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The volcanic suite of the Julier area (Grisons)
Part 1: volcanic and tectonic evolution

by *Ivan Mercolli*[1]

Abstract

A suite of Upper Paleozoic volcanic rocks outcropping in the North-West of the Julier pass (Grisons) belongs to the lowermost Austroalpine unit (Err nappe). That suite is composed of large masses of rhyolitic pyroclastics with minor amounts of rhyodacitic, andesitic rocks and basaltic andesites. The magmatic suite is completed by a small rhyolitic subvolcanic body and a large granitoid intrusion. The volcanics overlie polymetamorphic gneisses and the whole complex is covered by lower Triassic sediments. The Alpine orogeny (deformation and metamorphism) has obliterated many of the original characteristics of these magmatic rocks. Nevertheless, a careful interpretation of relic structures allows to model the Variscan magmatic and tectonic evolution of this area.

In this light the major results are:
- The Julier volcanics show the characteristics typical of a calcalkaline series evolving in a volcanic arc situation.
- The volcanics were affected by a tectonic phase prior to the sedimentation of the Triassic.
- During the Variscan orogeny, which was responsible for the generation of the volcanics and for their subsequent tectonic overprinting, the Julier area seems to have been part of a cordillera above a subduction zone.

Keywords: Volcanics, calcalkaline series, Variscan orogeny, Austroalpine, Julier area, Switzerland.

Introduction

Paleozoic metaigneous rocks outcrop in the area around the Julier Pass (Grisons). Their protoliths include plutonic assemblages (diorite, granodiorite, granite), subvolcanic elements (granophyre) and a volcanic series (basaltic andesite, andesite, dacite, rhyodacite, rhyolite). Together with the polymetamorphic basement and the Mesozoic sediments, they constitute the lowermost Austroalpine nappe (Err nappe), which is directly overthrusted on the Penninic Platta nappe.

This area has been mapped early in the century (1910-1929) by CORNELIUS who described in detail the lithologies (CORNELIUS, 1935) and the tectonic relations (CORNELIUS,1950). Between 1965 and 1985 TJ. PETERS and V. DIETRICH mapped the Oberhalbstein area in detail, integrating a series of master theses of the Geological Institute of the ETH Zurich (W. FINGER,1972; M. NOLD, 1972; F. GIOVANOLI, 1972; J. UTTINGER, 1972; P. NIEVERGELT, 1976; A. HANDKE 1977).

The aim of the present work is to understand the Variscan magmatism and its consequences on the tectonic evolution of this area.

Only few outcrops of this area are suitable to study the original magmatic relationships, because of intense wedging of the different rock units, as result of the superposition of the Alpine and Variscan tectonics. Therefore almost all data and petrogenetic discussions refer to the restricted area (about 20 km^2) NW of the Julier Pass (Fig. 1).

Definition of the lithotypes

CORNELIUS' rock terminology is based, particularly for the volcanics, on local names. In this work, a compromise between lithological, geochemical and genetical relationships is used. Table 1 summarizes the main lithologies and connects the terminology used here to the one used by CORNELIUS (1935).

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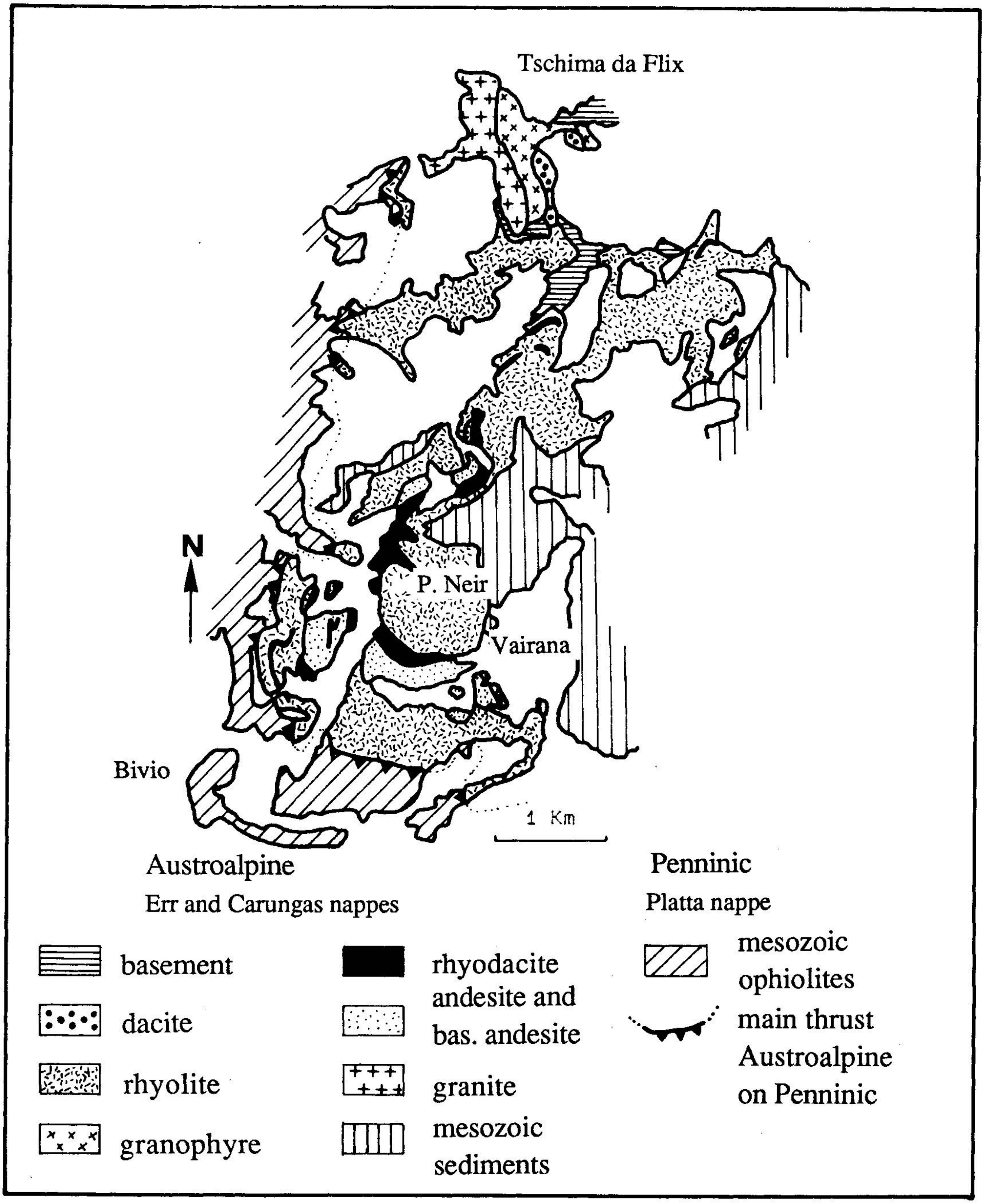


Fig. 1 Geological sketch map of the Julier area, simplified from CORNELIUS (1932): Geologische Karte der Err-Julier Gruppe, 1:25000, 1932, Schweiz. geol. Kommision, Spezialkarte Nr.115A.

Tab. 1 Definition of the lithotypes and correlation with CORNELIUS' rock terminology.

rock type	granitic to granodioritic intrusiv body	dioritic enclaves	granitic porphyric body	rhyolitic pyroclastics 2)	rhyodacitic to dacitic pyroclastics 2)	dacitic rock 3)	dacitic to andesitic pyroclastics 2)	andesitic to basaltic - andesitic rocks 4)
rock name	metagranite	metadiorite	metagrano-phyr	metarhyolite	metarhyodacite	metadacite	metaandesite	metabasaltic-andesite
Corne-lius	Err Granit	Diorit	Granit-porphyr	Neirporphy-roid	Violette sprenkelschiefer		Vairana Schiefer	Vairana Schiefer
	**	**	n = 7	n = 39	n = 14	n = 10	n = 12	n = 10
SiO2	66.20	52.64	70.62 # 0.30 ##	69.48 # 0.37##	66.27# 0.29##	64.12# 0.33##	60.50 # 0.53##	56.52 # 0.76##
TiO2	0.49	1.06	0.36 0.01	0.39 0.01	0.58 0.02	0.59 0.01	0.75 0.02	1.03 0.04
Al2O3	15.02	17.28	14.23 0.16	13.78 0.15	14.35 0.33	16.04 0.09	15.91 0.40	16.52 0.46
Fe2O3	1.72	2.64	1.75 0.13	1.98 0.13	4.42 0.22	1.76 0.08	3.03 0.39	3.74 0.26
FeO	1.83	5.28	0.84 0.07	1.11 0.09	0.33 0.07	2.59 0.13	2.73 0.32	4.39 0.46
MnO	0.08	0.24	0.05 0.01	0.07 0.01	0.09 0.01	0.09 0.01	0.11 0.01	0.13 0.01
MgO	1.76	4.32	1.24 0.07	1.27 0.09	1.69 0.17	1.80 0.12	3.18 0.15	5.17 0.20
CaO	2.29	6.68	0.81 0.12	1.87 0.22	2.28 0.38	2.54 0.19	3.31 0.56	3.37 0.64
Na2O	3.51	2.9	3.55 0.21	2.97 0.16	4.15 0.22	3.7 0.20	4.33 0.38	4.19 0.23
K2O	3.93	3.57	4.02 0.26	3.67 0.16	2.65 0.25	3.52 0.13	1.80 0.24	1.17 0.24
P2O5	0.14	0.15	0.09 0.01	0.10 0.01	0.14 0.01	0.13 0.01	0.18 0.01	0.20 0.01
H2O		3.56	1.74 0.06	1.80 0.06	1.63 0.10	2.65 0.07	2.83 0.15	3.59 0.25
CO2		0.20	0.24 0.09	0.87 0.21	1.04 0.31	0.30 0.03	1.26 0.50	0.67 0.23
Nb	12	16	9 0.94	8 0.31	9 0.41	13 0.76	9 0.58	8 0.83
Zr	139	122	130 3.65	136 2.13	138 3.87	178 2.02	145 4.00	146 6.58
Y	29	40	26 1.12	27 0.67	27 1.33	36 0.90	26 1.27	30 1.30
Sr	212	240	49 (35)* 12.60	127 (93)* 18.46	206 (136)* 52.79	176 (153)* 17.02	299 (248)* 62.95	263 (230)* 70.38
Rb	192	226	194 9.40	169 7.81	118 10.3	176 6.36	84 10.84	54 11.69
Th	-	-	13 2.84	9 0.65	10 1.00	- -	5 0.91	4 0.70
Pb	17	11	- -	20 2.39	18 1.83	22 1.27	15 2.85	- -
Ga	21	23	16 0.55	16 0.27	17 0.69	20 0.36	19 0.70	19 0.94
Zn	42	101	40 4.14	51 1.90	61 6.03	70 3.09	78 2.56	91 7.06
Cu	13	-	22 4.18	13 3.60	14 9.50	6 0.46	20 6.62	24 4.10
Ni	12	18	- -	10 0.33	11 0.60	14 0.37	13 0.60	27 2.10
Co	21	37	12 0.32	13 0.61	15 1.27	23 0.90	22 1.00	36 2.32
Cr	5	14	6 0.10	8 0.90	11 1.46	27 2.33	25 2.30	120 8.57
V	106	262	36 2.00	37 2.63	49 4.79	110 5.53	97 5.07	138 9.80
Ba	505	432	225 (186)* 44.5	416 (359)* 37.08	298 (317)* 28.18	608 (616)* 35.85	263 (245)* 41.71	288 (234)* 83.23
La	35	57	20 1.37	21 1.26	25 3.11	45 1.79	28 2.84	34 4.25
Sc	14	31	7 0.36	8 0.32	10 0.77	20 0.56	16 0.78	22 1.54

n : number of analysis
\# : mean value
* : median value
** : typical analysis
\#\# : standard daviation of the mean value

1) : The term granophyre refers to subvolcanic rocks with granophyric texture. Lacking evidence of such texture (Alpine metamorphism ?), the term will be used here in a genetic sense to indicate the subvolcanic origin.
2) : Textural relationships rather indicate a pyroclastic emplacement than lava flows.
3) : No textural evidence either for lava flow nor for pyroclastic flow.
4) : Some textural indications for lava flow.

Tab. 2 Summary of the mineralogical composition of the Julier magmatic series.

	rock type	*phenocrysts*	*relictic phenocrysts*	*matrix*	*textural observations*
volcanic	metarhyolite	qz (kfs,plag)	bi (amph, px)	qz, plag, ser, chl, epi, (stilp) variable cc	All stages between well defined pyroclastic texture and the strongest metamorphic deformation (mylonite) are visible
	metarhyodacite	qz, plag, kfs (both strongly altered)	bi	qz, plag, ser, chl, hem, (Mn-epi)	Fine grained schist to phyllite. Generally difficult to distinguish the metamorphic textures from the volcanoclastics
	metadacite	qz, plag (completly saussuritizated)	bi	qz, plag, ser, chl (stilp, pump ?)	The volcanic character is recognizable on the resorbtion figures in qz. No clear evidence for either lava or pyroclastic protolith
	metaandesite	plag (strongly altered) some qz	amph, px	plag, chl, ser, epi, cc	Strong metamorphic overprint. The pyroclastic character is debatable
	metabasaltic andesite	plag	amph,px	plag, chl, epi, cc	More homogeneuos and massive texture than metaandesite. Could be a lava flow
sub volcanic	metagranophyre	qz, plag, kfs, bi variable grade of alteration		qz, plag, (stilp)	Fine grained holocrystalline matrix. Interpreted as subvolcanic rock
plutonic	metagranite	Massive, medium to coarse grained, equigranular fabric of qz, plag, kfs, bi. Products of the Alpine metamorphism are ser, chl, stilp. The granite does not show strong Alpine foliation, but locally the cataclastic deformation can be important			
	metadiorite	Massive, medium grained amph, plag, bi fabric including some large plag (strong altered) and qz phenocrysts			

Mineral abbreviations: qz: quartz, kfs: alkalifelspar, plag:plagioclase, bi: biotite, amph: amphibole, px: pyroxene, ser: sericite, chl: chlorite, epi: epidote, cc: calcite, stilp: stilpnomelan, pump: pumpellyite, Mn-epi: manganese bearing epidote

The geochemical characterization of the volcanics is partly described in MERCOLLI (1982) and will be dealt with in a forthcoming paper.

All magmatic rocks underwent Alpine deformation and greenschist facies metamorphism. Consequently, all the magmatic rock names should be preceded by the prefix "meta" (metagranite, metarhyolite, ...). In this study, the prefix will only be used for important definitions; for the rest of the text the prefix "meta" will be implied for brevity.

Table 2 summarizes the mineralogical composition of the magmatic series. Unfortunately, the Alpine metamorphism has strongly altered the original mineral assemblages. Especially affected are phases like plagioclase, amphibole, pyroxene, biotite and the glassy matrix, which have reacted to sericite, chlorite, albite, epidote.

This mineralogical alteration greatly reduces the use of mineralogical arguments for the interpretation of the magmatic evolution.

For a detailed description of the basement rocks we refer to CORNELIUS (1935) and for the stratigraphy of the sedimentary cover see FINGER (1978).

Geological setting of the different rock units

The geological sketch (after CORNELIUS, 1932; integrated with personal observations) of the studied area (Fig. 1) illustrates the surface distribution of the different rock units and some geographical landmarks cited in the text.

In order to understand this complex tectonic edifice, attention will be focussed on the attitude of the volcanics.

The lithological profile A (Fig. 2) shows schematically (no true thickness scale) the contact relationships between basement, granophyre and volcanics. This profile should represent the base of the volcanic sequence.

Profile B (Fig. 2) demonstrates the stratigraphical succession between the different volcanic units (rhyolite, rhyodacite, andesite and basaltic andesite).

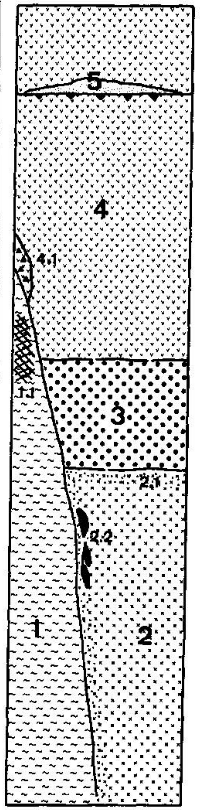
The top of the volcanic series is marked by the occurrence of an almost monogenic conglomerate or breccia (only rhyolite components) grading into a sandy shale (FINGER, 1972). Such deposits may be interpreted as epiclastics derived from the rhyolitic pyroclastics. They are stratigraphically overlain by the corneoles («Rauhwacken») of the lower Triassic. Locally Triassic sediments lie directly on the gneiss.

It must be underlined that the major difficulty in understanding the original attitude of the magmatic series is represented by the strong tectonic overprint (in Variscan and Alpine times) which has, in many cases, obliterated the primitive mutual relations of the rocks. Nevertheless, some important relations have been preserved:

- Gneisses in amphibolite facies are the substratum on which the volcanic rocks were deposited.
- These gneisses are intruded by a granite and very likely also by the granophyre, even though this latter relation cannot be clearly proven.
- Only the dacite and the rhyolites are in contact with the gneisses.
- Only the rhyolites and the gneisses are directly overlain by Triassic sediments.
- The rhyolites and the rhyodacites are sharply separated by an irregular surface (paleosurface).
- The rhyodacite passes gradually into the andesites.
- No mappable boundary has been found between the andesites and the basaltic andesites.
- The andesites and/or the basaltic andesites are always separated from the rhyolites by a layer of rhyodacite or by a clear tectonic contact.

Volcanological frame

The reconstruction of the eruptive and depositional mechanisms of the Julier volcanics is mainly based on few isolated observations and remains speculative. However, some general statements can be made. Macroscopically, rhyolites, rhyodacites and andesites exhibit the inhomogeneous character typical of pyroclastic rocks. Basaltic andesites and to some extent also the dacite, seem to be much more massive and homogeneous, suggesting that those rocks were extruded as lava flows. Microscopic features confirm these impressions. Rhyolites, rhyodacites and andesites show very inhomogeneous groundmass. A major difficulty consists in the distinction between primary and metamorphic structures. In some cases the differences of mineralogical compositions of various parts of the groundmass seem to reflect original compositional discontinuities. In other samples they are clearly the product of metamorphic reworking (micro-shear zones, small veins, etc.). Accepting the pyroclastic nature of the main part of the volcanics, one can attempt to define the depositional mechanism. In the genetic classification of pyroclastic flows by WRIGHT et al. (1980), the Julier pyroclastics would fall into the field of ignimbrite-pumice and ash flow deposits,



5. Rhyodacite: fine grained violet schist with white lenticular spots.

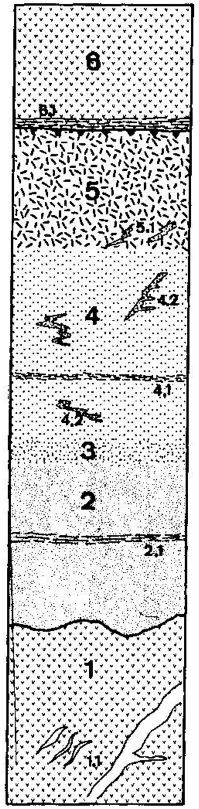
4. Rhyolite: greenschist of inhomogeneous appearance (variation in color intensity, schistosity and distribution of quartz phenocrysts). Tipically the contacts to the gneiss are strongly tectonized.
4.1 Brecciated rhyolite (vent breccia ?)

3. Dacite: almost massive, homogeneous, dark green rock. Unclear contacts to the rhyolite and gneiss.

2. Granophyre: mostly quite altered rock. Contacts with the gneiss and the dacite are sharp and marked by a fine-grained zone (2.1), the same at the contact to the dacite. Dioritic enclaves along the contact with the gneiss (2.2)

1. Basement: polymetamorphic gneisses. Generally two mica gneisses with pelitic and amphibolitic intercalations. The pre-Alpine high metamorphic assemblages (sillimanite + cordierite in the pelitic layers) suffer strong Alpine retromorphism at greenschist facies conditions.1.1 Hydrothermally alterated basement.

Fig. 2a Lithological relations at the bottom of the volcanic suite.
The angular discontinuity at the contact with the gneiss is overemphasized.



6. Rhyolite: same rock as 1. Near the contact with the basaltic andesite the rhyolite is strongly deformed (6.1)

5. Basaltic andesite: homogeneous greenschist (in some places porphyritic) frequently cut by vein of calcite, quartz, epidote (5.1). The contact to the rhyolite is clearly tectonic.

4. Andesite: inhomogeneous fine grained greenschist cut by mylonitic zones (4.1). Veins of calcite, quartz, epidote are abundant (4.2). The transition to basaltic andesite is unclear in the field.

3. Boundary zone between rhyodacite and andesite. The transition is gradual and marked by a change in color from violet to green.

2. Rhyodacite: extremely inhomogeneous, fine grained schist to phyllite with lenticular white spots of mm to cm size. 2.1 Phyllonitic (mylonitic ?) layers.

1. Rhyolite: greenschist of inhomogeneous aspect (variation in color intensity, schistosity and distribution of quartz phenocrysts). The contact to the rhyodacite is sharp and irregular (paleo-surface) though commonly tectonized. Quartz veins and quartz-filled tensional fractures are abundant (1.1).

Fig. 2b Lithological relations at the top of the volcanic suite.

produced by the collapse of a Plinian eruption column as envisaged by SPARKS et al. (1978). Following FISCHER and SCHMINCKE (1984) (Tab. 11.3, p. 310) in comparing unwelded ignimbrite with other types of volcanoclastic deposits, the general features of the Julier pyroclastics coincide with the following characteristics of ignimbrites: absence of large boulders - poor sorting - poor grading - appreciable thickness with an eventual vague internal layering - subangular shape of the rare fragments of basement.

Unfortunately, none of the other classical criteria for the definition of ash flow deposits (degree of vesiculation, shape of the shards, degree of welding, fiamme) are preserved. Fig. 3 shows features that could be interpreted as recrystallized fiamme and pumice shards.

IZETT (1981) tried to classify silicic fallout ashes chemically. In his Ca versus Fe diagram the Julier rhyolites plot in the field of dacite glass (Fig. 4). IZETT (op. cit.) also gives some general features for each group. The rocks falling in the dacite glass field have as phenocrysts quartz, sanidine, clinopyroxene, orthopyroxene, amphibole, magnetite, ilmenite and apatite. The SiO_2 content for these rocks ranges from 67 to 77 weight%. Glass shards show different shapes and can have a wide range of composition in a single bed. Some of these features have been observed (mainly as relics) in the Julier rhyolites (Tab. 1 and 2).

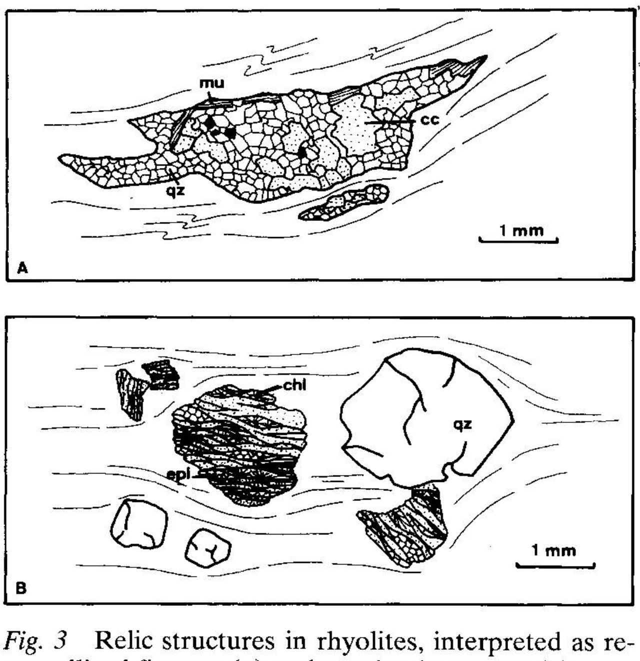


Fig. 3 Relic structures in rhyolites, interpreted as recrystallized fiamme (a) and pumice fragments (b). qz = quartz, chl = chlorite, ep = epidote, mu = muscovite, cc = calcite.

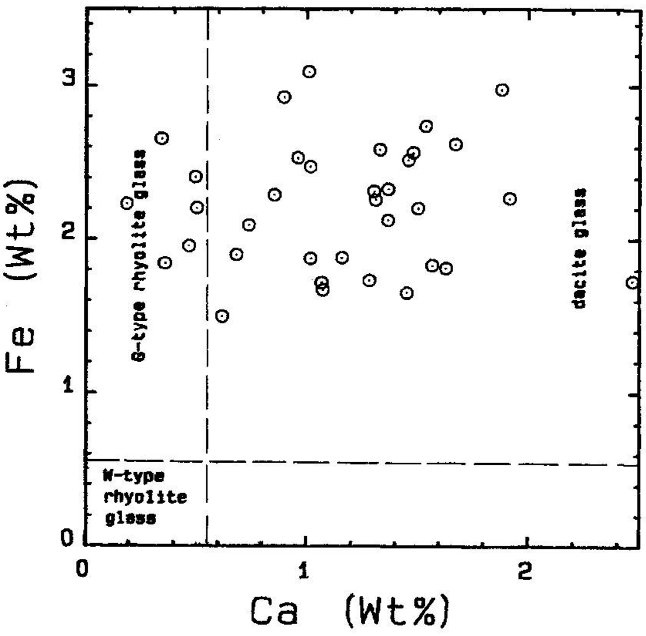


Fig. 4 Classification of rhyolite ash flow deposits after IZETT (1981). Data from Mercolli (unpublished).

The following observations help to understand the volcanic environment during the emplacement of the volcanics:

– The main volcanic activity was rhyolitic.

– The rhyolites form a more or less monotonous unit without any important lithological discontinuities, except for two outcrops of brecciated rhyolite containing some basement fragments.

– The top of the rhyolites is eroded, marking a time lapse (which can be short, days, months) between rhyolites and rhyodacites.

– Rhyodacites, andesites and basaltic andesites are not separated by an erosional surface; it seems, therefore, that these three rock types belong to the same eruption unit.

– Thick sequences of epiclastics are absent, indicating a facies proximal to the eruption center(s).

This setting could best be related to the formation of a caldera structure. What we see is obviously only a strongly deformed relic of such a structure, but comparing these features with classical caldera situations (SMITH and BAILEY, 1968; LIPMAN et al., 1978, LIPMAN, 1984) the similarities are striking. An intra caldera situation could also very well explain why it is in this area that the volcanic series maintain their original lithological and structural relations. Clearly the effects of regional tectonics and erosion in this protected situation, caldera inside, are much smaller than outside.

Following this train of thought it becomes possible to interpret the anomalous occurrence of dacite as a collapsed relic of the pre-caldera volcanism into the caldera itself.

If this reconstruction is correct, the normal stratigraphical sequence then is gneiss-(dacite)-rhyolite - rhyodacite - andesite - basaltic andesite. According to the current geochemical discrimination diagrams (KUNO, 1968; IRVINE and BARAGAR, 1971; PEARCE and CANN, 1973; MIYASHIRO 1974; PEARCE et al., 1984) geochemically the Julier volcanics belongs to the calcalkaline series (Fig. 5).

All the observations on the Julier volcanics, rock types, emplacement mechanism, chemical composition, association with granitoids, converge to the same result:

- These volcanic rocks are the product of a magmatism related to the subduction of oceanic crust under continental crust. In other words the Julier volcanics were produced in a continental arc environment, as displayed actually in the Andes.

The magmatic evolution of the Julier suite can be summarized as follows. During a subduction process, basaltic magmas were generated at upper mantle levels. These rose the lower continental crust where they met rocks at conditions of upper amphibolite facies. Upon magma arrival, parts of these rocks were already undergoing partial melting (migmatitisation). The intrusion of the basic magmas into such an environment increased the extend of melting of the crustal rocks. It was thus possible to produce large masses of granodioritic melt rather than leucogranitic magmas which would have formed if a smaller proportion of the migmatites had been partially molten. A complex ascent mechanism of these molten masses through the crust involving a magmatic differentiation (fractional crystallization, assimilation of country rocks, mixing of different magmas, ...) ultimately lead to different kinds of plutonic and/or volcanic association. This evolution could have been remarkably different for separated melt batches, even though these originated from the same source.

For the particular case of the Julier volcanics I would envisage an evolution as follows:

A batch of basaltic magma, evolved mainly by fractional crystallization, reached the surface and produced the dacite as a precursor of the main rhyolitc activity. Facilitated by this precursor activity, a large mass of rhyolitic magma subsequently reached the upper levels of the crust. The intrusion of basaltic magmas into this magma chamber triggered the eruption of voluminous rhyolitic pyroclastics (SPARKS et al., 1977). The consequence was subsidence of the chamber roof, leading to the formation of a caldera structure. The granophyre would represent part of the rhyolitic magma crystallised under subsurface conditions. The intense stirring of the magma due to the previous events, allowed the mixing of the basaltic and the rhyolitic magmas with the formation of intermediate compositions. These were then extruded in the caldera to form rhyodacite, andesite and basaltic andesite, marking the end of the volcanic activity in this area. A period of erosion and the wedging of the volcanics with the basement followed. Due to this tectonic phase granitic magma could reach the upper crust along thrust surfaces thus forming the granitic body.

The age problem

No radiometric age determination of the magmatic rocks in this area has yet been published. RAGETH (1984) cited a personal communication from Grünenfelder dealing with an upper Carboniferous age (305 ma.) for the Julier-Bernina granitoids.

A generally accepted statement of Alpine geology says that such rhyolitic volcanics were extruded in Permian time. This assumption is mainly based on stratigraphic evidence. Many of these rhyolites are stratigraphically overlain by lower Triassic carbonaceous sediments and some of them are interbedded with thick clastic sediments showing significant analogies with typical Permian deposits (DÖSEGGER, 1974). The stratigraphical arguments, however, are not totally independent. DÖSEGGER (1974) assigns the lower and middle Permian age to the clastic sediments with volcanics only because of lithological similarities of his volcanics (Austroalpine) with those of Bolzano dated from that period.

In the Aar massif, FRANKS (1968) situates the rhyolites in Westphalian times on the basis of datable related sediments (JONGMANS, 1960). In the central Aar massif, SCHENKER (1985) describes rhyolites (which can be well correlated with those of FRANKS) intruded by granitoids (central Aar granit) dated from the Permian-Carboniferous limit (281 ma., WÜTHRICH, 1965).

As can be seen, the problem of the age of the Variscan magmatism in the Central Alps is far from being solved. It becomes more and more evident that, at least for the most part, the rhyolitic volcanics are older than the often associated granitoids and not vice versa as generally accepted.

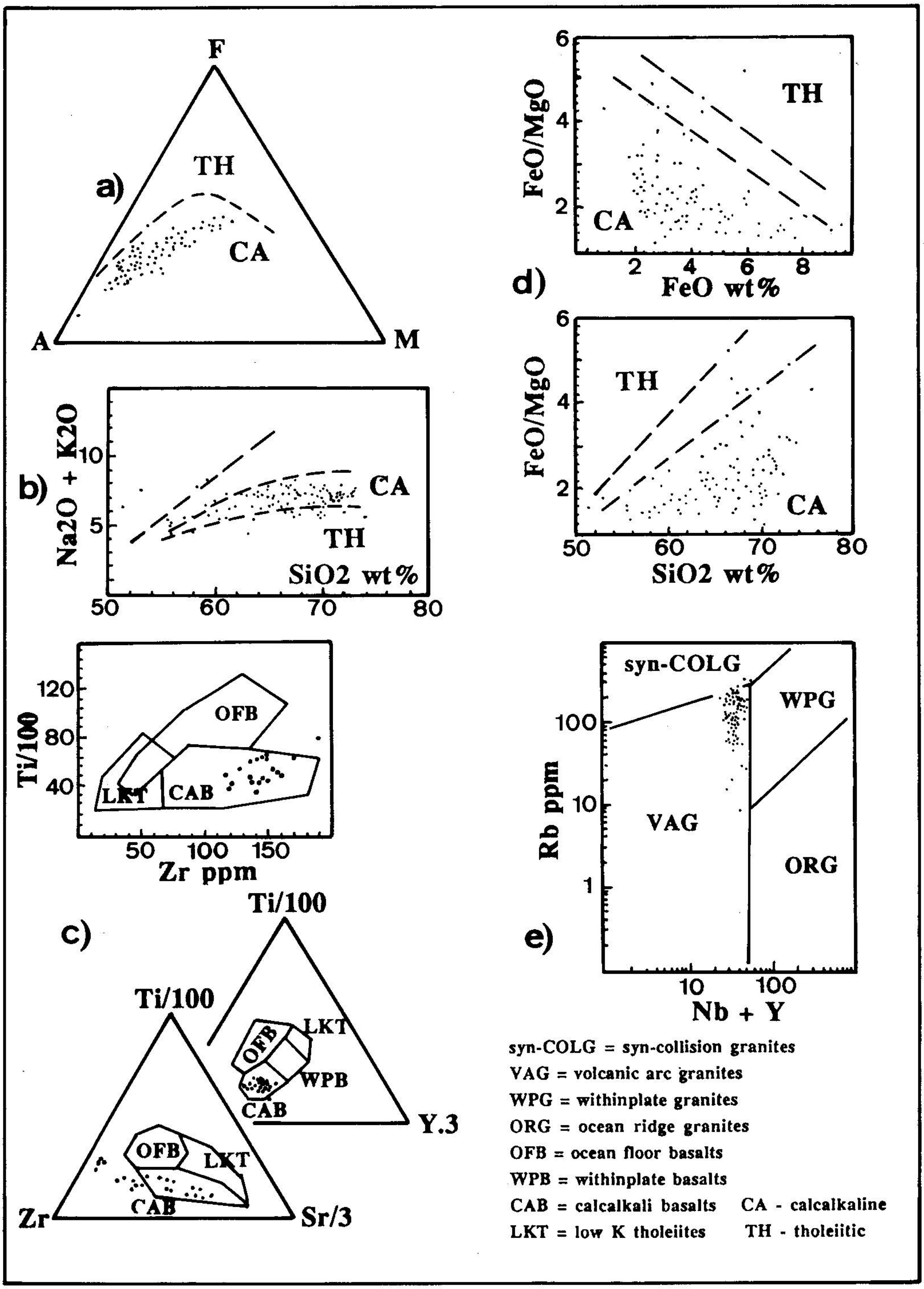


Fig. 5 Geochemical discrimination diagrams (a) KUNO, 1968; b) IRVINE and BARAGAR, 1971; c) PEARCE and CANN, 1973; d) MIYASHIRO 1974; e) PEARCE et al., 1984) showing that the Julier volcanics belongs to the calcalkaline series.

Lacking precise indications I consider that the evolution discussed previously, took place some time in the Upper Paleozoic.

Tectonic evolution

On the basis of the described stratigraphy one can try to discuss the tectonic evolution of the Julier area from the Upper Paleozoic to the Alpine time.

One of the major consequences of the previously described volcano-stratigraphy is that the sequence rhyolite-rhyodacite-andesite-basaltic andesite out-cropping in the Vairana region lays upside down. On this inverse sequence the Triassic sediments show a normal succession (even if partly disturbed by Alpine tectonics). Hence the upside down position of the volcanics must be the product of pre-Triassic tectonics. Admitting that an Upper Paleozoic tectonic event (i.e. Variscan) had affected the Julier volcanics after their emplacement, then it arises the problem of separating Alpine from Variscan tectonics.

Near the main Alpine thrust between the Platta nappe (Penninic) and the Err nappe (Austroalpine), Mesozoic sediments are wedged together with the rhyolites. This led CORNELIUS (1950) to distinguish the Carungas nappe from the Err nappe as the lowermost Austroalpine unit in this area. If one accepts wedging of Mesozoic sediments as a criterion characterizing Alpine tectonics, then structures like the reverse series in Vairana and the thrusting of rhyolite beneath gneiss, which does not involve Mesozoic sediments, can be interpreted as Variscan. A further indication that the wedging of the volcanics took place before the sedimentation of the Triassic units is given by Mesozoic sediments, stratigraphically overlaying only rhyolite or gneiss, but never the more basic units on the top of the volcanic series.

In other words, the Paleozoic volcanics suffered a thrusting and/or folding phase in Variscan times, leading to a first intense alteration of the primitive edifice. After a Permian erosional phase followed the sedimentation of the Mesozoic units. The Alpine tectonics (in this region mainly a thrust-wedging style) complicates the structures by wedging together the Variscan basement (including the volcanics) and the Mesozoic sediments. The intensity of this process can be deduced from the strong parallelism of Variscan and Alpine structures.

In summary, the geological history of this area can be sketched as follows:

Carboniferous-Permian

- Uplift and erosion of the high metamorphic gneisses. The age of this metamorphism is probably Variscan, though it could be older (Caledonian).
- Early volcanic activity of dacitic composition
- Main eruption of large masses of rhyolitic pyroclastics
- Subsequent extrusion of more basic material (rhyodacite, andesite and basaltic andesite)
- Tectonic phase leading to the wedging of the volcanic sequence together with the gneisses
- Syntectonic emplacement of the granite
- Erosion of the Variscan relief

Mesozoic

- Sedimentation of the Mesozoic units

Cretaceous-Tertiary

- Thrusting of the Austroalpine nappes over the Penninic units
- Regional Alpine metamorphism under greenschist facies conditions

Concluding remarks

This type of evolution can be extended from the Julier area to neighboring areas. The adjacent lower Austroalpine unit (Julier-Bernina nappe) chiefly consists of large plutonic bodies. BÜHLER (1983) and RAGETH (1984) in particular, point out the existence of two main series: one with diorites, granodiorites and granites belonging to the calcalkaline family and a younger one with quartz syenites, alkalifeldspar granites (sometimes with rapakiwi structures) and alkalifeldspar rhyolites which might belong to the alkaline family. If the first series agrees very well with the continental arc situation postulated for the Julier volcanics, the second series could be interpreted as a product of continental rifting subsequent to the lower Permian cratonisation of Gondwana and Europe. In this case this second series could be compared with the upper Permian-lower Triassic alkaline complex of Corsica and Predazzo-Monzoni and would represent magmatism related to the rifting of the Variscan continent which initiates the opening of the Tethys.

Similar evolutionary schemes for the Upper Paleozoic volcanics in the Central Alps have been proposed in recent times by SCHENKER (1985) for the Aar massif and BULETTI (1984), STILLE and BULETTI (1987) for the volcanics of the Lugano area (Southern Alps).

It is becoming more and more evident that the Variscan orogeny can be interpreted successfully in terms of plate tectonics. In particular, the late Variscan magmatism in the Central Alps appears to have evolved in a cordilleran situation, on the southern continental margin of the European block, above a subduction zone produced by the underplating of the Proto-Tethys oceanic plate (MERCOLLI and OBERHÄNSLI, 1988).

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