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**INTERNATIONAL JOURNAL OF  
 ADVANCED RESEARCH (IJAR)**

Article DOI: 10.21474/IJAR01/6114  
 DOI URL: <http://dx.doi.org/10.21474/IJAR01/6114>



### RESEARCH ARTICLE

## MESOZOIC BASALTIC MAGMATISM OF THE SIDI SAÏD MAACHOU BASIN (WESTERN MESETA, MOROCCO): PETROGRAPHY, GEOCHEMISTRY AND GEODYNAMIC IMPLICATIONS.

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#### Manuscript Info

##### Manuscript History

Received: 20 October 2017  
 Final Accepted: 22 November 2017  
 Published: December 2017

##### Key words:-

Petrology; Geochemistry; Upper Triassic; Coastal Meseta; Central Atlantic Magmatic Province (CAMP) .

#### Abstract

The late Triassic-early Jurassic volcanism of Sidi Saïd Maachou basin belongs to the coastal Meseta and the Central Atlantic Magmatic Province (CAMP). The volcanic pile conformably overlies the red siltstones of Machraa Boujamaa Formation. This set includes a stack of several lava flows 40 to 80 m thick. The petrographic study shows that the textures vary from porphyritic to microlitic porphyritic. These igneous rocks have the geochemical characteristics of an intra-continental tholeiitic series of an anorogenic context announcing the Triassic distension. On the basis of their petrographic and geochemical characteristics, the lava flows of Sidi Saïd Maachou tholeiitic basalts approach those of the Triassic Basin of Berrechid-El Gara-Benslimane and the High Atlas. With these data, we attempt to place these volcanic rocks in global geodynamic context by making comparisons with other Upper Triassic–Early Jurassic volcanic rocks genetically related to the breakup of Pangea and the Central Atlantic Magmatic Province resulting from thinning of continental lithosphere.

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#### Introduction:-

In Morocco, the end of Triassic (~200 Ma) is marked by large deposits of tholeiitic basalts during the final stages related to the rifting of the Central Atlantic Magmatic Province (CAMP) (Marzoli et al., 1999). In the Western Meseta, and in particular in the Sidi Saïd Maachou basin (Fig. 1), only a few studies have been carried out (Peretsman, 1985; Girard, 1987; Peretsman and Holser, 1988; Girard et al., 1989; Lyazidi et al., 2003; Bensalah et al., 2011; Farki et al., 2014). This strongly contrasts with the abundant scientific literature on volcanic rocks existing for the other basins in Morocco, such as those of the High Atlas (Termier, 1948; Verdier, 1971; Bertrand et al., 1982; De Pachtère et al., 1985; Bertrand, 1991; Ait Chayeb et al., 1998; Youbi et al., 2003; Knight et al., 2004; Marzoli et al., 2004; Verati et al., 2007; Font et al., 2011; El Hachimi et al., 2011), of the Middle Atlas (Charière, 1990; Fiechtner et al., 1992; Hamidi et al., 1997; Lachkar et al., 2000; Ouarhache, 2002; Mahmoudi and Bertrand, 2007), and of Central and Eastern Morocco (Corney et al., 1971, 1974 ; Corney and Faugères, 1975 ; El Wartiti, 1981).

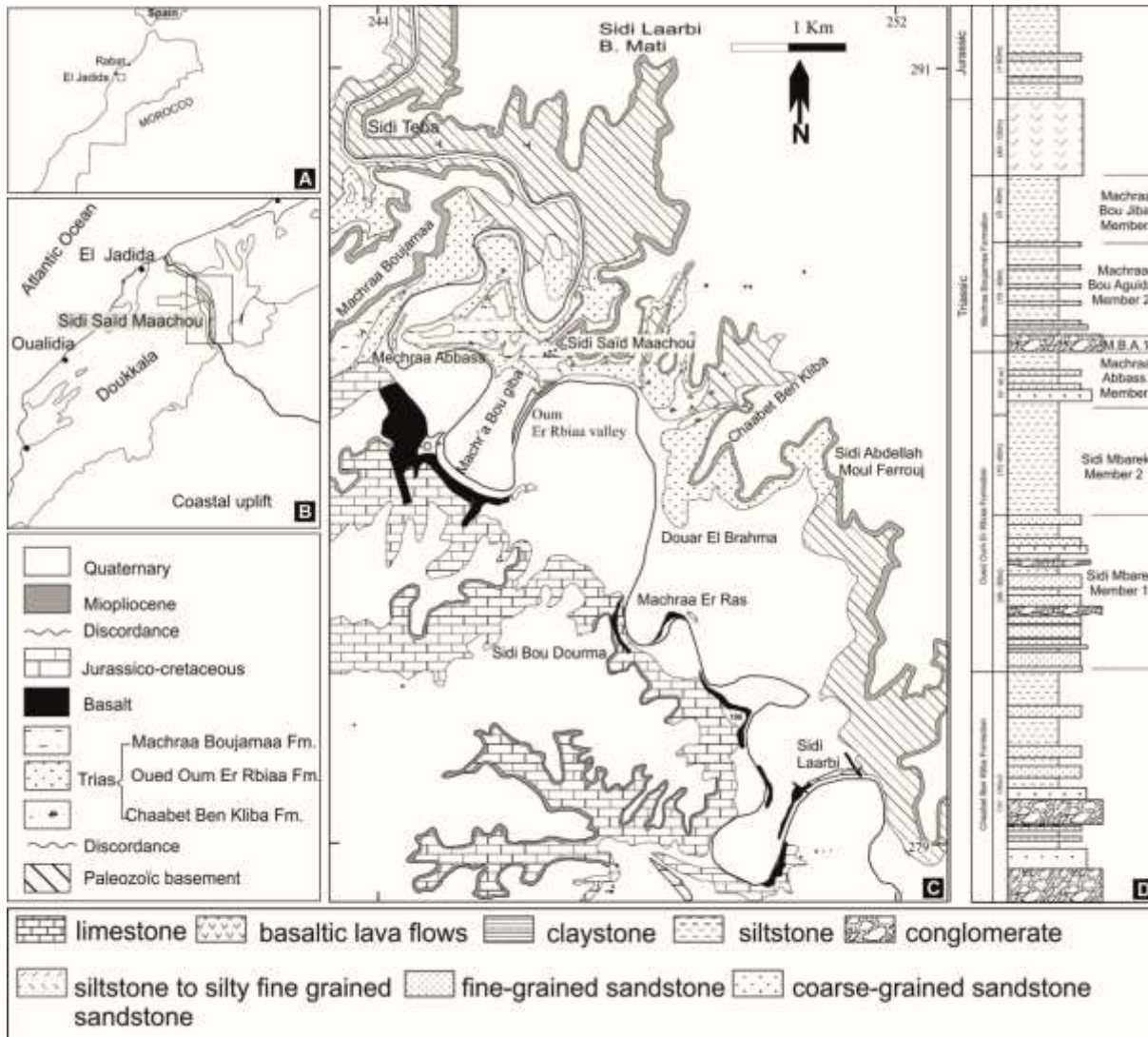
This work is a contribution to the knowledge of CAMP magmatism of the Moroccan coastal Meseta, presenting new petrographic and geochemical data on the Sidi Saïd Maachou basin.

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**Geological setting:-**

The approximately 40 km<sup>2</sup> study area, named after its village Sidi Saïd Maachou, is located in the coastal uplift of the Moroccan Western Meseta about 46 km South-East of El Jadida city (Fig. 1). Geological interest of this domain is based on numerous outcrops of pre-Cenozoic rocks along the Oued Oum Er Rbiaa valley. Along the Northern, Eastern and South-Eastern border of the area, Triassic sediments unconformably overlie Palaeozoic (Cambrian and Devonian) basement. To the West and South-West,



**Figure. 1:-** Location and geological overview of the study area. **A & B-** Position of the Sidi Saïd Maachou area in Morocco and the Western Meseta. **C-** Simplified geological map of the Sidi Saïd Maachou area. **D-** Lithostratigraphical profile of the Sid Saïd Maachou basin.

Triassic sediments are overlain by Rhaetian–Sinemurian tholeiitic basalts and Jurassic–Cretaceous sedimentary rocks (Gigout, 1956; Ouadia, 1998; Saber et al., 2007 ; Hminna et al., 2008 ; Bensalah et al., 2011 ; Hminna, 2013; Hminna et al., 2013). During the Early Mesozoic, accumulation of continental deposits took place in the Sidi Saïd Maachou area due to local subsidence most likely triggered by reactivated Late Palaeozoic faults.

The Sidi Saïd Maachou area (Fig. 1) is characterized by succession of red-beds about 500 m thick. Hminna et al. (2013) proposed a subdivision of the succession in seven lithostratigraphic units assigned to three formations (Fig. 1C, D). These formations are, from base to top: the basal Chaabet Ben Kliba Formation (10–100 m thick), The Oued Oum Er Rbiaa Formation (50–160 m thick), and the Machraa Boujamaa Formation (10–130 m thick). Each of these

is separated from older strata by either an angular or erosional unconformity.

The basal Chaabet Ben Kliba Formation consists of debris-flow conglomerates. They were deposited as alluvial fans, sandstones and siltstones according to Miall (1996), grading vertically into distal alluvial-fan to alluvial-plain and maybe floodplain sandstones and siltstones (Miall, 1996) and soil formation in overbank fines siltstones.

The Oued Oum Er Rbiaa Formation is represented by braided alluvial plain sandstones and mudstones (Sidi Mbarek Member 1), wet mudfla mudstones and siltstones (Sidi Mbarek Member 2), and shallow lacustrine laminated mudstones (playa lake system) (Machraa Abbass Member). The upper Machraa Boujamaa Formation starts with alluvial-fan conglomerates (Machraa Bou Aguida Member 1: M.B.A. 1, Fig. 1D) that grade into increasingly fine-grained sandstone–siltstone cycles. Those cycles record the transition into alluvial and floodplain deposition (Machraa Bou Aguida Member 2) and gypsiferous mudstones which are typical playa sediments that are probably formed under semiarid to arid climatic conditions.

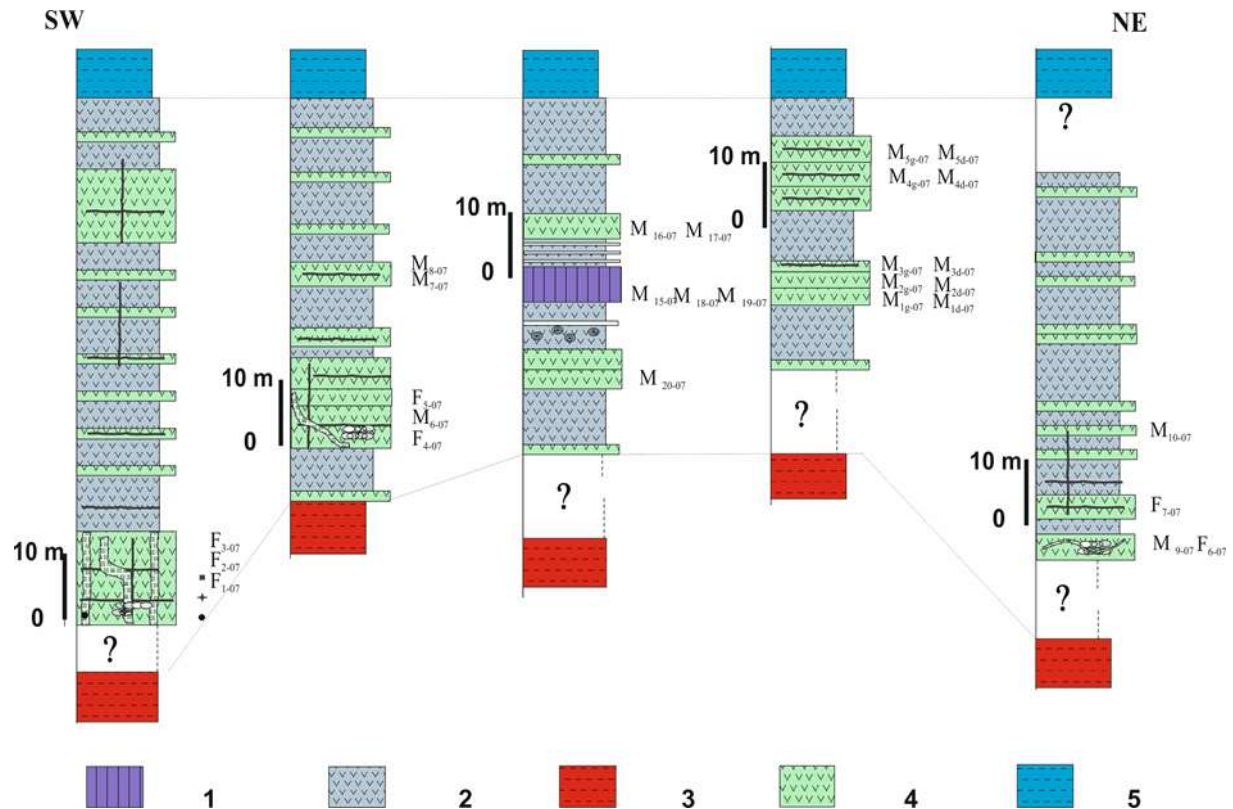
The Triassic sedimentary succession of the Sidi Saïd Maachou area is crowned by up to 80 m thick tholeiitic basalts that unconformably overlie slightly deformed mudstones. Based on tetrapod footprints of *Brachychirotherium parvum*, Hminna et al. (2009, 2013) concluded a Late Triassic age (Carnian–Rhaetian) for the upper part of the Oued Oum Er Rbiaa Formation.

During the Early Mesozoic, accumulation of continental deposits took place in the Sidi Saïd Maachou area due to local subsidence. It was most likely triggered by reactivated Late Paleozoic (Hercynian) structures such as the Sidi Laarbi fault. This fault reaches from the SE into the study area (Fig. 1C) and might continue to the North-Western corner, but it is covered by Mesozoic and Cenozoic deposits. Subsurface data are required to more precisely assess the dimension and tectonic structure of the Triassic strata in the Sidi Saïd Maachou area.

#### **Field observations:-**

In the Sidi Saïd Maachou area, a large number of profiles were realized through the well developed Triassic-Liasic basaltic pile from North to South along the Oum Er Rbiaa valley (Fig.1C). This makes it possible a good correlation and to specify the conditions for the emplacement of the product of this volcanic activity. However, we will limit the description to the most significant cuts. The stratigraphic data show a superposition of several flows lava intercalated between a lower red detrital strata with thin gypsiferous levels and higher red detrital layer alternating with limestone near the top (Fig. 2).

The base of the volcanic pile conformably overlies the red siltstones of Machraa Boujamaa formation. This set includes a stack of several lava flows that developed over a variable thickness from 40 to 80 m. In some places, we observe the intercalation of sedimentary levels among the lavas. The bottom of these flows is characterized by onion-skin weathering. Towards the middle of this volcanic pile begins a complex of both hard and altered lavas intersected by basaltic dykes (10 to 15 cm in diameter; Fig. 2 and



**Figure 2:-** Lithostratigraphic profiles through the volcanic complex of the Sidi Saïd Maachou basin. 1- Prismatic basalts. 2- Altered basalt. 3- Triassic red beds. 4- Basalt “little” altered. 5- Red silts and limestone of Jurassic. (M and F: Sample number)

3). These dykes are observed almost throughout the volcanic pile. They are hard, compact and arranged laterally, vertically or sometimes also in sinuous form (Fig. 3E and 3F) in relation to the volcanic lava flows. Silica veins are also present frequently. The assembly is surmounted by a succession of altered lavas flows, interrupted in its central part by a prismatic lava deposit of 2 m thick (Fig. 3C, D), which is disseminated into remarkable prisms or columns. The absence of pillow lavas and the presence of such prismatic flows are arguments in favor of sub-aerial conditions. Significant variations of thickness in volcanic profiles (30 to 80 m) can be explained either by differential subsidence of the ante-volcanic substratum during the effusion of the flows or by settling of these lavas on a substratum already structured either in graben or half-graben structures.

#### **Petrographic study:-**

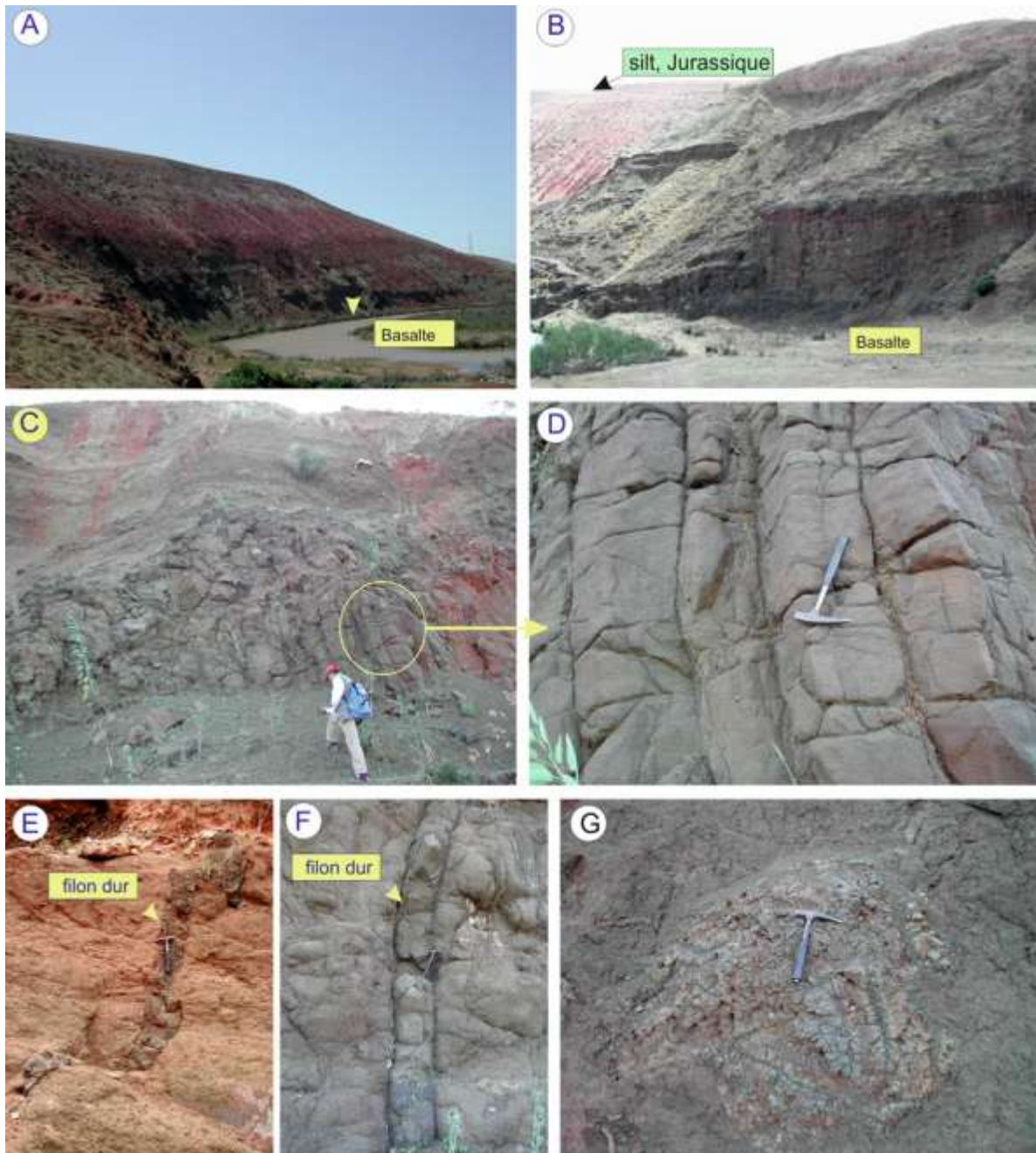
The basalts of Sidi Saïd Maachou are largely altered. Indeed, only a few samples were collected in relatively fresh or slightly altered levels. These basaltic rocks are characterized by three main textures: porphyritic, porphyritic intersertal to dolerite, and a slightly microlitic porphyry probably vacuolar microlitic texture.

Three volcanic facies are defined according to the textures of the rocks :

#### **Facies 1:-**

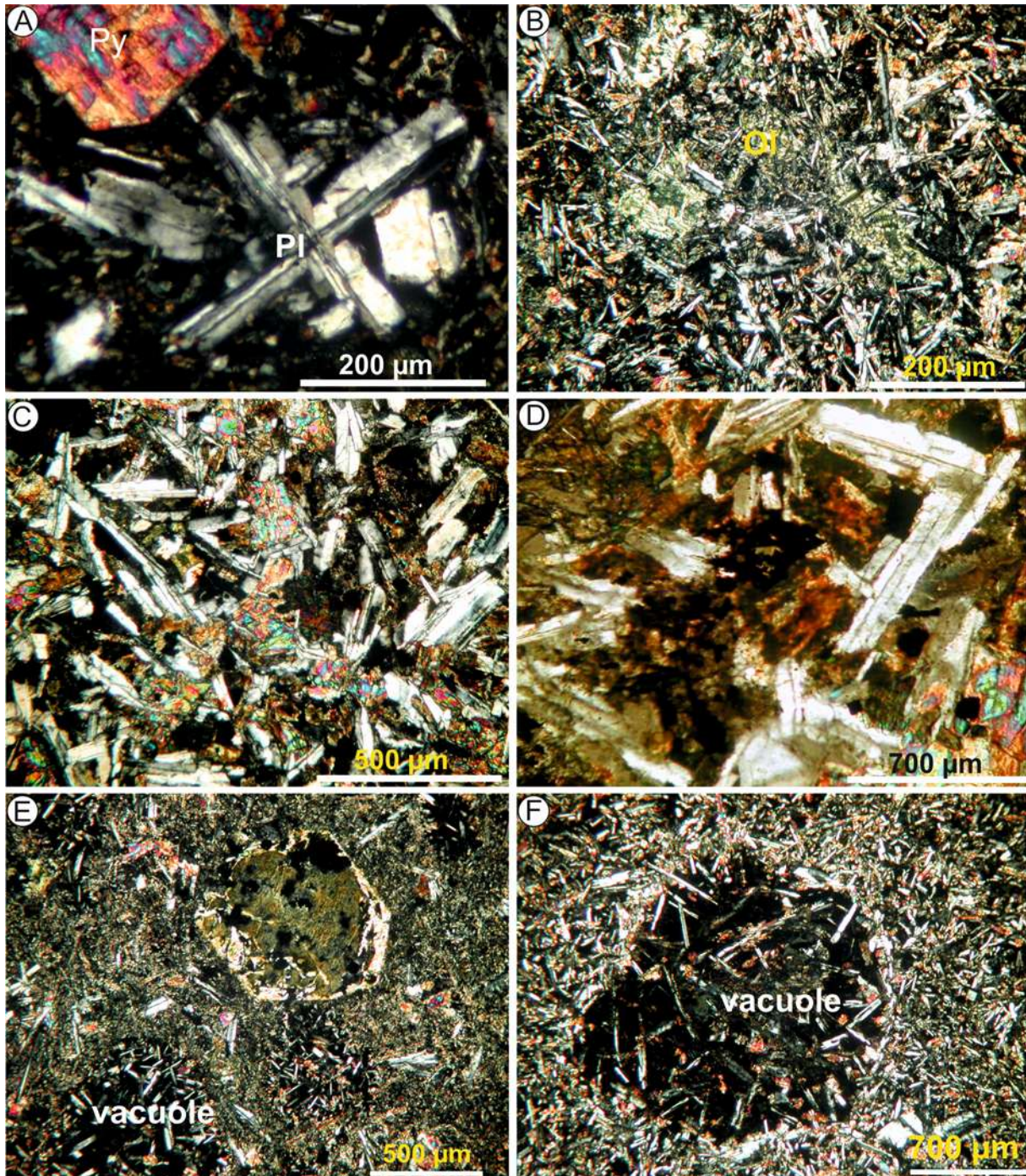
The rocks show a porphyritic microlitic texture, composed mainly of plagioclase, clinopyroxene, olivine and opaque minerals (Fig. 4A, B). The groundmass phases are represented by glass containing fine crystal of clear feldspars, and opaque minerals.





**Figure 3:-** A- View of the contact between the Jurassic levels and the basaltic complex (left bank of the Oum Rbiaa valley). B- Outcrop of superimposed basaltic lava flows showing hard levels and altered soft levels. C- Prismatic basalt. D- Detail of prismatic basalt. E-F - Late consolidated basalt dykes intersecting highly altered basaltic levels observed south of the basin. G- Basaltic alteration in onion structure.





**Figure 4:-** Microphotographic images taken under polarized light: **A-** Basalt with porphyritic microlitic texture (doleritic); **B-** Basalt with olivine gosh, completely transformed into chlorite (porphyritic microlitic texture); **C & D-** Basalt with a porphyritic microlitic texture with doleritic tendency; **E & F-** Basalt with a porphyritic microlitic vacuolar texture.

Olivine accounts for about 8% of the total volume of the rock. Its size varies from 0.2 to 1 mm. It appears as euhedral to subhedral crystals, sometimes isolated but more often grouped in clusters. During hydrothermal alteration, it is completely transformed in either chlorite or iddingsite. However, the preservation of their shape is generally easy to recognize.

Pyroxene represents approximately 25% of the total volume of rock. The crystals are subhedral with sizes from 0.1 to 0.7 mm. They appear intact and show augite optical characteristics. It exhibits a change in color, may be due to a chemical zoning.

Plagioclase is the most dominant phase (40%). It comes in laths ~0.1 to 0.7 mm long, either as phenocrysts with polysynthetic twins or as microlithes. Some of them are included in the pyroxene. Sometimes it has a symplectic structure, which suggests that these rocks may be the result of a fractional crystallization process.

Opaque minerals are very abundant (approximately 20%) and are present either in small crystals, square to sub-rounded, or sometimes in sharp crystals and skeletal appearance indicating fast cooling.

The mesostasis corresponds to a cryptocrystalline or microcrystalline material. It generally consists of a multitude of microlites and ferromagnesian plagioclase.

### ***Facies 2***

This type of basalts presents a porphyry dolerite texture to intersertal whose crystal size reaches a few hundred microns (Fig. 4C, D). The mineral paragenesis is composed of plagioclase, pyroxene and opaque minerals.

Plagioclase is the predominant mineral in these rocks (50%). They appear as phenocrysts (40%) and as subhedral microlites (less than 5%) which sometimes they overlap phenocrysts of pyroxene.

Occasionally plagioclase is partially transformed into sericite.

Pyroxene is less abundant than plagioclase and appears as anhedral to subhedral phenocrysts (10%) and also as microlites (8%). Some are twinned and chloritized the center and the rim. Some are transformed completely into chlorite.

Opagues are abundant and are represented by ilmenite and/or magnetite. They form, along small crystals of plagioclase and pyroxene, the rest of the groundmass. The matrix is also characterized by the presence of reddish glass, filling the interstices between the crystalline minerals.

### ***Facies 3:-***

The basalts of this facies are characterized by show microlitic vacuolar texture. The lava flow of particular composition shows generally the vacuoles clogged with opaque and plagioclase (Fig. 4E, F). The whole rock is formed by plagioclase microlites embedded in a fine-grained groundmass made up of plagioclase, pyroxene (present also as phenocrysts: 5% ; and microlites: 50%) and opaque minerals.

Vacuoles occur in large subhedral cavities formed by expanding gas. They are clogged with phenocrysts of plagioclase and pyroxene.

### ***Geochemical study:-***

The geochemical study performed in the magmatic rocks of Sidi Saïd Maachou area aims at determining their chemical characteristics and magmatic affinity. The chemical analyses (major and trace elements) performed on seven samples of volcanic rocks of Sidi Saïd Maachou area are reported in table 1. The dosage of the chemical elements was performed by X-ray fluorescence (XRF) at Laboratory of Geochemistry, Department of Geology, Faculty of Sciences, Chouaïb Doukkali University, El Jadida (Morocco).

The Triassic lava flows of Sidi Saïd Maachou area have the following characters:

- The silica content is relatively low (from 46.68 to 52.24%);
- Fire losses, ranging from 5 to 3.5%, reflect the rather altered nature of these rocks;
- The concentrations of TiO<sub>2</sub> (1.19-1.58%) and P<sub>2</sub>O<sub>5</sub> (0.11 to 0.20%) are low and comparable to those of MORB.
- The concentrations of Nb are particularly low compared to those of alkaline basalts (Nb content of 0.7-15 ppm) and are similar to those of MORB and to a lesser extent to those of intraplate tholeiites.
- The concentrations of transition elements (Ni, Cr, Co and Sc) are generally very low and have small variations, respectively with intervals of 49-81 ppm, 220-355 ppm, 50-65 ppm and 29-44 ppm.

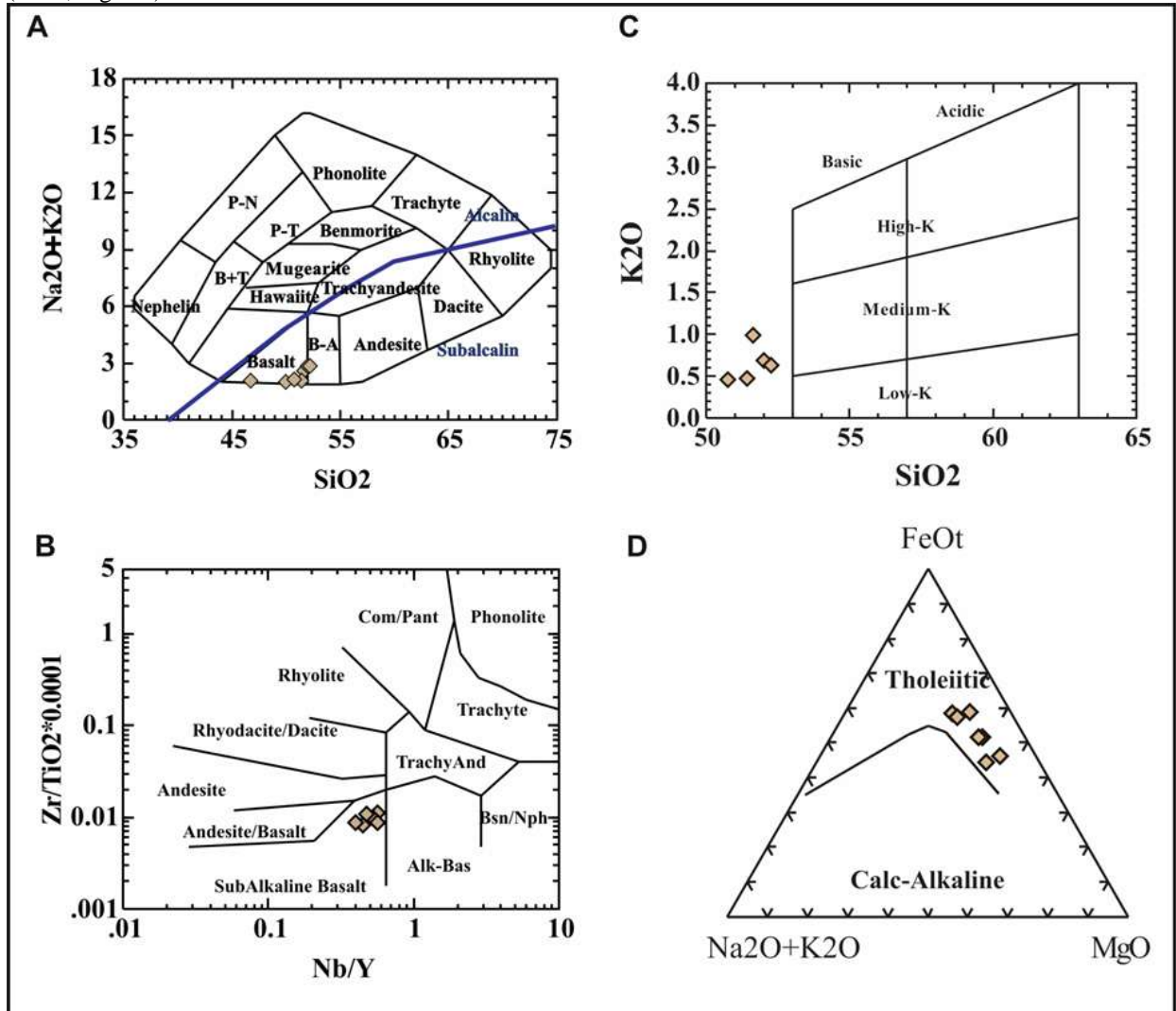
### ***Classification of rocks:-***

On the basis of the TAS diagram (Fig. 5A), analyzed samples are classified as sub-alkaline rocks (Irvine and



Baragar, 1971; Miyashiro, 1978) and are mainly represented by basalts to basaltic andesites (Le Maitre et al., 1989). In the diagram of Winchester and Floyd (1976), which involves elements considered as immobile during alteration and metamorphism (Ti, Zr, Nb and Y), the rocks plot in the field of subalkaline basalts (Fig. 5B).

These rocks are characterized by a low content of potassium ( $K_2O$ : 0.48-0.99 wt%), which situates the majority of these rocks in the field moderately to weakly potassic "Low-K" defined by Peccerillo and Taylor (1976) and Gill (1981; Fig. 5C).



**Figure 5:-** A- Classification of the Sidi Saïd Maachou basin volcanic rocks in the Total alkali vs.  $SiO_2$  (TAS) diagram (Le Maitre et al., 1989). The continuous line separates the field of alkaline lavas from the subalkaline lavas (Irvine and Baragar, 1971). B- Classification of altered magmatic rocks in the  $Zr/TiO_2$  vs.  $Nb/Y$  diagram of Winchester and Floyd (1976). C- Diagram of geochemical classification  $K_2O-SiO_2$  of Peccerillo and Taylor (1976) showing the weak to moderately potassic character of Triassic volcanic rocks. D- AFM diagram (Kuno, 1968) showing the tholeiitic character of Triassic magmatic rocks.

In order to determine the geochemical affinity of basalts in the study area, a number of discriminating triangular diagrams were used. This is the AFM diagram (A =  $Na_2O + K_2O$ ; F = FeOt; M = MgO) of Nockolds and Allen (1956),  $Al_2O_3-FeO_T-MgO$  diagram of Besson and Fonteilles (1974).

The AFM diagram (Fig. 5D) separates the tholeiitic from calcalkaline evolutionary trends, mostly based on the different iron enrichment in the residual melts (Kuno, 1968). The studied rocks clearly plot in the tholeiitic field, being characterized by iron enrichment (Fig. 5D).

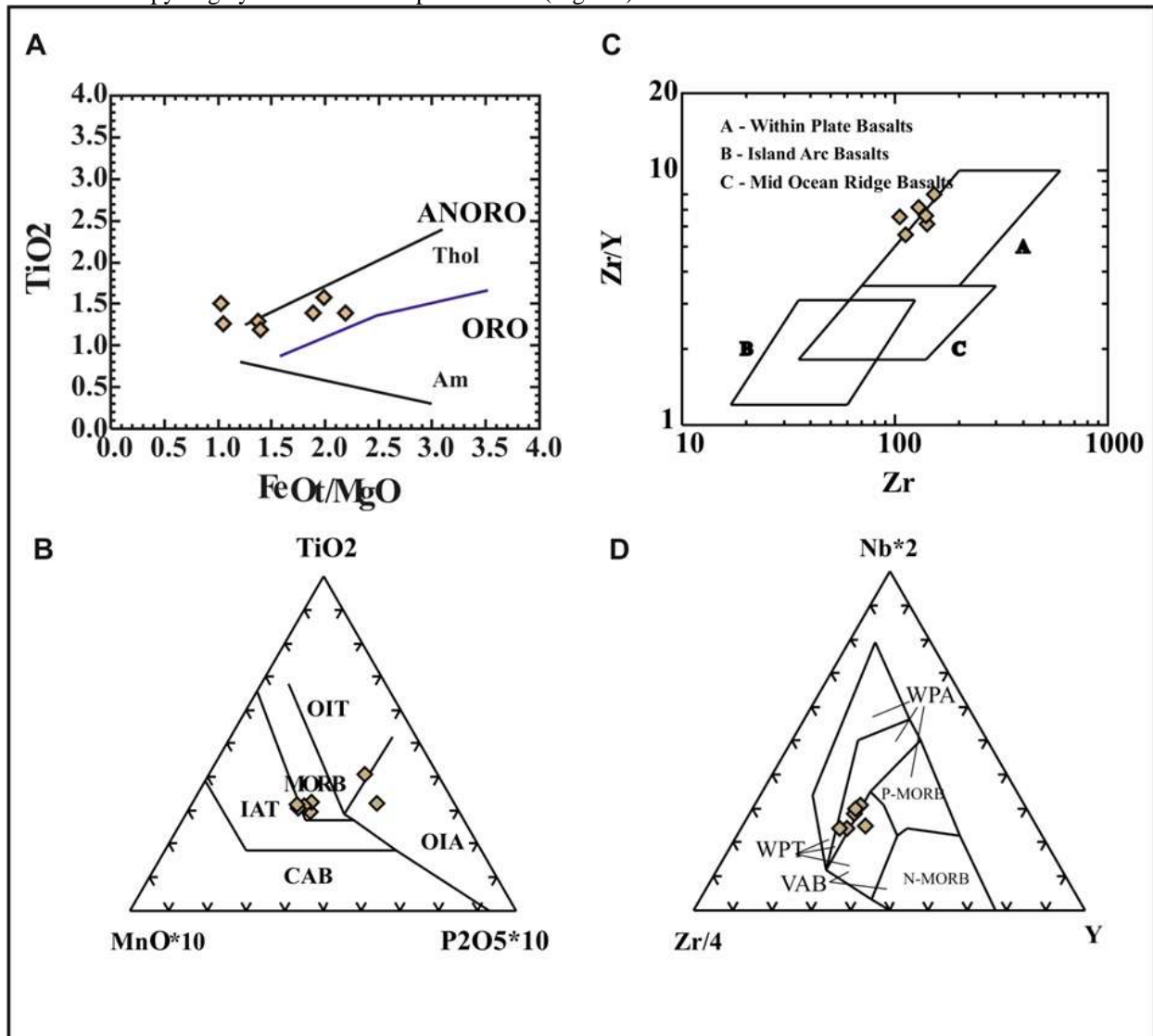


We used the diagram of Miyashiro (1974) of  $TiO_2$  vs.  $FeOt/MgO$  (Fig. 6A). The  $FeOt/MgO$  ratio in the residual melt increases with the fractional crystallization. The chemical data projection of these rocks on the diagram of  $TiO_2$  according to  $FeOt/MgO$  (Fig. 6A) shows a slight enrichment in the titanium during the differentiation of the characteristic of tholeiitic series. This diagram also separates the isotitanium field and the anisotitanium field characteristic of rocks of non-orogenic zones.

#### Geotectonic Site:-

Placed in the geotectonic discriminant diagrams (Fig. 6B, C and D), the Triassic lavas shows the characters of basalts with Anorogenic to sub-alkaline affinity. In the diagrams of  $TiO_2$ - $MnO$ - $P_2O_5$  (Mullen, 1983) (Fig. 6B), Nb-Zr-Y (Meschede, 1986) (Fig. 6D), the representative points of the samples studied are mostly situate in the MORB area and/or intra-continental tholeiites.

The projection of these rocks on the Zr/Y vs. Zr diagram, Pearce (1980), shows that the basalts of Sidi Saïd Maachou occupy largely the field of intraplate basalts (Fig. 6C).



**Figure 6:-** A- Diagram of Miyashiro (1974, 1978) showing the tholeiitic character of the Triassic Sidi Saïd Maachou basin volcanic rocks. The blue line of discrimination of series (ORO) and anorogenic (ANORO) is after Bebien (1980). B- Distribution of the magmatic rocks in the triangular diagrams  $TiO_2$ - $MnO$ - $P_2O_5$  of Mullen (1983); OIA: Ocean Island Alkali basalt; OIT: Ocean Island Tholeiite; MORB: Mid-Ocean Ridge Basalt; IAT: Island Arc Tholeiite; CAB: Calcalkaline basalt. C- Distribution of the magmatic rocks in the triangular diagram Nb-Zr-Y of

Meschede (1986). VAB: Volcanic Arc Basalt; MORB, Mid-Ocean Ridge Basalt (N: Normal, P: Plume); WPA: Within Plate Alkaline Basalt; WPT: Within Plate Tholeiitic Basalt. **D**- Distribution of magmatic rocks in the Zr-Zr/Y diagram of Pearce (1980).

### Conclusion:-

Petrographic and geochemical study of basaltic complex of Sidi Saïd Maachou area, consisting of stack doleritic and basaltic flows, clarifies the geochemical significance, magmatic affinity and geodynamic context of establishment of these basalts.

Petrographic study shows a porphyry to microlitic structure and texture.

The geochemical study (major and trace elements) allowed us to make the following conclusions:

- The igneous rocks have the characteristics of an intra-continental tholeiitic series.
- The magmatism is part of an anorogenic context announcing the Triassic distension.

This volcanism had close links with the opening of the central Atlantic, compared to diabase of the Eastern coast of North America (Bertrand and Westphal, 1977). For all their petrographic and geochemical characteristics, the lava flows of Sidi Saïd Maachou tholeiitic basalts approach those of the Triassic Basin of Berrechid-El Gara-Benslimane and the High Atlas.

With these data, we attempt to place these volcanic rocks in global geodynamic context by making comparisons with other Upper Triassic–Early Jurassic volcanic rocks genetically related to the breakup of Pangea and the Central Atlantic Magmatic Province resulting from thinning of continental lithosphere (CAMP, e.g., Marzoli et al., 1999, 2004 ; Callegaro et al., 2014).

### Acknowledgements:-

The authors thank reviewers for constructive remarks and the journal's editor for helpful comments that improved this work. Also, many thanks to Faculty of Sciences of Chouaïb Doukkali University El Jadida for logistical support during field trips.

**Table 1:-** Analysis of major and trace elements of Triassic lava flows in the Sidi Saïd Maachou basin.

N° d'échantillon	SM1-04	SM2-04	SM9-04	SM10-04	SM11-04	SM12-04	SM13-04
SiO <sub>2</sub>	49.93	51.62	52	52.24	51.43	50.75	46.68
Al <sub>2</sub> O <sub>3</sub>	12.60	13.80	15.50	14.5	15.4	15.4	14.4
Fe <sub>2</sub> O <sub>3</sub>	10.24	8.72	11.34	11.69	10.2	9.593	11.79
MgO	9.96	8.35	5.19	5.87	7.42	6.87	6.23
CaO	7.20	8.16	9.772	9.001	9.863	9.858	14.62
H <sub>2</sub> O	5.18	3.63	1.39	1.75	2.39	2.29	2.11
TiO <sub>2</sub>	1.51	1.27	1.39	1.58	1.29	1.19	1.39
Na <sub>2</sub> O	1.2	1.61	2.13	2.19	1.62	1.67	1.61
K <sub>2</sub> O	0.82	0.99	0.692	0.638	0.482	0.458	0.464
P <sub>2</sub> O <sub>5</sub>	0.15	0.19	0.146	0.149	0.124	0.113	0.119
MnO	0.07	0.09	0.184	0.177	0.164	0.161	0.178
<b>Total</b>	98.858	98.4397	99.734	99.785	100.383	98.353	99.591
V	300	260	270	310	280	260	300
Cr	263	258	258	220	288	331	355
Sr	254	247	176	184	178	175	246
Ba	220	250	210	220	130	130	200
Zr	145	141	139	129	112	105	152
Cl	130	086	239	150	110	130	250
W	120	430	480	650	570	260	480
Cu	088	035	150	120	180	170	
Ni	65	51	51	49	68	65	81
Co	55	62	51	54	60	49	52
Ce	46	49	43			37	

Sc	44	29	35	4	43		
Zn	35	44	89	91	86	84	110
Y	20	23	21	18	2	16	19
Hf	17	22	21	14	16		17
Ga	16	14	15	16	17	17	23
Nb	15	13	11	8.4	7.6	8.7	9
Rb	13	33	24	16	13	16	24
Ta	-	-	-	-	-	-	-
Nd			46				
Pb				54			

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