Early Ediacaran Volcanism of Taourirte Area (Western High Atlas, Morocco): Evidence for the Onset of a Post Pan-African Extension Event

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Abstract

Recently, early Ediacaran volcanic activity has been recorded in Tighardine area from the Moroccan High Atlas. The field investigation in Taourirte area allows the distinction of three volcanic and volcano-sedimentary units quite similar to those already described on Tighardine area. Volcanic rocks of Tighardine show high affinities to continental tholeiites typical of an extensional tectonic environment. This tholeiitic geochemical affinity contrasts with that of calc-alkaline types described from volcanic rocks belonging to the Lower Ediacaran Ouarzazate Supergroup in the Anti-Atlas. Whole-rock geochemical characteristics: high TiO_2 contents ranging from 1.2 to 2.81 wt%, high Zr/Y (5.43–12.08), Zr/Nb (23.81–10.50) and Zr/P_2O_5 (0.03–0.2) ratios suggest an intracontinental tholeiitic affinity for these volcanic. They have Ti/Y ratio varying from 240 to 1200 and Th/Ta ranging from 0.68 to 5.2 supporting their derivation from an enriched mantle source, akin to that of E-MORB, during an extensional regime. They were deposited in an extensive basin evolved during a post-collisional regime. Their geochemical signature is a result of complex interaction processes between parental asthenospheric mantle melt and the surrounding crust.

Keywords

Western High Atlas • Taourirte • Intracontinental tholeiites • Extension • Post-collision

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1 Introduction

The Moroccan Western High Atlas is a mountainous region that includes numerous volcanic and volcano-sedimentary formations. These volcanic rocks were previously attributed to the Cambrian. However, recently obtained U-Pb zircon geochronological data of tholeiitic volcanic rocks in the Tighardine area yielded an early Ediacaran age of about 600 ± 3 Ma (Boukerrou et al. 2018), and this volcanism shows a tholeiitic geochemical affinity. Ediacaran magmatism was earlier recognised in areas to the south, in the Ouarzazate Supergroup of the Anti-Atlas belt (Fig. 1a). However, the volcanic rocks of the Ouarzazate Supergroup show a high K-calc-alkaline affinity. Therefore, this high K-calc-alkaline signature confirms that the volcanism took place in a thick crust consistent with a post-collisional event during the final stages of the Pan-African orogeny. This study aims to characterise the nature and affinity of the Taourirte magmatism and discuss its age and geodynamic context and to compare it with equivalent rocks in the Anti-Atlas at the NW margin of the West African Craton (WAC).

2 Geological Setting

The Western High Atlas Massif belongs to the Atlas fold-thrust intracontinental belts raised by the Alpine tectonic event (Piqué et al. 2002; Teixell et al. 2003). Two NE-SW major dextral shear zones border it; (1) Imi-N-Tanout fault zone in the north and (2) Tizi-N-Test shear zone to the south (Fig. 1b). It is comprised mainly of Precambrian and Paleozoic formations folded, metamorphosed and granitised by the Variscan orogeny and unconformably overlain by Mesozoic to Cenozoic cover. The stratigraphic series of the basement consists of a succession of about 600–1000 m of Ediacaran to Ordovician metasedimentary and volcanoclastic sequences (Piqué et al. 2002; Ezzouhairi et al. 2008 *and references therein*). The oldest

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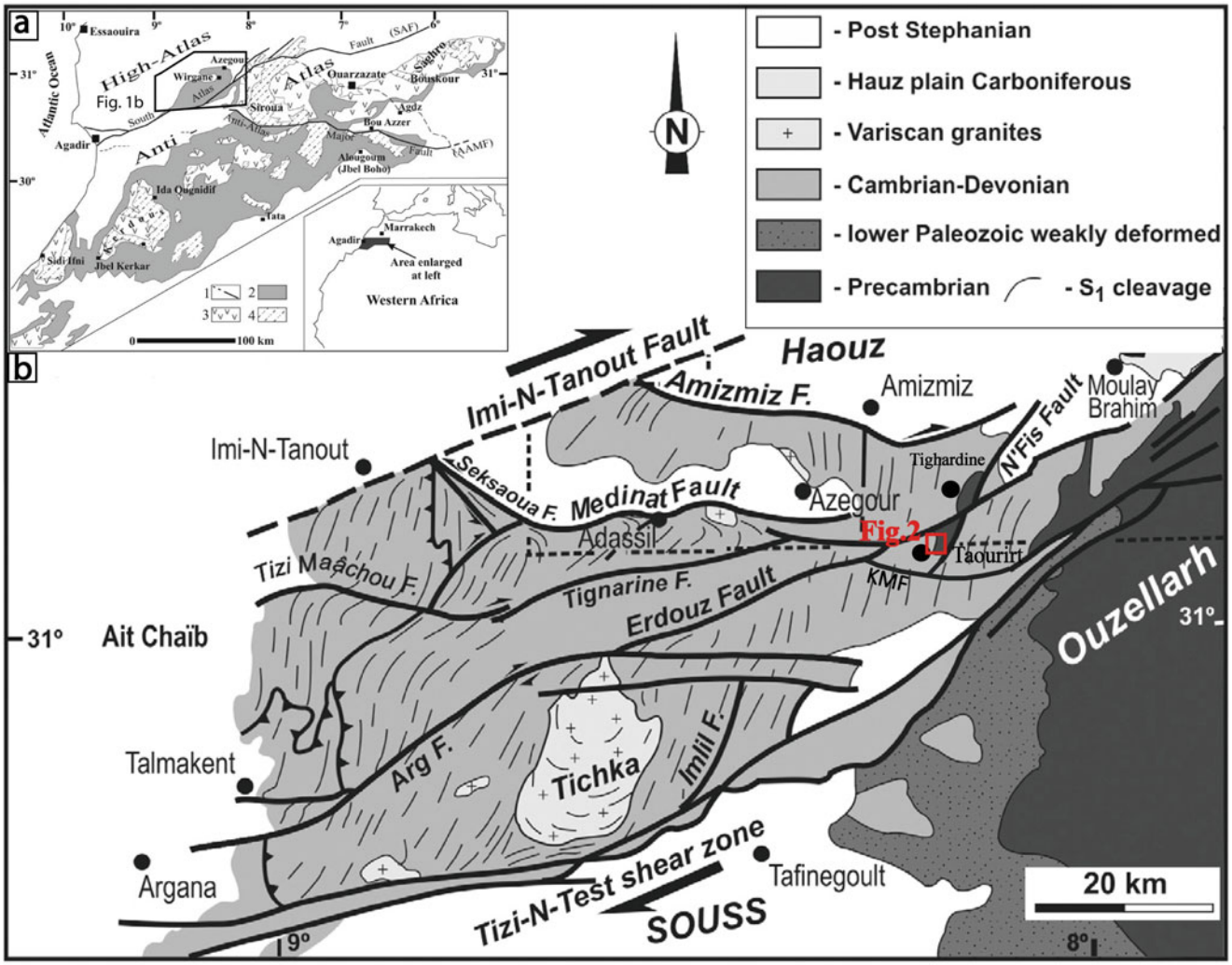

Fig. 1 (a) Simplified geological map showing the Proterozoic to the Early Cambrian formations in the High Atlas and Anti-Atlas domains (1, Fault; 2, Lower Cambrian; 3, Late Neoproterozoic; 4, Palaeoproterozoic and Early Neoproterozoic) (Ezzouhairi et al. 2008), and (b) Structural outline of Western High Atlas (Dias et al. 2011; modified)

terrains in this area are the Wirgane granodioritic intrusion and The Tighardine volcanic complex (including basalt, andesite and dacites) dated at about 625 ± 5 by Eddif et al. (2007) and c. 596–603 Ma by Boukerrou et al. (2018).The age of this volcanism is synchronous with the rhyolites age from the lower part of the Ouarzazate Supergroup in the Anti-Atlas belt at the northern WAC margin (Blein et al. 2014; Walsh et al. 2012).

3 Results

3.1 Taourirte Area: Mapping, Units and Field Relations

Detailed field observations, in the scope of this work, on the Taourirte area (Fig. 2) allowed to establish a new lithostratigraphic synthesis. The investigated area includes three volcanic and volcano-sedimentary units deposited on the early Ediacaran Takoucht-Wirgane granodiorites (625 ± 5 Ma; (Eddif et al. 2007)) and covered in discordance by a mudstone and siltstone formation assumed to be Cambrian in age.

The lower volcanic unit (LVU) is formed by basalt to the andesite lava flow, unconformably deposited on the Ediacaran granodiorite. The middle unit (MVU) is mainly volcano-sedimentary. It is formed by shale and tuffaceous siltstone including dolomitic and pyroclastic breccia layers and lenses. The lava flows are less abundant in this unit and are reduced to small lenses of basalt–andesite with few differentiated rocks. The upper volcanic (UVU) unit is formed mainly by a substantial basaltic to andesitic lava flow. The correlation with the stratigraphic column of Tighardine shows that the two areas have the same

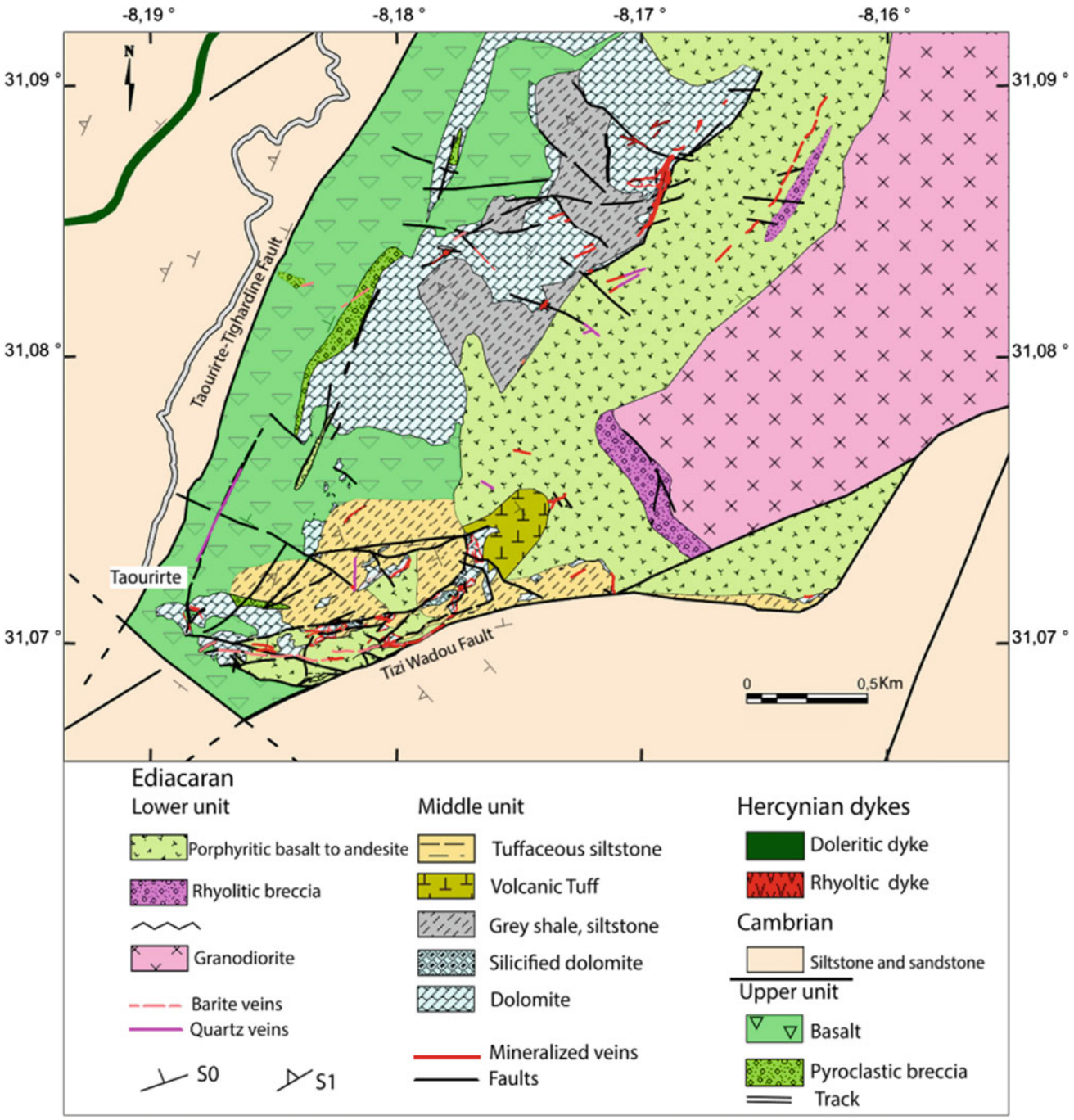

Fig. 2 Geological map of the Taourirte area

stratigraphic succession with significant variations in thickness. Indeed, the Taourirte area exhibits relatively thick volcanic and volcano-sedimentary formations. However, dolomitic beds and lenses are less developed. According to Froitzheim et al. (1988), the formation thickness is controlled by the inherited substrate morphology and syngenetic faults occurring in late Precambrian time.

3.2 Petrography

The Taourirte volcanic rocks have a quite similar mineral composition. They are microlitic to hyalo-microlitic, more or less porphyritic phenocrysts. Primary minerals have been partially to severely transformed into secondary minerals owing to low-grade metamorphic processes. The basal unit

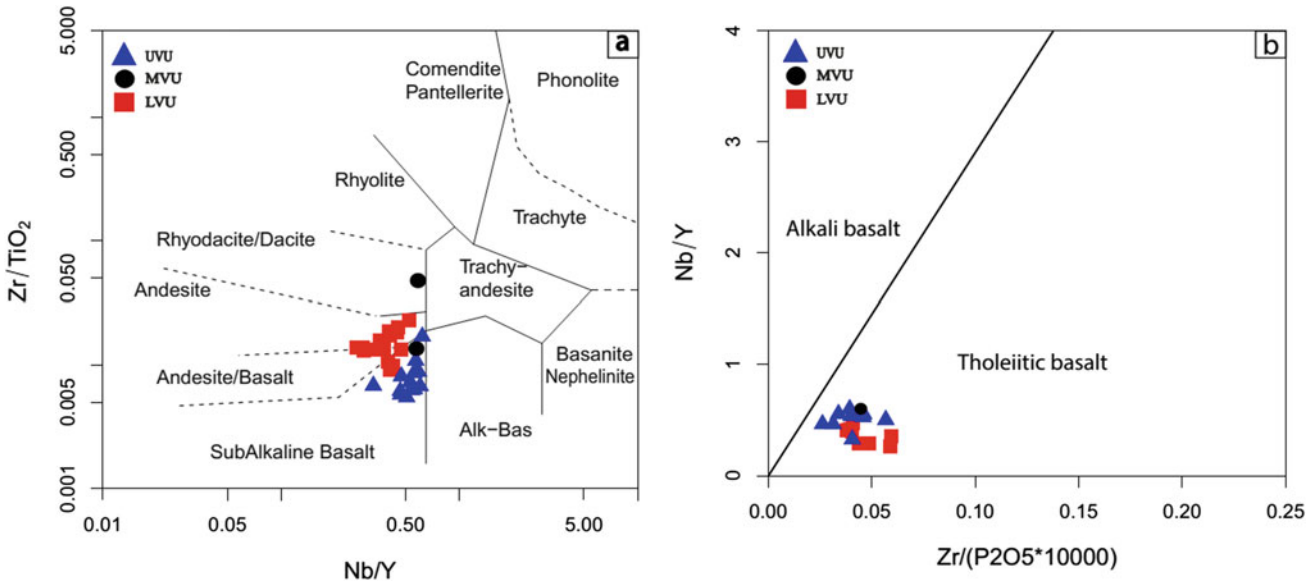

Fig. 3 **a** Classification of Taourirte volcanic rock on the Zr/TiO_2 vs Nb/Y diagram of Winchester and Floyd (1977); **b** (Winchester and Floyd 1977) diagram's Nb/Y vs. $Zr/P_2O_5*10^4$ discrimination diagram of Taourirte mafic volcanic rocks (*LVU: lower volcanic unit; MVU: middle volcanic unit; UVU: upper volcanic unit*)

is formed mainly by lava flow composed by Plagioclase phenocryst-bearing andesites, locally containing aphanitic basalt lenses. The middle unit is formed by andesites, basalt–andesites, basalts, tuffs and pyroclastic breccias with pelitic and carbonates intercalations. The summit unit is essentially a huge basaltic to andesitic lava flow.

3.3 Geochemistry

The studied metabasites cover a wide compositional range from basalt to rhyolite. Silica content ranges from 47.32–58.37 wt%, 52.43–72.05 wt% and 46.24–59.31 wt% from lower to upper units. Such silica variations allow the classification of the LVU into basalts to andesites, and the MVU as basalts with minor rhyolites and the UVU is ranging from basalts to andesites. Based on Nb/Y versus Zr/TiO_2 classification by Winchester and Floyd (1977), confirming the petrographic conclusions, the Taourirte metabasites are basalts to rhyodacites with a subalkaline signature (Fig. 3a, b).

Examining only metabasites with SiO_2 lower than 55 wt % and MgO higher than 4.5 wt%, in which most HFSE, Th and REE are incompatible, the Zr/Th, Nb/Ce and $TiO_2/P2O_5$ ratios are higher in the UVU and allow distinguishing these rocks from the other metabasites.

4 Discussion

In the commonly used Zr/Y versus Zr diagram of Pearce and Norry (1979) (Fig. 4a), Th/Ta versus Yb of Schandl and Gorton (2002) (Fig. 4b) and Zr-Nb-Y triangular diagram of Meschede (1986) (Fig. 4c), most of the Taourirte metabasites plot in the within plate basalt field suggesting an enriched mantle-derived source. It is noteworthy that the Ti/Y ratio is higher in the within-plate basalts than other basalts (Rollinson 1996). In the metabasites studied, the Ti/Y ratio varies from 240 to 1200 and the Zr/Y ratio from 5.43 to 12.08, supporting their derivation from an enriched mantle source.

Crustal contamination may occur during the mantle source melting or throughout melt ascension (Hawkesworth and Calsteren 1983). Chondrite- and primitive mantle-normalised plots are commonly used in an attempt to quantify this effect. The Nb-anomaly observed in such diagrams is indicative of the tectonic setting and reflects the effects of subducted slab or crustal contamination during magmatic processes (Gower and Swinden 1991). Plots of the average of Taourirte mafic rocks ($SiO_2 < 52$ wt% and $MgO > 5$ wt%) on a primitive mantle-normalised multi-element diagram (Sun and Mc Donough 1989) show a high enrichment of Ba, Rb, La and Ce with depletion of Sr in all

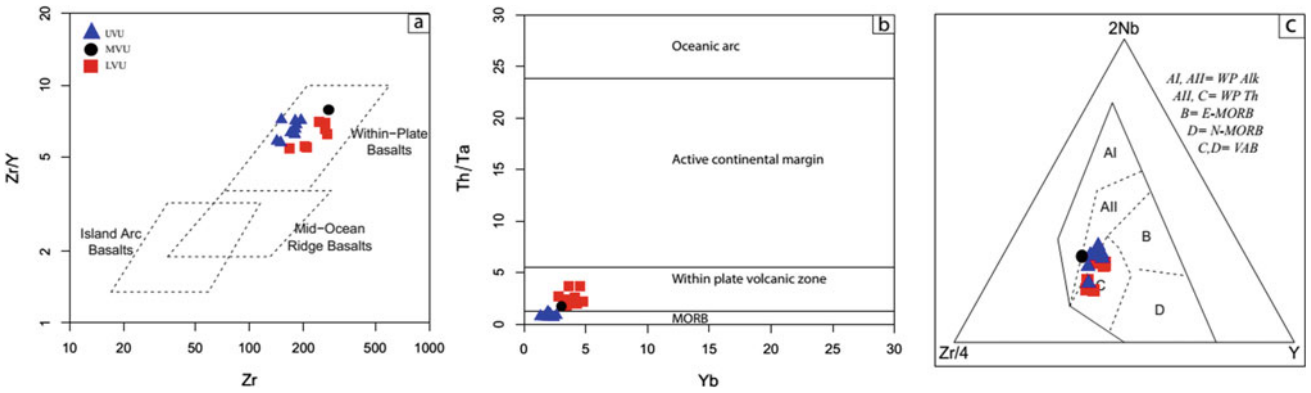

Fig. 4 Tectonic setting discrimination diagrams for Taourirte mafic volcanic rocks. **a** Zr vs Zr/Y (Pearce and Norry 1979); **b** Yb vs Th/Ta (Schandl and Gorton 2002); **c** Zr–Nb-Y triangular diagram (Meschede 1986); (*E-MORB: Enriched Mid-Ocean Ridge Basalt, N-MORB: Normal Mid-Ocean Ridge Basalt, VAB: Volcanic Arc Basalt, WP Alk: Within-Plate Alkaline, WP Th: Within-Plate Tholeiite*)

of the rocks studied. The metabasites from the lower and middle units are distinguished by their Nb negative anomaly and a flat slope between Ti and Yb (Fig. 5). Spectra of these metabasites are very similar to those of continental tholeiites of the Siroua Inlier (Fig. 5). The metabasites from the upper unit have no Nb-anomaly, exhibit enrichment in Nb compared to Th and depletion in Nb relative to La. This implies increased crustal contamination in lower and middle metabasites. Such variation in within plate environment supposes a setting up of lower and middle volcanic unit in a continental break-up region. With intensified extension, the upper volcanic unit took place in a relatively thinning crust.

Magmatic activity of the Early Ediacaran age has also been reported from the base of the Ouarzazate Supergroup (e.g. Tadmant and Tamriwine rhyolites, 606 ± 6 Ma and 605 ± 9 Ma (Thomas et al. 2002), Oued Alqantrat rhyolite, 588 ± 4 Ma (Walsh et al. 2012); Amlouggui tonalite, 586 ± 8 Ma (Thomas et al. 2002).

The Taourirte formation would be, therefore, a lateral equivalent of the Ouarzazate Supergroup, particularly the Bou Salda formation in Siroua inlier, which displays numerous similarities with the Taourirte sequence. According to Thomas et al. (2002), the Bou Salda formation was deposited in narrow fault-bound grabens. The Ediacaran Ouarzazate Supergroup remains a debate. All authors agree that volcanic and plutonic activities from its base display a high K-calc-alkaline affinity (Thomas et al. 2002; Gasquet et al. 2005); Ennih and Liégeois 2008; Walsh et al. 2012; Blein et al. 2014) and took place during a post-collisional stage.

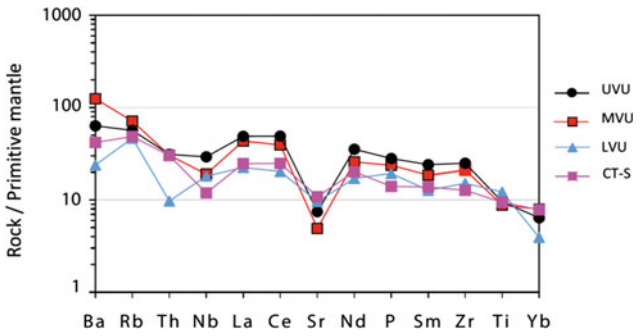

Fig. 5 Spider diagrams normalised to primitive mantle (Sun and Mc Donough 1989) for the average of Taourirte mafic volcanic rocks. Comparison with Siroua continental tholeiit (*CT-S*) (Touil et al. 2008)

5 Conclusion

The study of the early Ediacaran volcanic event in Taourirte area in Moroccan High Atlas allows us to distinguish three units dominated by volcanic and volcano-sedimentary rocks with interlayered dolomite beds and lenses. Geochemical and petrological studies performed on volcanic rocks of the Taourirte formation show that they are basalts, basalt–andesites and andesites with a few acidic derivatives. These rocks have geochemical signatures of intracontinental tholeiites, whose parental magmas should have been derived from an enriched mantle source, consistently with an extensional continental setting. The age of this volcanic activity is synchronous with the post-collisional stage of the Pan-African orogeny in the northern border of the West African Craton.

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