



HAL
open science

Petrogenesis of late Ediacaran volcanic rocks of the Kerdous and Tagragra d'Akka inliers (anti-atlas Morocco): Involvement of slab-failure

Olivier Blein, Thierry Baudin, Philippe Chevremont, Dominique Gasquet

► To cite this version:

Olivier Blein, Thierry Baudin, Philippe Chevremont, Dominique Gasquet. Petrogenesis of late Ediacaran volcanic rocks of the Kerdous and Tagragra d'Akka inliers (anti-atlas Morocco): Involvement of slab-failure. *Journal of African Earth Sciences*, 2023, 199, pp.104831. 10.1016/j.jafrearsci.2023.104831 . hal-03938018

HAL Id: hal-03938018

<https://hal.science/hal-03938018>

Submitted on 13 Jan 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Journal Pre-proof

Petrogenesis of late Ediacaran volcanic rocks of the Kerdous and Tagragra d'Akka inliers (anti-atlas Morocco): Involvement of slab-failure

Olivier Blein, Thierry Baudin, Philippe Chevremont, Dominique Gasquet



PII: S1464-343X(23)00004-3

DOI: <https://doi.org/10.1016/j.jafrearsci.2023.104831>

Reference: AES 104831

To appear in: *Journal of African Earth Sciences*

Received Date: 28 October 2022

Revised Date: 16 December 2022

Accepted Date: 5 January 2023

Please cite this article as: Blein, O., Baudin, T., Chevremont, P., Gasquet, D., Petrogenesis of late Ediacaran volcanic rocks of the Kerdous and Tagragra d'Akka inliers (anti-atlas Morocco): Involvement of slab-failure, *Journal of African Earth Sciences* (2023), doi: <https://doi.org/10.1016/j.jafrearsci.2023.104831>.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2023 Published by Elsevier Ltd.

1 **Petrogenesis of late Ediacaran volcanic rocks of the Kerdous and Tagragra**
2 **d'Akka inliers (Anti-Atlas Morocco): Involvement of slab-failure**

3 Olivier BLEIN¹, Thierry BAUDIN¹⁻², Philippe CHEVREMONT¹, Dominique GASQUET³

4 ¹ BRGM, ISTO, UMR 7327, 3 av. Claude Guillemin, BP 36009, 45060 Orléans Cédex, France,

5 o.blein@brgm.fr

6 ORCID : 0000-0003-3514-9641

7 ² CNRS/ISTO, UMR 7327, 1A rue de la Férollerie, 45071 Orléans Cédex, France

8 ³ Université Savoie Mont Blanc, Laboratoire EDYTEM, UMR 5204 CNRS, Bâtiment Pole Montagne,
9 Campus Scientifique, 73376 Le Bourget du Lac, France.

10 **Keywords.** Anti-Atlas, Ediacaran, ignimbrite, silicic LIPs, slab failure.

11 **ABSTRACT**

12 Late Ediacaran rocks of the Ouarzazate Group define a thin pile of sediments and pyroclastic deposits
13 between the Paleoproterozoic basement and the Cambrian sedimentary cover in the southern Kerdous
14 and Tagragra d'Akka inliers. In the Tafeltast area, terrigenous sediments with volcano-sedimentary and
15 pyroclastic rocks are located in grabens controlled by syn-sedimentary normal faults. The sedimentation
16 is characterized by a maximum flooding outlined by the Agoujgal carbonates. In the Tagragra-n-
17 Daouizid, the Ouarzazate Group represents the surficial emission of rhyolitic pyroclastic flows. This
18 pyroclastic activity was associated with continental coarse-grained sedimentary deposits. In the
19 Tagragra Ouahallal, the volcanic sequence is comparable to that observed in subglacial volcanoes.
20 Massive ash layers, intrusive pillow lavas in waterlogged deposits, stacking of lava flows, alternation of
21 emerged and submerged periods under shallow water, are characteristics described in sub-glacial mafic
22 volcanoes.

23 According to geochemical data, volcanic rocks of the Ouarzazate Group are: (i) mafic rocks with
24 continental flood basalt and calc-alkaline basalt affinity; (ii) high-K calc-alkaline felsic rocks, generated
25 by partial melting of crustal lithologies, or by an enriched mantle with involvement of crustal component;
26 and (iii) intermediate to felsic slab failure rocks derived through mantle processes including melting of
27 mafic upper portion of the subducted slab (Hildebrand and Whalen, 2017).

28 **1. Introduction**

29 In southern Morocco, the Anti-Atlas belt is characterized by inliers of Precambrian basement
30 unconformably overlain by a late Ediacaran to Palaeozoic sedimentary cover (Fig. 1). This Precambrian
31 bedrock is composed of: (1) Paleoproterozoic metamorphosed sediments and plutonic rocks; (2)
32 Cryogenian oceanic volcano-sedimentary rocks affected by the Pan African tectonics; (3) Early
33 Ediacaran continental volcano-sedimentary rocks affected by the last Pan African tectonic events; and
34 (4) and Late Ediacaran voluminous pyroclastic rocks (Ouarzazate Group).

35 Geological mapping, petrographic, geochemical and geochronological studies indicate that Ediacaran
36 volcano-sedimentary sequences consist of basaltic to rhyolitic lavas, dacitic to rhyolitic ignimbrite and
37 volcanoclastic rocks of variable thickness (Choubert, 1963; Hassenforder, 1987; Ouguir et al., 1996;
38 Youbi, 1998; Fekkak et al., 2000, 2003; Bajja, 2001; Piqué, 2003; Thomas et al., 2002, 2004; Gasquet
39 et al., 2005, 2008; Walsh et al., 2012; Blein et al., 2014b; Karaoui et al., 2014, 2015; Errami et al., 2020;
40 Yajjoui et al., 2020). These deposits formed in active tectonic settings, such as a rift or more probably
41 in transtensional and transpressional deformation zone (Doblas et al., 2002; Thomas et al., 2004;
42 Gasquet et al., 2005, 2008; Blein et al., 2014b; Errami et al. 2020). Understanding of these essential
43 felsic pyroclastic deposits highlights the late stage of the Pan-African orogeny.

44 Geological survey, within the framework of the Moroccan National Project of Geological Mapping
45 (1/50,000 scale sheet map of Sidi Bou'addi, Tamazrar, Awkarda and Tlatat Ida Gougmar), gave
46 opportunities to acquire new geological, geochemical, and geochronological data in the Kerdous massif
47 and the Tagragra d'Akka (Chalot-Prat et al., 2001; Gasquet et al., 2001; Roger et al., 2005; Chèvremont
48 et al., 2005). The volcanic and sedimentary deposits of the Ouarzazate Group crop out episodically
49 between the Paleoproterozoic poly-structured basement and the Paleozoic sedimentary cover.

50 The objectives of this publication are: (i) a better constraint of the lithological units of the western Anti-
51 Atlas; (ii) to present new petrographic and geochemical data on igneous rocks from the Tagragra d'Akka
52 and the Kerdous-Tafeltast inliers; (iii) to compare the two inliers; and (iv) to discuss the geodynamical
53 context at the end of the Ediacaran.

54 **2. Regional setting**

55 South of the South Atlas Fault, the Anti-Atlas belt is subdivided into three geographic domains (Fig. 1):
56 (i) the western Anti-Atlas characterized by Paleoproterozoic metamorphosed sediments and plutonic
57 rocks in the Bas Drâa, Ifni, Kerdous, Tagragra d'Akka, Tagragra de Tata, Zenaga, Iguerda, Agadir-

58 Melloul and Ighrem inliers; (ii) the central Anti-Atlas with Cryogenian island-arc – basin sequences in
59 the Sirwa massif and the Bou-Azer Inlier; and (iii) the eastern Anti-Atlas with thick Ediacaran volcano-
60 sedimentary sequences in the Saghro massif and the Ougnat inlier (Ennih and Liégeois, 2008).

61 Within the Kerdous-Tafeltast and Tagragra d'Akka inliers (Fig. 1), Precambrian rocks have been divided
62 in five main lithological units, corresponding to major geodynamic events: (1) Paleoproterozoic
63 metasedimentary schists, (2) Paleoproterozoic plutonic suites, (3) late Paleoproterozoic-
64 Mesoproterozoic sediments, (4) Ediacaran volcano-sedimentary and volcanic rocks, and (5) a late
65 Ediacaran - early Cambrian sediments.

66 **2.1. Paleoproterozoic rocks**

67 The Paleoproterozoic basement crops out in several inliers (Fig. 1; Ifni, Ighrem, Kerdous, Zenaga,
68 Tagragra d'Akka etc.), and is composed of metamorphic and magmatic rocks (Aït Malek et al., 1998;
69 Thomas et al., 2002; Walsh et al., 2002; Blein et al., 2022). The metamorphic rocks consist of
70 greenschist to amphibolite facies siliciclastic rocks and migmatites (Zenaga Group). The
71 metasedimentary rocks are fine-grained sandstones with interbedded volcanic layers. In the Tagragra
72 de Tata inlier, felsic metatuffs have been dated at 2072 ± 8 Ma (Walsh et al., 2002). In the Kerdous inlier,
73 metamorphosed siliciclastic sediments are intruded by Rhyacian (2187 ± 33 Ma, O'Connor, 2010;
74 2106 ± 12 Ma, Blein et al., 2022) and Orosirian granitoids (ca. 2.04-2.06 Ga, Gasquet et al., 2004;
75 O'Connor, 2010). According to Nd model ages (Mrini, 1993; Mortaji et al., 2000), the source of these
76 siliciclastic sediments is Archean.

77 Two main Orosirian plutonic events led to the intrusion of (Gasquet et al., 2008; Blein et al., 2022): (i) a
78 calc-alkaline suite composed of diorites, monzodiorites, granodiorites and granites originating from a
79 mantle source with involvement of crustal material (Azguemerzi Suite); and (ii) peraluminous granites
80 and leucogranites originating from a crustal source (Tazenakht Suite) into the metamorphosed
81 siliciclastic rocks.

82 **2.2. Proterozoic sediments**

83 From late Paleoproterozoic, the northern edge of the West African Craton is a passive margin which
84 sediments, unconformably overlying the Paleoproterozoic basement, are termed the Lkest-Taghdout
85 Group (Zenaga, Agadir-Melloul and Iguerda inliers; Thomas et al., 2002; Blein et al., 2013; Chèvremont

86 et al., 2013; Soullaimani et al., 2013), the Lkest Group (Kerdous inlier; BGS, 2001a, b) or the Tizi
87 n'Taghatine Group (central Anti-Atlas; Bouougri and Saquaque, 2004). These sediments are quartzites,
88 siltstones and stromatolitic carbonates, and were considered as Neoproterozoic, marking the opening
89 of the Bou Azer ocean (Clauer, 1976; Bouougri and Saquaque, 2004; Thomas et al., 2004). However,
90 this assumption is now questioned since detrital zircon ages of these sediments point to a maximum
91 age of deposition around 1.8 to 1.7 Ga (Abati et al., 2010; Soullaimani et al., 2019). This age estimate is
92 corroborated by age determinations on baddeleyite and zircon ages of crosscutting mafic sills and dykes
93 (ca. 1.71 Ga: Ikenne et al., 2017, Youbi et al., 2013; ca. 1.63 Ga: Kouyate et al., 2013, Aït Lahna et al.,
94 2020), and on pegmatites (ca. 1.76 Ga: Gasquet et al., 2004).

95 **2.3. Ediacaran sedimentary and magmatic events**

96 During Lower Ediacaran (before 580 Ma), volcano-sedimentary rocks are known as the Saghro Group
97 (central and Eastern Anti-Atlas), the Anezi series (western Anti-Atlas), the Tiddiline Group (central Anti-
98 Atlas), and the Bou Salda Group (eastern Anti-Atlas). During Upper Ediacaran (after 580 Ma), volcano-
99 sedimentary rocks associated with high-level granites are known as the Ouarzazate Group throughout
100 the entire Anti-Atlas.

101 Extending from the Sirwa to Ougnat massifs, the Saghro Group is composed of ca. 6000 m thick of
102 deformed turbidites; the sedimentary cycles tend to be composed of shales, siltstones and sandstones
103 that coarse upward, with carbonates (Thomas et al., 2002; Fekkak et al., 2003; Eddif et al. 2007; Pelleter
104 et al., 2007; Michard et al., 2017). Recent U-Pb datations on detrital zircons characterized a maximum
105 depositional age of 604 ± 5 Ma (Errami et al. 2020).

106 Volcano-sedimentary rocks of the Anezi-Tiddiline-Bou Salda Group were deposited in subsident narrow
107 grabens lined to a transtensive context (Thomas et al., 2004; Blein et al., 2014a). Felsic ignimbrites of
108 the Bou Salda and Tiddiline groups have given U-Pb zircons ages of ca. 607–605 Ma (Thomas et al.,
109 2002; Blein et al., 2014a). These volcano-sedimentary rocks deposits have been deformed between
110 these last ages and ca. 580 Ma, and unconformably overlain by pyroclastic flows of the Ouarzazate
111 Group (Blein et al., 2014a).

112 Upper Ediacaran rocks (post 580 Ma) comprise sedimentary, volcano-sedimentary, pyroclastic and
113 volcanic rocks, with locally sub-volcanic granitic rocks. Pyroclastic and volcanic rocks have high-K calc-
114 alkaline to shoshonitic affinities, and plutonic rocks are essentially I- and S-type granitoids, with local A-

115 type granitoids intrusions (Thomas et al., 2002; El Baghdadi et al., 2003; Gasquet et al., 2005; Errami
116 et al., 2009; Toummite et al., 2012; Walsh et al., 2012; Blein et al., 2014b; Baidada et al., 2017; Belkacim
117 et al., 2017). U-Pb zircon ages for these intrusions range between ca. 575–542 Ma (Hawkins et al.,
118 2001; Cheilletz et al., 2002; Walsh et al., 2002; Gasquet et al., 2005; Blein et al., 2014a, b; Karaoui et
119 al., 2015). In the Central Anti-Atlas, the large variations in the thickness of the Ouarzazate Group are
120 controlled by a pronounced paleo-relief. These volcano-sedimentary rocks are locally affected by syn-
121 sedimentary deformation (SE striking folding and NE-SW faulting; Blein et al., 2014b),

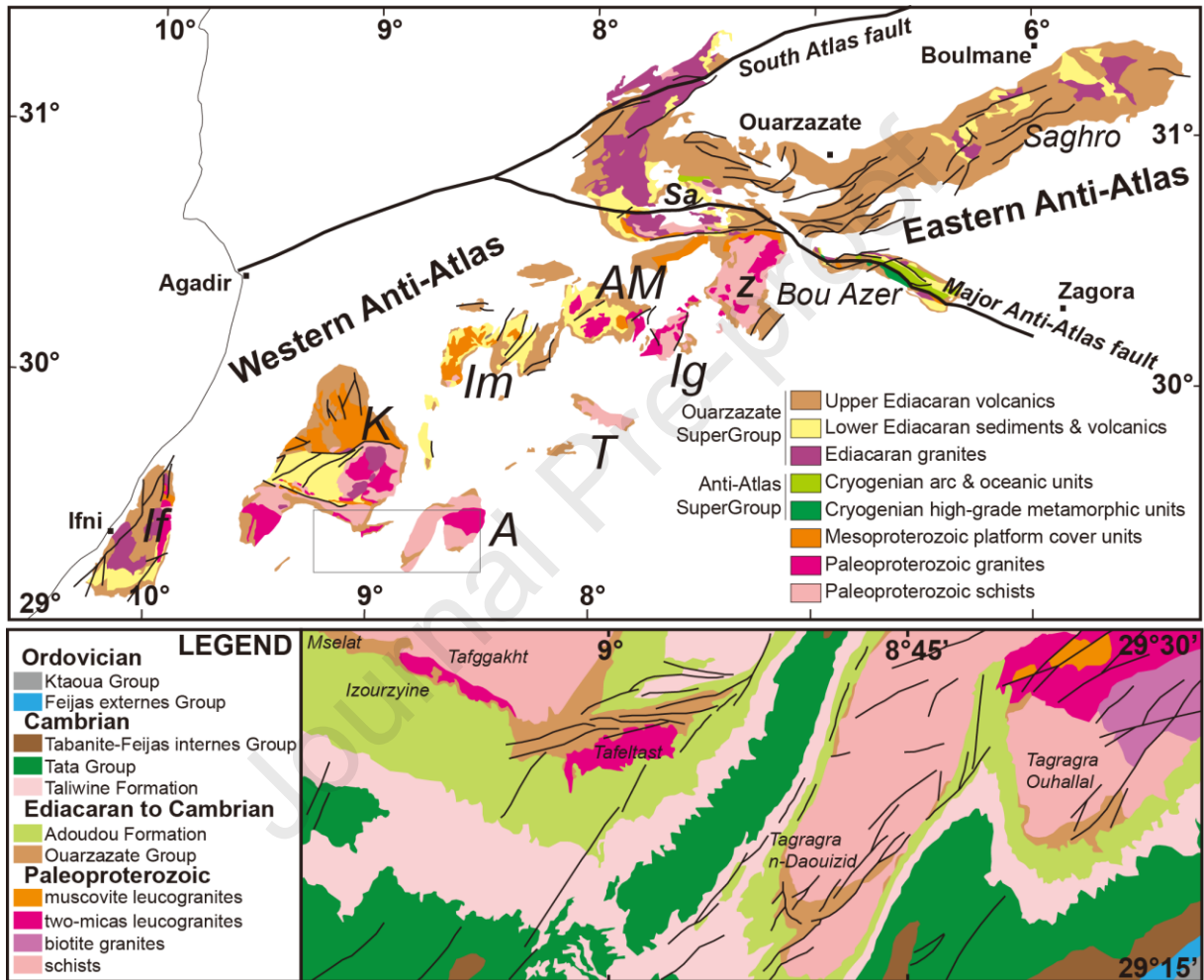
122 In the Central Anti-Atlas, the important thickness variations of the volcanoclastic Ouarzazate deposits
123 are controlled, at the first order, by an accented horst and graben paleogeography (Blein et al., 2014b).
124 Moreover, the successive volcanoclastic deposits are also linked to a syn-sedimentary tectonic event
125 such as NW-SE striking folding and NE-SW faulting (Blein et al., 2014b), suggesting contemporaneous
126 compressive and extensive zones in a transtensional regional context.

127 Two main geodynamic contexts have been proposed for the magmatism of the Ouarzazate Group: (i)
128 subduction related (Bajja, 1998; El Baghdadi et al., 2003; Benziane, 2007; Walsh et al., 2012; Hefferan
129 et al., 2014); or (ii) post-collisional with respect to the Pan-African arc-continental main collisional event
130 (Thomas et al., 2002; Gasquet et al., 2005, 2008; Toummite et al., 2012). Blein et al. (2014a, b) have
131 proposed an origin linked to a slab breakoff that occurred between ca. 580–575 Ma. The subsequent
132 magmatism following slab breakoff is felsic, and results from partial melting of continental crust.

133 **2.4. Late Ediacaran to Cambrian sedimentation**

134 The Late Ediacaran volcanic and volcano-sedimentary rocks of the Ouarzazate Group are
135 unconformably overlain by a thick carbonate to clastic sedimentary cover comprising from bottom to top:
136 (i) the transgressive late Ediacaran to early Cambrian Taroudannt Group, (ii) the Cambrian Tata Group,
137 and (iii) the Cambrian to Ordovician transgressive groups of internal Feijas, Tabanite, external Feijas,
138 and Ktaoua. The Taroudannt Group is composed by the carbonate-dominated Adoudou Formation and
139 the terrigenous-carbonate-dominated Taliwine Formation, which is dominantly carbonate westward and
140 exclusively terrigenous further east (Choubert, 1952, 1953a, b). Carbonates of the Adoudou Formation
141 have microbial origin structures, and characterize a regional subsidence context responsible for the
142 progressive flooding of the Anti-Atlas, from West to East (Boudda et al., 1979; Geyer, 1990; Benssaou
143 and Hamoumi, 2001; Alvaro et al., 2005, 2014). Locally, volcanic lavas occur interbedded within

144 sediments of the uppermost part of the Adoudou Formation. This context is interpreted as continental
 145 rifting (Piqué et al., 1999; Benssaou and Hamoumi, 2001, 2003; Soulaïmani et al., 2003).
 146 U/Pb age determinations from the Boho volcano (529 ± 3 Ma; Ducrot and Lancelot, 1977) and from the
 147 Aghbar trachyte sill (531 ± 5 Ma; Gasquet et al., 2005) suggests a Cambrian age for the Adoudou
 148 Formation, in which they are interlayered. Recently, an older U-Pb late Ediacaran age (542 ± 5 Ma; Blein
 149 et al., 2014b) has been obtained on volcanic breccia at the base of the Adoudou Formation.



150
 151 **Figure 1:** Precambrian geology of the Anti-Atlas inliers (modified from Hollard et al.1985, Walsh et al.
 152 2002, and Gasquet et al. 2008). A: Tagragra d'Akka; AM: Agadir-Melloul; BD: Bas Drâa; If: Ifni; Ig:
 153 Iguerda; Im: Igherm; K: Kerdous; Sa: Sirwa; T: Tagragra de Tata).

154

155 3. Field relationships and petrography

156 Geological mapping, carried out within the National Geological Mapping Plan of Morocco, allows to
157 establish a new lithostratigraphic chart of the Proterozoic rocks (Thomas et al., 2004). In discontinuity
158 with the Anti-Atlas Supergroup (800-680 Ma), the Ouarzazate Supergroup (615-542 Ma) is
159 characterized by continental deposits and post-orogenic magmatism accumulates in a graben system.
160 The Ouarzazate Group defined on the present Awkarda map sheet, as well as on the eastern sheets of
161 Sidi Bou'addi and Tamazrar is the upper part of the Ouarzazate Supergroup defined by Thomas et al.
162 (2004). In the entire Anti-Atlas, the deposits of the Ouarzazate Group are included in an age range
163 between ca. 575–542 Ma (Hawkins et al., 2001; Cheilletz et al., 2002; Walsh et al., 2002; Gasquet et
164 al., 2005; Blein et al., 2014a, b; Karaoui et al., 2015).

165 The Ouarzazate Group is mainly composed of fluvial-lacustrine deposits accumulated in small basins
166 bordered by high levels (Tagragra Ouhallal, Tagragra-n-Daouizid, Tafeltast, and south of Zawyat-n-
167 Dougadir; Fig. 1). This sedimentation is contemporary with volcanic and pyroclastic flows. Volcanic and
168 sedimentary deposits accumulate on the margin of narrow grabens, and exhibit high lateral and upward
169 variations. Volcanic and sedimentary rocks are sub-conformably overlain by the late Ediacaran
170 sediments of the Adoudou Formation.

171 3.1. Kerdous inlier

172 In the Tafeltast area, the Ouarzazate Group is composed of sediments with few volcano-sedimentary
173 rocks, and high vertical and lateral variations (Figs. 2A and 3), with a thickness ranging between 0 to
174 250 m. Volcano-sedimentary deposits are located in a NE striking narrow half-graben controlled by syn-
175 sedimentary normal faults. The NW limit is a SE dipping normal fault, and the SE limit is the top of a
176 tilted block. The Ouarzazate Group is conformably overlain by late Ediacaran marine sediments
177 (Adoudou Formation), which are contemporaneous with a less and less active syn-sedimentary
178 extensive tectonism.

179 The Ouarzazate Group sediments were deposited in a fluvial-lacustrine setting in a tectonic and
180 magmatic active system. The fluvial-lacustrine sediments unconformably overlie the Paleoproterozoic
181 basement with a basal sedimentary breccia. This breccia rapidly evolves laterally and upward to finer
182 silts (the lower silts facies, Fig. 3). The vertical aggradation of the rapid limit between breccia and
183 siltstone indicates a progressive deepening of the graben during the Upper Ediacaran. In the middle of
184 the sedimentary pile, breccia and silts are overlain by a carbonate sedimentation, the Agoujgal
185 carbonates (a carbonate key bed), which marks a maximum flooding (Figs. 2A and 3).

186 This lacustrine sedimentation presents therefore a complete transgressive and regressive cycle. The
187 basal and lateral breccia reaches one to 20 m thickness and includes heterometric blocks of
188 Paleoproterozoic basement: schist, quartzite, gabbro, dolerite and granite. The petrography of the
189 blocks reflects the lithology of the closer Paleoproterozoic basement, suggesting a very limited transport
190 of sediments. Two types of breccia may be mapped: breccia with schists or granite dominant blocks.

191 The basal breccia with Paleoproterozoic schist blocks outlines the northern border of the Ediacaran
192 graben (Fig. 2A). The clasts, angular and unclassified, suggest a limited transport. Volcanic lenses
193 stratified in these breccias outline the occurrence of a contemporaneous volcanism. The
194 Paleoproterozoic basement is often affected by metric faulting zones with tectonic breccias. The
195 progressive change from tectonic to sedimentary breccias suggests that the first feeds the second. Basal
196 breccias are related to the development of normal faults which are at the origin of the Ediacaran grabens.

197 The basal breccia with Paleoproterozoic granite blocks outlines the southern limit of the Upper
198 Ediacaran graben (Fig. 2A). Breccias result from reworking of a granitic arena on a slight slope dipping
199 to the north, and are pinching out to the south. Then, the Paleoproterozoic basement is overlain by the
200 last volcanic flows of the Ouarzazate Group, or by the sediments of the Adoudou Formation. This setting
201 suggests the existence of paleo-relief with horst structure composed of Paleoproterozoic basement to
202 the south.

203 The Agoujgal carbonates, representing a maximum flooding surface, are a key bed in the Ediacaran
204 sedimentary sequence of the Tafelst area. The number and thickness of carbonate levels increase
205 from the southern border to the middle of the basin. In the central part of the basin, six carbonate levels
206 with a decreasing thickness from 25 to 3 meters have been observed. The basal carbonate level crops
207 out from the southern border to the center of the basin. The Agoujgal Formation is characterized by the
208 following stratigraphic facies: i) the basal calcareous of Agoujgal; ii) alternating between carbonate,
209 siltstone and volcanic rock; and iii) alternating between carbonate, conglomerate and volcanic rock. The
210 two latter associations are contemporaneous. They overlie the basal carbonate level. The Agoujgal
211 carbonates are composed of light dolosparite stratified in decimetric beds. This lithofacies is
212 characterized by an algo-bacterial lamination, that is often silicified, and quartz-rich fine layers. Few
213 rhyolitic lenses are interbedded in these carbonates.

214 Alternating carbonates, siltstones and volcanic rocks (metric to decametric thickness) mark the
215 beginning of the regressive interval which results in a decreasing number, extension and thickness of
216 the carbonate levels in favor of the silty terrigenous sedimentation. Towards the top, carbonates and
217 volcanic rocks tend to disappear, giving way to the purely terrigenous sedimentation of the upper
218 siltstones.

219 On the southern edge of the graben, siltstones are laterally replaced by conglomeratic deposits, which
220 prograde and end up the upper conglomerates. Interlayered and lenticular volcanic emissions occur as
221 lava flows, ignimbrites or block lava flows.

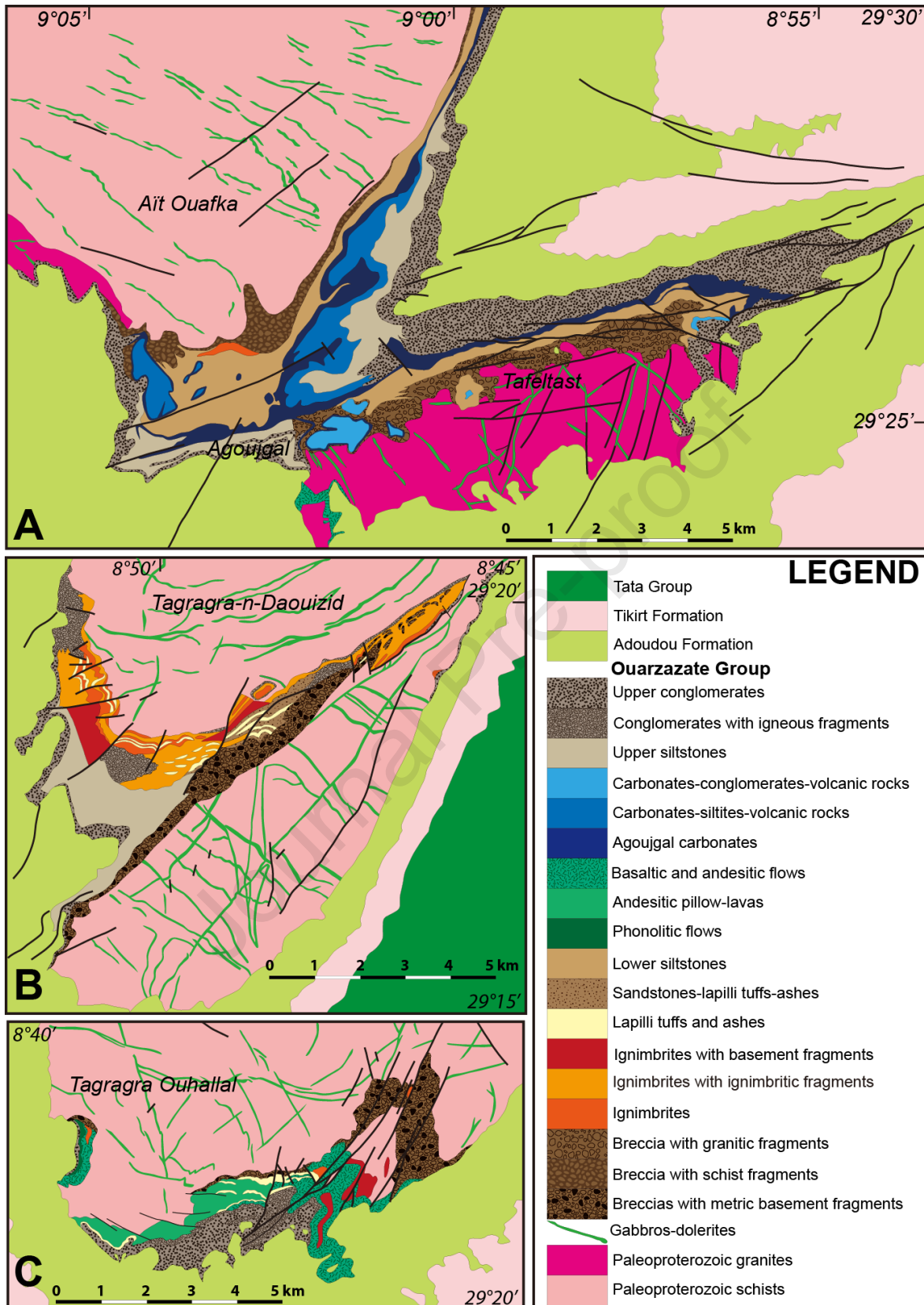
222 Volcanic deposits are localized on the emerging borders of the basin, and in lenses interbedded in the
223 sediments of the Agoujgal Formation (Figs. 2A and 3). Volcanic rocks are basaltic lavas flows or rhyolitic
224 pyroclastic deposits, with limited geographic extension. All the emission centers rest on the
225 Paleoproterozoic granitic basement. Volcanic deposits are overlain by the last sequence of the upper
226 conglomerates or by the basal deposits of the Adoudou Formation. The volcanic activity was locally still
227 active until the basal deposits of the Adoudou Formation. This mafic volcanism is latter than one which
228 outcrops in the Tagragra Ouhallal area localised than SE. Basalts have microlitic to intersertal, more or

229 less porphyritic textures with the following mineralogy: feldspar, oxides, apatite, sericite, chlorite, calcite,
230 hydroxides with sometimes the asserted presence of altered olivine.

231 Rhyolitic pyroclastic flows form an east-west trending crest that joins the north of Mselat to the peaks
232 east of Tafggakht. They are marked in the landscape by a multi-decameter alternation of white and dark
233 colors despite their comparable chemistry. The dark color could be the result of a higher proportion of
234 glass in the matrix. Pyroclastic flows are locally separated by lapilli tuffs of multi-decimetre thickness.
235 North of Mselat, the first volcanic level is a dark brecciated glass-clastic tuff that flows over basal
236 breccias with dominant granitic elements about 15 metres thick; the latter resting on Paleoproterozoic
237 schists. To the east and south of Tafggakht, the Paleoproterozoic granite is directly overlain by an
238 ignimbritic bedded rhyolite. These rhyolitic deposits are almost entirely covered by the upper
239 conglomerates. These conglomerates are characterized by - locally metric - rhyolitic blocks.

240 The second rhyolitic flow to the NE of Mselat, about 50 m thick, was U/Pb dated on zircon by the
241 SHRIMP method and provided an age of 561 ± 6 Ma (Chèvremont et al., 2005). This porphyritic rhyolite
242 shows a fluid glass-clastic texture with phenocrysts of feldspar, quartz, oxides, sericite, pumpellyite, and
243 micro-lapilli.

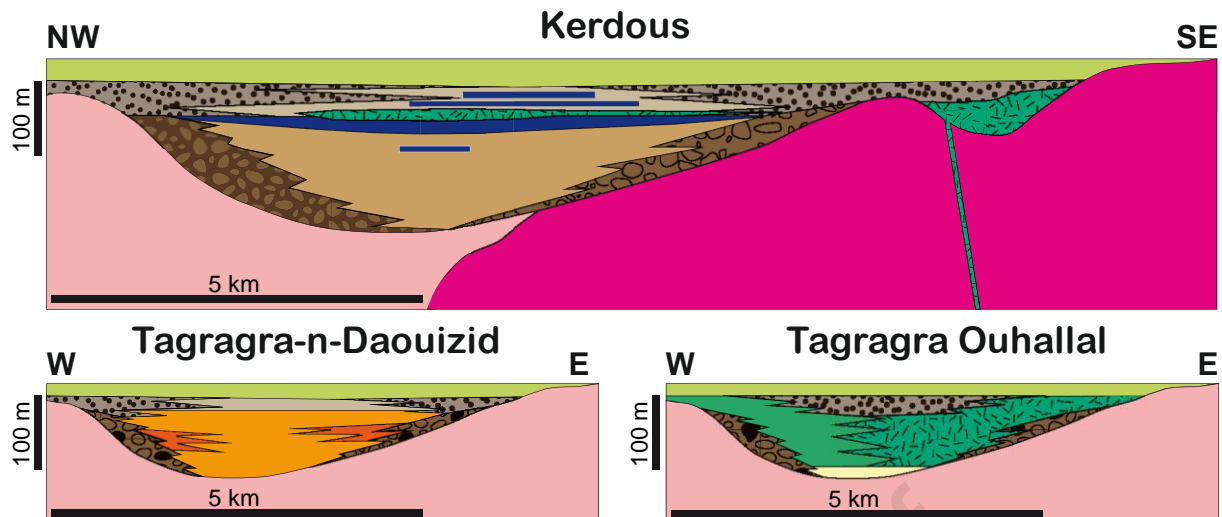
244 Andesitic to dacitic pyroclastic flows cap the tops of the Izourzine cliff and are clearly visible, with their
245 dark color contrasting with the light granite. They lie directly on the Paleoproterozoic granite and often
246 show flat- or cross-bedded ash cloud surge figures that outline gully channels and ash levels. This type
247 of structure is reminiscent of ash cloud deposits. These deposits are directly surmounted by the upper
248 conglomerates with rolled pebbles, and without volcanic elements.



249

250 **Figure 2:** Simplified geologic maps: **A.** the Kerdous inlier (Baudin et al., 2005; Hassenforder et al.,251 2001); **B.** the Tagragra-n-Daouizid area (Hassenforder et al., 2001); and **C.** the Tagragra Ouhallal

252 area (Roger et al., 2001).



253
254 **Figure 3:** Schematic distribution of the different lithostratigraphic units. Symbols as in Fig. 2.

255 3.2. Tagragra-n-Daouizid area

256 In the Tagragra-n-Daouizid area, the Ouarzazate Group is composed of conglomerates, volcano-
257 sedimentary rocks with pyroclastic rocks, and high vertical and lateral variations (Fig. 2B), with a
258 thickness ranging between 0 to 100 m. The basal chaotic breccias are characterized by heterometric
259 and heterolithic blocks, essentially substrate-derived rocks such as schist, granite, quartzite, dolerite
260 and gabbro (Figs. 2B and 3). The lithology of the clasts reflects the lithology of the local basement, the
261 distance of transport of clasts was limited. The breccias are observed at the base of clast-rich ignimbrites
262 which beginning the volcanic sequence. These breccias are not restricted to the base of the volcanic
263 sequence, they also crop out stratified in the middle and at the top of the volcanic sequence. They are
264 related to fault-controlled scarps which were activated prior to volcanic eruptions. The regular
265 occurrences of these chaotic breccias suggest that the faults were still active during all the volcanic
266 activity.

267 Sandstones stratified with lapilli tuffs and ashes are well established in the center of the volcano-
268 sedimentary sequence. Sandstones are light, fine to middle grained, and quartz-feldspathic in
269 composition. Stratified in beds, they are covered without transition with a few meter thick of chaotic
270 breccias observed at the top of an ignimbritic unit, and alternate regularly with well stratified tuffs. These
271 sandstones are river deposits in shallow water. The rapid change between breccias and sandstones,
272 suggest that the formation of the breccias is independent from the river system which control the
273 sandstone deposits.

274 On top, the Ouarzazate Group is characterized by pelitic facies such as silts. These silts are interbedded
275 with micro-conglomeratic sandstones which are more abundant at the top of the sedimentary sequence
276 (Figs. 2B and 3). These silts overlie conformably ignimbrites, conglomerates and breccias, and
277 constitute a lenticular lens in the central part of the grabens. Silts are certainly lake deposits, and mark
278 the end of pyroclastic density currents such as ignimbrites. The deposits herald the end of the maximum
279 basement deformation. However, ash fall deposits and coarse grained sandstones occur locally.

280 The youngest deposits of the Ouarzazate Group are polygenic conglomerates and coarse-grained
281 sandstones, with a large geographic extension overlying previous sedimentary and pyroclastic rocks
282 and the Paleoproterozoic rocks.

283 Ediacaran volcanism is characterized by numerous pyroclastic flows. Massive lapilli tuffs with basement
284 blocks overlie the Paleoproterozoic basement, chaotic breccias or basal conglomerates. Basement
285 blocks are derived from collapse or erosion of the eruption conduit or substrate by the density current.
286 These massive lapilli tuffs are non-welded, with little sub-rounded blocks which do not exceed one
287 centimetre in size. This lithofacies lacks internal stratification and comprises pumice, lithic lapilli, and
288 crustal fragments with a matrix of vitric ashes with crystals clasts. The thickness of volcanic deposits is
289 variable (a few m to 30 m maximum).

290 Massive homogenous welded pyroclastic tuffs cover the massive lapilli tuffs with basement blocks. This
291 ignimbrite forms massive, lenticular, 5 to 10 m thick layers, with a prismatic flow, often associated with
292 a planar flow. They are interbedded with inframetric layers of lapilli and ash tuffs or embedded within
293 thicker deposits of block ignimbrites. These ignimbrites have a vitroclastic texture, mostly unwelded and
294 uncompacted, with 40% splinters and pumice fragments in an ashy matrix. Some horizons have a
295 welded and hot compacted eutaxitic texture including a significant proportion of flames or compacted
296 pumice fragments. The lack of basement xenoliths and the great homogeneity of the material explain
297 the very frequent prismation of the deposits. The low frequency of welded tuffs means that the
298 pyroclastic flows have a relatively moderate temperature at the time of flow immobilization.

299 Ignimbrites may contain 20 to 50% of angular blocks of massive ignimbrite of very variable size. The
300 embedded blocks come from the pulverization of the older ignimbritic levels. The small width and
301 considerable number of interlocking channels suggest the successive and extremely rapid emission of
302 pyroclastic flows involving small volumes of magma.

303 Numerous fallout deposits, such as lapilli tuffs or ashes, are associated with the co-ignimbrite ash flow.
304 They are generally black, green or purplish grey rocks, and are fine- to medium-grained, relatively
305 homogeneous because they are always well sorted and locally with visible normal grading. They contain
306 40-50% volcanic fragments (crystal clasts; shredded pumice fragments), and angular xenoliths of
307 Paleoproterozoic basement, all in a matrix of very fine, siliceous ashes.

308 **3.3. Tagragra Ouhallal area**

309 In the Tagragra Ouhallal area, the Ouarzazate Group outcrops locally between the Paleoproterozoic
310 rocks and the late Ediacaran – Cambrian sediments, with a thickness ranging between 0 to 100 m (Figs.
311 2C and 3).

312 The volcanic sequence, highly diversified, consists of a succession of massive flows or pillow basalts of
313 alkaline mafic lava, and lapilli tuffs and ashes, all locally preceded by deposits of dacitic to rhyolitic
314 ignimbrites. All eruptions are continental and lenticular in nature. The sedimentary deposits consist of
315 accumulations of breccia with basement fragments, which are interbedded with conglomerate and
316 sandstone at the end of the volcanic sequence. The internal organization of the volcanic succession is
317 quite simple although it is different from east to west.

318 To the east, lava flows overlain unconformably the basement, breccias, and ignimbrites. These flows
 319 may be overlain by breccia. Flows are massive, and interstratified with lapilli tuffs and ashes. Lavas are
 320 porphyritic, and or microlitic and fluidal, with plagioclase and clinopyroxene and olivine.

321 In the western part, tubular and pillow lavas make up the bulk of the volcanic sequence. They cover
 322 either the basement, basement breccia, or massive non-layered cinerites. The first pillow lavas are
 323 secant and intrusive in finely layered lapilli tuffs and ashes. Above, pillows and tubes form extrusive
 324 lenticular units interlayered with pyroclastic breccias, hyaloclastites and finely layered tuffs. These lavas
 325 were deposited under water. They are covered by breccia with basement fragments.

326 4. Geochemistry

327 Whole-rock major and trace elements were analysed by ICP-AES and ICP-MS (CRPG-CNRS, Nancy),
 328 respectively (Tables S1, S2, and S3). Sample preparation, analytical conditions and limits of detection
 329 are detailed in Carignan et al. (2001).

330 4.1. Kerdous inlier

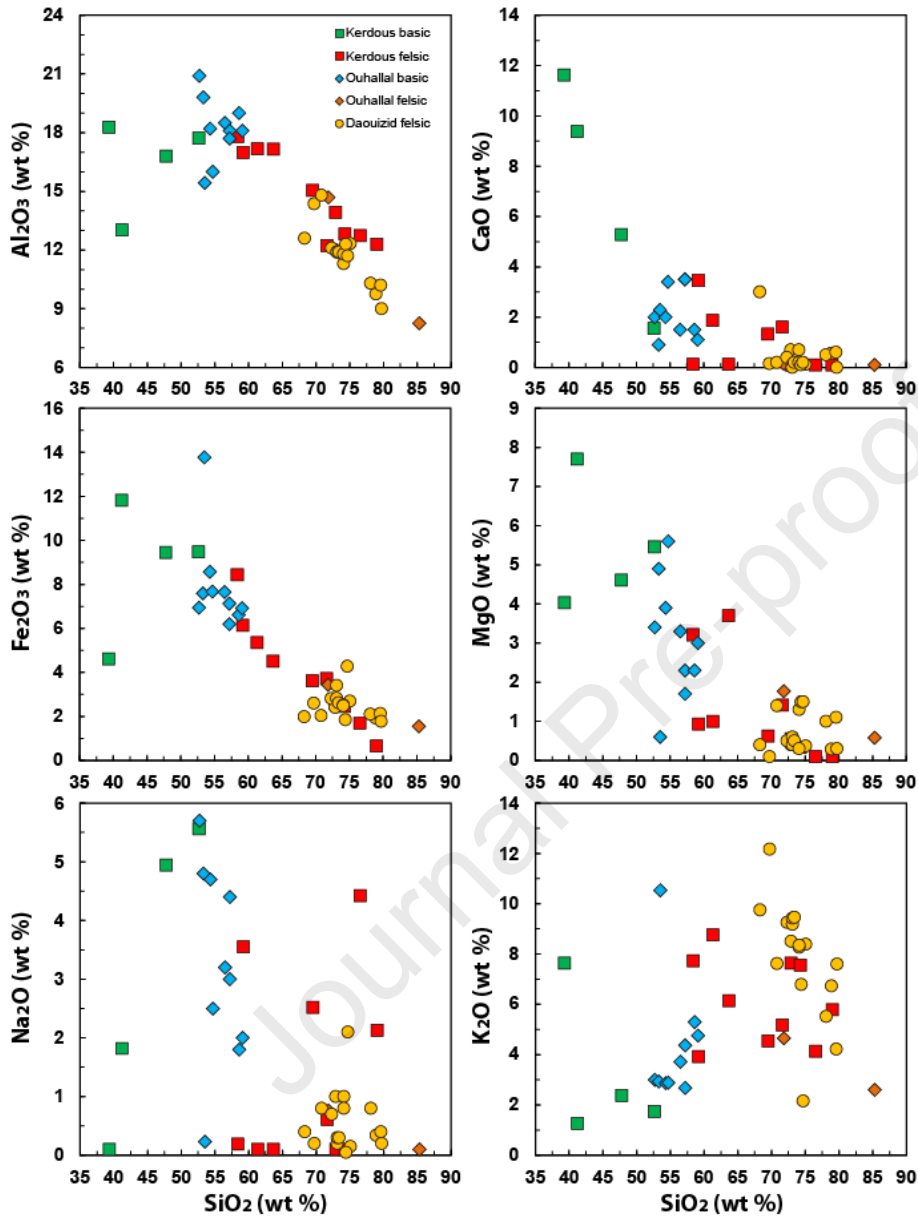
331 Four lavas are mafic in compositions ($\text{SiO}_2=39.3\text{-}52.6$ wt%), with high Al_2O_3 (13.0-18.3 wt%) and TiO_2
 332 contents (1.48-1.82 wt%), and low to high Fe_2O_3 (4.6-11.8 wt%), MgO (4.0-7.7 wt%), CaO (1.6-
 333 11.6 wt%), Na_2O (0.1-5.6 wt%), and K_2O contents (1.3-7.6 wt%; Fig. 4). Such variations on major
 334 elements are explained by a strong loss in ignition, which is generally higher than 3.5 wt%.

335 Basaltic flows display REE patterns with fractionated LREE ($2.1 < [\text{La}/\text{Sm}]_n < 4.3$), and slight or significant
 336 fractionation of HREE (Fig. 5A). The two basalts samples with the lower concentrations in LREE have
 337 $[\text{Gd}/\text{Yb}]_n$ ratios lower than 1.6. In contrast, the two other ones have fractionated HREE with $[\text{Tb}/\text{Yb}]_n$
 338 ratios higher than 2.6. Normalized to Primitive Mantle values, their patterns display negative anomalies
 339 in Ta, Nb and Ti (Fig. 6A).

340 Three samples (AWTB27, AWTB78, and AWTB44-1) have andesitic composition ($\text{SiO}_2=58.4\text{-}$
 341 61.3 wt%), with high Al_2O_3 (17.0-17.8 wt%), and K_2O contents (3.9-8.8 wt%), low to high Na_2O contents
 342 (0.1-3.6 wt.%), moderate Fe_2O_3 (5.4-8.4 wt%), and low MgO (0.9-3.2 wt%), CaO (0.1-3.5 wt%) and TiO_2
 343 contents (0.52-0.76 wt%; Fig. 4). These lavas are peraluminous with A/CNK ratio in the range 1.04–
 344 2.00, and show dominantly alkali, and magnesian to ferroan affinities (Fig. 7).

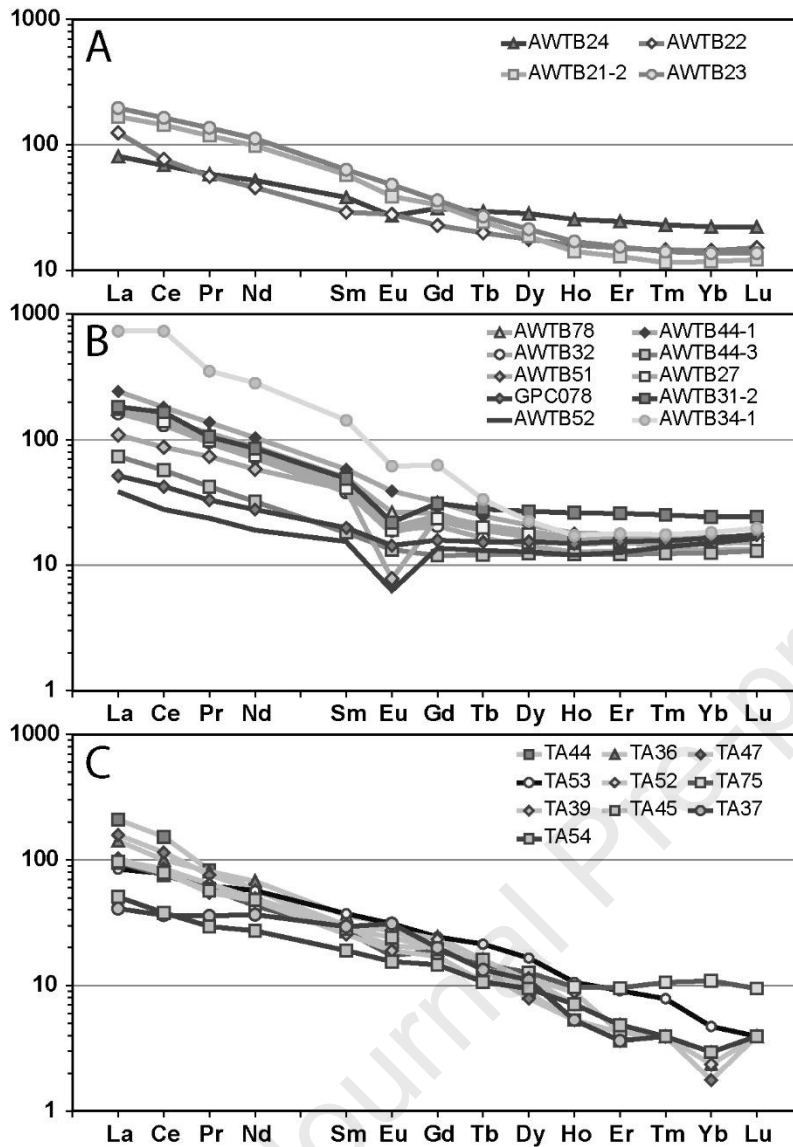
345 Intermediate lavas display REE patterns similar to basaltic lavas, with fractionated LREE
 346 ($3.5 < [\text{La}/\text{Sm}]_n < 4.3$), slightly fractionated HREE ($1.5 < [\text{Gd}/\text{Yb}]_n < 1.9$; Fig. 5B), and moderate negative Eu
 347 anomalies ($0.6 < \text{Eu}/\text{Eu}^* < 0.9$; Fig. 5B). The lack of significant HREE fractionation suggests that parent

348 liquids have been produced out of the garnet stability field. Intermediate lavas display systematic and
 349 high Ta, Nb and Ti negative anomalies relative to REE (Fig. 6B).

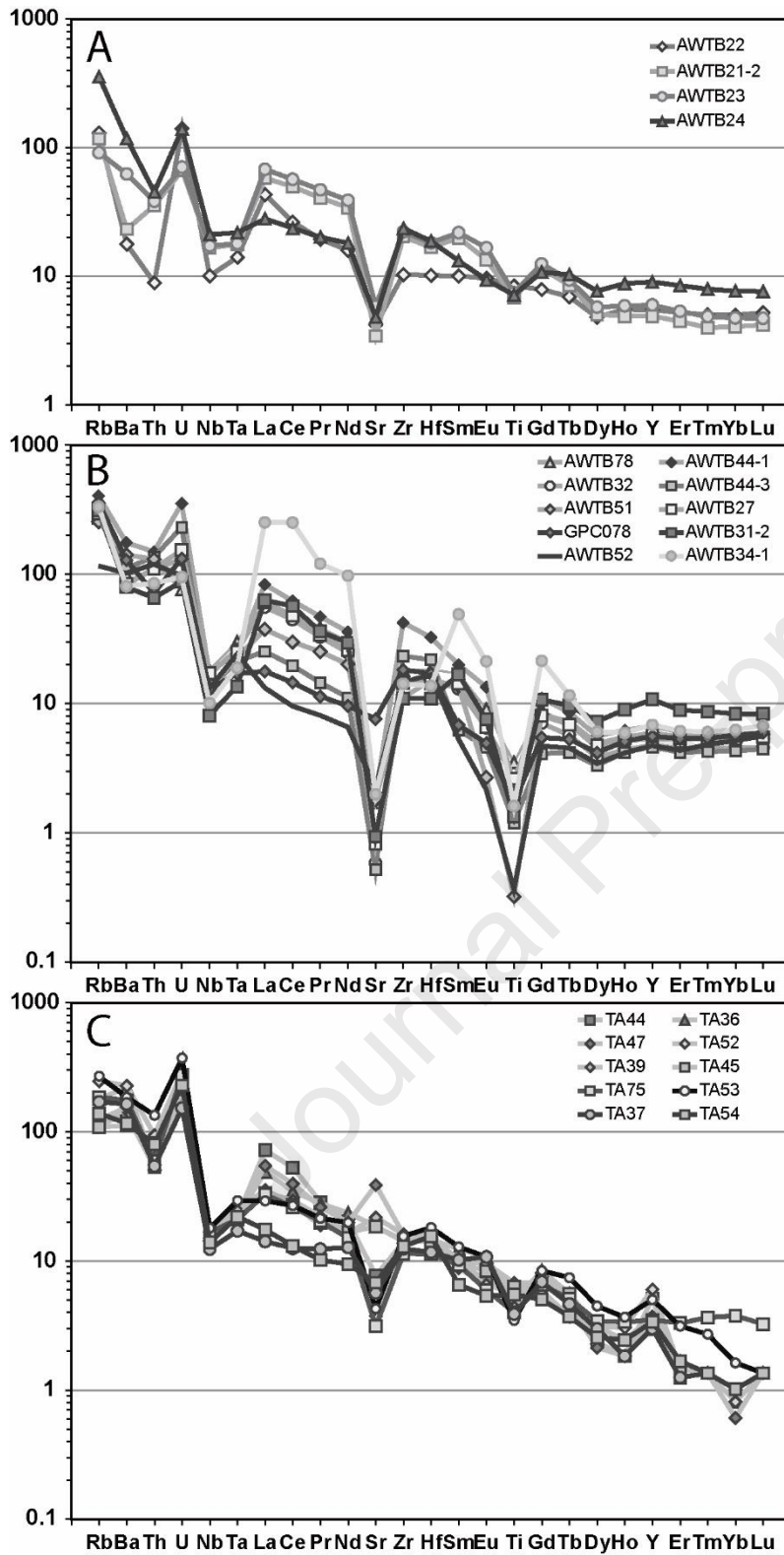


350
 351 **Figure 4:** Harker diagrams for volcanic rocks from the Ouarzazate Group.

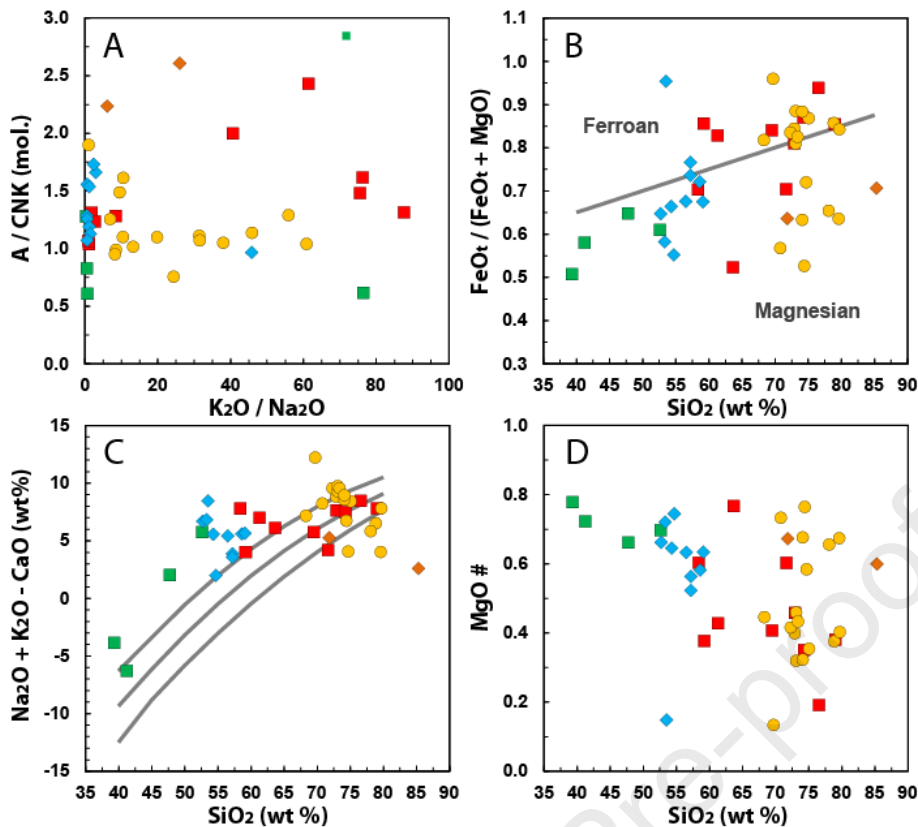
352



353
 354 **Figure 5:** Chondrite normalized rare earth element diagram of volcanic rocks from the Kerdous inlier
 355 and the Tagragra Ouhallal area. **A.** Kerdous basalts & rhyolites; **B.** Kerdous intermediate and felsic
 356 volcanic rocks; **C.** Tagragra Ouhallal samples. Normalization according to Sun and McDonough, 1989.



357
 358 **Figure 6:** Primitive Mantle normalized multi-element diagram of volcanic rocks from the Kerdous inlier
 359 and the Tagragra Ouhallal area. **A.** Kerdous basalts & rhyolites; **B.** Kerdous intermediate and felsic
 360 volcanic rocks; **C.** Tagragra Ouhallal samples. Normalization according to Sun and McDonough, 1989.



361
 362 **Figure 7:** Major-element geochemistry of the Ouarzazate Group volcanic rocks. **A.** K₂O/Na₂O vs.
 363 A/CNK; **B.** SiO₂ vs. FeO^t/(FeO^t+MgO); **C.** SiO₂ vs. MALI index ([Na₂O+K₂O]-CaO) diagram of Frost et
 364 al. (2001); **D.** SiO₂ vs. Mg#. Symbols as in Fig. 3.

365 Few samples have dacitic to rhyolitic composition (SiO₂=63.7-79.0 wt%), with high Al₂O₃ (12.2-
 366 17.2 wt%), and K₂O contents (4.1-7.6 wt%), low to high Na₂O contents (0.1-4.4 wt%), and low Fe₂O₃
 367 (0.7-4.5 wt%), MgO (0.1-3.7 wt%), CaO (0.1-1.6 wt%) and TiO₂ contents (0.07-0.57 wt%; Fig. 4). These
 368 lavas are peraluminous with A/CNK ratios in the range 1.03–2.47, and show dominantly alkali-calcic and
 369 magnesian to ferroan affinities. The K₂O/Na₂O ratios are higher than 1 (Fig. 7).

370 Rhyolitic lavas display REE patterns with fractionated LREE (2.5<[La/Sm]_n<5.2), with a high variability
 371 of LREE concentrations (38<[La]_n<730), a lack of HREE fractionation and moderate to pronounced
 372 negative Eu anomaly (0.2<Eu/Eu* <0.9; Fig. 5B). [Gd/Yb]_n ratios are generally lower than 1.6, except for
 373 one sample (AWTB34-1; Fig. 5B). The high variability in LREE contents has not been observed in high
 374 field strength elements, then negative Ta- and Nb-anomalies are less important than for intermediate
 375 lavas. But negative Ti-anomaly is systematic and high (Fig. 6B).

376

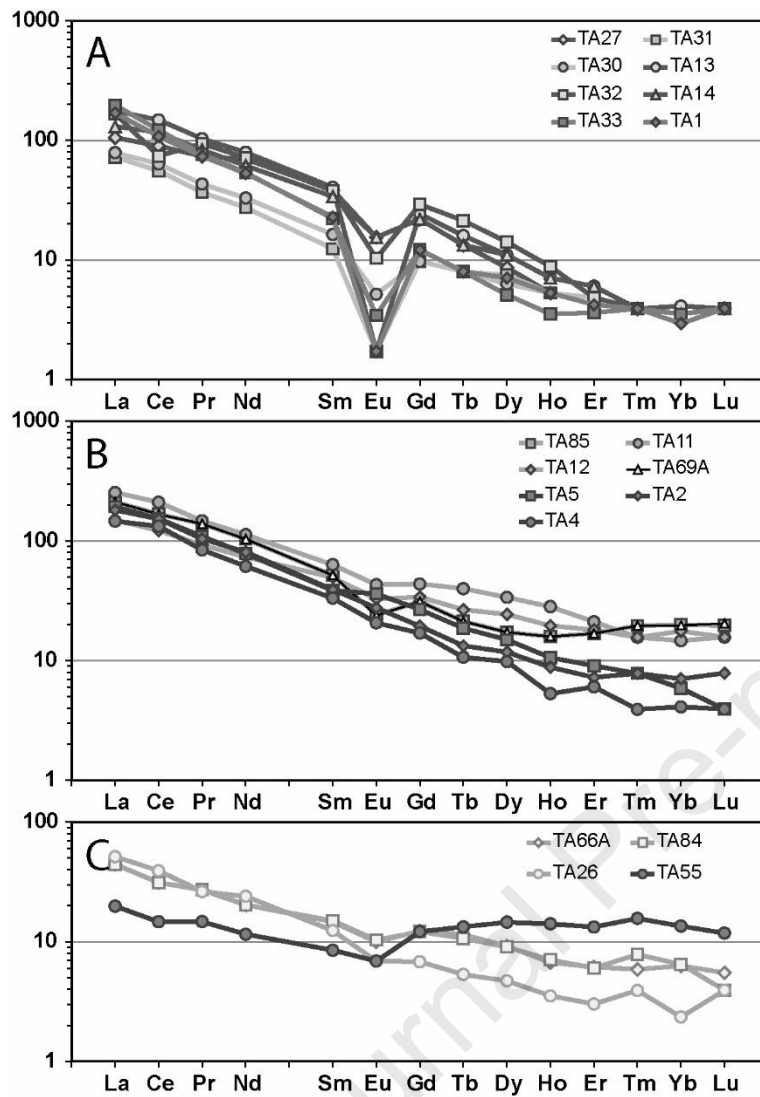
377 4.2. Tagragra-n-Daouizid area

378 Rhyolites display major element compositions typical of potassic to high-potassic rhyolites with SiO₂
379 contents ranging between 69.7 and 79.7 wt%,. The high alkali concentrations (> 4 wt%) are essentially
380 controlled by K₂O contents (2.2-12.2 wt%; Fig. 4). Na₂O concentrations are always lower than 1 wt%.
381 These potassic to highly potassic rhyolites are characterized by negative correlations between SiO₂ and
382 K₂O, and with Al₂O₃. The negative correlation between SiO₂ and K₂O may be related to the presence of
383 Si poor and K rich minerals in the source such as ferriferous biotite and/or potassic and ferriferous
384 amphibole.

385 Rhyolites display fractionated REE patterns, however four groups may be differentiated (Table 1). In the
386 first group, [La/Yb]_n ratios are higher than 20, with fractionated LREE (2.7<[La/Sm]_n<8.9) and HREE
387 (2.8<[Gd/Yb]_n<8.3; Fig. 8A), and negative Eu anomalies. HREE contents are lower than 10 times
388 chondrites. In the second group (TA5, TA2 and TA4), [La/Yb]_n ratios are higher than 25, with fractionated
389 LREE (4.4<[La/Sm]_n<5.0; Fig. 8B) and fractionated HREE (2.8<[Gd/Yb]_n<4.5), without negative Eu-
390 anomalies. HREE contents are lower than 10 times chondrites (Fig. 8B). In the third group (TA85, TA11,
391 TA12 and TA69A), [La/Yb]_n ratios are lower than 18, with fractionated LREE (3.0<[La/Sm]_n<4.1) and
392 slightly fractionated HREE (1.6<[Gd/Yb]_n<3.0), with light negative Eu anomalies. HREE contents are
393 higher than 10 times chondrites (Fig. 8B). Finally in the fourth group, [La/Yb]_n ratios are lower than 22,
394 with fractionated LREE (2.3<[La/Sm]_n<4.1; Fig. 8C) and flat to slightly fractionated HREE
395 (0.9<[Gd/Yb]_n<2.9). These samples are characterized by low REE contents (\sum REE<60 ppm).

396 In sample TA69A, the [La/Yb]_n ratio is lower than 11, with fractionated LREE ([La/Sm]_n=4.1) and slightly
397 fractionated HREE ([Gd/Yb]_n=1.6), with slight negative Eu anomalies. This pattern is similar to sample
398 TA85, suggesting that these two rhyolitic ignimbrites represent the same pyroclastic flow. In sample
399 TA66A, the [La/Yb]_n ratio is lower than 11, with fractionated LREE ([La/Sm]_n=3.0) and slightly fractionated
400 HREE ([Gd/Yb]_n=2.0), with light negative Eu anomalies. This pattern is similar to sample TA84,
401 suggesting that these two rhyolitic ignimbrites represent the same pyroclastic flow.

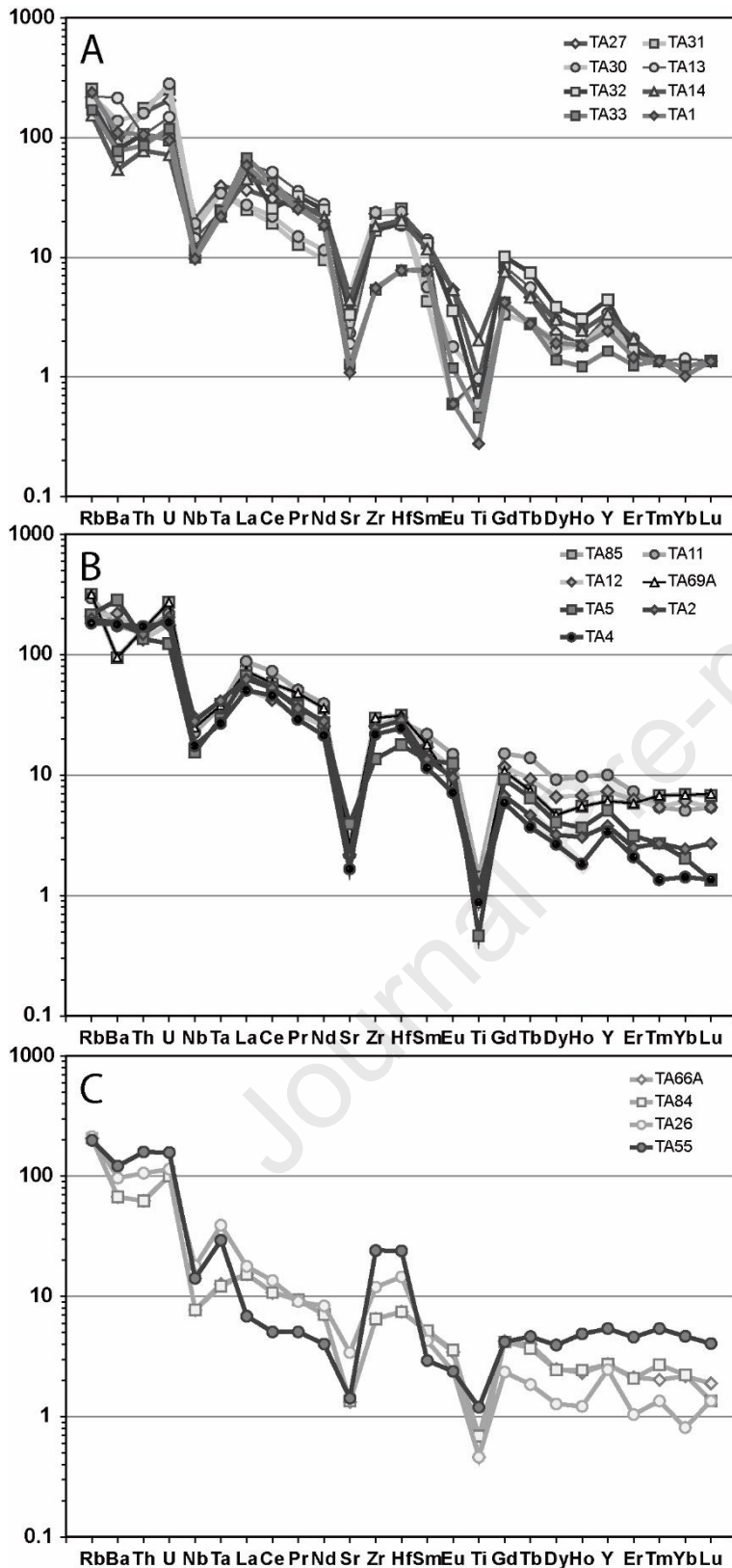
402 In the Primitive Mantle normalizing diagram (Fig. 9), patterns display systematic negative anomalies in
403 Ti and Sr, and sometimes in Nb and Ta.



404

405 **Figure 8:** Chondrite normalized rare earth element diagram of volcanic rocks from the Tagragra-n-406 Daouizid area. **A.** Group 1 rhyolites; **B.** Groups 2 and 3 rhyolites; **C.** Group 4 rhyolites. Normalization

407 according to Sun and McDonough, 1989.



408
 409 **Figure 9:** Primitive Mantle normalized multi-element diagram of volcanic rocks from the Tagragra-n-
 410 Daouzid area. **A.** Group 1 rhyolites; **B.** Groups 2 and 3 rhyolites; **C.** Group 4 rhyolites. Normalization
 411 according to Sun and McDonough, 1989.

412 **4.3. Tagragra Ouhallal area**

413 LOI of basaltic trachy-andesites and trachy-andesites are high, however we did not observe significant
414 correlation between LOI and an excess or a loss in alkali elements. The compositions are representative
415 of the original magma. Major elements variations are illustrated in Figure 4 using silica variations
416 diagrams. These lavas have intermediate compositions ($\text{SiO}_2=52.7-59.1$ wt%), with high Al_2O_3 (16-
417 21 wt%), intermediate to high Fe_2O_3 (6.2-8.6 wt%) and K_2O contents (2.7-5.3 wt%), low to intermediate
418 MgO (1.7-5.6 wt%), and Na_2O (1.8-5.7 wt%), and low CaO contents (0.9-3.5 wt%). These rocks are
419 alkaline and Ti-rich (0.75-1.47 wt%), with magnesian affinities (Fig. 7).

420 Basaltic trachyandesites and trachyandesites display REE patterns characterized by fractionated LREE
421 ($1.4 < [\text{La}/\text{Sm}]_n < 7.6$) and highly fractionated HREE ($5.0 < [\text{Gd}/\text{Yb}]_n < 11.0$) without negative Eu anomalies.
422 HREE are lower than ten times chondrites ($[\text{Yb}]_n = 1.8-4.7$; Fig. 5C). In the Primitive Mantle normalizing
423 diagram (Fig. 6C), patterns do not display systematic negative anomalies in Ta and Nb.

424 Rhyolites display major element compositions typical of potassic to high-potassic rhyolites with SiO_2
425 contents ranging between 71.8 to 85.3 wt%, and alkali concentrations control essentially by K_2O
426 contents (2.6-4.7 wt%; Fig. 4).

427 **5. Discussion**

428 **5.1. Summary of the depositional environment**

429 In the Tafeltast area, the Ouarzazate Group is essentially composed of terrigenous sediments with few
430 volcano-sedimentary rocks and pyroclastic deposits. These sedimentary deposits are located in narrow
431 grabens controlled by syn-sedimentary normal faults, and were formed in fluvial-lacustrine system. This
432 lacustrine sedimentation is characterized by a maximum flooding outlined by the development of a
433 carbonate key bed, the Agoujgal carbonates.

434 In the Tagragra-n-Daouizid area, the Ouarzazate Group represents the surficial emission of a rhyolitic
435 magma in pyroclastic flows. Effusive flows or domes are missing. This pyroclastic eruptive activity,
436 probably very brief in time, was closely associated with continental sedimentary deposits, mostly coarse
437 brecciated or conglomeratic.

438 In the Tagragra Ouhallal area, the massive ash layers at the base of the sequence, the intrusive pillow
439 lavas in waterlogged deposits, the stacking of lava flows, the geographical distribution of the flows on

440 one side and of the pillow lavas on the other side, the frequent alternation of emerged and submerged
441 periods under shallow water, are quite comparable to that described in subglacial mafic volcanoes
442 (Smellie and Skilling, 1994; Skilling, 1994); However, such a depositional environment is not observed
443 in the other areas where the depositional system is almost systematically fluvial-lacustrine.

444 In the neighboring Kerdous inlier, Upper Ediacaran rocks are essentially volcanoclastic rocks and rhyolitic
445 lavas and domes (O'Connor, 2010). Upper Ediacaran sedimentary, volcanoclastic and volcanic rocks
446 have been divided in three main groups: i) Oufoud; ii) Tanalt; and iii) Fiyzirt (O'Connor, 2010). On the
447 southern border of the Kerdous inlier, the Oufoud Group, characterized by a dominantly conglomeratic
448 sequence with rhyodacitic lava and ignimbrite. In the centre of the Kerdous inlier, the Tanalt Group
449 comprises a succession of matrix-supported conglomerate, coarse-grained to well-bedded fine
450 sandstone and siltstone, with locally interbedded rhyolitic welded pyroclastic tuff. On the eastern border
451 of the Kerdous inlier, the Fiyzirt Group comprises conglomerate, sandstone, basaltic lava and shallow
452 level intrusion. Lavas and tuffs were emplaced throughout the sedimentary rocks which were deposited
453 in a subaerial environment, probably on alluvial fan and flood plains with local shallow lakes (O'Connor,
454 2010). Geochemically, volcanic rocks have high-K calc-alkaline to alkaline affinities, characteristics of
455 both subduction and within-plate tectonic settings (O'Connor, 2010).

456 In the Bas Draâ inlier, the volcanic activity evolved in a continental extensional setting (Karaoui et al.,
457 2014). The Ouarzazate Group is characterized by four distinct units (Karaoui et al., 2014): i) rhyolitic
458 ignimbrite; ii) rhyolitic lava-dome and basaltic andesite scoria cone, with rare ignimbrite; iii) basaltic to
459 basaltic andesite lavas with minor pyroclastic deposits; and iv) rhyolitic lava-dome. Sedimentary
460 processes are characteristics of fluvial systems, and the lack of volcanosedimentary mass flow deposits
461 indicates a low relief environment (Karaoui et al., 2014). Geochemically, volcanic rocks have high-K
462 calc-alkaline, alkali-calcic and alkaline affinities, characteristics of both subduction and within-plate
463 tectonic settings (Karaoui et al., 2014).

464 **5.2. Tectonic discrimination diagrams**

465 Geochemical data of the mafic to intermediate lavas from the Kerdous inlier and the Tagragra Ouhallal
466 area provide important informations regarding their tectonic setting. On the $Y/15-La/10-Nb/8$ diagram
467 (Fig. 10), mafic lavas from the Kerdous inlier and the Tagragra Ouhallal area fall in the calc-alkaline
468 basalt and continental tholeiite fields. Like these lavas, basalts from the Bas Draâ (Karaoui et al., 2014)

469 and Agadir-Melloul (Blein et al., 2014b) inliers fall in the fields of calc-alkaline basalts and continental
470 tholeiites. Basalts from the southwestern or northeastern flank of the Kerdous inlier (Soulaimani et al.,
471 2004) fall on the boundary between the fields of the continental tholeiites and back-arc basalts. These
472 Upper Ediacaran basalts are distinguished from the Cambrian basalts of the jbel Boho (Bou Azer inlier;
473 Benaouda et al., 2017) which have an affinity of alkaline basalts to continental tholeiites. The Upper
474 Ediacaran mafic rocks show a clear south-north evolution from continental tholeiites to back-arc basalts,
475 characterized by a relative enrichment in Y compared to La and Nb. This volcanic activity occurred
476 during an extensional episode, certainly more important in the north than in the south because the
477 mantle source has a more asthenospheric signature in the north than in the south.

478 As shown in Figure 11 ($\text{FeO}^{\text{t}}+\text{MgO}$ versus $\text{Nb}+\text{Zr}+\text{Y}$, La_n and $\text{Sr}+\text{Ba}$), intermediate to felsic rocks can
479 be classified into two main groups: i) low $\text{FeO}^{\text{t}}+\text{MgO}$ (<7 wt.%) metaluminous to peraluminous rocks,
480 with moderate incompatible element contents, generated mainly by partial melting of crustal lithologies;
481 and ii) high $\text{FeO}^{\text{t}}+\text{MgO}$ (>7 wt.%) metaluminous intermediate to felsic rocks with moderate incompatible
482 element contents, generated by an enriched mantle source with variable involvement of crustal
483 component.

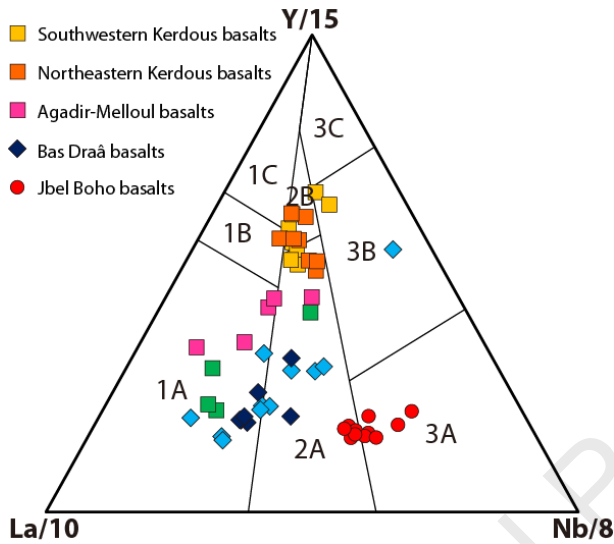
484 Whalen and Hildebrand (2019) developed new diagrams to discriminate between arc, slab-failure and
485 A-type granitoids. These diagrams are valid for non peraluminous samples ($\text{ASI} < 1.1$), with SiO_2
486 concentrations ranging between 55 and 70 wt%. Samples from the Ouarzazate Group that meet these
487 criteria have been plotted in such diagrams (Fig. 12A-B).

488 With high Nb/Y , Gd/Yb , and La/Yb ratios, samples from Tagragra Ouhallal plot in the slab-failure field,
489 while samples from the Kerdous and Agadir-Melloul inliers, with lower Nb/Y , La/Yb and Gd/Yb ratios
490 and plot at the limit between arc and slab-failure fields (Fig. 12A-B). As typical characteristic of magmas
491 generated by slab-failure, samples from Tagragra Ouhallal have low $\text{Ta}+\text{Yb}$ values (Fig. 12B). All
492 samples have Ta/Yb ratios higher than 0.3., and plot in the field of slab-failure magmas (Fig. 12B). Their
493 high La/Yb (>10), and Nb/Y (>0.4) ratios are typical of slab-failure rocks (Fig. 12A-B). Samples from the
494 Kerdous and Agadir-Melloul inliers, and the Tagragra-n-Daouizid area, with higher $\text{Ta}+\text{Yb}$ values, and
495 lower La/Yb , and Nb/Y ratios than samples from the Tagragra Ouhallal area. In Figure 12A-B, they plot
496 at the limit between arc and slab-failure fields.

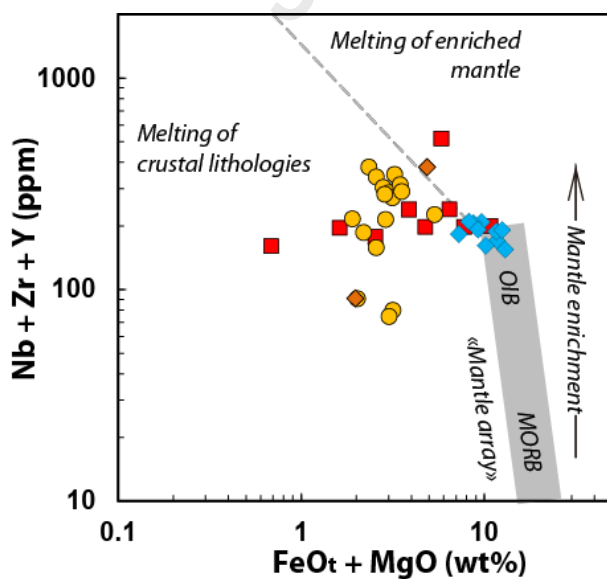
497 On Y vs. Nb and Yb vs. Ta diagrams (Fig. 12C-D), the samples from the Tagragra Ouhallal and
498 Tagragra-n-Daouizid areas also plot in the slab-failure field, while samples from the Kerdous inlier plot

499 close to the triple point between arc, slab-failure and A-type fields, which is characteristic of granites
 500 formed in post-collisional extensional settings (Förster et al., 1997).

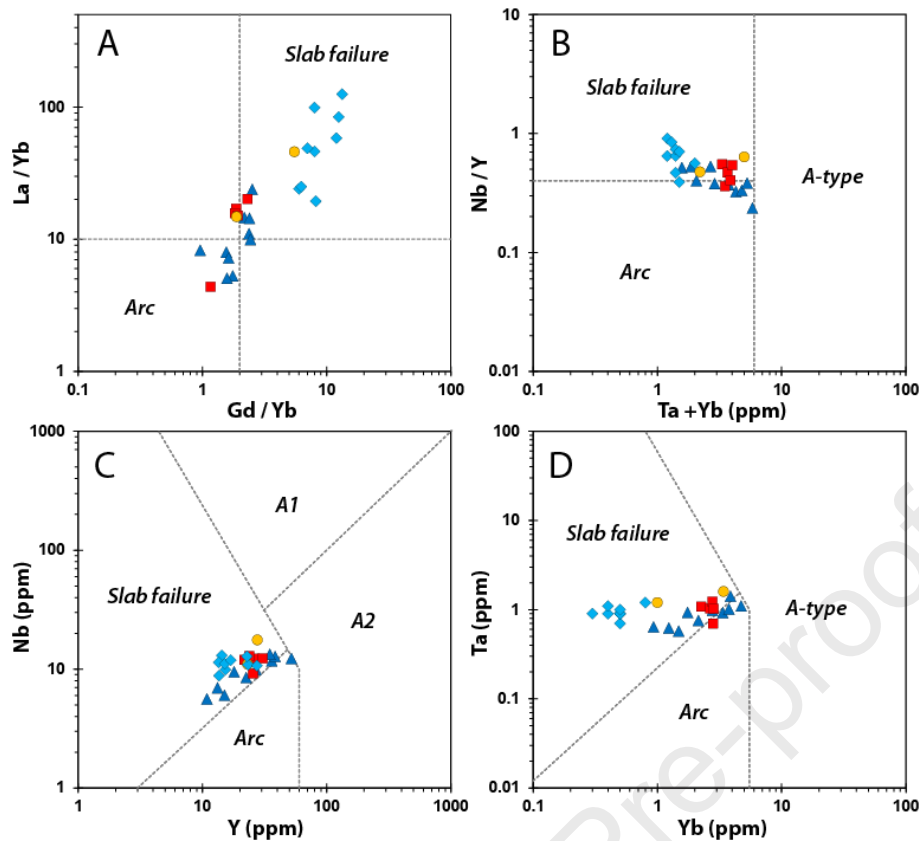
501 Geochemical data indicate that: (i) mafic rocks are essentially continental flood basalt; (ii) felsic rocks
 502 are high-K calc-alkaline rocks, generated by partial melting of an enriched mantle source with
 503 involvement of crustal component; and (iii) few intermediate and felsic rocks sharing characteristics with
 504 slab failure magma (Hildebrand and Whalen, 2017).



505 **Figure 10:** Y/15–La/10–Nb/8 diagram (Cabanis and Lecolle, 1989) for mafic rocks ($\text{SiO}_2 < 55 \text{ wt}\%$) of
 506 the Ouarzazate Group (1A: Calc-alkaline basalts; 1B: Calc-alkaline basalts and arc tholeiites; 1C:
 507 Volcanic arc tholeiites; 2A: Continental tholeiites; 2B: Back-arc basalts; 3A: Alkaline basalts; 3B: E-type
 508 MORB; 3C: N-type MORB; Symbols as in Fig. 3).



510 **Figure 11:** $(\text{FeO}^t + \text{MgO})$ vs. $(\text{Nb} = \text{Zr} + \text{Y})$ diagram (Symbols as in Fig. 3).



512

513

514

515

516

517

Figure 12: Discrimination diagrams showing slab failure, A-type and arc fields (Hildebrand and Whalen, 2014; Hildebrand et al., 2018; Whalen and Hildebrand, 2019). Samples, plotted on diagrams, have SiO₂ contents between 55 and 70 wt%, and alumina saturation index (ASI) value lower than 1.1: **A.** Gd/Yb vs La/Yb; **B.** Ta+Yb vs. Nb/Y; **C.** Y vs. Nb; and **D.** Yb vs. Ta. Symbols as in Fig. 3. Light blue triangle: Ouarzazate Group from the Agadir Melloul inlier (Blein et al., 2014b).

518

5.3. Geodynamic setting

519

520

521

522

523

524

525

526

527

528

Thomas et al. (2004) divided the Neoproterozoic igneous rocks of the Anti-Atlas belt in two main supergroups: Anti-Atlas and Ouarzazate supergroups. The lithostratigraphic units of the Anti-Atlas Supergroup are related to passive margin, oceanic and island-arc development phases of the Pan African orogen before ca. 650 Ma. All the younger plutonic, volcanic and sedimentary rocks have been grouped into the Ouarzazate Supergroup. The pre 580 Ma volcano-sedimentary rocks of the Ouarzazate Supergroup were deposited in narrow strike-slip pull-apart basins (Saghro, Bou Salda, Mgouna, Tafrawt and Anzi groups) contemporaneously with high-K calc-alkaline plutons (e.g., Assarag, Bardouz Suites). These rocks were followed by the unconformable continental deposition of voluminous pyroclastic deposits and volcano-sedimentary rocks (the Ouarzazate Group); the volcanic rocks were erupted from several volcanic centers and caldera complexes, and are younger than 580 Ma (Thomas et al., 2002;

529 El Baghdadi et al., 2003; Gasquet et al., 2005, 2008; Errami et al., 2009; Toummite et al., 2012; Walsh
530 et al., 2012; Blein et al., 2014b; Baidada et al., 2017; Belkacim et al., 2017).

531 Set up between ca. 575 and ca. 545 Ma, the Ouarzazate Group can be subdivided into three major
532 magmatic pulses dated between: (i) 575 and 570 Ma, (ii) 568 and 563 Ma, (iii) and 555 and 545 Ma. In
533 the Agadir-Melloul inlier, Blein et al. (2014b) highlighted angular unconformities between each volcanic
534 pulses. The first unconformity is placed around ca. 568 Ma and the younger at ca. 560 Ma. The latter
535 angular unconformity has been described in the Saghro massif (Walsh et al., 2012), and in the western
536 Anti-Atlas (Blein et al., 2014b). Finally, the last one is in continuity with the sedimentary rocks of the
537 Adoudou Formation. A complete stratigraphy of these three pulses has been observed in the Agadir-
538 Melloul inlier (Blein et al., 2014b) and in the Saghro massif (Errami et al., 2020; Yajjoui et al., 2020).

539 In the Saghro massif, before the deposition of the Ouarzazate Group, Imiter and Iknouan granodiorites
540 (600–603 Ma) were uplifted and exhumed. The Oussilkane charnockite, dated at 580 ± 19 Ma (Errami et
541 al., 2020), is contemporaneous with this phase of uplift. In the Bou Azer inlier, the ignimbrites of the
542 Ouarzazate Group were deposited unconformably on the volcano-sedimentary sequence of the Tiddiline
543 Group (602–606 Ma), and on the uplifted and exhumed Bleïda granodiorite (579 ± 2 Ma; Inglis et al.,
544 2004). These observations suggest the occurrence of an uplift between ca. 580 and ca. 575 Ma.

545 Late Ediacaran geodynamic models are the subject of much debate. A scenario suggest the occurrence
546 of a subduction ca. 625–560 Ma to explain the Ouarzazate high-K calc-alkaline magmatism (El Baghdadi
547 et al., 2003; Benziane, 2007; Walsh et al., 2012; Hefferan et al., 2014). Another scenario suggest a post-
548 collisional transtensional setting, without subduction, for the late Ediacaran Pan-African orogeny (Doblas
549 et al., 2002; Thomas et al., 2002; Gasquet et al., 2005; Karaoui et al., 2015). Blein et al. (2014b) propose
550 a subduction beneath the WAC ca. 625–580 Ma, followed by the arrival of a spreading ridge at the
551 subduction zone at ca. 580–575 Ma, and post ca. 575 Ma by the pyroclastic magmatism in a
552 transtensive setting (Ouarzazate Group).

553 Tuduri et al. (2018) put forward a closer model with the development of a subduction between 610 and
554 575 Ma, followed by the initiation of a slab roll-back around ca. 575 Ma. This slab roll-back results in
555 large volume of magma, leading to the pyroclastic flows of the Ouarzazate Group. And ongoing slab
556 roll-back along with more extensional tectonic setting initiate the second, and then the third ignimbritic
557 pulses (Tuduri et al., 2018).

558 Dominated by the eruptions of thousands of cubic kilometers of pyroclastic flows, volcanic activity of the
559 Ouarzazate Group is typical of ignimbrite flare-ups. Originally, flare-ups are short-lived large volumes of
560 silicic ignimbrites in orogenic setting, inland from the plate margin (Lipman et al., 1971; Noble, 1972).
561 These flare-ups are intercalated in the stable magmatism of an active margin, characterized by andesitic
562 volcanic and intrusive rocks. This stable active margin magmatism is characterized by low magmatic
563 addition rates (MAR). Flare-ups are typically short-time high-MAR episodes, alternating with longest
564 low-MAR episodes.

565 High-resolution zircon geochronological ages reveal multiple events and the intermittent nature of flare-
566 ups at various scales of space, time, and volumes (Folkes et al. 2011; Lima et al. 2012; Silva et al.,
567 2015). Considered as a primary pulse, the flare-up or high-volume event is a 40-50 my mantle activity
568 induced by: (i) post-collisional mantle delamination (Ducea, 2001), (ii) a regional transition from low-
569 angle to high-angle plate convergence in relation to slab roll-back (Lipman et al., 1972; Best et al., 2013),
570 or (iii) slab breakoff (Ferrari et al., 2002). This primary pulse can be broken down in secondary pulses.
571 These shorter secondary pulses (~10–20 my) must reflect the timescale of melt production and delivery
572 from the melting and assimilation zone, and its interaction with the upper crust (de Silva et al., 2015).
573 Typically observed in Andean volcano-plutonic systems, such 10 my secondary pulses are an essential
574 signal in orogenic magmatic activity (Coleman et al., 2004; Grunder et al., 2008). Due to its duration
575 (~30–35 my), the pyroclastic volcanism of the Ouarzazate Group is a typical primary pulse, the three
576 ignimbritic pulses observed in Agadir Melloul (Adrar-n-Takoucht, Tadoughast and Fajjoud formations)
577 and Imiter (~10 my in duration) are typically secondary pulses.

578 According to DeCelles et al. (2009), flare-ups are periods of high rates of magma production, relative to
579 the normal state rates of arc-magma production. A transition from low-angle to high-angle plate
580 convergence in relation to slab roll-back may explain such higher magmatic fluxes, and episodic
581 alternations between magmatic lulls and flare ups (Ferrari et al., 2007). In the Anti-Atlas, the late
582 Ediacaran magmatic activity is not characterized by episodic alternations between normal arc-magma
583 production and flare up activity, but by an individual flare up event predating the development of a
584 Cambrian marine carbonate platform (Alvaro et al., 2014). There are many mechanisms to explain such
585 individual flare up events such as: (i) slab break-off (e.g., Schwartz et al., 2017), (ii) subduction of
586 fracture zones (e.g., Manea et al., 2014), or (iii) subduction of continental lithospheric mantle before a
587 collision (e.g., Ganade et al., 2021). In our case, the late Ediacaran flare up event is related to a slab

588 break-off event. As the late Ediacaran Ouarzazate magmatism is not followed by a continental collision
589 event, it cannot be related to the subduction of continental lithospheric mantle, and the late Ediacaran
590 flare up event is widespread, and not geographically restricted like in subduction of fracture zones.
591 Moreover, volcanic rocks of the Ouarzazate Group fall in the field of slab-failure rocks (Fig. 11).

592 **6. Conclusions**

593 New constraints on the late Ediacaran evolution of the western Anti-Atlas New have been provided from
594 geological mapping, petrography and geochemistry of volcano-sedimentary rocks of the southern
595 Kerdous and Tagragra d'Akka inliers.

596 In the Kerdous and Tagragra d'Akka inliers, the Ouarzazate Group consists of terrigenous sediments,
597 volcano-sedimentary rocks, basaltic flows and dacitic to rhyolitic, welded or unwelded, pyroclastic tuffs.
598 These deposits are located in grabens controlled by syn-sedimentary normal faults. The sedimentation
599 is characterized by a maximum flooding outlined by the Agoujgal carbonates. Dacitic to rhyolitic
600 pyroclastic tuffs of the Ouarzazate Group have a high-potassic calc-alkaline affinity. Basalts observed
601 in the Kerdous inlier and the Tagragra Ouahallal area have transitional affinity between continental
602 tholeiites and calc-alkaline basalts. Few intermediate and felsic volcanic rocks are characteristics of slab
603 failure rocks derived from melting of mafic upper portion of the subducted slab (Hildebrand and Whalen,
604 2017).

605 The Ouarzazate flare up event is related to the cessation of a subduction, which induced a slab break-
606 off. The late Ediacaran Ouarzazate magmatism is not followed by a continental collision event, and
607 cannot be related to the subduction of continental mantle lithosphere; the late Ediacaran flare up event
608 is widespread, and not geographically restricted like in subduction of fracture zones.

609

610 **Credit authorship contribution statement**

611 Olivier Blein: Interpretation of chemical data and wrote the manuscript. Thierry Baudin, Philippe
612 Chèvremont, and Dominique Gasquet: Contributed in the field work, sampling, and to the writing of the
613 manuscript.

614 **Declaration of competing interest**

615 The authors declare that they have no known competing financial interests or personal relationships that
616 could have appeared to influence the work reported in this paper.

617 **Acknowledgements**

618 Funding was provided by the Moroccan Ministry of Energy, Mines, Water and Environment (contracts
619 19-2008/DG) with the production of geological four mapsheets and explanatory notes (Sidi Bou'Addi,
620 Awkarda, Tamazrar, Tlatat Ida Gougmar).

621 **References**

- 622 Abati, J., Aghzer, A.M., Gerdes, A., Ennih, N., 2010. Detrital zircon ages of Neoproterozoic sequences
623 of the Moroccan Anti-Atlas belt. *Precambrian Research* 181, 115–128.
624 <https://doi:10.1016/j.precamres.2010.05.018>.
- 625 Aït Lahna, A., Youbi, N., Tassinari, C.C.G., Basei, M.A.S., Ernst, R.E., Chaib, L., Barzouk, A., Mata, J.,
626 Gärtner, A., Admou, H., Boumehdi, M.A., Söderlund, U., Bensalah, M.K., Bodinier, J.L., Maacha,
627 L., Bekker, A., 2020. Revised stratigraphic framework for the lower Anti-Atlas supergroup based on
628 U-Pb geochronology of magmatic and detrital zircons (Zenaga and Bou Azzer-EI Graara inliers,
629 Anti-Atlas Belt, Morocco), *J. Afr. Earth Sci.* 171, 103946.
630 <https://doi:10.1016/j.jafrearsci.2020.103946>.
- 631 Aït Malek, H., Gasquet, D., Bertrand, J. M., Leterrier J., 1998. Géochronologie U-Pb sur les
632 granitoïdes éburnéens et panafricains dans les boutonnières protérozoïques d'Igherm, du Kerdous
633 et du Bas Drâa (Anti-Atlas occidental, Maroc). *Comptes Rendus de l'Académie des Sciences* 327,
634 819–826. [https://doi:10.1016/S1251-8050\(99\)80056-1](https://doi:10.1016/S1251-8050(99)80056-1).

- 635 Alvaro, J.J., Clausen, S., El Albani, A., Chellai, E.H., 2005. Facies distribution of Lower Cambrian
636 cryptic microbial and epibenthic archaeocyathan–microbial communities in the western Anti-Atlas,
637 Morocco. *Sedimentology*, 53, 35–53. <https://doi:10.1111/j.1365-3091.2005.00752.x>.
- 638 Álvaro, J.J., Bellido, F., Gasquet, D., Francisco Pereira, M., Quesada, C., Sánchez-García, T., 2014.
639 Diachronism in the late Neoproterozoic–Cambrian arc-rift transition of North Gondwana: A
640 comparison of Morocco and the Iberian Ossa-Morena Zone. *Journal of African Earth Sciences* 98:
641 113–132.
- 642 Baidada, B., Cousens, B., Alansari, A., Soulaïmani, A., Barbey, P., Ilmen, S., Ikenne, M., 2017.
643 Geochemistry and Sm-Nd isotopic composition of the Imiter Pan-African granitoids (Saghro massif,
644 eastern Anti-Atlas, Morocco): Geotectonic implications. *J. Afr. Earth Sci.* 127, 99–112.
645 <https://doi:10.1016/j.jafrearsci.2016.08.016>.
- 646 Bajja, A., 1998. Volcanisme syn à post-orogénique du Néoprotérozoïque de l'Anti-Atlas: implications
647 pétrographiques et géodynamiques (Thèse de doctorat d'Etat). Université Chouaib Doukkali, El
648 Jadida, Maroc (215 p.).
- 649 Bajja, A., 2001. Volcanisme syn a post orogénique du Néoprotérozoïque de l'Anti-Atlas: implications
650 pétrogénétiques et géodynamiques. In: De Wall, H., Greiling, R.P. (Eds.), *Magmatic Evolution of a*
651 *Neoproterozoic island-Arc syn-to Post-orogenic Igneous Activity in the Anti-Atlas (Morocco)*,
652 *Forschungszentrum Jülich GmbH*, vol. 45, pp. 9–228.
- 653 Baudin, T., Razin, P., Chèvremont, P., Calvès, G., Gabudianu, D., Roger, J., 2005. Carte géol. Maroc
654 (1/50 000), feuille Awkarda. *Notes et Mémoires Serv. Géol., Maroc*, n°497.
- 655 Belkacim, S., Gasquet, D., Liégeois, J.P., Arai, S., Ghalan, H., Ahmed, H.A., Ishida, Y., Ikenne, M.,
656 2017. The Ediacaran volcanic rocks and associated mafic dykes of the Ouarzazate Group (Anti-
657 Atlas, Morocco): Clinopyroxene composition, whole-rock geochemistry and Sr-Nd isotopes
658 constraints from the Ouzellarh-Sirwa salient (Tifnoute valley). *J. Afr. Earth Sci.* 127, 113–135.
659 <https://doi:10.1016/j.jafrearsci.2016.08.002>
- 660 Benaouda, R., Holzheid, A., Schenk, V., Badra, L., Ennaciri, A., 2017. Magmatic evolution of the Jbel
661 Boho alkaine complex in the Bou Azzer inlier (Anti-Atlas, Morocco) and its relation to REE
662 mineralization. *J. Afr. Earth Sci.* 129; 202–223. <https://doi:10.1016/j.jafrearsci.2017.01.003>.

- 663 Benssaou, M., Hamoumi, N. 2001. L'Anti-Atlas occidental du Maroc: étude sédimentologique et
664 reconstitutions paléogéographiques au Cambrien inférieur. *J. Afr. Earth Sci.* 32, 351–372.
665 [https://doi:10.1016/S0899-5362\(01\)90102-2](https://doi:10.1016/S0899-5362(01)90102-2)
- 666 Benssaou, M., Hamoumi, N. 2003. Le graben de l'Anti-Atlas occidental (Maroc) : contrôle tectonique
667 de la paléogéographie et des séquences du Cambrien inférieur. *C.R. Géoscience* 335, 297–305.
668 [https://doi:10.1016/S1631-0713\(03\)00033-6](https://doi:10.1016/S1631-0713(03)00033-6)
- 669 Benziane, F., 2007. Lithostratigraphie et évolution géodynamique de l'Anti-Atlas (Maroc) du
670 Paléoprotérozoïque au Néoprotérozoïque: exemples de la boutonnière de Tagragra de Tata et du
671 Jbel Saghro. PhD thesis. Université de Savoie CISM, Chambéry, France, 320 pp.
- 672 Best, M.G., Christiansen, E.H., Gromme, S., 2013. Introduction: the 36–18 Ma southern Great Basin,
673 USA, ignimbrite province and flare up: swarms of subduction-related supervolcanoes. *Geosphere*
674 9: 260–274.
- 675 BGS, 2001a. Carte géologique du Had-n-Tahala au 1/50 000. Notes et Mémoires, 403, Editions du
676 Service Géologique du Maroc, Rabat.
- 677 BGS, 2001b. Carte géologique d'Anzi au 1/50 000. Notes et Mémoires, 402, Editions du Service
678 Géologiques du Maroc, Rabat.
- 679 Blein, O., Chèvremont, Ph., Baudin, T., Ouanaïmi, H., Razin, Ph., Hafid, A., Admou, H., Soulaïmani,
680 A., Bouabdelli, M., Abia, E.H., Beni Akhy, R., 2013. Notice explicative carte géol. Maroc (1/50 000),
681 feuille Tabadrist, Notes et Mémoires Serv. Géol. Maroc, n°547, MEM/BRGM. Carte géologique par
682 Baudin, T., Blein, O., Chèvremont, Ph., Soulaïmani, A., Ouanaïmi, H., Roger, J., Admou, H., Hafid,
683 A., Bouabdelli, M., Abia, E.H., 2013.
- 684 Blein, O., Baudin, T., Chèvremont, P., Soulaïmani, A., Admou, H., Gasquet, D., Cocherie, A., Egal, E.,
685 Youbi, N., Razin, P., Bouabdelli, M., Gombert, Ph., 2014a. Geochronological constraints on the
686 polycyclic magmatism in the Bou Azzer-El Graara inlier (Central Anti-Atlas Morocco). *J. Afr. Earth*
687 *Sci.* 99, 287–306. <https://doi:10.1016/j.jafrearsci.2014.04.021>.
- 688 Blein, O., Baudin, T., Soulaïmani, A., Cocherie, A., Chèvremont, P., Admou, H., Ouanaïmi, H., Hafid,
689 A., Razin, P., Bouabdelli, M., Roger, J., 2014b. New Geochemical, Geochronological and Structural
690 Constraints on the Ediacaran Evolution of the South Sirwa, Agadir Melloul and Iguerda Inliers, Anti-
691 Atlas, Morocco. *J. Afr. Earth Sci.* 98, 47–71. <https://doi.org/10.1016/j.jafrearsci.2014.06.019>

- 692 Blein, O., Chèvremont, P., Baudin, T., Hafid, A., Admou, H., Soulaïmani, A., Ouanaimi, H., Bouabdelli,
693 M., Gasquet, D., Padel, M., 2022. Contrasting Paleoproterozoic granitoids in the Kerdous,
694 Tragraad'Akka, Agadir-Melloul and Iguerda inliers (western Anti-Atlas, Morocco). *J. Afr. Earth*
695 *Sci.* 189, 104500. <https://doi.org/10.1016/j.jafrearsci.2022.104500>
- 696 Boudda, A., Choubert, G., Faure-Muret, A., 1979. Essai de stratigraphie de la couverture sédimentaire
697 de l'Anti-Atlas : Adoudounien-Cambrien inférieur. Notes et Mémoires du Service Géologique du
698 Maroc 271, 96 p.
- 699 Bouougri, E.H., Saquaque, A., 2004. Lithostratigraphic framework and correlation of the
700 Neoproterozoic northern West African Craton passive margin sequence (Siroua – Zenaga - Bou
701 Azzer El Graara inliers, central Anti-Atlas, Morocco): an integrated approach. *J. Afr. Earth Sci.* 99,
702 287–306. <https://doi:10.1016/j.jafrearsci.2004.07.045>.
- 703 Cabanis, B., Lecolle, M., 1989. Le diagramme La/10-Y/15-Nb/8 : un outil pour la discrimination des
704 séries volcaniques et la mise en évidence des processus de mélange et/ou de contamination
705 crustale. *C. R. Acad. Sci. Ser. II* 309, 2023–2029.
- 706 Carignan, J., Hild, P., Mévelle, G., Morel, J., Yeghicheyan, D., 2001. Routine analyses of trace
707 elements in geological samples using flow injection and low pressure on-line liquid chromatography
708 coupled to ICP-MS: a study of reference materials BR, DR-N, UB-N, AN-G and GH. *Geostandards*
709 *Newsl.* 25, 187–198.
- 710 Chalot-Prat, F., Gasquet, D., Roger, J., Hassenforder, B., Chèvremont, P., Baudin, T., Razin, P.,
711 Benlakhdim, A., Benssaou, M., Mortaji, A., 2001. Carte géologique du Maroc au 1/50000. Feuille
712 de Sidi Bou'Addi avec Mémoire explicatif. Notes et Mémoires du Service Géologique du Maroc 414
713 & 414 bis, 84 p.
- 714 Cheilletz, A., Levresse, G., Gasquet, D., Azizi Samir, M.R., Zyadi, R., Archibald, D.A., 2002. The Imiter
715 epithermal deposit (Morocco): new petrographic, microtectonic and geochronological data.
716 Importance of the Precambrian–Cambrian transition for major precious metals deposits in the Anti-
717 Atlas. *Miner. Deposita* 37, 772–781.
- 718 Chèvremont, P., Razin, P., Baudin, T., Gabudianu, D., Roger, J., Thiéblemont, D., Calvès, G., Anzar-
719 Conseil, 2005. Notice explicative, carte géol. Maroc (1/50 000), feuille Awkarda, Notes et Mém.
720 Serv. Géol. Maroc, n°497bis, MEM/BRGM, 114 p. Carte géol. par Baudin T., Razin P., Chèvremont
721 P., Calvès G., Gabudianu D., Roger J. (2005), Notes et Mém. Serv. Géol. Maroc, n°497.

- 722 Chèvremont, P., Blein, O., Razin, P., Simon, B., Baudin, T., Ouanaïmi, H., Soulaïmani, A., El Janati,
723 M., Bouabdelli, M., Abia, E.H., Admou, H., Hafid, A., Beni Akhy, R., 2013. Notice explicative carte
724 géol. Maroc (1/50 000), feuille Ighriy, Notes et Mémoires Serv. Géol. Maroc, n°548, MEM/BRGM.
725 Carte géologique par Ouanaïmi, H., Chèvremont, Ph., Blein, O., Simon, B., Baudin, T., Razin, Ph.,
726 Smektala, F., Soulaïmani, A., El Janati, M., Abia, E.H., Admou, H., Hafid, A., Bouabdelli, M., 2013.
- 727 Choubert, G., 1952. Histoire géologique du domaine de l'Anti-Atlas. In: Géologie du Maroc. Notes et
728 Mémoires du Service Géologique du Maroc 100, 75–194.
- 729 Choubert, G., 1953a. Histoire géologique du domaine de l'Anti-Atlas. Notes et Mémoire de Service
730 géologique du Maroc 100, 1–77.
- 731 Choubert, G., 1953b. Le Précambrien III et le Géorgien de l'Anti-Atlas. Notes et Mémoire de Service
732 géologique du Maroc 103, 7–39.
- 733 Choubert, G., 1963. Histoire géologique du Précambrien de l'Anti-Atlas. Notes et Mémoires du Service
734 Géologique du Maroc 162, 443 p.
- 735 Choubert, G., Faure-Muret, A., 1970. Colloque international sur les corrélations du Précambrien,
736 Agadir-Rabat, 3–23 mai 1970, et livret-guide de l'excursion: Anti-Atlas occidental et central, Notes
737 Mém. Serv. Géol. Maroc 229, 259p.
- 738 Choubert, G., Boudda, A., Faure-Muret, A., 1973. Essai de Chronologie du Précambrien supérieur du
739 sud marocain: C. R. Somm. S.G.F, 123–124.
- 740 Clauer, N., 1976. Géochimie isotopique du Strontium des milieux sédimentaires. Application à la
741 géochronologie de la couverture du Craton Ouest-Africain. Strasbourg.
- 742 Coleman, D.S., Glazner, A.F., 1997. The Sierra Crest magmatic event: rapid formation of juvenile
743 crust during the Late Cretaceous in California. *International Geology Review* 39: 768–787.
- 744 DeCelles, P.G., Ducea, M.N., Kapp, P., Zandt, G., 2009. Cyclicity in Cordilleran orogenic systems.
745 *Nature Geoscience* 2: 251–257
- 746 De Silva, S.L., Riggs, N.R., Barth, A.P., 2015. Quickening the pulse: Fractal tempos in continental arc
747 magmatism. *Elements* 11, 113–118. <https://doi:10.2113/gselements.11.2.113>.
- 748 D'Lemos, R.S., Inglis, J.D., Samson, S.D., 2006. A newly discovered orogenic event in Morocco:
749 Neoproterozoic ages for supposed Eburnean basement of the Bou Azzer inlier, Anti-Atlas
750 Mountains. *Precambrian Research* 147, 65–78.

- 751 Doblas, M., Lopez-Ruiz, J., Cebria, J.M., Youbi, N., Degroote, E., 2002. Mantle insulation beneath the
752 west African craton during the Precambrian–Cambrian transition. *Geology* 30, 839–842.
- 753 Ducea, M., 2001. The California arc: thick granitic batholiths, eclogitic residues, lithospheric-scale
754 thrusting, and magmatic flare-ups. *GSA Today* 11, 4–10.
- 755 Ducrot, J., Lancelot, J.R., 1977. Problème de la limite Précambrien-Cambrien : étude radio-
756 chronologique par la méthode U-Pb sur zircons du volcan du Jbel Boho (Anti-Atlas Marocain).
757 *Canadian Journal of Earth Sciences* 14, 2771–2777.
- 758 Eddif, A., Gasquet, D., Hoepffner, C., Levresse, G., 2007. Age of the Wirgane granodiorite intrusions
759 (Western High Atlas, Morocco): new U–Pb constraints. *J. Afr. Earth Sci.* 47, 227–231.
- 760 El Baghdadi, M., El Boukhari, A., Jouider, A., Benyoucef, A., Nadem, S., 2003. Calc-alkaline arc I-type
761 granitoid associated with S-type granite in the Pan-African belt of eastern Anti-Atlas (Saghro and
762 Ougnat, South Morocco). *Gondwana Res.* 6 (4), 557–572. [https://doi:10.1016/S1342-
763 937X\(05\)71007-8](https://doi:10.1016/S1342-937X(05)71007-8).
- 764 Ennih, N., Liégeois, J.-P., 2008. The boundaries of the West African Craton, with special reference to
765 the basement of the Moroccan metacratonic Anti-Atlas belt. *Geological Society, London, Special
766 Publications* 297 (1), 1–17. <https://doi:10.1144/SP297.1>.
- 767 Errami, E., Bonin, B., Laduron, D., Lasri, L., 2009. Petrology and geodynamic significance of the post-
768 collisional Pan-African magmatism in the Eastern Saghro area (Anti-Atlas, Morocco). *J. Afr. Earth
769 Sci.* 55, 105–124. <https://doi:10.1016/j.jafrearsci.2009.02.006>.
- 770 Errami, E., Linnemann, U., Hofmann, M., Gärtner, A., Zieger, J., Gärtner, J., Mende, K., El Kabouri, J.,
771 Gasquet, D., Ennih, N., 2020. From Pan-African Transpression to Cadomian Transtension at the
772 West African Margin: New U–Pb zircon Ages from the Eastern Saghro Inlier (Anti-Atlas, Morocco).
773 *In* Murphy, J. B., Strachan, R. A. and Quesada, C. (eds). *Pannotia to Pangaea: Neoproterozoic and
774 Paleozoic Orogenic Cycles in the Circum-Atlantic Region*. Geological Society, London, Special
775 Publications, 503. <https://doi:10.1144/SP503-2020-105>.
- 776 Fekkak, A., Pouclet, A., Ouguir, H., Badra, L., and Gasquet, D., 1999, The Kelaat Mgouna early
777 Neoproterozoic Group (Saghro, Anti-Atlas, Morocco): Witness of an initial stage of the pre-Pan-
778 African extension: *Bulletin de la Société Géologique de France*, 170, 789–797.

- 779 Fekkak, A., Boualoul, M., Badra, L., Amenzou, M., Saquaque, A., El-Amrani, I. E., 2000. Origine et
780 contexte géotectonique des dépôts détritiques du Groupe Néoproterozoïque inférieur de Kelaat
781 Mgouna (Anti-Atlas Oriental, Maroc). *Journal of African Earth Sciences* 30, 295–311.
- 782 Fekkak, A., Pouclet, A., Benharref, M., 2003. The Middle Neoproterozoic Sidi Flah Group (Anti-Atlas,
783 Morocco): synrift deposition in a Pan-African continent/ocean transition zone. *J. Afr. Earth Sci.* 37,
784 73–87. [https://doi:10.1016/S0899-5362\(03\)00049-6](https://doi:10.1016/S0899-5362(03)00049-6).
- 785 Ferrari, L., Lopez-Martinez, M., Rosas-Elguera, J., 2002. Ignimbrite flare-up and deformation in the
786 southern Sierra Madre Occidental, western Mexico: Implications for the late subduction history of
787 the Farallon plate. *Tectonics* 21 (4). <https://doi:10.1029/2001TC001302>.
- 788 Ferrari L, Valencia-Moreno M, Bryan S (2007) Magmatism and tectonics of the Sierra Madre
789 Occidental and its relation with the evolution of the western margin of North America. *Geological*
790 *Society of America Special Paper* 422: 1-39.
- 791 Folkes, C.B., de Silva, S.L., Schmitt, A.K., Cas, R.A.F., 2011. A reconnaissance of U-Pb zircon ages in
792 the Cerro Galán system, NW Argentina: prolonged magma residence, crystal recycling, and crustal
793 assimilation. *Journal of Volcanology and Geothermal Research* 206: 136–147.
- 794 Förster, H.J., Tischendorf, G., Trumbull, R.B., 1997. An evaluation of the Rb vs. (Y+ Nb) discrimination
795 diagram to infer tectonic setting of silicic igneous rocks. *Lithos* 40 (2), 261–293.
- 796 Frost, B.R., Barnes, C.G., Collins, W.J., Arculus, R.J., Ellis, D.J., Frost, C.D., 2001. A geochemical
797 classification for granitic rocks. *J. Petrol.* 42, 2033-2048.
- 798 Ganade, C.E., Lanari, P., Rubatto, D., Hermann, J., Weinberg, R.F., Basei, M.A.S., Tesser, L.R.,
799 Caby, R., Agbossoumonde, Y., Ribeiro, C.M., 2021. Magmatic flare-up causes crustal thickening at
800 the transition from subduction to continental collision. *Commun. Earth Environ.* 2 (41).
- 801 Gasquet, D., Roger, J., Chalot-Prat, F., Hassenforder, B., Baudin, T., Chèvremont, P., Razin, P.,
802 Benlakhdim, A., Mortaji, A., Benssaou, M., 2001. Notice explicative carte géol. Maroc (1/50 000),
803 feuille Tamazrar, Notes et Mémoires Serv. Géol. Maroc, n°415 bis, MEM/BRGM. Carte géologique
804 par Roger, J., Gasquet, D., Baudin, T., Chalot-Prat, F., Hassenforder, B., Marquer, D.,
805 Chèvremont, P., Berrahma, A., Destombes, J. Razin, P., Benlakhdim, M., 2001.
- 806 Gasquet, D., Levresse, G., Cheilletz, A., Azizi-Samir, M.R., Mouttaqi, A., 2005. Contribution to a
807 geodynamic reconstruction of the Anti-Atlas (Morocco) during Pan-African times with the emphasis

- 808 on inversion tectonics and metallogenic activity at the Precambrian-Cambrian transition.
809 Precambrian Research 140, 157–182. <https://doi:10.1016/j.precamres.2005.06.009>.
- 810 Gasquet, D., Ennih, N., Liégeois, J-P., Soulaïmani, A., Michard, A., 2008. The Panafrican belt. In:
811 Michard A., Saddiqi O., Chalouan A., Frizon de Lamotte D. (Eds.), Continental Evolution: The
812 Geology of Morocco. Structure, Stratigraphy, and Tectonics of the Africa-Atlantic-Mediterranean
813 Triple Junction, Springer Verl., Berlin, Heidelberg, pp. 33–64.
- 814 Geyer, G., 1990. Proposal of formal lithostratigraphical units for the Terminal Proterozoic to early
815 Middle Cambrian of southern Morocco. *Newsl. Stratigr.* 22 (2/3), 87–109.
- 816 Grunder, A.L., Klemetti, E.W., Feeley, T.C., McKee, C.M., 2008. Eleven million years of arc volcanism
817 at the Aucanquilcha Volcanic Cluster, northern Chilean Andes: implications for the life span and
818 emplacement of plutons. *Transactions of the Royal Society of Edinburgh: Earth Sciences* 97: 415–
819 436.
- 820 Hassenforder, B., 1987. La tectonique panafricaine et varisque de l'Anti-Atlas dans le massif du
821 Kerdous, Maroc. Thèse Doctorat ès-Sciences, Université Louis Pasteur, Strasbourg, 249 p.
- 822 Hassenforder, B., Roger, J., Baudin, T., Chalot-Prat, F., Gasquet, D., Berrahma, A., Chèvremont, P.,
823 Marquer, D., Razin, P., Benlakhdim, M., 2001. Carte géol. Maroc (1/50 000), feuille Sidi Bou'addi.
824 Notes et Mémoires Serv. Géol. Maroc, n°414.
- 825 Hawkins, M.P., Beddoe-Stephens, B., Gillespie, M.R., Loughlin, S., Barron, H.F., Barnes, R.P., Powell,
826 J.H., Waters, C.N., Williams, M., 2001. Carte géologique du Maroc au 1/50 000, feuille Tiwit. Notes
827 et Mémoires du Service Géologique du Maroc 404.
- 828 Hefferan, K., Soulaïmani, A., Samson, S.D., Admou, H., Inglis, J., Saquaque, A., Latifa, C., Heywood,
829 N., 2014. A reconsideration of Pan African orogenic cycle in the Anti-Atlas Mountains, Morocco. *J.*
830 *Afr. Earth Sci.* 98, 34–46. <https://doi.org/10.1016/j.jafrearsci.2014.03.007>
- 831 Hildebrand, R.S., Whalen, J.B., 2014. Arc and slab-failure magmatism in Cordilleran batholiths II – The
832 Cretaceous Peninsular Ranges Batholith of southern and Baja California. *Geoscience Canada*, 41,
833 399–458. <https://doi.org/10.12789/geocanj.2014.41.059>
- 834 Hildebrand, R.S., Whalen, J.B., 2017. The tectonic setting and origin of Cretaceous batholiths within
835 the North American Cordillera: The case for slab failure magmatism and its significance for crustal
836 growth. *Geological Society of America Special Paper* 532, 113 p. <https://doi:10.1130/2017.2532>.

- 837 Hildebrand, R.S., Whalen, J.B. and Bowring, S.A. 2018. Resolving the crustal composition paradox by
838 3.8 billion years of slab failure magmatism and collisional recycling of continental crust.
839 *Tectonophysics*, 734–735, 69–88. <https://doi.org/10.1016/j.tecto.2018.04.001>
- 840 Hollard, H., Choubert, G., Bronner, G., Marchand, J., Sougy, J., 1985. Carte géologique du Maroc,
841 échelle: 1/1.000.000. Notes Mém. Serv. Géol. Maroc, n°260.
- 842 Ikenne, M., Soderlund, U., Ernst, R., Pin, C., Youbi, N., El Aouli, E.H., 2017. A c. 1710 Ma mafic sill
843 emplaced into a quartzite and calcareous series from Igherm, Anti-Atlas, Morocco: evidence that
844 the Taghdout passive margin sedimentary group is nearly 1 Ga older than previously thought. *J.*
845 *Afr. Earth Sci.* 127, 113–135. <https://doi:10.1016/j.jafrearsci.2016.08.020>.
- 846 Inglis, J.D., MacLean, J.S., Samson, S.D., D'Lemos, R.S., Admou, H., Hefferan, K., 2004. A precise U-
847 Pb zircon age for the Bleïda granodiorite, Anti-Atlas, Morocco: implications for the timing of
848 deformation and terrane assembly in the eastern Anti-Atlas. *J. Afr. Earth Sci.* 39, 277–283.
849 <https://doi:10.1016/j.afrearsci.2004.07.041>.
- 850 Karaoui, B., Bretkreuz, C., Mahmoudi, A., Youbi, N., 2014. Physical volcanology, geochemistry and
851 basin evolution of the Ediacaran volcano-sedimentary succession in the Bas Draâ inlier
852 (Ouarzazate Supergroup, Western Anti-Atlas, Morocco. *J. Afr. Earth Sci.* 99, 307–331.
853 <https://doi:10.1016/j.afrearsci.2014.06.022>.
- 854 Karaoui, B., Bretkreuz, C., Mahmoudi, A., Youbi, N., Hofmann, M., Gärtner, A., Linnemann, U., 2015.
855 U-Pb ages from volcanic and sedimentary rocks of the Ediacaran Bas Draâ inlier (Anti-Atlas
856 Morocco): Chronostratigraphic and provenance implications. *Precambrian Res.* 263, 43–58.
857 <https://doi:10.1016/j.precamres.2015.03.003>.
- 858 Kouyaté, D., Söderlund, U., Youbin N., Ernst, R., Hafid, A., Ikenne, M., Soulaïmani, A., Bertrand, H., El
859 Janati, M., R'kha Chaham, K., 2013. U-Pb baddeleyite and zircon ages of 2040 Ma, 1650 Ma and
860 885 Ma on dolerites in the West African Craton (Anti-Atlas inliers): Possible links to break-up of
861 Precambrian supercontinents. *Lithos* 174, 71–84. <https://doi:10.1016/j.lithos.2012.04.028>.
- 862 Leblanc, M., 1975. Ophiolites précambriennes et gîtes arseniés de cobalt (Bou Azzer - Maroc). Ph.D.
863 Dissertation. Paris, France, Université de Paris VI, 329 pp.
- 864 Lipman, P.W., Prostka, H.J., Christiansen, R.L., 1971. Evolving subduction zones in the western
865 United States, as interpreted from igneous rocks. *Science* 174, 821–825.

- 866 Pelleter, E., Cheilletz, A., Gasquet, D., Mouttaqi, A., Annich, M., El Hakour, A., Deloule, E., Féraud, G.,
867 2007. Hydrothermal Zircons: A tool for ion microprobe U-Pb dating of gold mineralization (Tamlalt-
868 Menhouhou Gold deposit - Morocco). *Chemical Geology* 245: 135–161.
- 869 Lima, S.M., Corfu, F., Neiva, A.M.R., Ramos, J.M.F., 2012. Dissecting complex magmatic processes:
870 an in-depth U-Pb study of the Pavia Pluton, Ossa-Morena Zone, Portugal. *Journal of Petrology* 53:
871 1887–1911.
- 872 Lipman, P.W., Prostka, H.J., Christiansen, R.L., 1972. Cenozoic volcanism and plate-tectonic
873 evolution of the western United States. I. Early and Middle Cenozoic. *Philosophical Transactions of*
874 *the Royal Society of London A* 271: 217–248.
- 875 Maacha, L., Azizi-Samir, M.-R., Bouchta, R., 1998. Gisements cobaltifères du district de Bou Azzer
876 (Anti-Atlas). Structure, minéralogie et conditions de genèse. *Chron. Rech. Minière*, 531-532, 65–
877 75.
- 878 Manea, V.C., Leeman, W.P., Gerya, T., Manea, M., Zhu, G., 2014. Subduction of fracture zones
879 controls mantle melting and geochemical signature above slabs. *Nat. Commun.* 5, 1–10.
- 880 Michard, A., Soulaïmani, A., Ouanaimi, H., Raddi, Y., Ait Brahim, L., Rjimati, E., Baidder, L., Saddiqi,
881 O., 2017. Saghro Group in the Ougnat Massif (Morocco), an evidence for a continuous Cadomian
882 basin along the northern West African Craton. *C. R. Geoscience* 349, 81–90.
883 <https://doi:10.1016/j.crte.2017.01.001>.
- 884 Mortaji A., Ikenne M., Gasquet D., Barbey P., Stussi J. M., 2000. Les granitoïdes paléoproterozoïques
885 des boutonnières du Bas Drâa et de la Tagragra d'Akka (Anti-Atlas occidental, Maroc) : un élément
886 du puzzle géodynamique du craton ouest- africain. *J. African. Earth Sci.*, 31: 523–538.
887 [https://doi:10.1016/S0899-5362\(00\)80005-6](https://doi:10.1016/S0899-5362(00)80005-6).
- 888 Mrini Z., 1993. Chronologie (Rb-Sr, U-Pb), traçage isotopique (Sr-Nd-Pb) des sources des roches
889 magmatiques éburnéennes, panafricaines et hercyniennes du Maroc. Thèse Doctorat es Sciences,
890 Université Cadi Ayad, Marrakech, 227 p.
- 891 Noble, D.C., 1972. Some observations on the Cenozoic volcano-tectonic evolution of the Great Basin,
892 western United States. *Earth Planet. Sci. Lett.* 17, 142–150.
- 893 O'Connor, E.A., 2010. Geology of the Draâ, Kerdous, and Boumalne Districts, Anti-Atlas, Morocco.
894 Technical Report IR/10/072, British Geological Survey, Keyworth, Nottingham, England.

- 895 Ouguir, H., Macaudiere, J., Dagallier, G., 1996. Le protérozoïque supérieur d'imitier, Saghro oriental,
896 Maroc: un contexte géodynamique d'arrière-arc. *Journal of African Earth Sciences* 22, 173–189.
897 [https://doi:10.1016/0899-5362\(96\)00002-4](https://doi:10.1016/0899-5362(96)00002-4).
- 898 Piqué, A., 2003. Evidence for an important extensional event during the latest proterozoic and earliest
899 paleozoic in morocco. *C. R. Geosci.* 335, 865–868.
- 900 Piqué, A., Bouabdelli, M., Soulaïmani, A., Youbi, N., Ilïani, M., 1999. The Late Proterozoic III
901 conglomerates of tthe Anti-Atlas (southern Morocco). Their relationships with the Panafrican
902 orogeny or a Late Proterozoic rifting episode. *Comptes Rendus de l'Académie des Sciences* 328,
903 409–414. [https://doi:10.1016/S1251-8050\(99\)80107-4](https://doi:10.1016/S1251-8050(99)80107-4).
- 904 Roger, J., Gasquet, D., Baudin, T., Chalot-Prat, F., Hassenforder, B., Marquer, D., Chèvremont, P.,
905 Berrahma, A., Destombes, J. Razin, P., Benlakhdim, M., 2001. Carte géol. Maroc (1/50 000), feuille
906 Tamazrar. Notes et Mémoires Serv. Géol. Maroc, n°415.
- 907 Roger, J., Chèvremont, P., Razin, P., Thiéblemont, D., Baudin, T., Calvès, G., Anzar-Conseil, 2005.
908 Notice explicative, carte géol. Maroc (1/50 000), feuille Tlatat Ida Gougmar, Notes et Mém. Serv.
909 Géol. Maroc, n°498bis, MEM/BRGM, 105 p. Carte géol. par Calvès G., Gabudianu D., Chèvremont
910 P., Roger J., Razin P., (2005), Notes et Mém. Serv. Géol. Maroc, n°498.
- 911 Saquaque, A., Benharref, M., Abia, H., Mrini, Z., Reuber, I., Karson, J. A., 1992. Evidence for a
912 Panafrican volcanic arc and wrench fault tectonics in the Jbel Saghro, Anti-Atlas, Morocco.
913 *Geologische Rundschau* 81, 1–13.
- 914 Schwartz, J.J., Klepeis, K.A., Sadowski, J.F., Stowell, H.H., Tulloch, A.J., Coble, M.A., 2017. The
915 tempo of continental arc construction in the Mesozoic Median Batholith, Fiordland, New Zealand.
916 *Lithosphere* 9, 343–365.
- 917 Skilling, I.P., 1994. Evolution of an englacial volcano: Brown Bluff, Antarctica. *Bull Volcanol* 56, 573–
918 591.
- 919 Smellie, J.L., Skilling, I.P., 1994. Products of subglacial volcanic eruptions under different ice
920 thickness: two examples from Antarctica. *Sedimentary Geology* 91, 115–129.
- 921 Soulaïmani, A., Bouabdelli, M., Piqué, A., 2003. L'extension continentale au Néoprotérozoïque
922 supérieur – Cambrien inférieur dans l'Anti-Atlas (Maroc). *Bull. de la Société Géologique de France*
923 174, 83–92. <https://doi:10.2113/174.1.83>

- 924 Soulainani, A., Essaifi, A., Youbi, N., Hafid, A., 2004. Les marqueurs structuraux et magmatiques de
925 l'extension crustale au Protérozoïque terminal-Cambrien basal autour du massif de Kerdous (Anti-
926 Atlas occidental, Maroc). *C. R. Geoscience* 336, 1433–1441. <https://doi:10.1016/j.carte.2004.03.020>
- 927 Soulainani, A., Blein, O., Chèvremont, Ph., Ouanaimi, H., Hafid, A., Admou, H., Baudin, T.,
928 Bouabdelli, M., Razin, Ph., Abia, E.H., Beni Akhy, R., 2013. Notice explicative carte géol. Maroc
929 (1/50 000), feuille Agadir Melloul, Notes et Mémoires Serv. Géol. Maroc, n°549, MEM/BRGM.
930 Carte géologique par Blein, O., Roger, J., Chèvremont, Ph., Baudin, T., Soulainani, A., Ouanaimi,
931 H., Admou, H., Hafid, A., Abia, E.H., Bouabdelli, M., 2013.
- 932 Soulainani, A., Ouanaimi, H., Michard, A., Monterod, P., Bead, F., Corsini, M., Molinad, J.-F., Rjimati,
933 E.-C., Saddiqig, O., Hefferan, K., 2019. Quartzite crests in Paleoproterozoic granites (Anti-Atlas,
934 Morocco); a hint to Pan-African deformation of the West African Craton margin. *J. Afr. Earth Sci.*
935 2019; 157(February):103501. <https://doi:10.1016/j.jafrearsci.2019.05.009>.
- 936 Sun, S.S., McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts:
937 implications for mantle composition and processes. In: Saunders, A.D., Norry, M.J. (Eds.),
938 *Magmatism in the Ocean Basins*, 42 (Special publication). Geological Society, 313–345.
- 939 Thomas, R.J., Chevallier, L.C., Gresse, P.G., Harmer, R.E., Eglington, B.M., Armstrong, R.A., de
940 Beer, C.H., Martini, J.E.J., de Kock, G.S., Macey, P., Ingram, B., 2002. Precambrian evolution of
941 the Siroua Window, Anti-Atlas Orogen, Morocco. *Precambrian Research* 118, 1–57.
942 [https://doi:10.1016/S0301-9268\(02\)00075-X](https://doi:10.1016/S0301-9268(02)00075-X).
- 943 Thomas, R.J., Fekkak, A., Errami, E., Loughlin, S.C., Gresse, P.G., Chevallier, L.P., Liégeois, J.-P.,
944 2004. A new lithostratigraphic framework for the Anti-Atlas Orogen, Morocco. *Journal of African*
945 *Earth Sciences*, 39, pp. 217–226. <https://doi:10.1016/j.jafrearsci.2004.07.046>.
- 946 Toummite, A., Liégeois, J.-P., Gasquet, D., Bruguier, O., Beraaouz, E.H., Ikenne, M., 2012. Field,
947 geochemistry and Sr-Nd isotopes of the Pan- African granitoids from the Tifnoute Valley (Sirwa,
948 Anti-Atlas, Morocco): a post-collisional event in a metacratonic setting. *Mineral. Petrol.* 107 (5),
949 739–763. <https://doi:10.1007/s00710-012-0245-3>.
- 950 Tuduri, J., Chauvet, A., Barbanson, L., Bourdier, J.L., Labriki, M., Ennaciri, A., Badra, L., Dubois, M.,
951 Ennaciri-Leloix, C., Sizaret, S., Maacha, L., 2018. The Jbel Saghro Au(-Ag, Cu) and Ag-Ah
952 metallogenetic province: Product of a long-lived Ediacaran tectono-magmatic evolution in the
953 Moroccan Anti-Atlas. *Minerals* 8, 592. <https://doi:10.3390/min8120592>.

- 954 Walsh, G.E., Aleinikoff, J.N., Benziane, F., Yazidi, A., Armstrong, T.R., 2002. U-Pb zircon
955 geochronology of the Paleoproterozoic Tagragra de Tata inlier and its Neoproterozoic cover,
956 western Anti-Atlas, Morocco. *Precambrian Research* 117, 1–20. [https://doi:10.1016/S0301-](https://doi:10.1016/S0301-9268(02)00044-X)
957 [9268\(02\)00044-X](https://doi:10.1016/S0301-9268(02)00044-X)
- 958 Walsh, G.J., Benziane, F., Aleinikoff, J.N., Harisson, R.W., Yazidi, A., Burton, W.C., Quick, J.E.,
959 Saadane, A., 2012. Neoproterozoic tectonic evolution of the Jebel Saghro and Bou Azer-El Graara
960 inliers, eastern and central Anti-Atlas, Morocco. *Precambrian Res.* 216-219, 23–62.
961 <https://doi:10.1016/j.precamres.2012.06.010>.
- 962 Whalen, J.B., Hildebrand, R.S., 2019. Trace element discrimination of arc, slab failure, and A-type
963 granitic rocks. *Lithos* 248-349, 105179. <https://doi:10.1016/j.lithos.2019.105179>.
- 964 Yajjoui Z., Karaoui, B., Chew, D., Breikreuz, C., Mahmoudi, A., 2020. U-Pb zircon geochronology of
965 the Ediacaran volcano-sedimentary succession of the NE Saghro inlier (Anti-Atlas, Morocco):
966 Chronostratigraphic correlation on the northwestern margin of Gondwana. *Gondwana Res.*, 87,
967 263-277. <https://doi:10.1016/j.gr.2020.06.015>.
- 968 Youbi, N., 1998. Le volcanisme « post-collisionnel »: un magmatisme intraplaque relié à des panaches
969 mantelliques. Etude volcanologique et géochimique. Exemples d'application dans le
970 Néoprotérozoïque terminal (PIII) de l'Anti-Atlas et le Permien du Maroc. (PhD thesis). Université de
971 Marrakech
- 972 Youbi, N., Kouyaté, D., Söderlund, U., Ernst, R.E., Soulaïmani, A., Hafid, A., Ikenne, M., El Bahat, A.,
973 Bertrand, H., Rkha Chaham, K., Ben Abbou, M., Mortaji, A., El Ghorfi, M., Zouhair, M., El Janati,
974 M., 2013. The 1750 Ma magmatic event of the West African Craton (Anti-Atlas), Morocco.
975 *Precambrian Res.* 236, 106–123. <https://doi:10.1016/j.precamres.2013.07.003>.

976 **Tables**

977 **Table 1:** Variation contents of REEs in the Tagragra-n-Daouizid rhyolites.

978 **Table S1:** Representative chemical analyses of volcanic rocks from Tagragra Ouhallal.

979 **Table S2:** Representative chemical analyses of volcanic rocks from Tagragra-n-Daouizid.

980 **Table S3:** Representative chemical analyses of volcanic rocks from south Kerdous inlier.

Journal Pre-proof

Tagrag-n-Daouizid rhyolites				
	Group I	Group II	Group III	Group IV
[La/Yb]_n	20 - 60	25 - 36	8 - 17	1.5 - 22
[Yb]_n	<5	<10	>10	<10
[La/Sm]_n	2.7 - 8.9	4.4 - 5.0	3.0 - 4.1	2.3 - 4.1
[Gd/Yb]_n	2.8 - 8.3	2.8 - 4.5	1.6 - 3.0	0.9 - 2.9
Eu anomalie	negative	no	light negative	light negative
ΣREE ppm	75 - 200	165 -210	185 -300	35 -55

Highlights

- An Upper Ediacaran felsic pyroclastic magmatism, the Ouarzazate Group
- Felsic rocks generated by partial melting of crustal lithologies.
- Rare mafic rocks evolve from calc-alkaline to continental tholeiitic affinities.
- Few intermediate and felsic rocks characteristics of slab failure context.

Journal Pre-proof

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Journal Pre-proof