorthosite, serpentinite, etc.; Arribas, 1968). This unit still remains unmapped in larger scales than 1:1.000.000. Nevertheless, Villeneuve et al. (2006) introduced a subdivision into four sub-units for the central and northern parts, referred to as "formations" including several K-Ar whole-rock ages:

- *Formation A* is situated at the western margin of the Dayet Lawda unit and overthrusted by the rocks of the eastern Sebkha Gezmayet unit. This formation is mainly composed of amphibolitic gneisses, granites and doleritic dykes. A K-Ar whole-rock age of 396 ± 9 Ma was obtained for one of the gneisses, which is inferred to have been affected by a subsequent metamorphic event. Therefore, the age is interpreted to reflect rejuvenation. One sample (D72) was taken from this formation for isotopic analyses.
- *Formation B* forms the northernmost part of the Dayet Lawda unit and is bordered by thrusts against the Sebkha Gezmayet and Sebkha Matallah units. The formation is dominated by olivine gabbro, with one of them dated at 1061 ± 25 Ma (K-Ar). Latest field observations made by our working group in 2014 gave evidence for the occurrence of pyroxenitic mantle as well as leucocratic granite xenoliths / dykes within the gabbro and a possible pop-up structure along the western margin of formation B. This structure includes an intercalation of amphibolites and orthogneisses with locally occurring marble lenses. Penetrative deformation and steeply dipping foliation classify the pop-up structure as one of the most important geotectonic boundaries between the different units of the Adrar Souttouf Massif. This newly discovered structure could be traced from the road Dakhla-Aoucert to the Sebkha Tidsit and is most probably evolved along the entire western margin of the Dayet Lawda unit.
- *Formation C* is located in the central regions of the Dayet Lawda unit. Its borders against formation D are not defined south of ca. N22°10′ due to the poor outcrop situation and difficult access. Most frequently occurring rocks are amphibolites, granites, gabbros, peridotites and basalts. One basalt sample was dated at 733 ± 17 Ma (K-Ar), which is inferred to represent the intrusion age (Villeneuve et al., 2006). A K-Ar whole-rock age of 274 ± 12 Ma and a K-Ar feldspar age of 251 ± 6 Ma from a gabbro (Villeneuve et al., 2006) are both interpreted to depict the rejuvenation of a possibly Variscan protolith. Within Formation C there is a possibly basement-related granitic inlier. Potentially slightly rejuvenated amphiboles of a cataclastic felsic rock sample yielded an age of 953 ± 23 Ma (Villeneuve et al., 2006). Rock specimens were sampled at two localities: D57 from Formation C and D52 from the granitic inlier.
- *Formation D* comprises the eastern regions of the Dayet Lawda unit and is built up from metamorphosed gabbros and gabbro-diorites. Because the rocks of this formation are thrusted over the Sebkha Matallah unit, they are supposed to show similarities to the rocks of the four ultramafic domains within the latter unit (see below). K-Ar intrusion ages between ~484 and 514 ± 12 Ma are known from three localities within this formation. A quartzitic diorite analysed by Gärtner et al. (2013a) did not contain zircons for age determination. Therefore, a set of five samples (D76, D178, D178a, D180, D180b) was taken from different localities of this formation.

2.2. Sebkha Matallah unit

This unit comprises several types of metamorphic rocks, such as phyllites, migmatites, orthogneisses and amphibolites, accompanied by numerous granitoid intrusions. These rocks crop out widespread in major parts of the eastern Sebkha Matallah unit (Rjimati et al., 2002a, b,c,d,e, 2010, 2011; Rjimati and Zemmouri, 2011). Four domains of mafic to ultramafic rocks are interpreted as klippen structures (Sougy, 1962a; Bronner et al., 1983; Marchand et al., 1984) and are named Entajjat, Mades, Tuisten and Agreb Labghar occur in the southwestern area of this unit (Fig. 1, Agreb Labghar is outside the map). They are dominated by gabbro, diorite and anorthosite and are supposed to be linked to the thrusting of the Dayet Lawda unit over the Sebkha Matallah unit (Sougy, 1962a,b; Bronner et al., 1983; Marchand et al., 1984; Villeneuve et al., 2006; Michard et al., 2008). Further bodies of similar composition but smaller dimensions are known. All of the mafic and ultramafic rocks are grouped into the Agrour Lafras suite, which is expected to be Archaean to Palaeoproterozoic in age (Rjimati and Zemmouri, 2011). There are only few radiometric ages published on minerals from the Sebkha Matallah unit: An age of 1110 ± 26 Ma on amphiboles of a gabbro-diorite represents most likely an event of rejuvenation, while the host rock displays a K-Ar age of 1761 ± 42 Ma (Villeneuve et al., 2006). More recent data on zircon are given by Montero et al. (2014), who describe a gneissose noritic gabbro anorthosite with an age at 2435 ± 9 Ma and a leucotonalite having two discordias with upper intercepts at 2936 ± 10 and 3112 ± 8 Ma. A total amount of ten samples was taken from the Sebkha Matallah unit (D62, D63, D158a, D162, D174, D175, D176a, D177, D181, D182c) for