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Timing and duration of the Central Atlantic magmatic province in the Newark and Culpeper basins, eastern U.S.A.

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ABSTRACT

New major and trace element data and $^{40}Ar/^{39}Ar$ plateau ages constrain the timing, duration and time-related geochemical evolution of the Central Atlantic magmatic province in the U.S.A. (Newark and Culpeper basins) and refine correlations with basaltic lava flows from other Late Triassic–Early Jurassic circum-Atlantic basins. The precise, statistically robust $^{40}Ar/^{39}Ar$ plateau ages were obtained on biotite and on fresh plagioclase and calculated using the latest ^{40}K decay constants. These ages are supported by a general consistency of the Ca/K calculated from $^{37}Ar/^{39}Ar$ of the plateau steps and the Ca/K obtained by detailed electron microprobe analyses on plagioclase phenocrysts. The ages of five analyzed basalt lava flows, from all three lava flow units in the Newark basins, and the ages of two sill samples are indistinguishable, indicating a brief magmatic peak phase at 201.8 ± 0.7 Ma. Recalibrated $^{40}Ar/^{39}Ar$ plateau ages from the entire province indicate a near-synchronous onset and peak volcanic activity at the Triassic–Jurassic boundary within the circum-Atlantic basins from the U.S.A., Canada and Morocco. The early erupted magmas (Moroccan Lower to Upper basalts, the Fundy basin North Mountain Basalt, and Orange Mountain and equivalent U.S.A. flows) yield an enriched geochemical signature (e.g., with relatively high La/Yb), whereas late magmas in the U.S.A. (Hook Mountain and Hampden basalts) and Morocco (Recurrent basalt) yield relatively depleted geochemical compositions (low La/Yb). A slight, but significant age difference for eruption of Hook Mountain and Hampden basalts (200.3 ± 0.9 Ma) and Recurrent basalts (198.2 ± 1.1 Ma) is interpreted as evidence of a diachronous northward rift–drift transition during break-up of Pangea. Our data indicate also a prolonged intrusive sequence that continued until about 195 Ma at the Palisades sill and is consistent with sporadic late CAMP magmatism for dykes from the south-eastern U.S.A. and for intrusions from Guinea.

1. Introduction: Triassic–Jurassic magmatism in the circum-Atlantic basins

The Central Atlantic magmatic province (CAMP; Fig. 1A) basaltic magmas were erupted in circum-Atlantic basins in Europe, Africa, North and South America over a total surface in excess of 10^7 km^2 (Marzoli et al., 1999; McHone et al., 2005), making this one of the largest known Phanerozoic igneous provinces. Crucial for the definition of the CAMP was recognition of nearly synchronous magmatic activity (mean $^{40}Ar/^{39}Ar$ age ca. 200 Ma) and the largely similar geochemical composition of the magmatic products over the entire province, e.g., from France to Bolivia (Bertrand et al., 2005; Jourdan et al., 2003). Some of the thickest lava piles of the CAMP occur in the once contiguous extensional basins of eastern North America (ENA) and Morocco, where they are interlayered with continental sediments of Triassic–Jurassic age. The North American basins, which probably represent the best-studied continental basins of Late Triassic to Early Jurassic age, contain continuous, or nearly so, accumulations of sediments and volcanics collectively termed the Newark Supergroup. Although the position of the Triassic–Jurassic boundary has long been claimed as occurring below the oldest CAMP flows in the Newark basins (cf. Whiteside et al., 2007), recent research demonstrates that the boundary lies above the oldest CAMP flows (Cirilli et al., 2009; Kozur and Weems, 2010; see below).

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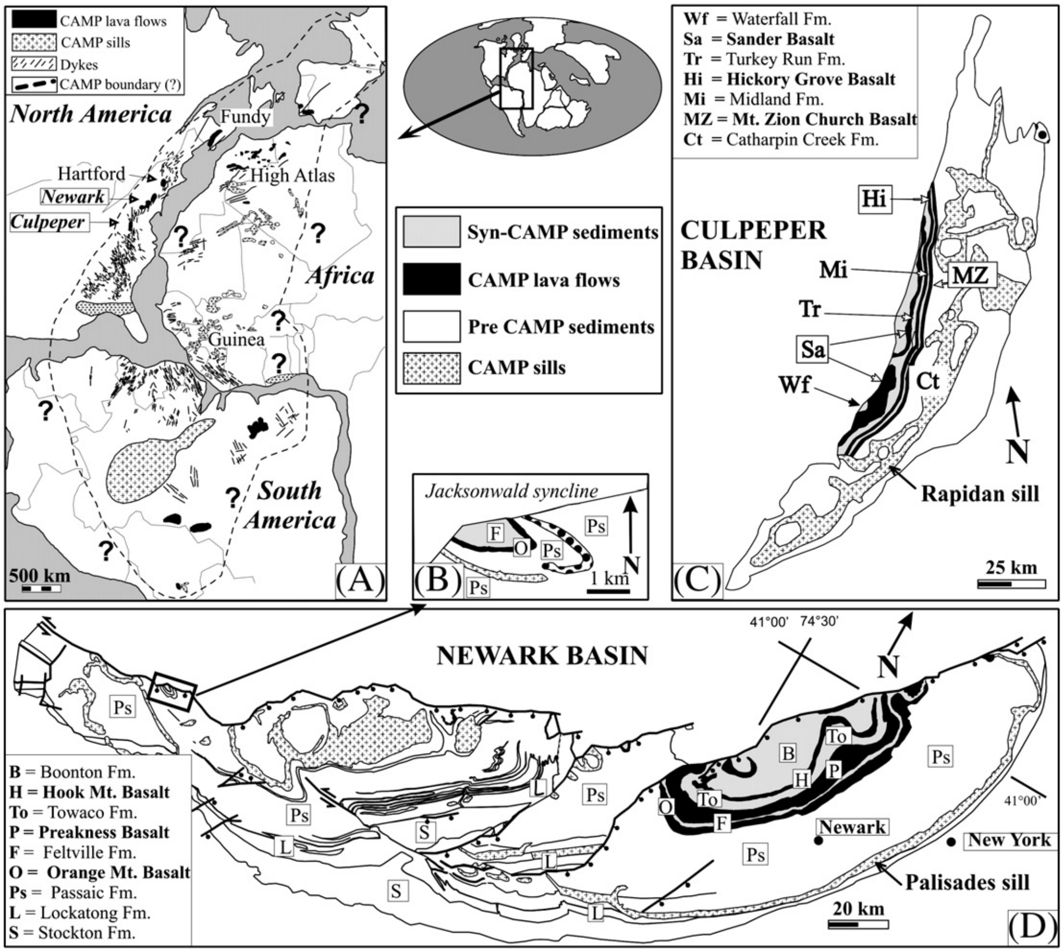

Fig. 1. Schematic map of the CAMP (A) and of Culpeper (C) and Newark (D) basins. Inset B shows the Jacksonwald syncline where Orange Mountain basalt NEW133 was sampled.

The "absolute age anchor" for the Newark sediments is given by the radio-isotopic ages of the CAMP lava flows. As we show below, however, and according to the rigorous data filtering criteria of Baksi (2003) and of Nomade et al. (2007), the previously published isotopic ages for the Newark basaltic flows cannot be considered statistically robust. Precise ages are required also to support bio- and magneto-stratigraphic correlations among the circum-Atlantic basins, notably those from the U.S.A. and Morocco. Therefore, we present here precise $^{40}Ar/^{39}Ar$ plateau ages for ten Culpeper and Newark basin (U.S.A.; Fig. 1C and D) basaltic lava flows and related sills (Rapidan and Palisades). Combined with new major and trace element geochemical data for the basalts, these ages better constrain inter-basin correlations, the age and duration of the magmatism and its geodynamic significance within the framework of the rifting of Pangea and opening of the Central Atlantic Ocean.

2. CAMP in the eastern U.S.A basins

In ENA, CAMP igneous rocks occur onshore from Newfoundland (Canada) to Florida (U.S.A.), but are exposed at the surface as basaltic lava flows, dykes and sills only in the Newark Supergroup basins from Nova Scotia (Canada) to Virginia (U.S.A. (Fig. 1)). The Triassic–Jurassic basins of the eastern U.S.A. (Massachusetts to Virginia) contain lava piles that are up to 450 m thick and consist of a maximum of three main units (Fig. 2), each comprising multiple flows. In the Newark basin (Fig. 1D) the units are the Orange Mountain (comprising three individual flows), Preakness (five flows) and Hook Mountain basalts (two or three flows; e.g., Puffer and Student, 1992). Based on detailed field-work, biostratigraphic data and basalt geochemistry (e.g., Fowell and Olsen, 1993; Olsen et al., 2002; Tollo and Gottfried, 1992), these three units can be correlated with the basalts from the nearby basins; e.g. in the Hartford basin the correlative units are the Talcott, Holyoke and Hampden basalts, respectively (Fig. 2). In the Culpeper basin (Fig. 1C) also the CAMP lava flows comprise three main units: the Mt. Zion Church (two flows), the Hickory Grove (two flows) and the Sander basalt (at least three flows). The geochemical composition of the Mt. Zion Church basalt is similar to the Orange Mountain and Talcott basalts, whereas the Hickory Grove and Sander basalts (separated locally by more than 100 m of sediments of the Turkey Run formation) resemble the Preakness and Holyoke basalts (Tollo and Gottfried, 1992). Lava flows geochemically similar to the Hook Mountain and Hampden basalts are absent in the Culpeper basin.

Basic rocks in the Culpeper and Newark basins occur also as rather thick, shallow intrusive sills, e.g. the Rapidan and the Palisades sills, respectively. The latter reaches a thickness of about 350 m and is well exposed along the Hudson River in New Jersey, where it intruded conformably within the mainly lacustrine sediments of the Carnian Lockatong Formation. The geochemistry of the Palisades sill exhibits a general trend of upward decreasing MgO and increasing SiO_2, yet significant mineralogical and geochemical fluctuations also occur from base to top (e.g., Gorring and Naslund, 1995; Puffer et al., 2009; Shirley, 1987; Walker, 1969). The most significant variations are associated with the highly mafic olivine-rich layer that occurs at about 10 m above the base of the sill and in the so-called "sandwich horizon," an evolved, granophyre-bearing level near the sill's top. Puffer et al. (2009) have shown general geochemical similarities between the lower part of the Palisades sill and the Orange Mountain basalt, and between the upper half of the sill and the Preakness basalt.