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The Austroalpine Layered Gabbros of the Matterhorn and Mt. Collon – Dents de Bertol

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Abstract

The gabbro masses of the Matterhorn (Mt. Cervino) and the Mont Collon-Dents de Bertol occur as intercalations in the Arolla series of the Austro-Alpine Dent Blanche nappe. The continous mylonitic to blasto-mylonitic contact between the gabbro masses and the surrounding Arollagneisses point to a tectonic emplacement of the gabbro complex. The Alpine metamorphism in green schist facies has partly overprinted the gabbros of the Dent Blanche nappe. The degree of this Alpine overprint decreases from the border to the core of the lenticoid gabbro layers, so that the cores represent the best preserved gabbros of the whole western Alps, with primary magmatic mineral assemblages. The excellent preservation of some of these gabbros even allows the detection of cumulitic structures, in some cases a repeated magmatic layering was found. This layering comprises scarce peridotites and melagabbros, olivine bearing gabbros, leuco gabbros and anorthosites. The magmatic cumulus minerals are: olivine, orthopyroxene ± spinell; orthopyroxene, plagioclase ± olivine ± clinopyroxene; plagioclase ± pyroxene. The most widespread intercumulus minerals are: brown hornblende, poikilitic phlogopite and in the more femic rocks plagioclase and clinopyroxene. The layered as well as the homogeneous parts of the gabbroic bodies are cut by numerous melanocratic to leucocratic dykes.

22 whole rock analyses were performed (main components and traces). In addition 2 clinopyroxenes, 2 brown hornblendes, 1 phlogopite and 2 biotites were analyzed. The cumulitic character and the absence of chilled margins does not allow to use the whole rock chemistry to define the series character or the evolutional trend of the primary magma; the chemistry of the clinopyroxenes nevertheless points to a subalcalic affinity.

Concordant Rb-Sr and K-Ar age determinations on 2 biotites from leucocratic and melanocratic dykes and on 1 phlogopite from a pyroxenite yielded ages of 250 ± 5 m.a. i.e. of the Permotriassic boundary. The $^{87}Sr/^{86}Sr$ initial values of below 0.7040 and the Rb/Sr ratios of smaller than 0.02 for the best preserved mafic and ultramafic rocks, point to a subcrustal origin. On the basis of these data, the gabbros of the Matterhorn-Mont Collon-Dents de Bertol are interpreted as products of the proto-Alpine

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extensional processes that lead to a thinning of the Hercynian continental crust and a subsequent mantle updoming, leading to the opening of the Mesozoic liguro-piemontese ocean basin with its ophiolites.

Riassunto

Le masse gabbriche del Cervino (Matterhorn) e del Mt. Collon-Dents de Bertol sono intercalate, assieme ad altre minori, nella Serie d'Arolla della falda austroalpina della Dent Blanche (Alpi occidentali, valle d'Aosta e Vallese). Il loro contatto è di evidente natura tettonica, sottolineato da una fascia potente e regolare di miloniti e blastomiloniti.

L'evento metamorfico alpino in facies scisti verdi, che ha rigenerato i granitoidi tardoercinici della Serie d'Arolla, ha coinvolto anche le masse gabbriche, ma con effetti relativamente modesti e discontinui, tanto che esse appaiono di gran lunga le meglio preservate dell'intero edificio a falde alpino-occidentale. Le masse gabbriche mostrano infatti trasformazioni metamorfiche complete o molto progredite soltanto alla periferia ed in alcuni settori interni, mentre altrove conservano, anche integralmente, la struttura e le associazioni mineralogiche primarie. È quindi possibile constatare la loro natura cumulitica e, in certi casi, anche la presenza di una ripetuta stratificazione magmatica che si estende da rare peridotiti e melagabbri, a gabbri ± olivinici, leucogabbri ed anortositi. I minerali d'accumulo magmatico sono costituiti rispettivamente da ol – opx ± spin; opx – plag ± ol ± clpx; plag ± px. I più comuni minerali d'intercumulo sono rappresentati da abbondante orneblenda bruna, a volte in quantità superiore al 10% in volume, e da flogopite, spesso in individui pecilitici di grandi dimensioni; vi si associano, nelle rocce più femiche, plagioclasio e clinopirosseno. Al contatto tra olivina e plagioclasio si sviluppano corone di reazione formate da ortopirosseno (verso l'olivina) e da una simplectite di anfibolo verde pallido + spinello.

Il layering magmatico e le masse relativamente più omogenee sono intersecate da numerosi filoni differenziati il cui spessore varia da alcuni cm a qualche m. Si osservano sia filoni melanocratici, caratterizzati in genere da struttura microgranulare e composizione mineralogica molto uniforme (orneblenda bruna ≧ plagioclasio calcico ± scarso ortopirosseno), sia filoni leucocratici. Questi ultimi sono più eterogenei, corrispondono a trondjemiti, quarzodioriti, apliti e pegmatiti ed appaiono spesso zonati.

È stata eseguita l'analisi chimica (elementi maggiori; Cr, Ni, Rb, Sr, Zr) di 15 rocce cumulitiche e di 7 filoni differenziati e determinata la composizione di 2 clinopirosseni, 2 orneblende brune, 1 flogopite e 2 biotiti (da pegmatiti).

A causa del carattere cumulitico di queste masse ed in assenza di margini raffreddati, non è possibile utilizzare il chimismo della roccia totale per definire con precisione il carattere seriale, il trend evolutivo ed il significato paleoambientale del magma originario.

Una sua affinità subalcalina appare tuttavia suggerita dalla composizione dei clinopirosseni calcici di due rocce gabbriche, il cui contenuto in Al_2O_3 e TiO_2 è simile a quello di alcune olivin-tholeiiti.

Sono state inoltre eseguite 8 determinazioni di età radiometrica K-Ar e Rb-Sr su roccia totale e miche brune. I risultati sono concordanti e cascano attorno a 248 m.a., un'età che corrisponde grosso modo al limite Permiano-Trias definito da ARMSTRONG e McDOWALL (1974).

Si pone quindi il problema se le masse gabbriche della falda Dent Blanche rappresentino una coda della fase magmatica e metamorfica permiana del ciclo ercinico (290–270 m.a.; HUNZIKER, 1974) o se stiano piuttosto ad indicare un prodromo di

quello alpino. È immediato escludere la prima eventualità sulla base del basso valore dei rapporti di Sr^{87}/Sr^{86} e di Rb/Sr, i quali sono rispettivamente inferiori a 0.7040 ed a 0.02. Questi valori non trovano riscontro nel quadro geochimico del magmatismo ercinico nelle Alpi che comunemente viene attribuito a fusione anatettica di crosta continentale; essi attestano invece la natura sottocrostale del magma originario che ha prodotto i complessi gabbrici ed il loro corteo filoniano. Si ritiene pertanto che le masse gabbriche del Cervino e del Mt.Collon-Dents de Bertol debbano essere inserite nel quadro di quei processi geodinamici proto-alpini di divergenza, assottigliamento crostale e lenta risalita del mantello caldo che porteranno in seguito all'apertura del bacino oceanico ligure-piemontese, processi che sarebbero quindi già attivi al limite Permiano-Trias.

Il consolidamento delle masse gabbriche si svolse in una camera magmatica chiusa situata ad un livello relativamente profondo, tale da consentire la coesistenza stabile di olivina e ortopirosseno, cioè all'interno della crosta continentale inferiore o, più probabilmente, al limite tra il mantello ed una crosta in parte già assottigliata. La attuale posizione strutturale dei gabbri del Cervino e del Mt. Collon-Dents de Bertol, in seno ai metagranitoidi della Serie d'Arolla, è attribuibile in ogni caso ad una fase postmagmatica di intrusione tettonica.

1. GENERAL SETTING

The Austroalpine system of the Western Alps comprises the Dent Blanche Nappe on the external side and the Sesia-Lanzo Zone on the internal side, both being subdivided into a lower and an upper tectonic element (A. H. Stutz and R. Masson, 1938; G. I. Elter, 1960; F. Carraro et al., 1970; G. V. Dal Piaz et al., 1972; J. C. Hunziker, 1974; R. Compagnoni et al., 1975; G. V. Dal Piaz, 1976), also known respectively as the Arolla and the Valpelline Series of Argand's recumbent fold (1908, 1909, 1911, 1916, 1934).

a) In the *upper element* of the Austroalpine system, a slice of lower continental crust, Ordovician granulites and high-temperature paragneisses occur, locally with interbedded amphibolites and marbles (E. Diehl et al., 1952; G. V. Dal Piaz et al., 1971; 1972; A. Boriani et al., 1974; R. Compagnoni et al., 1975, with references). This lithologic complex also shows a hercynian overprint and a weak and irregularly distributed Alpine metamorphism with Na-amphibole, chloritoid, phengite, garnet and low-temperature kyanite assemblages, followed by a partial greenschist facies overprinting (G. V. Dal Piaz, 1971; G. V. Dal Piaz et al., 1971, 1972; R. Compagnoni et al., 1975).

b) The *lower tectonic element* of the Austroalpine system instead shows an almost complete structural reworking and metamorphic overprinting of Alpine age. Two different tectonic and metamorphic events can be discerned: the first, *the early-Alpine event* of upper-Cretaceous age, produced lower-temperature eclogitic assemblages on the internal side before the Dent Blanche thrusting phase (G. V. Dal Piaz et al., 1972; J. C. Hunziker, 1974). The second one, *the Lepontine event* of Eocene-lower Oligocene age, developed a greenschist facies overprinting, mainly distributed on the external side of the Austroalpine system (J. C. Hunziker, 1969, 1970, 1974; G. V. Dal Piaz et al., 1971, 1972; M. Frey et al., 1974; R. Compagnoni et al., 1975, with references).

In spite of this metamorphic reworking, the pre-Alpine lithological setting of the lower Austroalpine element is still recognizeable. Late-Hercynian granitoids and pregranitic high-temperature paragneisses of undetermined facies series, with interbedded lenses and layers of metabasites and marbles, have been detected in the Sesia-Lanzo Zone (G. V. Dal Piaz et al., 1972; A. Boriani et al., 1974; A. Isler and A. Zingg, 1974; R. Compagnoni et al., 1975). Some gabbro masses which never appear connected with ophiolite-type volcanic and sedimentary sequences, and scattered relics of the post-Hercynian sedimentary cover are also found in the lower element (G. V. Dal Piaz, 1976; R. Compagnoni et al., 1975; with references).

The magmatic assemblages of the gabbro masses are either well preserved (in the Dent Blanche Nappe s.s.) or show a more or less complete greenschist facies overprinting (the Pillonet Klippe and the Mt. Pinter area on the external Sesia-Lanzo Zone), or show low-temperature high-pressure conditions (Corio and Monastero area, in the Southern Sesia-Lanzo Zone) (A. Bianchi et al., 1965; G. V. Dal Piaz et al., 1972; R. Compagnoni et al., 1975; G. V. Dal Piaz, 1976). Thus these gabbro masses are tectonically associated with the ancient continental margin of the Insubric or African plate.

2. GEOLOGIC OUTLINE

The areal distribution of the gabbro masses within the lower tectonic element of the Dent Blanche Nappe s.s. is shown as Fig. 1 and their structural setting in Fig. 2, which has been modified after E. Argand (1909). Two major masses outcrop at the Matterhorn (M. Cervino) and at the Mt. Collon-Dents de Bertol, and other minor lenses are found at Untergabelhorn-point 3182 and Schallihorn, near the Weisshorn. First pointed out by H. Gerlach (1869) and by F. Giordano (1869), they have been mapped in detail by E. Argand (1908) and by the Italian Geological Survey (1908, 1912) and by P. Bearth (1953; 1964). The first mineralogical study, with five whole rock chemical analyses, were carried out by A. Brun (1892, 1894, 1899). Additional mineralogic data on the mineral assemblages was supplied by F. Bartholmes (1920) and by A. H. Stutz (1940), and field observations by O. Mattirolo (1903, 1904), V. Novarese (1904), E. Argand (1909, 1934) and P. Bearth (1964). The magmatic layering at the Dent de Bertol masse has been studied by P. Bearth (1974) and G. V. Dal Piaz (1974).

Their chronologic and genetic history of the gabbro masses has always

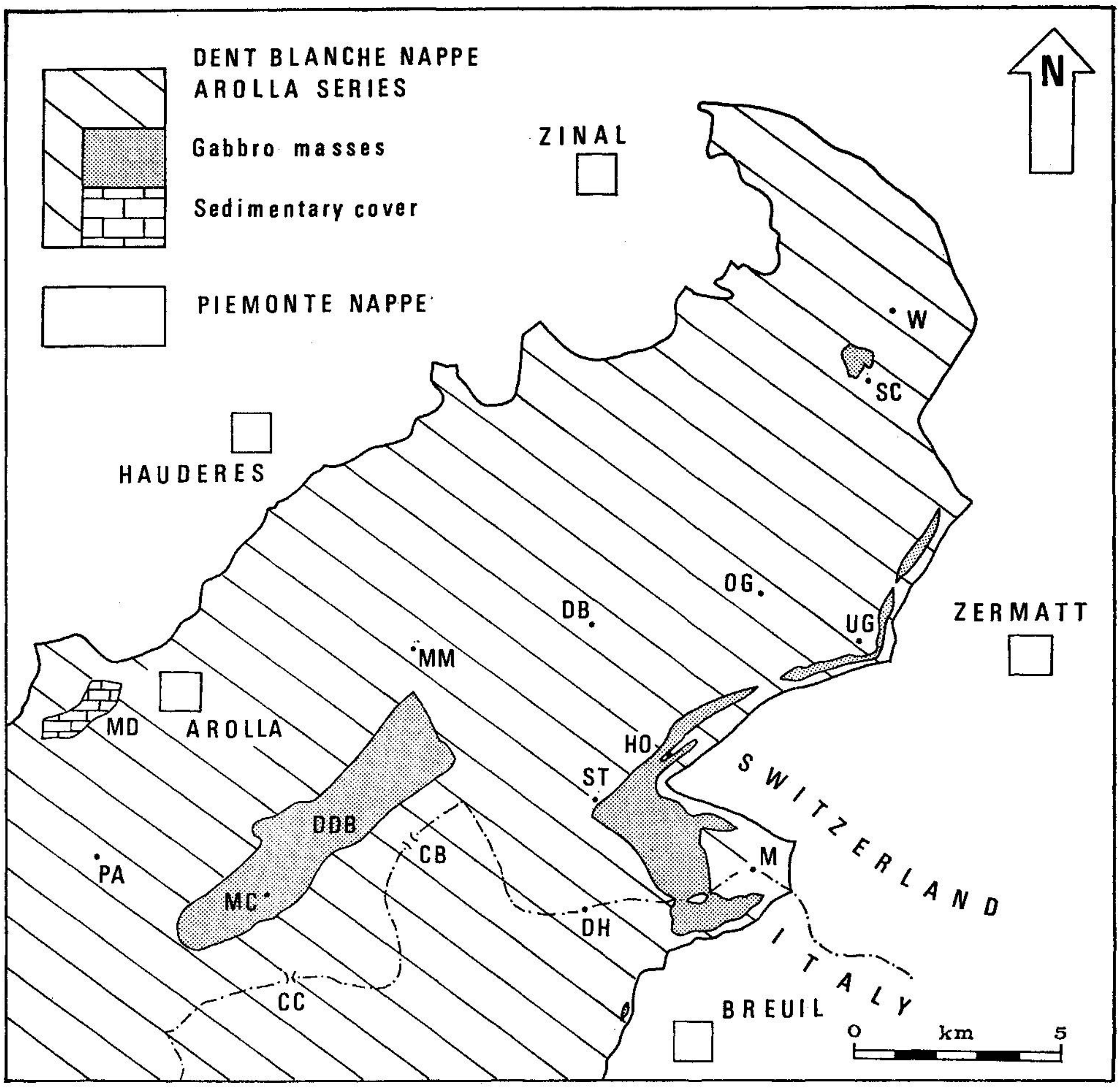

Fig. 1. The Austroalpine gabbro masses within the Northern sector of the Arolla Series, the Dent Blanche Nappe. W: Weisshorn; SC: Schallihorn; OG: Obergabelhorn; UG: Untergabelhorn; DB: Dent Blanche; MM: Mt. Minè; MD: Mt. Dolin; PA: Pigne d'Arolla; HO: Holenbielen-Schönbiel; ST: Stockje; DDB: Dents de Bertol; MC: Mt. Collon; M: Matterhorn; DH: Dent d'Hérens; CB: Col de Bouquetins; CC: Col Collon.

been a controversial point in the literature. H. Gerlach (1869) leans towards a cognate relation with the surrounding metagranitoids and gneisses of the Arolla Series, a hypothesis which was later exhumed by A. H. Stutz (1940). E. Argand originally believed that the Dent Blanche gabbros belonged to the lower-Paleozoic continental crust of the Valpelline Series (1908), then to the upper Paleozoic Arolla Series as loccolitic intrusions within the nucleous of recumbent folds of the Alpine orogenesis during Mesozoic or Tertiary age (1909, 1934). F. Bartholmes (1920) underlined the similarity between the Dent Blanche gabbros and the ophiolitic metagabbros associated with the underlying Piemonte Nappe, both being believed to be the product of the same magmatic process of the ophiolitic cycle, ascribed to a post-thrusting Oligocene phase.

G. V. Dal Piaz (1974) has noted that all Dent Blanche gabbros are separated from the surrounding Arolla gneisses by a thick blastomylonitic horizon, which had been already locally observed by O. Mattirolo (1903) in the southern wall of the Matterhorn. In the opinion of G. V. Dal Piaz (1974), the gabbro masses were introduced into the Arolla metagranitoids of the lower Austroalpine element by a tectonical emplacement, rather than by a magmatic process. The gabbro emplacement very likely occurred between the end of the late-Hercynian granitic cycle and the beginning of the upper-Jurassic ophiolitic volcanism.

In the present paper only the largest and most significant gabbro masses of the Matterhorn and of Mt. Collon-Dents de Bertol are considered.

a) The first body, partly hidden by the Tiefenmatten, Matterhorn and Cervino glaciers, is 580–600 m thick, and covers about 12 km^2. On the southern, western and northern walls of the Matterhorn, the gabbro mass is completely surrounded by the Arolla metagranitoids and gneisses (Fig. 1 and 2). The latter comprise frequent K-feldspar, biotite and rare hornblende as late-Hercynian magmatic relics, and show a greenschist facies overprinting, probably of Lepontine age, characterized by chessboard albite, phengite, epidote, quartz ± actinolite, chlorite, green biotite and stilpnomelane (G. V. Dal Piaz and M. Govi, 1968; G. V. Dal Piaz, 1976). The tectonic contact separating the Matterhorn gabbro from the Arolla gneisses consists of 100 to 250 m thick grey and brown blastomilonites derived from granitoids, and pale green blastomilonites derived from gabbros (Fig. 3). These rocks are particularly well exposed on the Mt. Leone, near the Matterhorn, and in the Stockje and p. 2490 (Schönbiel) areas, sometimes appearing displaced by extension faults (southern wall of the Matterhorn). The granitic blastomylonite contains phengite, epidote, albite, ± green biotite, chlorite and carbonates, often showing new s_1 and s_2 schistosities. Relics of allanite also occur. The gabbroic blastomilonite, on the contrary consists of actinolite, chlorite, epidote and albite ± carbonate, titanite and opaques. Relics of primary brown hornblende are occasionally found.

Generally on its borders the Matterhorn gabbro mass shows a weak to strong metamorphic alteration, mostly of pseudomorphic type and normally preserving the original magmatic textures. A metamorphic enucleation of actinolite after clinopyroxenes or pseudomorphic actinolite I and the growth of independent assemblages rarely and only partially occur. Instead, the nucleous of the gabbro mass often perfectly preserves the magmatic mineral assemblages. The primary structure generally is homogeneous, a poorly defined

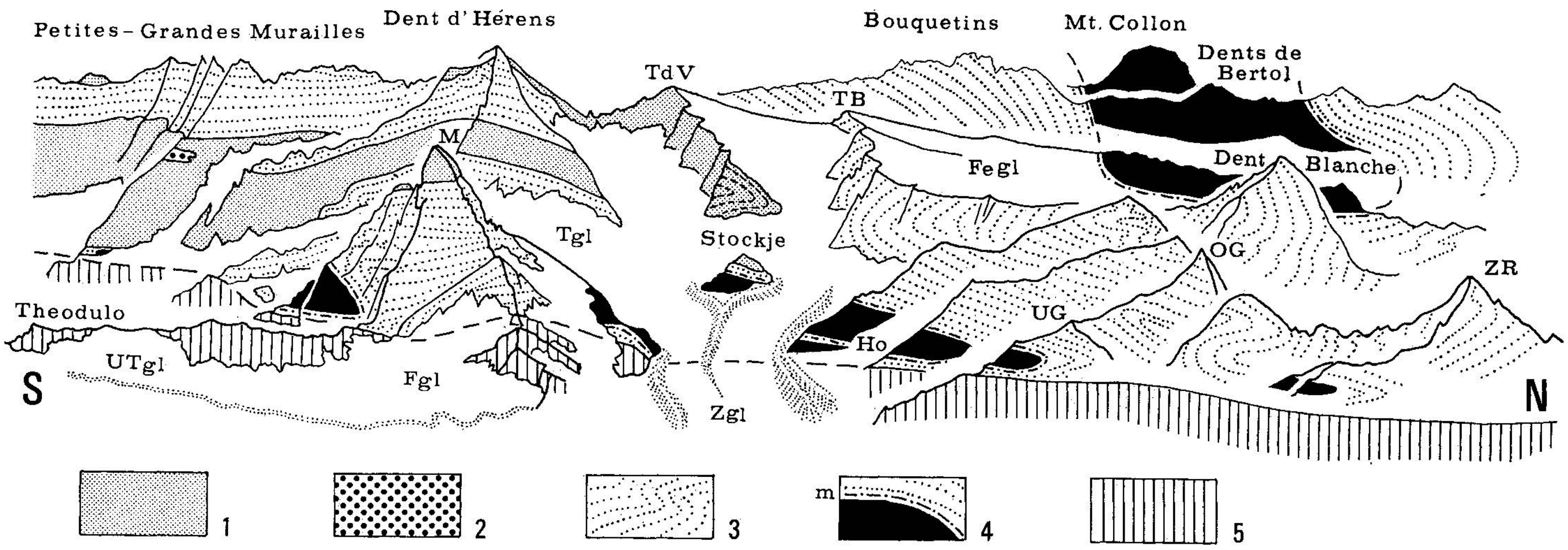

Fig. 2. Panorama of the Northern part of the Austroalpine Dent Blanche Nappe, partly modified after E. ARGAND (1909). 1. The Valpelline Series; 2. the Mt. Blanc du Creton-bivacco Balestrieri unit (G. V. DAL PIAZ, 1976); 3. the Arolla Series, mainly comprising metagranitoids and orthogneisses; 4. the Austroalpine gabbro masses (black) and the surrounding milonite and blastomilonite horizon (m); 5. the underlying ophiolite Piemonte Nappe and the Great St. Bernhard Nappe (only on the right). TdV: Thête de Valpelline; TB: Thête Blanche; M: Matterhorn; OG: Obergabelhorn; UG: Untergabelhorn; ZR: Zinalrothorn; Ho: Holenbielen (or Hohle Bielen); Fegl: Ferpècle glacier; Zgl: Zmutt glacier; Fgl: Furgg glacier; UTgl: Unter Theodul glacier; Tgl: Tiefenmatten glacier (or Tiefmatten gl.).

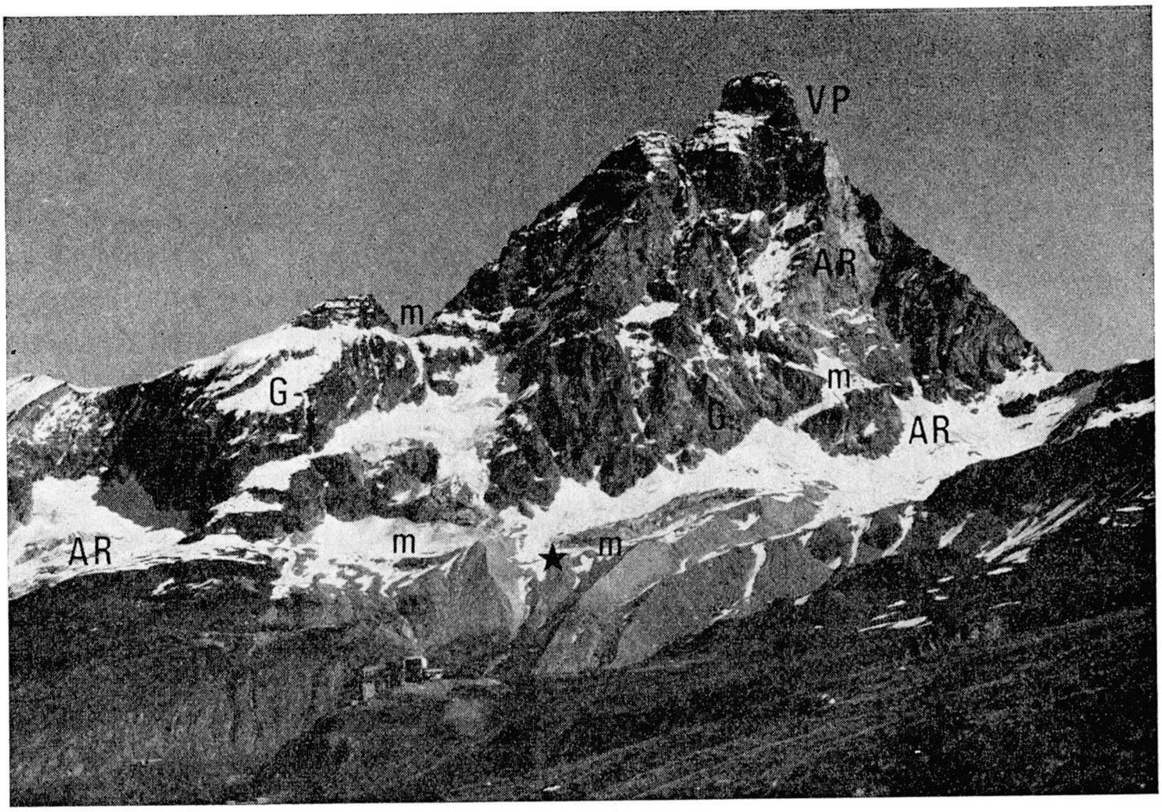

Fig. 3. The Southern wall of the Matterhorn. G: the Matterhorn gabbro lens; m: milonite and blastomilonite horizon; AR: metagranitoids, orthogneisses and scarce paraschists of the Arolla Series; VP: high-temperature paragneisses with interbedded marbles and metabasics of the Valpelline Series; asterisk: the recent landslide with cumulus melagabbros and plagioclase-peridotites. On the bottom of the Matterhorn the Combin Zone and the underlying Zermatt-Saas Zone of the metamorphic ophiolite Piemonte Nappe.

widely spaced mineral layering appears only rarely in the Matterhorn gabbro, and varies from olivine-gabbro to leucogabbro.

Melanocratic and leucocratic dykes of 1 cm to 4 m thickness also occur in the Matterhorn gabbro. Finally on its Southern and Northwestern walls the Matterhorn gabbro contains some intercalations of cumulus ultrabasites, generally as lenticular bodies, corresponding to plagioclase-peridotite and dominantly melagabbro. Access to the outcrops is difficult. Blocks of the recent landslide fallen on the Cervino glacier are easily observable near the Oriondè (Fig. 3) and in the Tiefenmatten moraine. Some anorthosite, troctolite and gabbro layers also occur in these plagioclase-peridotite and melagabbro, sometimes they appear gently folded.

b) The more preserved Mt. Collon-Dents de Bertol gabbro mass is situated by the external side of the Dent Blanche Nappe s.s., near the Arolla village (Fig. 2 and 3). It covers about 14 km^2 partly hidden by the Mt. Collon, Arolla and Miné glaciers, and its actual preserved thickness locally exceeds 1000 m. Like the Matterhorn gabbro, the Mt. Collon-Dents de Bertol mass is

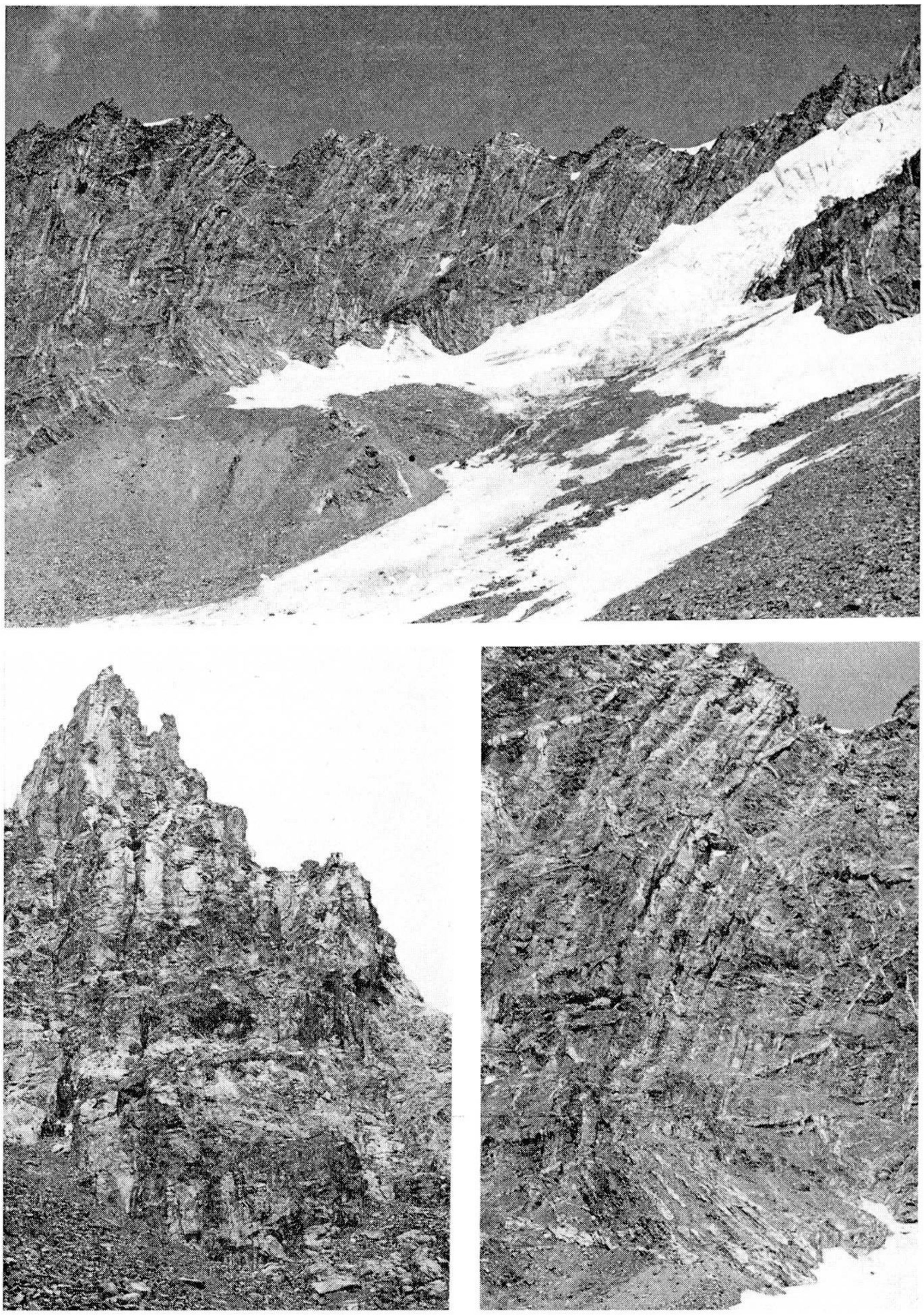

Fig. 4. The steeply dipping and gently folded layered gabbro complex and the cross cutting differentiated dykes of Dents de Bertol Western wall.

also intercalated within the metagranitoids and gneisses of the Arolla Series, and its contact is strongly sheared. Here instead the original roof of the gabbro mass is not preserved, as seen in Fig. 2. In the Arolla metagranitoids, which are mainly composed of metagranodiorites and quartzdiorites, K-feldspar, biotite, quartz and green hornblende frequently occur as relics of the magmatic assemblage. The Alpine metamorphic overprinting is characterized by greenschist facies associations with albite, epidotes, chlorite, white micas, green biotite, ± actinolite and stilpnomelane, belonging to the Lepontine event (J. Bocquet et al., 1974).

The Mt. Collon-Dents de Bertol mass, though lithologically and structurally similar to the Matterhorn gabbro, is distinguished by the large presence of magmatic layering, particularly well exposed on the western wall of the Dents de Bertol (Fig. 4 and 5). In this area the layered sequence is steeply dipping and appears to be about 2.5 km long. According to E. Argand (1909), it probably forms a large asymmetric synform (Fig. 2). The rhythmic layering in the Dents de Bertol area is related to conspicuous variations in the amounts of olivine, pyroxenes and plagioclase, giving rise to repeated sequences of plagioclase-peridotite, melagabbro, gabbro and anorthosite. The melanocratic layers are usually much thinner and are not always present. An igneous lamination rarely occurs in some gabbros and anorthosites, and is defined by the parallelism of tabular crystals.

Fig. 5. The magmatic layering of the Dents de Bertol gabbro sequence.

Numerous melanocratic and leucocratic dykes, more abundant than in the Matterhorn area, cut across the magmatic layering (Fig. 4). In turn, they are transposed and abruptly interrupted by the tectonic contact between the gabbro mass and the surrounding Arolla metagranitoids, and have not been found in the latter.

The Mt. Collon-Dents de Bertol gabbro, like the Matterhorn mass, also shows a weak to pronounced but generally discontinuous alteration, which usually does not destroy the magmatic texture. A more diffuse metamorphic overprinting and structural reworking occur only on its border with greenschist facies mineral assemblages, increasing towards the peripheric milonite horizon and consistent with those of the surrounding Arolla gneisses.

3. MAGMATIC MINERAL ASSEMBLAGES

The main minerals of the Matterhorn and Mt. Collon-Dents de Bertol magmatic assemblages do not differ appreciably, hence they will be described together.

Plagioclase-peridotites and melagabbros

A great part of the ultrabasites which appeared in the field as more or less serpentinized cumulus peridotites, were found to contain more than 10 percent of plagioclase and are therefore classifiable as melagabbros and melanorites (JUGS Subcommission, 1973–1974; A. STRECKEISEN, 1976). They appear as typical cumulates with important amounts of brown hornblende, sometimes more than 10%, and minor phlogopite as intercumulus minerals, the latter two often as large poikilitic crystals (Fig. 6).

The cumulus olivine is frequently well preserved, and sometimes as well as the orthopyroxene corroded, both in plagioclase-peridotites and melagabbros. Its composition, determinated from 5 samples by X-ray measurements (d/130; E. D. JACKSON, 1960) in some cumulus crystals ranging from about Fo 80 to Fo 95. Nevertheless a more significant compositional gap is suggested by its alteration products, which vary from tremolite or talc in fine-grained pseudomorphic aggregates to serpentine + opaques. Sometimes the olivine contains rare drops or little crystals of a first plagioclase generation, often completely altered.

The orthopyroxene is a very common cumulus mineral in these ultrabasites, and coexists in stable association with olivine. It appears in variable amounts, and normally corresponds to a Mg-rich pyroxene.

The plagioclase is commonly zoned. Its rim varies in composition from approximately An_{65} to An_{60}, while the nucleus, which reaches An 80, always appears completely altered to pseudo-opaque saussurite, is indeterminable, but

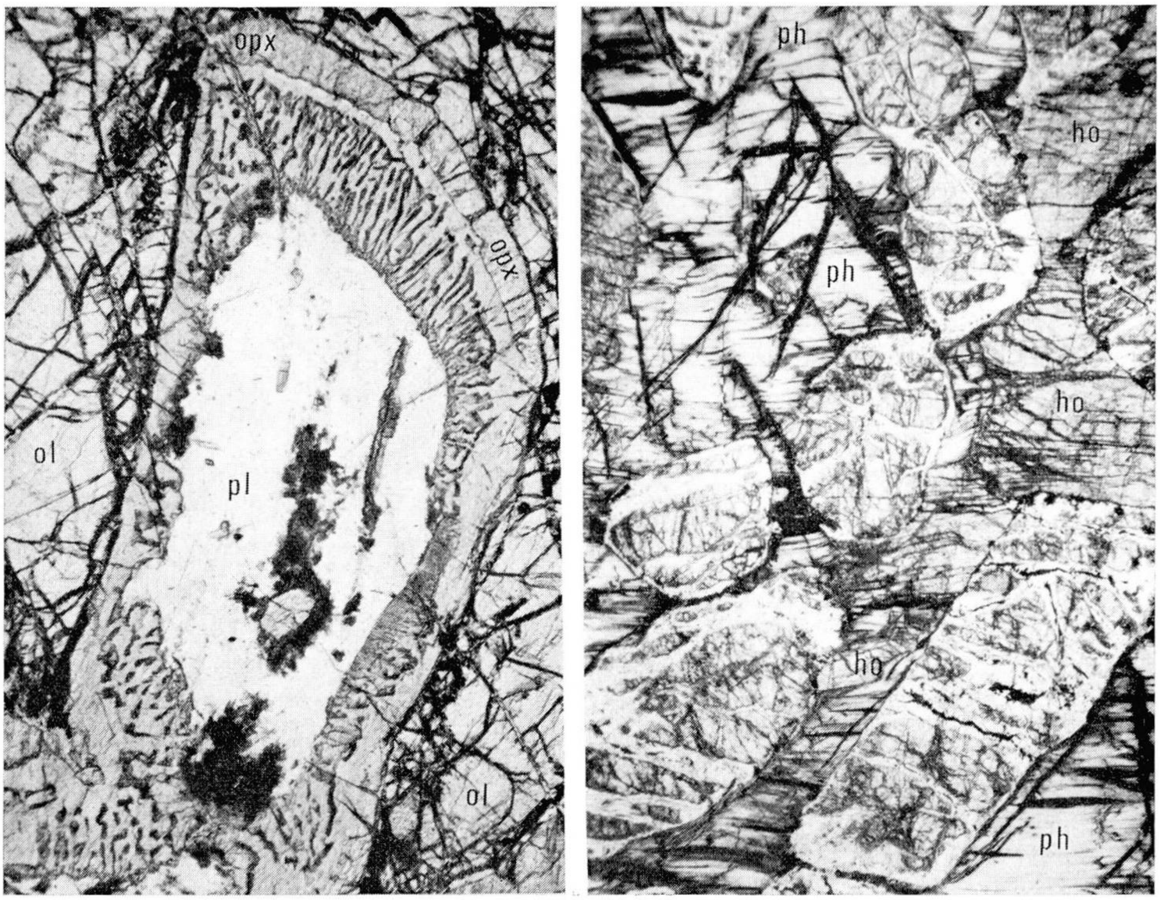

Fig. 6. On the left: orthopyroxene (opx) and pale-green amphibole + green spinel as symplectitic intergrowth giving rise to a reaction corona between olivine (ol) and plagioclase (pl) in a well preserved cumulus gabbro. On the right: partly altered cumulus olivine and large poikilitic krystals of intercumulus brown hornblende (ho) and phlogopite (ph) in the Matterhorn melagabbro.

Table I. *Chemical composition of clinopyroxenes, brown amphiboles and brown micas*

	Cpx 1	Cpx 2	Amph 1	Amph 2	Bi 1	Bi 2	Phl 1
SiO_2	52.21	51.22	42.75	42.99	33.56	33.69	36.55
TiO_2	0.54	0.87	3.19	3.00	3.53	3.57	2.79
Al_2O_3	2.90	3.73	12.80	12.64	19.13	19.18	18.16
Fe_2O_3	4.70*	4.02*	7.68*	7.31*	1.51	2.10	0.06
FeO					20.15	21.28	8.32
MnO	0.09	0.06	0.09	0.06	0.16	0.29	0.11
MgO	17.25	15.64	15.27	15.58	9.17	6.39	20.53
CaO	22.63	23.40	12.07	12.19	0.88	0.75	0.17
Na_2O	1.17	0.54	2.74	1.72	0.28	0.15	1.15
K_2O	0.02	0.05	0.83	0.79	7.76	8.82	7.73
H_2O	n.d.	n.d.	n.d.	n.d.	3.87	3.78	4.43
	101.51	99.53	97.42	96.27	100.00	100.00	100.00

Cpx 1–2, Amph 1–2: microprobe analyses (L. Riccio, Geol. Dept., London, Canada) of clinopyroxenes and brown hornblende from cumulus gabbro of the Matterhorn southern wall, moraine of Cervino glacier; Fe tot. as Fe_2O_3*. Bi 1 (KAW 1367), Bi 2 (KAW 1369): X-ray fluorescence chemical analyses of biotites from leucocratic differentiated dykes cross cutting the magmatic layering of the Dents de Bertol gabbro sequence; Phl 1 (KAW 1305): phlogopite from pegmatite-like pyroxenitic vein associated to cumulus melagabbro of the Matterhorn southern wall.

the epidote-rich saussuritic products still suggest a high-An content. A magmatic reaction zone always occurs between the olivine and the plagioclase. When the olivine is completely surrounded by the plagioclase, it appears as a continuous corona and the following sequence can be observed: olivine; orthopyroxene (1 st, often discontinuous coronitic rim); pale-green edenitic-like amphibole + green spinell as symplectitic intergrowth (2 nd coronitic rim); plagioclase (Fig. 6).

All the plagioclase-peridotites and melagabbros comprise variable amounts of clinopyroxenes and brown hornblende and minor phlogopite. The latter, in spite of frequent kinked deformations, never appears altered. Table I shows one chemical analysis of phlogopite from the Matterhorn melagabbro.

Gabbros

The gabbros of the Dents de Bertol layered sequences and the poorly layered and more altered Matterhorn gabbros look like a two pyroxenes ± olivine type, with minor norite, euphotide and leucogabbro, which normally appear weakly to conspicuously altered. Their magmatic minerals mainly repeat the features of the plagioclase-peridotite and melagabbro group, in spite of a different mineral ratio. Moreover, the gabbros show a larger compositional range of the cumulus plagioclase, from An_{85} to An_{52}, a greater amount of clinopyroxene, often of diallage type and sometimes as unique mafic mineral, and rare to absent olivine.

An intercumulus poikilitic brown hornblende commonly occurs again. Table I shows two microprobe analyses (L. Riccio) of cumulus clinopyroxenes and two of the brown amphibole, all from the Matterhorn gabbro mass.

In the Matterhorn and Dents de Bertol gabbros rare phlogopite are again found, but often as very small lamella.

Leucogabbro-Anorthosites

Numerous leucocratic layers, containing from 70 to 95 percent Ca-rich plagioclase, commonly outcrop within the Dents de Bertol layered sequences and more rarely in the poorly layered or homogeneous masses. Their thickness varies from some cm to some m. The anorthosites commonly show a more pronounced saussuritic alteration than the gabbros. Some well preserved plagioclases vary in composition from An_{75} to An_{70}. Thin troctolitic layers rarely occur in the cumulus melagabbros (Fig. 7).

Dykes

Numerous differentiated dykes of melanocratic to leucocratic composition cut both the layered and the more uniform gabbro masses (Fig. 8 and 9). Their thicknesses vary from 1–2 cm to 4–5 m.

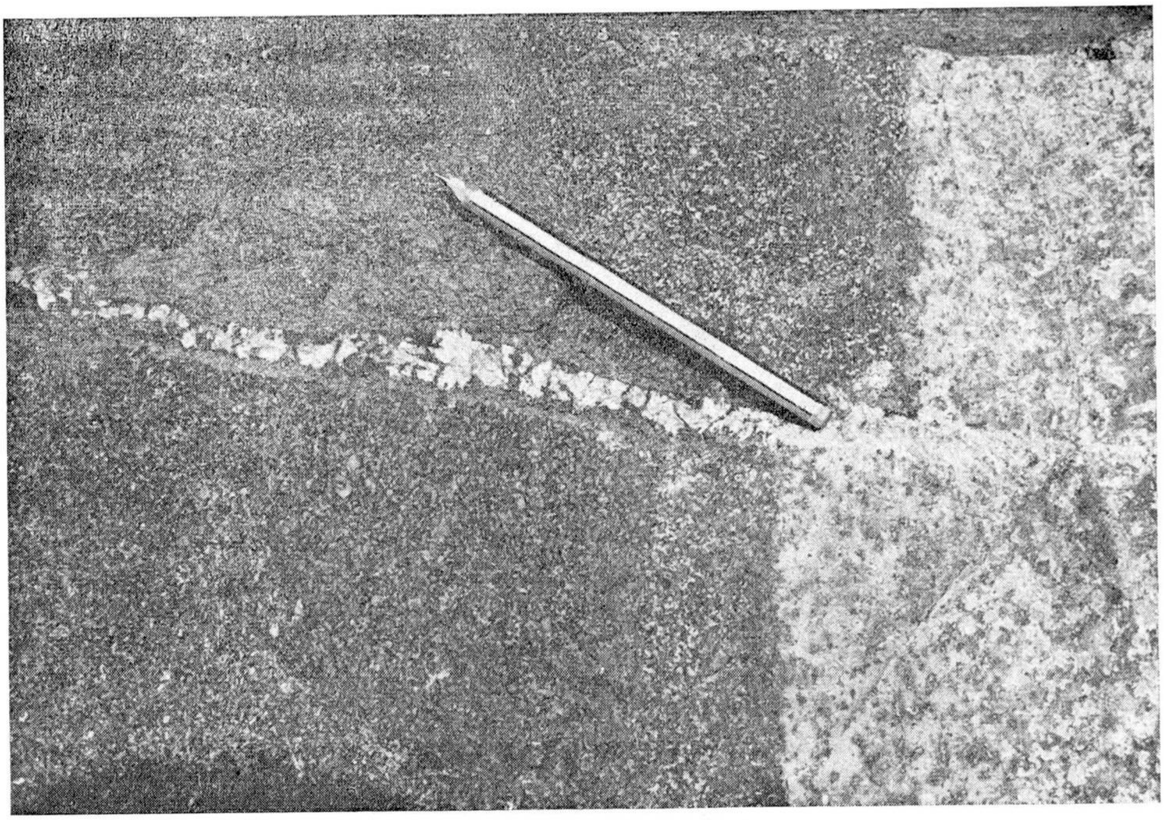

Fig. 7. The cumulus melagabbro and troctolite of the Matterhorn Southern wall have been faulted during a late-magmatic stage and injected by a eufotide-like pegmatite vein.

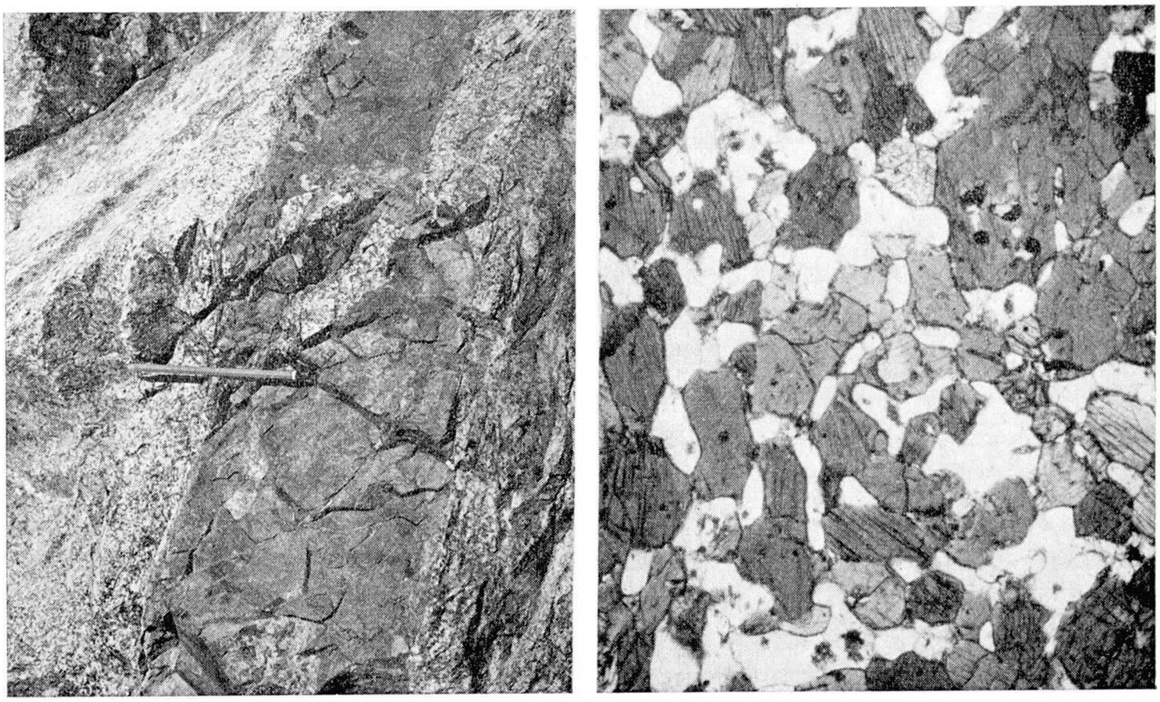

Fig. 8. Melanocratic differentiated dyke of the Dents de Bertol Western wall.

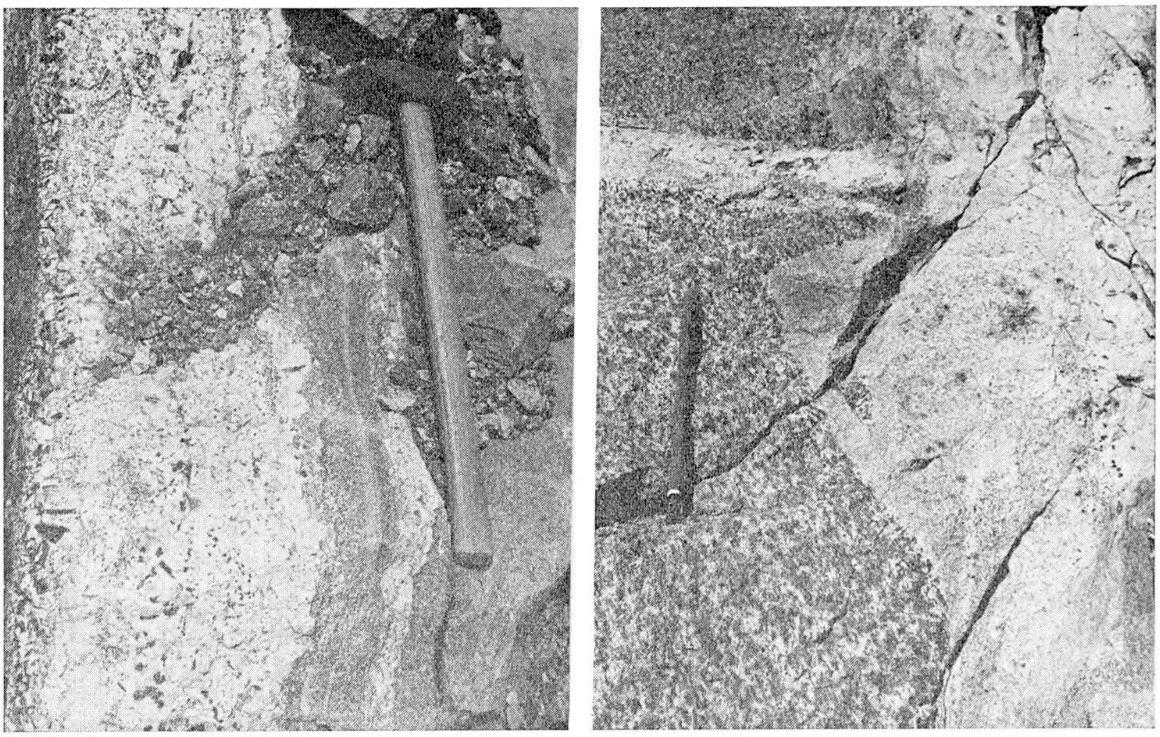

Fig. 9. Leucocratic differentiated dykes from the Dents de Bertol layered sequence. K-feldspar-quartz pegmatite with large crystals of biotite (left); middle-grained quartz-intermediate plagioclase leucocratic dyke grading to irregularly distributed pegmatite (right).

The *melanocratic dykes*, normally fine-grained, show a granular texture, sometimes with a parallel mineral orientation and composition banding. Only one strongly altered ophitic-type dyke has been found, on the Southern wall of the Matterhorn, between the Oriondè and the Leone Hill. The magmatic assemblage of the granular dykes is relatively constant, and normally well preserved, consisting of brown hornblende and plagioclase (An_{70-55}) in about equal amount or with predominating amphibole (Fig. 8). Some comprise minor pyroxene, others scarce brown mica. All dykes are very rich in apatite and opaques, the latter mainly corresponding to magneto-ilmenite and titanite. Thus there is no doubt on their differentiated nature.

Two different groups of *leucocratic dykes* can be distinguished. A first corresponds to quartz-intermediate plagioclase trondhjemites and to middle-grained quartz-diorites with green hornblende, biotite, quartz and a more or less saussuritic plagioclase. The second and more differentiated group is represented by scarce "granophyres" and granites and by abundant pegmatites and fine-grained aplites. Their mineral assemblages comprise K-feldspar, quartz + acid plagioclase and micas, sometimes as centimeter size lamella. Cataclastic to sheared textures often also occur. Some leucocratic dykes show a peculiar zonation, comprising a middle- to fine-grained trondhjemite or quartzdiorite in the core and a pegmatitic rim, often with large crystals of biotite and strongly deformed quartz (Fig. 9). The chemical composition of two biotites, collected from the Dents de Bertol pegmatites, is shown in Table I. Minor amounts of apatite, zircon, titanite and opaques commonly occur in these leucocratic differentiates.

Finally there are also some veins, often irregular, of pegmatitic pyroxenites and euphotides, found within the melagabbro and plagioclase-peridotite masses.

4. ALTERATION PRODUCTS

The Matterhorn and the Mt. Collon-Dents de Bertol gabbro masses represent by far the best preserved mafites of the Western Alps.

In spite of the relative good state of preservation, they show a weak or pronounced mineral alteration, related either to a late-magmatic stage or sometimes also to a rarer metamorphic reworking, which normally has been developed without penetrative deformation. In short, the more unstable minerals and their alteration products can be summarized as follows:

Mg-olivine → talc and/or actinolitic amphiboles.
Fe-olivine → serpentine + opaques.
Orthopyroxenes → talc ± actinolitic amphibole – tremolite.
Plagioclase → saussuritic felt, mottle or tuft,
sometimes with enucleation of rare epidote.

The stabler clinopyroxene and brown hornblende have been only rarely and partially transformed to patches of brown hornblende, and to decolorized hornblende and/or pale, green amphibole respectively.

These mineral alterations are irregularly distributed even at the microscopic scale.

Mineral transformations related to a greenschist facies metamorphic event have been found. An incipient stage, developed under locally static conditions, produces a partial crystallisation of epidotes ± albite after saussurite and an enucleation of tremolite-actinolite aggregates after olivine, pyroxenes and pseudomorphic green amphiboles. These metamorphic transformations are progressively more important towards the border of the gabbro masses or in the internal shear horizons, and become predominant where an alpine schistosity appears. Thus a progressive although discontinuous mineral and structural evolution of the gabbro and related rocks can be observed, from fresh gabbro over saussuritic gabbro and metagabbro with well preserved magmatic structure, towards flaser metagabbro and blastomilonite with a greenschist facies mineral assemblage of Alpine age, comprising tremolite-actinolite amphiboles, epidotes, albite, chlorite, titanite ± white micas ± scarce relics of brown hornblende and clinopyroxene. This late metamorphic re-

Table II. *Bulk rock analyses from the Matterhorn and Dents de Bertol*

Samples (DBL)	229	573	569	612	153	232	611	590	586	28	585	130	595	26	129
SiO_2	39.99	40.00	41.10	41.83	42.40	45.08	46.01	48.56	48.90	48.90	49.07	49.71	49.84	50.19	50.58
Al_2O_3	10.21	6.17	6.40	5.23	12.38	25.83	20.28	29.96	19.59	16.65	15.77	17.47	17.70	17.07	18.93
Fe_2O_3	4.26	5.08	3.70	3.80	2.09	1.70	0.73	0.06	0.55	1.38	0.65	0.74	0.58	1.09	0.71
FeO	6.18	9.02	10.74	11.90	6.75	1.74	4.75	0.63	3.68	4.88	5.16	4.34	4.30	4.61	4.52
MnO	0.13	0.24	0.20	0.24	0.15	0.07	0.09	0.02	0.08	0.13	0.10	0.10	0.09	0.10	0.10
MgO	24.45	25.80	26.50	26.30	22.10	5.93	10.78	0.90	9.03	9.32	11.35	8.35	8.27	8.93	8.48
CaO	5.73	4.03	4.12	6.08	7.32	11.62	11.73	14.31	14.44	11.44	13.21	12.48	13.63	10.31	11.57
Na_2O	0.13	0.78	0.90	0.74	0.88	2.82	1.91	3.04	1.93	2.63	2.07	2.73	2.55	2.74	2.84
K_2O	0.07	0.26	0.28	0.12	0.12	0.92	0.16	0.46	0.15	0.55	0.22	0.32	0.46	0.40	0.28
TiO_2	0.12	1.49	1.38	0.27	0.16	0.08	0.23	0.14	0.34	0.90	0.50	0.60	0.88	0.86	0.54
P_2O_5	0.03	0.07	0.05	0.09	0.04	0.03	0.02	tr	0.02	0.11	0.04	0.08	0.17	0.15	0.03
Cr_2O_3	0.04	0.04	0.04	0.07	0.05	tr	0.05	tr	0.11	0.08	0.06	0.04	tr	tr	0.01
H_2O^+	7.99	6.43	4.00	2.96	4.88	3.87	2.60	1.26	0.81	3.00	1.40	3.05	1.29	3.37	0.94
H_2O^-	0.14	0.11	0.12	0.09	0.22	0.09	0.14	0.10	0.12	n.d.	0.13	0.15	0.09	0.06	0.14
	99.47	99.52	99.53	99.72	99.54	99.78	99.48	99.44	99.75	99.97	99.83	100.16	99.85	99.88	99.67
(ppm)															
Cr	280	255	250	500	368	15	380	60	730	580	390	270	130	130	170
Ni	72	94	95	28	67	37	28	25	23	28	23	28	23	30	29
Rb	2	2	2	2	10	42	15	42	17	2	15	15	10	2	15
Sr	50	105	90	94	272	1186	620	844	515	380	445	390	390	340	405
Zr	>5	20	10	10	72	276	148	231	130	108	127	108	135	104	110
(C.I.P.W.)															
Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	0.41	1.53	1.65	0.70	0.70	5.43	0.94	2.71	0.88	3.25	1.30	1.89	2.71	2.36	1.65
Ab	21.10	6.60	7.61	6.26	7.44	14.62	16.16	21.42	16.33	22.25	17.51	23.10	21.57	23.18	24.03
An	27.07	12.56	12.59	10.59	29.47	55.10	46.29	66.74	44.34	32.00	33.09	34.47	35.49	33.09	38.07
Ne	0.00	0.00	0.00	0.00	0.00	5.00	0.00	2.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di Wo	0.48	2.91	3.13	7.92	2.74	0.97	4.91	1.77	11.34	10.03	13.64	11.24	12.95	7.12	7.98
Di En	0.38	2.24	2.31	5.62	2.06	0.77	3.47	1.16	8.17	7.13	9.64	7.83	9.12	5.06	5.51
Di Fs	0.04	0.36	0.51	1.60	0.40	0.09	1.02	0.47	2.14	2.02	2.83	2.46	2.71	1.44	1.82
Hy En	20.94	15.47	10.87	6.81	8.90	0.00	1.75	0.00	2.99	3.95	2.61	3.44	0.83	13.17	6.48
Hy Fs	2.70	2.49	2.43	1.94	1.72	0.00	0.51	0.00	0.78	1.12	0.76	1.08	0.24	3.75	2.15
Ol Fo	27.72	32.60	36.99	37.17	30.87	9.80	15.14	0.75	7.93	8.48	11.21	6.66	7.44	2.80	6.39
Ol Fa	3.94	5.79	9.11	11.70	6.60	1.30	4.91	0.33	2.29	2.64	3.62	2.31	2.44	0.87	2.33
Mt	6.17	7.36	5.36	5.50	3.03	2.46	1.05	0.08	0.79	2.00	0.94	1.07	0.84	1.58	1.02
Il	0.22	2.82	2.62	0.51	0.30	0.15	0.43	0.26	0.64	1.70	0.94	1.13	1.67	1.63	1.02
Ap	0.07	0.16	1.11	0.21	0.09	0.07	0.04	0.00	0.04	0.26	0.09	0.18	0.40	0.35	0.07

working postdates the shear and milonite horizon separating the gabbro masses from the surrounding Arolla gneisses, and in accordance with the greenschist facies overprinting of Lepontine age shown by the Arolla Series.

5. CHEMISTRY

Previous conventional gravimetric analyses of the Mt. Collon gabbro mass include 5 published by A. Brun (1894) and reproduced by A. H. Stutz (1940).

X-ray fluorescence bulk chemical analyses on 22 samples of the Matter-

Table III. *Bulk rock analyses of differentiated dykes from Matterhorn and Mt. Collon gabbro masses*

Samples (DBL)	605	139	32	591c	591r	622	610
SiO_2	42.10	46.13	48.89	58.80	72.55	75.68	78.40
Al_2O_3	13.95	17.97	17.60	21.30	15.55	14.12	12.80
Fe_2O_3	2.00	1.95	3.16	0.21	0.02	0.05	0.02
FeO	8.92	7.91	5.17	2.34	0.20	0.50	0.06
MnO	0.14	0.16	0.12	0.05	tr	0.03	0.01
MgO	12.25	6.25	7.04	2.05	0.06	0.18	0.18
CaO	11.40	10.74	8.99	5.95	1.37	1.60	2.58
Na_2O	2.47	3.20	2.43	5.89	3.50	5.90	4.98
K_2O	0.50	0.39	0.04	0.50	6.25	1.28	0.16
TiO_2	2.30	2.63	1.66	0.49	0.03	0.07	0.06
P_2O_5	0.32	0.72	0.30	0.29	tr	0.03	0.02
Cr_2O_3	0.09	tr	tr	tr	tr	tr	tr
H_2O^+	2.83	1.64	4.50	1.92	0.38	0.42	0.51
H_2O^-	0.15	0.05	0.11	0.16	0.10	0.06	0.04
	99.42	99.74	100.01	99.95	100.01	99.92	99.82
(ppm)							
Cr	600	120	170	15	60	10	10
Ni	38	18	29	26	27	28	26
Rb	2	2	15	37	171	70	30
Sr	510	380	405	390	216	120	265
Zr	132	112	110	132	170	100	102
(C.I.P.W.)							
Q	0.00	0.00	4.92	6.08	25.10	32.47	43.19
Or	2.95	2.30	0.23	2.95	36.93	7.55	0.94
Ab	7.24	27.05	20.56	49.84	29.61	49.92	42.13
An	25.50	33.51	36.99	27.62	6.79	7.74	12.10
Ne	7.39	0.01	0.00	0.00	0.00	0.00	0.00
Di Wo	12.09	6.28	2.35	0.00	0.00	0.00	0.23
Di En	8.17	3.79	1.71	0.00	0.00	0.00	0.20
Di Fs	2.99	2.16	0.42	0.00	0.00	0.00	0.00
Hy En	0.00	0.00	15.81	5.10	0.14	0.44	0.24
Hy Fs	0.00	0.00	3.93	3.40	0.30	0.81	0.00
Ol Fo	15.64	8.24	0.00	0.00	0.00	0.00	0.00
Ol Fa	6.32	5.18	0.00	0.00	0.00	0.00	0.00
Mt	2.89	2.82	4.58	0.30	0.02	0.07	0.02
Il	4.36	4.99	3.15	0.93	0.05	0.13	0.11
Ap	0.75	1.70	0.71	0.68	0.00	0.07	0.04
C	0.00	0.00	0.00	0.94	0.53	0.19	0.00

horn and Dents de Bertol gabbro masses were performed for the present study by GP. DE VECCHI and G. MEZZACASA. The employed analytical method used is described by GP. DE VECCHI et al. (1968). The data are reported on Tables II and III respectively for 17 ultrabasites, gabbros and anorthosites and for 7 differentiated dykes. Location and mineral assemblage of the samples are summarized in the Appendix.

The first 5 analyses in Table II correspond to cumulus ultrabasites showing a modal composition of melagabbro. Except for the well preserved sample DBL 612, the other ones appear partly altered, above all the olivine and plagioclase. The common characteristic of these ultrabasics is the relatively high amount of whole alkalis (0.20–1.18 percent) and the low MgO content (from 22.10 to 26.50).

Other analyses in Table II correspond to 8 different types of gabbro, either from the Dents de Bertol layered sequence (DBL 585, 586, 595, 611) or from the more homogeneous Matterhorn mass (DBL 26, 28, 129, 130), and to 1 anorthosite from the Dents de Bertol layered gabbro (DBL 590) and 1 leucotroctolite from the Southern Matterhorn layered peridotites (DBL 232). Only the samples DBL 129, 585, 586 and 595 still show well preserved magmatic assemblages, the other ones being more or less altered. All samples do not show particular differences, except a variable H_2O amount which corresponds to the content of brown hornblende and mica and above all to the degree of alteration of olivine. The oxidization state ($Fe^{2+} \rightarrow Fe^{3+}$) of the analyzed gabbros is weak. These samples distinguish themselves from the previous group in relation with respect to their strong increasing content of Al_2O_3, CaO, Alkalis and some minor elements (Rb, Sr, Zr) and with a corresponding decrease of MgO and whole Fe.

The analyzed dykes exposed in Table III are subdivided as following: 3 of them correspond to melanocratic differentiates either with a microgranular texture and well preserved magmatic assemblage (DBL 139, Matterhorn; DBL 605, Dents de Bertol), or appearing strongly altered and with ophitic texture (DBL 32, Matterhorn). The other 4 correspond to leucocratic dykes, either zoned (DBL 591c: trondhjemitic core; DBL 591r: pegmatitic rim) or to homogeneous pegmatite (DBL 610) and aplite (DBL 622). All the leucocratic dykes were collected from the Dents de Bertol gabbro mass, cross cutting the magmatic layering. Except for the aplites and pegmatites, other leucocratic and all melanocratic differentiates have a very high Ti and P content.

The AFM and CFM diagrams are shown in Fig. 10, along with the tholeiitic (R. L. WAGER and W. A. DEER, 1939), and calc-alkaline (R. A. DALY, 1933) differentiation trends. The plagioclase-peridotites plus melagabbros and the gabbros are concentrated into two restricted and well separated fields respectively, the second also comprising most of the metagabbros of the ophiolite Piemonte Nappe (G. V. DAL PIAZ et al., in press).

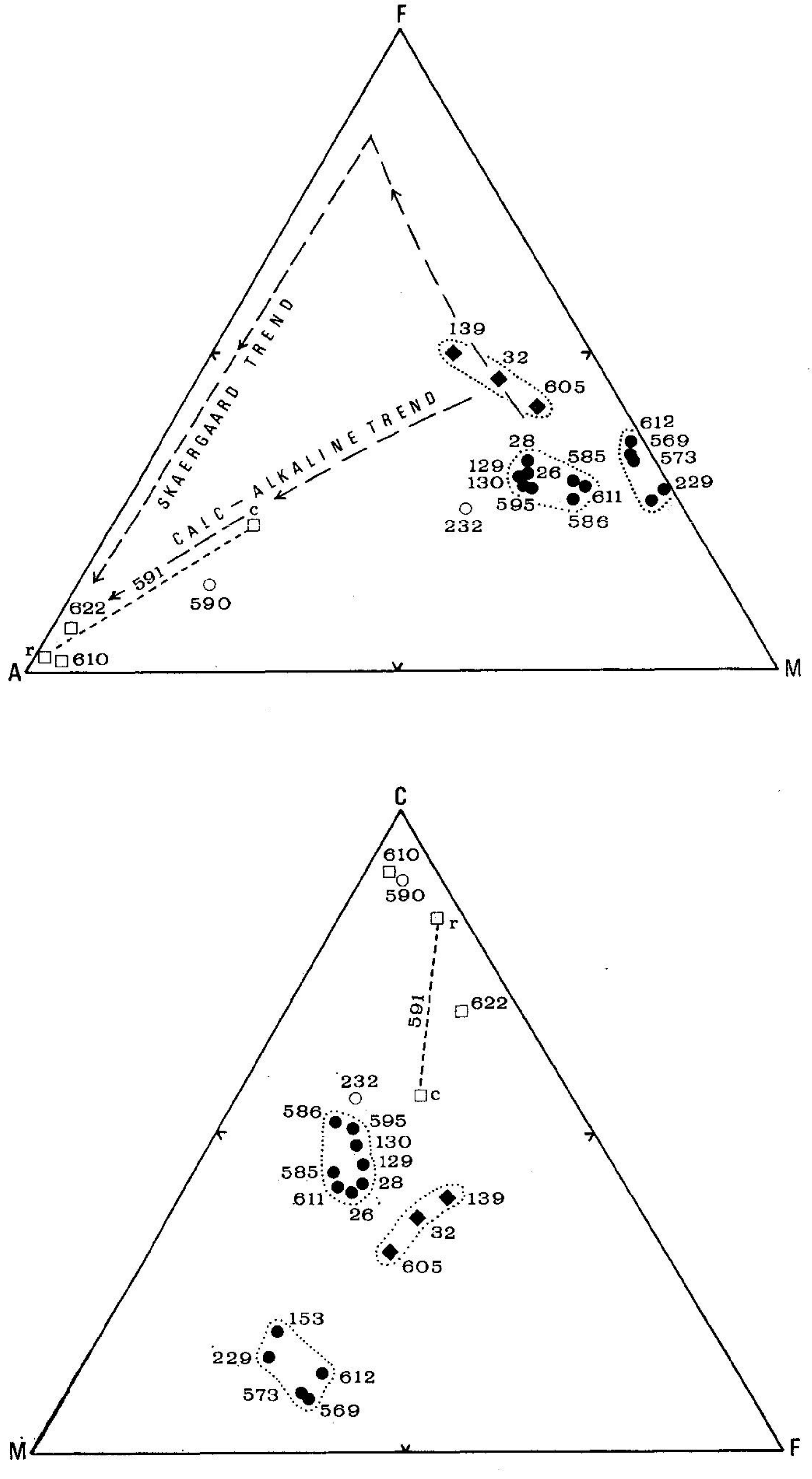

Fig. 10. The AFM and CFM diagrams of the analysed samples from the Matterhorn and Dents de Bertol gabbro masses. Closed circles: cumulus melagabbros and gabbros; open circles: cumulus anorthosites from the layered sequences; closed squares: melanocratic dykes; open squares: leucocratic dykes; c–r) core and rim of a zoned dyke (sample 591).

The plotted cumulates seem to indicate a calc-alkaline differentiation trend, this alone is not sufficient evidence, because the rocks in question are cumulates. Nevertheless the absence of typical ophiolitic Ferrogabbros seems to exclude an oceanic ridge origin. A chilled margin has not been found in the Matterhorn and Mt. Collon-Dents de Bertol masses.

6. K-Ar AND Rb-Sr DETERMINATIONS

On 8 samples of this work Rb-Sr and K-Ar determinations were performed. The isotope data and age determinations are listed in table IV and the sample locations in the appendix.

Table IV. *Rb-Sr and K-Ar Results*

KAW No.	Mineral	^{40}Ar 10^{-6} cm^3/g	% rad.	% K	Age m.y.
1369	Biotite	65.38	93.8	6.25	250 ± 8
1367	Biotite	66.30	96.8	6.46	246 ± 8
1305	Biotite	57.72	86.7	5.46	252 ± 9

KAW No.	Mineral	^{87}Rb	^{87}Sr rad.	Sr common	% rad.	Age	corr. age
1367	Biotite	123.8	0.4467	11.56	35.7	254 ± 11	257 ± 6
1369	Biotite	126.1	0.4355	7.20	46.6	242 ± 9	245 ± 5
1305	Biotite	80.56	0.2584	59.77	5.86	226 ± 70	251 ± 16

	Rb ppm	Sr common ppm	Sr^{87}/Sr^{86} meas.	$^{87}Sr/^{86}Sr$	initial
1303 total	6.82	481	0.014	0.70505 ± 20	0.7036
1305 total	9.42	145	0.065	0.70540 ± 20	0.7038
1306 total	3.63	389	0.009	0.70515 ± 20	0.7042

Rb + Sr were determined on an AVCO solid source mass-spectrometer, the analytical techniques are described in JAEGER (1962) and BRUNNER (1973). For the Rb-Sr and K-Ar measurements the isotopic ratios and constants were used, following the convention of the I.U.G.S. subcommission on geochronology, compiled by STEIGER and JAEGER, 1977.

$$^{86}Sr/^{88}Sr = 0.1194 \text{ atomic ratios}$$
$$^{84}Sr/^{86}Sr = 0.056584 \text{ atomic ratios}$$
$$\lambda^{87}Rb = 1.42 \cdot 10^{-11}/y$$
$$^{85}Rb/^{87}Rb = 2.59265 \text{ atomic ratios}$$
$$\lambda 40_{K\beta-} = 4.963 \cdot 10^{-10}/y$$
$$\lambda 40_{K\epsilon} + \lambda 40_{K\epsilon'} = 0.581 \cdot 10^{-10}/y$$

Isotopic abundance of ^{40}K in K = 1.167×10^{-4} moles/mole.

K was determined on a Beckmann flame photometer, and Ar on a Varian GD150 mass spectrometer. The spike comes from Clusius, Zurich, and is 99.99% ^{38}Ar. The spike was calibrated against P 207 of the US. GS. with a value of 28.15×10^{-6} CM^3 $^{40}Ar/g$ STP. A more detailed description is given in HUNZIKER (1974).

The low $^{87}Sr/^{86}Sr$ value of less than 0.704 as well as the Rb/Sr ratio of less than 0.02 for the best preserved mafic and ultramafic rocks, show that the present tectonic setting in the continental crust is not original. Most likely these mafites originated in the Upper Mantle and a cool tectonic emplacement with very little or no contamination during transport can be considered. The concordant K-Ar and Rb-Sr data on biotites from leucocratic dykes and whole rocks of fine grained melanocratic dykes and on phlogopite from a pyroxenite of around 248 m.y., i.e. according to ARMSTRONG and MCDOWALL (1974) the Permo-Triassic boundary (about 247 m.y.), poses chronological problems – are these rocks late Hercynian or early Alpine?

The Hercynian cycle in the Alps shows a late Hercynian metamorphic and magmatic stage around 270–290 m.y. On the other hand the Mesozoic ophiolitic cycle marks the beginning of the Alpine events.

The chemical trend between the Matterhorn – Mont Collon – Dents de Bertol mafic and ultramafic rocks and the Mesozoic ophiolites (see following chapter), is the best argument in favour of a protoalpine age of our rocks. The tectonic setting is in good agreement with such an interpretation. Unfortunately, the Rb-Sr ratios are too unfavorable to allow a precise total rock Rb-Sr age determination, and the ages we have measured must be considered as cooling ages. On the other hand control on the cooling rate of these mafic and ultramafic bodies is lacking so that the argument of a considerable time gap at least 20 m.y. between the late Hercynian event and the cooling ages of the Matterhorn Collon-Dents de Bertol rocks alone is not very convincing.

The 30 available isotopic age data on ophiolites of the Alps (BERTRAND and DELALOYE, 1976) suggests two groups: 165 to 180 m.y. and 135 to 150 m.y. However it must be held in mind that the range of 210 to 38 m.y. was covered by these data and that all the dated ophiolites came from an Alpine prehnite-pumpellyite to greenschist facies environment, so that the question arises as to how much of the primary age and how much of the metamorphic overprint is reflected by the scattering ages, so that we are not at all sure that completely unmetamorphosed ophiolites could not be older than 180 m.y. In the light of this interpretation our data on the Matterhorn – Mont Collon – Dents de Bertol rocks of around 250 m.y. marking the beginning of the "ophiolite" cycle is in good agreement with the reinterpreted data of BERTRAND and DELALOYE (1976) and with the geodynamic setting presently envisaged.

7. CONCLUDING REMARKS

The most important feature of the Matterhorn and Mt. Collon–Dents de Bertol gabbro masses appears to be their cumulus structure and the magmatic layering which above all is well exposed on the Dents de Bertol area. The cumulus minerals of the layered sequences can be summarized as following: ol – opx ± spin; ol – opx – plag ± clpx; opx – plag ± clpx; plag. The intercumulus mineral assemblage always comprises aboundant brown hornblende, sometimes more than 10 percent in volume, often with minor phlogopite, pointing out the H_2O role in the magmatic cristallisation. In the relatively most mafic rocks also the plagioclase and the clinopyroxene can appear as intercumulus crystals.

No traces of basaltic flows and sediments have been found in association with the gabbros, which are directly intercalated within the Arolla metagranitoids.

At present the Matterhorn and Mt. Collon-Dents de Bertol gabbro, as well as other minor masses, belong to the lower tectonic element of the Dent Blanche Nappe, also known as ARGAND's Arolla Series. This unit, a slice of very thinned and upper continental crust, correspond to a dismembered and transported fragment of the Austroalpine continental margin (G. V. DAL PIAZ et al., 1972; J. C. HUNZIKER, 1974; R. COMPAGNONI et al., 1975). However none of the field observations and of the geochemical data can indicate that these gabbro masses have been always associated with this granitic crust and always have maintained the present structural position. The gabbro masses on the contrary appear to be clearly separated from the surrounding Arolla metagranitoids and gneisses by a large and uninterrupted shear zone, comprising milonites and blastomilonites, which also abruptly cut the differentiated dykes. Beside none of these dykes, except some similar but not equivalent gneissic aplites, have been found in the Arolla Series. The general features of the gabbro masses suggest the significant role played by a tectonic intrusion mechanism for their emplacement in the Austroalpine continental crust.

Concerning some features above all of macroscopic type, as were pointed out by R. W. SCHAEFER (1896), F. BARTHOLMES (1920) and E. ARGAND (1934), the Austroalpine gabbros appear to be similar to the ophiolite metagabbros of the underlying Piemonte Nappe, obviously disregarding the strong metamorphic overprinting of this latter.

Nevertheles there are also some more significant differences. The Matterhorn and Mt. Collon-Dents de Bertol gabbro masses commonly comprise important amounts of cumulus ortopyroxene (in stable coexistence with olivine) and of brown hornblende and minor phlogopite as intercumulus crystals, which seem to be absent or very scarce as magmatic minerals in the ophiolite metagabbros and gabbros of the Ligure-Piemontese Zone. In fact the ophiolite gabbros normally correspond to an euphotide-like or to a more scarce olivine-clinopyroxene gabbro and the sporadic occurrence of brown and/or green hornblende is commonly referred to a high-grade ocean floor metamorphism (L. Cortesogno et al., 1975, with references). In the Alpine ophiolitic metagabbros the ortopyroxene, which has been found at the Allalin mass, appears only as reaction mineral between olivine and plagioclase (P. Bearth, 1967). Hence the coexisting alovine-orthopyroxene as cumulus crystals and the occurring brown hornblende and minor phlogopite as intercumulus minerals respectively seem to indicate for the Austroalpine gabbros a relatively deeper consolidation level and likely higher P_{H_2O} value than the common ophiolite gabbros.

Other differences concern the occurrence of a well preserved Ca-rich plagioclase, normally altered in the ophiolites, and moreower the remarkable abundance in the Matterhorn and Mt. Collon-Dents de Bertol gabbros of leucocratic differentiates, which are absent or very scarce in the Piemonte ophiolites. At last no traces of an oceanic low- to intermediate-grade alteration have been found in the first, while this process commonly appears in the second ones (G. V. Dal Piaz, 1974, with references).

The gabbro masses of the Dent Blanche Nappe show a isotopic age of around 248 m.a., approximately corresponding to the Permo-Triassic boundary. In spite of this more recent age, they could be referred to the late metamorphic and magmatic stage of the Hercynian orogenesis, occurring around 290–270 m.a. (J. C. Hunziker, 1974). Nevertheless this hypothesis is clearly unallowable. While the late-Hercynian magmatism is characterized with very high Sr^{87}/Sr^{86} ratios, resulting from a continental crust melting (C. D'Amico, 1974, with references), the Sr^{87}/Sr^{86} and Rb/Sr very low ratios and other features of the Dent Blanche gabbros indicate at the contrary their undercrustal origin and supply a different geodynamic interpretation.

The chemical whole-rock data unfortunately can not define the composition of the parent magma and its evolutionary environment. However the chemistry of two analysed Ca-rich clinopyroxenes, whose Al_2O_3 and TiO_2 contents are similar to those of some olivin-tholeiites (I. S. E. Carmichael et al., 1974), suggest a subalkaline affinity of the original melt.

The gabbro masses of the Austroalpine Dent Blanche Nappe could derivate from a subalkaline parent magma consolidated within a closed magmatic chamber which was situated:

a) Within a lower continental crust, subsequently destroyed during the Mesozoic crustal tearing and thinning and/or during the early-Alpine tectonic event. At present it is without relation with the gabbros which appear tectonically intercalated within the upper continental crust of the Arolla Series;

b) more likely at the boundary between an upwelling hot mantle and an already partly thinned continental crust.

Hence the Matterhorn and Mt. Collon-Dents de Bertol gabbro masses are indicative of thermal doming, mantle upwelling and crustal spreading, which afterwards led to the growth of the Piemonte oceanic crust and ophilite sequence. This crustal spreading and the related extensional magmatism started in Proto-Alpine time and not in the Hercynian.

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APPENDIX

Location and mineral assemblages of the analysed samples

1. Southern wall of the Matterhorn

DBL 26 Saussuritic metagabbro, still preserving the primary texture, outcropping near the pluviometer (3400 m) between the Oriondè and the Leone Hill. Mineral assemblage: policrystal aggregates of tremolite-actinolite amphiboles, after pyroxenes; fine-grained pseudo-opaque saussurite; scarce epidotes and altered phlogopite; rare relics of clinopyroxene and brown hornblende; minor green amphibole, chlorite, albite, sericite, titanite and opaques.

DBL 28 Saussuritic metagabbro, completely perserving the magmatic texture, near the "Sasso dello zucchero" (3300 m), between the Oriondè and the Leone Hill. Mineral assemblage: cumulus corroded clinopyroxene, almost completely substituted by tremolite-actinolite ± chlorite aggregates; pseudo-opaque saussurite ± epidotes, chlorite, albite and sericite replacing the original Ca-rich plagioclase; aboundant amount of intercumulus brown hornblende; green hornblende, phlogopite, titanite, rutile and opaques as minor components.

DBL 32 Fine-grained metabasic dyke cross cutting the gabbro at 3160–3120 m, northward the Oriondè. Mineral assemblage: actinolite, epidotes, chlorite and albite with minor opaques and apatite; phantoms of ophitic texture.

DBL 129 Middle-grained olivin-gabbro from the right moraine of the Cervino glacier. Mineral assemblage: poorly altered olivine and orthopyroxene, plagioclase (An_{68-62}), clinopyroxene, brown hornblende and scarce phlogopite; minor green hornblende, saussuritic tufts, epidotes, chlorite, carbonate and opaques.

DBL 130 Saussuritic olivin-metagabbro, still preserving the magmatic texture, from the left moraine of the Cervino glacier. Mineral assemblage: scarce and completely transformed olivine, partly altered orthopyroxene, clinopyroxene more or less substituted by tremolite-actinolite amphiboles, brown hornblende; scarce talc and epidotes; minor chlorite, albite, carbonate, green hornblende, phlogopite and opaques.

DBL 139 Melanocratic granular dyke, cross cutting the gabbro; loc. idem. Mineral assemblage: brown hornblende, plagioclase (An_{58-57}) and partly altered orthopyroxene; apatite, opaques, saussuritic tufts and dark-green hornblende as minor minerals.

DBL 153 and KAW 1304 Cumulus melagabrro from the recent landslide fallen from about p. 3558 of the Matterhorn Southern wall on the Cervino glacier Western side. Mineral assemblage: partly serpentinised olivine and orthopyroxene as cumulus crystals; almost completely saussuritized plagioclase (An_{80}); clinopyroxene; poikilitic brown hornblende and scarce phlogopite as intercumulus minerals; minor opaques.

DBL 229 Completely altered cumulus melagabbro, still preserving the magmatic texture; loc. idem. Mineral assemblage: aboundant aggregates of tremolite-actinolite amphiboles and serpentine; scarce relics of pyroxenes and of intercumulus brown hornblende; scarce saussuritized plagioclase; minor opaques and carbonate.

DBL 232 and KAW 1303 Metamorphic leucotroctolite as thin layer within the cumulus melagabbro; loc. idem. Mineral assemblage: tremolite + serpentine pseudomorphic aggregates after olivine; predominating saussuritic plagioclase, partly recrystalized to epidotes + scarce albite and sericite; traces of decolorized phlogopite.

KAW 1305 Vein of pegmatitic pyroxenite, cross cutting the cumulus melagabbro; loc. idem.

KAW 1306 Middle-grained two-pyroxenes saussuritic gabbro; loc. idem.

2. *Western and Northern walls of the Matterhorn*

DBL 569 Cumulus melagabbro from the lowest part of the right moraine of the Zmutt glacier. Mineral assemblage: cumulus orthopyroxene, poorly altered to serpentine + opaques; scarce saussuritized plagioclase; orthopyroxene and pale-green amphibole + spinel symplectite as reaction rim between olivine and plagioclase; aboudant intercumulus crystals of poikilitic clinopyroxene, brown hornblende and phlogopite; minor cumulus green spinel and opaques.

DBL 573 Cumulus melagabbro; loc. idem. Mineral assemblage: cumulus orthopyroxene, partly altered to fine-grained talc aggregates, and irregularly transformed olivine (to serpentine + opaques or to tremolite); scarce cumulus green spinel; clinopyroxene, brown hornblende, scarce saussuritized plagioclase and kinked phlogopite as intercumulus minerals; minor symplectite, green amphibole, tremolite, talc and opaques.

3. Western wall of Dents de Bertol

DBL 585 Cumulus olivin-gabbro from the layered sequence of the Dents de Bertol Western wall. Mineral assemblage: well preserved plagioclase (An_{66-63}), olivine and clinopyroxene; scarce orthopyroxene partly substituted by fine-grained talc aggregate; pale-green amphibole + spinel or plagioclase symplectites; spotted transformation of pyroxene to brown hornblende; intercumulus brown hornblende; minor saussuritic tufts, green amphibole, titanite and opaques.

DBL 586 Olivin-gabbro; loc. idem. Mineral assemblage: strongly deformed plagioclase (An_{75-72}), olivine and brown hornblende; scarce orthopyroxene, symplectite and phlogopite; minor saussurite, talc, serpentine and opaques.

DBL 590 Anorthosite from the layered sequence near p. 2818 of the Dents de Bertol Western wall. Mineral assemblage: poorly saussuritized zoned plagioclase (An_{80-58}) with parallel mineral orientation; minor amount of epidotes, carbonate and sericite.

DBL 591 Zoned leucocratic dyke cross cutting the magmatic layering. The Dents de Bertol Western wall. Core (c): middle- to fine-grained quartzdiorite with partly saussuritized intermediate plagioclase, strongly deformed quartz, almost completely altered biotite (to chlorite), titanite, opaques ± epidote; minor green hornblende. Rim (r): coarse-grained pegmatite with pertitic microcline, tape-like deformed quartz and minor amount of biotite, albite and chlorite.

DBL 595 Two-pyroxene gabbro from the right moraine of the lower Arolla glacier. Mineral assemblage: plagioclase (An_{80-58}), clinopyroxene and scarce orthopyroxene; intercumulus brown hornblende and kinked phlogopite; minor opaques, talc, tremolite.

DBL 605 Fine-grained melanocratic dyke with granular texture from the Dents de Bertol Western wall. Mineral assemblage: brown hornblende and poorly saussuritized plagioclase (An_{68}); apatite, opaques as minor components; veins of albite and carbonate.

DBL 610 Pegmatitic rim of a zoned trondhjemite dyke, cros cutting the magmatic layering near p. 2818 of the Dents de Bertol Western wall. Mineral assemblage: sheared quartz and partly altered plagioclase.

DBL 611 Olivin-gabbro from the Dents de Bertol Western wall. Mineral assemblage: partly altered olivine (serpentine + opaques, tremolite) and orthopyroxene (talc) as more or less corroded cumulus crystals; reaction zones between olivine and plagioclase, with relic of orthopyroxene rim and aboundant symplectites (pale-green amphibole + spinel); poorly saussuritized plagioclase (An_{77-73}); brown hornblende and scarce phlogopite as intercumulus minerals; minor chlorite, epidote and other alteration products.

DBL 612 Cumulus melagabbro; loc. idem. Mineral assemblage: poorly altered olivine (serpentine + opaques) and pyroxenes as corroded cumulus crystals; scarce cumulus opaques; scarce and partly saussuritized intercumulus plagioclase; brown hornblende and phlogopite as other intercumulus minerals.

DBL 622 Fine-grained aplite dyke cross cutting the magmatic layering. Loc. idem. Mineral assemblage: microcline, quartz, poorly altered plagioclase and chloritized biotite; minor epidote and sericite.

KAW 1367 Pegmatite plagioclase-brown mica vein, associated to partly altered gabbro, from the moraine below p. 3105 of the Dents de Bertol Western wall. Mineral assemblage: biotite, poorly saussuritized plagioclase, green hornblende.

KAW 1368 Fine-grained quartzdiorite dyke; loc. idem, at about 2770 m. Mineral assemblage: green hornblende, biotite, quartz, zoned and partly altered plagioclase; minor apatite.

KAW 1369 Pegmatite plagioclase vein with large crystals of biotite; loc. idem KAW 1367.

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