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Volcanic clast-rich turbidites of the Taveyanne sandstones from the Thônes syncline (Savoie, France): records for a Tertiary postcollisional volcanism

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Abstract

To investigate the nature and the provenance of the volcanic clasts of the Taveyanne sandstones from the Thônes syncline (Savoie, France), modal petrographic, mineralogical and geochemical analyses were performed on selected samples in some stratigraphic sections. The content of the volcanic materials ranges from 65 to 92% by volume. Non volcanic components include plutonic/gneissic rock fragments and intrabasinal and extrabasinal carbonates. Lithic clasts of volcanic origin range from basaltic-andesites to dacites and minor rhyolites, with a predominance of andesites. Detailed modal petrographical investigations on two selected stratigraphical sections have shown significant differences in the ratio mafic/acid volcanic lithics. Whole-rock analyses of samples with more than 90% by volume of volcanic clasts combined with microprobe analyses of the main mineral phases of the volcanic clasts (clinopyroxene, plagioclase, amphibole, biotite) suggest a derivation from an orogenic, medium to high K calc-alkaline volcanism. The proved Lower Oligocene age of the Taveyanne volcanics and their orogenic character strongly suggest that the Taveyanne volcanism is related to the high-K igneous activity proving rocks which crop out in a more internal part of the Alpine belt (andesitic to ultrapotassic dikes, plutons and rare volcanic flows). It is proposed that all these high-K magmatic manifestations are genetically linked; they do not correspond to an Upper Cretaceous island arc system as previously suggested by other authors, but they represent the record of the Tertiary postcollisional Alpine magmatic activity.

Keywords: geochemistry, sedimentary petrography, volcanic clast, turbidite, post-collisional magmatism, Taveyanne formation, Western Alps.

Introduction

The Tertiary Alpine volcanism is one of the most attractive and complex problems of the Alpine geological history. Many studies have been dedicated to this problem since the beginning of this century, but the hypotheses on the magmatic sources, the original position of the edifices and especially the temporal relationships with the orogenic cycle remained highly controversial. Evidences of magmatic activity during middle Tertiary are scattered throughout the whole collisional belt: volcanic clast-rich flysch deposits in outer and inner molasses, dikes and plutons in the proper belt, volcanites under the Po plain infillings and ash layers in the Apennines (DAL PIAZ and VENTURELLI, 1983; VUAGNAT, 1983; CASSANO et al., 1986; TATEO, 1992; WAIBEL, 1993). Nevertheless, there are no primary traces of a Cretaceous subduction-related orogenic volcanism. In this picture, the volcanic clast-rich turbidites of the Taveyanne Formation are crucial for any hypotheses on Tertiary subduction-related volcanism.

Previous works concentrated on the geological setting (e.g. DOUDOUX et al., 1987), petrographical and chemical composition of the sandstones (DE QUERVAIN, 1928; VUAGNAT, 1952; MARTINI, 1968; SAWATZKY, 1975; VITALLY, 1980; GIRAUD, 1983; RAHN et al., 1995) and on the sedimentology (LATELTIN, 1988; CHAPLET, 1989; WAIBEL, 1990). Biostratigraphical analyses (LATELTIN and

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MULLER, 1987; D'ATRI et al., 1994; RUFFINI et al., 1995) indicated a Lower Oligocene age for the deposition of the turbidites; geochronological analyses (FONTIGNIE, 1980; 1981; FONTIGNIE et al., 1987; FISCHER and VILLA, 1990; RUFFINI, 1995; RUFFINI et al., 1995) yielded a Lower Oligocene age for the Taveyanne volcanism.

70 new samples of the volcanic clast-rich Taveyanne Formation from the Thônes syncline and the Platé Massif (Savoie) have been studied. The following analytical techniques were used: (a) modal analyses (29 samples) to investigate compositional variations and the sources of the clasts; (b) microprobe analyses (15 samples) on the main volcanic mineral phases in order to constrain the serial characteristics of the magmatism; (c) petrographical and whole rock (13 samples) geochemical investigations in order to define the character of the original magmas and their geotectonic significance. The samples were collected from five

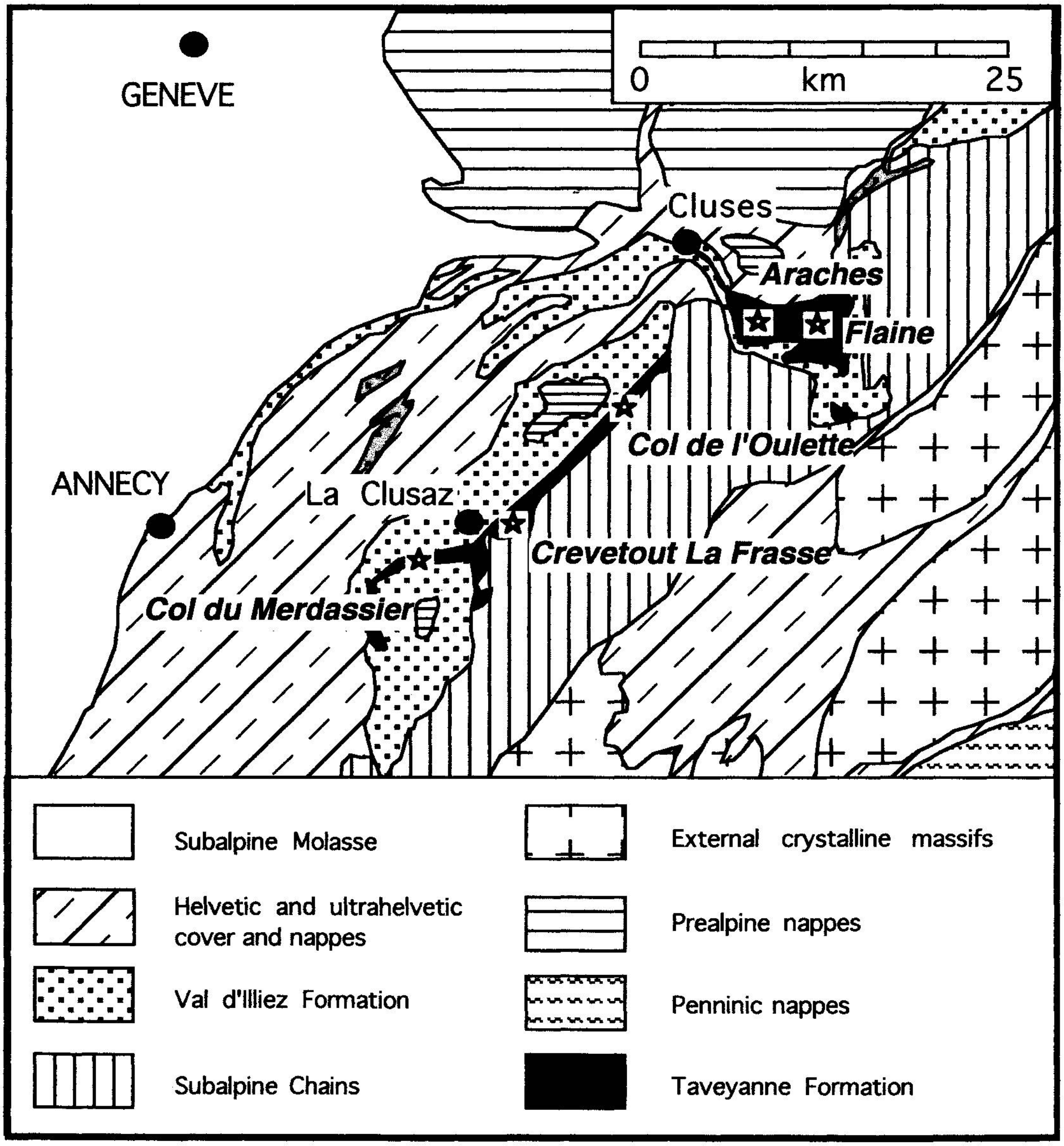


Fig. 1 Geological sketch map of the external subalpine massifs in the Haute Savoie, France. Sample localities of Taveyanne sandstones presented in this paper are indicated with stars.

different localities in the Thônes syncline and the Platé Massif in Haute Savoie (sample localities in Fig. 1). Two stratigraphic sections were analysed in detail: Col de l'Oulette section, in the Thônes syncline (see also CHAPLET, 1989; LATELTIN, 1988) and Flaine section, in the Platé massif (see also MARTINI, 1968; LATELTIN, 1988).

On the basis of the results, we will attempt a comparison with other Tertiary Alpine magmatic rocks, presenting some hypotheses on the possible location of the Lower Oligocene volcanic system in the Alpine collisional framework.

Modal petrography

29 medium- to coarse-grained sandstones mainly from the two selected stratigraphic sections (Col de l'Oulette and Flaine) were analysed by the Gazzi-Dickinson method including the revision suggested by ZUFFA (1980; 1985) to minimize the dependence of rock composition on the grain size. Within each thin section, about 400 points were counted using the petrographical classes listed in table 1. Grains were grouped according to the scheme of ZUFFA (1980; 1985). In addition to the classical parameters (QFL = Quartz-Feldspars-Lithics, LmLvLs = metamorphic-volcanic-sedimentary lithics), we used the parameters BL-IL-AL (basic-intermediate- acid lava clasts) in order to stress the information about different types of lava. Recalculated to 100% point-count results are given in table 2. Averaged values obtained on the samples from the different stratigraphical sections are given as % volume in table 2.

NON-CARBONATE EXTRABASINAL GRAINS (NCE)

This group comprises individual grains (quartz, plagioclase, K-feldspar, mica) and lithics (group L) including several types of volcanic rocks.

Great importance has been dedicated to the nature of the volcanic lithic clasts. According to their petrographical nature, the latter were grouped into three main categories: basic, intermediate and acid litho-clasts (BL-IL-AL). In the following we give a detailed description of the main classes of the recognized volcanic lithics.

Basic volcanic rocks (BL: 1–10% by vol.). They are represented by porphyritic basaltic andesites (Fig. 2a) with intergranular or pilotaxitic groundmasses. Bytownitic to labradoritic plagioclase and augitic clinopyroxene ± magnetite are the most common phenocrysts; olivine, always completely replaced by iron oxides, may be rarely present as

Tab. 1 Rock categories used for point-counting the framework grain of the Taveyanne sandstones and assigned grains in recalculated plots. (1) NCE, NCI, CE, CI (non-carbonate extrabasinal, non carbonate intrabasinal, carbonate extrabasinal and carbonate intrabasinal; from ZUFFA, 1985); (2) Q, F, L (quartz, feldspar and lithics; from DICKINSON, 1985); (3) Lm, Lv, Ls (metamorphic, volcanic and sedimentary lithics; from DICKINSON, 1985); (4) BL, IL, AL (basic, intermediate and acid lava clasts). m. = monocrystalline; r.f. = rock fragment.

Petrographic classes	1	2	3	4
Quartz (Qz) m	NCE	Q		
Coarse-grained polixx qz	NCE	Q		
Fine-grained polixx qz	NCE	Q		
Qz in plutonic/gneissic r.f.	NCE	Q		
Qz in volcanic r.f.	NCE	Q		AL
Qz in sandstone	NCE	Q		
Kfeldspar (Kf) m	NCE	F		
Kf in plutonic/gneissic r.f.	NCE	F		
Kf in volcanic r.f.	NCE	F		AL
Kf in sandstone	NCE	F		
Plagioclase (Plg) m	NCE	F		IL
Plg in plutonic/gneissic r.f.	NCE	F		
Plg in basalto-andesitic r.f.	NCE	F		BL
Plg in two px-andestic r.f.	NCE	F		IL
Plg in hbl-andesitic r.f.	NCE	F		IL
Plg in plg-andesitic r.f.	NCE	F		IL
Plg in dacitic r.f.	NCE	F		AL
Plg in rhyolitic r.f.	NCE	F		AL
Plg in pumiceous r.f.	NCE	F		AL
Plg in cumulitic r.f.	NCE	F		BL
Pyroxene (Px) m	NCE			IL
Px in basalto-andesitic r.f.	NCE			BL
Px in two px-andestic r.f.	NCE			IL
Px in hbl-andesitic r.f.	NCE			IL
Px in dacitic r.f.	NCE			AL
Px in pumiceous r.f.	NCE			AL
Px in cumulitic r.f.	NCE			BL
Hornblende (Hbl) m	NCE			IL
Hbl in hbl-andesitic r.f.	NCE			IL
Hbl in dacitic r.f.	NCE			AL
Hbl in pumiceous r.f.	NCE			AL
Hbl in cumulitic r.f.	NCE			IL
gneissic r.f.	NCE	L	Lm	
Shale	NCE	L	Lm	
Meta-limestone	NCE	L	Lm	
Basaltic andesite	NCE	L	Lv	BL
Two px-andesite	NCE	L	Lv	IL
Hbl-andesite	NCE	L	Lv	IL
Plg-andesite	NCE	L	Lv	IL
Dacite	NCE	L	Lv	AL
Rhyolite	NCE	L	Lv	AL
Pumices	NCE	L	Lv	AL
Undistinguished groundmass	NCE	L	Lv	
Micas and chlorites	NCE	L		
Iron oxides	NCE	L		
Glauconite	NCI			
Pelitic rip-up clasts	NCI			
Chert	CE	L	Ls	
Dolostone/limestone	CE	L	Ls	
Mudstone-wackestone	CE	L	Ls	
Packstone-grainstone	CE	L	Ls	
Non-coeval bioclasts	CE	L	Ls	
Coeval bioclasts	CI			

Tab. 2 Recalculated modal point-count data for different sections of Taveyanne Formation. n° = number of samples. For abbreviations see table 1.

Section name	n°	NC	NCI	CE	Cl	Q	F	L	Lm	Lv	Ls	BL	IL	AL
Oulette (Thones syncline)	11	98	0	2	0	20	49	31	5	90	5	11	85	4
Flaine (Platé Massif)	11	94	1	2	3	27	48	25	20	74	6	1	85	14
Araches (Platé Massif)	5	96	0	2	2	23	63	14	5	94	1	4	84	12
La Clusaz (Aravis Massif)	2	98	0	2	0	17	50	33	2	96	2	1	94	5

anhedral micro-phenocrysts. Plagioclase microlites, small augite grains and octahedral magnetite constitute the groundmass.

Intermediate volcanic rocks (IL: about 85%). This group includes three types of volcanic lithoclasts: (1) two-pyroxene andesites (Fig. 2b) with different types of textures (vesiculated, glassy, felsitic). Textural observations and probe analyses on the mineral phases show what follows (RUFFINI, 1995): plagioclase is mostly euhedral and zoned; it ranges in composition from 70 to 55% An in the core and 55–35% An in the rim. Clinopyroxenes are augitic to salitic in composition, whereas orthopyroxene is always completely replaced by chlorite. Magnetite and Ti-magnetite are common. The same minerals are common constituents of the fine-grained groundmass. (2) Hornblende-andesites (Fig. 2c) with vitrophyric texture. Plagioclase and ferroan pargasitic hornblende are the ubiquitous phenocrysts, clinopyroxene and orthopyroxene occur as smaller subhedral phenocrysts. (3) Plagioclase-bearing andesites containing labradorite-andesine plagioclase phenocrysts and minor small grains of augite in a glassy groundmass. Glass is always completely altered (mostly to chlorite).

Acid volcanic rocks (AL – 5–15%). They comprise volcanic rock fragments with amphibole, biotite and quartz as phenocrysts in a felsitic groundmass. (1) Dacites (Fig. 2d) have phenocrystals of andesine/oligoclase, ferroan pargasite and biotite with subordinate salitic clinopyroxene. (2) Rhyolites (Fig. 2e), mainly represented by quartz-biotite-sanidine volcanic fragments, are scarce. Pumiceous textures are commonly observed among the rhyolites.

Some plutonic and/or gneissic, metamorphic and sedimentary clasts are also present.

Plutonic and/or gneissic rock fragments (< 10%). Granodiorites/granites and gneissic rocks (Fig. 2f) are quite common and may represent up to 10% of NCE.

Metamorphic rock fragments (< 1%). Slates, very rare mica-schist, quartzites and marbles.

Sedimentary rock fragments (1–5%). Arenites, siltstones, marls and very few cherts.

CARBONATE EXTRABASINAL CLASTS (CE)

They are represented by clasts of oolitic carbonates, micrites and dolostones (Fig. 2f).

NON CARBONATE INTRABASINAL CLASTS (NCI)

Very rare glauconite grains and pelitic rip-up chips.

CARBONATE INTRABASINAL CLASTS (CI)

Mainly bioclasts, including planktonic Foraminifera, macroforaminifers and Corallinae algae.

Metamorphism

The Taveyanne Formation was affected by very low grade metamorphism, with development of mineral assemblages typical for the laumontite and prehnite-pumpellyite facies (MARTINI, 1968; MARTINI and VUAGNAT, 1965, 1970; SAWATZKI and VUAGNAT, 1971; COOMBS et al., 1976; STALDER, 1979; RAHN et al., 1994). The major mineralogical transformations we observed agree with those already known in literature. They can be resumed as follows:

a) magmatic plagioclase has been partially to totally replaced by albite and laumontite;

b) orthopyroxene and olivine have been totally replaced by chlorite and iron oxides respectively;

c) clinopyroxene and amphibole have been partially altered into chlorite and/or calcite;

d) the groundmass of the volcanic-clasts has been altered to an aggregate of chlorite + leucoxene or to a microcrystalline aggregate of albite, K-feldspar, quartz in the mafic and in the acid rock-fragments respectively.

The original volcanic texture is still preserved. Metamorphic laumontite is more common in the fine-grained sandstone layers; it replaces both the

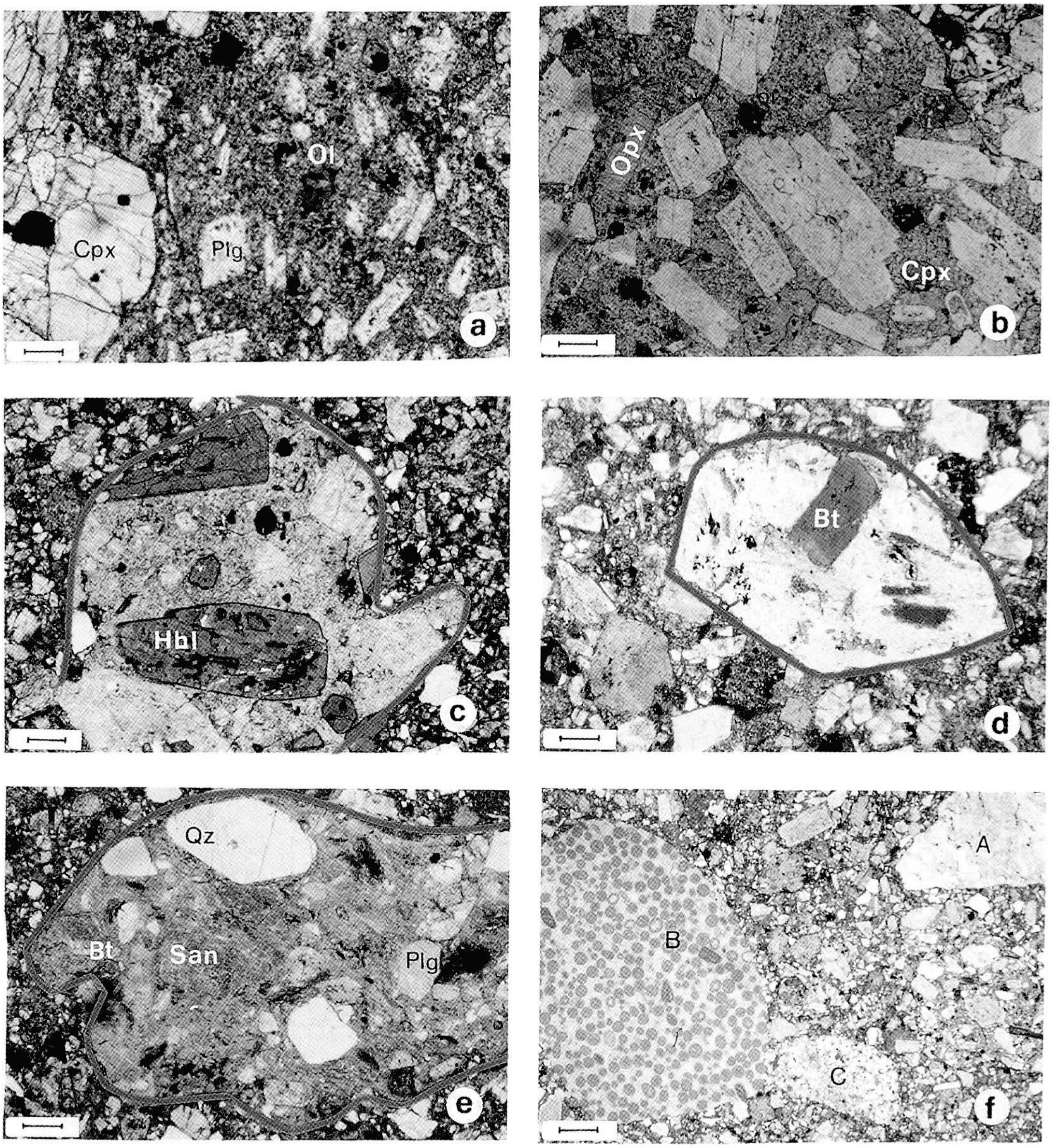


Fig. 2 Examples of rock fragments from Taveyanne sandstone of the sampled area. All microphotographs are at polarized light. Volcanic rock fragments : (a) Basaltic andesite lava clast with plagioclase (Plg), clinopyroxene (Cpx) and olivine (Ol) altered to iron oxide (La Clusaz, Aravis Massif). The bar corresponds to 0.2 mm. (b) Two-pyroxene andesitic lava clast with euhedral plagioclase (Plg), clinopyroxene (Cpx) and orthopyroxene (Opx) altered to chlorite (Col d'Oulette, Bornes Massif). The bar corresponds to 0.7 mm. (c) Hornblende andesite lava clast (La Clusaz, Aravis Massif). The bar corresponds to 0.4 mm. (d) Dacite lava clast with phenocrysts of plagioclase and biotite (Flaine, Platé Massif). The bar corresponds to 0.7 mm. (e) Rhyolite lava clast with phenocrysts of quartz (Qz), sanidine (San), plagioclase (Plg) and biotite (Bt) altered to chlorite (La Clusaz, Aravis Massif). The bar corresponds to 0.6 mm. Non volcanic rock fragments: (f) gneissic grain (A), oolitic carbonate (B), arenites (C) (Col d'Oulette, Bornes Massif). The bar corresponds to 1.8 mm.

matrix and the plagioclase phenocrysts and forms small white aggregates (cf. MARTINI, 1968; MARTINI and VUAGNAT, 1965; WAIBEL, 1990). Prehnite and pumpellyite are locally present in small veins crosscutting the rocks.

Bulk rock chemistry

METHODOLOGY

Special attention was paid to the choice of the samples to be analysed. They must fulfill the following requirements (e.g. BATHIA and CROOK, 1986; MCLENNAN et al., 1990; HISCOTT and GILL, 1992): (a) > 90% clasts by volume of volcanoclastic material in order to minimize the influence of non volcanic components; (b) poorly sorted turbiditic in order to prevent compositional variation linked to selective hydraulic sorting; (c) weak Alpine metamorphic variation.

According to these criteria, 13 samples of arenites were selected out of seventy collected specimens and were analysed for major and trace elements at the University of Lausanne, using a Philips PW1400 spectrometer with standard X-ray fluorescence techniques. Trace elements were analysed on pressed powder pellets and major element oxides on glass discs. The water content was calculated from the loss on ignition data and photometric FeO and coulometric CO_2 analyses.

Notwithstanding of the great care in the selection of the analysed samples, most of them actually contain a small fraction of non volcanic components (Tab. 2). To eliminate the effects due to the presence of foreign clasts, the original analytical data (Tab. 3a) were corrected as follows on the basis of modal counting:

(a) the silica value equal to the measured non volcanic quartz content was subtracted from SiO_2;

(b) the CaO value was corrected for the amount of CaO and CO_2 corresponding to the observed amounts of modal carbonate clasts and bioclasts;

(c) Al_2O_3 and K_2O were corrected to match with the contribution of plutonic K-feldspar, using analytical data from a microcline with low content of Ab (DEER et al., 1978);

(d) Ba, Rb and Sr were corrected for the corresponding amounts present in a plutonic K-feldspar having the following concentrations: Ba = 4000 ppm; Rb = 185 ppm; Sr = 230 ppm, consistent with feldspars from orogenic plutons (DE PIERI and JOBSTRAIBIZER, 1989). The corrected analytical data are reported in table 3b on a volatile-free (H_2O and CO_2) basis.

These corrected analyses were compared to the GILL's (1981) mean composition of andesitic rocks. They show a good match except for higher Na_2O and lower CaO of the Taveyanne rocks. This difference may reflect a low-grade metamorphic mobilization of CaO and Na_2O; the higher Na_2O content may be linked to the diffuse albitization in the Taveyanne rocks; the lower CaO content may reflect a weak Ca mobility during the formation of secondary aggregates of calcite and laumontite (MARTINI, 1968; RAHN et al., 1994). It is observed, however, that the molar sum of these oxides is roughly constant; this means that the loss of CaO is compensated by the gain of Na_2O. This agrees with previous conclusions obtained by MARTINI (1968), MARTINI and VUAGNAT (1965) and RAHN et al. (1994). According to above considerations we assume that, except for the two latter oxides, the bulk chemical composition of the sandstones in table 3b gives a crude approximation of the average composition of the Taveyanne magma.

CHARACTERIZATION OF THE MAGMA

Uncertainty of the magmatic abundance of Na_2O and CaO precludes the use of common geochemical discriminant diagrams based on these elements. Nevertheless, as no diagenetic or metamorphic K-phases were detected in the sampled areas, we argue that K_2O has not undergone major changes in its original abundance. For this reason, we use the plot K_2O vs SiO_2 to classify the rocks and to identify the serial affinity. In figure 3, most points are scattered throughout the medium to high-K andesite field with only a few points in the basaltic andesite field.

Some remarkable informations can be derived from relatively immobile elements such as TiO_2, Zr and Y. The low TiO_2 content of the sandstones, ranging from 0.81 wt % to 1.10 wt%, points to-

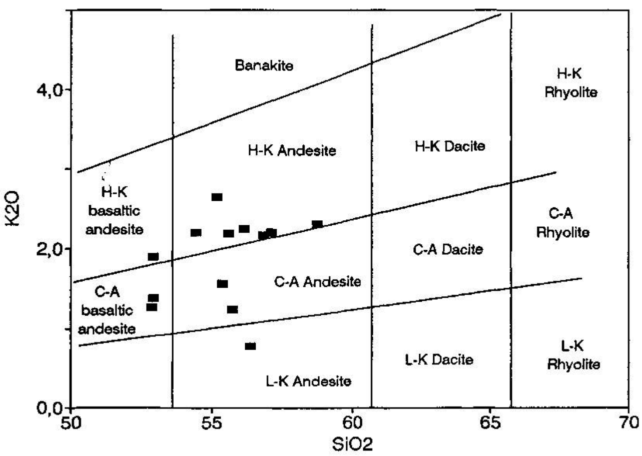


Fig. 3 K_2O vs SiO_2 diagram for Taveyanne samples. Fields from PECCERILLO and TAYLOR (1976).

Tab. 3 Major and trace element composition of selected samples of the Taveyanne formation from the Thônes syncline and Platé Massifs in Savoie, France. (a) Original non-corrected data of the sandstones. (b) Calculated compositions of the Taveyanne magmas on a volatile-free basis by substraction of the non-volcanic contribution determined by modal counting (for details see text). n.i. = under the identification limit. TV5-TV13, TV38-TV43: samples from Col de l'Oulette (Thônes syncline); TV15-TV19: samples from Araches (Platé Massif).

Tab. 3a													
wt%	TV5	TV6	TV8	TV9	TV10	TV11	TV13	TV15	TV16	TV17	TV19	TV38	TV43
SiO_2	56,99	46,26	59,02	55,22	57,16	60,15	60,77	55,15	58,22	59,71	59,64	56,61	56,34
TiO_2	0,72	0,63	0,64	0,71	0,68	0,65	0,60	0,91	0,77	0,61	0,72	0,70	0,88
Al_2O_3	15,86	12,22	15,20	16,04	16,40	15,00	14,30	15,66	14,52	14,89	15,39	16,31	15,55
Fe_2O_3	3,61	2,05	3,29	1,92	6,16	4,24	2,97	4,61	3,41	2,79	3,69	4,32	4,23
FeO	3,61	3,26	3,25	5,32	1,78	2,32	3,03	3,81	3,91	2,66	2,77	2,96	3,74
MnO	0,10	0,36	0,10	0,09	0,09	0,10	0,08	0,12	0,10	0,08	0,09	0,09	0,11
MgO	3,98	2,35	2,95	3,37	3,13	2,72	2,67	3,47	3,10	2,16	2,73	2,99	3,28
CaO	4,38	15,08	4,17	6,23	4,24	3,15	4,73	4,84	6,36	5,59	4,53	5,18	7,33
Na_2O	3,39	3,08	3,12	3,48	3,22	4,39	3,51	4,51	2,91	2,64	3,38	3,87	3,40
K_2O	2,10	1,95	2,33	1,19	1,96	2,15	1,98	1,38	1,71	1,97	2,11	2,49	1,39
P_2O_5	0,18	0,15	0,15	0,20	0,18	0,17	0,17	0,21	0,19	0,17	0,19	0,21	0,21
H_2O	3,58	1,80	3,70	3,14	2,75	3,54	2,25	4,24	2,41	4,71	4,12	3,19	2,02
CO_2	0,56	9,89	1,14	2,50	1,28	0,50	2,61	0,30	1,69	1,41	0,37	0,51	1,41
Total	99,06	99,08	99,06	99,41	99,03	99,08	99,67	99,21	99,30	99,39	99,73	99,43	99,89
ppm													
Ba	498	495	585	399	585	495	521	356	396	413	550	529	439
Rb	59	56	65	32	59	60	57	33	47	63	63	70	36
Sr	683	772	551	539	557	345	509	450	473	423	486	594	569
La	22	19	20	22	15	24	21	23	23	20	21	22	19
Ce	52	44	45	45	37	53	55	44	47	41	45	46	41
Nd	14	16	15	17	9	20	14	16	17	9	14	15	14
Y	18	18	15	17	15	18	18	20	18	17	18	18	17
Zr	115	84	87	98	107	142	142	128	122	116	114	104	107
V	212	157	174	176	177	152	147	231	187	115	158	192	222
Cr	71	23	30	25	26	31	33	40	27	24	22	44	24
Ni	26	4	14	4	6	7	9	7	6	7	5	17	3
Ga	16	9	13	16	17	15	15	17	15	14	14	16	16
Hf	3		2	2	3	3	3	3	2	3	2	3	3

Tab. 3b													
wt%	TV5	TV6	TV8	TV9	TV10	TV11	TV13	TV15	TV16	TV17	TV19	TV38	TV43
SiO_2	54,43	55,73	55,17	56,38	52,87	55,59	56,83	55,40	52,94	58,75	57,13	56,17	52,94
TiO_2	0,89	1,07	0,86	0,86	0,93	0,85	0,88	1,04	1,11	0,83	0,92	0,82	1,07
Al_2O_3	19,25	18,33	19,87	18,59	20,81	18,96	20,20	17,83	20,24	19,86	19,02	18,29	18,55
Fe_2O_3	4,49	3,48	4,43	2,32	8,42	5,57	4,38	5,25	4,90	3,80	4,69	5,04	5,14
FeO	4,49	5,53	4,37	6,42	2,43	3,05	4,46	4,34	5,62	3,63	3,52	3,46	4,55
MnO	0,12	0,61	0,13	0,11	0,12	0,13	0,12	0,14	0,14	0,11	0,11	0,11	0,13
MgO	4,95	3,99	3,97	4,07	4,28	3,57	3,93	3,95	4,46	2,94	3,47	3,49	3,99
CaO	4,74	4,62	4,18	6,06	4,24	4,13	1,63	5,11	4,24	3,94	4,40	5,63	7,88
Na_2O	4,20	5,16	4,18	4,18	4,36	5,74	5,15	5,14	4,17	3,59	4,28	4,50	4,12
K_2O	2,21	1,24	2,64	0,78	1,27	2,19	2,16	1,57	1,90	2,31	2,21	2,25	1,38
P_2O_5	0,22	0,25	0,20	0,24	0,25	0,22	0,25	0,24	0,27	0,23	0,24	0,25	0,26
ppm													
Ba	532	219	523	280	346	395	415	376	315	370	481	406	389
Rb	58	48	65	28	46	57	54	35	45	64	62	67	34
Sr	582	864	579	566	571	356	529	475	491	449	505	612	586
La	23	22	21	23	16	25	22	24	24	21	22	23	20
Ce	55	50	48	48	39	56	58	46	49	44	47	48	43
Nd	15	18	16	18	9	21	15	17	18	10	15	16	15
Y	19	21	16	18	16	19	19	21	19	18	19	19	18
Zr	121	96	92	105	113	149	150	135	128	124	120	109	111
V	223	180	185	188	186	160	155	244	196	123	166	201	230
Cr	75	26	32	27	27	33	35	42	28	26	23	46	25
Ni	27	5	15	4	6	7	9	7	6	8	5	18	3
Ga	17	10	14	17	18	16	16	18	16	15	15	17	17
Hf	3	n.i.	2	2	3	3	3	3	2	3	2	3	3

wards an orogenic rock series (EWART and LE MAITRE, 1980). Basaltic andesites with SiO_2 < 56% plot in the field of calc-alkaline basalts in the PEARCE and CANN's (1973) diagrams (Fig. 4). The MORB-normalized Taveyanne spider-diagram (Fig. 5) closely resembles that for the high-K (HK) orogenic andesite of WILSON (1989).

Mineral chemistry

Some chemical analyses of the main phenocryst phases have already been reported in RUFFINI et al. (1995). In this paragraph some complementary data are presented. Representative analyses of the main phases are in table 4.

Tab. 4 Representative analyses of plagioclase (1, 2), clinopyroxene (3, 4), amphibole (5) and biotite (6) from volcanic clasts of Taveyanne sandstones.

	Plg 1	Plg 2		Cpx 3	Cpx 4	Amph 5	Bt 6
SiO_2	51.72	59.13		51.31	52.68	41.01	34.49
TiO_2	–	–		0.69	–	2.41	2.84
Al_2O_3	30.03	24.80		1.86	1.36	12.75	15.63
FeO	0.77	0.81		10.24	8.69	12.67	19.95
MnO	–	–		0.58	0.76	–	0.42
MgO	–	–		14.35	13.51	12.90	11.28
CaO	14.37	7.34		20.94	22.90	11.93	0.08
Na_2O	3.65	6.51		0.45	–	2.75	0.25
K_2O	0.18	1.40		–	–	0.77	7.09
TOT	100.72	99.99		100.42	99.90	97.19	92.03
An	0.68	0.35	Wo	0.43	0.46		
Ab	0.31	0.57	En	0.46	0.40		
Or	0.01	0.08	Fs	0.11	0.14		

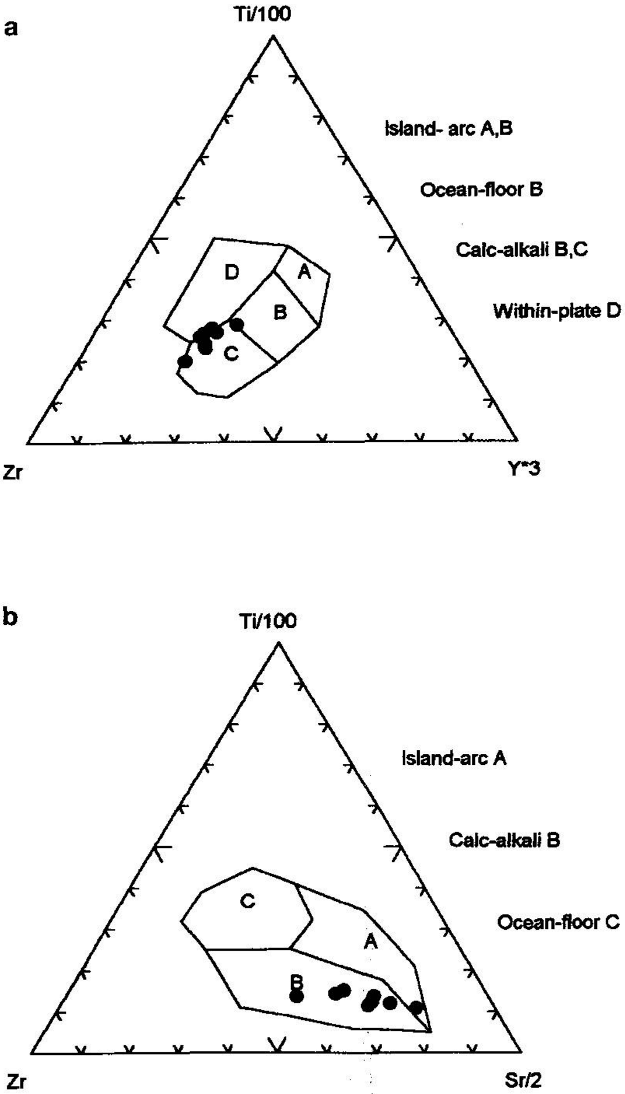


Fig. 4 (a) and (b): Ternary diagrams of PEARCE and CANN (1973) involving concentration of Ti, Zr, Sr and Y. Only 9 samples from Taveyanne sandstones having composition of basic andesites (SiO_2 < 56%) have been plotted.

Plagioclase composition ranges from labradorite to andesine; some cores show bytownitic composition (up to An77). The Or content of plagioclase (0.5 wt % in the basic to 7 wt% in the acid plagioclases) agrees with the assumed derivation from a HK volcanic rocks series (GILL, 1981). The coupled variation of An and Or contents in plagioclase with the increasing acidity of their host rocks is typical of rock series evolved by fractional crystallization.

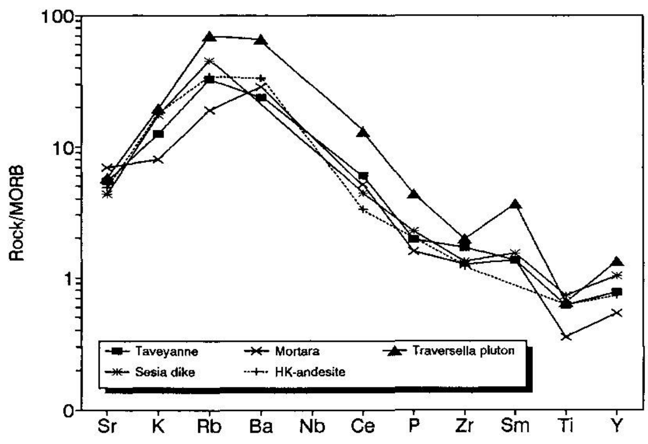
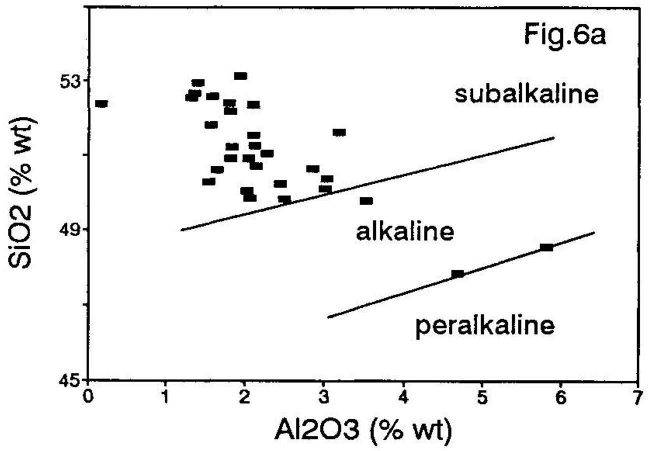


Fig. 5 N-MORB-normalized trace element patterns for the average of Taveyanne sandstones, some Periadriatic magmatic rocks (data for Traversella are from VAN MARKE DE LUMMEN and VANDER AUWERA, 1990; data for Sesia dike are from VENTURELLI et al., 1984) and Mortara volcanics (RUFFINI, 1995). The dotted line represents the distribution of trace elements from a high-K andesite (from WILSON, 1989). Normalizing values from PEARCE (1982): Sr = 120 ppm; K_2O = 0.15 wt%; Rb = 2.0 ppm; Ba = 20 ppm; Nb = 3.5 ppm; Ce = 10.0 ppm; P_2O_5 = 0.12 wt%; Zr = 90 ppm; Sm = 3.3 ppm; TiO_2 = 1.5 wt%; Y = 30 ppm; Yb = 3.4 ppm.

Clinopyroxene is the only pyroxene still preserved in the lava clasts. Most clinopyroxenes are augitic in composition; a slight increase in Ca relative to Fe and Mg is observed in clinopyroxenes from the more acid lava clasts; this is typical for clinopyroxenes of high-K calc-alkaline series (GILL, 1981). High SiO_2 together with low TiO_2 and Al_2O_3 contents in the Taveyanne clinopyroxene (Fig. 6) are typical of pyroxenes crystallizing from orogenic, subalkaline magmas (LE BAS, 1962; LETERRIER et al., 1982).

The amphibole composition ranges from ferroan pargasite to ferroan pargasitic hornblende according to LEAKE's nomenclature (1978). The biotite in the acid andesites is a typical Ti-biotite (with Ti > 0.25 per formula unit); according to GILL (1981), the presence of biotite in andesitic lavas is essentially recorded in rocks belonging to the high-K series.



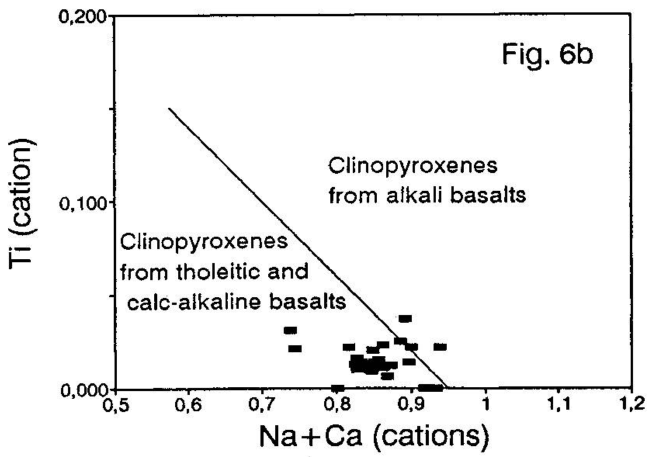


Fig. 6 (a) SiO_2–Al_2O_3 covariation diagram for clinopyroxenes of basic volcanic rock-fragments from the Taveyanne sandstones of the sampling area. Boundaries from LE BAS (1962). (b) Plot of Ti vs Ca + Na (LETERRIER et al., 1982) for clinopyroxenes of basic volcanic rock-fragments from the Taveyanne sandstones.

Discussion

INTERPRETATION OF THE VOLCANIC COMPONENTS IN TAVEYANNE SANDSTONES

The relative proportions of volcanic vs non volcanic detrital components (Tab. 2) indicate that the Taveyanne Formation of the Thônes syncline and Platé Massif in Savoie originated essentially from volcanic source rocks with only subordinate contribution from plutonic and sedimentary sources. In the QFL diagram (DICKINSON, 1985), the Taveyanne sandstones plot in the field of mag-

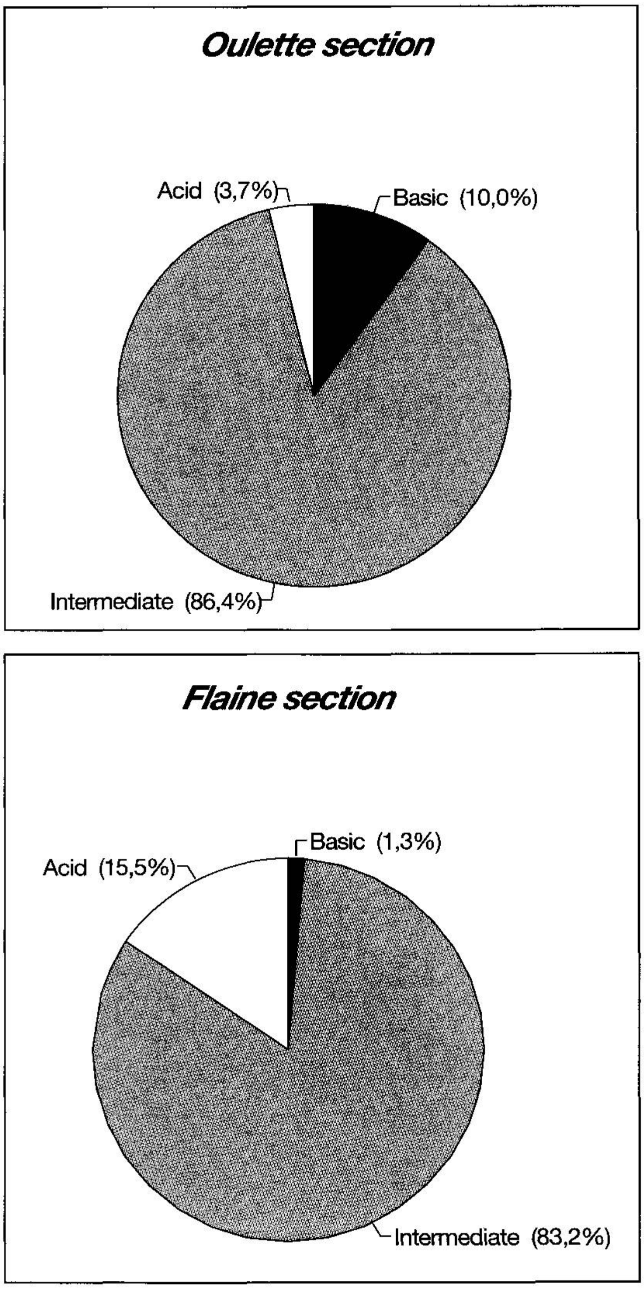


Fig. 7 Modal distribution of detrital fragments from the analysed sections of Thônes syncline (Oulette) and Platé Massif (Flaine).

matic arc provenance, straddling the boundary between transitional and dissected arcs (RUFFINI et al., 1995). From the modal compositions of table 2, it is clear that the main contribution occurred from volcanics of andesitic compositions (IL), mostly represented by plagioclase-phyric, two-pyroxene andesites or plagioclase-phyric, pyroxene-hornblende andesites. However, it is evident that a minor but still relevant contribution, estimated to represent an average 15% by volume of total volcaniclastics, occurred from other volcanic rocks including both basaltic andesites (BL) and dacitic and rhyolitic rocks (AL). It is worthnoting the rather important contribution of the acid volcanic fragments in the Flaine section (Fig. 7). As acid volcanites are only sporadically described in literature as components of the Taveyanne sandstones, the question is if they represent volcanites genetically linked with the andesitic collisional magmatism or if they come from the volcano-sedimentary cover of the hercynian basement. We favour the former interpretation considering that:

a) most acid rocks are fresh;

b) mineral phases display the same petrographical characters in both the acid and the andesitic rocks;

c) the chemistry of the mineral phases plot in the same field both for acid and andesitic samples (RUFFINI, 1995);

d) we did not observe clasts of the Permian-Triassic cover as one could reasonably expect.

We interpreted the different modal distribution of volcanic fragments of figure 7 as due to separate volcanic supplies and we thus suggest that *the volcanoes supplying the Taveyanne sandstones constituted composite volcanic edifices.* These volcanic sources were mainly composed of *medium to high-K calc-alkaline rock series*, ranging from basaltic andesites to andesites and dacites-rhyolites. Chemical analyses of the main mineral phases in the lava fragments and whole rock trace elements indicate *orogenic high-K magmas*. The presence of plutonic and minor metamorphic and sedimentary rock fragments provide information on the Alpine basement and cover nappes exposed at that time.

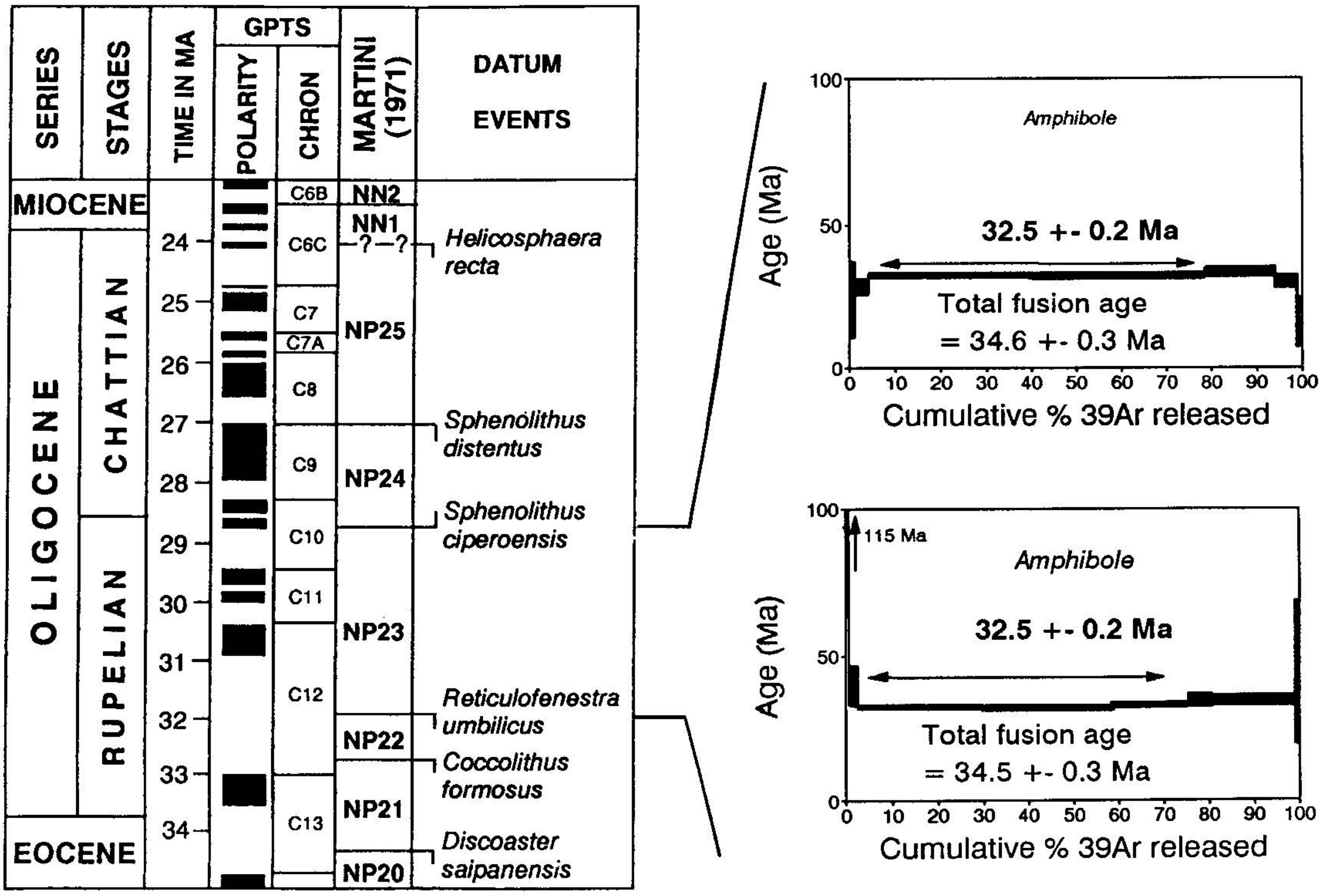


Fig. 8 Comparison between geochronological and biostratigraphical data. The biostratigraphical analyses are from Thônes syncline and Platé Massif; $^{39}Ar/^{40}Ar$ datings are from Flaine (TV17) and from Col du Merdassier (TV 22) (cf. Fig. 1). Modified after RUFFINI et al. (1995).

AGE, TECTONIC SIGNIFICANCE AND REGIONAL RELATIONSHIPS OF THE TAVEYANNE MAGMATISM

The primary sources of the volcanic clasts of Taveyanne Formation have been object of discussion (e.g. VUAGNAT, 1983 and references therein). Some French authors (e.g. GIRAUD and DIDIER, 1981; GIRAUD, 1983; LAPIERRE et al., 1995) still consider the Taveyanne sediments as primary volcanic deposits, derived by "in situ" phreatomagmatic explosions. Due to the absence of volcanic signature in the field and the sedimentologic characteristics of the Taveyanne turbidites (VUAGNAT, 1983; LATELTIN, 1988; SINCLAIR, 1992), one is forced to suggest that these volcanic rich-sediments were produced from dismantlement of extrabasinal volcanic bodies. Unfortunately, the exact location of the volcano system is still a matter of conjecture. Except for the above mentioned French authors, there was broad consensus in the past literature on an internal position of the volcanic edifices, but all the hypotheses given on this topic resulted from erroneous age attribution to the Eocene for the Taveyanne magmatism (e.g. DAL PIAZ and VENTURELLI, 1983; VUAGNAT, 1983).

New geochronological $^{40}Ar/^{39}Ar$ datings on four volcanic amphiboles from Taveyanne samples recently performed (RUFFINI, 1995; RUFFINI et al., 1995) yielded plateau ages of 32.5 ± 0.2 Ma (i.e. Lower Oligocene; Fig. 8). Biostratigraphical data (D'ATRI et al., 1994; RUFFINI et al., 1995) on calcareous nannofossil associations on the Taveyanne Formation referred it to Zone NP23 of MARTINI (1971), i.e. to the upper portion of the Lower Oligocene. This constrains the depositional age of the Taveyanne Formation to the interval between ca. 32 and 29 Ma. The overlapping of biostratigraphical and geochronological results suggest a short time span between volcanic events and turbidite deposition.

The Oligocene age of the Taveyanne volcanism unequivocally proves that the emplacement of this magmatism was post-collisional. Thus the volcanic source of the Taveyanne turbidites could not be an island arc related to an active subduction system, as previously suggested (GIRAUD, 1983; RAHN et al., 1995), the latter being assumed to have occurred in the Upper Cretaceous (HUNZIKER et al., 1992 and references therein).

The high-K serial affinity of the Taveyanne lavas fits well both the overall high-K characters

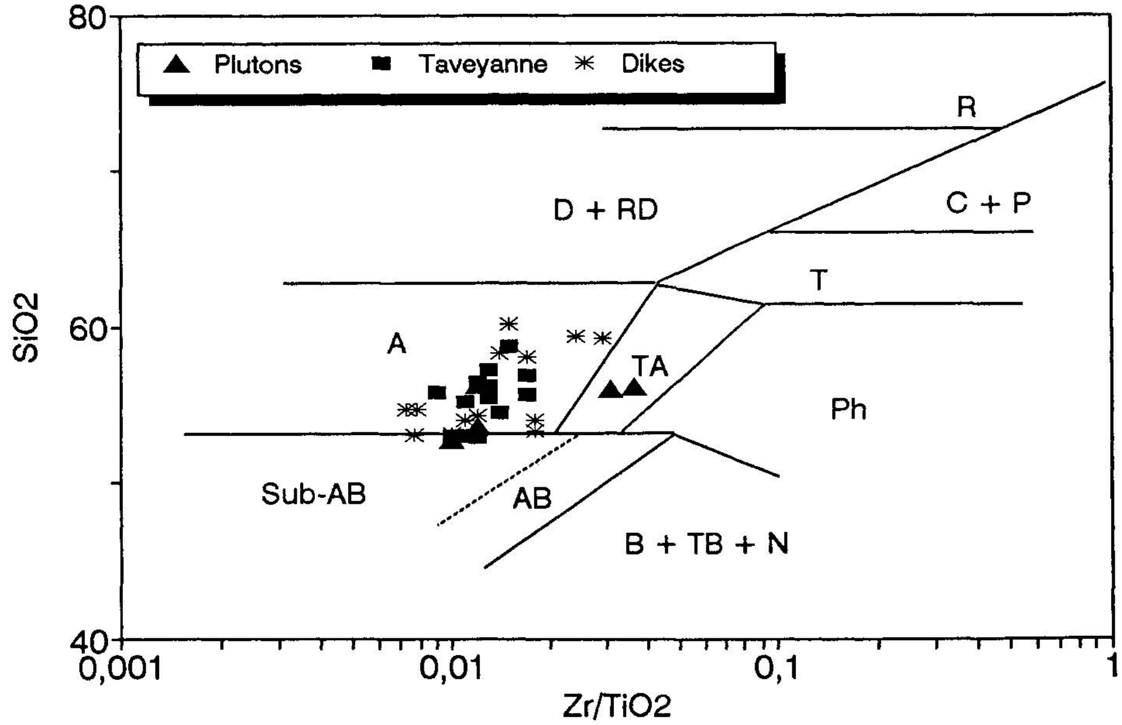


Fig. 9 SiO_2 vs Zr/TiO_2 (WINCHESTER and FLOYD, 1978) for our Taveyanne samples and Periadriatic magmatites of comparable chemical composition. Data for Western and Central Alpine dikes are from VENTURELLI et al. (1984) and BECCALUVA et al. (1983); data for plutons from Adamello (MACERA et al., 1983), and from Traversella (VAN MARKE DE LUMMEN and VANDER AUWERA, 1990).
AB = alkali basalts, hawaiites, mugearites, trachybasalts; Sub-AB = sub-alkaline basalts (tholeitic and high-alumina); B + TB + N = basanites, trachybasanites, nephelinites; A = andesites; D + RD = dacites and rhyodacites; R = rhyolites; TA = trachyandesites; T = trachytes; Ph = phonolites; C + P = comendites and pantellerites.

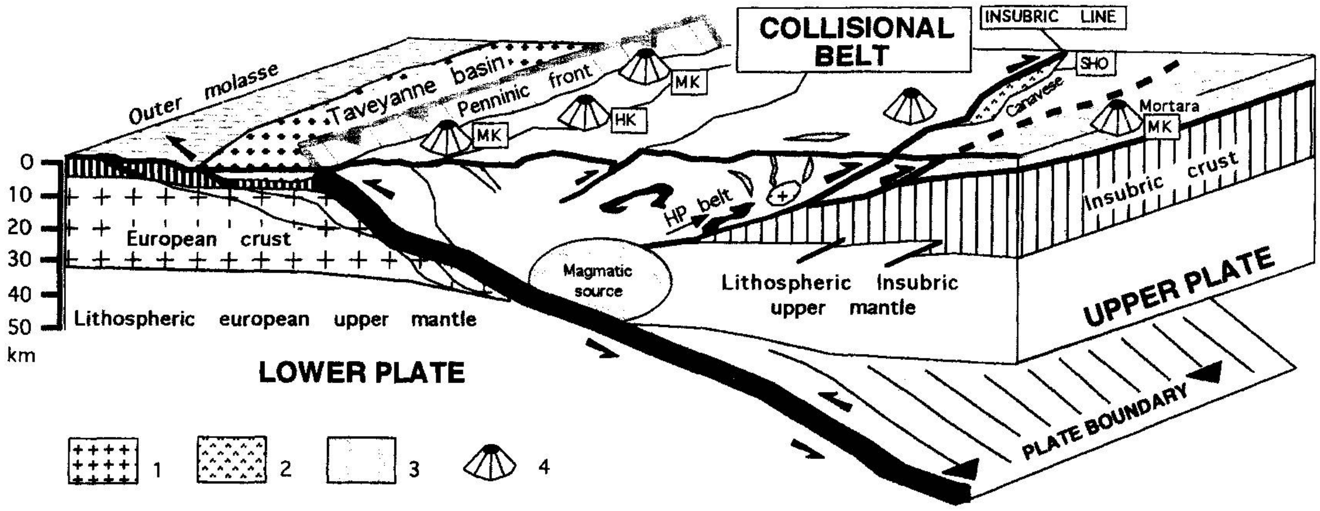


Fig. 10 Simplified sketch representing the position of the volcanic bodies whose dismantlement gave origin to the Taveyanne volcanic clasts in the Oligocene Alpine collisional belt. 1 = periadriatic plutons; 2 = Canavese volcanic flows; 3 = periadriatic dikes; 4 = volcanic bodies.
MK, HK and SHO: medium potassium, high potassium and shoshonitic affinity of volcanites. The serial affinity of volcanic apparata in the outer position of the collisional belt is inferred and indicative of the heterogeneous distribution of the effusive centers.

of the perimediterranean Alpine belts (e.g. BELLON and BROUSSE, 1977; HERNANDEZ et al., 1987) and, in particular, the geochemical characters and the time interval of the development of the magmatic activity in the internal sector of the Western Alps (DAL PIAZ et al. 1979; DAL PIAZ and VENTURELLI, 1983; BECCALUVA et al., 1983; CALLEGARI, 1983; VENTURELLI et al., 1984; BELLINI et al., 1993). In the plot SiO_2 vs Zr/TiO_2 (Fig. 9), the Taveyanne sandstones largely overlap the field of the periadriatic dikes and plutons. MORB-normalized spider-diagrams of the Taveyanne rocks (Fig. 5) remarkably follows a nearly identical trend of those from the volcano-plutonic rocks in the Western Alps.

The above considerations strongly suggest the hypothesis that the volcanism of the Taveyanne sandstones and the Periadriatic magmatism should have had a common magmatic source. This kind of volcano-plutonic association is well known in most present-day orogenic belts (GILL, 1981). Geodynamic constraints on the gross structure of the Alpine chain (POLINO et al., 1990; RUFFINI et al., 1995) demand that orogenic magmatism is located in the upper plate of the colliding system (Fig. 10). On this ground one is forced to locate the Taveyanne volcanism in an internal position with respect to the Penninic thrust front, which is here regarded as the Tertiary Alpine plate boundary (POLINO et al., 1990). Records of this magmatic activity are now almost completely disappeared and only scattered preserved in the Periadriatic igneous bodies, Mortara volcanites, Apennines ash layers and volcanic-rich sediments deposited in both outer and inner position of the uprising belt. The very short time span between the volcanism and the deposition of the volcanic clasts of Taveyanne, suggest that only a rapid tectonic transport of the volcanic sources at the front of the active "fold and thrust" Alpine belt can account for the assumed distance between the original position of the volcanic edifices in the more internal chain and the present-day position of the Taveyanne sandstones in the Helvetic nappes (DAL PIAZ and VENTURELLI, 1983; VUAGNAT, 1983; RUFFINI et al., 1995). Subsequent complete erosion of the volcanic edifices supplied the volcanic clasts that were deposited in a migrating basin of the accretionary wedge (SINCLAIR, 1992).

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