Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Terre, 2014, n° 36, 55–67. ***e-ISSN : 2458-7184***

Geodynamic setting context of the Permian and Triassic volcanism in the northwestern Moroccan Meseta from petrographical and geochemical data

Contexte géodynamique de la mise en place du volcanisme permien et triasique de la Meseta nord occidentale marocaine à partir des données pétrographiques et géochimiques

**Hassan EL HADI[1], Abdelfatah TAHIRI[2*], Ayoub EL MAIDANI[3], Omar SADDIQI[3],
Fernando SIMANCAS[4], Francisco González LODEIRO[4], Antonio AZOR[4],
David MARTINEZ-POYATOS[4], Mounia TAHIRI[1] & Jesus DE LA ROSA DIAZ[5]**

1. *Hassan II University of Casablanca, Faculty of Sciences, Laboratory of Applied Geology, Geomatic & Environnement, , Ben Msik Sidi Othmane, Casablanca, Morocco.*
2. *Mohammed V University of Rabat, Scientific Institute, Department of Earth Sciences, Laboratory of Geology and Remote sensing, GEOTEL, URAC46, BP. 703, Rabat-Agdal, Morocco *(abdelfatahtahiri@gmail.com).*
3. *Hassan II University of Casablanca, Faculty of Sciences, Department of Earth Science, Laboratory of Moroccan Orogens Geodynamics, Aïn Chock, Casablanca, Morocco.*
4. *Universidad de Granada, Facultad de Ciencias, Departamento de Geodinamica, Avenida Fuentenueva s/n, 18071 Granada, Spain.*
5. *University of Huelva, Center for Research in Sustainable Chemistry (CIQSO), Campus de El Carmen, s/n E-21071 Huelva, Spain.*

Abstract. The northwestern Moroccan Meseta registered two important and successive volcanic events from the Early Permian to the Late Triassic: (1) a calc-alkaline bimodal volcanism consisting of basalts to trachy-andesites and dacites to rhyodacites in the Early Permian (Autunian); and (2) a tholeiitic volcanism of basalts and andesites, magmatic marker of the Central Atlantic evolution, in the Middle and the Late Triassic. The geochemical study of those mafic and acidic rocks demonstrates the enriched character of a mantle previously metasomatized by crustal component, probably during periods of ancient subduction (s) (Variscan?).

Keywords : Petrography, Geochemistry, Geodynamic setting context, Permian–Triassic volcanism, northwestern Moroccan Meseta.

Résumé. La Meseta nord occidentale marocaine a connu du Permien inférieur au Trias moyen et supérieur, deux principaux événements volcaniques successifs : (1) un volcanisme bimodal calco-alcalin, au Permien inférieur (Autunien); et (2) un volcanisme tholéiitique de basaltes et d'andésites, traceur magmatique de l'évolution de l'Atlantique central, au Trias moyen et supérieur. Les données géochimiques de ces roches volcaniques acides et basiques montrent le caractère enrichi du manteau antérieurement métasomatisé par un composant crustal, probablement lors de subduction(s) ancienne(s) (Varisque?).

Mots-clés : Pétrographie, géochimie, géodynamique de mise en place, volcanisme Permien–Trias, Meseta nord occidentale marocaine.

INTRODUCTION

In the northwestern Moroccan Meseta (of which the main geological units are, from the North to the South, the Central Morocco, Rehamna and Jebilet) are localized mountainous Westphalian (Sidi Kassem basin) and Permian (Autunian) basins in red continental detrital sedimentation, associated with an important bimodal volcanism (Fig. 1). The main Permian basins are localized in western central Morocco, Souk Sebt-Tiddas, Bouterehla, Bouachouch, Khenifra and Chougrane basins (Cailleux *et al.* 1983, Zouine 1986, El Wartiti 1990, Youbi 1998, Saidi 2005) (Fig. 1a, b); in Rehamna, Mechra Ben Abbou and Dalaat basins (El Wartiti 1990, Muller *et al.* 1990) and finally in western and eastern Jebilet basins (Essamoud 1989, Sebban 1990).

In those basins, detrital sediments are dated Early Permian (Autunian), based on paleoflora of *Walchia pinniformis*, recorded particularly in the cinerite layers of the Bouachouch basin (El Wartiti 1990, Broutin *et al.* 1987, 1998) (Fig. 1a, b, c). Volcanism has also occurred outside the basins (Fig. 1a, b) in the west border of western central Morocco (Khellata River area, south of Rabat) (Bandet *et al.* 1990, Saidi 2001).

The volcanism associated with the basin deposits crops out as sills, dykes and flows interstratified in the detrital layers. The Permian sediments and associated volcanics unconformably overlie the Pre-Permian substratum (mainly Carboniferous: Westphalian conglomeratic mollasses being the most recent sediments). The metamorphic events of the Variscan major phase dated 368±8 Ma and 372±8 Ma U/Pb (Huon *et al.* 1987), do not affect either the Westphalian molassic deposits or the Permian volcano-sedimentary deposits (Zouine 1986, El Wartiti 1990, Youbi 1998, Saidi 2005). In the Khenifra basin (East of central Morocco), the Permian volcanism dated 264±10 Ma K/Ar (Jebrak 1985, Youbi 1998) is essentially marked by two episodes of eruption (e.g., Youbi & Cabanis 1995): 1) andesitics and dominant rhyolitic calc-alkaline eruptions synchronous with a calc-alkaline granite plutonism (e.g., El Hadi *et al.* 2003, 2006); and 2) alkaline or "mixed" eruptions with basalts, gabbros and dolerites, microdiorites and lamprophyres.

Early Permian materials are covered (after a middle to upper Early Permian to middle Triassic gap) by Upper

Triassic deposits (Zouine 1986, El Wartiti 1990, Youbi 1998, Saidi 2005) consisting of lower evaporitic red clay that are separated from the upper red clay by several basaltic lava flows (Cogney *et al.* 1974a, Cogney & Faugères 1975, Et Touhami 1992). Palynological datations (Taugourdeau-Lantz 1978) suggest a Late Triassic (Carnian) age for these deposits. In northwestern Moroccan Meseta, the Triassic Khemisset-Rommani basin (Fig. 1) is elongated according to NE-SW trending (Et Touhami 1992). The basalt flow thickness is variable (20 to 100 meters). The local presence (north and west of Rommani) of pillowed structures (Cogney *et al.* 1974a, b, Cogney & Faugères 1975) suggests an under-water flowing.

Volcanic flows are altered and enriched in secondary calcite. The flows would be synchronous with a NW-SE trending extension responsible of NE-SW to ENE-WSW trending normal faults.

The main purpose of this work is: 1) to complete petrographical and geochemical data (previously published in El Maidani *et al.*, 2013) of the volcanic rocks from main Permian basins of the northwestern Moroccan Meseta (Souk Sebt-Tiddas, Bouterehla, Khellata River) and Khemisset-Rommani Triassic basin; 2) to compare the volcanism of the same age in the Moroccan Meseta, the High Atlas and in the Iberian zone and to discuss the importance of these new analytical data in the late Variscan shortening geodynamic at the dawn of the Mesozoic Atlantic rifting; and 3) to propose a new model of the geodynamical setting context.

GEOLOGICAL FRAME OF PERMIAN AND TRIASSIC VOLCANISM OF WESTERN CENTRAL MOROCCO

The volcanic formations are investigated in Souk Sebt-Tiddas and Bouterehla Permian basins, Khellata river area and Khemisset-Rommani Triassic basin.

Souk Sebt-Tiddas

This Permian basin is NE-SW trending from Tiddas to Souk Sebt (Fig. 1). Over the Carboniferous substratum, Permian deposits framed by magmatic flows show (Gonord et al. 1980; Zouine, 1986, Fig. 1a, b, c): 1) andesitic volcanic flows southwestward (near Tiddas) and rhyolitic dykes and domes in the NE of Souk Sebt; 2) poudingues, red clays (argillites) and conglomerates with substratum pebbles (quartzites, pelites and limestones) and volcanic rocks, pebbles are heterometric, badly classified, sometimes arranged in strata, the red cement is silty-clayey. In this material, volcanic rocks (ignimbrites and/or tuffs) and unrefined sandstone (rich in laminations figures) are intercalated; several syn-sedimentary faults were reported (Zouine 1986, Saidi, 2005); the thickness may reach 200 meters; 3) volcanic flows of trachyte, trachyandesite and rhyolite composition. The detrital material delivered a flora of *Walchia pinniformis* dated Early Permian (Autunian; El Wartiti 1990, Broutin *et al.* 1987, 1998).

Bouterehla basin

In this basin, located in the north of Oulmès (Fig. 1), Permian deposits outcrop in the southern front of the latest Variscan overlapping thrust of Tafoudeit (Izart *et al.* 2001). Therefore, it is difficult to draw up the stratigraphic column of Permian deposits and the associated volcanic dyke. Nevertheless, the central part of the basin shows the following succession (Saidi 2005) (Fig. 1c):

1) alternations of grey-red clays with siliceous lenses of conglomerates; these are formed by badly classified pebbles (from 1 to 80 cm) of essentially siliceous, rarely calcareous, silty and volcanic (rhyolites) nature; the red cement is greywacke; 2) sandstones followed by a unrefined coarse clastic set, including red conglomerates with greywacke cement and decimetric greywacke layers alternating with grey-red silty layers; and 3) red sandy clays and micro-conglomerates. A rhyolitic dyke (where the studied samples are collected), 1.5 to 2 m thick, crosscut the series. These deposits delivered spores of *Cryptogams* (El Wartiti, 1990) and some pollen grains, suggesting an Early Permian (Autunian) age.

Khellata River area

The Permian volcanic outcrops are situated south of Rabat in the coastal western band of western central Morocco (Fig. 1). It corresponds to the west part of the Devono–Dinantian Sidi Bettache basin with Famenno–Tournaisian to Visean detrital, essentially turbiditic filling-up (Izart & Vieselet 1988, Izart 1990). The volcanic rocks that are inserted into the detrital Famenno–Tournaisian deposits are represented by spilites, andesites and trachyandesites (Piqué 1979, Kharbouch *et al.* 1985, Bandet *et al.* 1990, Saidi 2001). These volcanic rocks crop out in the Khellata river corridor (3 km width) N160 trending (Saidi 2001). Andesites are arranged in the form of: 1) dykes interstratified or crossing the Tournaisian series with probably a parallelism with the stratification, but these rocks do not show the same tectonic evolution (cleavage) as the Carboniferous host; 2) secant dykes; and 3) intrusive volcanic masses, of which the stratification relations are not very visible because of faulted contacts.

The volcanic rocks host is structured by the syncleaved major Variscan phase, which is post-Upper Visean (last dated deformed deposits; Izart & Vieselet 1988) and ante-Triassic (first overlying deposits, southeastward near Rommani; Et Touhami 1992). All the described magmatic bodies are not affected by the Variscan cleavage (Bandet et al. 1990, Saidi 2001). An age of 228±5 Ma (Middle Triassic) obtained by the K/Ar method (isochronal diagram on whole rock) on samples coming only from two magmatic bodies (probably poorly representative) was proposed by Bandet *et al.* (1990).

Most of the described dykes show a higher brittle deformation, as a large number of fault planes and several fracturing episodes (Saidi 2001). The overlying Triassic deposits don't register highlighted fracturing. However, the states of tectonic stress are similar to those recorded eastward in the Tiddas-Souk Sebt and Bouterehla neighbouring Permian deposit basins (Ait Brahim & Tahiri 1996, Tahiri *et al.* 1996a, b, Saidi 2001, Saidi 2005). This tectonic consideration suggests a Permian (Autunian ?) to upper Triassic age for this so fractured magmatism (Tahiri *et al.* 1997).

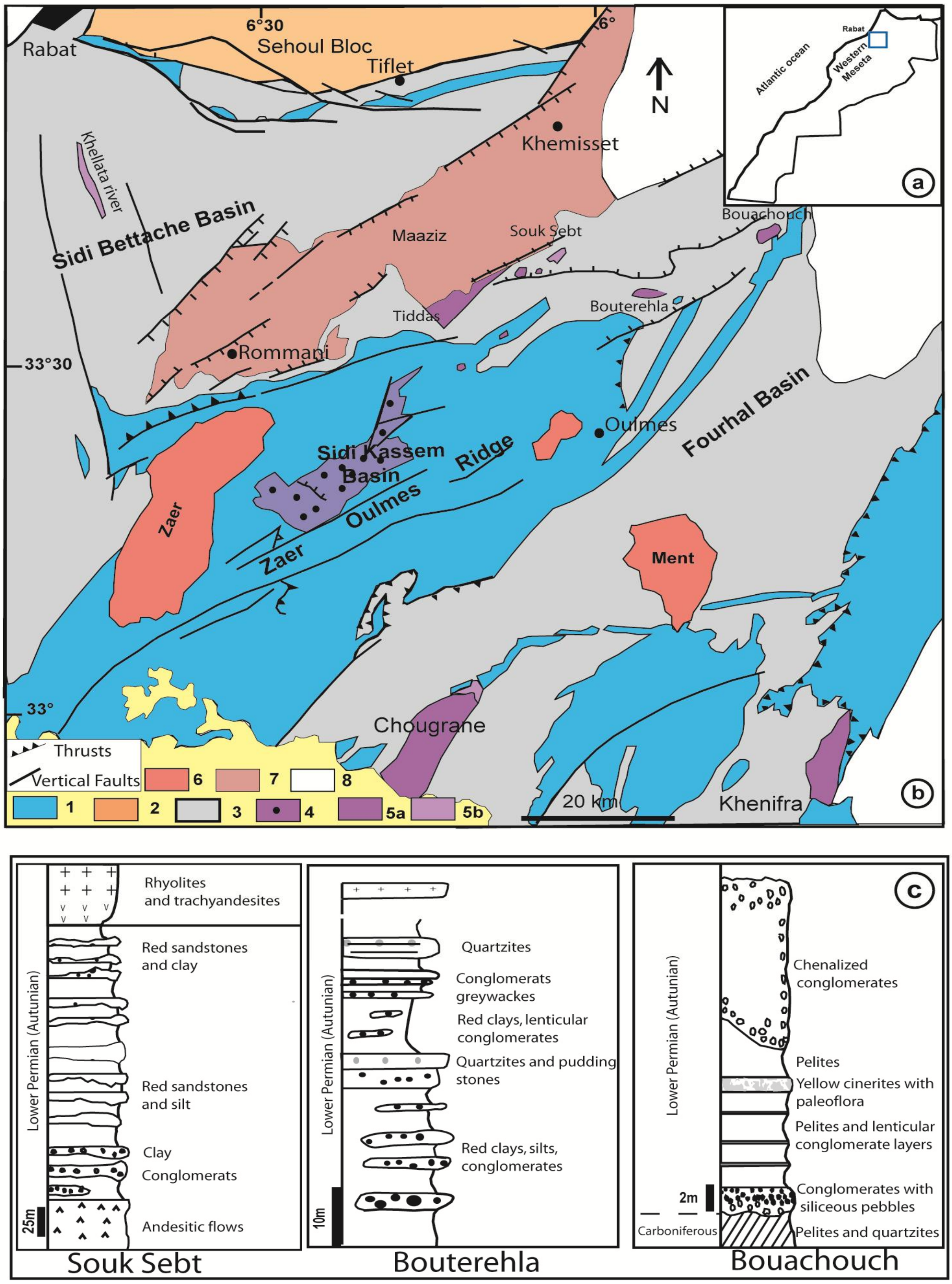

Figure 1. (a) Location of the studied area. (b) Geological sketch of western central Morocco summarized from the geological map of Morocco at 1/100.000, scheet of Khemisset. (c) Sketch stratigraphical column of the main Permian basins; 1, Pre-Carboniferous deposits; 2, Sehoul bloc; 3, Carboniferous basins; 4, Westphalian deposits; 5a, Autunian basins; 5b, Autunian magmatism; 6, Variscan granites; 7, Triassic Khemisset-Rommani basin; 8, post Triassic. (El Maidani *et al.*, 2013 completed).

Khemisset-Rommani basin

Triassic basin elongated along a NE-SW trending (Fig. 1a) shows deposits of clayey evaporitic facies, grouped into the Triassic formation (Et Touhami 1992). The synthesis of drilling data carried out in the basin shows that this formation includes: 1) after basal conglomerates (3 m) un-conformably overlying the Paleozoic (Viseo–Namurian) basement, lower red clay (500 m), occasionally silty or sandy and containing important intercalations of brownish clay salt, blackish salt with potassium inclusions and thinly bedded ore salt; 2) dolerites or basalts (50 to 60 m) often in the form of flows with inclusions of rock salt and anhydrite nodules, sometimes surmounted by lenticular carbonate layers, licks or anhydrite; and 3) alternating red clay (500 to 550 m), clay salt and rock salt to massive potassium inclusions covered by upper red clay (50m).

For this volcano-sedimentary series, previously attributed to the Permo–Triassic, palynological investigations in the NE edge of the basin (near Souk Sebt), thin sedimentary intercalations in the basalts have provided a great abundance of *Classopolis* associated to cf. *Alisporites* and an abundance of spores *Equisetales* that are dated Upper Triassic (Carnian) (Taugourdeau-Lantz 1978). Basalt dating K/Ar (whole rock) provided 182±13 to 191±13 Ma (Manspeizer *et al.* 1978). This volcanism is commonly dated Triassic–Liassic.

PERMIAN AND TRIASSIC VOLCANISM PETROGRAPHY

Permian volcanism

Despite the effects of weathering on the sampled rocks, the original texture and primary minerals have been preserved.

Andesite of Tiddas

The texture is microlitic, occasionally dendritic. Mineral paragenesis consists of plagioclase and opaque shaped microlitic fibers. We also note the presence of iron oxides and fractures filled with quartz or calcite.

Rhyolites of Souk Sebt

Exhibit dendritic or sometimes porphyritic texture and glass include mineral paragenesis consisting of plagioclase and altered polysynthetic twinned calcite, sericite, epidote, iron oxides or rarely muscovite.

The paragenesis includes the perthitic feldspar and biotite, sometimes locally altered to chlorite or totally transformed into opaque muscovite or biotite, some of these "fantomes" are twisted (SRT5). Quartz phenocrysts display crystallization lacunae.

Rhyolites of Bouterhela

The rock is highly altered with opaque abundance, which is needle shaped or amoeboid subcircular. "Fantomes" and plagioclase phenocrysts are completely altered.

Trachyandesites of the Khellata River

The texture is microlitic phyric and/or doleritic (KH2.2). The groundmass is locally chloritized or sometimes clouded with spherulites (KH24). Primary paragenesis contains carlsbad twinned plagioclase, sanidine, opaque grains, chlorite and glassy rock fragments. Secondary paragenesis consists of quartz, calcite and magnesian chlorite, often filling fractures.

Triassic basalt of Khemisset-Rommani basin

In the central part of the basin (Maaziz area*;* Fig. 1*)*, the texture is microlitic, locally doleritic (subophitic). Mineral paragenesis consists of plagioclase, pyroxene and opaque. The chlorite, calcite and iron oxides in addition to quartz are the secondary paragenesis. Vacuoles, formed of quartz filled by calcite and chlorite, are present. In the southern part of the basin (SW Rommani), the texture is microlitic, locally doleritic subophitic. Mineral paragenesis has pyroxene and plagioclase in microliters phenocrysts and more opaque minerals. Secondary assemblage is formed by chlorite.

PERMIAN VOLCANISM GEOCHEMISTRY

Chemical analyses of representative samples were performed at the University of Huelva (trace elements) and the University of Granada (major elements). The major elements were determined by X-ray fluorescence and trace elements by ICP-MS (Tab. 1). In the Zr/TiO2-Nb/Y diagram of Winchester & Floyd (1977) (Fig. 2), compositions of the Permian volcanic rocks are basaltic in the Khellata river, andesitic to trachyandesitic in the Khellata river, the Tiddas Souk Sebt and Bouterehla basins, and dacitic to rhyodacitic in the Tiddas Souk Sebt basin. The values of the Nb/Y ratio being less than 1, discard the alkaline character of all the studied rocks.

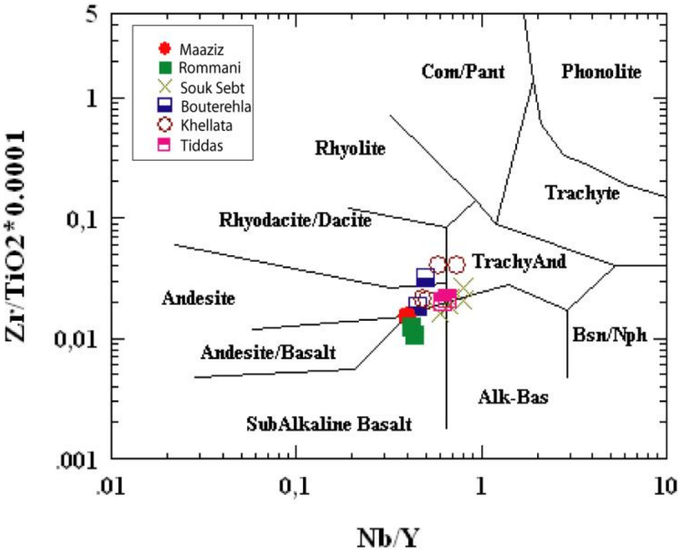

Figure 2. Winchester & Floyd (1979) plots for the studied rocks (El Maidani *et al.* 2013).

Table 1. Major, traces and rare earth elements of Permian (Tiddas, Bouterehla, Souk Sebt, Khellata) and Triassic (Khemisset-Rommani) rocks.

	Tiddas		**Bouterehla**		**Khellata**				**Souk Sebt Ait Ikkou**					**Rommani**		**Maaziz**	
	TID-5	TID-4	BOUTR	BOUTE1.1	KH1,1	KH2,3	KH2,1	KH2,2	SRT5	SRT4	SRT3	SRT2	SRT1	ROM-2	ROM-1	MZ	MAZ
SiO2	58,76	61,31	50,78	45,95	43,70	54,14	57,82	52,52	70,85	69,58	68,79	68,68	68,62	52,09	51,51	53,44	52,8
Al2O3	16,86	15,89	16,12	15,66	17,01	15,58	14,63	14,58	17,80	16,18	19,38	15,41	15,64	14,17	14,28	14,45	14,03
Fe2O3	4,24	4,65	7,19	9,27	12,52	11,68	11,19	13,68	1,77	1,91	1,85	2,04	1,99	11,14	10,67	10,12	9,42
MnO	0,05	0,04	0,13	0,17	0,70	0,15	0,26	0,27	0,01	0,06	0,07	0,06	0,05	0,173	0,135	0,151	0,08
MgO	0,26	0,23	1,79	2,79	4,08	2,22	2,17	2,16	0,09	0,09	0,12	0,56	0,32	7,8	8,99	7,53	10,08
CaO	5,11	4,63	8,00	7,61	5,11	2,98	2,55	4,14	0,29	1,53	0,27	2,03	2,72	10,08	9,47	9,46	6,95
Na2O	0,87	0,83	1,05	0,59	5,16	5,27	4,53	4,28	4,49	4,21	3,32	4,39	4,52	1,54	1,43	1,57	1,53
K2O	4,65	2,94	1,34	0,36	0,11	0,16	0,09	0,19	0,77	3,00	0,55	2,56	2,45	0,4	0,24	0,5	0,34
TiO2	1,30	1,19	1,75	1,86	1,47	1,82	1,89	1,41	0,40	0,43	0,43	0,40	0,34	1,17	1,2	1,12	1,11
P2O5	0,47	0,45	0,34	0,44	0,50	0,72	0,75	0,49	0,08	0,09	0,08	0,10	0,10	0,121	0,119	0,132	0,122
LOI	7,15	7,24	11,02	15,30	8,68	4,42	3,68	5,79	3,10	2,39	4,67	3,32	3,73	0,43	1,17	0,72	2,59
Somme	99,71	99,40	99,50	100,00	99,04	99,15	99,56	99,51	99,65	99,47	99,53	99,56	100,48	99,114	99,214	99,193	99,052
Li	74,94	62,00	29,79	151,44	76,25	35,61	52,84	27,22	39,29	47,54	196,14	24,04	17,62	13,17	9,18	11,27	26,61
Sc	12,36	10,35	16,44	18,60	37,80	23,38	27,95	34,03	2,58	2,52	2,88	3,49	2,83	27,73	23,76	28,64	28,47
V	103,86	86,76	90,42	151,18	47,77	162,70	131,27	39,58	12,88	17,35	20,52	17,10	15,59	228,86	187,40	232,68	241,02
Cr	104,83	90,43	35,95	120,02	12,62	17,32	14,26	9,89	7,21	12,19	11,46	10,40	10,48	293,34	220,97	262,73	202,09
Co	7,68	6,67	16,96	22,63	6,80	18,62	16,69	8,73	0,75	2,71	4,77	3,56	3,27	42,23	30,42	37,21	37,95
Ni	36,18	35,56	8,65	92,64	5,32	8,39	6,37	7,71	5,57	10,17	13,88	8,80	7,65	104,92	74,98	103,53	112,55
Cu	19,49	27,98	8,52	22,35	17,41	23,85	23,04	16,67	2,85	6,60	7,85	5,64	4,18	49,56	31,64	135,71	170,95
Zn	30,71	24,78	171,71	148,13	263,18	104,02	153,90	133,65	13,53	52,64	17,62	105,14	27,04	63,91	151,94	78,81	56,41
Ga	20,98	60,63	19,05	18,09	19,17	23,86	19,54	22,63	22,20	31,79	29,69	32,86	29,54	16,57	12,63	15,37	16,48
Ge	<0,01	<0,01	<0,01	<0,01	<0,01	0,98	1,32	1,05	0,43	0,27	<0,01	0,22	<0,01	<0,01	<0,01	<0,01	<0,01
As	0,80	1,58	13,81	1,19	49,82	6,83	4,88	0,54	0,17	1,21	5,25	1,25	0,23	1,28	0,85	1,11	0,31
Se	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,19	0,94	<0,01	<0,01	<0,01	<0,01
Rb	69,64	43,47	47,49	21,86	1,01	5,55	2,18	4,80	26,85	55,82	15,49	52,00	48,53	5,91	13,26	21,82	12,41
Sr	89,48	110,45	239,70	645,30	63,90	243,10	61,06	185,31	249,72	285,98	219,24	335,14	334,49	142,49	108,09	145,60	150,55
Y	21,18	18,96	29,30	26,24	29,14	31,31	33,30	29,09	2,94	4,02	2,71	3,94	3,38	16,91	14,01	18,43	17,95
Zr	278,16	239,08	316,55	217,59	597,32	389,95	388,44	571,59	82,92	79,88	69,22	85,55	88,40	148,32	122,65	171,00	168,21
Nb	13,32	11,93	12,21	12,72	21,33	14,90	16,72	16,69	1,97	2,47	1,85	2,38	1,98	6,19	5,47	6,62	6,82
Mo	0,99	0,85	1,33	0,81	1,63	1,62	1,26	1,70	0,53	1,47	0,39	1,25	1,26	1,31	0,97	1,60	1,02
Cd	0,10	0,03	0,37	0,09	0,36	0,11	0,14	0,45	0,06	0,07	0,10	0,07	0,11	<0,01	0,03	<0,01	<0,01
Cs	3,94	3,48	13,94	5,22	0,19	0,32	0,26	0,39	2,79	6,21	4,01	1,88	6,60	0,70	0,80	1,30	1,07
Ba	259,50	2740,91	194,39	101,02	42,98	173,11	59,94	137,43	178,84	634,54	350,91	862,33	748,52	168,12	127,14	153,80	127,18
La	34,37	30,98	28,24	63,23	25,37	23,74	27,59	25,74	20,04	23,07	19,81	22,21	21,95	8,66	7,22	10,81	10,97
Ce	70,50	64,85	60,53	130,66	54,32	53,88	62,98	54,77	36,18	43,10	36,96	41,87	40,89	19,61	16,14	23,56	23,87
Pr	9,08	8,41	7,61	17,83	7,44	7,48	8,62	7,59	4,04	4,99	4,19	4,73	4,70	2,56	2,14	3,05	3,14
Nd	34,32	31,23	29,87	69,23	32,12	32,17	36,89	30,56	13,88	16,89	13,80	16,13	15,63	11,15	8,75	12,77	13,33
Sm	6,49	5,87	6,68	11,82	8,00	7,51	8,64	6,93	2,30	2,84	2,30	2,79	2,61	2,99	2,29	3,42	3,41
Eu	1,75	1,52	1,72	3,05	2,22	2,40	2,69	2,25	0,50	0,86	0,64	0,86	0,80	0,93	0,80	1,07	1,03
Gd	5,63	5,35	6,71	8,82	8,31	7,76	8,85	7,34	1,55	1,95	1,49	1,95	1,77	3,26	2,84	3,72	3,94
Tb	0,85	0,77	1,07	1,15	1,18	1,21	1,31	1,14	0,17	0,22	0,17	0,22	0,20	0,61	0,51	0,65	0,64
Dy	4,93	4,38	6,21	6,02	6,54	7,12	7,50	6,62	0,79	0,96	0,76	1,13	0,90	3,64	3,05	4,00	3,93
Ho	0,93	0,83	1,32	1,19	1,33	1,43	1,50	1,37	0,11	0,14	0,12	0,16	0,15	0,75	0,61	0,84	0,82
Er	2,52	2,28	3,47	3,21	3,43	3,84	3,87	3,60	0,32	0,33	0,30	0,40	0,41	2,06	1,71	2,27	2,35
Tm	0,34	0,31	0,52	0,43	0,51	0,54	0,56	0,56	0,02	0,03	0,03	0,04	0,05	0,32	0,23	0,33	0,31
Yb	2,20	1,96	3,15	2,66	3,14	3,39	3,43	3,32	0,22	0,24	0,23	0,32	0,27	1,91	1,65	2,10	2,14
Lu	0,31	0,28	0,46	0,38	0,50	0,51	0,52	0,59	0,02	0,03	0,03	0,04	0,03	0,30	0,23	0,31	0,31
Hf	7,68	6,71	8,07	6,14	13,51	9,23	8,93	13,01	2,49	2,49	2,27	2,52	3,01	4,07	3,45	4,73	4,56
Ta	1,16	2,15	1,53	3,99	3,82	2,23	1,43	2,33	1,25	0,87	1,46	0,63	2,48	2,88	1,35	1,16	3,31
Tl	0,27	0,20	0,31	0,13	0,03	0,08	0,07	0,10	0,23	0,31	0,09	0,33	0,25	0,04	0,03	0,04	0,03
Pb	11,60	9,79	36,98	20,12	22,03	4,74	4,50	5,95	1,76	7,41	6,74	13,68	9,56	5,25	7,09	5,45	3,71
Th	11,91	10,80	8,08	13,05	4,90	4,68	5,30	5,18	5,08	4,62	4,45	4,54	4,41	2,16	1,83	2,69	2,65
U	3,20	2,68	1,96	1,35	1,62	1,45	1,44	1,72	1,65	1,11	0,98	0,99	1,24	0,51	0,43	0,60	0,63

In the Permian **basalts** (BOUTE11, Boutr, KH11), values vary as follow: silica (43.7%–50.78%), TiO2 (1.47%–1.86%), Al2O3 (15.66%–17.01%), Fe2O3 (7.19%–12.52%), CaO (5.11%–8%, MgO (1.79%–4.08%) and the alkalis (0.95%–5.27%). Mafic Permian lavas display very high LOI, probably due to alteration events.

The contents of the trace elements are marked by relatively high values of Zr (597–217.59 ppm), Nb (12.21–21.33 ppm), Y (26.24–29.30 ppm), and Cr (12.62–120ppm). The sum of REE varies from 154 to 319 ppm. The REE normalized to chondrite (Nakamura, 1974; Fig. 3a1, a2), show some similarity for all volcanic rocks with a major split. In LREE relative to HREE; La/Yb ratios are between 8.97 and 23.8 in mafic rocks. No Eu anomaly exists. The HREE are moderately fractionated relatively to LREE. Normalized Tb/Yb ratios are lower than 1.

In normalized E-MORB multi-element diagrams (Fig. 3b1, b2), incompatible element spectra display fractionation of the most incompatible elements, with La_N/Yb_N ranging from 2.63 to 8.95, enrichment of the lithophile elements, and moderate Nb and Ta anomalies ($0.15<Nb_N/La_N<0.49$). The associated Sr negative anomaly could be due to plagioclase fractionation.

In the Permian trachyandesites (Tiddas basin and Khellata River; cf. Tab. 1), values vary as follow: silica (52.52%–61.31%), TiO2 (1.19%–1.89%), Al2O3 (14.58%–16.86%), Fe2O3 (4.24%–13.68%), CaO (2.55%–5.11%, MgO (0.23%–2.22%) and alkali (3.77%–5.52%). The contents of the trace elements are marked by relatively high values of Zr (239.08–571.59 ppm), Nb (11.93–16.72 ppm), Y (18.96–33.30 ppm), and Th (4.68–11.91 ppm). The sum of REE ranges varies from 151.58 to 174.44 ppm and REE (Fig. 3c) show a very important fractionation in LREE (especially for Tiddas-Souk Sebt samples) comparatively to HREE (La/Yb between 8 and 15.77) and a total absence of negative anomaly Eu. HREE are moderately fractionated.

In normalized E-MORB multi-element diagrams (Fig. 3d), spectra of Permian volcanic rocks are parallel and split with a relative dispersion at LIL elements and show very pronounced negative anomalies in Nb and positive Th and Zr.

Rhyolites (samples Souk Sebt; SRT1, SRT2, SRT3, SRT4, SRT5) contain high levels of silica (68.62%–70.85%) and alkalis (3.87%–6.97%) and low TiO_2 (<0.43%), Fe_2O_3 (<2.04%), CaO (<2.72%) and MgO (<0.56%).

The contents of the trace elements are marked by relatively low values of Zr (<85.55 ppm), Nb (average: 2.12 ppm), Y (average: 3.39 ppm). The sum of REE ranges from 80.12 to 95.62 ppm and REE (Fig. 3e) show a very important fractionation in LREE and HREE (La_N/Yb_N = 26 to 36).

E-MORB normalized multi-element plots (Fig. 3f), indicates that the profiles of Permian volcanic rocks are parallel and fractionated with a relative dispersion at LILE (Ba, Rb and Th) and show Nb negative and Hf - Zr positive anomalies. Unlike studied Permian rocks, there is no Sr negative anomaly. Also, we may note a significant enrichment of Zr, Hf, depletion of Nb ($Nb_N/La_N<0.1$), Y, Yb and Sr. Throughout the Permian rocks, negative anomalies in Nb and Zr and positive in Hf are typical of calc-alkaline magmas**.**

TRIASSIC VOLCANISM GEOCHEMISTRY

The chemical compositions of Triassic rocks (Tab. 1) are similar to those found in the more or less altered basalts. In the Zr/TiO_2-Nb/Y diagram of Winchester & Floyd (1977), the Triassic volcanic rocks (Rommani-Khemisset basin) are in the field of basalts and andesites (Fig. 2). Nb/Y ratio values being less than 1, discard the alkaline character of all the studied rocks. The values of MgO range from 7.53 to 10.08%. Silica varies between 51.51% and 53.44%. Al_2O_3 contents are averaged 14%, CaO varies from 6.95% to 10.08%, Fe_2O_3 from 9.42% to 11.14% and TiO2 values are averaged 1.15%. The contents of alkali are low (<2.07%). Normative composition displays saturated rocks with proportions of quartz ranged between 15.19 and 16.95. Olivine, nepheline and corindon are absent.

The rocks contain relatively high levels of Zr (122.65–171ppm). Y varies from 14.01 to 18.43 ppm, V from 187.40 to 241.02 ppm, Cr from 202.09 to 293.34 ppm. Nb values are lower (average: 8 ppm). The amount of rare earth REE varies from 47.94 to 69.88 ppm. Chondrite-normalized REE display parallel and almost unfractionated patterns (La/Yb less than 4) (Fig. 3g). The latter ratios are similar to those of the tholeiitic basalts, as evidenced by the values of Ti/V ratios. The La/Yb ratios are similar to those encountered in the Triassic basalts of Group I of the High Atlas (Bertrand *et al.* 1982).

In E-MORB normalized multi-element plots (Fig. 3h), spectra of Triassic volcanic rocks are parallel and display enrichment in the lithophile elements and moderate Nb and Ta anomalies ($Nb_N/La_N< 0.50$). The Sr negative anomaly associated could be due to plagioclase fractionation.

The Permian and Triassic rocks have low Ce/Pb and Nb/U ratios, indicating significant crustal contamination (fig. 5). Furthermore, low Y/Nb values (1.36 %<Y/Nb<2.78%) attest the no alkaline character of these rocks.

DISCUSSION-GEODYNAMIC CONTEXT

Granitoids and associated lavas (Carboniferous and Permian) of moroccan variscan belt are similar to calc-alkaline orogenic series, this led to consider, in previous work, different setting up models more or less controversial. Lagarde (1987) proposes a model, characterized by a continental subduction zone dipping to the west in the internal mesetian domain. From a geochemical study of Devono–Dinantian lavas, Kharbouch (1994) offers a similar pattern, except that the subduction plane is oriented to the east. In both models, the melting of occurring upper mantle and generated mafic magmas would cause during their rise, melting of the continental crust. Piqué & Michard (1989) proposed a model with east subduction verging, while Roddaz *et al.* (2002) proposed a westward subduction model. Finally Rheiic subduction to the East was considered and largely documented by Simancas *et al.* (2005, 2006, 2009), Michard *et al.* (2008, 2010) and this work (Fig. 6 and 7). The Triassic tholeiitic basaltic volcanism is not subject to any debate regarding its genesis in connection with the opening of the Atlantic Ocean (e.g., Bertrand 1991, Youbi *et al.* 2003, Knight *et al.* 2004, Marzoli *et al.* 2004 2006, El Hachimi *et al.* 2010, Bensalah *et al.* 2011).

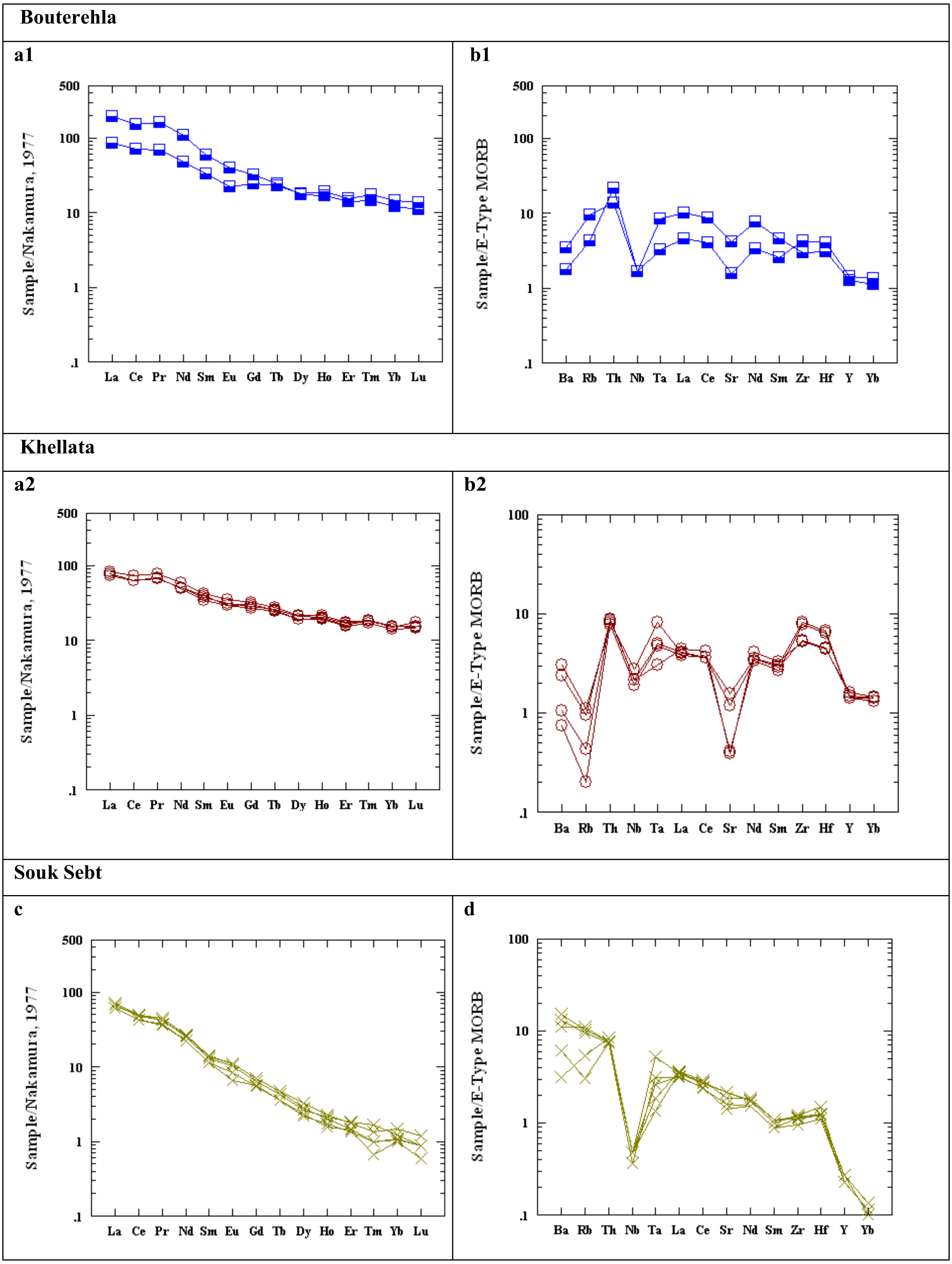

Figure 3 (completed in the next page). a1, a2, c, e, g: Chondrite-normalized REE patterns (Nakamura 1974).

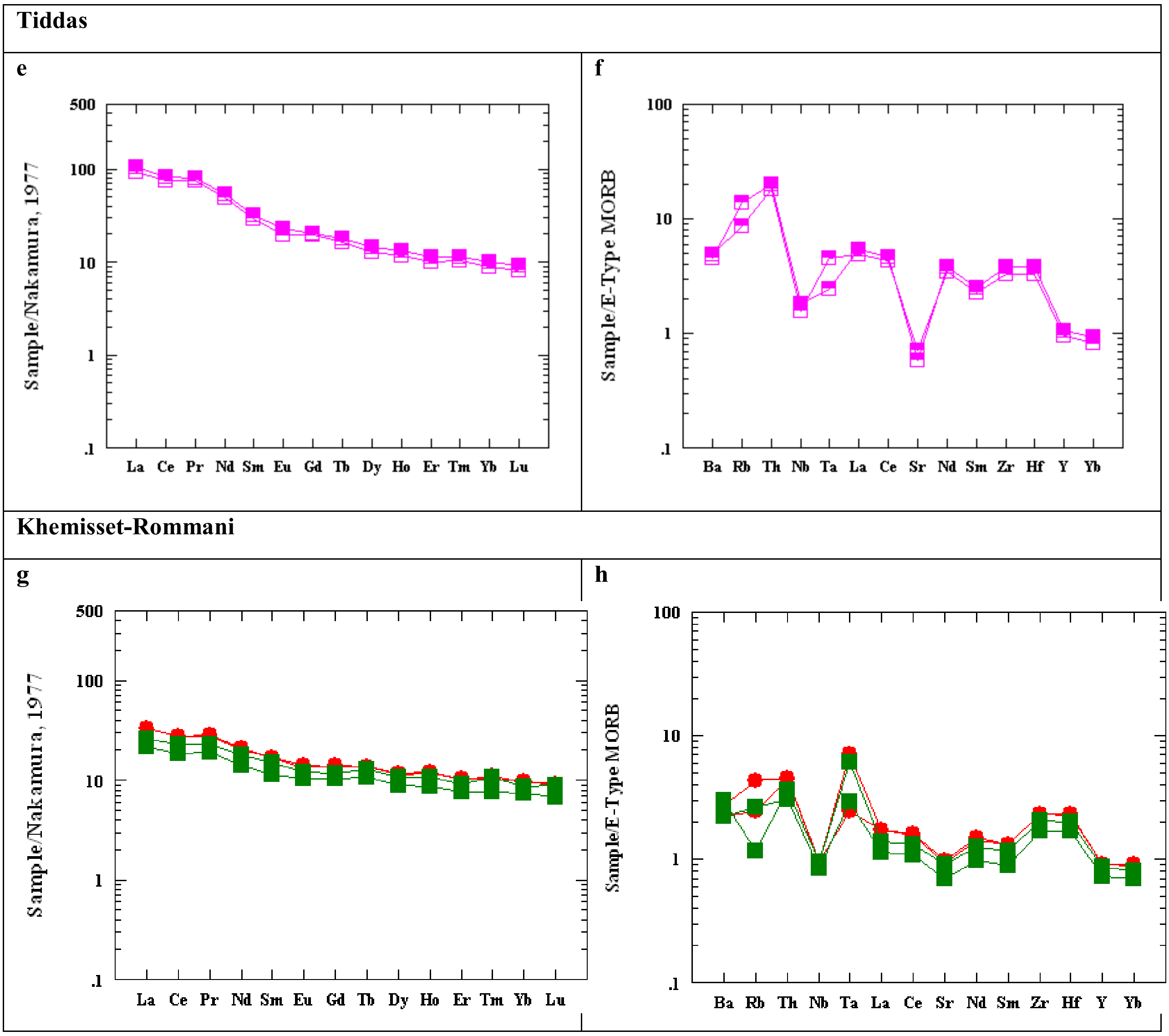

Figure 3 (continued). b1, b2, d, f, h: Normalization diagram with respect to the E-type MORB (El Maidani *et al.*, 2013, completed).

Geotectonic Zr/Y vs Zr diagram allow to place Triassic and Permian studied rocks in the field of intraplate basalts contexts (Fig.5). The (Zr/Sm) ratios > 20 are the same to those found in intraplate basalts.

In the Th/Yb versus Ta/Yb diagram of Pearce (1982a), most of the studied rocks overlap calc-alkaline and shoshonitic fields (Fig. 4). Rocks from Tiddas and Bouterehla are significantly enriched in Th due probably to assimilation and fractional crystallization (AFC) combined processes. In addition, E-MORB normalized multi-element display the same enrichment in Th, Lile and REE relative to Nb, which might suggest that these magmas were affected by crustal contamination (e.g., Dostal *et al.* 1986) or extracted from a mantle source enriched in incompatible elements (e.g., Hawkesworth *et al.* 1983, Menzies *et al.* 1983). Similarly, the values of La/Ce ratio are always greater than 1 and suggest an enriched mantle origin (Marcelot *et al.* 1989). Similarly, the values of La/Nb ratios consistently above 1.5 indicate a lithospheric source (Fitton *et al.* 1988). Results of the geochemical study of Permian and Triassic volcanic rocks from north-western Meseta are consistent with the results obtained on the same rocks in other regions of Morocco (e.g., Youbi 1998, Bertrand 1991). Permian volcanism is chemically similar and probably cogenetic to the majority of Late Variscan granites in Morocco (e.g., Gasquet *et al.* 1996, El Hadi *et al.* 2006) and also to the first Permian eruptive volcanism cycle (e.g., Youbi *et al.* 1995). The Triassic–Liassic volcanism of Khemisset-Rommani basin reminds magmatism defined in the Moroccan part of CAMP (Central Atlantic Magmatic Province) (Youbi *et al.* 2003, Knight *et al.* 2004, Marzoli *et al.* 2004, 2006, El Hachimi *et al.* 2010, Bensalah *et al.* 2011), especially the Triassic–Liassic magmatism of Berrechid basin (Bensalah *et al.* 2011).

In general, the geochemical data (Triassic and Permian rocks) show enrichment in most of the geochemical elements. This could be linked to a crustal contamination of the studied rocks (Fig. 4) in connection with the events of ancient subduction (probably Variscan, Fig. 6, 7). The introduction of a crustal component is evidenced by low values of the Ce/Pb (2–20) (Fig. 5) and Nb/U ratios, very sensitive to the incorporation of crustal material.

In this part of the western Moroccan Meseta, the importance of transtensional phase in the opening of Permian basins has been demonstrated (Saidi *et al.* 2001), confirming the reactivation of old accidents (sub-equatorial and sub-meridian) guiding sedimentation and Permian volcanism, thereby confirming the role of heritage in the Variscan configuration of Permian basins. After this transtension and following rotational constraints, extensive system took place in the western Moroccan Meseta and the High Atlas (Saber, 1994, Saidi, 2001, Saber *et al.* 2007) during Permian–Triassic transition. In the western High Atlas (High Atlas of Marrakech), especially in the Argana basin and Zat River, the latest Permian deposits (El Arabi 2007) are regarded as witnesses of the first episodes of the Atlantic rifting (Laville & Piqué 1991, Leroy *et al.* 1997, El Arabi 2007).

The evolution of the Late Variscan (Permian) calc-alkaline magmatism to the continental tholeiitic magmatism in the Triassic period confirms the change of tectonic regime described above, from the end of the Variscan compressive cycle (Stephanian–Permian; Michard 1976, Piqué & Michard 1989, Michard *et al.* 2008, 2010) to the Atlantic rifting (Triassic; Bertrand 1991, Laville & Piqué 1991, Leroy *et al.* 1997).

The same result was admitted to the Iberian Massif (e.g., Innocent & Briqueu, 1995; Villaseca *et al.* 2002). Indeed, the West Mediterranean calc-alkaline orogenic cycle (Lower Permian?) reminds unequivocally magmas of subduction zones and active continental margins (e.g., Cabanis *et al.* 1990, Doublas *et al.* 1998). Thus, in the Iberian Centre Zone, calc-alkaline microdiorites and quartz diorite dykes of the lower Permian (290±10My) show negative anomalies in Nb and Ta (Villaseca *et al.* 2002).

Triassic gabbros dykes (203My) are tholeiitic. In the Ossa Morena area, continental tholeiitic diabase exists, representing the extensional episode of the upper Permian (250±5My, Galindo *et al.* 1991). In the Spanish Pyrenees, the lower Permian is represented by calc-alkaline andesites, the transitional Permian is represented by trachyandesites and middle Permian by basalts, dolerites and alkaline lamprophyres (e.g., Innocent & Briqueu 1995). Triassic magmatism is represented by subvolcanic sills of tholeiitic dolerites from a sub-continental metasomatized mantle (e.g., Lago *et al.* 2000). According to geochemical characteristics obtained in these Iberian area, we believe that all the Permian Triassic magmatism was set up in a continental intraplate context.

The more or less enriched character in these studied rocks suggests the origin from magmas previously metasomatized (before the Carboniferous–Permian) by an ancient oceanic crust (probably related to the closure of the Rheic Ocean or earlier?) "fossilized" below this intra-continental context (Fig.6, 7). However, the suture of this ocean has not been (yet?) identified in Morocco but would be represented by the Collector anomaly (Lefort *et al.* 1996, Simancas *et al.* 2005, 2006, 2009).

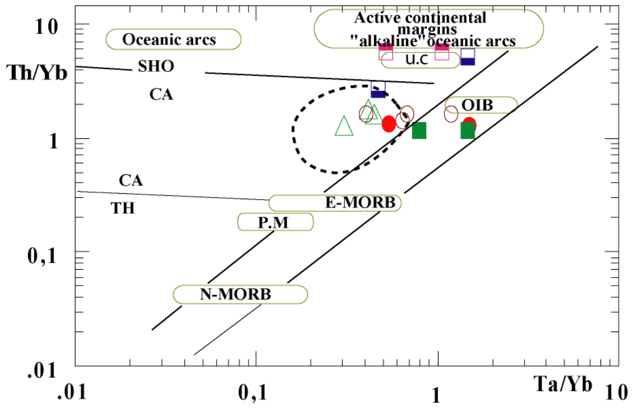

Figure 4. Th/Yb-Ta/Yb plot of Pearce (1982) for the studied rocks. Green triangle: groupe 1 of High Atlas (Bertrand *et al.* 1982). Dashed black line: Rocks from Spanish central system (Villaseca *et al.* 2002). Rest of legend idem Fig. 2.

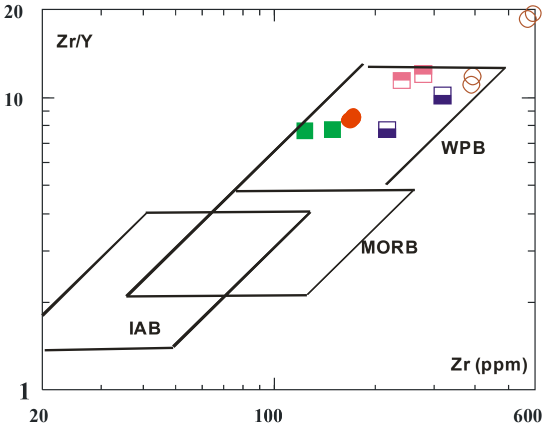

Figure 5. Zr/Y – Zr plot for studied mafic rocks (Pearce 1982). WPB: Within plate basalts.

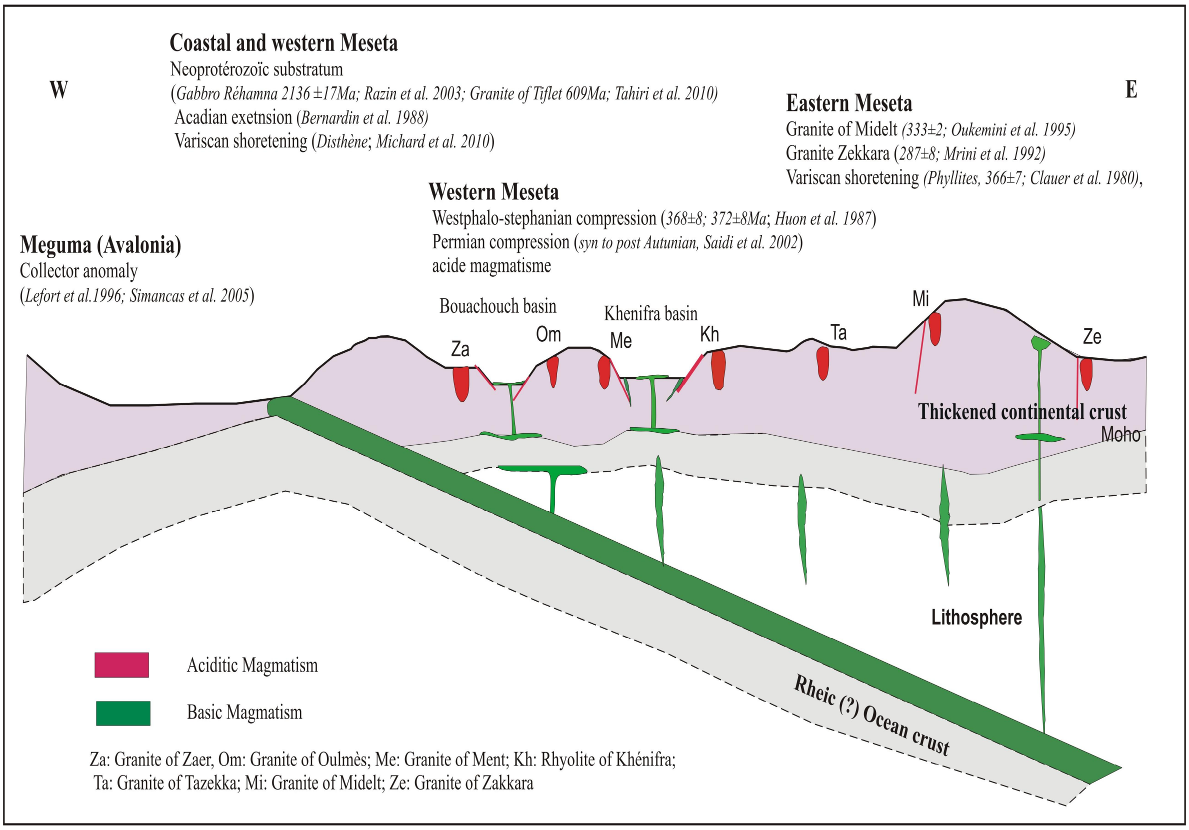

Figure 6. Interpretative model of the Permian/Triassic magmatic setting of the Moroccan Meseta.

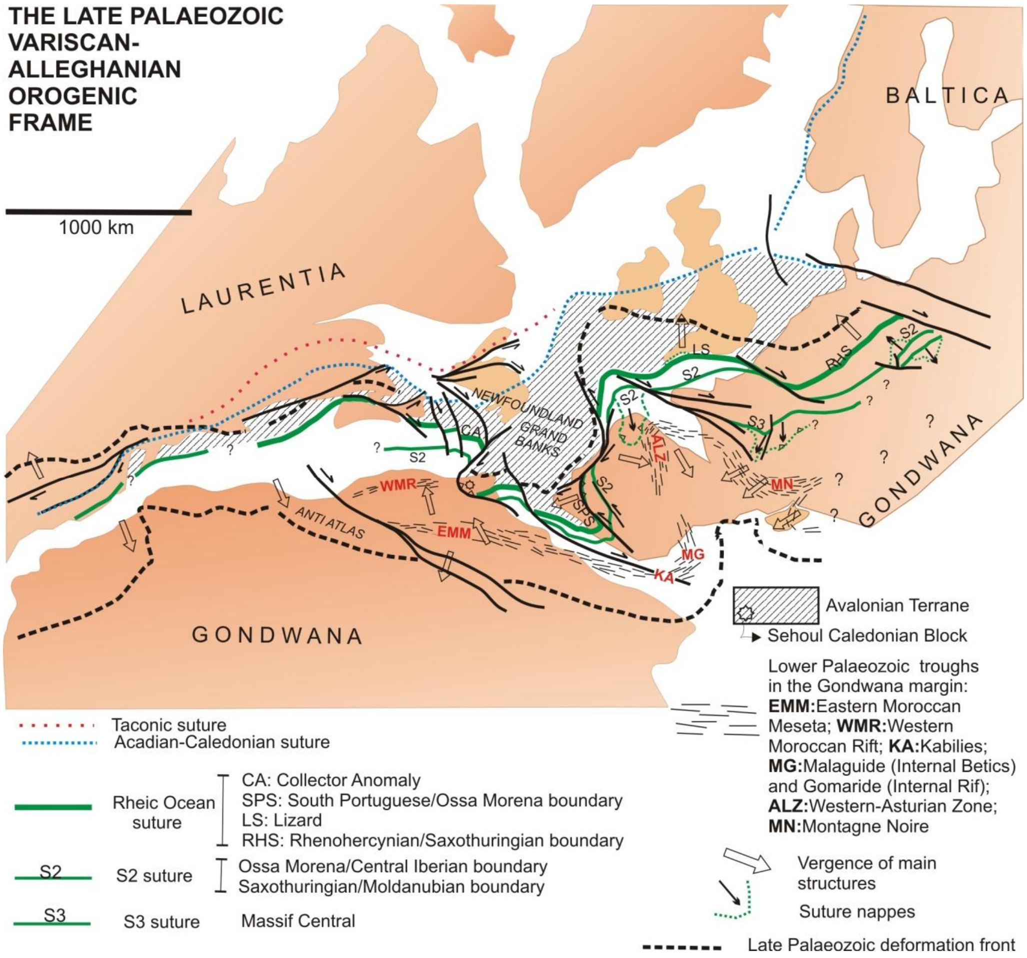

Figure 7. Tectonic framework of the Variscan (Acadian–Alleghanian) Orogenic belt at the end of the Palaeozoic (Simancas *et al.* 2005)

CONCLUSION

The geochemical study of mafic and acidic rocks emplaced in the western Moroccan Meseta from the Variscan collision episodes until the early Mesozoic Atlantic rifting (Laville & Piqué 1991, Leroy *et al.* 1997) demonstrates the enriched character of a mantle metasomatized by crustal component, probably during periods of ancient subduction (Variscan?). A certain degree of contamination by continental crust during the passage and implementation of these magmas should be considered for all the Permian and Triassic studied rocks, which show low values of the Ce/Pb and Nb/U ratios (Fig. 5) that are very sensitive to the incorporation of crustal material.

The proposed geodynamic model (Figs. 6, 7) complete those proposed and widely discussed by Simancas *et al.* (2005, 2006, 2009), El Hadi *et al.* (2006), Michard *et al.* (2008, 2010). New elements of the model reported in this study emphasize: (i) the calc-alkaline chemical nature and orogenic magmatism signature during the Permian; (ii) the permanence below the Moroccan Meseta in a back-arc position, of an enriched mantle whose partial melting gave rise to the Permian and Triassic magmas.

ACKNOWLEDGEMENTS

Authors thank Projet "Niches d'excellence" and "ReNSA Center" University Hassan II of Casablanca, URAC46 "Programme d'Urgence Université Mohammed V of Rabat", GEOTEL and Universities of Granada and Huelva (Spain). The journal reviewers Prof. Dominique Gasquet and an anonymous are kindly thanked for their reviews.

REFERENCES

Ait Brahim L. & Tahiri A. 1996. Rotation horaire des contraintes et mécanismes d'ouverture et de fermeture des bassins permiens du Maroc central. *In*: F. Medina (Ed.) - le Permien et le Trias du Maroc: états de connaissances. Edition PUMAG, Marrakech, 87–98.

Bandet Y., Gonord H., Cailleux Y. *et al.* 1990. Age K-Ar triasique des volcanic rocks des Béni Abid (Bassin dévono–dinantien de Sidi Bettache, Meseta marocaine nord occidentale). *Comptes Rendus de l'Académie des Sciences, Paris*, 310, 1665–1671.

Bensalah M.K., Youbi N., Mahmoudi A. *et al.*. 2001. The Central Atlantic Magmatic Province (CAMP) volcanic sequences of Berrechid and Doukkala basins (Western Meseta, Morocco): volcanology and geochemistry. *Comunicações Geológicas,* 98, 15–27.

Bernardin C., Cornée J.-J., Corsini M. *et al.* 1988. Variations d'épaisseur du Cambrien moyen en Meseta marocaine occidentale : signification géodynamique des données de surface et de subsurface. *Canadian Journal of Earth Sciences*, 25, 2104–2117.

Bertrand H. 1991. The Mesozoic province of Northwest Africa: a volcano-tectonic record of the early opening of Central Atlantic. *In*: M. Kampuzu & R. Lubala (Eds.) - *Magmatism in extensional structural setting,* Springer Verlag, Berlin, Heidelberg, 147–188.

Bertrand H., Dostal J. & Dupuy C. 1982. Geochemistry of Early Mesozoic tholeiites from Morocco. *Earth and Planetary Sciences Letters,* 58, 225–239.

Broutin J., El Wartiti M., Freytet P. *et al.* 1987. Nouvelles découvertes paléontologiques dans le bassin détritique carbonaté permien de Tiddas (Maroc central), *Comptes Rendus de l'Académie des Sciences, Paris,* 305, 143–148.

Broutin J., Assoumi H., EL Wartiti M. *et al.* 1998. The Permian basins of Tiddas, Bou Achouch and Khenifra (central Morocco). Biostratigraphic and palaeophytogeographic implications. *In:* S. Crasquin-Soleau & E, Barrier (Eds.) - Peri-Tethys Memoir 4: epicratonic basin of Peri-Tethyan platforms. *Mémoires du Muséum National d'Histoire Naturelle, Paris,* 179, 257–278.

Cabanis B., Cocheme J.J., Vellutini J.L. *et al.* 1990. Post-collisional Permian volcanism in northwestern Corsica: an assessment based on mineralogy and trace-element geochemistry. *Journal of Volcanology and Geothermal Research,* 44, 51–67.

Cailleux Y., Gonord H., Le Guern M. & Sauvage M. 1983. Taphrogenèse et magmatisme permien dans le Maroc central. *Bulletin de la faculté des sciences de* Marrakech, 1, 24–39.

Carte géologique du Maroc au 1/100.000, feuille de Khémisset. *Notes et Mémoires du Service géologique du Maroc,* 398.

Clauer N., Jeannette D. & Tisserant D. 1980. Datation isotopique des cristallisations successives du socle cristallin et cristallophyllien de la Haute Moulouya (Maroc hercynien), *Geologishe. Rundschau,* 69, 68-83.

Cogney G., Normand P., Termier H. & Termier G. 1974a. Observation sur le basalte du bassin triasique de Rommani-Maaziz (Maroc occidental). *Notes et Mémoires du Service géologique du Maroc,* 36, 264, 153–173.

Cogney G., Normand P., Termier H. & Termier G. 1974b. Sur la présence de pillow-lavas dans le basalte du Permien–Trias au Maroc central. *Comptes Rendus de l'Académie des Sciences, Paris*, 273, 446–449.

Cogney G. & Faugères J.P. 1975. Précision sur la mise en place des épandages basaltiques de formations triasiques de la bordure septentrionale du Maroc central. *Bulletin de la Société Géologique de France*, 5, 721–733.

Doblas M., Oyarzun R., López-Ruiz J. *et al.* 1998. Permo–Carboniferous volcanism in Europe and north-western Africa: a superplume exhaust valve in the center of Pangea. *In :* Kinnaird J. (Ed.) - Aspects of tensional magmatism in Africa, *Journal of African Earth Sciences*, 26, 1, 89–99.

Dostal J., Baragar W.R.A., Dupuy C. 1986. Petrogenesis of Natkusiak continental basalts, Victoria Island, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 23, 622–632.

El Arabi E.H. 2007. *La série permienne et triasique du rift haut-atlasique: nouvelles datations; évolution tectono-sédimentaire.* Thèse de Doctorat, Université Hassan II Casablanca, 225 p.

El Hachimi H., Youbi N., Madeira J. *et al.* 2010. *Morphologies and emplacement mechanisms of the lava flows of the Central Atlantic Magmatic Province (CAMP) of Morocco.* II Central and North Atlantic Conjugate Margins Conference-Lisbon. Portugal, 96–100.

El Hadi H, Tahiri A. & Reddad A. 2003. Les granitoïdes hercyniens post-collisionnels du Maroc Oriental: une province magmatique calco-alcaline à shoshonitique. *Comptes Rendus Geosciences, Paris*, 335, 959–967.

El Hadi H., Tahiri A., Simancas F. *et al.* 2006. The variscan granitic associations of Morocco: petrography, geochemistry and its comparisons with the variscan granite of the Iberian massif. *Geodinamica Acta*, 19, 2, 103–116.

El Maidani A., El Hadi H., Saddiqi O. *et al.* 2013. Le volcanisme post varisque (permien et triasique) du Maroc central occidental : Pétrographie, géochimie et contexte de mise en place. *ScienceLib* Editions Mersenne, 5, n°130107.

El Wartiti M. 1990. *Le Permien du Maroc hercynien: étude géologique et implications paléogéographiques*. Thèse de Doctorat d'Etat, Université Mohammed V, Rabat, 500p.

Essamoud R. 1989. *Dynamique fluviatile dans la série stéphanopermienne de la région de Marrakech (Haut Atlas nord–sondages du Haouz–Jebilet orientales). Dynamique sédimentaire. Pétrographie*. Thèse de Doctorat, Université de Bourgogne, Dijon, 279 p.

Et Touhami M. 1992. *Le Trias évaporitique du bassin de Khémisset (Maroc central): géométrie des dépôts, évolutions sédimentaires et géochimie*. Thèse de Doctorat, Université Claude Bernard, Lyon I, 242 p.

Fitton J.G., James D., Kempton P.D. *et al.* 1988. The role of lithospheric mantle in the generation of Late Cenozoic mafic magmas in the western United States. *In:* X. Cox, Y. Menzi, *et al.* (Eds.) - Oceanic and continental lithosphere: similarities and differences. *Journal of Petrology* (special issue), 331–349.

Galindo C., Munoz M. & Casquet C. 1991. El enjambre filoniano mafico intrusivo en el Complejo plutonico Tiliga-Barcarrota (Ossa-Morena, Badajoz). *Geogaceta*, 10, 87–90.

Gasquet D., Stussi J.M. & Nachit H. 1996. Les granites varisques du Maroc dans le cadre de l'évolution géodynamique régionale. *Bulletin de la Société Géologique de France*, 167, 4, 517–528.

Gonord H., Le Guern M., Turiot D. & Rebourd H. 1980. Mise en évidence d'un volcanisme rhyolitique stéphano–permien sur la bordure nord du massif hercynien central du Maroc extension et importance du volcanisme tardy-hercynien. *Comptes Rendus de l'Académie des Sciences, Paris,* 291, 51–54.

Hawkesworth C.J., Erlank A.J., Marsh J.S. *et al.* 1983. *Evolution of the continental lithosphere: evidence from volcanics and xenoliths in Southern Africa*. *In:* C.J. Hawkesworth & M.J. Norry (Eds.) - *Continental basalts and mantle xenoliths, Shiva*. Cheshire, U.K, 111–138.

Huon S., Piqué A. & Clauer N. 1987. Etude de l'orogenèse hercynienne au Maroc par la datation K/Ar de l'évolution métamorphique de schistes ardoisiers. *Sciences Géologiques. Bulletin.* Strasbourg, 40, 273–284.

Innocent C. & Briqueu L. 1995. The origine of Pyrenean Variscan volcanic rocks (France-Spain): REE and Sm-Nd isotope constraints-Comments. *Chemical Geology*, 121, 295–297.

Izart A. & Vieslet J.L. 1988. Stratigraphie, sédimentologie et micropaléontologie du Famennien, Tournaisien et Viséen du bassin de Sidi Bettache et de ses bordures (Meseta marocaine nord-occidentale). *Notes et Mémoires du Service géologique du Maroc,* 44, 334, 7–41.

Izart A., Chèvremont P., Tahiri A. *et al.* 2001. Carte géologique du Maroc au 1/50 000, feuille de Bouqachmir, *Notes et Mémoires du Service géologique du Maroc,* 411bis.

Jébrak M. 1985. *Contribution à l'histoire naturelle des filons F-Ba du domaine varisque. Essai de caractérisation structurale et géochimique des filons en extension et en décrochements. Massifs centraux français et marocains.* Thèse de Doctorat d'Etat, Université d'Orléans, 470 p.

Kharbouch F., Juteau T., Treuil M. *et al.* 1985. Le volcanisme dinantien de la Meseta marocaine Nord-occidentale et orientale: caractères pétrographiques et géochimiques et implications géodynamiques. *Sciences Géologiques Bulletin,* 38, 2, 155–163.

Knight K.B., Nomade S., Renne P.R., *et al.*. 2004. The Central Atlantic magmatic province at the Triassic–Jurassic boundary: paleomagnetic and 40Ar/39Ar evidence from Morocco for brief, episodic volcanism. *Earth and Planetary Science Letters*, 228, 143–160.

Lago M., Galé C., Arranz E. *et al.* 2000. Triassic tholeiitic dolerites (ophites) of the El Grado diapir (Pyrenees, Huesca, Spain): emplacement and composition. *Estudios Geologicos*, 56, 3–18.

Laville E. & Piqué A. 1991. La distension crustale atlantique et atlasique au Maroc au début du Mésozoïque: le rejeu des structures hercyniennes. *Bulletin de la Société Géologique de France,* 162, 6, 1161–1171.

Lefort J.P., Ben Salmia A. & Miller H.G. 1996. Age and mode of emplacement of the Collector Anomaly (Canada): is it the northwestern boundary of Gondwana? *Journal of Geodynamics,* 21, 177–190.

Le Roy P., Piqué A., Le Gall B. *et al.* 1997. Les bassins côtiers triasico-liasiques du Maroc occidental et la diachronie du *rifting* intra-continental de l'Atlantique central. *Bulletin de la Société Géologique de France,* 168, 637–648.

Marcelot G., Dupuy C., Dostal J. *et al.* 1989. Geochemistry of mafic volcanic rocks from the Lake Kivu (Zaire and Rwanda) section of the western branch of the African Rift. *Journal of Volcanology and Geothermal Research*, 39, 73–88.

Marzoli A., Bertrand H., Knight K. *et al.* 2004. Synchrony of the Central Atlantic Magmatic province and the Triassic–Jurassic boundary climatic and biotic crisis. *Geology*, 32, 973–976.

Marzoli A., Bertrand H., Chiaradia M. *et al.* 2006. The genesis of CAMP basalts (Morocco) from enriched lithosphere to late asthenosphere mantle sources. Goldschmidt Conference, *Geochimica et Cosmochimica Acta*, 70, 18, A396.

Menzies M.A., Leeman W.R. & Hawkesworth C.J. 1983. Isotope geochemistry of Cenozoic volcanic rocks reveals mantle heterogeneity below western U.SA. *Nature*, 303, 205–209.

Michard A. 1976. Éléments de géologie marocaine, *Notes et Mémoires du Service géologique du Maroc,* 252, 408 p.

Michard A., Hoepffner C., Soulaimani A. & Baidder L. 2008. *The Variscan Belt. In:* A. Michard, O. Saddiqi A. Chalouan & D. Frizon de Lamotte (Eds.) - *Continental evolution: The Geology of Morocco. Lecture Notes Earth Sciences*, Springer Verlag, 116, 65–132.

Michard A., Soulaimani A., Hoepffner C. *et al.* 2010. The South-Western Branch of the Variscan Belt: Evidence from Morocco. *Tectonophysics,* 492, 1–24.

Mrini Z., Rafi A., Duthou J.L. & Vidal Ph. 1992. Chronologie Rb/Sr des granites varisques du Maroc: Conséquences. *Bulletin de la Société Géologique de France*, 163, 429–443.

Muller J., Cornée J.J. & El Kamel F. 1990. Évolution tectono-sédimentaire d'un bassin molassique post-orogénique: l'exemple des séries conglomératiques stéphano-triasiques de Mechra Ben Abbou, Rehamna, Maroc. *Géologie Méditerranéenne,* 17, 109–122.

Nakamura N. 1974. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. *Geochimica Cosmochimica Acta*, 38, 757–775.

Oukemini D., Bourne J.H. & Krogh T.E. 1995. Géochronologie U-Pb sur zircon du stock d'Aouli, Haute Moulouya. Maroc. *Bulletin de la Société Géologique de France*, 166, 15–21.

Pearce J.A. 1982. Trace element characteristics of lavas from destructive plate boundaries. *In:* R.S. Thorp (Ed.) - *Andesites: Orogenic Andesites and Related Rocks*, John Wiley and Sons, New York, 525–548.

Philpotts J.A. & Schnetzler C. 1968. Genesis of continental diabases and oceanic tholeiites considered in light of rareearth and barium abundances and partition coefficients. in: L.H. Ahrens (Ed.) - *Origin and Distribution of the Elements*. (Pergamon Press), 939–947.

Piqué A. 1979. Évolution structurale d'un segment de la chaîne hercynienne: la Meseta marocaine nord-occidentale. *Sciences Géologiques, Mémoire,* 56, 243p.

Piqué A. & Michard A. 1989. Moroccan Hercynides: A synopsis. The Paleozoic sedimentary and tectonic evolution at the northern margin of West Africa. *American Journal of Science*, 289, 286–330.

Ragland P.C., Brunfelt A.O. & Weigand P.W. 1971. *Rare earth abundance in Mesozoic dolerite dikes from eastern United States. In:* A.O. Brunfelt & E. Steinnes (Eds.) - *Activation Analysis in Geochemistry and Cosmochemistry,.* (Universitetsforlaget). 227–235.

Razin P.T., Baudin P., Chévremont D. *et al.* 2003. Mémoire explicatif de la Carte géologique du Maroc au 1/50 000, feuille de Jebel Kharrou. *Notes et Mémoires du Service Géologique, du Maroc*, 436, 105p.

Roddaz M., Brusset S., Soula J.-C., Béziat D. *et al*. 2002. Foreland basin magmatism in the Western Moroccan Meseta and geodynamic inferences. *Tectonics,* 21, 1043, 7, 1–23.

Saber H. 1994. Sédimentologie et évidence d'une tectonique tardi-hercynienne d'âge Permien inférieur dans le bassin des Ida Ou Ziki, Sud-Ouest du massif ancien du Haut Atlas (région d'Argana, Maroc). *Journal of African Earth Sciences*, 19, 99–108.

Saidi M. 2001. *Perturbation des contraintes hercyniennes le long des structures paléogéographiques Devono–Carbonifères dans la Meseta Nord Occidentale Marocaine*. Thèse de Doctorat, Université Mohammed V, Rabat, 287 p.

Saidi A. 2005. *Etat de contrainte et mécanismes d'ouverture et de fermeture des bassins permiens de la Meseta marocaine. Apport de la Télédétection à la reconnaissance des faciès et des réseaux de failles*. Thèse de Doctorat, Université Mohammed V, Rabat, 222 p.

Saidi A, Tahiri A, Ait Brahim L & Saidi M. 2002. Etats de contraintes et mécanismes d'ouverture et de fermeture des bassins permiens du Maroc hercynien. L'exemple des bassins des Jebilet et des Réhamna. *Comptes Rendus Geosciences, Paris,* 334, 221–226.

Shervais J.W. 1982. Ti-V plots and the petrogenesis of modem and ophiolite lavas. *Earth and Planetary Sciences Letters,* 59, 101–118.

Sebban S. 1990. *Étude palynologique du Permien inférieur du Haouz oriental (Maroc)*. Thèse de Doctorat, University de Paris VI, 216 p.

Simancas F., Tahiri A., Lodeiro F.G. *et al.* 2005. The tectonic frame of the Variscan-Alleghanian orogen in Southern Europe and Northern Africa. *Tectonophysics*, 398, 3–4, 181–198.

Simancas F., Tahiri A., Lodeiro F.G. *et al. 2006*. The central segment (Iberia and Morocco) of the Variscan-Alleghanian orogen: main tectonic features. *Notes et Mémoires du Service géologique du Maroc*, 514, 65–70.

Simancas J.F., Azor A., Martínez Poyatos D. *et al.* 2009. Tectonic relationships of Southwest Iberia with the allochthons of Northwest Iberia and the Moroccan Variscides. *Comptes Rendus Géosciences,* 341, 103–113.

Tahiri A., Ait Brahim L. & Saidi A. 1996a. Analyse de la fracturation tardi-hercynienne dans le bassin permien de Bou Achouch. Modèles de réactivation des accidents hercyniens dans le Maroc central. *In*: F. Medina (Ed.) - le Permien et le Trias du Maroc: états de connaissances. Edition PUMAG, Marrakech, 99–112.

Tahiri A, Ait Brahim L & Saidi A. 1996b. *Etat de contrainte et cinématique de la structuration du bassin permien de Souk Sebt (Maroc central septentrional)*. Actes de la 1ère réunion du Groupe Marocain du Permien et du Trias, Oujda, 59–70.

Tahiri A., Saidi M. & Ait Brahim L. 1997. *Le volcanisme des Beni Abid (Meseta occidentale marocaine) considérations microtectoniques pour un âge permien anté-trias*. Actes de la 1^{ere} réunion du Groupe Marocain du Permien et du Trias, Oujda, p. 55.

Tahiri A., Montero P., El Hadi H. *et al.* 2010. Geochronological data on the Rabat-Tiflet granitoids: their bearing on the tectonics of the Moroccan Variscides. *Journal of African Earth Sciences*, 57, 1–13.

Taugourdeau-Lantz J. 1978. Pollens des niveaux sédimentaires associés aux basaltes du Trias sur la bordure septentrionale du Maroc central. Précisions stratigraphiques. *Notes et Mémoire du Service géologique du Maroc*, 275, 135–146.

Villaseca C., Martin Romera C. & Barbero L. 2002. Estimaciones termobarometricas en los metagabros coroniticos de la region de Segovia (Sierra de Guaderrama). *Geogaceta*, 32, 11–14.

Winchester J.A. & Floyd P.A. 1977.Geochemical discriminations of different magma series and their differentiations products using immobile elements. *Chemical Geology,* 325–345.

Wood D.A. 1980. The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province. *Earth and Planetary Sciences Letters*, 50, 11–30.

Youbi N. 1998. *Le volcanisme "post-collisionnel": un magmatisme intraplaque relié à des panaches mantelliques, étude volcanologique et géochimique exemples d'application dans le Néoprotérozoïque Terminal (PIII) de l'Anti-Atlas et le Permien du Maroc*. Thèse de Doctorat d'Etat, Université Cadi Ayyad, Marrakech, 505 p.

Youbi N. & Cabanis B. 1995. Le volcanisme permien du Maroc : un magmatisme relié à une subduction de type B associé à des failles transformantes. *In :* A. El Boukhari *et al.* (Eds.) - Résumés de la Réunion extraordinaire de la Société géologique de France sur le thème: Accrétion continentale au Protérozoïque supérieur et au Paléozoïque du Nord Ouest africain., p.84.

Youbi N., Cabanis B., Chalot-Prat F. & Cailleux Y. 1995. Histoire volcano-tectonique du massif permien de Khénifra (Sud-Est du Maroc central). *Geodinamica Acta,* 8, 3, 158–172.

Youbi N., Martins L.T., Munhá J.M., *et al.* 2003. The Late Triassic–Early Jurassic Volcanism of Morocco and Portugal in the Framework of the Central Atlantic Magmatic province: An Overview. *In:* W. E. Hames, J. G. Machone, P. R. Renne & Ruppel, C. (Eds.) - The Central Atlantic Magmatic Province: Insights from Fragments of Pangea. *American Geophysical Union, Geophysical Monograph Series*, 136, 179–207.

Zouine E.M. 1986. *Evolution structurale tardi-hercynienne de la bordure NW du Maroc central entre Tiddas et Jebel Tariona*. Thèse de Doctorat, Ecole Nationale Supérieure, Rabat, 131 p.

Manuscrit reçu le 17/04/2014
Version révisée acceptée le 23/02/2015
Version finale reçue le 28/10/2015
Mise en ligne le 09/11/2015