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Metadiorites in the Dora-Maira polymetamorphic basement (Cottian Alps)

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ABSTRACT. — Previously unreported bodies of metamorphic diorite occur in the polymetamorphic basement of the north-central part of the Dora-Maira Massif in Val Pellice (Cottian Alps), their size being no more than 100 m.

The relation of these intrusives to the country rock is obscured by low-angle tectonics; the rock may be either massive or schistose, and displays abundant melanocratic inclusions, as well as mafic and aplitic dikes; when unfoliated, it preserves igneous textural features, whereas the mineralogy was re-equilibrated during Alpine-age metamorphism. The paragenesis includes quartz, albite, zoisite and/or clinozoisite, amphibole, chlorite, white mica ± biotite and garnet; accessory minerals are rutile and/or sphene, apatite, zircon and ore. Major element chemistry confirms the classification of the intrusives as mainly diorite. The REE patterns show uniform downward-convex trend for HREE with LREE enrichment, no or slight negative Eu anomaly and no substantial fractionation of HREE. On the whole, chemical and geochemical data suggest that these rocks formed by variable degrees of partial melting of amphibolitic sources.

Two amphiboles were analysed by the $^{40}Ar/^{39}Ar$ method. The spectra are internally discordant and probably have no immediate chronological value. The K/Ar ages differ (63-84 Ma). The Ca/K ratios are also erratic. We therefore suppose that the step-ages reflect irregularities in the individual microstructural domains, rather than a geochronological memory. However the presence of step-ages around 16 Ma in both samples suggests a final disturbance in the Lower-Middle Miocene.

Similar rocks in nearby Val Chisone intrude the Carboniferous sequence and, on general geological grounds, are thought to be Permian. The crowding of pre-Alpine diorite bodies into a small area, both in a supposedly allochthonous basement unit and in the supposedly autochtonous terrains of the Pinerolo inlier, calls for critical assessment of the nappe tectonics model for the Dora-Maira Massif, especially the existence of large-scale displacements.

Key words: diorites, Hercynian plutonism, Alpine metamorphism, Ar/Ar dating, Dora-Maira Massif.

Introduction

The data in the literature on intrusives and their metamorphic products referable to the Hercynian magmatic cycle in the Western Alps (rewiev in D'AMICO C., 1974; BONIN B. et al., in press) reveal a distinct prevalence of acid terms over intermediate and basic lithologies. Moreover, in the Penninic Domain, the latter lithologies (Fig. 1) appear to characterise only Briançonnais Units (Internal Zone and Ambin Massif) or Briançonnais-like Units (« Serie Grafitica » of the Dora-Maira Massif), and their intrusion level is very high.

In the Internal Zone of the Great St. Bernard- Briançonnais Zone, which is the Aosta Valley equivalent of the Vanoise-Mt. Pourri Zone (BOCQUET J., 1974), the Cogne-Val Savaranche pluton is in fact composed of prevalent tonalites with minor granodiorites,

diorites and gabbros, which were probably intruded in Permian times (NOVARESE V., 1894, 1909; FENOGLIO M., RIGAULT G., 1957, 1959, 1962; AMSTUTZ A., 1962; GRASSO E., 1974).

In the Ambin Series (Ambin Massif), metadiorites associated with aplitic gneisses have been reported by CALLEGARI E. et al. (1980), and small metagabbroic masses have also been described by POGNANTE U. et al. (1984).

If we leave aside the small Guglietta mass (Vallone Giulian Cruello) in upper Val Pellice, identified by the authors of the Pinerolo Sheet of the geological Map of Italy (1913), dioritic gneisses in the broad sense have so far only been described for the Dora-Maira Massif within the (Permo)-Carboniferous cover exposed in the « Pinerolo Tectonic Half-Window » (FRANCHI S., NOVARESE V., 1895, ZANETTIN E., 1964; VIALON P., 1966; MICHARD A., 1967; ZANETTIN LORENZONI E., 1967). The Briançonnais affinity of this cover has been accepted by MICHARD A. (1967), OGNIBEN L. et al. (1975) and BORGHI A. et al. (1984).

New detailed surveys have led to the discovery in the Pellice-Angrogna ridge of several diorite bodies within the micaschists of the polymetamorphic basement of the Massif (Fig. 2).

This paper describes the petrographic and geochemical features of these rocks and discusses their geological implications as far as the reconstruction of the structure of the Dora-Maira massif is concerned.

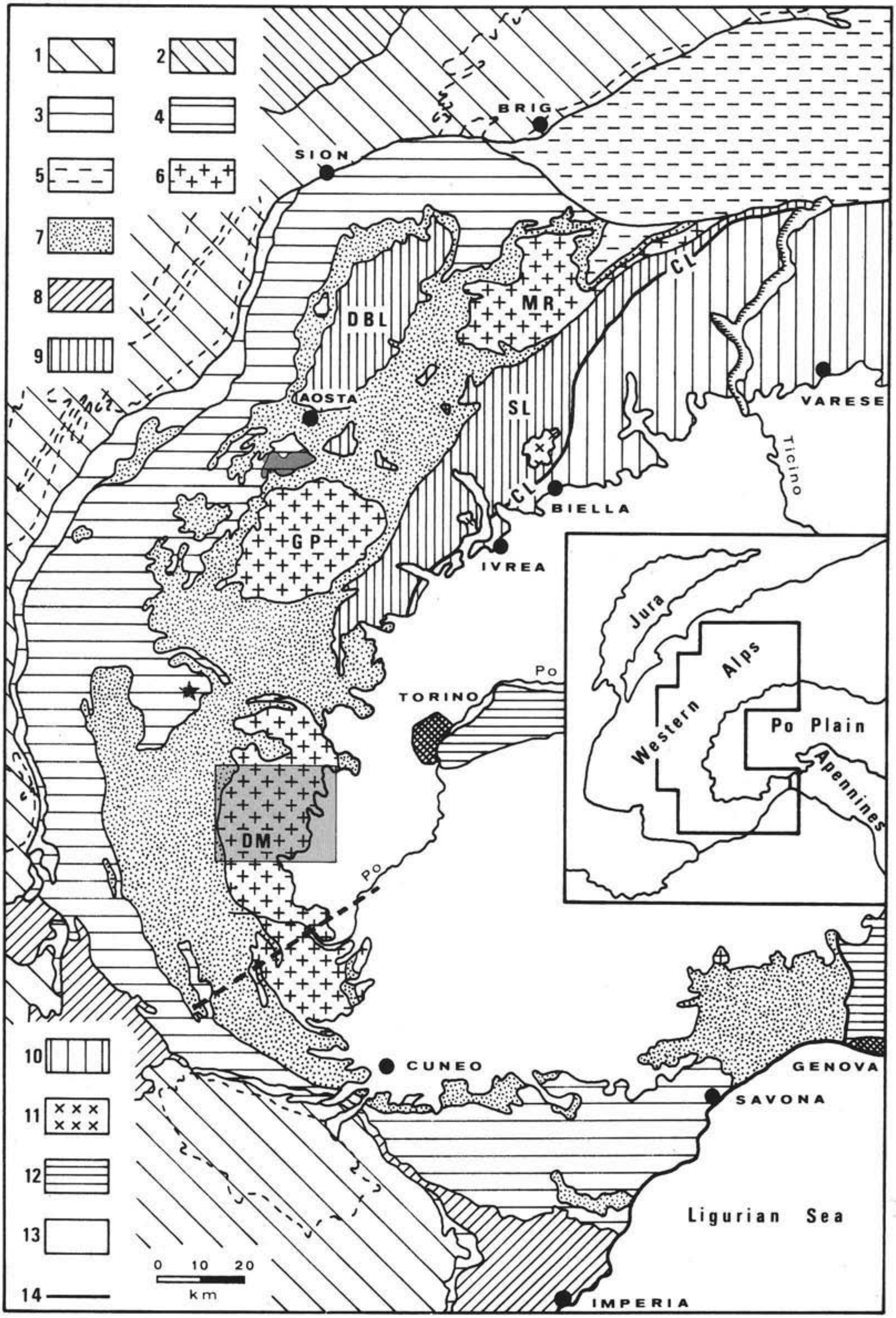
Regional geological setting

The Dora-Maira Massif is a Penninic unit made of continental crust. It consists of an upper member formed of pre-Carboniferous metasediments and metabasites, and a lower member composed of probably (Permo)-Carboniferous metasediments. Both members contain metagranitoids with granite to tonalite chemistry (VIALON P., 1966; MICHARD A., 1967; ZANETTIN LORENZONI E., 1967; BORTOLAMI GC., DAL PIAZ G.V., 1970; BORGHI A. et al., 1984).

A « Lepontine » metamorphic re-equilibration in the greenschist facies may be observed in all these lithologies. Eclogite relics of probably early-Alpine age are locally preserved in the metabasites (STELLA A., 1895, 1896; FRANCHI S., 1900; COMPAGNONI R., SANDRONE R., 1981; SACCHI R. et al., 1983; POGNANTE U., 1984; BORGHI A. et al., 1984, 1985; POGNANTE U., SANDRONE R., submitted). Moreover, assemblages including chloritoid, zoisite, phengite, paragonite, kyanite, garnet and rutile, are reported in the metasediments (GRILL E., 1925; VIALON P., 1966; BORGHI A. et al., 1984, 1985). An unusual paragenesis containing coesite and pyrope has recently been described in the central portion of the Massif (CHOPIN C., 1984).

By contrast with the well-documented picture for the other internal crystalline massifs of Monte Rosa (BEARTH P., 1952; DAL PIAZ G.V., 1971) and Gran Paradiso (COMPAGNONI R. et al., 1974; DAL PIAZ G.V., LOMBARDO B., 1986 and bibliography), the Dora-Maira Massif displays blurred evidence of a pre-Alpine metamorphic event (COMPAGNONI R., SANDRONE R., 1981; BORGHI A. et al., 1984, 1985; SANDRONE R. et al., 1986; SANDRONE R., submitted). The sedimentary protoliths in the pre-Carboniferous basement are mainly represented by pelites with subordinate, more

Fig. 1. — Structural sketch-map of Western Alps with location of metadioritic bodies in the Penninic Domain (grey rectangle: Dora-Maira massif in Fig. 2).
1: Dauphinois-Helvetic Domain (dashed line: external crystalline massifs); 2: Prealps; 3: Subbriançonnais Zone; 4: Briançonnais Zone (grey: pluton of Cogne-Val Savaranche; star: metadiorites in Ambin Massif); 5: Sempione-Ticino Nappes and Camughera-Moncucco Zone; 6: Internal crystalline massifs (MR = Monte Rosa, GP = Gran Paradiso, DM = Dora-Maira); 7: Piedmontese Zone, Versoyen, Montenotte and Sestri-Voltaggio Units; 8: Alpine Helminthoid Flysch of Ubaye-Embrunais and Liguria; 9: Sesia-Lanzo Zone (SL) and Dent Blanche Nappe (DBL); 10: Southern Alps; 11: Tertiary, post-kinematic intrusives of Traversella and Valle del Cervo; 12: Apennines and Monferrato; 13: Quaternary and Tertiary sediments of Ligurian-Piedmontese basin and Po Plain; 14: Canavese Line (CL) and boundary between Alps and Apennines (Sestri-Voltaggio Line Auct.). Heavy dashed line: sections of Fig. 8.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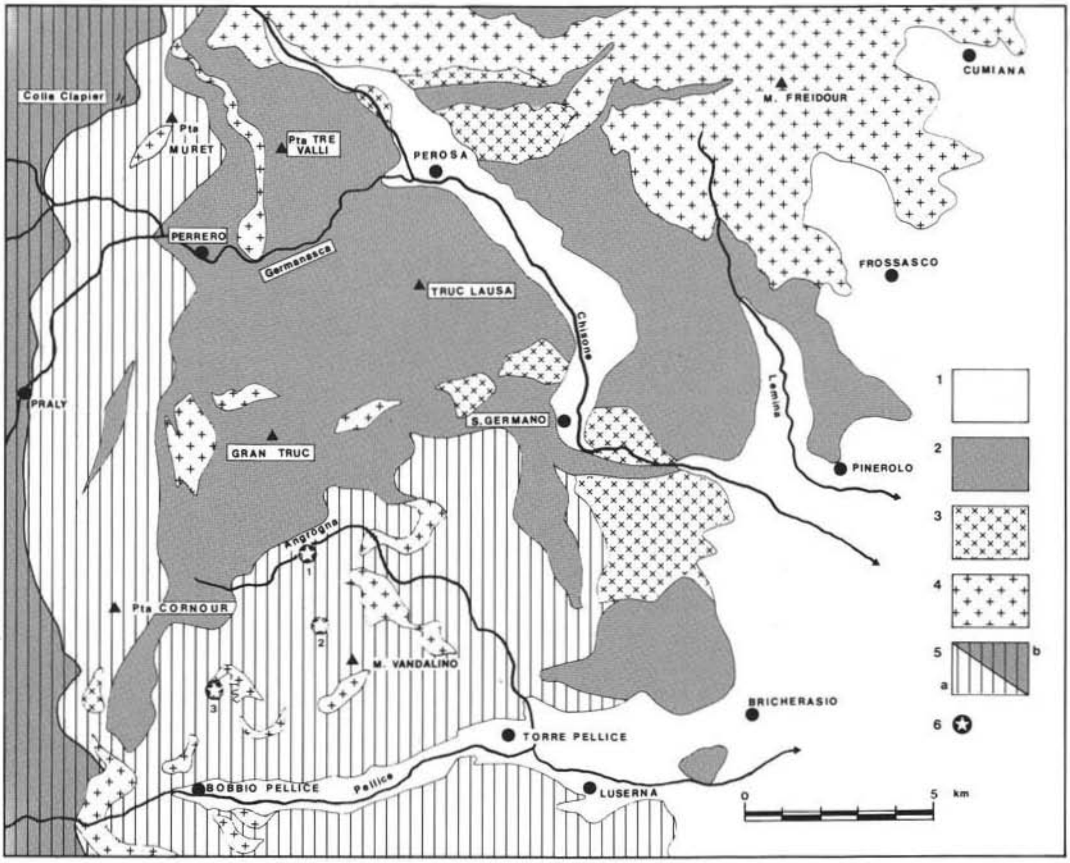

Fig. 2. — Sketch map of north-central Dora-Maira Massif (from VIALON P. (1966) and authors' unpublished data). 1: Quaternary cover; 2: Permian/Carboniferous terrains («Serie Grafitica»); 3: metadiorites; 4: granitoids; 5: pre-Carboniferous, polymetamorphic basement (a) and Mesozoic metaophiolites and «Schistes Lustrés» of Piedmontese Zone (b); 6: new occurrences of metadiorites (1: Giasset; 2: Colle dei Fons; 3: Subiaschi).

or less dolomitic limestones, whereas coarser clastic facies predominate in the (Permo)-Carboniferous cover.

In the light of field evidence and petrographical and chemical data, the metagranitoids can be divided into:

— gneisses with granite chemistry and mainly augen structure, consisting of quartz + microcline + albite + clinozoisite/epidote + biotite + white mica (VIALON's «gneiss oeillés homogènes» and the «Freidour-type» gneisses of BORGHI A. et al.);

— gneisses with granite chemistry and an augen structure, a very much finer grain, and richer in white mica («Luserna» gneisses of PAGLIANI G. 1954, BARISONE G. et al., 1979, SANDRONE R. et al., 1982, and COMPAGNONI R. et al., 1982-1983; VIALON's «porphyroïdes arkosiques» and «Jouglard-Selleries Complex» gneisses of BORGHI A. et al.);

— gneisses with pluricentimetric, polycrystalline feldspar eyes, abundant red-brown biotite, and granodiorite chemistry (VIALON's «gneiss amygdalaires»);

— medium- to fine-grained dioritic, granodioritic and tonalitic gneisses, consisting of quartz + plagioclase (albite-oligoclase) + biotite + chlorite + blue-green amphibole + clinozoisite/epidote and/or zoisite.

With the exception of the certainly older «gneiss amygdalaires» (SANDRONE R. et al., 1986), these metaintrusives are regarded as

Hercynian by analogy with lithologies dated in other sectors of the Penninic Domain (review and discussion in DAL PIAZ G.V., LOMBARDO B., 1985).

A different view is expressed by ZANETTIN E. (1964) and VIALON P. (1966).

Field occurrences

The examined metadiorites are located in the ridge between the Pellice and Angrogna Valleys, where they form a series of lenticular bodies of varying, though always relatively modest, size.

They outcrop as more or less dark grey-greenish gneisses with a regular medium to fine grain. The original magmatic structure can still be at least partly discerned in the best preserved facies. In this case, the rocks have a granular appearance. They are usually more deformed on the borders of the bodies with a structure that is first flaser, with small, pale, very flat eyes, and then more or less markedly banded.

A body of approximately 100 m dimension outcrops along the bed of the Angrogna stream near the Giasset district between 1520 and 1700 m above sea level. The country rocks are garnet and chloritoid micaschists belonging to the polymetamorphic basement of the Dora-Maira Massif. The contact is masked by a detritic-eluvial cover. Aplite dikes parallel to the regional foliation (dipping 10° towards 280°) and displaced by shear zones cut the metadioritic body locally.

A second outcrop of comparable size lies on the crest separating Val Pellice from Valle Angrogna near the Colle dei Fons (2200 - 2296 m a.s.l.). The rock is well exposed on a vertical wall and contains abundant basic dikes of decimetric thickness, always parallel to the regional foliation (dipping 30° towards 10°). The contact with the surrounding micaschists is marked by mylonitic levels.

A third outcrop is located around 1300 - 1500 m a.s.l. in the Subiaschi Valley, a left-hand tributary of the Pellice stream. The metadiorites contain basic dikes and centimetric to decimetric melanocratic inclusions. They show a strongly tectonised contact with metabasites and a gradual contact with «gneiss amygdalaires». All the lithologies display a transposed foliation as well as isoclinal folds with a subhorizontal axial plane, and referable to Alpine tectonics by comparison with the deformation of the Mesozoic «Schistes Lustrés».

Preserved magmatic relations and thermometamorphic effects cannot be discerned in any of these outcrops.

Minor occurrences of semi-in-situ diorite (not indicated in Fig. 2) were found at Prà del Torno and Rocca Sparviera in Angrogna Valley.

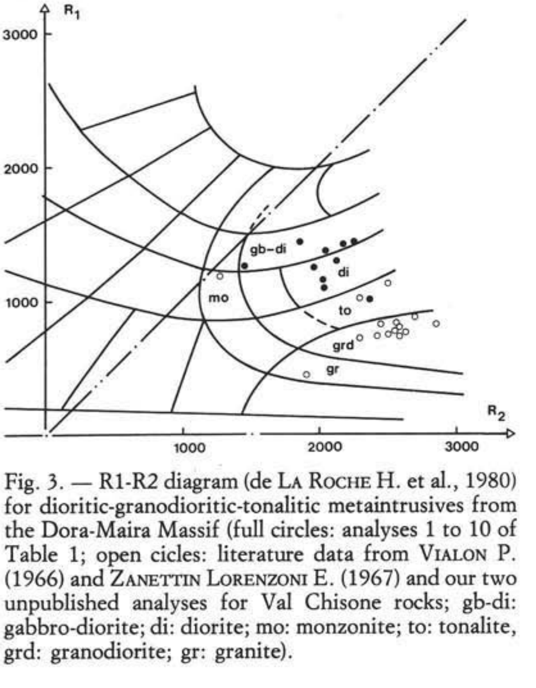

Fig. 3. — R1-R2 diagram (de LA ROCHE H. et al., 1980) for dioritic-granodioritic-tonalitic metaintrusives from the Dora-Maira Massif (full circles: analyses 1 to 10 of Table 1; open cicles: literature data from VIALON P. (1966) and ZANETTIN LORENZONI E. (1967) and our two unpublished analyses for Val Chisone rocks; gb-di: gabbro-diorite; di: diorite; mo: monzonite; to: tonalite, grd: granodiorite; gr: granite).

Petrography

Microscopic examination shows that these metadiorites are composed of quartz, albite, zoisite and/or clinozoisite, amphibole, white mica, biotite, chlorite and garnet, with accessory rutile, sphene, apatite, zircon and ores.

The mineralogy is in keeping with the well-documented metamorphism of the northern part of the Dora-Maira Massif (BORGHI A. et al., 1985, with references; POGNANTE U., SANDRONE R., submitted), namely, an earlier event under high-pressure conditions followed

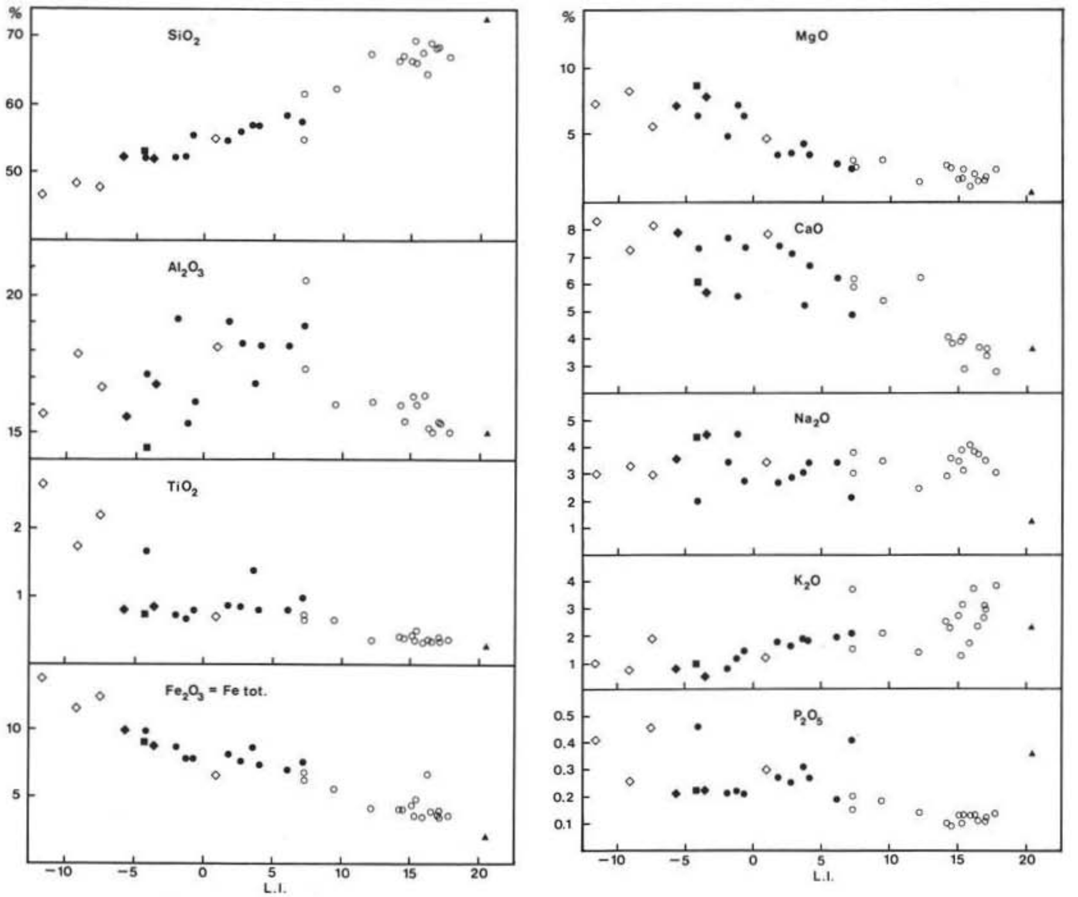

Fig. 4. — Major elements vs. Larsen Index diagrams for metadiorites (circles), melanocratic inclusion (square) and mafic (diamonds) and aplitic (triangle) dikes. Full symbols refer to samples of Table 1; open symbols represent literature data (VIALON P., 1966; ZANETTIN LORENZONI E., 1967) and our two unpublished analyses for Val Chisone rocks.

by re-equilibrations in the greenschist facies.

The primary paragenesis was probably represented by quartz, plagioclase, hornblende and biotite. This, however, has been completely transformed by metamorphic recrystallisation, though the sites of the original magmatic minerals can still be discerned in the less deformed facies.

Primary plagioclase is transformed into albite + zoisite, itself often incipiently or even competely replaced by clinozoisite ± garnet, the latter usually marking the contacts with the original amphibole and biotite.

The magmatic amphibole has undergone two types of transformation. In the less deformed rocks it is replaced by millimetric, poikilitic pycnochlorite filled with colourless actinolite, locally containing relics of glaucophane, and/or biotite-bearing symplectites pseudomorphous on a previous amphibole. In the more deformed rocks, however, it is replaced only by biotite symplectite, at whose expense blue-green actinolitic hornblende and ripidolite grew. Microprobe checks confirmed the compositions of amphiboles and chlorites.

The original biotite sites can usually be readily identified owing to their local enrichement in titaniferous minerals (rutile ± sphene) and the growth of coronitic garnet. Other biotite trasformation products are: white mica, chlorite, blue-green amphibole and newly formed biotite.

Melanocratic inclusions and mafic dikes show very similar mineralogic compositions and, apart from the greater abundance of mafic minerals and ores and the lack of quartz, their minerals are the same of the host metadiorites.

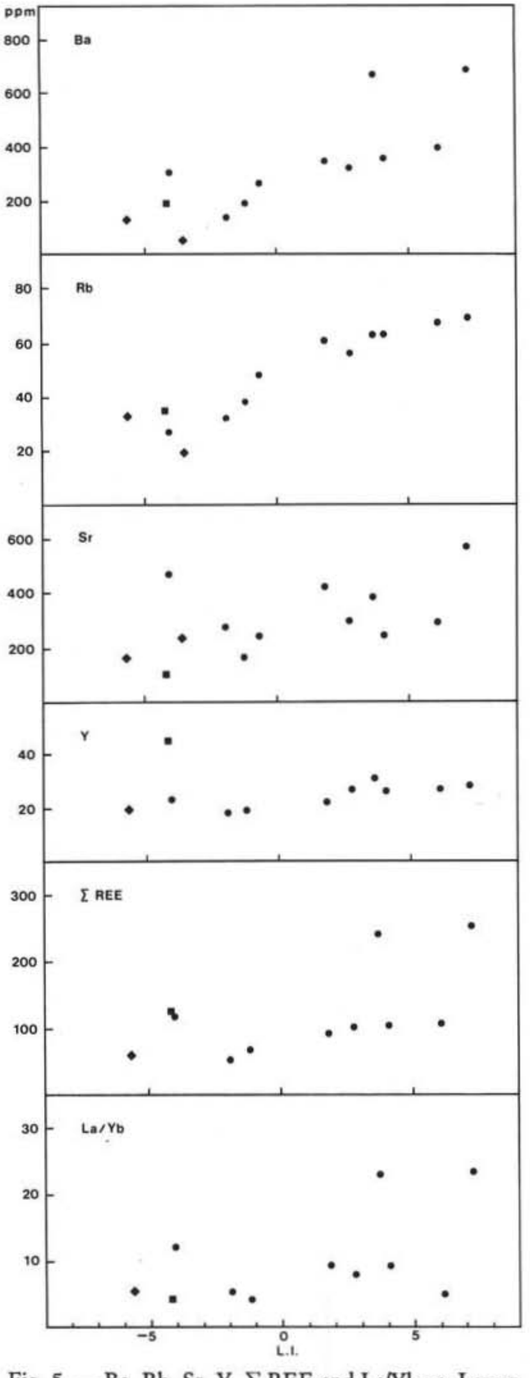

Fig. 5. — Ba, Rb, Sr, Y, Σ REE and La/Yb vs. Larsen Index diagrams (symbols as in Fig. 4).

Chemistry

Table 1 sets out the analytical data for the major elements, some trace elements and rare earth elements (REE) determined in the diorites, melanocratic inclusions and dikes cutting the dioritic bodies.

Except for an aplitic dike, the chemistry is remarkably uniform: intermediate SiO_2 values (52-59%), distinct peraluminous trend, and prevalence of Na_2O over K_2O. The analyses fall within the diorite and gabbro-diorite fields (Fig. 3) on the classification diagram of de La Roche H. et al. (1980), in keeping with their mineralogical characters and their normative composition (Mielke P., Winkler H.G.F., 1979). This covers a relatively broad range, though it is substantially formed of quartz (0-26%), plagioclase (18-54%, composition An_8-An_{52}), hornblende (5-49%), usually predominant over biotite (7-22%), and corundum (1 - 6%), in keeping with the peraluminous nature of these rocks.

There is considerable scattering of the representative points on the major elements vs. Larsen Index (L.I.) diagrams (Fig. 4), which also include data from the literature and our two unpublished analyses of diorites s.l. from the (Permo)-Carboniferous terrains of Val Chisone, for the purpose of comparison. The data of the literature, though 20 years old, compare well with our unpublished analyses plotted in figures 3 and 4.

SiO_2 and (albeit with even greater scattering for the Val Chisone rocks) K_2O are positively correlated with the L.I. The values of Al_2O_3 are so scattered that a significant trend cannot be detected, even though the samples from Valle Angrogna and Val Pellice seem to display a positive correlation; taken all together, the data are arranged in a bell-shaped curve. The values for CaO, Na_2O, and P_2O_5 are rather scattered, though a negative correlation with the L.I. can be observed for CaO, MgO, total Fe_2O_3 and

MnO (not shown in Fig. 4). TiO_2 tends to display two different trends, one with a slope (distinct negative correlation) given by the three samples from the Giasset body plus the data from Val Chisone bodies, the other with a nearly-flat trend. The Giasset analyses also display higher MgO and Fe_2O_3 contents for the same L.I.

The trace elements vs. L.I. diagrams are set out in Fig. 5. Apart from the rather flat pattern for Y, there is a variously marked positive correlation. In the diagrams for Ba, Σ REE and La/Yb the highest values for the same L.I. belong to the points representing the Giasset diorites.

The REE patterns in Fig. 6 are normalized to chondrite CI (EVENSEN N.M. et al., 1978). The trends are very similar: LREE enrichment (La_N/Yb_N = 15.87-3.85), absence of substantial HREE fractionation (Dy_N/Yb_N = 1.34-1.07), slightly negative or nil Eu anomaly (Eu/Sm = 0.22-0.33) and a total REE range of 52 to 252 ppm.

The patterns for the melanocratic inclusion and the basic dike are also very similar: a slight negative Eu anomaly (Eu/Sm = 0.20-0.25) and less REE fractionation than in the diorites (La_N/Yb_N = 3.73-2.92; Dy_N/Yb_N = 1.06-1.05).

If the two analyses of the Giasset metadiorites (MDM 143 and MDM 147 of Table 1) are left out, and only the patterns falling in the grey fields of Fig. 6 are considered, both LREE enrichment and total REE range decrease (La_N/Yb_N = 8.19-3.58; 52-114 ppm). We are then dealing with rather flat patterns, downward-convex for HREE.

We are aware that the chemical and geochemical features of metamorphic rocks should be viewed with caution (see e.g. HUMPHRIS S.E., 1984; VOCKE R.D. et al., 1987, with references); however, the above

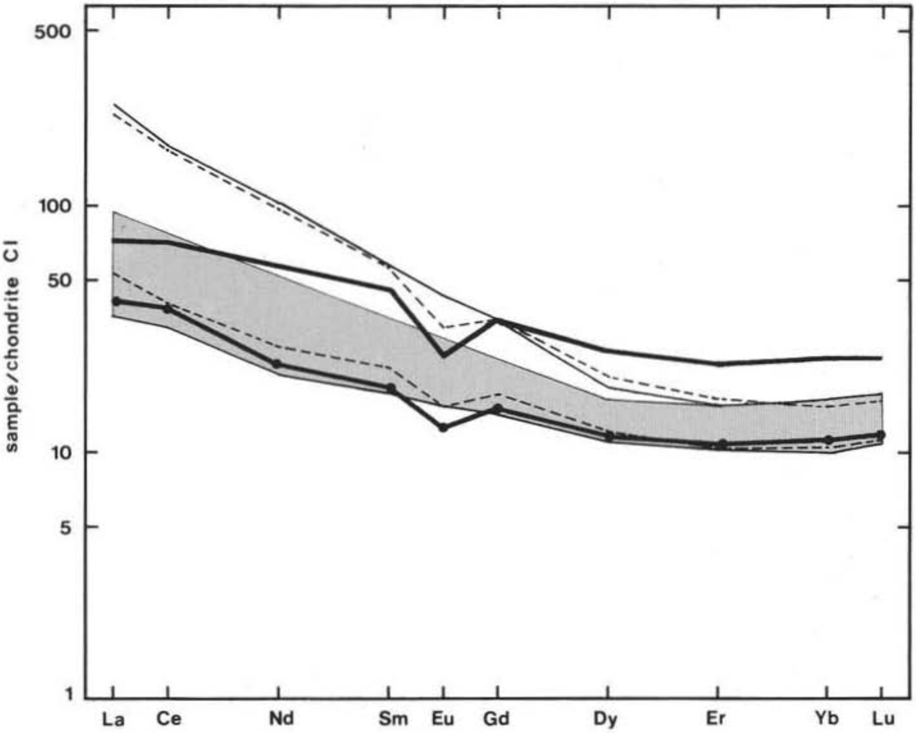

Fig. 6. — Rare earth element patterns for 11 metadiorites, one melanocratic inclusion (heavy line) and one mafic dike (heavy line with circles). Thin dashed lines and thin full lines: patterns with respectively slightly negative and nil Eu anomaly. Except for MDM 143 and MDM 147, all metadiorite analyses (Table 1 and two unpublished analyses for Val Chisone rocks) plot in grey field.

TABLE 1

*Chemical analyses for metadiorites (anal. 1-10), melanocratic inclusion (anal. 11), mafic (anal. 12-13) and aplitic (anal. 14) dikes. MDM 139, MDM 143 and MDM 147: Giasset metadiorites (normal, mica-rich and foliated facies; U.T.M. coordinates: 32TLQ533695); MDM 158 and MDM 168: Prà del Torno metadiorites (massive facies; coord. 32TLQ557703); MDM 169 and MDM 170: Prà del Torno metadiorites (foliated and dark facies; coord. 32TLQ557703); MDM 164: metadiorite from Vallone Subiaschi (coord. 32TLQ517664); MDM 165: metadiorite from Colle dei Fons (coord. 32TLQ537679); MDM 167: metadiorite from Rocca Sparviera (coord. 32TLQ527701); MDM 161: melanocratic inclusion in MDM 158; MDM 163: mafic dike in MDM 164; MDM 166: mafic dike in MDM 165; MDM 134: aplitic dike in Giasset metadiorite. *: Fe_2O_3 as total Fe*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample	MDM 139	MDM 143	MDM 147	MDM 158	MDM 168	MDM 169	MDM 170	MDM 164	MDM 165	MDM 167	MDM 161	MDM 163	MDM 166	MDM 134
(wt. %)														
SiO_2	52.23	56.96	57.48	54.63	56.83	58.37	52.58	55.41	52.45	55.87	52.95	52.07	52.40	72.46
TiO_2	1.65	1.37	0.98	0.87	0.80	0.80	0.66	0.80	0.72	0.85	0.73	0.85	0.81	0.28
Al_2O_3	17.08	16.78	18.92	19.06	18.16	18.14	15.30	16.11	19.14	18.25	14.41	16.74	15.54	14.98
Fe_2O_3 *	9.79	8.59	7.50	8.06	7.30	6.95	7.71	7.73	8.59	7.53	9.01	8.77	9.87	1.89
MnO	0.17	0.13	0.09	0.14	0.14	0.13	0.13	0.15	0.17	0.13	0.15	0.12	0.19	0.05
MgO	6.35	4.27	2.48	3.54	3.43	2.80	7.42	6.39	4.79	3.58	8.64	7.82	7.10	0.69
CaO	7.35	5.21	4.87	7.43	6.71	6.24	5.56	7.34	7.72	7.13	6.09	5.71	7.93	3.61
Na_2O	2.00	3.04	2.13	2.66	3.41	3.41	4.46	2.73	3.43	2.86	4.32	4.44	3.56	1.26
K_2O	0.99	1.87	2.13	1.78	1.81	1.95	1.20	1.43	0.81	1.63	1.01	0.52	0.78	2.27
P_2O_5	0.46	0.31	0.41	0.27	0.27	0.19	0.22	0.21	0.21	0.25	0.22	0.22	0.21	0.36
I.L.	1.97	1.60	2.36	1.44	1.27	1.32	3.39	1.59	1.44	1.73	1.54	3.04	1.09	1.56
Total	100.04	100.13	99.35	99.88	100.13	100.30	98.63	99.89	99.47	99.81	99.07	100.30	99.48	99.41
(ppm)														
Ba	296	667	684	337	354	390	185	257	133	314	186	46	121	533
Rb	27	63	69	61	63	67	38	48	32	56	35	19	33	67
Sr	469	385	571	418	239	291	160	240	272	295	101	235	162	791
Y	23	31	28	22	26	27	19	n.d.	18	27	45	n.d.	19	n.d.
La	23.05	57.92	62.54	18.57	18.95	20.30	13.01	-	8.79	19.07	17.60	-	10.22	-
Ce	47.11	106.08	111.47	37.65	44.30	43.68	25.67	-	20.52	41.43	45.46	-	24.67	-
Nd	24.50	46.66	48.99	16.60	19.76	20.06	13.00	-	9.88	18.87	27.13	-	10.90	-
Sm	5.25	8.64	8.89	3.92	4.57	4.61	3.43	-	2.74	4.45	7.15	-	2.89	-
Eu	1.74	1.88	2.55	1.15	1.18	1.16	0.90	-	0.89	1.25	1.44	-	0.73	-
Gd	4.56	7.11	7.14	3.85	4.51	4.62	3.54	-	2.94	4.46	7.09	-	3.10	-
Dy	3.73	5.22	4.63	3.25	4.01	4.17	3.10	-	2.80	3.98	6.65	-	2.98	-
Er	2.01	2.74	2.59	1.89	2.34	2.33	1.74	-	1.70	2.23	3.88	-	1.78	-
Yb	1.90	2.53	2.66	1.97	2.28	2.47	1.73	-	1.66	2.39	4.07	-	1.85	-
Lu	0.29	0.41	0.43	0.39	0.33	0.33	0.29	-	0.28	0.42	0.62	-	0.30	-

data suggest some inferences, namely:

1. The various diorite bodies of Valle Angrogna are co-magmatic;

2. The good linear correlation of La/Sm and La/Yb ratios with La (coefficient of determination $r^2 = 0.966$ and 0.980 respectively) suggests that these rocks formed by variable degrees of partial melting (see TREUIL M., JORON J.L., 1975);

3. Among the various protoliths deemed suitable to yield melts chemically similar to those of the Angrogna rocks (see e.g. CULLERS R.L., GRAF J.L., 1984; STERN R.J., GOTTFRIED D., 1986, with references), an amphibolitic protolith is indicated by the patterns in Fig. 6;

4. The patterns of MDM 143 and MDM 147 display rather high LREE values for these lithologies, although the La/Sm to La and La/Yb to La ratios are not unlike those of the other samples. The Giasset rocks might thus be taken to represent the product of either early-phase partial melting or metamorphic modification. The two samples belong, in fact, to an abnormally mica-rich and a markedly foliated rock respectively;

5. On chemical grounds, the metadiorites from Val Chisone and Valle Angrogna would

TABLE 2

$^{40}Ar/^{39}Ar$ step-heating data. Ar concentrations all in pl/g. Entry «rad» in total is radiogenic ^{40}Ar, in nl/g. K concentrations are determined from known production ratios, total ^{39}Ar and J. Total ages represent conventional K/Ar age.

A3 .189 g J = 2.06 E-4

T	$^{40}Ar_t$	$^{39}Ar_t$	^{37}Ar	^{36}Ar	t (Ma)
600	128.4 ± .1	0.240 ± 2	0.316 ± 2	0.341 ± 3	42.4 ±1.4
700	364.9 ± .3	1.464 ± 10	0.964 ± 5	0.397 ± 3	61.8 ± .5
900	1197 ± 3	6.299 ± 25	1.713 ± 6	0.622 ± 4	58.8 ± .3
1000	3007 ± 2	15.458 ± 70	16.642 ± 60	0.970 ± 5	64.3 ± .3
1100	548 ± 1	2.262 ± 30	15.651 ± .150	0.365 ± 4	71.5 ±1.0
1150	136.6 ± .5	0.302 ± 6	4.425 ± 23	0.292 ± 4	61.9 ±1.9
1200	97.7 ± .5	0.145 ± 7	0.838 ± 4	0.312 ± 3	14.1 ±2.3
1400	327.3 ± .2	0.124 ± 4	0.567 ± 3	1.092 ± 5	14.3 ±4.7
Total	(rad = 4.51) (K = 1.8%)				62.7

A4 .137 g J = 2.08 E-4

T	$^{40}Ar_t$	$^{39}Ar_t$	^{37}Ar	^{36}Ar	t (Ma)
700	517 ± 6	2.218 ± 24	2.67 ±.11	1.410 ± 9	17.0 ± .5
900	1437 ± 1	5.000 ± 48	4.78 ± 2	1.337 ± 7	76.4 ± .8
1000	2442 ± 7	7.708 ± 62	23.98 ± 8	1.196 ± 7	98.8 ± .8
1050	1415 ± 2	4.742 ± 31	7.67 ± 3	0.686 ± 6	93.3 ± .6
1150	650 ± 1	0.893 ± 13	11.07 ± 5	0.763 ± 6	170.7 ± 2.5
1400	631 ± 1	0.222 ± 3	2.02 ± 1	1.790 ± 15	164.1 ± 7.1
Total	(rad = 4.97) (K = 1.4%)				84.2

seem to belong to one and the same magmatic suite, the Val Chisone rocks being the most fractionated products (Fig. 4).

Ar/Ar data

Two new samples (A3 and A4) of massive metadiorite from Prà del Torno were collected for Ar/Ar dating in order to pinpoint the recrystallization phase and to look for possible chronological links with known tectonic phases.

The separation of pure actinolitic

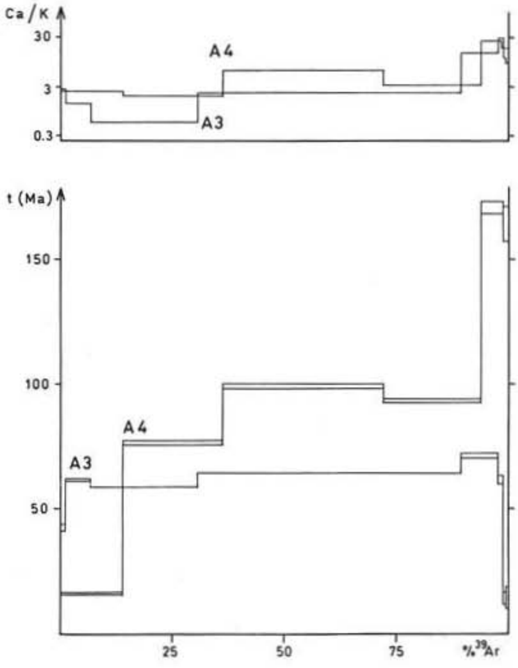

Fig. 7. — Age and Ca/K spectrum for actinolitic hornblendes A3 and A4. All spectra are heavily disturbed; see text for discussion.

hornblendes was only partly satisfactory. The crushed rock was sieved and the mafic minerals magnetically enriched. However, visual inspection of the finest fraction (100 μm) revealed the ubiquitous overgrowths of other minerals besides amphibole. Treatment with heavy liquids produced a series of density fractions, none of wich was completely pure. The least contaminated fractions were chosen.

Irradiation and analysis of samples follow ODDONE M., VILLA I.M. (1986). The data are shown in Table 2, after mass spectrometer background and discrimination and ^{37}Ar decay corrections. Ages calculated after correcting for Ca interference are shown in Fig. 7.

Both age and Ca/K spectra are strongly discordant, indicating a very disturbed system. Ages vary between 14 and 170 Ma, and interpretations are necessarily very speculative. The low ages of steps A3-1200 and 1400 suggest that most of the gas released by A3 is fraught with excess Ar. Its two 14 Ma step ages are also compatible with that of A4-700. The spectrum of A4 could, in principle, reflect a very strong Oligo-Miocene thermal disturbance of a sample older than 200 Ma. Even if this is consistent with the presumed geological history of the Dora-Maira Massif, the present data cannot be used to support it. Firstly, samples A3 and A4 seem to record two antithetical histories, but the petrography fails to show a substantial difference such as to justify their contrasting behaviour. Secondly, the pervasive recrystallization visible both in thin section and from the Ca/K spectrum should have prevented the newly formed amphibole from preserving chronologically meaningful ^{40}Ar gradients.

The Ca/K spectra reveal a number of features. The ratios change by two orders of magnitude, which is fairly surprising in a separated mineral. The very irregular behaviour points to two explanations:

1. At temperatures below 1100°C, the presence of micron-sized biotite intergrowths (confirmed by microprobe analyses on the separates) has the effect of lowering the Ca/K ratio, at the same time contributing some of the uncomfortably high K concentration (Table 2).

2. At temperatures where biotite is degassed, the Ca/K ratio is still not constant, very probably owing to complexities in the amphibole microstructure. These complexities are expected to occur in a low-temperature reaction such as fluid-induced recrystallization, where successive generations of unmixing episodes follow from varying regimes of subsolidus reactions.

The presence of biotite intergrowths may be used to draw one final chronological inference. The step with the lowest Ca/K ratio, A3-900, is presumably the richest in newly formed biotite. It is well known that excess Ar makes metamorphic biotite one of the worst chronometers there is (see e.g. BREWER M.S., 1969). Its age (59 Ma) thus represents a strict upper limit for the recrystallization event.

This limit is consistent with the limit of «29 Ma or younger» (30 Ma with the new decay constants) given by VIALETTE Y., VIALON P. (1964) for biotite in a metagranodiorite from Val Chisone. However it is impossible to discuss these authors' results because no measured isotopic composition are given, and calculated ages may be wrong because of an incorrect initial. Our limit, on the contrary, conflicts with the conclusions of CARPENA J. et al. (1986) for the Piedmontese unit. Three points are controversial, in their reconstruction:

1. The temperature is postulated to have remained below the fading temperature for apatite, 100°C, during the last 44 Ma. This implies that the uplift rate was at most 70 μm/a (or less, according to the assumed gradient in the Dora-Maira nappe). This is not implausible in itself, but should be proved by independent, non-radiometric arguments;

2. The evidence for a Cretaceous greenschist phase rests on the erroneous determination of T_c in zircons by HURFORD A.J. (1983, 1986), who calibrated it against biotite T_c, using the discredited value of 300°C (see discussion in DEL MORO A. et al., 1982). CARPENA J. et al. (1986) themselves realize, but quickly dismiss, that 350°C did not reset zircons in the Schistes Lustrés blueschists. This means that the observed zircon ages do not conflict with a Tertiary greenschist phase;

3. The existence of an orogen-wide Lepontine Phase at 38 ± 2 Ma is also being challenged in more recent works (PLATT J.P., 1986, 1987) and extensive radiometric data compilation (DESMONS J., HUNZIKER J.C., 1987) shows that the situation is more shaded than a simple single peak. It is thus not longer necessary to twist all the data to fit an interpretation in the light of a synchronous uplift of the whole Alpine chain, and the northward migration pattern of the data of CARPENA J. et al., (1986) simply means that rocks which were originally 30 km deep were brought up at different times in the different portions of the orogen. Clearly 2 amphiboles, 3 biotites, 3 apatites and 4 zircons are not quite sufficient to unravel the complete history of the Dora-Maira nappe.

In conclusion, the Ar/Ar data show that the amphiboles are very disturbed, which we already knew, and that they recrystallized for the last time in the Tertiary, possibly as recently as the Miocene.

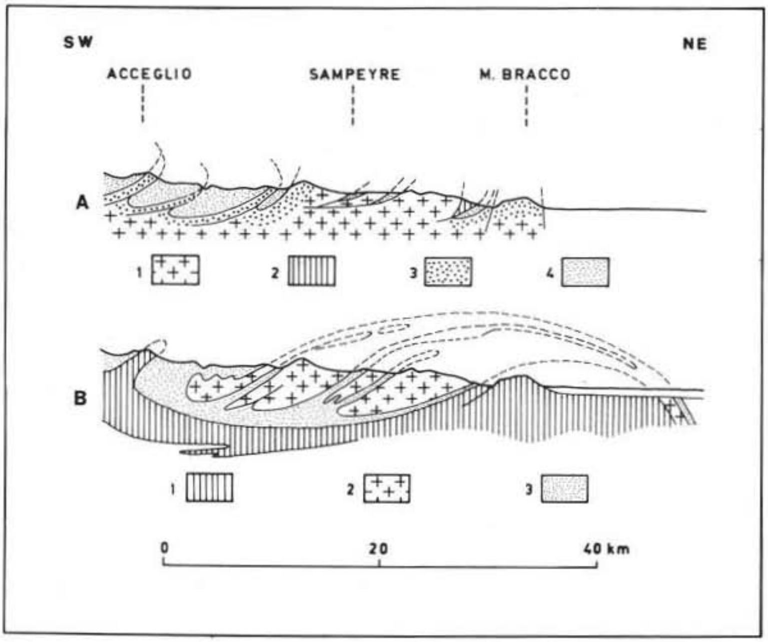

Fig. 8 - Contrasting interpretations of Dora-Maira Massif by VIALON (A) and ARGAND (B) (from VIALON P., 1966). A - 1: Dora-Maira pre-Carboniferous; 2: Carboniferous; 3: Permian and «siliceous» Trias; 4: Schistes Lustrés and «carbonatic» Trias.
B - 1: «Serie Grafitica» (Great St. Bernard Nappe); 2: Dora-Maira pre-Carboniferous basement (Monte Rosa Nappe); 3: Trias and Schistes Lustrés.

Discussion and conclusions

In the last 60 years, the Middle Penninic crystalline massifs (Dora-Maira, Gran Paradiso and Monte Rosa) have been of central importance in the controversy concerning the nappe structure of the Alps. Although the debate has now virtually subsided, owing to general acceptance of the view that the chain has indeed a nappe structure, this consensus become less general when the discussion turns to the details of the structure and to the relative importance of fragile and ductile tectonics.

The Gran Paradiso and Dora-Maira Massifs are of particular interest in this connection. In the former, COMPAGNONI R. et al. (1974) have detected a sequence of metasediments affected by Alpine age metamorphism only — the Money Complex — outcropping in a tectonic window below the polymetamorphic terrains. They regard it as Carboniferous in view of its affinity with terrains of this age («Serie Grafitica del Pinerolese») in the Dora-Maira Massif.

The relation between this series and the polymetamorphic terrains in the Dora-Maira Massif has been the subject of controversy ever since the publication of the Argentera-Dronero (78-79), Pinerolo (67) and Susa (55) sheets of the 1:100,000 Geological Map of Italy. ARGAND's «nappe» interpretation (1911) was contested by the autochthonistic view of FRANCHI S. (1929) and his colleagues from the Regio Ufficio Geologico. These contrasting views were taken up again several decades later by VIALON P. (1966) and MICHARD A. (1967). In ARGAND's opinion, shared by OGNIBEN L. et al. (1975) in the «Structural Model of Italy», in the Dora-Maira Massif a palaeogeographically more internal unit (polymetamorphic crystalline schists with the remains of Permian-Mesozoic «Piedmontese» covers) was tectonically superimposed on the more external, Briançonnais unit, i.e. the «Serie Grafitica del Pinerolese», which outcrops through a tectonic window in the Pinerolo district. According to the «autochtonists», on the other hand, the

Carboniferous terrains constitute the stratigraphic cover of the overlying polymetamorphic complex. These two viewpoints are illustrated in simple graphic form in Fig. 8. The allochthonist interpretation has recently been adopted by SACCHI R. et al. (1983) and BORGHI A. et al. (1984).

A few words may now be said with regard to the contribution offered by our data to the problems just described.

We feel it reasonably certain that the eruptive bodies we have identified in the Pellice basin are coaeval and consanguineous with the more extensive pluton of the lower Val Chisone (Malanaggio diorite and satellite bodies). The lithology and fabric are analogous and the chemistries are compatible, as already argued.

As far as the age of this magmatism is concerned, no geological or radiometric evidence has come forward against its traditional attribution to the Permian. It should not be forgotten, however, that this is based on somewhat slender grounds, namely (1) the intrusive relations with the terrains assumed as Carboniferous in age and (2) the general metamorphic transformation into greenschist facies, this being manifestly of Alpine age. A pre-Cretaceous age would be confirmed if high-pressure metamorphic transformations were to be detected in the metadiorites. Such evidence, in fact, is given by the occurrence of glaucophane, Mg-chlorite, zoisite and rutile.

If the Permian age is accepted, our findings involve certain implications that invite reflection.

1. As has been stated, the chemistry of the diorites points to an origin by melting of amphibolites. This does not conflict with the data of regional geology, if we consider the widespread metabasites interbedded within pre-Carboniferous metasediments. The most likely scenario is mantle activity under post-orogenic stretching conditions that served as the vehicle for the surplus heat responsible for partial melting in the deep crust.

In the more internal portion of the Western Alps, there is no lack of products indicative of mantle activity in Permian times (see e.g. DAL PIAZ G.V. et al., 1977; BIGIOGGERO B. et al., 1981, 1983). In particular, BIGIOGGERO B. et al. (1981, 1983) described several bodies of anorogenic Ti-rich olivine diabase spatially associated with the late Hercynian granite in the Biella district. It may also be noted that a similar petrogenetic mechanism (melting in the deep crust triggered by the rise of asthenospheric material) appears in the early orogenic phase in evolution models widely accepted for the Proterozoic, such as that of KRÖNER A. (1983). In NW Scotland, a similar evolution accompanied the early phases of the opening of the Atlantic Ocean, as shown by Sr and Pb isotope compositions (MOORBATH S., 1978, p. 410).

2. The age and position of the diorite bodies are of substantial relevance to a problem of Alpine tectonics. In the lower Val Chisone the diorites intrude rocks belonging to a Briançonnais formation (the Carboniferous in the Pinerolo district). Some 7 to 8 km away — a very small distance on the scale of the orogen — the rocks we have described are included in a basement of Piedmontese affinity. This crowding of pre-Alpine diorite bodies into a small area, both in a supposedly allochthonous basement unit and in the supposedly autochthonous terrains of the Pinerolo inlier, imposes critical re-assessment of the nappe tectonic model for Dora-Maira, especially the existence of large-scale displacements. As an alternative, the age of intrusion could be doubted, a problem that has not yet been settled by the available radiometric data.

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