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Pretectonic tholeiitic volcanism and related transitional plutonism in the Kidal assemblage (Iforas Pan-African Belt, Mali)

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Abstract—The Kidal assemblage corresponds to a high-grade tectonometamorphic unit situated beneath the IGU granulitic nappe Pretectonic magmatic rocks of intermediate to ultrabasic compositions form more than 60% of the volume and were intensely foliated during the D1 event Four groups have been defined (i) alkaline leptynites associated with aluminous quartzites and dated at 1837 + 17/−9 Ma (Caby and Andreopoulous-Renaud 1983, *J Afr Earth Sci* **1**, 193–197), (ii) metadiorites–metatonalite plutons, far the most abundant, (iii) amphibolite bands, locally associated with metaconglomerates (O Bourhessa), lying directly upon the quartzites and marbles attributed to the Upper Proterozoic, (iv) narrow lenses and large bodies of metagabbros associated with metaperidotites and some meta-anorthosites

The amphibolites show T MORB affinities (low alkali and incompatible element contents and almost flat REE patterns), and this suggests a spreading environment The gabbroic suite magmas with various cumulates, are distributed between three end-members (olivine peridotites, pyroxenites, anorthosites) The fine grained gabbros show a close chemical similarity with the amphibolites and this suggests a direct genetic relationship between the two suites The chemical characters of the metadiorite–metatonalite suite conform to typical diorite–tonalite–trondhjemite continental suites in a spreading environment

The magmatic units of the Kidal assemblage show significant lithological and geochemical similarities with the supracrustal basic volcanics and intrusive complexes of Archean high-grade belts

The postulated extensional behaviour of the Kidal assemblage may be considered to have indirectly induced the high-strain and dominantly rotational tectonic regime evidenced in this domain

INTRODUCTION

THE KIDAL assemblage was defined by Boullier *et al* (1978) as the high-grade gneissic unit underlying the Iforas granulitic unit (IGU) which forms a major basement nappe (Boullier 1982) Tectonic lenses of quartzites and marbles showing similarities with the Upper Proterozoic Stromatolite Series (Caby 1970) suggest that the assemblage corresponds proparte to late Precambrian rocks The only available geochronological data confirm the Pan-African age of the tectonometamorphic evolution of the area, this 690 Ma old U/Pb age on zircon may be interpreted either as the emplacement age of a pretectonic intrusive (Caby and Andreopoulos-Renaud 1985) or as approaching the age of the main nappe-forming event in the area (Boullier *et al* 1978, Boullier 1982)

The main structural characteristics and the metamorphic evolution of the nappe pile were presented by Boullier (1982) and are discussed in a paper by Champenois *et al* (1986) The nappes were emplaced, probably toward the N, under amphibolite-facies conditions of Barrow type

Our purpose is to present preliminary geochemical results on mafic metavolcanics and ultrabasic–gabbroic intrusives These data, combined with previously published data on the pretectonic metatonalitic plutons (Bertrand *et al* 1984), are used to discuss the geotectonic significance of the Kidal assemblage

GEOLOGICAL SETTING

Three major components make up the Kidal assemblage (Fig 1)

(1) *A gneissic component* comprises banded grey gneisses where a part of the mobilizates predates the main deformation Some of these gneisses may be interpreted as retrogressed granulites They are associated on the field with red alkaline leptynites which yielded a U/Pb on zircon age of 1837 +17/−9 Ma (Caby and Andreopoulos-Renaud 1983) Numerous meta-aplites and metapegmatites are also present and show a typical platten–quartz structure more or less obscured by the post-kinematic migmatitic recrystallization The gneissic component, which forms 10–30% of the assemblage, is interpreted as the result of deep-seated reworking of Eburnean gneisses, granulites and Middle Proterozoic intrusives during an early stage of the Pan-African orogeny

(2) *Metasupracrustals* define three different zones from East to West

In the Tin Elor area, close to the IGU, polyphase folded alumina-rich quartzites are closely associated with the 1837 Ma old alkaline leptynites

In the central part of the domain (O Bourhessa), discontinuous tectonic lenses are formed by a polyphase folded trilogy of quartzites, marbles and banded amphibolites, metapelitic rocks occur in places Local occurrence of pebbly quartzites at the bottom of the

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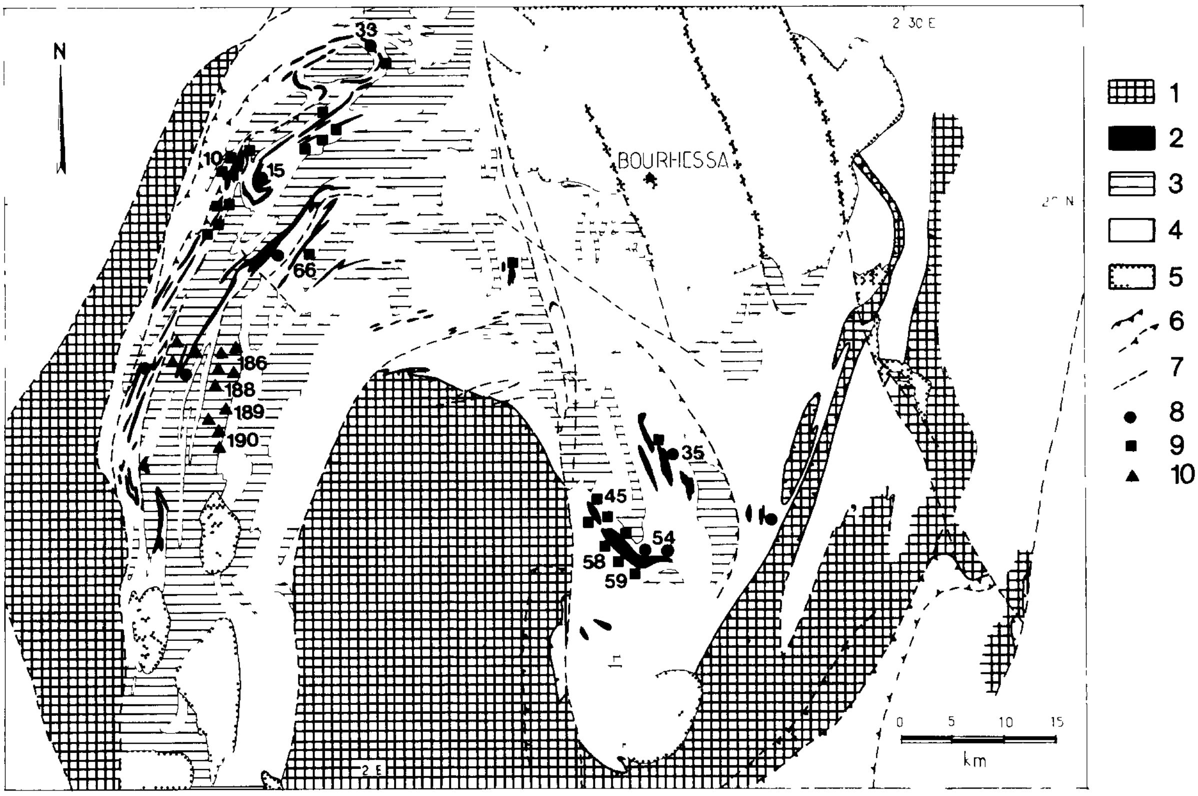

Fig 1 Geological map of northern Central Iforas belt 1 Eburnean granulites 2 Amphibolites and gabbroic intrusives 3 Metadioritic–metatonalitic pretectonic plutons 4 Gneisses and metasediments (2 + 3 + 4 = Kidal assemblage) 5 Post-tectonic intrusives 6 Thrusts 7 Faults Sample locations 8 Amphibolites 9 Metagabbros 10 Metatonalites

sequence suggests a correlation with the base of the Stromatolite Series but any basement–cover type stratigraphic contact is completely rubbed out by the deformation

In the westernmost part of the domain, highly deformed conglomerates have been found, interleaved with plagioclasic gneisses and banded amphibolites

The metasupracrustals form 0–10% of the assemblage and are interpreted as the result of the infolding of cover in the reactivated basement

(3) *An intrusive component* forms in many places the bulk of the assemblage Most of these intrusives clearly predate the main tectonometamorphic evolution (the D1 event of Boullier 1982) They consist of

Foliated lenses of meta-ultrabasics metagabbros and meta-anorthosites Close association on the field with small occurrences of unretrogressed OPX-bearing granulites suggests either an early contact metamorphism or basement slices or xenoliths

Metatonalites associated with leucocratic terms having trondjhemitic affinites Their magmatic texture is never preserved, a late-kinematic blastic recrystallization being the rule, locally associated with remelting

True syntectonic intrusives were not recognized with certainty but the late-kinematic remelting is sometimes so large that almost homogeneous new tonalite and granodiorite may be reached A metatonalitic ghost structure and/or irregular xenoliths are present in all cases

Along the western contact of the domain, porphyritic monzodiorites and granodiorites cross-cut the S1 foliation of the metatonalites and gneisses Together with a large aplitic and pegmatitic complex (the RAPU = red aplo–pegmatitic unit), they predate the D2 deformation which dominates the westernmost batholitic domain (Bertrand and Wright in prep)

PETROGRAPHY

The magmatic units of the Kidal assemblage have all been submitted to the D1 tectono–metamorphic event (Boullier 1982) Their primary textures and mineral associations are rarely preserved, being replaced by amphibolite facies metamorphic paragenesis

Amphibolites occur as elongated lenticular bands of various sizes interleaved with metasediments or grey gneisses In most cases they lie upon the marbles and are believed to constitute an upward sequence by comparison with the sequence observed in less metamorphic tectonic units (Ibedouyen, Ourdjan) where the unconformity of the basal quartzite upon a basement has been recognized Other amphibolites are interbedded with ubiquitous gneisses which may contain metaconglomerates (O Bourhessa) Amphibolites are highly foliated and have a fine grained granoblastic texture with the mineral assemblage hornblende + calcic andesine + epidote + sphene + quartz + ilmeno–magnetite

The metagabbros and serpentinized ultramafic rocks occur as numerous lenticular bands varying in thickness from 1 m to up to 100 m Their contacts with the enclosing metasediments and gneisses are sharp Field studies reveal that they constitute a complex association of serpentinized dunites, metapyroxenites, meta-anorthosites and fine grained, texturally isotropic metagabbros Primary mineral associations are partly preserved in some samples and associate olivine with coronitic texture, orthopyroxene, clinopyroxene and basic plagioclase

The metadiorite–metatonalite suite is widely distributed within the Kidal assemblage and occurs as large, highly foliated plutons The rocks are medium to coarse-grained with orthogneissic texture and contain numerous deformed amphibolite xenoliths They consist of oligoclase–andesine plagioclase, hornblende, biotite, some quartz and allanite + sphene + epidote + magnetite as accessory minerals

ANALYTICAL METHODS

Major and trace element abundances of the 33 selected samples of amphibolites and metagabbros were determined by ICP on an ARL 31 000 spectrometer combined with a micro-wave plasma source unit Analytical errors are 5% for major elements and 10% for trace elements The REE, Nb and Zr values on eight samples were determined by ICP on a JY48P spectrometer combined with an inducted plasma source unit The precision of this method, which has been tested by isotope dilution, is in the 3–5% range Analyses of the metatonalites are from Bertrand *et al* (1984)

RESULTS

Analytical data of the selected samples are presented in Tables 1 and 3 and their normative compositions in Tables 2 and 3

The amphibolites

Except for the most differentiated terms which are quartz normative, all the analyzed samples of amphibolites are olivine tholeiites with normative olivine and pyroxene ranging between 1–14% and 27–43%, respectively Their relatively low alkali (mean values for Na_2O and K_2O = 2 47% and 0 56%, respectively) and incompatible element contents may be a primary feature or it could be the result of alkali depletion during high-grade metamorphism The almost linear distribution of the amphibolites within the field of modern unmetamorphosed basalts in the logarithmic oxide molecular proportion ratio diagrams of Beswick and Soucie (1978) suggests that no major change has occurred in the

Table 1 Representative analyses of amphibolites and gabbroic rock suite from the Kidal assemblage

	Amphibolites				Gabbroic complexes				
					Serpentinized peridotite	Orthopyroxenite	Clinopyroxenite	Anorthosite	Fine grained gabbro
	LM33	LM35	LM15	LM54	LM10	LM59	LM66	LM45	LM58
SiO_2 (wt%)	47 26	45 32	48 48	46 09	36 89	53 05	51 91	46 80	46 30
Al_2O_3	14 25	15 68	14 73	12 36	2 19	3 21	6 37	31 23	14 51
Fe_2O_3*	12 17	13 55	13 45	17 62	8 32	12 09	5 31	1 50	13 69
MnO	0 18	0 22	0 19	0 27	0 12	0 18	0 79	0 04	0 20
MgO	8 19	7 52	6 84	5 46	36 18	24 70	15 57	1 41	8 70
CaO	11 56	12 76	11 75	9 81	0 86	4 35	16 73	14 09	12 24
Na_2O	2 47	1 56	2 19	2 13	0 01	0 20	0 69	1 85	1 84
K_2O	0 57	0 68	0 49	0 36	0 05	0 13	0 35	0 66	0 38
TiO_2	1 39	1 88	1 40	4 87	0 18	0 36	0 33	0 20	1 10
P_2O_5	0 37	0 05	0 16	nd	0 20	nd	nd	nd	0 02
L I	0 79	0 76	0 61	0 29	14 36	2 09	0 63	1 70	0 66
Total	99 20	99 98	100 26	99 26	99 36	100 36	98 68	99 48	99 64
Ba (ppm)	90	141	94	123	<10	11	78	201	119
Cr	367	335	123	82	2494	2093	1220	250	250
Ni	152	153	140	69	2305	1217	730	22	173
Sr	175	257	213	256	<10	20	93	1267	164
Rb	5	6	7	3	nd	2	4	10	3
La	4 4	5 6	6 3	18 6	x	2 2	1 4	1 7	4 0
Ce	11 6	16 4	19 7	49 3	x	6 4	4 0	4 9	10 4
Nd	8 1	10 2	13 9	32 5	x	3 3	3 1	0 85	7 3
Sm	2 3	3 2	4 3	8 4	x	0 91	1 1	0 05	2 1
Eu	0 82	1 03	1 50	2 5	x	0 3	0 4	0 24	0 75
Gd	2 3	3 3	4 5	7 9	x	1 2	1 3	0 07	2 7
Dy	3 0	3 8	4 7	8 1	x	1 0	1 2	0 01	2 8
Er	1 6	1 8	2 2	4 0	x	0 6	0 7	0 01	1 8
Yb	1 6	1 9	2 2	3 8	x	0 5	0 5	0 01	1 6
Lu	0 24	0 30	0 4	0 6	x	0 1	0 1	0 01	0 24
Nb	10 0	11 4	11 9	33 2	x	3 1	2 5	2 1	10 5
Y	25 8	22 6	26 9	46 4	x	6 1	5 6	0 3	20 8
Zr	60 8	84 2	105 6	252 8	x	20 2	18 3	1 5	55 4

* Total iron as Fe_2O_3 x not analyzed, nd not detected

Table 2 Normative compositions of the selected amphibolites, meta-ultrabasite, metapyroxenites, meta-anorthosite and metagabbro from the Kidal assemblage

	LM33	LM35	LM15	LM54	LM10	LM59	LM66	LM45	LM58
Qz	0	0	0	2 20	0	1 31	0	0	0
Or	3 45	4 15	3 00	2 30	0 30	0 75	2 10	3 95	2 30
Ab	22 85	14 50	20 20	20 45	0 10	1 80	6 25	16 80	17 00
An	26 85	34 90	29 70	24 70	4 15	7 45	13 40	71 90	31 10
Di	23 84	24 28	23 40	21 96	0	11 24	56 48	0	25 24
Hy	3 94	3 10	14 44	18 02	23 28	74 98	19 42	6 82	4 62
Ol	14 19	13 92	4 59	0	69 69	0	1 02	0	15 81
Mt-Il	4 06	5 02	4 28	10 36	1 72	2 48	1 34	0 54	3 90
Ap	0 80	0 11	0 35	0	0 45	0	0	0	0

In the calculation Fe_2O_3 is set at 0 15 FeO—for petrographic information see Table 1

composition of the rocks since their origin (Fig 2) The MFA plot (Fig 3) shows for the amphibolites a strong iron enrichment trend which precludes affinites with calc-alkaline suites According to the nomenclature applied by Wood (1978) to the Icelandic Tertiary tholeiitic series, the Kidal amphibolites are distributed between high-magnesia basalts and Ti-rich ferrobasalts Their general low content of incompatible elements suggests affinities with oceanic domains These affinities are also indicated by the distribution of the amphibolites within the ocean floor basalts field of the discrimination diagrams of Pearce and Cann (1973) (Fig 4)

The most magnesian amphibolite (LM33) has a low REE content (Σ REE = 36 ppm), poorly fractionated pattern [$(Ce/Yb)_N$ = 1 9] and no Eu anomaly (Table 1, Fig 5) These characters and its high Cr and Ni contents suggest that it may represent a primary magma The transition to ferro-basalt type (LM54) induces a marked increase of the REE content (*ca* 136 ppm) but the REE pattern remains practically unchanged [$(Ce/Yb)_N$ = 3 4] The lack of Eu anomaly suggests that plagioclase fractionation was not involved in the primitive evolution of the rock series

Table 3 Chemical and normative composition of selected samples from the Kidal metadiorite–metatonalite suite −1 to 4 comparison with the Nuk gneisses from Labrador (McGregor 1979)

	N190	N186	N188	N189	1	2	3	4
SiO_2 (wt%)	52 87	55 62	59 79	66 58	51 65	55 29	64 50	67 65
Al_2O_3	18 89	17 26	16 91	15 15	18 28	19 58	17 28	16 42
Fe_2O_3*	8 37	7 46	6 32	3 96	9 04	6 25	3 39	3 10
MnO	0 14	0 12	0 10	0 04	0 12	0 08	0 04	0 04
MgO	4 69	3 74	3 00	1 93	4 55	2 88	1 68	1 20
CaO	7 20	6 37	5 83	4 04	7 74	7 54	4 41	3 87
Na_2O	4 25	3 94	3 93	3 85	4 40	4 70	5 00	5 30
K_2O	1 82	2 01	1 74	1 58	1 59	1 24	1 54	1 24
TiO_2	0 97	1 09	0 81	0 64	1 06	0 81	0 44	0 42
P_2O_5	0 25	0 32	0 31	0 11	0 75	0 36	0 18	0 17
L I	0 92	0 88	0 76	0 71	0 50	0 85	0 88	0 74
Total	100 37	98 81	99 50	98 59	99 68	99 58	99 34	100 15
Ba (ppm)	730	769	760	791	1010	480	859	440
Cr	34	40	42	34	90	80	40	30
Ni	26	29	25	12	54	48	26	6
Sr	784	695	656	703	1119	800	737	604
Rb	52	66	54	47	40	43	51	35
La	21 2	19 5	17 8	12 1				
Ce	49 3	40 6	39 3	23 8				
Nd	30 7	25 3	16 9	12 2				
Sm	6 9	6 0	3 9	2 3				
Eu	1 86	1 84	1 15	0 73				
Tb	0 87	0 79	0 55	0 30				
Yb	2 20	2 04	1 35	0 68				
Lu	0 31	0 32	0 20	0 11				
Nb	14	14	10	9	6	6	3	5
Zr	220	169	226	143	113	48	139	124
Qz	0	4 32	11 29	24 03	0	2 08	15 56	19 74
Or	10 80	12 20	10 50	9 65	9 50	7 40	9 20	7 35
Ab	38 25	36 25	35 95	35 60	39 75	42 50	45 35	47 70
An	27 10	24 00	23 75	19 95	25 60	28 85	20 35	17 40
Di	5 68	5 00	2 92	0	6 60	5 24	0 52	0 64
Hy	6 32	14 72	12 74	8 94	2 98	11 00	7 48	5 74
Ol	8 61	0	0	0	11 01	0	0	0
Il-Mt	2 74	2 82	2 20	1 60	2 98	2 18	1 18	1 10
Ap	0 53	0 69	0 67	0 24	1 57	0 75	0 37	0 35

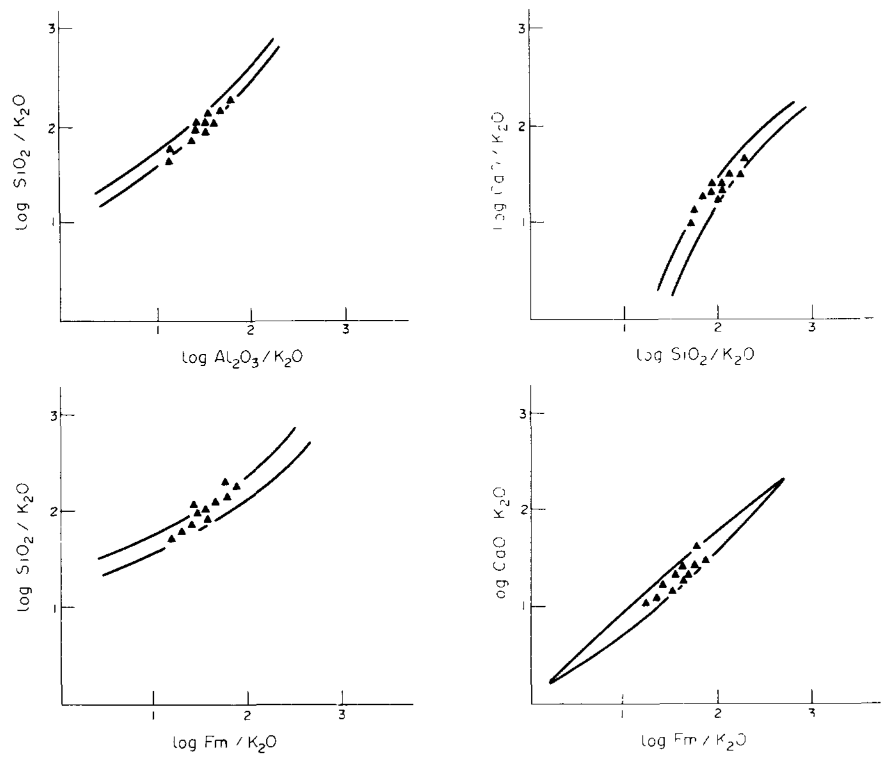

Fig 2 Logarithmic oxide molecular proportion ratio plot of Kidal amphibolites Fields given are those of modern unmetamorphosed basalts (after Beswick and Soucie 1978)

The meta-ultrabasic–metagabbroic suite

This unit shows a considerable range in chemical composition reflecting the large diversity of the associated rock types (Tables 1 and 2) The serpentinized ultrabasites and coarse-grained gabbros have cumulate compositions ranging from olivine peridotites to pyroxenites, in which the chemical spread is controlled by the variations of the clinopyroxene/orthopyroxene ratio, and to anorthosites The olivine peridotites and pyroxenites are strongly enriched in Cr and Ni and, by contrast, depleted in incompatible elements The anorthosites are characterized by their high anorthite normative content (*ca* 80%) and their Sr enrichment The cumulative character of this rock suite is also attested by their very low REE contents and normalized patterns strictly controlled by their dominant minerals

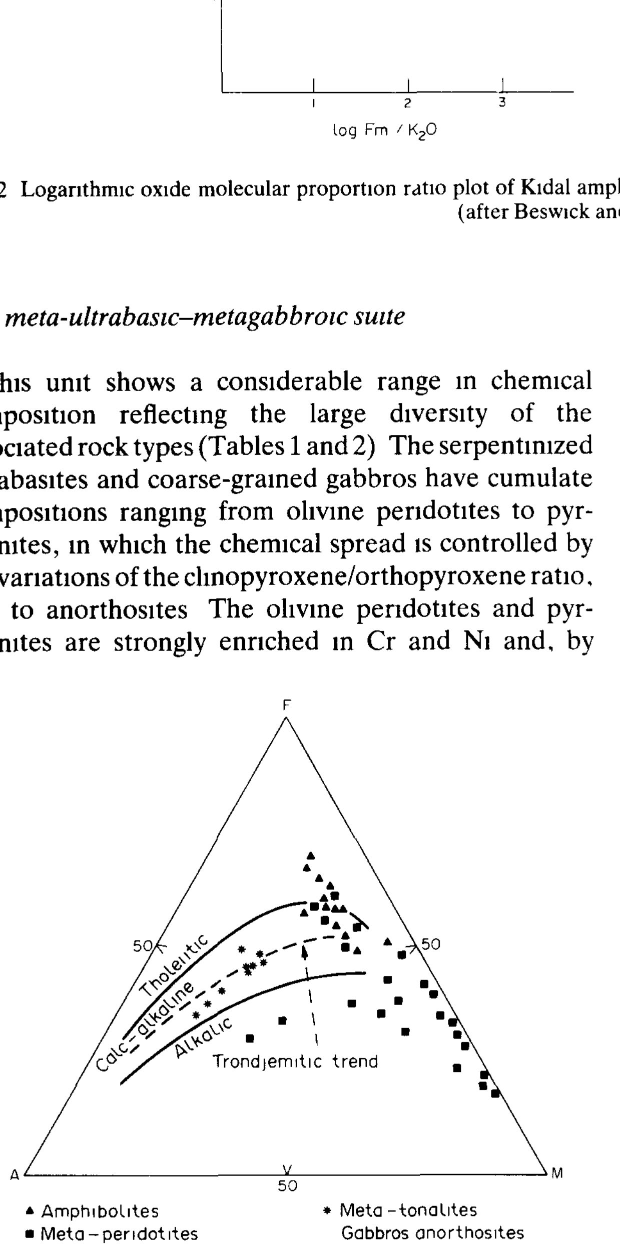

Fig 3 AFM plot of the Kidal igneous suite A = $Na_2O + K_2O$, F = total Fe as FeO, M = MgO Reference fields and trondhjemitic trend after Barker and Arth (1976)

The fine-grained, texturally isotropic, gabbros have basaltic compositions and exhibit characters almost identical to the Kidal amphibolites They have olivine tholeiite affinities with low alkali and incompatible element contents They are REE depleted (34 ppm) with an almost flat pattern [$(Ce/Yb)_N$ = 1 65] (Fig 5) and plot within the ocean floor basalts field of the discrimination diagram of Pearce and Cann (1973) (Fig 4)

The metadiorite–metatonalite suite

The different plutons appear similar in composition and have a wide range of SiO_2 contents (53–67%—Table 3), whereas their alkali and more particularly K contents remain almost constant (K_2O varies between 1 35 and 2 01%) In the AFM diagram the series follows a well-defined trondhjemitic trend as defined by Barker and Arth (1976) (Fig 3) Over all the compositional range the suite is enriched in incompatible elements with only slight positive or negative correlations with SiO_2, except for Rb which follows K All four analyzed samples have relatively fractionated REE patterns with no significant Eu anomaly (Fig 6), with the increase of the silica content the total REE content decreases (from 113 to 52 ppm) whereas the fractionation between LREE and HREE increases [$(Ce/Yb)_N$ varies from 6 to 9] This

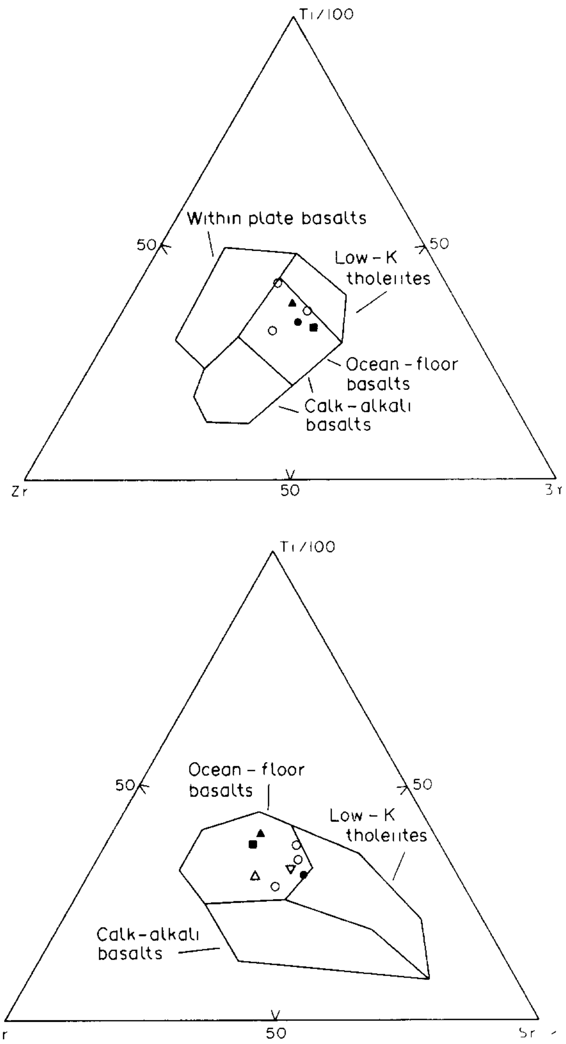

Fig 4 Trace element discrimination diagrams according to Pearce and Cann (1973) showing the distribution of the Kidal amphibolites (circles) and fine grained metagabbro (black circle) Comparison with T-MORB olivine tholeiites from Iceland (black triangle) (Wood 1978) and Skye (black square) (Mattey *et al* 1977) and Archaean amphibolites from Labrador and Greenland (triangles) (Rivalenti 1976 Collerson *et al* 1976)

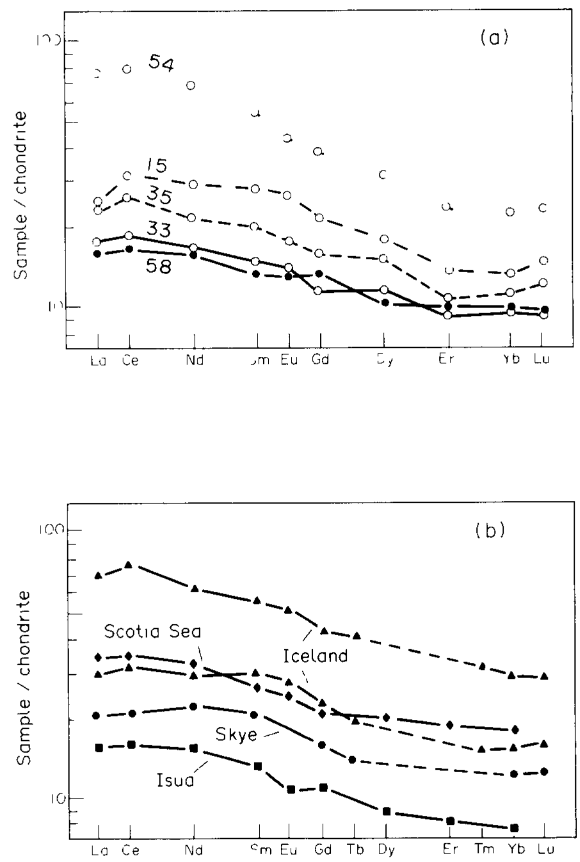

Fig 5 Chondrite-normalized REE patterns for a Kidal amphibolites (LM33, 35, 15 and 54) and fine-grained gabbro (LM58), b T-MORB olivine tholeiites from Iceland (Wood 1978), Skye (Mattey *et al* 1977) and Scotia Sea back-arc basin (Hawkesworth *et al* 1977), and Archaean amphibolite from Isua Greenland (Sun and Nesbitt 1978)

evolution suggests that hornblende fractionation was involved in the production of the more siliceous magmas (Arth and Hanson 1975, Cocherie 1978, Fourcade and Allegre 1981)

An Rb–Sr isotope study has been previously performed over nine samples of the metadiorite–metatonalite suite (Bertrand and Davison 1981) The data present a large scatter which exclude any isochron age and may be attributed to an inhomogeneous effect of the Pan-African metamorphism

DISCUSSION

When compared with modern, unmetamorphosed, volcanic series, the Kidal amphibolites present affinities with enriched Transitional (T)-MORB (Sun *et al* 1979) (Figs 4 and 5) which occurs in several spreading environments These include ridge segments such as the 61–63°N Reykjanes Ridge (Sun *et al* 1975), islands on a ridge

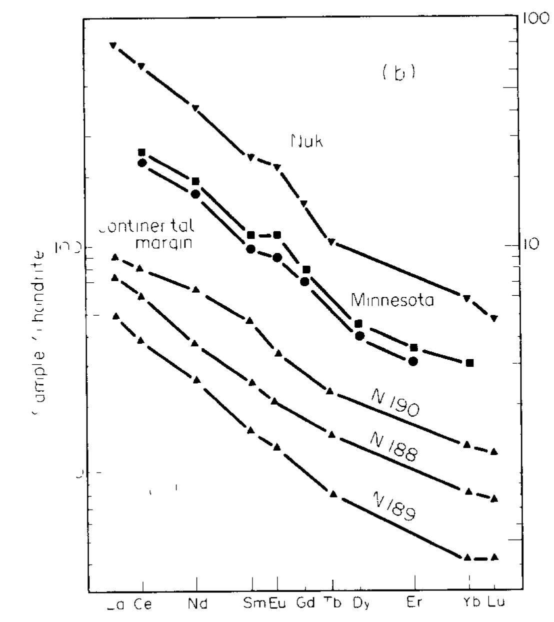

Fig 6 Chondrite-normalized REE patterns for a Kidal metadiorite–metatonalite suite, b Cenozoic–Mesozoic tonalitic–trondhjemitic suites from continental margin and continental interior (Arth 1979) and Archaean metadiorites–metatrondhjemites from Minnesota (Arth and Hanson 1975) and Nûk, Greenland (Compton 1978)

such as Eastern Iceland (Wood 1978), back-arc spreading centers such as the Scotia Sea (Hawkesworth *et al.* 1977) or continental dyke warms such as Skye (Mattey *et al.* 1977). All these basaltic suites exhibit Fe-enrichment trends, no marked depletion in highly incompatible elements and almost flat REE patterns (Table 4, Fig. 5). Taking into account the close association of the Kidal amphibolites with supracrustal metasedimentary rocks (pelites, quartzites and marbles) and grey gneisses, we suggest that they may represent the metamorphosed and deformed equivalent of a back-arc spreading center.

The close chemical similarity of the fine-grained gabbros with the amphibolites suggests a direct genetic relationship between the two units.

The high incompatible elements enrichment, and the fractionated REE patterns of all the terms of the metadiorite–metatonalite suite, preclude any genetic relationship with the amphibolites. The chemical characters of this suite conform to Barker's (1979) and Arth's (1979) definition of typical diorite–tonalite–trondhjemite suites which are known in four main geologic environments: (1) Archaean grey gneiss terranes (McGregor 1979), (2) Continental margins or interiors in relation to subduction or to subsidiary back-arc spreading (Barker and Millard 1979), (3) Island arc as part of arc-tholeiitic suites (Phelps 1979), (4) Ocean ridge or ophiolites as a member of the plagio-granite suite (Coleman and Peterman 1975). Some major elements, such as Al_2O_3, and trace elements, such as REE, appear able to distinguish the geotectonic setting of these suites. According to Arth's (1979) criteria the Kidal metadiorite–metatonalite suite is comparable to the high-Al_2O_3, low-Yb continental type (Fig. 6). Taking into account the geotectonic setting previously defined for the amphibolites into which the plutonic suite is emplaced, we can suggest for this suite a back-arc spreading environment.

The exact age of the pre-D1 Kidal magmatism is unknown, as it is also for the D1 event itself. An Rb–Sr isotopic study did not succeed in dating the metadiorite–metatonalite suite (Bertrand and Davison 1981). Unpublished U/Pb data on zircons (Bertrand and Dautel) have yielded useless low intercept ages of 554 ± 10 Ma and 605 ± 8 Ma for two similar samples of the same plutonic body (a striking feature, yet unexplained, is the same upper intercept, *ca* 3000 Ma, for the two samples). As these ages are lower (or in the same range) than the biotite ages (Bertrand and Davison 1981, Bertrand *et al.* 1984), they cannot correspond to the emplacement of the plutonic bodies. More likely, they may result from an open system behavior at the time of the collision, estimated at *ca* 600 Ma and accompanied by the emplacement of a large batholithic complex (Liegeois *et al.* 1986). Assuming, on the basis of many indirect arguments, a Pan-African age for its tectono-metamorphic evolution, two age possibilities for the Kidal pretectonic plutonism are to be checked:

(1) It could be related to the major distensive event evidenced by Caby (1970), dated at *ca* 800 Ma (Clauer 1976, La Boisse 1979) and interpreted as the initiation of the oceanic stage of the Trans-saharan Belt,

or (2) it could be associated with a still undated stage of the eastward subduction and corresponds to a back-arc spreading.

The Arabian–Nubian shield is currently regarded as one of the best examples that display the development of the Pan-African magmatic activity from 900–950 Ma to some 640 Ma ago (Kroner 1985, Marzouki *et al.* 1982). Geochemical data provide evidence of general affinities of volcanic as well as plutonic suites with island-arc

Table 4. Mean composition of Archaean meta-volcanics, meta-ultramafics, meta-anorthosites and metagabbros compared with recent T-MORB olivine tholeiites

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2 (wt%)	49.50	51.05	49.07	50.59	46.00	38.83	49.60	49.20	48.86	47.23	47.05	47.91	50.02
Al_2O_3	14.43	14.13	14.52	12.08	14.53	0.95	5.20	26.60	17.22	15.03	14.60	13.01	16.13
Fe_2O_3t	12.56	13.16	13.46	13.28	13.91	10.56	8.40	3.41	10.29	12.97	14.95	17.06	11.05
MnO	0.20	0.20	0.23	0.21	0.06	0.10	0.15	0.07	0.17	0.19	0.20	0.24	0.18
MgO	6.90	7.63	7.22	8.56	11.41	38.02	29.80	1.55	6.90	7.55	5.96	4.71	6.01
CaO	10.55	8.95	10.22	11.00	10.61	0.61	5.40	11.03	11.10	11.50	10.05	9.31	11.62
Na_2O	2.78	2.55	2.08	2.16	1.78	0.09	0.85	3.31	2.35	2.27	2.92	2.88	2.99
K_2O	0.46	1.03	0.39	0.74	0.33	0.01	0.09	1.13	0.71	0.26	0.51	0.59	0.16
TiO_2	1.12	1.03	1.03	0.68	0.85	0.07	0.12	0.21	0.62	2.05	3.00	3.68	1.67
P_2O_5	0.14	0.25	0.27	0.07			0.03	0.42	0.06	0.22	0.35	0.41	0.15
L.I.	1.37		2.18	1.37	1.37	11.88	1.50	2.14	1.17	1.30	1.07	1.06	1.31
Ba	20	140	116	115		8	27	129	187	96	162	202	
Sr	121		134	79		24	18	414	143	245	309	285	80
Rb	11		23	26		4	4	118	21	2	6	5	12
Cr	366	310	337	599	607	3132	2646	66	359	239	92	27	224
Ni	141	217	100	147	151	2064	1178	47	132	117	75	26	70
Zr	80		55	45		17	17	35	43	101	176	215	42

1. Amphibolites from Fiskenaesset, Greenland (Rivalenti 1976). 2. Neria amphibolites, Greenland (Kalsbeek and Leake 1970). 3. Amphibolites from Munt River belt, Labrador (Collerson *et al.* 1976), 4. Amphibolites from Saglek area, Labrador (Collerson *et al.* 1976). 5. Amphibolites from Sargur belt, India (Venkataramana 1982), 6–9. Metaperidotites, metapyroxenites, meta-anorthosites and metagabbros from Labrador (Collerson *et al.* 1976), 10–12. Tertiary olivine tholeiites suite from Eastern Iceland (Wood 1978), 13. Olivine tholeiite from Mariana back-arc basin (Dietrich *et al.* 1978).

setting No back-arc setting environment has been so far described in this region and no valuable comparison may be established with the Kidal assemblage

Another comparison may be proposed with the tectono–magmatic evolution of Archaean high-grade belts Such complexes are now well known and a relevant chronology has been proposed by Windley and Smith (1976) (1) formation of gneissic basement, (2) deposition of supracrustal rocks (pelitic schists, quartzites, marbles, basic volcanics), (3) interthrusting of supracrustals and basement with intrusion of layered ultramafic–gabbroic–anorthositic complexes, (4) intrusion of tonalite–granodiorite plutons, (5) deformation and high-grade metamorphism of all rock units The metabasic volcanics of various Archaean high-grade belts such as Labrador (Collerson *et al* 1976), Greenland (Rivalenti 1976) and Canada (Goodwin 1968) have, for their majority, olivine–tholeite affinities (Table 4) Their REE and incompatible element contents are low with a small LREE enrichment (Rivalenti 1976, Collerson *et al* 1976, Gill and Bridgwater 1976, Sun and Nesbitt 1978) The ultabasic–gabbroic–anothrositic complexes associate metaperidotites, metapyroxenites and meta-anorthosites characterized by the very high anorthite content (*ca* 90%) of their plagioclase (Collerson *et al* 1976, Venkataramana 1982) (Table 4) The intrusive gneissic complexes which, in some belts, make up 80–85% of the present surface associate dominant low-K dioritic–tonalitic suites with subsidiary granodioritic–granitic suites (Windley and Smith 1976, Kalsbeek 1976, O'Nions and Pankhurst 1978) (Table 3) From these data it appears that the Kidal assemblage shares many common features (lithology, geochemistry and even tectonic evolution) with the Archean high-grade complexes and thus may be considered as a 'modern' equivalent for the Archaean geodynamic environment

CONCLUSION

The pre-D1 Kidal assemblage associate four major lithological units (1) old gneissic basement, (2) supracrustal rocks (leptynites, metapelites, quartzites, marbles, amphibolites), (3) meta-ultrabasic–metagabbroic–meta-anorthositic intrusive sequence, (4) metadiorite–metatonalite plutons

The T-MORB affinities of the amphibolites and their association with a platform-type sedimentary sequence suggest a back-arc spreading center setting A comparison with the post-Eburnean, pre-Pan-African dykes cross-cutting the granulites of the Iforas Granulitic Unit (Boullier 1982, Davison 1980) remains to be done

The high incompatible element contents and the LREE enrichment of the metadiorite–metatonalite suite preclude any direct genetic relationships with the amphibolites and suggest a significant change in the geotectonic environment A continental setting in relation to a subsidiary back-arc spreading developed during the subduction stage seems to be the most suitable possibility

The magmatic units of the Kidal assemblage show significant lithological and geochemical similarities with the supracrustal basic volcanics and intrusive complexes of Archaean high-grade belts

The high-strain and dominantly rotational tectonic regime evidenced in the Kidal assemblage (Champenois *et al* 1986) may be considered as an indirect consequence of the extensional behavior postulated from our geochemical data As for Archaean equivalents, we can guess that such an early thinning has reduced drastically the crust strength, inducing lately the preferential development of tangential tectonics

Nevertheless the age of the Kidal assemblage as well as the proposed geotectonic model are still at the highly speculative stage They cannot be ensured since (a) precise geochronological data are not available and (b) it has not been demonstrated that present day analogues are realistic Proterozoic or Archaean models

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