The composition and origin of the Kef Lakhal amphibolites and associated amphibolite and olivine-rich enclaves, Edough, Annaba, NE Algeria

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Abstract

The Kef Lakhal amphibolites and associated amphibolite and olivine-rich enclaves are described and their major and trace element chemistry indicates that both amphibolites were evolved medium to high alumina tholeiitic basalts with calc-alkaline affinities probably formed within plate settings. The olivine-rich enclaves are disrupted periodotites of the type lherzolite-harzburgite and probably represent mantle residua after melting.

KEYWORDS: Algeria, amphibolite, Edough, peridotite, Within-Plate tholeiite.

Introduction

THE Edough Massif, which extends over 40 km in a NE-SW direction from Cap de Garde to Boumaiza (Fig. 1), is the easternmost metamorphic complex of northern Algeria (Villa, 1970). The metamorphic rocks were first described by Renou (1843, 1848) who distinguished between the gneisses and mica schists and subsequently Fournell (1849) noted the intimate association of garnetiferous mica schists containing marbles and iron ore and later discovered some local polymetallic mines, one of which at Ain Barber, is still being worked for Pb, Zn, Cu etc. Parran (1883), Séligman-Lui (1887-90) and Séligman-Lui and Ficheur (1905) made further contributions and Joleaud (1936) published the first memoir on the region. Hilly (1962) presented a more coherent and comprehensive account of the geology of the Edough region and more recently Gleizes *et al.* (1988) discussed structural features of the eastern parts of the complex but coherent structural maps of the massif are still not available.

The Edough metamorphic rocks consist essentially of partly migmatized gneisses with interlayered lenses of tourmaline-rich foliated leptynites and massive aplites; garnet–biotite–quartz–feldspar–muscovite schists; and kyanite-sillimanite-andalusite-staurolite-garnet-bearing pelites sometimes containing discontinuous layers and disoriented metre-sized slabs of marbles. This unit is followed upward by a regular alternation of Paleozoic (Silurian–Devonian; Ilavsky and Snopková, 1987) fine grained, aluminous and andalusite-rich mica schists and feldspathic metaquartzites which also contain towards its base decametre lenses of amphibolites and augen gneisses. These metamorphic rocks were subsequently intruded by Tertiary (Marignac, 1985) igneous intrusions 1–3 km in diameter causing metamorphic recrystallization of the country rocks up to 100 m from the contact but the centimetre-sized country rock xenoliths suffered complete recrystallization and incipient partial melting.

The regional conditions of metamorphism are still being evaluated but preliminary results of the garnet-clinopyroxene geothermometer of Dahl (1980) and garnet–clinopyroxene-plagioclase geobarometer of Perkins and Newton (1981) undertaken on the studied amphibolites give values of 680°C and 8.5 kbar respectively. The garnet-biotite geothermometry of Thompson (1976) and garnet–plagioclase–aluminosilicate–quartz geobarometry of Ghent (1976) and Newton and Haselton (1981) of the host pelites also

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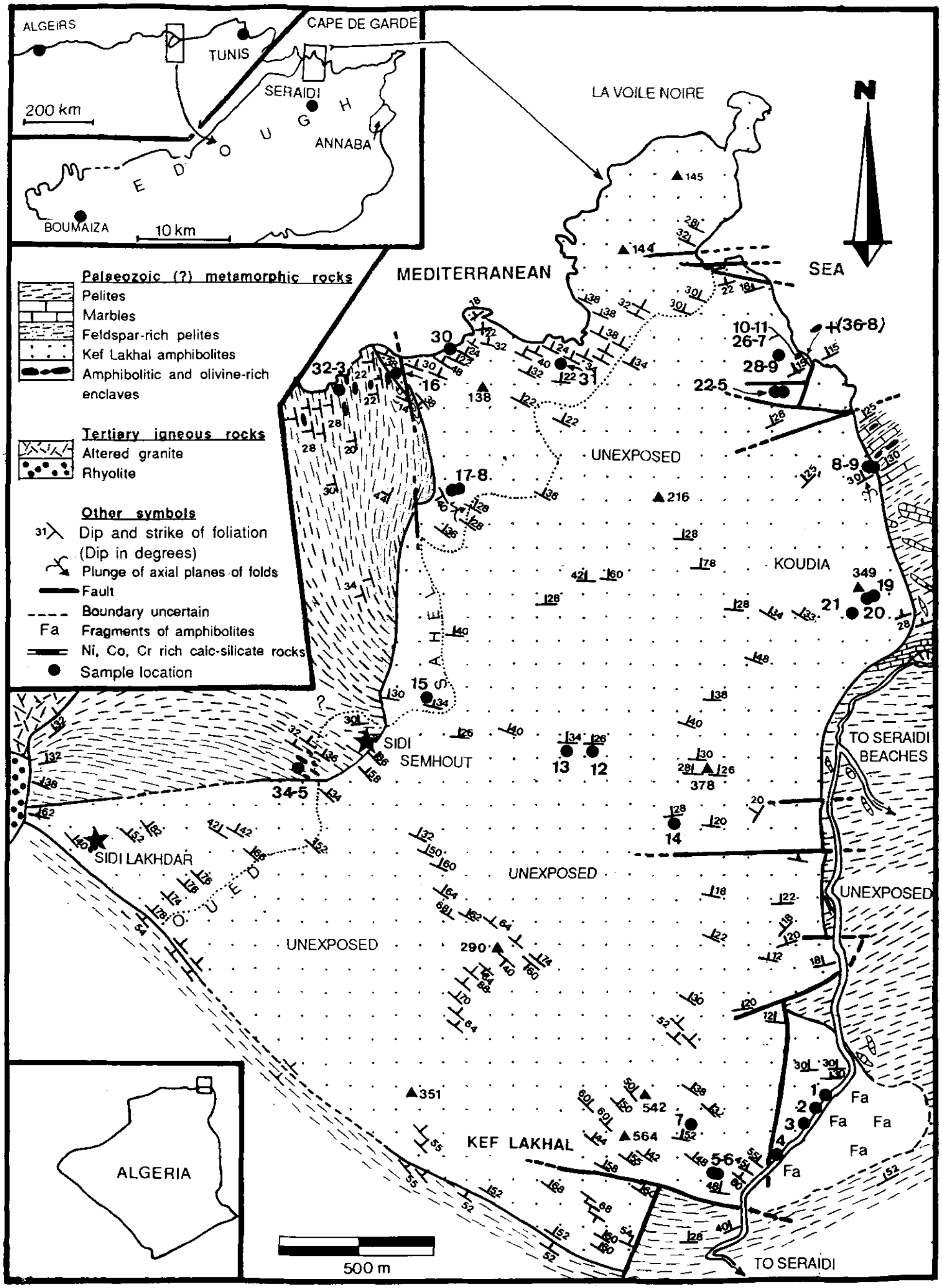

FIG. 1. Geological sketch map of the northwestern parts of the Edough massif showing sample locations (+ = location of the olivine-rich enclaves).

generally give similar values of 597–627 °C and 7–9kbar.

The present paper is concerned only with the composition and origin of the Kef Lakhal amphibolites and some associated mafic and ultramafic enclaves and thus excludes the decametre lenses of the fine grained and schistose amphibolites which are always interlayered with the Paleozoic mica schists. The minerals have been analysed in Glasgow University with a Cambridge Mark V microprobe and the rocks by XRF analysis using the methods of Leake *et al.* (1969) and Harvey *et al.* (1973) for the trace and major elements respectively.

Petrology

The amphibolites. The Kef Lakhal amphibolites are both massive and striped with gradation from one to the other. The massive amphibolites are generally coarser, less common, and consist of 70–90% green hornblende, 10–30% An_{34} plagioclase, 0.5–10% garnet, 0.5–3% titanite, 0.5–3% magnetite and ilmenite, and possible quartz, epidote, scapolite, diopside, K-feldspar, chromite, zircon, apatite, and secondary carbonates. The amphibolite–plagioclase striped rocks are made of different proportions of the minerals listed above with hornblende–plagioclase–garnet–titanite–magnetite-ilmenite dark bands alternating with off-white to pale green stripes of plagioclase–quartz with possible epidote, diopside and hornblende. Epidotite bands, which consist of 90–95% epidote and about 5–10% of epidotized hornblende, zoisite, clinozoisite, diopside, plagioclase, and quartz, also occur especially boundinaged epidotites, e.g. near La Voile Noire (Fig. 1). The epidotite bands are later than the plagioclase–quartz-rich ones.

The green hornblende (Table 1 and Fig. 2; 36 analyses) is mostly ferroan pargasitic hornblende (Leake, 1978) and although no attempt has been made to calculate Fe^{3+}, the fact that the total tetrahedral and octahedral ions always approaches 13 (Table 1) indicates that Fe^{3+} is probably very low. Garnet averages 2 mm in diameter but large poikiloblasts up to 5 cm in diameter and containing inclusions of magnetite, ilmenite, amphibole, zircon and apatite are common between Sidi Semhout and La Voile Noire. The garnets (10 analysed) are zoned almandines ranging from Alm_{53} $Gros_{21}$ Pyr_{14} $Spes_{12}$ for a typical core to Alm_{59} Pyr_{27} $Gros_{13}$ Sp_3 for a typical rim with normal zoning (Hollister, 1966), the core being poorer in Mg and Fe and the rims poorer in Ca and Mn (Table 1). Such a pattern is typical of primary zoning, thus excluding the possibility that Ca was subsequently released from the margins to later crystallizing epidote. The plagioclase is largely fresh and albite twinned. Analyses of 36 plagioclases from seven samples show great compositional variability; from as low as An_{10} to An_{85} (average An_{34}) but individual crystals are unzoned.

Pyroxene is very rare and usually limited to the epidote-rich bands and is diopside verging on

Table 1: Microprobe analyses of some representative minerals (the number of minerals analysed is given between parentheses)

The amphibolites	amphibole			pyroxene	Epidote		garnet (AS10)			Titanite
	AS18(7)	AS26(4)	AS27(4)	AS14	AS14(3)		core	rim		AS18(3)
SiO_2	40.05	44.53	41.42	50.55	37.31		37.57	38.07		29.72
TiO_2	1.38	0.56	1.13	0.27	0.18		0.14	trace		37.57
Al_2O_3	13.35	14.35	13.37	2.79	22.88		20.78	21.86		1.92
Fe_{tot}	18.70	10.50	16.19	10.48	12.38		25.11	28.08		0.64
MgO	8.09	13.75	10.28	12.20	0.14		3.59	6.62		0.15
MnO	0.26	0.23	0.31		-		5.70	1.66		-
CaO	11.48	10.62	11.41	22.08	23.05		8.02	4.76		27.72
Na_2O	1.66	1.84	1.85	0.77			0.11	0.30		
K_2O	1.72	0.15	0.76	-	-			-		-
Total	96.69	96.53	96.72	95.94	96.26		101.02	101.35		97.72
Number of ions per unit formula based on 23 oxygens for amphibole, 6 for pyroxene, 25 for epidote, 24 for garnet and 20 for titanite										
Si	6.182	6.469	6.265	1.922	6.046		5.930	5.909	Si	3.968
Al^{IV}	1.818	1.531	1.735	0.078	4.371		0.070	0.091	Ti	0.032
Al^{VI}	0.616	0.906	0.649	0.047	-		3.797	3.853	Ti	3.740
Ti	0.161	0.062	0.129	0.008	0.022		0.017	0.00	Al	0.302
Fe_{tot}	2.415	1.276	2.049	0.333	1.506*		3.328	3.645	Fetot	0.021
Mn	0.034	0.028	0.041	-	-		0.762	0.218	Mg	0.030
Mg	1.863	2.978	2.319	0.691	0.038		0.844	1.531	Ca	3.966
Ca	1.896	1.652	1.851	0.899	4.002		1.333	0.792		
Na	0.496	0.516	0.545	0.014	-		0.034	0.090		
K	0.349	0.105	0.169	-	-		-	-		
				%Fe=17.3		Alm.	53.10	58.92		
				%Mg=36.0		Spes.	12.16	3.52		
				%Ca=46.7		Pyr.	13.47	27.75		
						Gros.	21.27	12.8		

* Fe_{tot} is calculated as Fe_2O_3

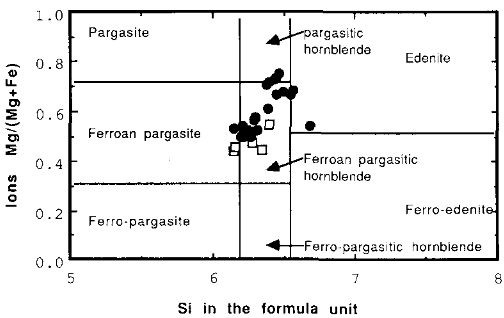

FIG. 2. Mg/(Mg + Fetot) versus Si in formula unit of amphiboles. Kef Lakhal amphibolites (filled circles) and amphibolite enclaves (open squares).

augite (Table 1). The epidote (Table 1) occurs as irregular spongy grains clearly replacing hornblende and pyroxene along the cleavages and parting zones. In the epidotite bands, epidote tends to be more euhedral and is often accompanied by colourless to pale yellow tabular crystals of zoisite and very rarely yellow greenish clinozoisite. In the plagioclase and epidote-rich bands, quartz is larger and more abundant than in the hornblendic layers which suggests late Si mobility. Veins of pure quartz cross the amphibolites and could be tectonically controlled. Light brown euhedral titanite contains zircon inclusions and forms thin layers (0.8 mm thick) parallel to the schistosity, suggesting that significant metamorphic segregation has taken place. The analyses of three titanites (Table 1) show that Al_2O_3 + MgO + Fe_{tot} (as Fe_2O_3) = 2.71 wt. %, suggesting octahedral substitution of Ti by Al, Fe and Mg; this is a common feature in titanite (e.g. Sahama, 1946; Higgins and Ribbe, 1978; Coombs *et al.*, 1976, Deer *et al.*, 1982).

The enclaves. These enclaves occur as centimetre to metre in diameter inclusions within the metasediments to the east and west of La Voile Noire and immediately to the west of Sidi Semhout (Fig. 1). Most enclaves examined and particularly the small ones are rounded to subrounded or oval in shape, have smooth surfaces and are concordant with the schistosity of the host pelites. There are two different types of enclaves; amphibolites and olivine-rich rocks.

The amphibolites, black–greenish rocks averaging 20 × 10 cm in size, are by far the most abundant and consist of 70–90% ferroan pargasitic hornblende (Table 2, Fig. 2), 10–20% unzoned An_{87} bytownite, 0.5–10% unzoned garnet, typically $Alm_{44.52}$ $Gros_{39.7}$ $Pyr_{14.37}$ $Spes_{1.41}$ (Table 2), 0.5–3% magnetite and ilmenite, 0–2% of epidote and chlorite, and accessory titanite, K-feldspar, zircon and apatite.

Five olivine-rich enclaves were also found, oval to subrounded in shape, 20 to 200 cm in diameter and about 2 m away from the main amphibolite–pelite contact to the east of La Voile Noire (Fig. 1). They are surrounded by a 2–5 cm corona of fibrous serpentine and chlorite and are 80–95% partly serpentinized and chloritised olivine and 5–10% chromite, magnetite and ilmenite and orthopyroxene. The relic olivine is forsterite with mg (ions Mg/(Mg + Fe_{tot} + Mn)) of between 89 and 91, 0.44 to 0.64 wt. % NiO (Table 2) and is clearly higher in Ni than the 31 olivines examined by Smith and Stenstrom (1965) but approaches the upper level of those olivines from the dunites of the Higasiakaisi mass, central Sikoko, Japan, which range from 0.24 to 0.46 (Banno and Yoshino, 1965). O'Hara and Mercy (1963) reported olivines containing up to 0.57 wt.% NiO in garnet-bearing peridotites. Based on data from Fleet *et al.* (1977), Deer *et al.* (1982) noted that on a MgO versus NiO diagram, olivines from upper-mantle peridotites plot at the Mg-rich side of the diagram compared with olivines from basalts, diabases and layered intrusions. The eight olivines analysed are consistent with being derived from upper-mantle crystallization. The orthopyroxene is untwinned, partly chloritised Ca-free enstatite (mg = 90%, Table 2) with insignificant Al, Ti, Mn and Cr. The magnetite, ilmenite and chromite are usually intergrown and occur as euhedral grains inside olivine. Table 2 shows the considerable substitution of Cr by Fe^{3+} in the chromite.

Chemistry

34 Kef Lakhal amphibolites, four amphibolite and three olivine-rich enclaves have been analysed and 16 representative analyses are given in Table 3 and are graphically compared with other amphibolites and basic igneous rocks in Fig. 4 (A–D). Plots of Niggli mg versus c and mg, c, (al-alk) (Fig. 3 A and B), (Evans and Leake, 1960; Leake, 1964) clearly suggest a basic-ultrabasic igneous origin for the Kef Lakhal amphibolites, the amphibolite and olivine-rich enclaves and this is further supported by major and trace element Harker-type diagrams (not shown). The particularly high c value of sample AS13 (c = 50.23) is due to the abundance of epidote veins. The amphibolite chemistry compares fairly well with 1996 superior basalts (Manson, 1967) and 200 tholeiitic basalts from Hawaii, Macdonald (1968).

The composition of the amphibolite enclaves

Table 2: Microprobe analyses of some representative minerals (the number of minerals analysed is given between parentheses)

The enclaves						
amphibolitic			olivine-rich			
	Amphibole AS35(4)	garnet AS35(3)	pyroxene AS36(3)		olivine AS36(4)	chromite As36(2)
SiO_2	41.89	38.05	56.69		40.17	0.21
TiO_2	0.81	trace	trace		0	0.91
Al_2O_3	13.38	21.47	0.63		0	2.44
Fe_{tot}	16.11	20.77	6.74		10.27	57.34
MgO	9.58	3.76	34.69		49.00	2.92
MnO	0.21	0.65	0.09		0.12	0.98
CaO	11.84	14.45	0.19	Na_2O	0.17	0.49
Na_2O	1.04	0.09	0	Cr_2O_3	trace	30.41
K_2O	1.69	-	0.07 (Cr)	NiO	0.55	0.10
Total	96.55	99.24	98.82		100.28	95.80
Number of ions per unit formula based on 23 oxygens for amphibole, 24 for garnet, 6 for pyroxene, 4 for olivine and 32 for chromite.						
Si	6.357	5.948	1.988	Si	0.986	0.060
Al^{IV}	1.643	0.052	0.009	Al	0	0.817
Al^{VI}	0.752	3.903	-	Ti	0 0	0.194
Ti	0.093	trace	-	Fe_{tot}	0.211	12.263
Fe_{tot}	2.046	2.715	0.197	Mn	0.003	0.235
Mn	0.028	0.086	-	Mg	1.794	1.229
Mg	2.168	0.876	1.813	Na	0.008	0.269
Ca	1.926	2.421	-	Ni	0.011	0.022
Na	0.305	0.029	-	Cr	0	6.832
K	0.329	-	-			
	Alm.	44.52	%Mg=90.17	mg	89.34	
	Pyr.	14.37	%Fe = 9.83			
	Spes.	1.41				
	Gros.	39.70				

mg = ions Mg/(Fetot+Mg)

matches that of the main amphibolites with only a slight tendency for the latter to be richer in Na and poorer in K and this trend is expected as sodic plagioclase is restricted to the latter and there is a tendency for the former to be richer in K-rich alteration products. The olivine-rich enclaves are different and their chemistry reflects their ultramafic nature (Table 3). The Kef Lakhal amphibolites also generally compare well with garnet-free and garnetiferous Connemara amphibolites, Evans and Leake (1960), Leake (1972), and garnet-free, and garnetiferous Scottish Green Beds (Van De Kamp, 1970) except that the studied amphibolites tend to be higher in Ca, Ti and have higher $Fe^{3+}/(Fe^{3+} + Fe^{2+})$ ratios and lower in Mn and alk. The tendency of the Edough amphibolites to be richer in Ca is probably related to the abundance of epidote veins whereas their high Niggli w ($Fe^{3+}/(Fe^{3+} + Fe^{2+})$) of 0.42 ± 0.10 compared with 0.15 ± 0.06 for garnetiferous and 0.19 ± 0.04 for garnet-free Connemara amphibolites, and 0.25 ± 0.08 for garnetiferous and 0.29 ± 0.06 for garnet-free Scottish Green Beds indicate that significantly higher oxidizing conditions prevailed in the Edough amphibolites.

It seems likely therefore that the composition of the Edough amphibolites (high Fe/Mg and low Ca, Na and K) was an important factor in the formation of garnet although the high pressure experienced by the rocks was also important.

The tendency of the amphibolite enclaves to be poorer in Cr, Ni and to a lesser extent Co, and richer in Ce, La, Ba and Rb compared to the main amphibolites suggest that they were more fractionated end members of the magma but their very An-rich plagioclase and high MgO and Cr contents do not support this interpretation. However, sinced the enclaves vary widely in terms of their trace element contents and only four samples were chemically analysed, their petrogenetic relations to the main amphibolites is uncertain but they were presumably derived from the same magma series, but with various degrees of crustal contamination during ascent.

Table 3: Rock chemistry

	The amphibolites									The enclaves						
										amphibolitic				olivine-rich		
	AS7	AS8	AS10	AS13	AS15	AS20	AS22	AS25	AS27	AS32	AS33	AS34	AS35	AS36	AS37	AS38
Major elements																
SiO_2	44.33	55.35	40.37	52.39	56.36	49.42	47.48	47.26	45.43	46.78	51.61	49.07	46.83	42.41	42.32	48.66
TiO_2	2.49	1.33	4.29	1.77	1.05	1.35	1.42	1.20	1.80	1.19	0.98	0.94	1.43	0.07	0.00	0.11
Al_2O_3	15.29	14.79	15.45	15.34	16.78	15.91	17.55	17.82	17.74	18.25	15.26	14.04	16.07	2.02	1.73	3.26
Fe_2O_3	4.14	2.82	7.19	9.25	3.12	4.88	2.90	2.30	2.97	2.81	1.58	1.28	4.79	4.22	3.91	3.99
FeO	9.28	5.70	10.42	0.98	2.85	5.21	5.98	5.51	6.79	8.24	5.52	7.34	8.56	4.24	3.84	4.74
MnO	0.22	0.16	0.40	0.20	0.09	0.13	0.10	0.10	0.13	0.20	0.09	0.14	0.29	0.14	0.08	0.16
MgO	10.04	7.19	7.74	1.29	3.11	5.25	8.16	8.34	6.08	4.97	10.93	11.60	5.25	44.48	46.47	32.99
CaO	10.8	7.02	9.39	17.73	9.88	13.10	11.69	11.25	10.98	10.84	9.88	8.50	12.26	0.70	0.18	2.70
Na_2O	1.95	1.55	1.62	0.08	3.87	2.83	3.60	3.07	2.56	2.53	1.86	1.46	0.00	0.00	0.00	0.00
K_2O	0.49	1.64	0.56	0.00	0.42	0.20	0.25	0.40	0.70	1.37	0.86	0.72	1.17	0.00	0.00	0.11
P_2O_5	0.23	0.16	0.44	0.19	0.14	0.13	0.15	0.08	0.17	0.07	0.26	0.02	0.15	0.00	0.00	0.00
L.O.I	2.21	277	1.94	1.60	1.95	1.55	1.50	1.78	4.07	2.20	1.05	1.98	1.60	0.70	0.78	2.06
Total	99.67	99.55	99.81	100.82	99.62	99.96	100.78	99.09	99.32	99.45	99.88	97.09	98.40	99.98	99.31	98.78
Trace elements																
Rb	11	59	88	7	16	12	8	28	18	90	27	22	29	3	bdl	3
Ba	87	208	314	112	85	93	57	53	125	270	222	241	186	33	2	377
La	8	18	30	10	4	4	4	bdl	7	67	18	4	53	2	bdl	bdl
Ce	16	32	42	4	8	8	6	10	10	113	33	7	88	bdl	bdl	bdl
Y	47	26	40	39	19	27	26	23	37	33	27	33	48	0	0	8
Cu	67	72	23	10	59	71	55	2	16	52	3	4	92	26	bdl	52
Zn	82	87	150	50	31	68	57	51	75	140	70	70	116	86	33	164
Zr	199	146	245	151	99	135	107	281	265	189	137	106	199	0	0	0
Sr	274	187	124	179	378	133	271	281	265	281	289	165	158	10	5	34
Ga	20	17	20	20	15	17	16	15	19	24	14	13	18	1	1	2
Co	58	40	50	38	23	42	45	37	40	36	30	42	35	106	103	94
Ni	129	158	105	73	43	67	119	77	66	101	200	173	95	1970	1953	2001
Cr	246	294	416	287	128	348	337	218	261	207	383	325	241	2226	1949	2171

L.O.I = Lost On Ignition

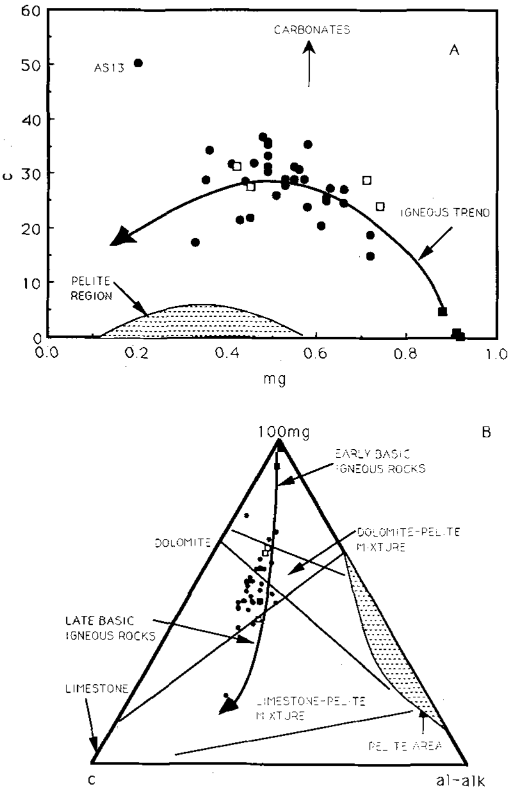

FIG. 3. Binary diagram of Niggli mg versus c (A), and Ternary diagram of Niggli 100mg c, (al-alk) (B) for the Kef Lakhal amphibolites and associated enclaves. Note that the three rocks types follow the igneous trend and the olivine-rich enclaves plot near the mg apex which is consistent with their residual nature (see text). Kef Lakhal amphibolites (filled circles), amphibolite enclaves (open squares), and olivine-rich enclaves (filled squares).

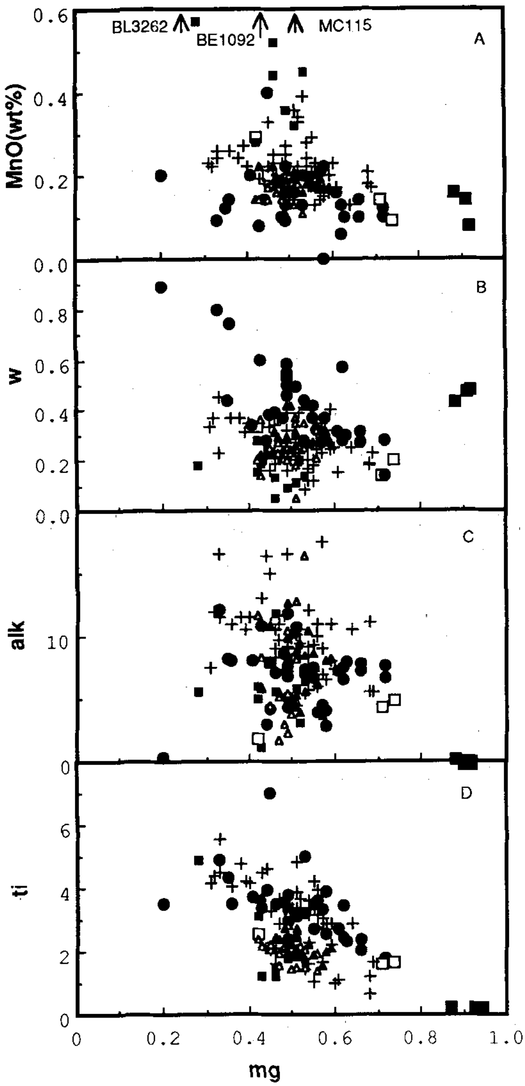

FIG. 4. Graphic comparison of the Edough amphibolites with those from Connemara, Ireland and Scotland. Niggli mg versus MnO(wt%) [A], w[B], alk[C] and ti[D]. Note the lower MnO, higher w and the mixing of alk and ti values of the Edough amphibolites compared to the Connemara garnetiferous amphibolites (small filled squares) and garnet-free (crosses), and garnetiferous Scottish green beds (filled triangles) and garnet-free (open triangles). Symbols of the Edough samples are as in Figure 3.

Origin of the amphibolites and associated enclaves

Fig. 5 (A and B) indicates the predominantly tholeiitic character of the studied rocks and indeed most of the Kef Lakhal amphibolites and the amphibolite enclaves fall within the fields of high alumina tholeiitic basalts as defined by Kuno (1966), Irvine and Baragar (1971), Middlemost (1985) and Wilson (1989). Nine samples out of the 41 available Edough amphibolites and enclaves fall within the calc-alkaline basalt field in Fig. 5B or straddle the line separating the tholeiite-calc-alkaline field which therefore indicates that the suite has also partly calc-alkaline affinities such as is common in continental margin, continental tholeiites and within plate basalts (e.g. Windley, 1977).

The particularly high MgO of two enclaves (wt% MgO 44.48–46.47) is typical of mg-rich lherzolite-harzburgite peridotites (e.g. Middlemost, 1985) of mantle origin.

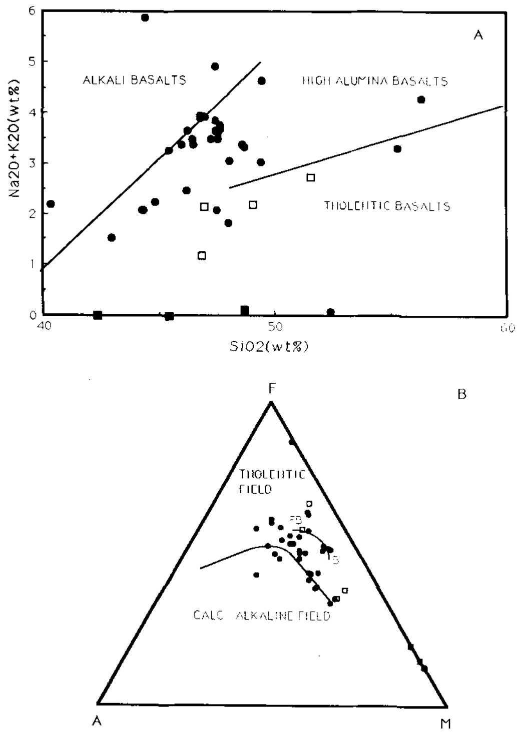

FIG. 5. Binary diagram of SiO_2(wt. %) versus Na_2O + K_2O(wt. %) (A) showing the predominantly medium to high alumina tholeiitic character of the amphibolites. Lines separating the three types of basalts are from Kuno (1966) and Irvine and Baragar (1971). B: AFM diagram (A = Na_2O = K_2O, F = FeO + 0.9 Fe_2O_3, M = MgO) showing the predominantly tholeiitic character of the amphibolites. The line separating the two field are taken from Irvine and Baragar (1971) and the trends of basalts (B) to ferro-basalts (FB) from Wilson (1989). Symbols as in Figure 3.

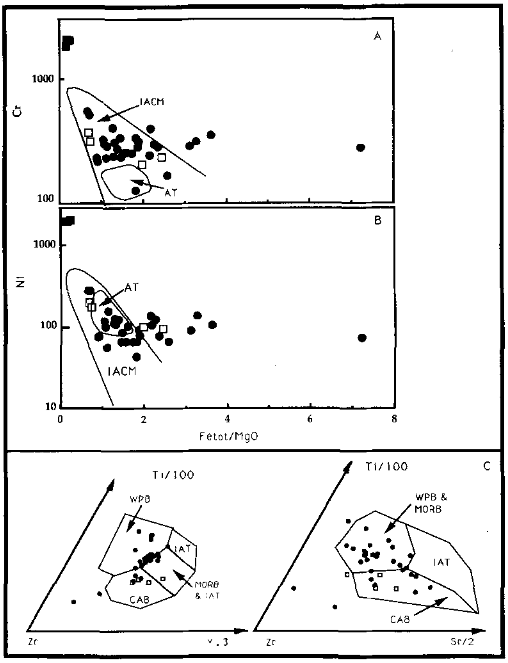

FIG. 6. A = Binary diagrams of FeO/MgO versus Cr (A) and Ni (B) showing the likely tectonic setting of the Edough metavolcanic amphibolites. The fields of island arc-continental margin (IACM) and abyssal tholeiites (AT) are taken from Miyashiro and Shido (1975). C = ternary diagrams of Ti/100-Zr-Y.3 and Ti/100-Zr-Sr/2 after Pearce and Cann (1973) which show the predominantly within plate tectonic setting. CAB = mid-oceanic ridge basalts, IAT = island arc tholeiites, CAB = island arc calc-alkaline basalts, WPB = within plate basalts. Symbols as in Fig. 3.

FeO/MgO versus Cr and Ni binary diagrams and Ti–Zr–Y and Ti–Zr–Sr ternay plots, Figure 6 (A–C), show that most of the amphibolites and amphibolite enclaves fall within the field of island arc and continental margin (IACM) of Miyashiro and Shido (1975) but the rocks fall within nearly all the fields on the diagrams suggested by Pearce and Cann (1973) except island arc basalts. Clearly, the Edough metavolcanic amphibolites cannot be of pure oceanic origin when they are interlayed with metapelites whereas a within plate setting, as continental flood basalts, is feasible. The olivine-rich enclaves have much higher Ni and Cr and they plot separately presumably because of their residual character.

Discussion and conclusion

The Kef Lakhal amphibolites and associated amphibolite enclaves have similar mineralogies and major element chemistries and both were medium to high alumina tholeiitic basalts probably formed within plate setting as continental flood basalts. The differences between the two sets of rocks in terms of their trace elements are presumably due to various degrees of crustal contamination. The olivine-rich enclaves were mantle residua after non-modal melting but it is still not certain whether they belong to the same magma series as the metavolcalnic amphibolites or not.

Ahmed-Said and Leake (1992) showed that the kyanite-bearing pelitic rocks in which the amphibolites occur were illite-rich deep water marine sediments enriched in intermediate-basic volcanoclastic material and that both the palaeon-

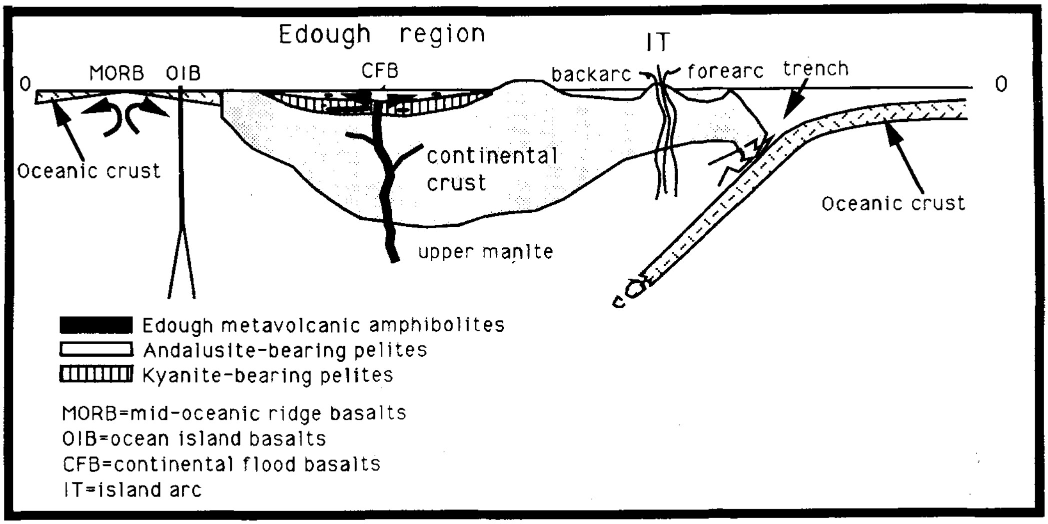

FIG. 7. Likely tectonic setting of the Edough region during Silurian-Devonian times (not to scale).

tological evidence of Ilavsky and Snopková (1987) and geochemical evidence of Ahmed-Said *et al.* (in preparation) indicate that the Paleozoic (Silurian–Devonian) andalusite-bearing pelitic group directly overlying the kyanite-bearing pelitic group were shallow water marine sediments deposited in a volcanic sedimentary environment. Further, two schistose amphibolites interlayered with the andalusite pelites show the same chemical characteristics as the Kef Lakhal amphibolites which therefore indicates a relatively similar tectonic setting during Silurian-Devonian times. The fact that both the kyanite and andalusite-bearing pelites do not contain major volcanic components coupled with their illite-rich deep water nature tends to exclude an intra-arc depositional environment (Dickinson, 1974). It seems likely that the upper mantle originated basalts were emplaced in a relatively deep sedimentary basin most likely as both subsurface basic dykes and sills and near to surface basalts. The likely tectonic setting of the region during Silurian-Devonian time is shown in Figure 7.

Acknowledgement

The first author is particularly grateful to his student A. Djerrab who often accompanied him to some parts of the field during mapping. Mr L. Bouabsa and Mr R. Laouar are also thanked for constructive discussions. The Fire Brigade of Seraidi is especially thanked for help in reaching inaccessible areas by boat.

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[*Manuscript received 23 October 1991: revised 24 February 1992*]