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The Cap de Garde pelites and gneisses, Edough, Annaba, NE Algeria: their petrology, geochemistry and origin.

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Abstract : The geochemistry of the Cap de Garde kyanite-rich pelites shows that the rocks, which suffered high pressure (P=7-9kb) and medium temperature (T=600±30 °C) metamorphism, were well sorted illite-rich sediments with only a minor basic igneous component. Based on major and trace chemical analyses, the Edough biotite gneisses, whether augen-bearing or not, are shown to have been isochemically metamorphosed acidic calc-alkaline granitic rocks containing country rock sheets and xenoliths and this is compatible with evidence deduced from whole rock Rb - Sr isotopic studies ((87Rb/86Sr)199=0.71448±19). The major tectonic shearing phase (N140E) which is very well developed in Cap de Garde probably took place at 199±30 MA. The volatile - rich muscovite gneisses and the aplites were probably more evolved acid igneous rocks whereas the leptynites are thought to have a similar origin to the biotite gneisses.

Key words : Calc-alkaline, Edough, Isochemical, Leucosome, Migmatite, Tholeiite.

Résumé : La géochimie des pélites à disthène de la région de Cap de Garde montre que ces roches, qui ont subi un métamorphisme de haute pression (P=7-9Kb) et basse température (T=600±30 °C), étaient des sédiments riches en illite avec quelques fragments ignées intermédiaires. Les éléments majeurs et traces revèlent que les gneiss à biotite de l'Edough, oeillés ou pas, ont subi un métamorphisme isochimique et étaient des roches magmatiques calco-alcalines contenant des xénolites des roches encaissantes. Cette conclusion est compatible avec celle obtenue de l'étude isotopique du Rb - Sr((87Rb/86Sr)199=0.71448±19). La phase tectonique de cisaillement (N140E) bien développée dans la région de Cap de Garde a probablement un âge 199±30MA. Les gneiss à muscovite qui sont riches en éléments volatiles et ayant une composition comparable à celle des aplites, étaient probablement des roches magmatiques plus différenciées. Les leptynites pourraient avoir une origine comparable à celle des gneiss à biotite.

Mots clés : Calco-alcalin, Edough, Isochimique, Leucosome, Migmatite, Tholeiitique.

INTRODUCTION

The Edough massif is the easternmost metamorphic complex of northern Algeria, (Vila, 1970) and extends over 40 Km in a NE SW direction (fig.1). Although its geology has been described by many authors (*e.g* Renou, 1843; Hilly, 1962; Marignac, 1985; Gleizes *et al.* 1988; Ahmed-Saïd and Leake, 1992; Ahmed-Said *et al.* 1993) coherent structural maps and detailed petrogenetic studies are not yet available. The metamorphic complex consists of two major units; gneissic and pelitic. The gneisses are well foliated biotite-rich rocks interlayered with lenses of tourmaline-rich foliated leptynites and occasionally cross-cut by massive aplites. The pelitic unit is made of three formations; a garnet-biotite-quartz-feldspar-muscovite schist at the base to be referred to as garnet pelites, overlain by kyanite -andalusite-staurolite-sillimanite-garnet-bearing pelites sometimes containing discontinuous layers and disoriented slabs of marbles which will be termed the kyanite-rich pelites, and

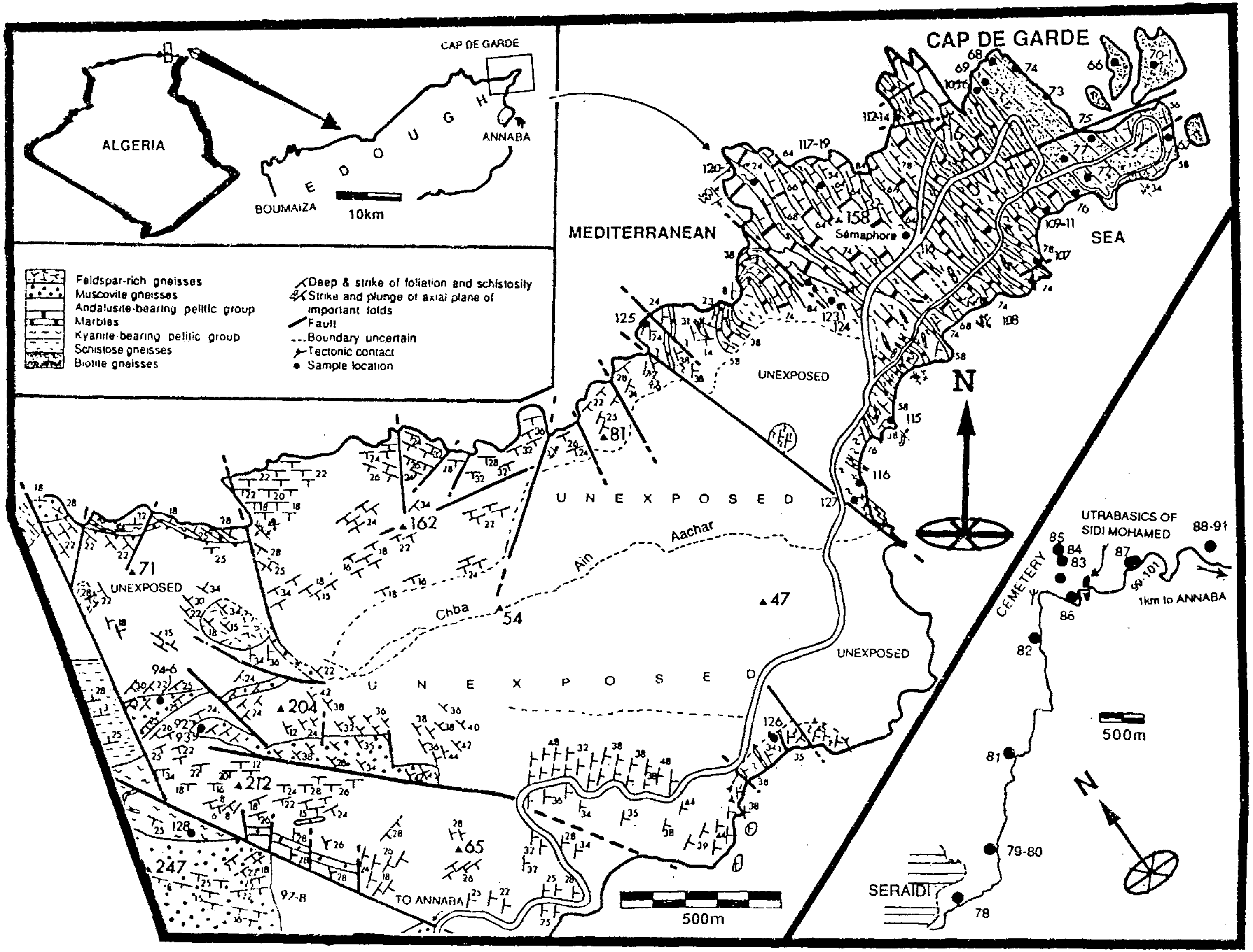

Fig. 1 - Geological sketch map of Cap de Garde, Eastern Edough, showing sample locations. The inset map shows gneisses collected between Annaba and Seraidi. The aplites were collected between Sidi Moussa and Kef Lemette; see 1/25000 map of Bône (1960), Institut National français de Cartographie (Paris).

at the top is a regular alternation of Paleozoic (Ilavsky and Snopkova, 1987) fine grained aluminous schists and feldspathic metaquartzites which will be termed the andalusite-rich pelites. At the base of this latter formation crop out some 0.5-100m thick muscovite and tourmaline-rich augen gneisses which will be named the muscovite gneisses. The aim of this account is to investigate the geochemistry of the kyanite-rich pelites from Cap de Garde and to deduce the origin of the biotite and muscovite gneisses.

METHODS

The chemical analyses (table 1) were carried out in the Department of Geology and Applied Geology, University of Glasgow using the methods of Leake *et al.* (1969) and Harvey *et al.* (1973) for the trace and major elements respectively. FeO was determined by standard wet chemical techniques. The Rb-Sr isotopic analysis (table 4) was undertaken at the Scottish Universities Research and Reactor Centre (SURRC), East-Kilbride. Throughout the paper much use is made of Niggli numbers, the calculation of which is given fully in Niggli (1954). Basically Niggli numbers are based on percentaging the sum of the molecular proportions of Al_2O_3 (*al*), CaO (c), Fe_2O_3+FeO+MgO+MnO (*fm*), K_2O+Na_2O (*alk*), and computing *si* and *ti* using the same normalizing factor; *mg* is mol (MgO/(MgO+FeO+2Fe_2O_3+MnO)); *k* is mol (K_2O/(Na_2O+K_2O)), w (oxidation ratio) is mol (Fe^{+3}/(Fe^{+3}+Fe^{+2})).

I Pelites

The kyanite-rich pelites usually contain disoriented meter-sized slabs and layers up to 100m thick of pure and dolomitic limestone sometimes with cherts. Practically all varieties of the kyanite-rich sub groups have been sampled (fig. 1) and they fall between two major types, deep blue kyanite-rich and light yellowish garnet-rich pelites, some of which lack kyanite. The deep blue type is by far the dominant at Cap de Garde and the contact between the two extreme types can be knifesharp although gradation between many subgroups also occurs. The pelite-limestone contact is usually marked by the formation of fine to medium grained calc-silicates formed by reaction although sharp contacts are also present. This indicates at least two major end-members, one carbonatic and the other pelitic, but due to the petrological variation of the pelites, the pelitic end-member could well include volcanoclastic material. If the protoliths of the gneisses are to be identified then it is first necessary to understand the principal materials which constituted the pelites as some of these source materials may also be protoliths of the gneisses.

Geochemistry

The parameter *al-alk* is useful because it removes the effects of Si, not easily achieved otherwise, and enables recognition of the original presence of clays and sheet minerals and hence enables identification of the trace elements associated with these sheet minerals from those added mostly in feldspars and/or carbonates. This is because *al-alk* is a measure of Al contained in the original clay and sheet minerals rather than in feldspar because *al-alk* is zero in albite and orthoclase while the presence of detrital anorthite (An $_{100}$), which is rare, will plot at *al-alk* 50 and c.50 and is excluded in the present samples by the lack of a positive correlation of *al-alk* and Ca. Consequently, most igneous differentiation series cluster around or parallel the feldspar line (i.e. the line joining An_0 to An_{100}) whereas rocks of sedimentary origin commonly plot almost perpendicular to it; being mixtures of dolomitic or calcareous carbonates, clays and sands.

The studied pelites are clearly lower in Mg, Mn, Ca and Na but higher in K compared to the Connemara Dalradian pelites (Senior and Leake, 1978), post-Archean shales (Taylor and McLennan, 1985), and the continental crust of Krauskopf (1967) and are also high in Al compared to the post-Archean

Table 1 - Chemical analyses of gneisses, leptynites, aplites and pelites.

Biotite gneisses

	AS66	AS67	AS68	AS69	AS70	AS71	AS72	AS73	AS74
Major elements									
SiO_2	72.65	68.63	69.35	67.59	66.73	67.42	68.14	68.48	67.76
TiO_2	0.36	0.64	0.65	0.74	0.86	0.81	0.83	0.79	0.49
Al_2O_3	14.47	15.56	14.47	16.05	15.72	15.98	15.80	15.95	14.43
Fe_2O_3	0.63	0.56	0.56	0.74	0.72	0.66	0.67	0.62	0.73
FeO	1.80	3.72	3.74	3.99	4.59	4.54	4.60	4.31	2.85
MnO	0.06	0.08	0.03	0.00	0.04	0.05	0.0	0.0	0.06
MgO	0.58	1.06	1.15	1.18	1.26	1.23	1.22	1.16	1.45
CaO	1.12	1.82	1.72	2.09	2.17	2.10	2.28	2.22	2.45
Na_2O	1.99	2.08	1.79	2.05	1.75	1.98	2.17	2.07	2.78
K_2O	4.73	4.08	4.43	3.84	3.78	3.78	3.57	3.16	4.00
P_2O_5	0.14	0.16	0.15	0.18	0.20	0.19	0.18	0.17	0.16
L.O.I.	1.49	1.53	1.46	1.37	1.50	1.37	0.97	1.20	1.32
Total	100.02	99.92	100.5	99.82	99.32	100.11	100.43	100.13	98.48
Trace elements									
Rb	180	193	193	160	160	164	172	154	153
Ba	397	496	591	532	541	514	520	517	490
La	31	29	29	34	35	39	34	36	33
Ce	63	68	71	74	85	81	78	76	69
Y	21	18	16	22	25	25	21	26	39
Cu	8	11	6	7	3	6	7	13	3
Zn	40	56	36	53	68	55	57	61	34
Zr	204	227	212	229	253	235	220	235	206
Sr	132	138	124	149	127	133	145	143	121
Ga	18	19	18	18	19	19	18	19	19
Co	7	10	12	12	13	14	13	13	12
Ni	12	15	15	19	23	18	17	19	23
Cr	30	39	46	42	53	55	48	46	70

	AS75	AS76	AS77	AS78	AS79	AS80	AS81	AS82	AS83
Major elements									
SiO_2	71.61	71.31	71.52	68.78	71.25	70.35	74.88	72.80	72.90
TiO_2	0.49	0.61	0.61	0.59	0.41	0.46	0.43	0.38	0.39
Al_2O_3	14.43	14.42	14.44	14.81	14.81	14.46	12.92	13.99	13.57
Fe_2O_3	1.04	1.31	0.89	0.70	0.60	0.75	0.86	0.66	0.49
FeO	2.15	2.71	1.69	3.24	1.98	3.26	1.77	2.44	2.24
MnO	0.05	0.08	0.05	0.08	0.09	0.06	0.03	0.07	0.02
MgO	0.48	0.73	0.52	0.77	0.65	0.76	0.66	0.52	0.56
CaO	1.64	1.76	1.14	1.76	1.23	1.15	0.72	0.95	0.98
Na_2O	2.62	2.45	1.89	2.08	2.81	2.02	2.63	1.80	1.81
K_2O	4.02	3.90	6.42	4.32	4.72	4.75	3.58	5.04	4.57
P_2O_5	0.16	0.17	0.18	0.17	0.15	0.17	0.16	0.13	0.15
L.O.I.	0.95	0.88	1.20	1.45	1.17	0.67	0.60	0.54	1.24
Total	99.64	99.63	100.55	98.75	99.87	98.86	99.24	99.32	98.92
Trace elements									
Rb	143	144	149	186	234	152	198	235	220
Ba	566	480	502	509	286	588	179	284	283
La	30	38	34	29	26	19	17	20	21
Ce	53	79	60	61	53	44	43	45	45
Y	32	33	27	26	13	29	15	10	14
Cu	10	9	6	10	6	5	4	6	2
Zn	28	46	41	35	26	22	21	36	40
Zr	193	218	220	229	160	157	158	157	153
Sr	154	137	140	108	92	126	81	82	88
Ga	17	19	17	20	15	18	18	17	17
Co	6	10	7	9	8	2	3	6	6
Ni	9	14	13	13	13	10	8	11	10
Cr	30	43	42	41	27	21	25	27	23

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Table 1: Continued

	AS84	AS85	AS86	AS87	AS88	AS89	AS90	AS91
Major elements								
SiO_2	74.70	70.28	66.07	70.40	68.67	69.38	67.64	72.63
TiO_2	0.39	0.57	0.77	0.55	0.56	0.66	0.75	0.36
Al_2O_3	12.71	14.16	15.75	15.22	15.24	15.05	15.72	14.29
Fe_2O_3	0.59	1.08	0.94	1.62	1.06	1.04	1.59	0.69
FeO	2.32	2.70	3.83	1.98	2.89	3.22	3.16	2.03
MnO	0.03	0.02	0.08	0.03	0.08	0.08	0.09	0.06
MgO	0.52	0.90	1.28	0.78	0.86	0.84	0.91	0.38
CaO	0.91	0.52	2.16	1.76	1.70	2.83	2.06	1.15
Na_2O	1.97	1.74	1.97	2.10	2.44	3.49	2.06	2.24
K_2O	4.41	4.92	3.07	4.21	4.25	2.12	3.44	4.76
P_2O_5	0.14	0.17	0.21	0.16	0.16	0.17	0.19	0.16
L.O.I.	0.72	1.52	1.97	1.08	1.82	1.07	1.98	1.54
Total	99.41	98.58	98.10	99.89	99.73	99.95	99.59	100.29
Trace elements								
Rb	220	223	131	147	199	92	165	233
Ba	246	392	427	570	460	302	443	341
La	21	22	33	31	33	39	33	25
Ce	49	50	73	63	65	78	74	60
Y	14	11	31	27	29	36	29	17
Cu	2	12	15	10	7	12	17	12
Zn	40	32	47	36	42	31	49	36
Zr	153	171	250	177	204	230	248	162
Sr	88	76	168	146	117	254	133	88
Ga	17	16	21	18	20	18	20	17
Co	6	4	12	5	9	7	10	7
Ni	10	11	15	10	15	16	20	11
Cr	23	25	88	31	33	42	50	21

Muscovite Gneisses								Leptynite	
	AS92	AS93	AS94	AS95	AS96	AS97	AS98	AS99	AS100
Major elements									
SiO_2	76.04	78.19	78.0	76.68	76.96	74.23	78.57	78.20	76.09
TiO_2	0.08	0.09	0.14	0.11	0.27	0.39	0.14	0.10	0.10
Al_2O_3	13.20	12.23	12.07	11.79	12.97	13.01	12.48	11.79	12.50
Fe_2O_3	0.42	0.75	0.61	0.81	0.73	1.66	1.09	0.14	0.18
FeO	0.49	0.44	0.65	0.24	0.36	0.85	0.36	0.0	0.00
MnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.07	0.30	0.49	0.06	0.0	0.26
CaO	0.44	0.43	0.49	0.35	0.40	0.43	0.33	0.59	1.90
Na_2O	2.26	2.17	1.75	1.84	2.64	2.17	2.10	3.46	4.60
K_2O	5.42	5.20	5.27	4.64	4.51	4.24	4.70	3.97	4.08
P_2O_5	0.19	0.16	0.17	0.17	0.19	0.17	0.16	0.13	0.13
L.O.I.	0.60	0.54	0.62	1.16	0.85	0.97	0.68	1.19	1.27
Total	99.14	100.2	99.77	96.7	100.18	98.61	100.67	99.57	100.11
Trace elements									
Rb	638	651	545	409	292	292	488	160	13
Ba	77	77	98	113	210	251	102	156	29
La	1	8	5	6	6	17	8	5	10
Ce	13	11	13	17	30	48	20	19	28
Y	0	0	0	0	0	0	8	11	13
Cu	0	0	4	0	0	0	0	0	0
Zn	14	20	25	23	5	12	36	0	0
Zr	62	63	85	74	132	168	87	71	54
Sr	38	38	38	48	51	54	95	126	82
Ga	21	19	16	16	16	16	17	13	11
Co	0	0	0	0	4	4	1	0	0
Ni	2	3	3	5	4	8	3	0	2
Cr	17	20	60	43	34	28	17	6	9

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Table 1: Continued

		Aplite		
	AS101	AS102	AS103	AS104
Major elements				
SiO_2	76.88	79.18	78.27	78.62
TiO_2	0.08	0.09	0.10	0.09
Al_2O_3	12.59	11.30	13.37	12.43
Fe_2O_3	0.36	0.18	0.16	0.21
FeO	0.35	0.0	0.0	0.0
MnO	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.0
CaO	0.67	0.37	0.44	0.39
Na_2O	4.15	5.73	6.67	6.36
K_2O	3.23	0.15	0.29	0.42
P_2O_5	0.14	0.11	0.15	0.12
L.O.I.	1.08	1.38	1.03	0.64
Total	99.63	98.49	99.32	100.44
Trace elements				
Rb	162	103	37	15
Ba	96	130	26	19
La	3	5	9	6
Ce	13	14	20	16
Y	17	12	15	16
Cu	0	0	0	0
Zn	2	1	0	0
Zr	73	76	59	69
Sr	101	155	69	70
Ga	16	13	13	14
Co	0	0	0	0
Ni	1	1	0	0
Cr	18	20	5	27

Pelites

	AS105	AS106	AS107	AS108	AS109	AS110	AS111	AS112	AS113
Major elements									
SiO_2	61.56	67.23	58.39	65.85	57.87	53.86	63.62	59.53	61.52
TiO_2	0.85	0.74	0.93	0.93	0.97	1.04	0.93	0.96	0.95
Al_2O_3	20.54	17.62	21.14	17.73	21.90	24.83	18.95	22.98	20.45
Fe_2O_3	0.70	1.23	3.93	1.95	1.93	3.90	3.78	0.94	2.30
FeO	3.74	3.46	3.34	3.78	5.25	3.58	4.37	4.81	4.88
MnO	0.08	0.07	0.11	0.05	0.05	0.03	0.10	0.07	0.15
MgO	1.32	1.23	1.90	1.32	2.03	2.20	1.86	1.61	1.90
CaO	1.42	0.70	1.15	0.90	1.21	1.52	0.28	1.11	1.22
Na_2O	2.12	0.39	0.76	0.42	1.23	0.81	0.32	0.97	0.43
K_2O	4.73	3.67	5.33	3.88	4.53	4.65	3.67	4.20	3.84
P_2O_5	0.13	0.12	0.18	0.14	0.16	0.17	0.13	0.15	0.20
L.O.I.	1.82	1.98	1.88	2.09	2.41	2.31	1.81	2.29	1.90
Total	99.01	98.44	99.04	99.04	99.54	98.90	99.82	99.62	99.74
Trace elements									
Rb	243	168	239	187	218	238	185	194	199
Ba	752	600	807	553	576	692	515	707	510
La	33	36	42	39	29	39	33	37	33
Ce	73	74	84	79	75	88	59	90	68
Y	11	15	13	20	13	14	15	17	16
Cu	0	7	16	17	28	26	15	12	17
Zn	22	80	78	36	115	95	81	104	95
Zr	184	258	197	307	229	150	232	172	210
Sr	159	211	221	190	336	462	54	432	106
Ga	24	23	27	22	28	31	25	31	24
Co	20	18	17	15	20	23	14	21	19
Ni	24	24	29	32	38	42	35	30	46
Cr	98	87	109	136	136	122	103	118	104

cntd

Table 1: Continued

	AS114	AS115	AS116	AS117	AS118	AS119	AS120	AS121	AS122
Major elements									
SiO_2	63.28	60.30	63.93	65.30	60.70	63.38	57.45	62.24	60.40
TiO_2	0.93	0.97	0.72	0.91	0.83	0.86	0.89	0.95	0.99
Al_2O_3	19.48	21.11	18.93	19.46	22.10	19.82	22.89	20.27	21.75
Fe_2O_3	3.18	2.31	3.16	1.83	0.87	2.00	3.00	3.71	3.80
FeO	3.67	4.51	1.83	3.34	6.10	4.37	1.31	3.15	3.73
MnO	0.0	0.0	0.0	0.0	0.0	0.01	0.07	0.0	0.02
MgO	1.68	1.59	1.72	1.40	1.33	1.48	1.87	1.42	1.47
CaO	1.21	0.70	1.33	0.90	0.66	1.09	0.66	0.54	0.30
Na_2O	0.61	0.22	0.79	0.37	0.12	0.44	0.62	0.52	0.12
K_2O	3.50	3.96	3.56	3.57	4.09	3.57	6.99	3.65	4.04
P_2O_5	0.16	0.13	0.11	0.11	0.17	0.14	0.16	0.14	0.14
L.O.I.	1.88	2.99	2.79	1.92	2.49	2.49	2.87	2.97	2.71
Total	99.58	98.79	98.87	99.11	99.40	99.65	98.78	99.56	99.47
Trace elements									
Rb	191	203	n.d	188	265	169	303	172	168
Ba	442	560	"	479	475	189	598	545	452
La	33	28	"	33	38	29	47	35	36
Ce	61	55	"	76	73	69	99	82	85
Y	21	18	"	15	0	17	10	19	24
Cu	35	27	"	11	36	21	8	25	8
Zn	74	91	"	81	73	86	60	71	43
Zr	242	214	"	221	175	198	148	234	257
Sr	94	89	"	440	129	110	639	222	143
Ga	24	26	"	22	25	23	28	25	19
Co	21	21	"	17	17	14	8	17	12
Ni	52	47	"	35	45	28	18	34	17
Cr	107	106	"	97	114	98	111	95	54

	AS123	AS124	AS125	AS126	AS127	AS128
Major elements						
SiO_2	44.73	56.38	64.97	57.85	58.90	64.40
TiO_2	0.90	0.98	0.93	0.88	0.76	0.85
Al_2O_3	40.12	25.43	18.68	20.75	18.64	15.32
Fe_2O_3	0.91	3.29	1.95	1.40	1.94	1.29
FeO	4.12	4.40	4.37	6.90	5.50	5.81
MnO	0.0	0.0	0.0	0.18	0.22	0.10
MgO	1.49	1.46	1.22	2.82	3.05	2.72
CaO	0.14	0.20	0.48	0.74	7.06	6.13
Na_2O	0.44	0.08	0.44	0.0	0.0	0.09
K_2O	3.12	5.23	3.37	5.39	2.76	2.39
P_2O_5	0.03	0.09	0.13	0.08	0.10	0.08
L.O.I.	3.09	2.87	2.27	1.84	1.53	0.78
Total	99.09	100.41	98.81	98.83	100.46	99.96
Trace elements						
Rb	277	204	174	314	141	103
Ba	392	590	453	442	417	371
La	31	32	31	30	37	27
Ce	70	70	73	67	66	69
Y	10	19	18	8	19	24
Cu	0	10	22	69	52	43
Zn	32	89	83	116	118	88
Zr	250	244	281	169	158	223
Sr	115	143	97	71	284	228
Ga	41	30	20	27	23	18
Co	14	18	17	27	20	20
Ni	22	35	34	71	66	49
Cr	90	123	93	139	141	146

L.O.I = Lost On Ignition

shales and continental crust but similar to the Connemara pelites which are slightly lower in Si (table 2). Rb is much higher in the Edough pelites but Ni, Cu, Y, Sr, and Co are lower compared to the other pelites, shales and continental crust. The small variation of *c* (0.26-6.26), low *mg* values (0.26-0.45) and the high *al-alk* (27.38-65.19) indicate relatively homogeneous clay-rich original sediments. Particularly relevant is *al-alk* versus *c* (fig. 2) which shows that the pelites not only plot at almost a right angle to the igneous trend line but also largely outside the field of igneous rocks thus excluding significant fresh clastic igneous contributions to the original sediments. Figure 3 shows that the original clay and sheet minerals were not the only major controlling factors over the distribution of most trace elements but much K, Ti, Ga, Zr, Y and to a lesser extent Ba, Rb, Ce, La, and Fe were at least partly added in the clay and sheet minerals. The covariance of *al-alk* and *k* suggests that much of K is added in the clay minerals but the spread of the data towards K-feldspar also indicates that some K was indeed added in detrital K-feldspar as is supported by the plot of *al-alk* versus Rb and Ba which, coupled with figure 4 (A & B), indicate that Ba and Rb were controlled by both clay with sheet minerals and K-feldspar. Clearly while most Ca is coming in plagioclase (fig. 4 C), Sr versus Ca indicates that neither plagioclase nor carbonates were the only control over Sr (fig. 3 and 4). Combination of *al-alk* vs Sr, CaO vs Sr and K_2O vs Sr (fig. 4 F) indicate that much Sr was added in detrital feldspar and little in clay and sheet minerals. La and Ce (fig. 4 G) also probably had a felds-

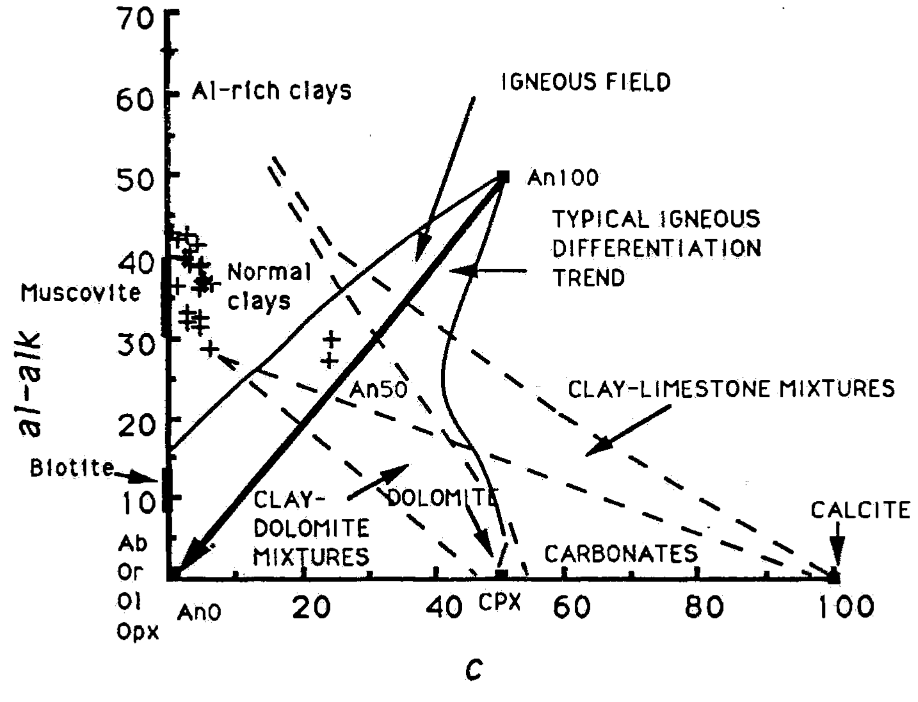

Fig. 2 - Niggli al-alk against c for the Cap de Garde pelites.

The thick arrow is the feldspar variation line (An 0-100) in which K-feldspar (Or) and albite (Ab) plot at zero, and anorthite (An 100) at al-alk=50 and c=50. Muscovite, biotite, olivine (Ol), orthopyroxene (Opx), clinopyroxene (Cpx) and mixtures of various sediments are shown. The field of igneous rocks (also extends to negative *al-alk*) and their trends (parallel to the An 0-100 line) are also shown. Typical sands plot between the feldspar line and the clay region depending on the clay content or between the feldspar line and the carbonate field if calcareous or dolomitic. Please refer to figure 7 for representation of other Edough formations.

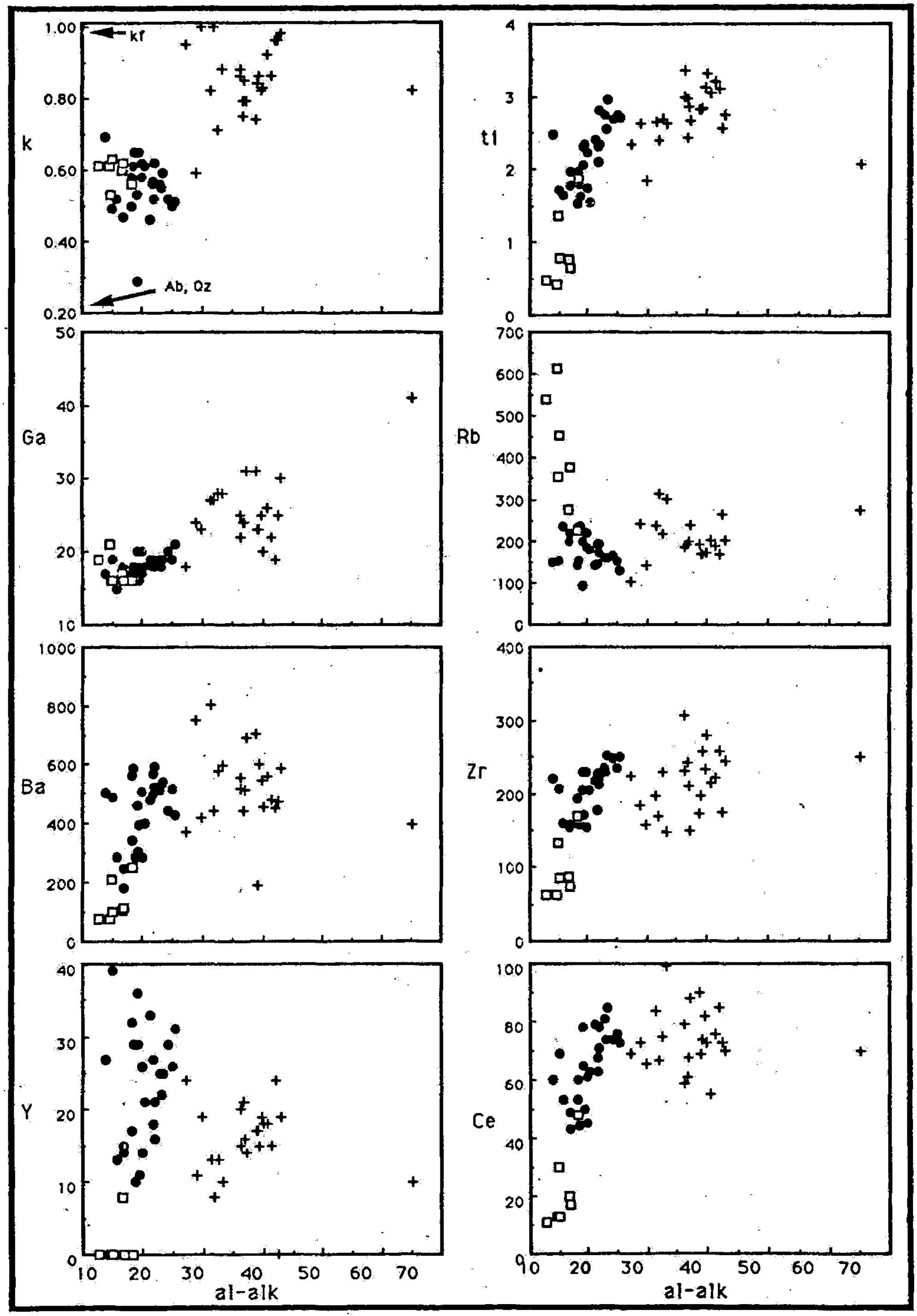

Fig. 3 - Plots of Niggli *al-alk* versus the trace elements, Niggli *ti* and *k*, and Fe_{tot} (as Fe_2O_3) for the pelites and gneisses.

K-feldspar (kf) plots at *al-alk*=0 and *k*=1, Anorthite (An) at *al-alk*=50 and *k* = 0, Albite (Ab) and quartz (Qz) at *al-alk*= 0 and *k*=0. Biotite gneisses (filled circles), muscovite gneisses (open squares), pelites (crosses).

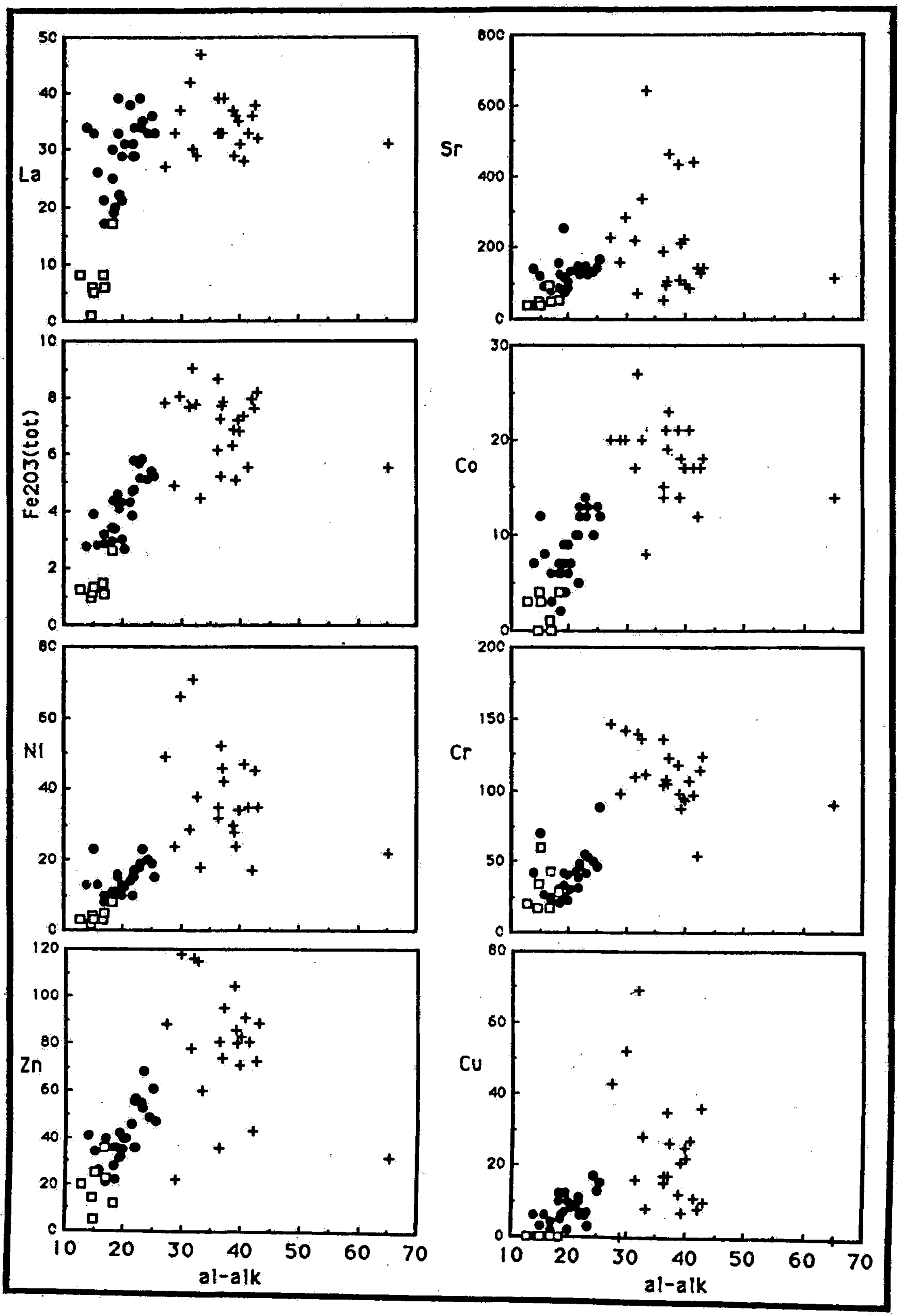
La
0
10
20
30
40
50
Sr
0
200
400
600
800
Fe2O3(tot)
0
2
4
6
8
10
Co
0
10
20
30
Ni
0
20
40
60
80
Cr
0
50
100
150
200
Zn
0
20
40
60
80
100
120
Cu
0
20
40
60
80
10
20
30
40
50
60
70
al-alk
10
20
30
40
50
60
70
al-alk

FIGURE 3

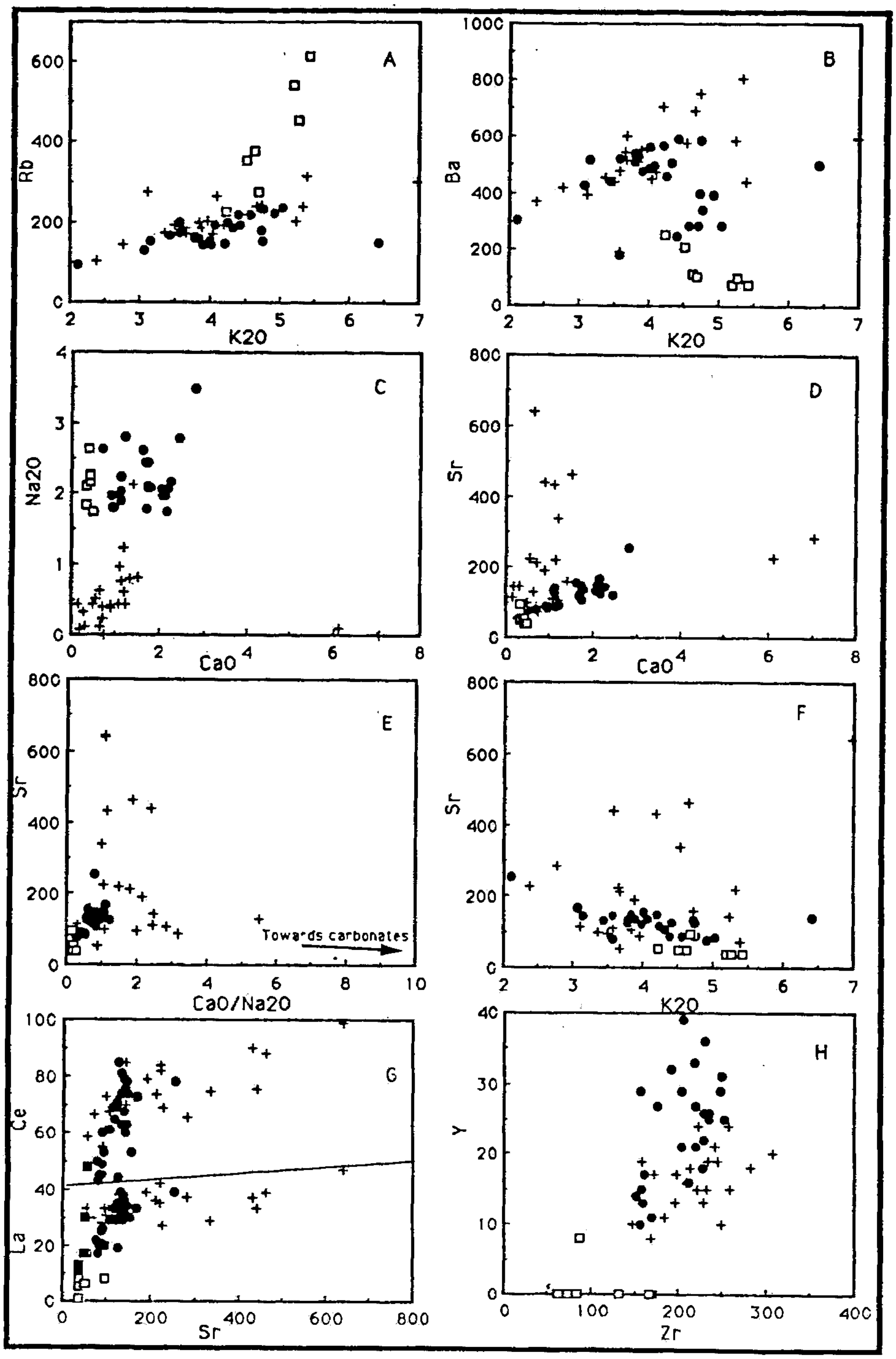

Fig. 4 - Plots of K_2O versus Rb & Ba, CaO versus Na_2O & Sr, CaO/Na_2O versus Sr, K_2O versus Sr, Sr versus La and Ce, and Zr versus Y for the pelites and gneisses.

Symbols as in figure 3 except that in figure 4G Ce and La contents of the muscovite gneisses are represented in filled and open squares respectively.

par-source. Some Zr was controlled by Y-rich zircon (fig. 4 H) but some Y was probably also added in clay minerals rather than in apatite (negative correlation of P_2O_5 versus Y (not shown)).

Particularly intriguing is the co-variance of Cr and Ni and possibly Co with *mg* (fig. 5) which when combined with the poor negative correlation of *al-alk* with Cr and Ni (fig. 3) suggests that Cr and Ni may have been added partly in sheet minerals but also in a small detrital intermediate to mafic (moderate ppm Ni=36±13, ppm Cr=109±21, Co=17±4) igneous component but not in chromite which would give a negative correlation of *mg* versus Cr plot and would not give a positive correlation of Ni and Cr. The pelites are clearly not pelagic in chemical character from their insignificant Mn contents although the occasional association with cherts and reducing conditions (w = 0.33) and the rarity or absence of quartzites suggests deep water isolated from coarse clastic sediments. Although Ni and Co can be influenced by authigenically-derived fluids in pelagic sediments (Krishnaswami, 1976) the fact that Mn is so low suggests that such fluids were not inportant in the present pelites.

Cu, Zn (and Pb, not shown) (fig. 3) were clearly not added to the original clay fractions of the rocks. Their generally low concentrations (table 2) and the absence of S determinations of the rocks makes further comment unwise.

Thus the kyanite-rich pelites were well sorted typical marine sediments as is shown by the small scatter of the data and the low K/Rb (166±24), K/Ba(67±23), and typical La/Ce (0.46±0.05) ratios. The pelites were illite-rich shales (fig. 6) but montmorillonite and kaolinite were probably also important components since the Al-rich kyanite-bearing rocks would shift the points towards the montmorillonite-kaolinite end-member. Any contribution from igneous sources was quantitively unimportant to significantly alter the sedimentary trends of the pelites.

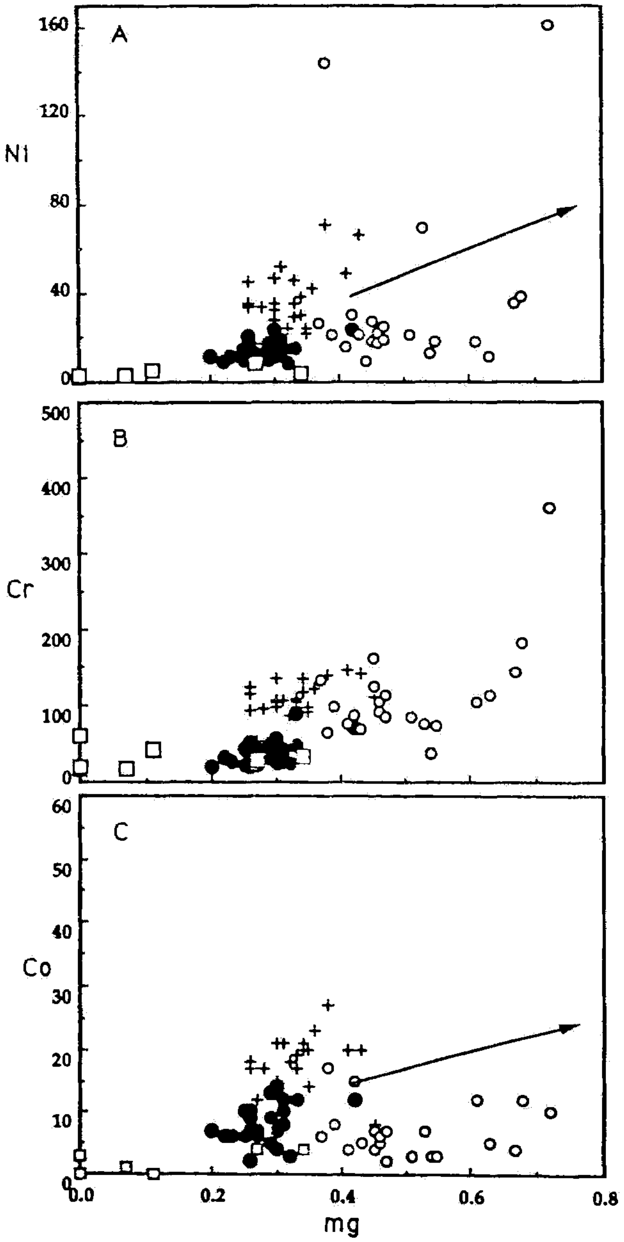

Fig. 5 - Niggli mg against Cr, Ni and Co for the pelites and gneisses.

Symbols as in figure 3 except that the arrow is the best fitting line through 38 Great Valley sandstones (Van de Kamp and Leake, 1985) and the open circles are the Californian arkoses (Van de Kamp *et al.*, 1976).

Table 2 - Comparison of the Cap de Garde Kyanite-bearing pelitic groups with other pelites.

	1		2	3	4
Major elements					
	$\bar{x}$	σ	$\bar{x}$	$\bar{x}$	$\bar{x}$
SiO_2	62.57	4.95	57.31	64.17	61.56
TiO_2	0.91	0.17	1.22	1.02	1.0
Al_2O_3	22.43	4.70	21.47	19.31	18.29
Fe_2O_3	2.49	1.10	2.78	6.64*	7.4*
FeO	4.04	1.05	6.74	-	-
MnO	0.03	0.03	0.16	0.11	0.13
MgO	1.64	0.27	3.00	2.25	2.70
CaO	0.87	0.42	1.41	1.33	4.20
Na_2O	0.60	0.45	1.88	1.23	1.10
K_2O	4.28	0.87	3.77	3.78	3.40
P_2O_5	0.14	0.03	0.26	0.16	0.22
Total	100		100	100	100
Trace elements					
Rb	210	40	160	160	140
Ba	552	110	781	650	580
La	34	4	n.d	n.d	n.d
Ce	75	10	"	"	"
Y	15	5	39	"	"
Cu	16	10	n.d	50	57
Zn	76	26	"	85	80
Zr	219	41	230	210	200
Sr	208	155	196	200	450
Ga	25	4	n.d	20	19
Co	17	3	31	23	20
Ni	33	9	86	55	95
Cr	104	18	102	110	100
K/Rb	166	24			
K/Ba	67	23			
La/Ce	0.46	0.05			

KEY TO TABLE 2

1= average 24 kyanite-bearing pelitic groups, 25 samples for the trace elements.
2= average 85 Connemara pelites, Senior and Leake (1978)
3= Post-Archean Shales, Taylor and McLennan (1985)
4= representative continental crust, Krauskopf (1967)
* = Fe_{tot} as Fe_2O_3
n.d = not determined

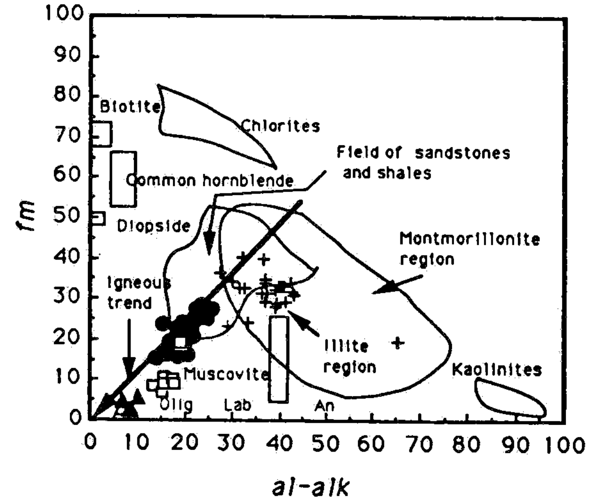

Fig. 6 - Plot of Niggli *al-alk* against *fm* for the pelites (pluses), biotite gneisses (filled circles), muscovite gneisses (open squares), aplites (open triangles), leptynites (filled triangles).

Some common clay and igneous minerals are also shown. The igneous line represents the trend of the Sierra Nevada plutonic suites. Note the cluster of the pelites in the illite region but extending to the montmorillonite and kaolinite region and their perpendicular trends relative to the biotite gneisses which follow an igneous trend.

The application of the garnet-biotite geothermometry of Thompson (1976) and garnet-plagioclase-aluminosilicate-quartz geobarometry of Newton and Haselton (1981) on four pelites from Kef Lakhal, NW of Cap de Garde give values of 600±30 °C and P=7-9kb. These values were further supported by the application of garnet-clinopyroxene thermometry of Dahl (1980) and garnet-clinopyroxene-plagioclase barometry of Perkins and Newton (1981) on the Kef Lakhal amphibolites (Ahmed-Saïd and Leake, 1992) which give a temperature of 650±50 °C and pressure of 8.5kb.

II Gneisses

A major problem is whether the biotite gneisses represent migmatized metasediments formed from the overlying or another pelitic succession or whether the gneisses are arenaceous or igneous rocks. The purpose of this section is to use the geochemistry to establish which alternative is correct. Previously, e.g. Hilly (1962) and Gleizes *et al.* (1988) have proposed that the augen-bearing gneisses were originally igneous and the augen-free varieties were metasediments but the intimate gradation between the two groups and the high grade of metamorphism experienced by the rocks suggest that the textural differences could well be of metamorphic origin leaving open the question of the ultimate origin and whether ortho-or para-gneisses are present. The contacts between the gneisses and the pelites examined so far, if not tectonic, are always sharp which does not suggest the gneisses were derived by migmatization from the overlying pelites. No contact thermal aureole adjoins the gneisses so the field evidence gathered so far does not provide a solution to the origin of the gneisses. The augen muscovite gneisses, which are interlayered with the andalusite-bearing pelites, are well foliated but sometimes reveal a typical igneous massive texture. Field and petrological evidence suggest that the muscovite gneisses are igneous injections, probably of granitic rather than rhyolitic type, synmetamorphically emplaced into the pelites which were already undergoing medium grade metamorphism and this would explain the absence of a distinct metamorphic aureole.

27 augen to augen-free biotite gneisses were sampled with 2-3 kg of rock to ensure adequate sample size. Nine were sampled from Cap de Garde (fig. 1) because these rocks are practically augen-free and were previously classified as para-gneisses (e.g. Gleizes *et al.*, 1988). The large masses of two feldspar leucosomes have been avoided as they clearly represent metamorphic segregations and are unlikely to reveal the origin of the protolith out of which they segregations and are unikely to reveal the origin of the protolith out of which they segregated. Seven muscovite gneisses, three leptynites and three aplites were also sampled and analysed (table 1).

Mineralogy

The biotite gneisses are well foliated rocks and usually contain abundant augen of K-feldspar megacrysts but grade to augen-free varieties. Generally there is 15-60% biotite (XMg (ions Mg/(Mg+Fe)=0.30-0.40)), 25-35% quartz, 15-30% Or_{80-90} K-feldspar, 10-25% An_{10-45} plagioclase, 0-10% garnet (XMg (ions Mg/(Mg+Fe) = 0.08-0.25)) but fibrolite, andalusite, muscovite, amphibole, tourmaline together with accessory apatite and zircon can also occur. The augen are megacrysts (average 2.5x1.8cm but up to 10x8.5cm) of pertithic and partly sericitized K-feldspar which can include rare muscovite, biotite, tourmaline, albite, quartz, zircon, apatite and secondary carbonates. The augen muscovite gneisses are essentially made of 40-60% quartz, 20-40% An_{5-20} plagioclase, 20-40% Or_{80-95} K-feldspar, 2-8% muscovite and tourmaline with occasionally a little biotite. The leptynites are 10-100 cm thick well foliated slabs interlayered with the biotite gneisses and are mineralogically and chemically similar to them except that the leptynites are poorer in biotite. The aplites, which form small domes up to 1.5 x 4 m in diameter or as thin 10-20 x 100-400 cm veins cross-cutting the biotite gneisses, are rare trondhjemites consisting of 50-80% quartz and 20-45% albite with minor amount of tourmaline, very rarely primary muscovite and biotite. Preliminary PTX calculations of the biotite gneisses using the biotite-garnet thermometry of Thompson (1976) and garnet-aluminosilicate-quartz barometry of Newton and Haselton (1981) give values of 750-850 °C and 4-5Kb respectively; sufficiently high for partial melting or igneous crystallization.

Geochemistry

Determining the protoliths of gneisses such as those of the Edough massif is difficult because many of their primary mineralogical and chemical features may be obliterated by partial melting or metasomatism if they were originally sediments (Cooper and Field, 1977; O'Hara and Yarwood, 1978; Pride and Muecke, 1980; Rollinson and Windley, 1980; Sheraton and Black, 1983; Ahmed-Saïd and Leake, 1990).

Geochemically it is necessary to show that the variation in composition in the suite was either controlled by igneous processes (i.e. the trends follow distinctive igneous fractionation trends) or sedimentary processes (i.e. the trends follow those shown by sediments). Previous studies (e.g. Van de Kamp *et al.*, 1976) have emphasized that many variations typically shown by igneous rocks; e.g. declining Fe, Mg, Al, Ti, Ca, Cr, Ni, etc. with increase in Si are also found in sedimentary suites with Si often being mobile and are therefore not helpful in discriminating between the two possible origins. The abundance levels of certain elements have been proposed as a discriminator between ortho and para origins (e.g. Shaw, 1972) but on the whole this approach has been unsuccessful because both igneous and sedimentary rocks vary widely in composition but it may be helpful with respect to a limited number of elements. More fundamental is to match variations to a characteristic of either igneous or sedimentary variation and for that purpose, the Califomain arkoses (Van de Kamp *et al.*, 1976), the Cap de Garde Kyanite-bearing pelites (present study) are plotted with the gneisses. The best fitting lines showing the trends of the Great Valley sandstones from California (Van de Kamp and Leake, 1985) are also shown for comparison whenever the data permits.

The chemistry, Tables 1 and 3, shows that the gneisses were either broadly granitic-rhyolitic or arkosic with detrital quartz, feldspar and mica. Characteristic and distinctive features of igneous variation is a decline of Fe, Mg, Ti, Ca, Cr, Ni, Co, and sometimes Zr with fall in MgO/(MgO+Fe-tot+MnO) as is denoted for instance by Niggli *mg* and this is generally related to falling temperature. These elements are mainly immobile under most metamorphic conditions even up to significant degrees of partial melting (Ahmed-Saïd and Leake, 1990).

Table 3 - Comparison of the Edough gneisses with possible protoliths.
(recalculated to 100% on volatile-free basis).

	1		2		3		4	
Major elements								
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
SiO_2	71.30	2.41	77.98	1.50	77.92	1.06	79.95	0.45
TiO_2	0.59	0.16	0.17	0.11	0.09	0.01	0.09	0
Al_2O_3	15.04	0.90	12.70	0.53	12.43	0.44	12.57	1.03
Fe_2O_3	0.85	0.30	0.87	0.40	0.24	0.11	0.19	0.02
FeO	3.04	0.93	0.49	0.20	0.12	0.20	0.0	-
MnO	0.05	0.02	0	-	0	-	0	-
MgO	0.87	0.30	0.13	0.19	0.09	0.13	0	-
CaO	1.66	0.59	0.42	0.06	1.06	0.73	0.41	0.04
Na_2O	2.22	0.40	2.16	0.29	4.12	0.57	6.36	0.47
K_2O	4.22	0.80	4.91	0.44	3.80	0.46	0.30	0.13
P_2O_5	0.16	0.02	0.17	0	0.13	0	0.13	0.02
Total	100.0		100.0		100.0		100.0	
Trace elements								
Rb	177	36	473	149	112	85	52	45
Ba	440	117	132	69	94	63	59	62
La	29	6	7	5	6	3	7	2
Ce	64	12	21	13	20	7	17	3
Y	23	8	0	-	14	3	15	2
Cu	8	4	0	-	0	-	0	-
Zn	41	12	19	10	0	-	0	-
Zr	202	34	96	39	66	10	68	8
Sr	126	36	51	20	103	22	98	49
Ga	18	1	17	2	14	2	13	0
Co	8	3	2	2	0	-	0	-
Ni	14	4	4	2	1	1	0	-
Cr	39	15	31	16	11	6	18	11
K/Rb	198	41	107	30	210	47	103	114

	5	6	7	8		9	10
	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	σ	$\bar{x}$	$\bar{x}$
SiO_2	73.95	74.24	72.46	71.84	4.26	80.23	84.93
TiO_2	0.28	0.22	0.37	0.31	0.30	0.31	0.27
Al_2O_3	13.47	13.56	13.93	14.43	1.98	9.05	5.17
Fe_2O_3	1.50	1.26	0.83	1.22	1.21	1.56	1.17
FeO	1.13	0.76	1.68	1.65	1.42	0.73	0.32
MnO	0.06	0.03	0.06	0.05	0	0.21	0.01
MgO	0.40	0.32	0.53	0.72	0.77	0.52	0.18
CaO	1.16	1.14	1.34	1.85	1.40	2.81	5.96
Na_2O	3.60	3.01	3.10	3.71	1.09	1.56	0.48
K_2O	4.37	5.39	5.49	4.10	1.44	2.91	1.42
P_2O_5	0.07	0.07	0.18	0.12	0	0.11	0.09
Total	100	100	100	100		100	100

1= average 27 biotite gneisses (1 analysis is taken from Hilly, 1962)
2= average 7 muscovite gneisses
3= average 3 leptynites
4= average 3 aplites
5= average 670 Rhyolites (Le Maitre, 1976a)
6= average calc alkali rhyolites (Nockolds, 1954)
7= average calc alkali granites (Nockolds, 1954)
8= average 2485 granites (Le Maitre, 1976a)
9=average Arkose (Pettijohn, 1963)
10= average sandstone (Pettijohn, 1963)

The plots of *mg* against Ni, Cr, Co (fig. 5), *al-alk* against *c* and *mg* (fig. 7A-B) and Rb/Sr against Sr (fig. 8) all show that the gneisses vary in composition in a manner more consistent with igneous fractionation than with sedimentary variation. Although some of the plots show overlap of the pelites with the range of the gneiss variation (e.g. K_2O versus Ba) the pelites do not follow the igneous fractionation trends shown by the gneisses nor do the gneisses follow the sedimentary trends established for typical arkoses and sandstones by Van de Kamp and Leake (1985) as indicated on figure 7. This is taken to indicate an igneous origin for the gneisses. In figure 5 the biotite and muscovite gneisses have consistently lower Cr, Co and Ni than the pelites at the same *mg* value and even correcting for the different abundances of SiO_2 in the gneisses from the pelites changes the differences between the Cr, Ni and Co values insignificantly. This ower abundance of Cr, Ni and Co in acidic igneous rocks compared with pelites, semipelites and arkosic sediments is well established (Leake and Singh, 1986). The igneous trend of the Cr and Ni versus *mg* do not smoothly agree with any trend in the pelites.

In figure 3 the gneisses and the pelites plot in two separate fields separated at *al-alk*=26. Some of the plots (e.g. Fe $_{tot}$, La, Ni, Co, Zn, Cu) show trends for the gneisses which are dissimilar from those shown by the pelites even if the gneisses are garnetiferous . These two points are again consistent with an igneous origin for the gneisses.

An igneous origin was further confirmed by the examination of more than 700 crystals of zircon and about 3000 of apatite from the gneisses which do not show any sign of pitted or abraded surfaces. All the zircons examined are clear intact non-metamict euhedral crystals which are virtually inclusion-free and two thirds of the apatite are euhedral and the rest are sub-euhedral to subrounded but with intact surfaces. These criteria suggest that the zircon and apatite are igneous being crystallized in situ rather than being transported and hence favour an igneous origin for the gneisses. It is very unlikely that all the zircons and apatites could have been totally recrystallized during metamorphism nor could they have all been protected as inclusions in other minerals during transport. The rarity of fibrolite or andalusite is entirely consistent with a gene-

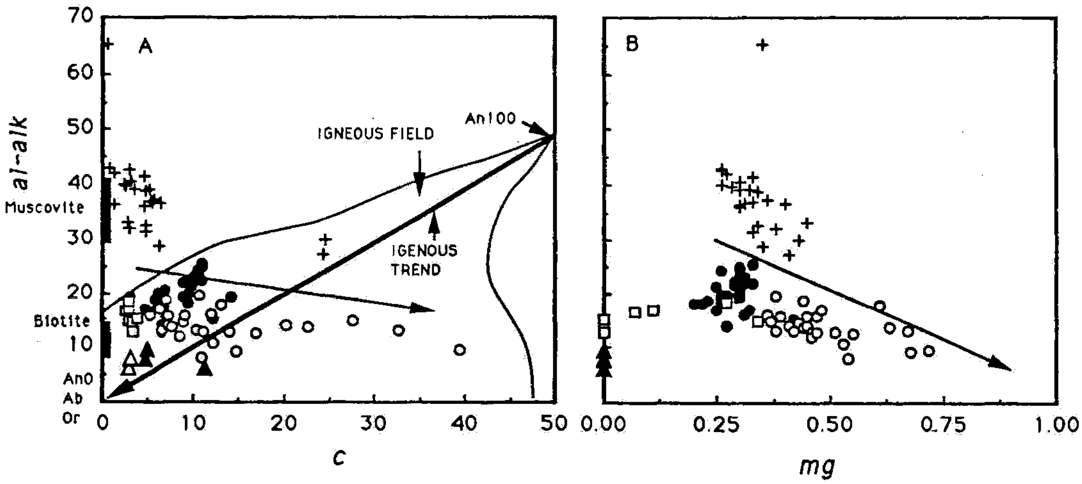

Fig. 7 - Plot of Niggli *al-alk* vs *c* (A) and *mg* (B) for the gneisses.

The igneous trend in (A) (Thick arrow) and the positions of albite and orthoclase are plotted. The thin arrow is the best fit line through 38 Great Valley sandstones (Van de Kamp and Leake, 1985). Note the Cap de Garde pelites (crosses), the Californian arkoses (open circles), Van de Kamp *et al.* (1976) and the Great Valley sandstones have different trends to the biotite and muscovite gneisses. The trends of the leptynites and aplites are not clear due to their small sample size. Symbols as in figure 6.

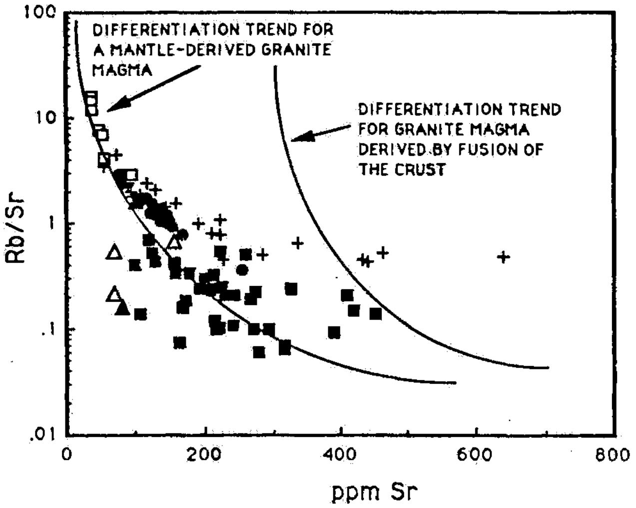

Fig. 8 - Plot of Sr versus Rb/Sr of Peterson (1980) for the pelites, biotite and muscovite gneisses, aplites, leptynites, and the Great Valley sandstones (filled squares).
Other symbols as in figure 6.

ral igneous origin in which some inclusions of pelites, sometimes partly digested, account for the fibrolite and andalusite.

The K/Rb ratios of the biotite gneisses and associated leptynites at 198 ± 41 and 210 ± 47 are low for crustal matter (average 249, Taylor and Mc Lennan, 1981) but both are within the normal range of Heier and Billings (1970). The muscovite gneisses and aplites are even lower and fall outside the normal range. As Rb is a highly incompatible element low K/Rb ratios do not suggest that the rocks have suffered either significant partial melting with loss of any of the melt or high grade metasomatism of the type identified by Sheraton *et al.* (1973) in the granulite facies of the Lewisian rocks of NW Scotland. Overall, the low K/Rb ratio favours isochemical metamorphism of an orthogneiss low in K/Rb and this is supported by the low levels of Cr, Ni, Co, Mg and Ti. Thus figure 9 shows that the gneisses, the aplites and the leptynites fall in the calc alkaline field of Irvine and Baragar (1971) and this is supported by SiO_2 versus Cr and FeO_{tot}/MgO, and FeO_{tot}/MgO versus TiO_2 and FeO_{tot} of Miyashiro (1974) and Miyashiro and Shido (1975) (not shown) which therefore suggests that the parent magmas have calc-alkaline affinities.

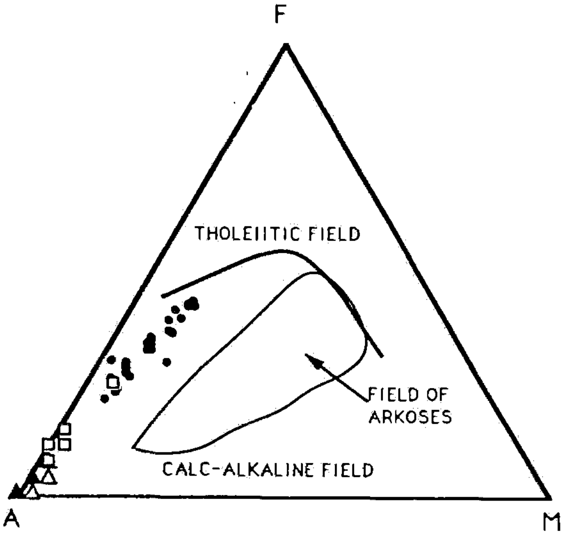

Fig. 9 - AFM ternary diagram showing the tholeiitic-calc-alkaline fields of Irvine and Baragar (1971)
The field of arkoses is after the data of Van de Kamp *et al.* (1976). Symbols as in figure 6 where appropriate.

Rb-Sr isotopic data

Seven biotite gneisses, six from the peninsula of Cap de Garde and one from Sidi Mohammed between Annaba and Seraidi (fig. 1) have been selected for whole rock Rb-Sr analysis. The main aims were to approximately date the gneisses and then use the isotopic data to derive their ortho or para origin. The data as shown in table 4 and plotted in figure 10 define an age of 199 ± 30 (2σ) MA (MSWD = 43) and give an initial $(^{87}Sr/^{86}Sr)_{199MA}$ of 0.71448 ± 19. Sample AS70, being relatively altered (sericitized plagioclase and K-feldspar and chloritized biotite), plots away from the best fitting isochron and hence was excluded from age calculations (the age of 213 Ma could be derived using all the seven data set). It is very interesting to note that the augen-bearing gneiss (AS85) collected some 20 km away from the rest of the

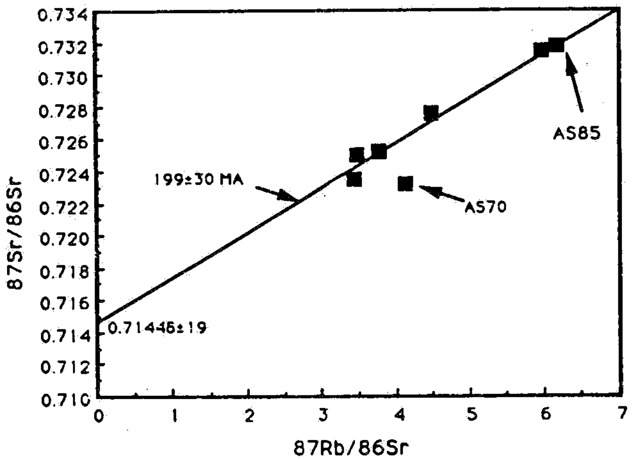

Fig. 10 - Plot of $^{87}Rb/^{86}Sr$ versus $^{87}Sr/^{86}Sr$ for the biotite gneisses.

samples has a very similar Rb-Sr isotopic signature to the practically augen-free Cap de Garde gneisses thus supporting the evidence deduced from the petrology and major and trace element geochemistry that all the Edough biotite gneisses whether augen-bearing or not, have a similar origin.

The initial $(^{87}Sr/^{86}Sr)_{199MA}$ at 0.71448 ± 19 excludes the gneisses from being pure mantle-derived magmatic rocks but falls within the range of crustally contaminated igneous rocks as well as metasedimentary rocks. The Rb-Sr isotopic data are therefore ambiguous in confirming the para or ortho origin of the gneisses although the results do not contradict the proposed crustally contaminated calc-alkaline igneous rocks as an origin for the biotite gneisses. In view of the strongly deformed and highly metamorphosed nature, the value of 199 ± 30MA cannot be the true age of the gneisses as they are overlain by less deformed Paleozoic (Silurian-Devonian) metapelites (Ilavsky and Snopkova, 1987) and by transgressive presumed Liassic flysch (Vila, 1970). The age can only reflect a major tectonic event at which the Rb-Sr isotopic values were reset, probably at about 550 ± 50 °C. Gleizes et al. (1988) noted that the compressional SE shearing and the inverse faulting which are well developed in the SE and NW of massif respectively are post Liassic events and hence are post the major N 140E flat shearing tectonic event. It is very unlikely that the proposed Liassic trangression could affect the Rb-Sr isotopic signature of the gneisses and therefore the 199 ± 30MA value probably reflects the age of the N140E flat shearing tectonic event which is extremely well developed in Cap de Garde and consequently suggests an Alpine rather than Hercynian age for the Edough major tectonic event.

Table 4 - Rubidium- Strontium isotopic analyses of the Edough biotite gneisses.

Samples	ppmRb	ppmSr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
AS67	173.6	132.7	3.79281	0.72520
AS68	180.02	116.06	4.50188	0.72755
AS70	168.9	118.4	4.13482	0.72316
AS72	162.5	136.4	3.45354	0.72351
AS77	194.5	161.4	3.49385	0.72502
AS78	197.2	95.7	5.97437	0.73144
AS85	466.6	218.7	6.18791	0.73177

Strontium and rubidium were analysed on a VG-Isomass 54E and VG Micromass MM30 respectively, after chemical separation by standard cation-exchange chromatography; concentration determination was by isotope dilution. Powdered samples weighing about 10 mg were used. Strontium isotopic ratios were corrected for mass fractionation during mass spectrometry by normalising $^{86}Sr/^{88}Sr$ ratios to value of 0.1194, and λ Rb was taken as $1.2 \times 10^{-11} a^{-1}$. Data are reported relative to a NBS987 $^{87}Sr/^{86}Sr$ ratio of 0.71022.

Conclusion

The Cap de Garde kyanite-bearing pelites were well sorted illite-rich deep water sediments which included minor mafic clastic material with the clay and sheet minerals being the main control over many of the trace elements. These pelites subsequently underwent medium temperature high pressure metamorphism (600 ± 30 °C at 7-9kb).

The isochemically metamorphosed biotite gneisses, whether augen bearing or not, have the same whole rock chemistry and exhibit the same geochemical characteristics and trends indicating the same origin. Major and trace element trends coupled with zircon and apatite crystal studies indicate calc-alkaline acidic igneous protoliths for the gneisses and this conclusion is not in contradiction with Rb-Sr isotopic studies. Although granitic rocks could also contain garnet, the presence of almandine in the biotite gneisses (maximum of 8%) and the occasional association with fibrolite and andalusite are clearly two major drawbacks against a purely igneous origin although the presence of partly digested country rock xenoliths and sheets could account for garnet and the aluminosilicates. More detailed field studies should provide further valuable information. The biotite gneisses experienced high temperature (T=750-850 °C) and low pressure (4 ± 1kb) metamorphism. The 199 ± 30 MA value is believed to represent the age of the N140E Edough major shearing tectonic event hence indicating a dominantly Alpine phase. The muscovite gneisses were probably well differentiated syntectonically emplaced granites and the aplites were trondhjemites but due to their small sample size, the ultimate origin of the leptynites remains uncertain but they probably have a similar origin as the biotite gneisses.

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