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The polycyclic evolution of the Penninic Maggia nappe, Central Alps: a summary report

by *Armin W. Günthert*[1], *Willem B. Stern*[2] and *Hans Schwander*[3]

Abstract

The Maggia nappe mainly consists of a series of fine-grained hornblende-free psammitic (arkosic), psephitic, and pelitic gneisses and schists of Archeaen to early Paleozoic origin, as well as of pre-Alpine layers of amphibolites, hornblende gneisses and -schists. These series form the country rock of a group of coarse-grained peraluminous S-type metagranitoids called Matorello Gneiss, that were generated by Hercynian ultrametamorphism. Isochemical transitions between Matorello Gneiss and the surrounding arkosic gneisses confirm their origin within the country rocks by in situ anatexis. Several generations of pre- and post-granitic aplites, pegmatites and newly discovered tonalite porphyrites as well as hornblende-bearing dikes, stocks and sills can be observed, and are of pre-Alpine origin as they show a strong Alpine schistosity.

All hornblende-bearing rocks are of pre-Alpine igneous origin and reveal a normal calc-alkaline basalt trend; a second rather abnormal trend of the newly discovered contaminated basaltic rocks is probably the result of pre-Alpine assimilation.

The Maggia nappe underwent Alpine amphibolite facies metamorphism, during which all the rocks were strongly recrystallized. Pre-Alpine ages of the zircon U–Pb and Rb–Sr whole-rock systems were not affected during the Alpine orogeny.

Keywords: S-type granite, dikes and sills, pre-Alpine rocks, polycyclic evolution, geochemistry, Maggia nappe, Switzerland.

1. Introduction

The Maggia nappe is situated south of the Gotthard massif at the northern border of the Lepontine area (Fig. 1). The nappe comprises several polymetamorphic units: Within the core of the nappe granitoid gneisses, called Matorello Gneiss (PREISWERK, 1918 a and b), are dominant. This gneiss is the only S-type granitoid so far known in the Penninic realm of the Swiss Alps. Contacts between different lithologies are often complex and reflect the polymetamorphic and polydeformational history of these rocks. The granitoid core is surrounded by two different types of country rocks: Hornblende-free rocks include country rocks of paragneisses, chiefly of arkosic composition, metapelites, and leucocratic dikes. Hornblende-bearing country rocks are found mainly in the eastern part of the nappe, hornblende-bearing dikes, stocks, and sills are concentrated south of Laghetti (Fig. 1). They all show Alpine schistosity. The nappe as a whole is surrounded by monometamorphic Mesozoic rocks (Bündnerschiefer series).

PREISWERK (1918 a and b) first mapped and described the Maggia nappe as consisting of psammitic to pelitic country rocks intruded by granite and hornblende-bearing rocks both of pre-Alpine origin. Later mapping was carried out on scales of 1 : 25'000 (BURCKHARDT and GÜNTHERT, 1957; HAFNER et al., 1975) and on larger scales (GÜNTHERT et al., 1992). BUCHMANN (1953) thought the Matorello Gneiss to be of Alpine plutonic origin. GÜNTHERT (1954) discovered psephitic gneisses within the country rocks and transitions between the granitic to quartz-

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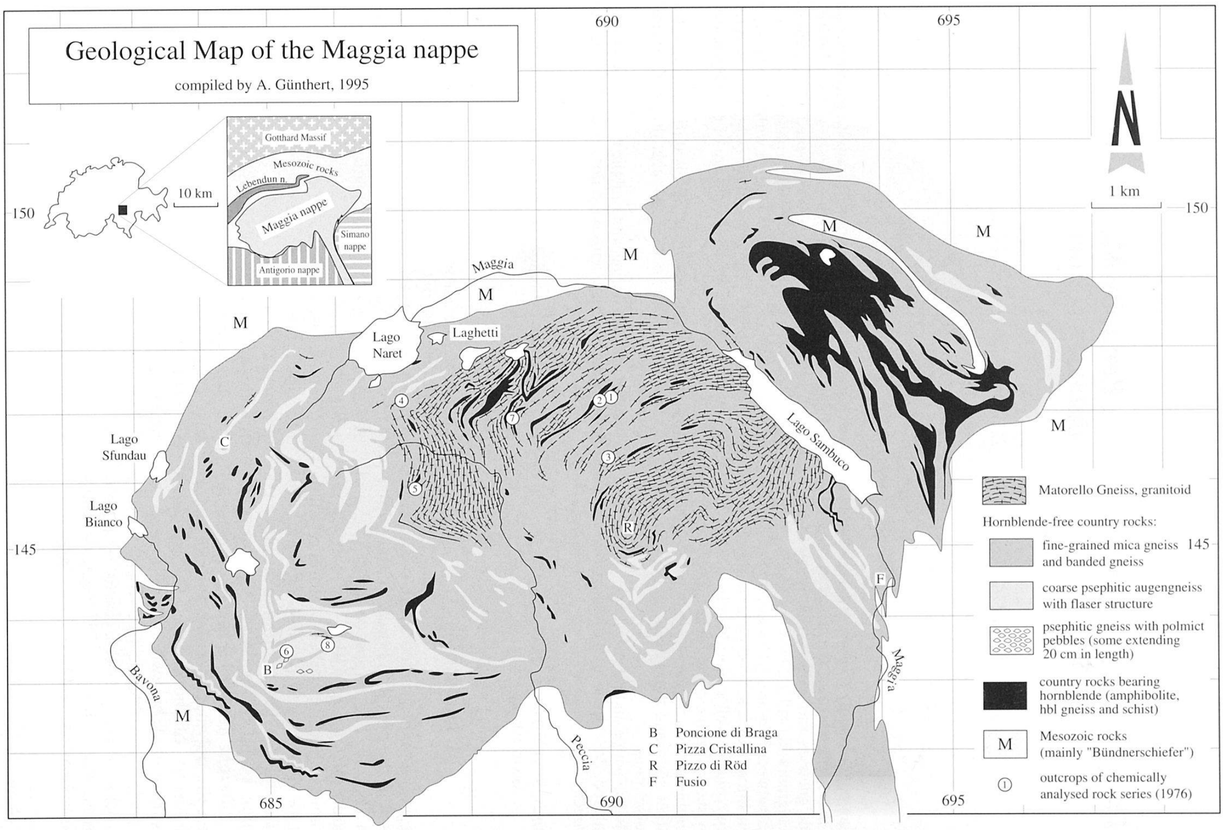

Fig. 1 Geologic map of the Maggia nappe compiled by A. GÜNTHERT. The Valle dell'Ospedale is situated south of "Laghetti" (NW of locality no 7). Localities 1–8 comprise examples of isochemical and allochemical transitions between country rocks and Matorello Gneiss (from GÜNTHERT et al., 1976). Discordant contacts are found SSE of R (Pizzo di Röd) as well as near the transitional series of localities 1, 5, 7.

dioritic Matorello Gneiss and the surrounding country rocks, and he interpreted the gneiss as a product of Alpine granitization of arkosic gneisses in parts showing migmatitic structures due to Alpine ultrametamorphism. GÜNTHERT et al. (1976) found isochemical transitions between the Matorello Gneiss and meta-arkosic country rocks, as well as beds of the latter projecting along the strike into the area of the Matorello Gneiss, in part with ghost stratigraphy. New field interpretations and age determinations of the rocks by KÖPPEL et al. (1981) and JÄGER (pers. comm.) proved the Hercynian age of the Matorello protolith and aplites and higher ages for the hornblende-free country rocks. Thus, polymetamorphism and polycyclic tectonics became obvious.

With the development of analytical techniques minor and trace elements became more and more important to distinguish between ortho- and paragneisses as well as between different types of granite and of hornblende rocks (LEAKE, 1964; PEARCE et al., 1984; BARBARIN, 1990; SEIM and TISCHENDORFF, 1990).

The aim of this paper is to review field observations, optical analyses, and element distribution patterns of whole-rock analyses from the Maggia nappe to clarify the origin of metagranitoids and dikes and to develop a summarizing outline of the metamorphic history of this tectonic unit. For this purpose a total of more than 2000 rock specimens and thin sections have been investigated, including universal stage determinations of plagioclase. 161 whole-rock analyses were performed (W.B. STERN, see appendix) and are reported with all major, some minor and trace elements. Numerous minerals (feldspars, hornblende, biotite, chlorite, clinozoisite, titanite, rutile) have been analysed by electron microprobe (H. SCHWANDER). The presented results are a summary of mainly unpublished data (GÜNTHERT, 1991; GÜNTHERT et al., 1992), and for more informations and detailed study of the data pattern, the reader is referred to these unpublished papers (kept at the Mineralogisch-Petrographisches Institut, University of Basel, and at Landeshydrologie und -geologie, Schweiz. Geol. Dokumentationsstelle, 3003 Bern).

2. Field observations and chemical results

2.1. GENERAL REMARKS

In the following the term "Hercynian" was used synonymously to "Variscan" (VON RAUMER, 1988). Since all rocks of the Maggia nappe have undergone Alpine metamorphism, they always should be termed with "meta", e.g. "meta-granitoids", "meta-dike", etc. By brevity, however, the prefix "meta" was neglected.

According to a former collection system at the Mineralogisch-Petrographisches Institut, Basel, all collected samples have been marked by an "Mto" number neglecting whether they come from a Matorello Gneiss locality or not. From hand specimen and field observations all rocks easily can be divided into hornblende-free and hornblende-bearing rocks. Selected chemical patterns of all groups are presented in a set of diagrams (Figs 2–4).

2.2. HORNBLENDE-FREE ROCKS

Country rocks are psephitic to arkosic to pelitic gneisses and mica schists, in parts bearing garnet, staurolite, and kyanite. Some psephitic gneisses with polymict pebbles are found in the SW of the nappe (Fig. 1, outcrop no 6 and R South). Observed pebbles include aplites, hornblende-free augen gneisses, biotite-hornblende gneisses, and mica schists in parts bearing garnet. Exotic pebbles are several types of quartzites rich in K-feldspar, epidote, or garnet, respectively. The matrix of the psephitic gneiss is a fine-grained arkosic gneiss or an augengneiss of clastic origin.

Granitoids are of granitic, granodioritic, and tonalitic composition with chemical transitions among each other, they all show the same Alpine structure and texture, and cannot be discerned in the field. They are named *Matorello Gneiss* (PREISWERK, 1918 a and b) and consist of the following rocks (Fig. 5):

granodioritic composition:
> 90% (Fig. 5, areas 1–6, Mto 826),
tonalitic composition:
< 10% (Mto 6),
granitic composition:
< 1% (G 79 A).

The area of outcrops of Matorello Gneiss amounts to about 10 km^2 (including areas covered with Quaternary deposits and lakes). Granitoid rocks show – chiefly along the Alpine strike – isochemical transitions into paragneisses, i.e. arkosic country rocks with or without psephitic texture, or form sheets, and very rarely fluidal textures and discordant contacts of a few m^2 only each (GÜNTHERT, 1954). Mineralogical and chemical inhomogeneities, as well as partial oversaturation are similar to those of arkosic country rocks (NIGGLI et al., 1930; GÜNTHERT, 1953; WEDEPOHL, 1978; SEIM and TISCHENDORFF, 1990).

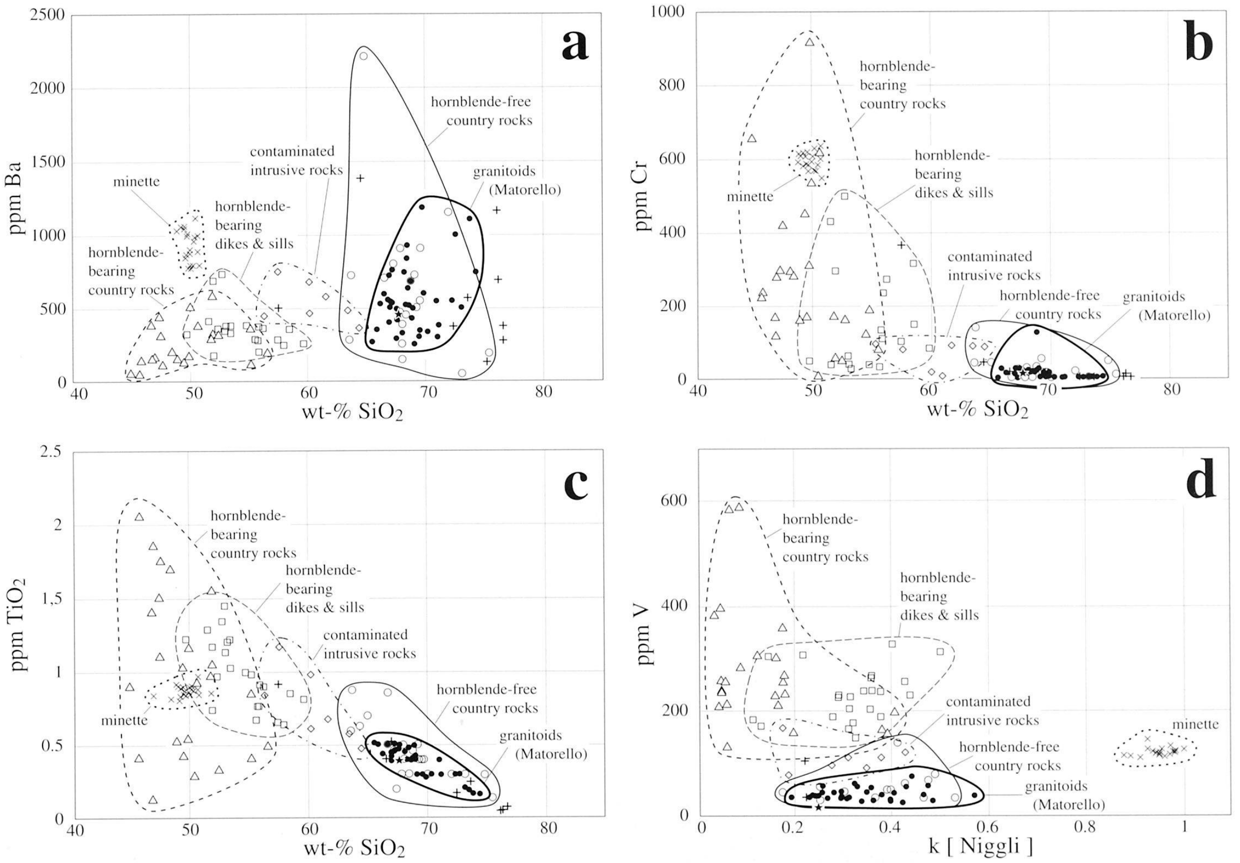

Fig. 2 Whole-rock compositions: Minor and trace elements versus SiO$_2$ (a–c) and k_{Niggli} versus V (d) from different lithologies of the Maggia nappe. For the legend of symbols and lines see figure 3.

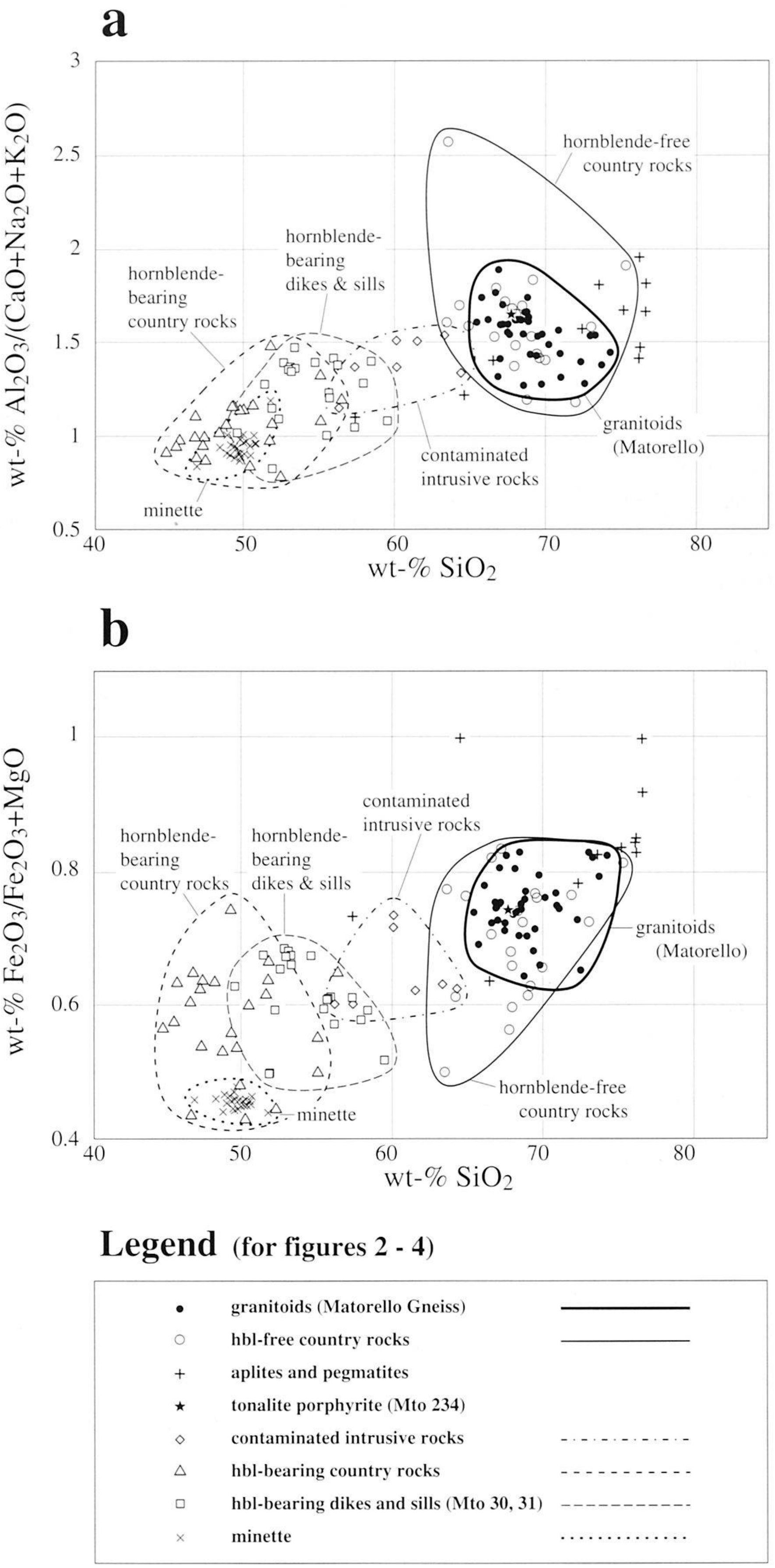

Fig. 3 Whole-rock compositions: Major element ratios versus SiO_2 for different lithologies of the Maggia nappe.

The following features point to a granite or granodiorite containing sedimentary material (= "COLG" = collision granite, PEARCE et al., 1984; WIMMENAUER, 1985; BARBARIN, 1990; SEIM and TISCHENDORFF, 1990):

- isomodal and isochemical transitions into country rocks (GÜNTHERT et al., 1976),
- compositional fields of the Matorello Gneiss lie within the field of the hornblende-free country rocks (Figs 1–4),
- high contents of biotite, quartz, K_2O (Fig. 4) and Ba (Fig. 2a),
- presence of accessory garnet, kyanite, and inherited zircons (KÖPPEL et al., 1981),
- excess of alumina (Fig. 3a, $Al_2O_3/CaO + K_2O + Na_2O$, see NIGGLI et al., 1930) or of corundum CIPW 0–2%, respectively,
- absence of regular variations of chemical elements in the field (Fig. 5) that would indicate typical intrusion features such as aureole, zoning, ballooning, contaminated wall rocks of "massif circonscrit" (RAGUIN, 1957), and
- low Fe/Fe + Mg ratio of the whole-rock composition (Fig. 3b).

Matorello Gneiss samples rich in Na_2O (e.g. Mto 6, Fig. 5) are of tonalitic composition, but do not represent metamorphic I-type tonalites, which contain less SiO_2, less alkali and more Fe_{tot}, CaO and MgO (NIGGLI et al., 1930; DE QUERVAIN and FRIEDLÄNDER, 1942; DE QUERVAIN and JENNY, 1956; WIMMENAUER, 1985; STRECKEISEN, pers. comm., 1990).

Leucocratic dikes and veins: Aplitic and pegmatitic veins are of varying composition (Figs 2, 3, 6) with volume percentage of quartz to feldspar ranging from 70:30 to 20:80, An of plagioclase 0–68. Various aplites have been compared with the surrounding country rocks, but no chemical correlation was found (Fig. 6). Such variations are unknown from aplites of igneous, i.e. non-anatectic origin. Aplites brecciating country rocks and dikes of the type Mto 29, 31 (see below) form agmatites (GÜNTHERT, 1954). A hitherto unknown type of leucocratic dike has been found south of Laghetti in the Valle dell'Ospedale (Fig. 1). For this type STRECKEISEN (1990, pers. comm.) proposed the term *tonalite porphyrite* (Mto 234), but he emphasized that these dikes do not represent

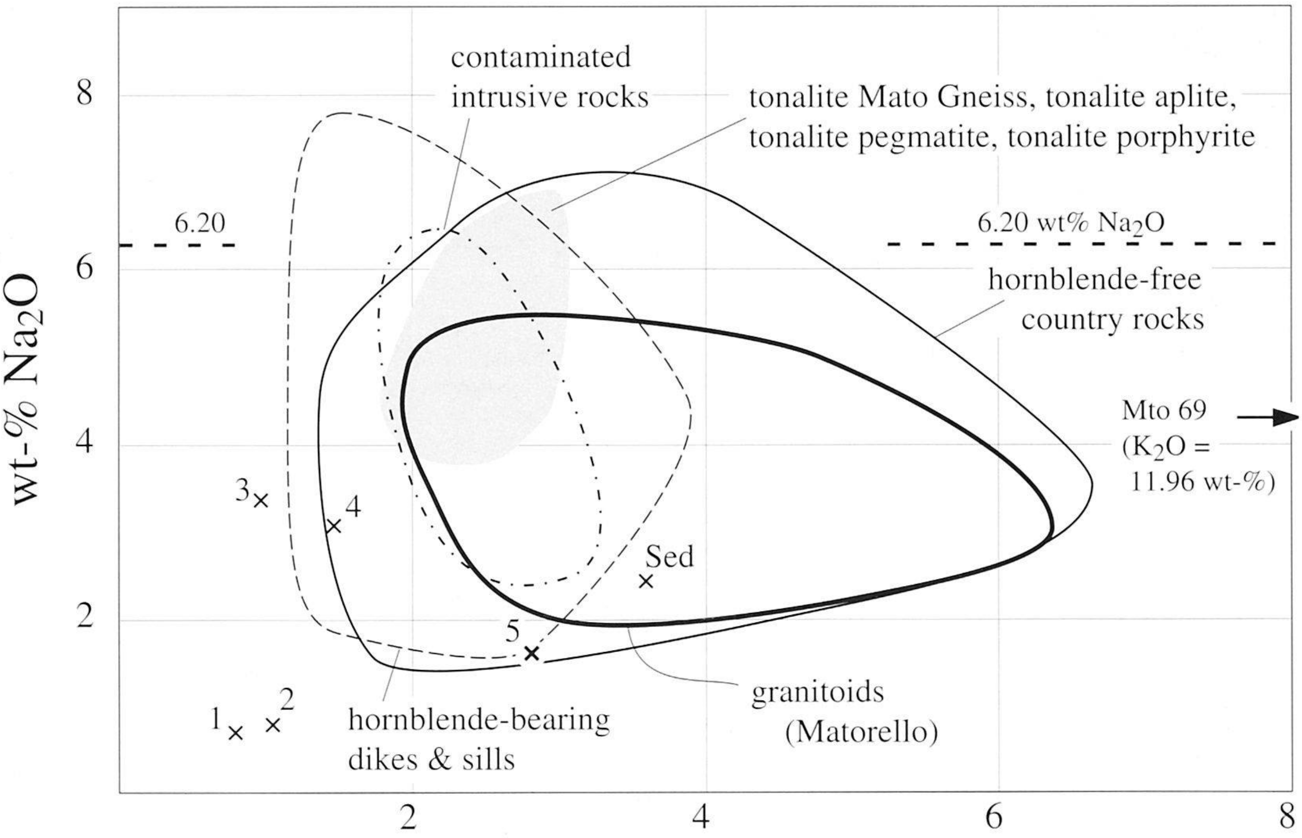

Fig. 4 Whole-rock compositions: Na_2O versus K_2O diagram for different lithologies of the Maggia nappe. The marked line of 6.20 wt% is the highest percentage of Na_2O ever found in sandstones (WEDEPOHL, 1978). Sed = medium value of all sediments, 1–5 = medium values of sandstones (data from SEIM and TISCHENDORFF, 1990). The dotted field of tonalitic rocks lies within the field of hornblende-free country rocks (arkosic gneisses).

classical tonalite porphyrites since they contain much more SiO_2 as quartz and they show biotite coating coarse quartz and plagioclase. Some of the dikes, which are cut by tonalite aplites and mela-tonalites bear relics of idiomorphic phenocrysts of quartz. The analysed specimen Mto 234 (with 0–5 vol.% K-feldspar) belongs to the field of tonalite (quartz 35.2, albite 8.2, plagioclase 56.6, Streckeisen, pers. comm.).

2.3. HORNBLENDE-BEARING ROCKS:

Hornblende-bearing country rocks are amphibolites, hornblende gneisses, and hornblende schists. They are concordant with hornblende-free country rocks, which together form banded structures (Hasler, 1949; Buchmann, 1953; Günthert, 1954, 1991). The hornblende-bearing country rocks chiefly originated from sheet-like intrusions, that took place prior to the development of the Matorello gneiss as indicated by inclusions of hornblende-bearing rocks within the Matorello gneiss (Tab. 2). Rueffer (1991, pers. comm.) detected one dike feeding a sheet-like intrusion east of Lake Sambuco.

Dikes, stocks, and sills of tonalite to mela-quartzdiorite (types Mto 29–31, Tab. 1) cut granitoids and country rocks as well as each other. They occur chiefly in the Valle dell'Ospedale, south of Laghetti (Fig. 1). In general, type Mto 30 is coarse and of low Cr content, type Mto 31 is finer in grain size and mainly foliated. Some dikes of types Mto 29–31 have similar mineralogical and chemical composition as many hornblende-bearing country rocks, but are easily discerned in the field by their dike structure. The dikes are not combined with shearing or folding features, but sometimes show blastophyric texture ± quartz ocelli and relictic fluidal and schlieren structures. In figure 7 analyses of the hornblende-bearing rocks are plotted within a FeO–(Na_2O + K_2O)–MgO ternary system, and compared with the compositional fields of the leucocratic rocks. The diagram shows a compositional overlap between the hornblende-bearing rocks and the hornblende-free country rocks. In addition, data of the tonalites of type 30 and 31 strongly follow calc-alkaline and alkaline trends.

Contaminated intrusive rocks are dikes of type Mto 29, aplite F (Simpson, 1981, p. 251) and Matorello Gneiss (Mto 83). Their plottings connect the fields of darker hornblende-bearing rocks with the fields of rocks without hornblende (Figs 2–4).

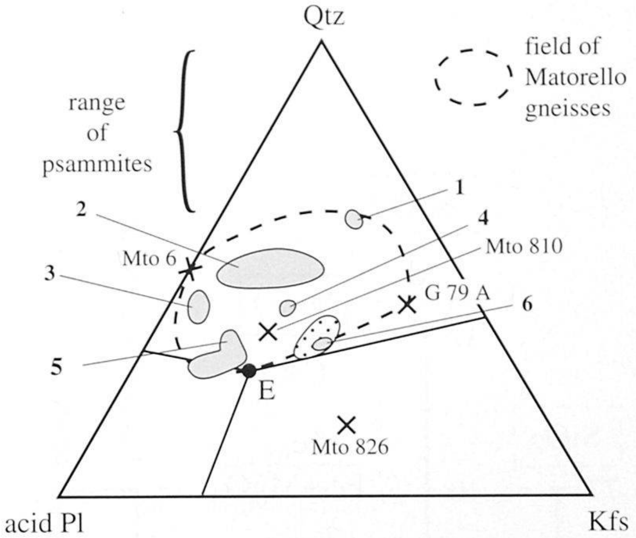

Fig. 5 Modal vol.% proportions in the ternary system of quartz, acid plagioclase, and K-feldspar of the Matorello Gneiss and aplites. The stippled area represents the field of I-type granites (Carmichael et al., 1974). E is the eutectic point. The fields 1–6 (not to be confounded with series no 1–8 in Günthert et al., 1976 and Fig. 1) represent groups of specimens from different localities: Each group 2, 3, 5, and 6 comprises specimens of similar composition, but from different localities up to 5 km distant from each other. On the other hand, the group 1 and 4, as well as samples G79A (granite), G79B (granodiorite), Mto 810 and 825 have been sampled within the vicinity of each other. The tonalitic Matorello Gneiss Mto 6 and the granodioritic Mto 810 are singular occurrences. In the field, the outcrops of group 2 to 6 show transitions into country rocks of arkosic to psephitic origin. These observations strongly suggest an origin of the Matorello Gneiss from sedimentary material rather than intrusion of an alien magma.

Minette: Two dark dikes (Mto 91, 1011) cut the Matorello Gneiss in the Valle dell'Ospedale (Fig. 1, Ramsay and Allison, 1979) and show Alpine foliation. Their mineralogical composition (vol.%) ranges from: 2.5–20 quartz, 0.5–20 plagioclase (An 14–28), 0.5–20 K-feldspar, 25–55 biotite, 0.5–50 hornblende, 0.5–15 epidote s.l., 0.3–1 carbonate. Numerous analyses form a narrow field (Figs 2, 3, 7, 8), which points to a chemically homogeneous melt. The southern dike grades into a mela-tonalite (type Mto 31).

Xenoliths (Tab. 1, 2): Present xenoliths are petrographically identical with corresponding host rocks, hence exogeneous (resisters). With few exceptions they show Alpine orientation.

The *chemical composition of hornblende* has been analysed by microprobe (Tab. 3). According to Leake (1978) they all are Ca-amphiboles with a small content of Na; the contents of Al, Fe, and Mg, however, vary considerably. The discussion of

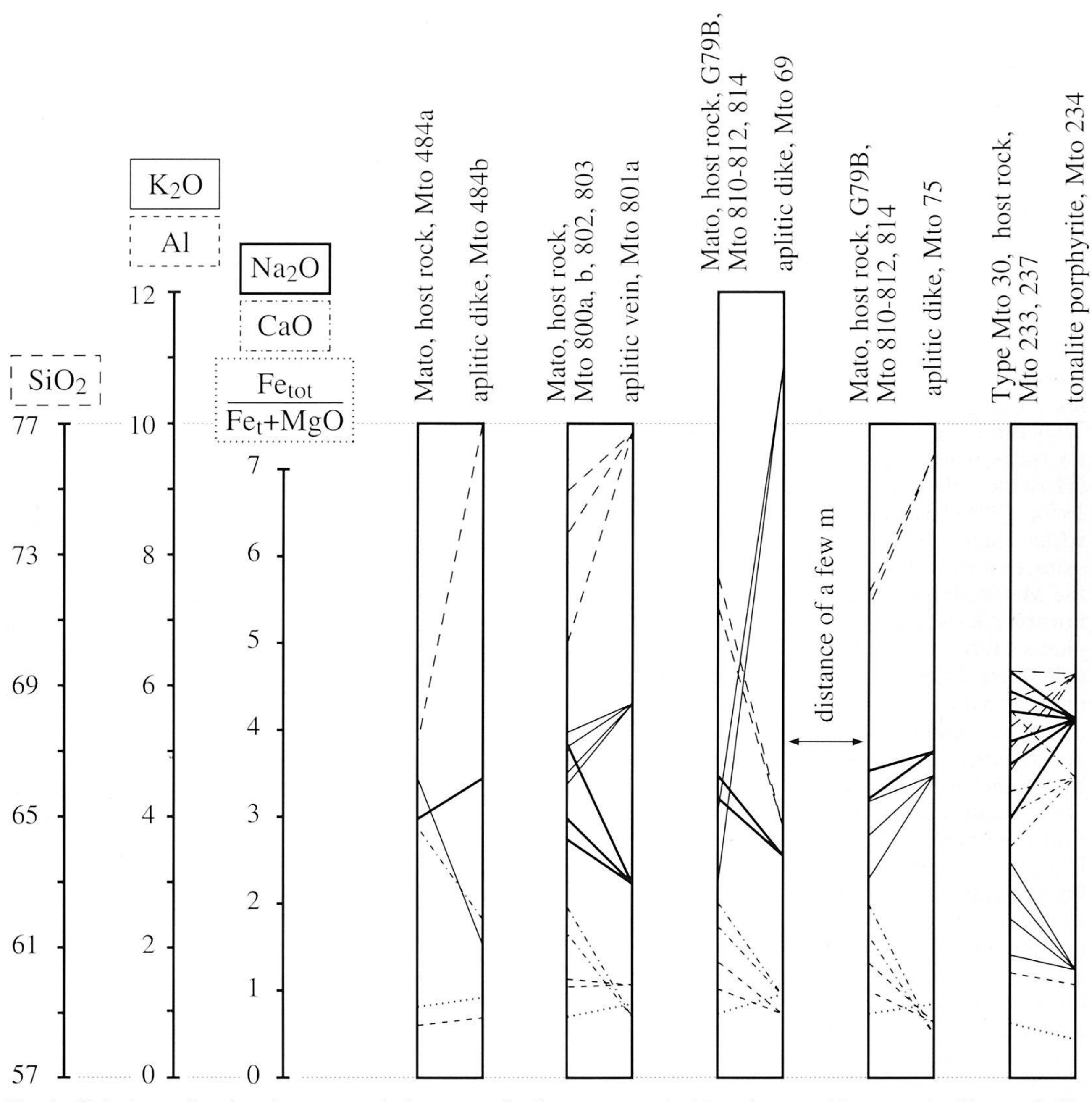

Fig. 6 Relations of major elements and element ratios between granitoid gneisses and leucocratic dikes and sills within the Matorello Gneiss. Shown Al values are Al_{excess}, Mato = Matorello Gneiss. For sample localities see GÜNTHERT et al. (1992).

genesis of the hornblende is difficult, because the chemical composition may vary from crystal to crystal within 2 cm distance, although optically identical. Even within one crystal, all cations may change in direction of the c-axis. Hornblende in mela-tonalites and mela-quartzdiorites (type Mto 30, 31) are sometimes zoned with dark brown to black cores rich in needles of rutile or titanite (HASLER, 1949; p. 108). The dark cores are mantled by fresh green hornblende. Within the hornblende-bearing rocks, biotites rich in Ti and hornblende interpenetrate each other. Highest amounts of Al and Fe are found for amphiboles from the country rocks. Cr, V, and TiO_2, respectively, are chiefly included in the amphiboles. Textural and compositional observations point to a primary magmatic origin.

Biotite and hornblende of the rock types Mto 29–31 show no increase in grain size near to their intrusive contacts and never lie across observed contacts, which suggests a marked temperature difference between intruding and host rock.

Tab. 1 Textural features of three different types of hornblende-bearing dikes, stocks and sills from the Maggia nappe.

Mto 29	Mto 30	Mto 31
mesocratic	melanocratic with light to dark coloured spots	meso- to melanocratic with some spots
fine-grained	coarse	fine-grained
foliated, seldom massive	massive, rarely foliated	foliated, rarely massive
with irregular light and dark coloured patches and "schlieren", rarely with quartz ocelli, in parts blastoporphyric due to plagioclase	spots due to aggregates containing quartz, quartz and plagioclase, biotite, or biotite and hornblende, and some idioblasts of plagioclase	with smaller and less frequent aggregates compared with Mto 30, some quartz-ocelli and idioblasts of plagioclase
with or without hornblende	rich in hornblende (rarely missing)	hornblende less frequent than in type Mto 30
strong variation in biotite content		
transitions between types Mto 29–31		

3. Discussion of origin and chronology of the Maggia nappe rocks

3.1. PRECEEDING REMARKS

Several radiometric age determinations are known from the Maggia nappe (for review see Hunziker et al., 1992). Table 4 shows a correlation of radiometric ages and the events of evolution of the Maggia nappe, that also includes data from the Hercynian Cocco tonalite and Ruscada granite south of the Maggia nappe within the Maggia Querzone (Köppel et al., 1981).

Within the Penninic realm the rock series of NW Tessin and of near Italy form a small bridge of knowledge between Western and Eastern Alps. However, these two areas do not correspond to each other. Thus, any comparisons of radiometric and petrographic data with rocks towards the west and east are limited.

The evolution of the nappe is divided into pre-Alpine and Alpine events.

3.2. PRE-ALPINE EVENTS

3.2.1. Hornblende-free rocks

Country rocks: The sedimentary origin is given by the following features:

- psephitic structure, although partially tectonized by Alpine deformation (Günthert, 1954, 1991),
- a strongly variable chemical composition typical for psammitic and pelitic rocks (for comparison see Günthert, 1953; Füchtbauer, 1988; Seim and Tischendorff, 1990) (Figs 2–4, 7, 8),

Tab. 2 Distinction between xenoliths and host rocks from the Maggia nappe. For description of the different types of dikes, stocks, and sills see table 1.

Xenoliths	Host rocks
Dark coloured country rocks (gneisses and schists rich in biotite ± hornblende)	light coloured country rocks (K-feldspar gneisses); Matorello Gneiss; meta-aplite
Two mica schist (country rocks free of hornblende)	Amphibolite (country rock)
meta-aplite	Matorello Gneiss
Matorello Gneiss	meta-aplite
type Mto 29	Matorello Gneiss; meta-aplite; type Mto 31
type Mto 30	type Mto 29; pegmatite
type Mto 31	Matorello Gneiss; meta-aplite; type Mto 29, 30

Tab. 3 EMS analyses of amphiboles from different hornblende-bearing lithologies of the Maggia nappe. Analyses have been executed on a JEOL 8600 with 20 kV and 15 mA. For description of xenolith types Mto 30 and 31 see table 1. Amphiboles from sample Mto 82a (type Mto 31 mela-quartzdiorite) contain many small titanite and rutile inclusions.

lithology	xenolith type Mto 30, mela-tonalite					minette, biotite or hornblende rich lamprophyre							bl-bearing country-rock	xenolith type Mto 31, meta-mela-quartzdiorite
Analysis	Mto 237.1	Mto 237.2	Mto 237.3	Mto 237.4	Mto 237.5	Mto 91.1.1	Mto 91.1.2	Mto 91.1.3	Mto 91.2.1	Mto 91.2.2	Mto 91.3.1	Mto 91.3.2	Mto 252	Mto 82a
SiO_2	46.55	47.03	46.33	46.31	48.31	54.57	54.93	54.75	54.78	52.50	54.56	53.83	41.20–43.40	41.65–43.71
TiO_2	0.68	0.41	1.43	2.11	0.40	0.07	0.09	0.10	0.08	0.17	0.10	0.16	0.40–0.50	0.48–3.43
Al_2O_3	9.97	9.88	9.73	9.73	9.96	3.23	2.79	3.01	2.63	4.93	3.17	4.32	15.00–17.90	12.76–13.58
FeO	11.67	11.72	11.87	11.74	11.33	7.55	7.29	7.37	7.46	8.23	7.10	7.59	15.80–16.80	13.92–14.65
MnO	0.32	0.32	0.40	0.42	0.42	0.29	0.25	0.24	0.28	0.27	0.28	0.24	0.48–0.67	0.35–0.39
MgO	13.00	13.32	13.13	13.01	14.20	18.31	18.37	18.22	18.34	17.24	18.52	17.73	7.90–9.35	10.36–10.75
CaO	12.16	11.92	11.19	11.14	11.73	12.65	12.65	12.81	12.72	12.52	12.76	12.62	9.98–11.18	11.56–11.74
Na_2O	1.02	0.95	1.08	1.11	0.95	0.36	0.29	0.28	0.23	0.53	0.28	0.38	1.28–1.56	1.33–1.47
K_2O	0.35	0.36	0.41	0.40	0.28	0.18	0.14	0.17	0.14	0.37	0.37	0.37	0.31–0.42	0.47–0.50
$\sum$	95.72	95.91	95.57	95.97	97.58	97.21	96.80	96.95	96.66	96.76	97.14	97.24	(n = 10)	(n = 5)
	calculated for 23 oxygens													
Si	6.890	6.934	6.868	6.835	6.966	7.708	7.773	7.744	7.773	7.502	7.706	7.612		
Al^{IV}	1.110	1.066	1.132	1.165	1.034	0.292	0.227	0.256	0.227	0.498	0.294	0.388		
Al^{VI}	0.629	0.651	0.568	0.528	0.659	0.246	0.238	0.246	0.213	0.333	0.234	0.332		
Ti	0.076	0.045	0.159	0.234	0.043	0.007	0.010	0.011	0.009	0.018	0.011	0.017		
Fe^{2+}	1.444	1.445	1.472	1.449	1.366	0.892	0.863	0.872	0.885	0.984	0.839	0.898		
Mn	0.040	0.040	0.050	0.053	0.051	0.035	0.030	0.029	0.034	0.033	0.033	0.029		
Mg	2.868	2.928	2.902	2.863	3.053	3.856	3.875	3.842	3.880	3.673	3.900	3.738		
Ca	1.928	1.883	1.777	1.762	1.812	1.914	1.918	1.941	1.934	1.917	1.931	1.912		
Na^B	0.072	0.117	0.223	0.238	0.188	0.086	0.082	0.059	0.066	0.083	0.069	0.088		
Na^A	0.221	0.155	0.088	0.079	0.078	0.013	–0.003	0.018	–0.003	0.064	0.008	0.016		
K	0.066	0.068	0.078	0.075	0.052	0.032	0.025	0.031	0.025	0.067	0.067	0.067		

- presence of aluminosilicates,
- high amounts of biotite, muscovite, and quartz.
- The zircons of the biotite-rich paragneiss (= "brauner Gneis", of sedimentary origin after Preiswerk, 1918 a and b) are rounded and euhedral (Günthert et al., 1976, Tab. 5; Köppel et al., 1981). The zircons of pebbles and matrix, both, revealed Caledonian ages (Tab. 4). Obviously, the pebbles are of pre-Caledonian origin since the pre-Paleozoic and the Paleozoic zircons from unknown origin must have been deposited in a basin prior to the Caledonian event which was of orogenic nature (Köppel et al., 1981; von Raumer and Neubauer, 1993).

Since Hercynian meta-sediments chemically have not been altered by Alpine metamorphism (Jäger, 1973; Günthert et al., 1976), present aluminosilicates may have formed already during former metamorphism.

The meta-sediments of the Maggia nappe can be compared with those of neighbouring tectonic units. The psephitic and psammitic gneisses of the Lebendun Series in NW Tessin (Burckhardt, 1942) correspond to those of the Maggia nappe (Hasler, 1949; Günthert, 1954), the psammitic to pelitic meta-sediments of the Maggia nappe correspond to those of the Campo Tencia-complex (part of the Simano nappe Keller, 1968; Keller et al., 1980). Preiswerk (1918 a and b) connected them with rocks of the "Grand St. Bernard nappe" (polymetamorphic basement of the Siviez-Mischabel nappe, Escher, 1988) thinking of one old Paleozoic syncline (Keller, 1968). In contrast to Western Penninic series, however, volcanics, ultramafic and carbonate rocks are lacking and part of the augen gneisses are of psephitic origin in the Lebendun and Maggia Series.

Ultrametamorphism in the Maggia nappe concentrated on acid and – to a lesser extent – intermediate rocks. For the evaluation of the P-T conditions of small amounts of in situ anatexis, the following observation have to be considered:

- granitoid gneisses and aplite do not show

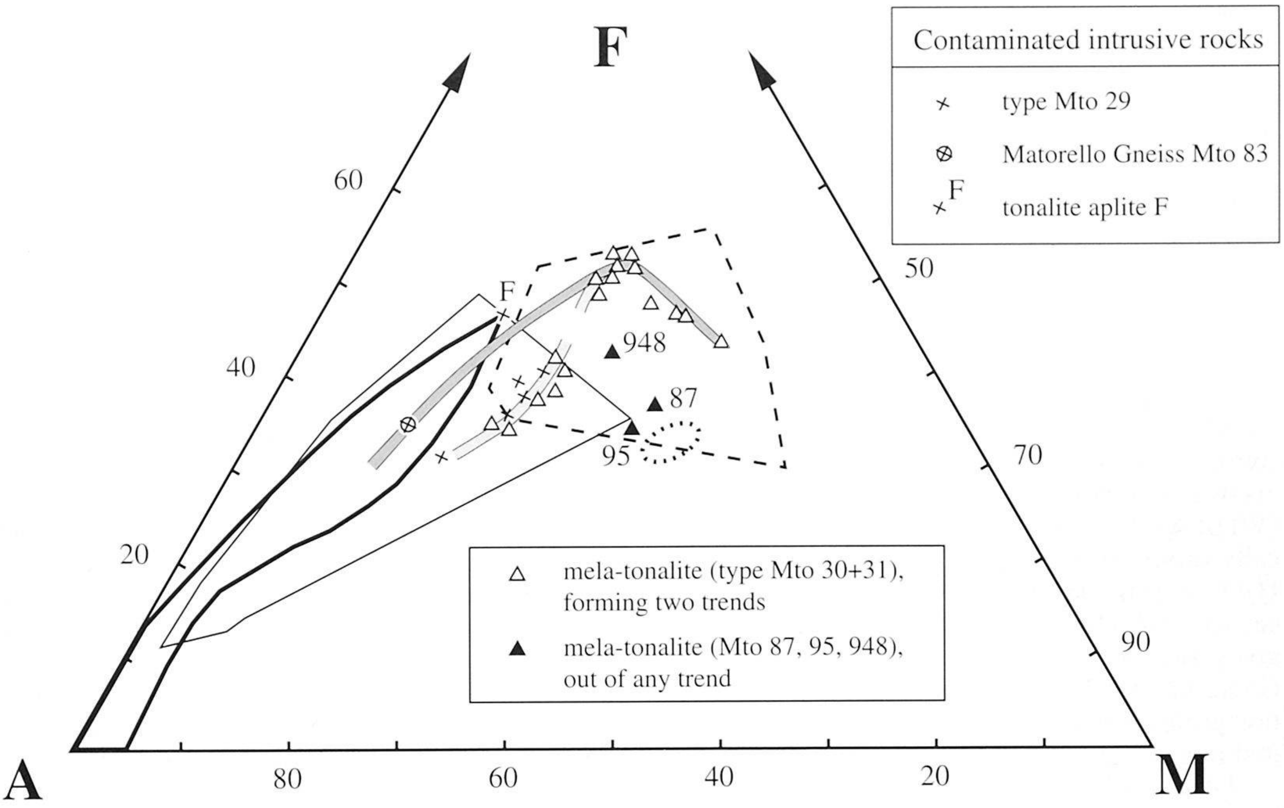

Fig. 7 Ternary AFM diagram for different lithologies of the Maggia nappe. The variation of the data is shown within different areas: thick line = Matorello Gneiss, aplites, pegmatites, thin line = hornblende-free country rocks, dashed line = hornblende-bearing rocks, dikes stocks, and sills, stippled line = minette. The calc-alkaline trend (after CARMICHEAL et al., 1974) is shown by a dark grey path, the alkali-basaltic trend with light grey. Aplites and pegmatites form the alkali-rich part of the field of the Matorello gneiss.

any tendency towards one single homogeneous or eutectic relationship. In figure 5, the compositional range of the Matorello Gneiss is compared with a homogeneous granite, that has been differentiated from an undisturbed basaltic host magma (CARMICHAEL et al., 1974). In figure 7 data are plotted together with a general trend of differentiation for magmatic rocks, but indicate no correlation to it.

– discordant contacts, transitions, and xenoliths (Tab. 2). Granitoid rocks do not cut Alpine folding or shearing structures;

– only part of the arkosic gneisses (country rocks) of the Maggia nappe, but no psephitic gneisses, became granitoids, hence Hercynian ultrametamorphism – areally seen – has been incomplete;

– the granitoids include numerous beds and few xenoliths of in part isochemical country rocks, and vice versa;

– the strong compositional variation was probably depending on local chemical variations of the country rocks and local melting conditions at presence of varying amounts of fluids (Figs 1–3, 5–7).

The granitic to granodioritic *Matorello Gneiss* was generated during syntectonic Hercynian ultrametamorphism and in situ anatexis of arkosic country rocks, the age being proved by determinations of zircon and of Rb/Sr whole-rock analysis (KÖPPEL et al., 1981; STEINER, 1984). With few exceptions all zircons are idiomorphic and therefore show formation during Hercynian anatexis. Aplites cutting the Matorello Gneiss also show Hercynian ages.

BÄRTSCHI (1957) and HOERNES et al. (1980) exclude a large-scale supply of water into the highly metamorphic gneisses of the Penninic nappes during Alpine metamorphism. This corresponds to the data from GÜNTHERT et al. (1976), which show that in the Maggia nappe no Alpine metasomatism and intrusion nor homogenization has taken place on a larger scale. Thus, the rocks still reflect pre-Alpine conditions.

All variations of the Matorello Gneiss are of S-type, and therefore represent peraluminous collision granites (COLG; PEARCE et al., 1984; BARBARIN, 1990; SEIM and TISCHENDORFF, 1990). The chemical data pattern and the percentage of areal distribution of granodioritic, tonalitic and granitic varieties point to an extremely "compositionally restricted S-type of granites" (PITCHER, 1979), closely related to regional metamorphic metasedimentary rocks of pre-Hercynian origin. According to FINGER et al. (1993), FRISCH et al. (1993) and WYSS (1993) S-type granites are scarce in the Penninic realm of the Alps (Granatspitz Kern, and migmatite belt of the Zentralgneis, both in the Tauern Window).

The Na_2O content of tonalitic Matorello Gneiss south and southwest of Laghetti may be the result of locally sodium-rich arkosic rocks (for comparison see GÜNTHERT, 1953). The surrounding hornblende-free country rocks show similar maximum Na contents (Fig. 9). However, arkosic sediments of such high Na_2O content (WEDEPOHL, 1978) are rather rare and suggest locally different mobilizations of Na_2O, SiO_2, and H_2O during Hercynian ultrametamorphism, caused probably by subduction, which also easily gives rise to granodioritic and tonalitic melts (PITCHER, 1987). In the same area also pre- to postgranitic, hornblende-free dikes, xenoliths, and migmatites rich in Na_2O are concentrated.

Leucocratic dikes: The compositions of aplites, pegmatites and their host rocks exhibit a strong variation (Figs 2–4, 6, 8). They can be assumed to be the product of local in situ mobilization (STEINER, 1984a; STERN, 1966). There is no hint to a unique homogeneous igneous aplitic melt. Rb/Sr whole-rock determinations of two sills of aplite in country rocks (Laghetti W) and of two aplites cutting the Matorello Gneiss (Fig. 1, outcrop no 5 and L. Naret) yielded Paleozoic ages (Tab. 4).

The tonalite porphyrites are derived from pre-Alpine melts, dike Mto 234 being enriched in Ca and Mg compared with the tonalitic aplites (Fig. 8).

3.2.2. Hornblende-bearing rocks

The low values of $K_2O/(K_2O + Na_2O)$ together with high values of Cr, V, Ti, Fe_{tot}, MnO, MgO of all hornblende-bearing rocks point to an igneous origin (Figs 2, 3b, 7, 8). They may be the result of Hercynian crust thickening and/or subduction, which increase the amount of volatiles and with mantle components give rise to melts of calc-alkaline, and/or alkali-basalt (Fig. 7) trends as well as Na-rich metamorphic facies, respectively (ERNST, 1975, 1976). Rb-values of the hornblende-bearing rocks are distinctly higher than those of basaltoids (SEIM and TISCHENDORFF, 1990) and point to assimilation of crustal material.

Country rocks in parts represent pre- or early-Hercynian intrusions of calc-alkaline basaltic composition showing similar chemical composi-

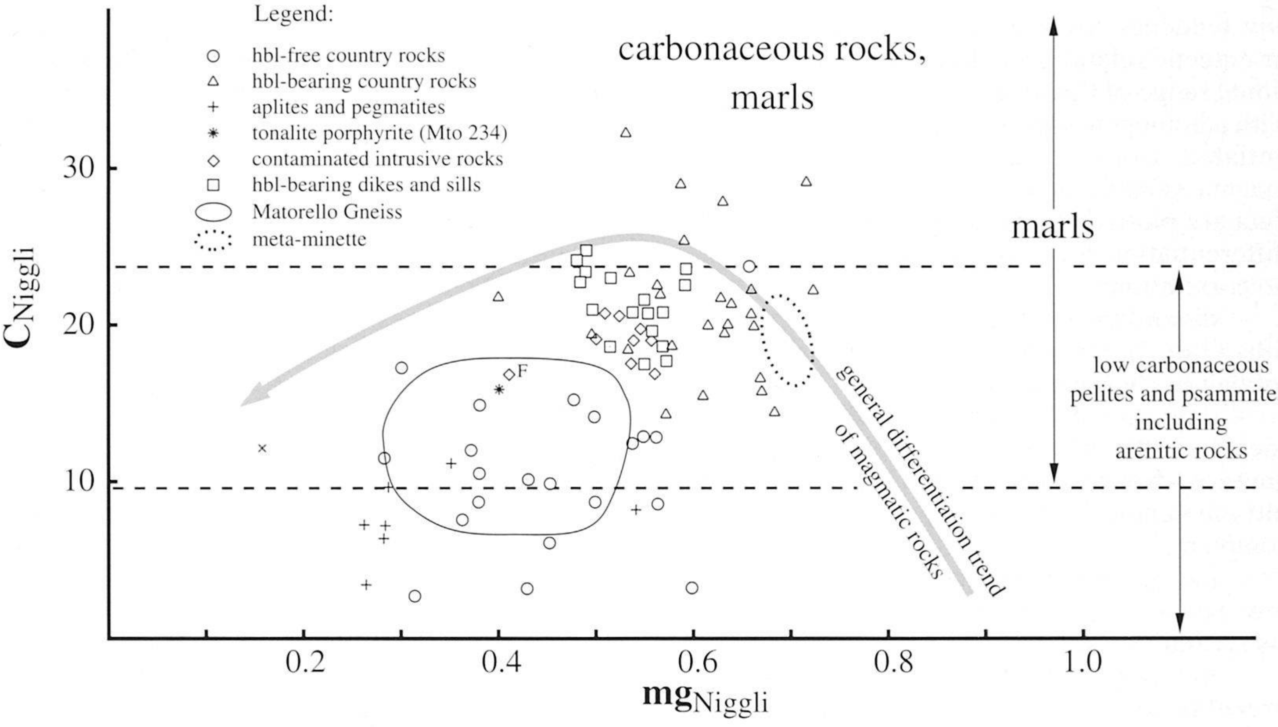

Fig. 8 Niggli diagram c versus mg for the rocks of the Maggia nappe. Hornblende-bearing dikes and sills are of the type Mto 30, 31 (Tab. 1). Extension of sedimentary rocks according to WEDEPOHL (1978), NIGGLI et al. (1930), SEIM and TISCHENDORFF (1990), and GÜNTHERT (1953).

Tab. 4 Chronological development of the rocks of the Maggia nappe, correlated with existing age determinations from JÄGER (pers. comm., J), KÖPPEL et al. (1981, K), STEINER (1984, St), HURFORD (1986, Hf) and HUNZIKER et al. (1992, Hz). FT = fission track.

Orogeny	Age determinations	Event
Pre-Caledonian	zircon in bt-plag-gneiss (country rock): 1400–2000 Ma (K)	Sedimentation of psephites, arkosic sandstones, and schists rich in biotite, in part bearing garnet, kyanite, and staurolite.
Caledonian orogeny	zircon of arkosic matrix and of augengneiss pebble of psephitic gneiss, both 400–450 Ma (K); two aplites of palaeozoic ages (Hz), (J)	Regional metamorphism of country rocks. Intrusions of aplite. – Pre-Hercynian and/or Hercynian syntectonic intrusions, mostly as sheets or sills of calc-alkaline basalt or alkaline basaltic trends (in part forming banded structures), now hornblende-bearing country rocks.
Hercynian orogeny		
pre-granitic	no determinations	Intrusion of dikes (type Mto 29-31) into country rocks (e.g. south of Passo del Sasso Nero, S of Lago Naret), and intrusions of aplite (with xenoliths).
evolution of Matorello granitoids	zircon of granodiorite (K) and Rb/Sr whole-rock (St): both about 300 Ma	Ultrametamorphism with anatexis of arkosic gneisses (country rocks) and locally melt of tonalitic composition intruding country rocks and type Mto 29–31. – Aplites cut type Mto 29–31. Xenoliths of type Mto 29–31 in granitoids and in aplite with in part agmatitic structures.
post-Matorello	aplite in granodiorite Rb/Sr whole rock (St): 258 Ma; two aplites in granite, both of Hercynian age (J)	Chronologically different intrusions of type Mto 29–31 (xenoliths) and of several generations of aplite, pegmatite, tonalite porphyrite: intrusions of protoliths of hornblende-fels, biotite-diorite, mela-hornblende-quartzdiorite, and of minette.
	zircon (K): about 250–350 Ma	Intrusion of Cocco tonalite, later of Ruscada granite.
Alpine orogeny	Rb/Sr muscovite (St): 35 Ma = climax of metamorphism K/Ar and Ar/Ar muscovite, biotite, and amphibole (Hz): 15–45 Ma	Amphibolite facies metamorphism, three main phases of deformation, granulation of quartz and feldspar, shredding of coarse biotite. Syn- to post-tectonic recrystallization without significant change of chemical bulk composition of rocks (GÜNTHERT et al., 1976). – Aplites and pegmatites possible, but not yet proved.
	U/Pb monazite (K): 22.4 Ma	
	zircon FT ages (St, Hf): 12–13.5 Ma	Strong cooling and uplift between 22 and 16 m.y. (WERNER et al., 1976; HURFORD, 1986)
	apatite FT ages (St, Hf): 6–8 Ma	Late tectonic movements causing cataclastic and mylonitic phenomena (GÜNTHERT, 1954; 1971; GÜNTHERT et al., 1992)

tion as types Mto 30, 31; in parts hornblende-bearing country rocks depict sedimentary characteristics (Figs 2, 3, 8). Due to $Na_2O > 5.5$ wt%, some rocks plot within the basalt field (WIMMENAUER, 1985). These may in part also have assimilated sedimentary material, as shown by the very low Cr, but high TiO_2 content (Fig. 2), which is typical for arkosic sandstones and for amphibolites of sedimentary origin (SEIM and TISCHENDORFF, 1990), and the c/mg_{Niggli} ratios (Fig. 8).

Dikes, stocks, and sills originated from deeper sources than the hornblende-free rocks and they normally show sharp contacts, since their path of intrusion was long and the intruded rocks must have been colder. The volumetrically very small proportion of these intrusive rocks bearing hornblende and the concentration of their occurrence (Figs 1, 8) as well as the presence of xenoliths point to a small magma chamber.

Figure 7 reveals two trends: Most specimens of type Mto 30 and 31 exhibit a calc-alkaline trend; some specimens of type Mto 29 (Figs 2, 3, 7) and of types Mto 30, 31, however, are grouped on an abnormally curved alkali basalt trend, or drop between these trends (Mto 87, 95, and 948). Type Mto 29 shows alumina excess of 1.152–1.542. It is suggested, that the anomalies in composition are caused by assimilation of rocks rich in Mg, Al and alkalies, e.g. country rocks rich in biotite and hornblende (see alumina excess of type Mto 29–31, Fig. 3a). The following two field observations support these suggestions:

- the granitoids Mto 83 (and 84) locally contact and mix with dike type Mto 31 (Mto 85);
- tonalitic aplite F shows transitions into partly resorbed, dark coloured xenoliths with F enriched in biotite and amphibole (SIMPSON, 1981, photos therein).

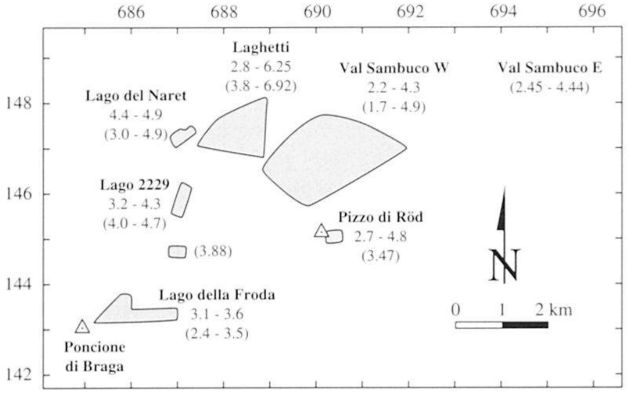

Fig. 9 Sketch of areas of chemical investigations showing contents of Na_2O from granitoid Matorello Gneiss and (within brackets) hornblende-free country rocks. The x- and y-values correspond to the Swiss coordinate grid (in kilometer scale).

The culmination of the calc-alkaline trend curve reveals 10 wt% of excess SiO_2 (compared with Carmichael et al., 1974) which can be explained by assimilation from the Matorello gneiss cut by the dikes and sills of type Mto 30, 31 (Fig. 7).

Minette: The intrusion occurred in the late Paleozoic since no xenoliths of minette have been found in the Matorello Gneiss. Both dikes probably originate from the same melt rich in H_2O, Ca, and Mg. According to the ratio of c/mg (Fig. 8) the trend of the melt is alkaline (Oberhänsli, 1985). The contents of MgO, Cr (520–638 ppm) and Ni (164–248 ppm) of dike Mto 91 and the high content of MgO of the hornblende suggest an origin within the mantle. According to the plottings in figure 7, however, the very high content of biotite and of Ba, and the contents of Rb and TiO_2 (Fig. 2, Steiner, 1984b, p. 267), respectively, cannot be explained similarly (Oberhänsli, 1985). They may be the result from assimilation of (nearby situated) biotite schists (country rocks) during intrusion. The transition of minette Mto 1011 into Mto 90 (similar to type Mto 31) indicates an origin within the same magma chamber, e.g. from a hybrid melt.

3.3. ALPINE EVENTS

Within the Maggia nappe, main rock constituents show a strong Alpine orientation. Three phases of deformation (Günthert, 1954, terminology of Sander, 1930; F1–F3 of Ramsay et al., 1979) are distinguished, that belong to the Alpine formation of the nappes. According to Simpson (1981) the deformation has been penetrative. However, several observations show the structural development to have remained incomplete:

- relics of massive structure within the granitoids and dikes,
- aggregates of unorientated biotite coexisting with quartz of Alpine orientation in the Matorello Gneiss,
- several outcrops of aplite and country rocks both showing the same Alpine orientation of biotite without any Alpine orientation of quartz and feldspar (Günthert et al., 1992),
- xenoliths without any Alpine orientation.

Alpine deformation also caused the peculiar texture and structure of the Matorello Gneiss: Dark clusters or aggregates of shredded biotite and the aggregates of granulated quartz and feldspars (in parts blastophyric) are thought to be the result of Alpine crushing and recrystallization of very coarse equigranular to porphyric Matorello granitoids. The size of these aggregates is the same as the maximum size of relictic quartz, feldspar, and biotite, respectively, both in granitoids and in dikes of type Mto 29, 30. In the field the Matorello Gneiss is easily discerned from other rocks of the Swiss Alps except from the Cocco Gneiss, Ticino.

According to Pfeifer et al. (1993), one occurrence of ultramafic rocks is found in the Maggia nappe (talc-magnesite-chlorite schist, Pizzo di Röd). This paragenesis may represent a relic of early high-pressure metamorphism (eo-Alpine). In the following, however, only the syn- to posttectonic low amphibolite facies recrystallization and metamorphism (meso-Alpine), that took place some 35 to 18 m.y. ago (Werner et al., 1976), is taken into consideration.

Following recent data by Engi and Schmatz (1993) and Engi et al. (1995), P-T conditions within the area displayed in figure 1, reached approximately 580–620 °C and 6.5–7.0 kbar ($P_{H_2O} = P_{tot}$), which corresponds to conditions of recrystallization of biotite and muscovite during progressive metamorphism and concordant meso-Alpine monazite ages of 23 to 20 m.y. (Köppel et al., 1981, p. 116). The Hercynian ages (Tab. 4) of Rb/Sr whole-rock analyses and of zircon U–Pb ages were not reset. Hoernes and Friedrichsen (1980, p. 22) found that the highly metamorphic gneisses of the Tessin area did not change their oxygen isotope composition during Alpine metamorphism. Hence, "pre-Alpine minerals have been stewing in their own juices" (Frey et al., 1976). No isotopic equilibrium has been reached among those minerals, which fixed their $^{18}O/^{16}O$ ratios at the time of recrystallization.

Plagioclases within the Maggia nappe and within the surrounding Mesozoic schists have not been homogenized during Alpine metamorphism. Optically homogeneous and inhomogeneous low-temperature plagioclases (metastable, SMITH, 1974) coexist in varying compositions in hornblende-free rocks with An 0–68, in hornblende-bearing rocks with An 0–(90–100). The ubiquitous coexistence of different plagioclases, in Ca-rich and -poor rocks, and the varying composition of hornblende, both, are strong arguments for disequilibrium in feldspars, in hornblende, and in the rocks rich in them as well as a hint to temporary low activity of H_2O, CO_2, O_2 during Alpine recrystallization. The throughout metastable low-temperature plagioclase and the compositional variation of the hornblende strongly advise against the mapping of any isograd including these minerals (GÜNTHERT et al., 1985). The compositional inhomogeneity of these phases, together with the lack of Alpine ages of aplites, granitoid rocks, and country rocks, as well as the mineral parageneses of different rock contacts within the nappe and at the boundary between the nappe and the surrounding rocks (GÜNTHERT, 1954; GÜNTHERT et al., 1976, 1985) document the lower grade of the last Alpine metamorphism in this area compared with the Hercynian ultrametamorphism.

Several minor and trace elements seem to have been redistributed during polymetamorphism. Only the maximum values of Ba, Rb, Cr, and TiO_2, respectively, can be used to discriminate present rock types (Fig. 2).

Alpine metamorphism possibly ranged from 35 to 16.8 m.y. as indicated by Rb/Sr whole-rock and U/Pb monazite ages. A recently published tectonic scenario for the Lepontine units proposes a metamorphic climax around 35–38 m.y. in our study area due to ongoing subduction of the European plate (ENGI et al., 1995). Dextral transpression movements during amphibolite facies conditions caused the peculiar structure of the Maggia nappe and the syncline (Fig. 1) with stretching lineations in manifold directions. Metamorphism also accompanied the backfolding of the nappe at around 35–30 m.y. (ENGI et al., 1995) and went on thereafter (GÜNTHERT, 1954), until obduction separated the northern Penninic nappes from the southern dome units. In the southern units, the temperature climax was reached later (some 21 m.y. ago) and migmatization (STERN, 1966) and magmatic intrusions occurred (e.g. SHARMA, 1969). The uplift of the Maggia nappe is documented by Rb/Sr muscovite and biotite ages, combined with fission track zircon (12–13.5 m.y.) and apatite ages (6–8 m.y., STEINER, 1984 a; HURFORD, 1986). Cooling was influenced by a period of strong uplift between 20 to 15 m.y. and markedly slowed down some 12 m.y. ago (cf. WERNER et al., 1976).

By late tectonic movements, parts of the psephitic gneisses and of the augen gneisses became brecciated and cataclastic to mylonitic deformation occurred in a zone crossing the Maggia nappe and the series further north (GÜNTHERT, 1971).

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Appendix

Whole-rock data from the Maggia nappe. X = xenoliths, L = analyses from the literature: Gü 038 and 633 from GÜNTHERT (1954), A-G from SIMPSON (1981).

Sample Mto		Swiss coordinates x	Swiss coordinates y	SiO$_2$ %	Al$_2$O$_3$ %	Fe$_2$O$_3$ %	MnO %	MgO %	CaO %	Na$_2$O %	K$_2$O %	TiO$_2$ %	P$_2$O$_5$ %	LoI %	Sum %	Ba ppm	Cr ppm	Rb ppm	V ppm
Hornblende-free Country Rocks																			
0034		688.250	147.900	75.33	13.73	1.78	0.03	0.40	0.49	3.81	2.87	0.14	0.17	1.15	99.9	190	3	218	1
0260		690.000	147.200	72.00	13.70	1.30	0.00	0.40	1.60	3.50	6.50	0.30		0.50	99.8	1150	10		10
0263		689.900	147.080	66.60	16.80	4.10	0.00	0.90	3.90	3.00	4.10	0.50		0.60	100.5	700	20		70
0264		689.900	147.080	67.90	15.00	3.60	0.00	1.70	3.40	3.90	3.60	0.50	0.00	0.70	100.3	900	21		40
0268		689.900	147.080	63.50	15.80	4.20	0.00	4.20	6.30	1.70	1.80	0.60		1.30	99.4	280	130		140
0270		690.060	146.170	69.20	15.40	3.40	0.00	2.00	2.60	3.50	2.30	0.40		0.80	99.6	500	16		46
0271		690.060	146.170	69.10	14.90	3.20	0.00	2.00	2.70	3.30	3.70	0.50		0.70	100.1	720	19		60
0784		687.025	147.250	68.40	16.10	3.70	0.00	1.30	1.40	3.50	4.60	0.30		1.20	100.5	450	24		35
0791		687.025	147.250	67.80	14.80	3.50	0.00	2.70	0.70	3.00	5.10	0.30		1.60	99.5	400	35		35
0801b		690.500	144.660	64.94	16.61	4.91	0.07	1.51	2.46	3.47	4.52	0.70	0.13	0.36	99.7	2212	43	165	41
0813		687.000	145.800	67.30	17.70	2.50	0.00	0.50	2.40	4.00	3.90	0.20		0.70	99.2	800	32		30
0815		687.000	145.800	70.00	14.80	1.90	0.10	1.00	1.70	4.70	4.10	0.30		0.80	99.4	400	55		35
0816		685.250	143.350	69.50	15.30	3.30	0.00	1.00	2.50	4.10	4.00	0.40		0.80	100.9	550	0		50
0817		685.380	143.500	69.60	14.40	3.20	0.00	1.00	3.00	3.60	3.60	0.40		1.20	100.0	900	60		50
0818		688.600	146.920	73.10	13.00	3.70	0.00	1.40	2.00	4.70	1.50	0.30		0.80	100.5	50	25		45
0819a		688.600	146.920	68.00	15.00	3.30	0.00	1.70	3.00	4.70	2.40	0.40	0.00	1.10	99.6	150	30		55
0819c		688.600	146.920	68.00	15.00	4.30	0.00	2.90	2.00	4.10	3.00	0.40		1.40	101.1	250	35		60
0827		685.900	143.500	72.50	12.90	2.20	0.00	0.90	1.10	3.10	6.20	0.30		0.50	99.7	600	40		35
0854		688.200	147.850	68.72	13.38	3.56	0.04	1.35	0.71	6.92	3.54	0.47	0.15	1.00	99.9	675	28	144	28
Gü 038	L	686.750	143.350	64.26	17.09	3.90	0.04	2.46	3.27	3.41	3.37	0.63	0.19	1.48	100.1				
Gü 633	L	686.750	143.350	66.65	16.44	3.93	0.05	1.64	2.09	2.42	4.65	0.85	0.24	1.80	100.8				
A	L	689.900	147.000	63.65	18.10	6.60	0.09	1.93	1.83	2.12	3.08	0.87	0.16		98.4	721	65	93	81
Hornblende-bearing Country Rocks																			
0028		688.400	147.470	49.90	15.33	9.12	0.16	9.83	6.76	3.44	3.19	1.16	0.25	0.68	99.8	520	530	142	166
0847fr		687.300	148.060	47.48	13.87	12.72	0.21	7.27	9.76	5.54	0.60	1.76	0.12	0.55	99.9	113	157	244	585
0848		689.700	147.850	48.64	14.75	9.13	0.16	8.32	9.06	6.39	1.92	0.84	0.18	0.52	99.9	183	108	74	200
0849		689.330	147.750	53.26	14.89	8.94	0.13	6.07	7.98	6.06	1.15	0.99	0.13	0.28	99.9	116	71	39	315
0852		688.060	147.050	51.00	17.18	8.94	0.14	4.67	7.04	6.77	2.18	1.02	0.20	0.72	99.9	324	26	72	224
0853		688.060	147.050	51.86	17.24	8.32	0.12	4.19	6.89	7.02	2.11	1.05	0.22	0.83	99.8	330	23	74	212
0855		688.800	147.880	51.70	16.34	8.28	0.12	5.17	7.27	7.28	2.11	0.97	0.13	0.48	99.9	282	47	75	231
0856		694.400	146.121	49.30	17.78	11.65	0.19	4.03	8.29	6.70	0.35	1.03	0.21	0.38	99.9	131	14	9	383
0857		694.500	147.470	56.49	16.90	7.35	0.12	4.00	6.81	6.79	0.46	0.50	0.06	0.44	99.9	197	71	22	211
0858		694.000	146.500	45.56	16.70	10.77	0.18	7.98	13.10	4.15	0.31	0.42	0.04	0.72	99.9	50	221	5	398
0859		692.130	147.800	46.70	18.02	8.48	0.14	5.54	9.05	6.75	2.24	1.41	0.13	1.39	99.9	385	252	91	234

Sample	Swiss coordinates		SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LoI	Sum	Ba	Cr	Rb	V
Mto	x	y	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm
0860	693.310	147.500	48.34	15.40	11.72	0.18	6.75	8.13	5.70	1.22	1.70	0.21	0.53	99.9	207	278	60	307
0863	691.900	143.720	44.84	16.84	10.21	0.12	7.81	13.01	4.64	0.67	0.90	0.09	0.76	99.9	60	644	10	284
0866	684.250	143.625	52.38	11.91	8.58	0.17	10.71	9.00	5.51	0.53	0.34	0.08	0.73	99.9	311	76	23	215
0868	684.250	143.625	49.38	17.91	8.94	0.13	7.04	8.28	6.58	0.51	0.43	0.09	0.60	99.9	27	411	14	260
0870	683.630	143.775	48.80	17.44	8.12	0.14	7.14	7.83	7.93	0.61	0.53	0.10	0.97	99.6	158	273	15	236
0871	683.430	143.850	49.72	17.64	8.39	0.14	7.22	8.02	6.72	0.62	0.54	0.12	0.73	99.9	178	271	18	257
0872	686.620	142.920	48.74	15.10	10.28	0.16	6.94	7.83	7.28	1.18	1.16	0.14	1.04	99.8	553	434	35	298
0873	686.510	143.040	50.61	17.48	9.05	0.11	6.04	5.51	7.13	2.30	0.93	0.13	0.57	99.9	380	174	97	256
0874	686.480	143.080	47.32	15.20	12.09	0.18	7.34	7.73	6.22	2.00	1.51	0.18	0.08	99.9	444	263	81	359
0875	687.200	143.730	46.75	20.10	6.21	0.11	8.03	12.91	4.69	0.45	0.13	0.00	0.56	99.9	157	104	16	134
0876	687.030	144.120	50.35	12.53	9.17	0.17	12.12	9.93	4.56	0.36	0.29	0.05	0.41	99.9	43	914	6	240
0877fr	686.690	144.280	48.31	8.63	9.16	0.18	15.67	11.49	5.27	0.43	0.30	0.07	0.41	99.9	7	1812	7	226
0878	689.100	144.760	45.11	12.82	11.80	0.22	13.49	7.00	4.58	2.95	0.99	0.05	0.87	99.9	182	821	163	331
Gü 019	687.250	143.000	47.38	16.05	9.86	0.15	8.45	8.59	5.65	1.85	1.11	0.16	0.61	99.9	314	268	76	268
Gü 086	687.030	145.880	55.08	15.86	8.25	0.16	6.67	5.69	3.15	3.07	0.85	0.17	0.88	99.8	364	119	137	158
Gü 108	689.200	143.600	51.82	18.14	9.55	0.17	5.44	6.17	2.97	3.07	1.56	0.18	0.74	99.8	588	164	155	198
Gü 115	687.050	144.200	45.74	16.30	11.32	0.18	6.60	13.84	2.10	0.62	2.06	0.35	0.72	99.8	145	268	42	303
Gü 328	689.160	147.360	55.10	13.58	8.83	0.16	8.86	9.65	2.03	0.75	0.42	0.09	0.43	99.9	115	192	55	161
Matorello Gneiss, Granitic, with Transitions to Granodioritic Varieties																		
0275	690.060	146.170	68.80	15.30	3.60	0.00	2.00	3.60	2.20	3.00	0.50		0.80	99.8	680	25		58
0800a	690.500	144.660	73.75	13.74	1.46	0.03	0.38	1.64	2.96	5.37	0.17	0.05	0.23	99.8	1107	4	183	8
0800b	690.500	144.660	73.35	14.41	1.69	0.04	0.37	2.02	2.87	4.48	0.19	0.05	0.39	99.9				
0802	690.500	144.660	74.29	13.75	1.42	0.03	0.31	1.44	2.74	5.33	0.17	0.04	0.34	99.9	738	2	216	10
0803	690.500	144.660	69.71	14.85	2.26	0.04	0.58	2.16	4.79	4.66	0.28	0.04	0.42	99.8	1183	0	113	0
0810	687.000	145.800	70.90	14.40	3.30	0.00	1.00	1.80	3.20	4.20	0.40		0.90	100.1	550	29		40
0811M	687.000	145.800	71.10	13.40	3.20	0.03	1.10	2.00	4.10	4.10	0.30		0.60	99.9	380	23		30
0812	687.000	145.800	71.00	14.70	2.70	0.04	0.90	2.20	4.30	3.70	0.30		0.70	100.5	300	39		30
0829	685.900	143.500	72.60	13.60	1.50	0.00	0.80	1.30	3.10	6.20	0.30		0.50	99.9	1000	35		40
Matorello Gneiss, Granodioritic, with Transitions to Tonalitic Varieties																		
0026	688.580	147.975	66.88	15.18	3.85	0.07	1.25	2.85	5.12	3.53	0.43	0.13	0.55	99.8	722	2	184	37
0265	689.900	147.080	68.20	16.20	3.70	0.00	0.90	3.20	3.70	3.10	0.40		0.60	100.0	740	20		54
0266	689.900	147.080	68.50	16.40	2.90	0.00	0.60	2.90	4.00	3.70	0.30		0.60	99.9	920	17		42
0267	689.900	147.080	68.50	14.90	3.10	0.00	1.30	3.00	4.30	4.40	0.40		0.50	100.4	840	18		44
0273	690.060	146.170	69.80	15.10	3.10	0.00	1.60	3.40	3.00	3.40	0.40		0.70	100.5	600	29		56
0484a	688.700	148.020	67.16	15.87	5.03	0.10	1.21	2.86	3.07	3.39	0.53	0.12	0.51	99.9	760	13	139	26
0783	687.025	147.250	70.20	15.00	3.20	0.10	1.00	2.50	4.90	2.70	0.30		0.80	100.7	340	28		35
0792	687.025	147.250	69.50	15.20	2.50	0.10	1.00	2.70	4.40	2.80	0.30		0.70	99.2	350	23		35
0794	687.025	147.250	66.90	17.60	3.20	0.10	1.10	2.60	4.40	2.30	0.40	0.00	0.80	99.4	400	32		45

Sample Mto	Swiss coordinates x	 y	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LoI %	Sum %	Ba ppm	Cr ppm	Rb ppm	V ppm
0814	687.000	145.800	65.80	17.60	3.35	0.10	1.50	2.70	4.30	3.10	0.50		0.70	99.7	350	65		60
0820	688.600	146.920	69.00	15.10	3.10	0.00	1.30	3.50	4.40	2.60	0.30		0.90	100.2	250	40		45
0821	688.600	146.920	69.40	14.60	3.20	0.10	1.50	3.50	3.70	3.00	0.40		0.80	100.2	300	120		45
0826	685.900	143.500	72.30	13.80	2.40	0.00	0.90	1.20	3.60	5.10	0.30		0.50	100.1	550	25		30
1108	688.381	147.418	67.03	16.04	4.09	0.08	1.37	3.37	4.06	2.60	0.47	0.13	0.59	99.8	543	16	90	37
1110	688.381	147.407	67.18	15.90	4.21	0.08	1.36	3.26	4.09	2.60	0.47	0.14	0.54	99.8	537	11	89	47
1111	688.423	147.418	65.47	16.52	4.62	0.07	1.63	4.22	3.97	2.09	0.52	0.13	0.62	99.8	265	14	78	56
1112	688.413	147.417	67.50	15.82	3.92	0.05	1.59	3.38	4.39	2.11	0.49	0.12	0.49	99.9	290	13	73	38
C	L 688.500	147.300	66.65	15.78	4.83	0.08	1.84	2.72	2.81	3.37	0.51	0.16		98.8	569	46	118	77
D	L 689.900	146.800	66.19	16.67	3.85	0.09	1.10	3.55	3.36	3.35	0.44	0.14		98.7	530	35	125	27
Matorello Gneiss, Tonalitic																		
0006	688.275	147.900	67.55	15.12	4.44	0.07	1.70	2.11	5.22	2.41	0.47	0.14	0.64	99.9	499	3	127	40
0036	688.250	147.900	67.03	15.21	4.03	0.08	1.52	2.28	6.25	2.24	0.45	0.10	0.66	99.9	512	6	123	36
0083	688.353	147.374	60.18	17.56	5.58	0.10	2.21	4.56	6.18	2.14	0.61	0.18	0.51	99.8	676	21	119	79
0261a	690.000	147.200	67.60	15.40	4.20	0.00	0.90	3.40	3.80	2.80	0.50		1.00	99.6	420	27		56
1093	688.373	147.414	68.91	15.28	3.90	0.07	1.16	3.17	3.78	2.55	0.43	0.12	0.49	99.8	504	5	92	34
1096	688.373	147.410	68.59	15.73	3.58	0.07	1.23	3.02	3.62	2.81	0.41	0.11	0.65	99.8	640	12	93	28
1102	688.373	147.412	68.35	15.32	4.04	0.08	1.41	3.09	3.93	2.46	0.48	0.14	0.53	99.8	522	12	93	35
1103	688.413	147.408	68.58	15.76	3.65	0.07	1.20	2.95	4.00	2.53	0.41	0.09	0.53	99.8	526	11	81	34
1107	688.381	147.416	68.02	15.77	3.87	0.05	1.38	2.95	4.68	2.09	0.46	0.14	0.44	99.9	326	16	79	37
1109	688.381	147.407	68.85	15.51	3.67	0.06	1.16	3.14	4.25	2.12	0.40	0.10	0.58	99.8	427	9	73	40
G	L 689.400	147.200	73.07	14.35	1.69	0.05	0.35	1.59	3.28	4.44	0.21	0.11		99.1	501	5	149	11
Aplites																		
0069	687.295	145.935	64.60	18.90	0.39	0.01	0.00	0.91	2.57	11.96	0.02	0.01	0.44	99.8	1381	53	288	3
0075	687.295	145.935	76.20	13.31	0.55	0.01	0.10	0.53	3.84	4.68	0.05	0.04	0.59	99.9	691	27	98	7
0081b	688.500	147.300	76.58	13.95	0.48	0.01	0.00	1.30	3.65	3.44	0.02	0.01	0.56	100.0	271	10	70	9
0231	688.448	147.302	76.24	14.08	0.98	0.05	0.20	0.93	4.42	1.86	0.05	0.10	1.01	99.9	38	29	122	9
0235	688.439	147.300	73.58	14.43	2.11	0.05	0.45	1.64	4.38	1.95	0.25	0.07	0.95	99.9	565	0	135	7
0240	688.464	147.330	66.52	15.00	3.78	0.07	2.17	1.90	6.12	2.66	0.41	0.10	1.14	99.9	593	3	153	35
0484b	688.700	148.020	76.61	13.94	1.00	0.01	0.09	1.86	3.74	2.06	0.08	0.02	0.52	99.9	377	5	53	7
0801a	690.500	144.660	76.13	13.26	0.47	0.01	0.09	1.10	2.46	5.85	0.05	0.00	0.39	99.8	1161	0	155	10
0851	698.150	146.800	57.41	16.26	7.14	0.11	2.61	4.93	6.79	2.93	0.91	0.16	0.59	99.9	504	1	125	105
F	L 689.900	147.300	60.15	16.77	7.29	0.12	2.64	5.36	2.70	3.04	0.97	0.19		99.2	467	7	106	122
Pegmatites																		
0050	688.350	147.284	75.20	14.25	0.74	0.01	0.14	1.13	4.82	2.56	0.03	0.11	0.92	99.9	121	0	122	10
0093	688.334	147.269	72.39	14.69	1.86	0.04	0.52	2.32	4.79	2.24	0.17	0.07	0.77	99.9	369	1	106	13

Sample Mto	Swiss coordinates x	y	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LoI %	Sum %	Ba ppm	Cr ppm	Rb ppm	V ppm
Meta-Tonalite Porphyrite																		
0234	688.445	147.305	67.73	15.74	3.93	0.07	1.34	3.47	4.06	2.04	0.41	0.12	0.91	99.8	459	4	125	15
Contaminated Intrusive Rocks of Type Mto 29																		
0089	688.370	147.433	57.43	16.60	6.84	0.10	4.54	5.22	4.09	2.80	1.16	0.32	0.68	99.8	748	71	130	112
0222	688.280	147.204	64.38	15.34	4.44	0.06	2.68	4.49	4.46	2.58	0.48	0.14	0.81	99.8	360	63	104	96
0236	688.440	147.312	56.26	16.36	6.64	0.11	4.40	6.27	6.00	1.94	0.84	0.21	0.83	99.8	448	75	99	168
0947	688.292	147.212	61.57	16.22	6.04	0.10	3.70	5.35	2.82	2.60	0.68	0.11	0.69	99.9	577	89	85	113
0952	688.291	147.207	63.36	16.30	5.21	0.09	3.05	5.35	2.89	2.33	0.58	0.10	0.60	99.9	486	89	82	91
Dikes, Stocks and Sills, Meta-Tonalite to Meta-Mela-Quartzdiorite (Type Mto 30)																		
0030	688.453	147.392	59.55	11.17	8.84	0.16	8.22	6.70	2.10	1.51	0.81	0.16	0.65	99.9	253	91	107	177
0045	688.363	147.295	52.69	16.99	10.06	0.13	5.37	7.95	1.99	2.24	1.34	0.14	0.96	99.9	727	74	82	256
0052	688.250	147.252	53.39	17.91	9.10	0.14	4.69	7.00	2.69	2.48	1.22	0.10	1.17	99.9	323	34	97	237
0225 a	X 688.388	147.291	55.72	16.52	7.46	0.12	4.78	6.81	4.08	2.83	0.76	0.15	0.62	99.8	204	127	73	203
0225 b	X 688.388	147.291	55.49	15.52	7.02	0.12	4.84	6.44	7.53	1.49	0.67	0.13	0.62	99.9	286	146	49	184
0227	688.388	147.291	52.33	15.88	8.69	0.13	6.03	6.24	4.43	3.79	0.96	0.14	1.24	99.9	353	63	176	238
0237	688.430	147.310	49.63	16.48	9.57	0.14	5.73	8.02	5.70	2.41	1.22	0.09	0.88	99.9	324	52	106	307
0946	688.318	147.183	54.69	17.34	8.86	0.13	4.32	7.81	2.59	2.06	0.99	0.15	0.94	99.9	382	45	79	237
0950	688.288	147.209	53.19	17.33	9.55	0.14	4.54	8.37	2.44	2.06	1.20	0.18	0.86	99.9	353	54	69	262
0951	688.288	147.209	53.00	17.62	9.47	0.14	4.64	8.19	2.54	2.17	1.13	0.14	0.84	99.9	374	49	69	267
0953	688.291	147.204	53.38	17.63	9.06	0.13	4.40	7.97	2.28	2.71	1.03	0.18	1.08	99.8	379	42	93	230
0954	688.291	147.204	51.47	16.54	10.80	0.16	5.27	8.50	1.76	2.68	1.29	0.17	1.22	99.9	409	60	95	313
0955	688.287	147.203	52.91	17.03	10.21	0.12	4.77	7.83	2.32	2.37	1.45	0.09	0.78	99.9	343	43	81	327
Dikes and Sills, Meta-Tonalite to Meta-Mela-Quartzdiorite (Type Mto 31)																		
0047	688.362	147.293	56.22	15.71	8.44	0.14	6.33	7.76	2.24	1.40	0.90	0.18	0.57	99.9	360	256	53	225
0048	688.362	147.293	55.92	16.39	8.55	0.13	5.45	7.35	2.60	1.62	0.91	0.20	0.77	99.9	373	213	60	230
0087	688.369	147.400	51.94	15.02	8.68	0.14	8.86	6.17	3.97	2.91	1.17	0.25	0.70	99.8	683	505	107	148
0095	688.463	147.366	51.92	13.25	8.43	0.15	8.56	8.32	6.09	1.60	0.74	0.11	0.70	99.9	179	432	64	304
0224 a	X 688.388	147.291	57.38	15.34	6.82	0.10	4.34	5.74	7.24	1.65	0.65	0.14	0.46	99.9	278	106	59	172
0224 b	X 688.388	147.291	55.64	16.31	7.94	0.12	5.15	6.55	3.64	3.06	0.76	0.13	0.55	99.9	273	147	92	203
0948	688.288	147.212	58.43	16.08	7.13	0.12	4.96	6.54	2.93	2.03	0.85	0.20	0.61	99.9	354	153	72	167
0949	688.286	147.212	57.92	14.77	8.14	0.16	5.97	7.68	2.23	1.57	0.64	0.14	0.67	99.9	246	306	53	226

Sample	Swiss coordinates		SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LoI	Sum	Ba	Cr	Rb	V
Mto	x	y	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm
Meta-Minette (Meta-Lamprophyre)																		
1050	688.430	147.420	48.93	14.20	8.81	0.17	10.12	7.43	0.47	6.19	0.90	0.23	2.37	99.8				
1051	688.424	147.390	49.27	14.00	8.23	0.16	9.50	7.94	0.75	6.20	0.87	0.25	2.62	99.8				
1052	688.416	147.380	49.74	13.77	8.52	0.16	9.34	8.24	0.38	6.00	0.84	0.23	2.60	99.8				
1055	688.398	147.368	49.09	13.25	8.22	0.15	9.99	8.05	0.19	6.53	0.80	0.22	3.33	99.8				
1056	688.390	147.367	46.90	13.30	7.97	0.14	9.44	8.29	0.00	7.52	0.83	0.18	5.31	99.9				
1057	688.390	147.367	50.14	14.18	8.31	0.14	9.88	7.24	0.43	6.91	0.90	0.23	1.46	99.8				
1061	688.396	147.417	48.38	13.61	8.00	0.15	9.41	7.45	0.30	6.65	0.81	0.25	4.89	99.9				
1062	688.395	147.413	49.17	13.44	7.97	0.15	9.61	8.24	0.12	6.60	0.83	0.23	3.50	99.9				
1063	688.395	147.415	49.60	13.48	8.42	0.15	9.45	8.27	0.03	6.49	0.83	0.23	2.92	99.9				
1064	688.380	147.417	51.81	15.02	7.62	0.13	9.77	6.70	0.11	5.80	0.85	0.23	1.86	99.9				
1065	688.393	147.417	50.30	14.26	7.92	0.14	9.57	7.73	0.09	7.09	0.87	0.20	1.64	99.8	952	594	255	119
1066	688.393	147.417	49.65	13.78	8.07	0.14	9.82	8.43	0.28	6.81	0.86	0.23	1.72	99.8	1015	583	240	118
1070	688.389	147.417	50.01	14.14	8.28	0.14	10.24	7.64	0.54	6.52	0.87	0.26	1.18	99.8	773	632	234	114
1071	688.389	147.417	50.68	14.84	7.75	0.13	9.51	7.13	0.65	6.97	0.96	0.29	0.89	99.8	996	542	254	116
1072	688.389	147.417	50.22	14.09	8.29	0.15	10.21	7.52	0.27	6.81	0.87	0.26	1.13	99.8	792	638	244	121
1073	688.388	147.417	50.64	14.19	8.17	0.14	9.81	7.53	0.32	6.92	0.88	0.24	0.98	99.8	886	584	250	124
1076	688.385	147.416	49.93	14.23	7.89	0.14	9.41	7.84	0.50	6.86	0.87	0.23	1.90	99.8				
1077	688.385	147.416	49.94	13.86	8.32	0.15	9.81	7.77	0.30	6.81	0.87	0.27	1.72	99.8				
1078	688.385	147.416	49.71	14.50	7.93	0.13	9.50	7.73	0.30	6.73	0.87	0.23	2.20	99.8				
1079	688.384	147.416	49.17	14.47	8.21	0.14	9.74	7.48	0.21	7.45	0.89	0.24	1.79	99.8	1055	604	269	113
1080	688.384	147.413	50.39	14.11	8.04	0.14	9.47	7.84	0.25	7.04	0.88	0.23	1.41	99.8	986	590	257	114
1082	688.384	147.415	49.82	14.11	8.77	0.15	9.66	7.89	0.34	6.30	0.89	0.24	1.66	99.8	776	600	249	146
1083	688.384	147.415	49.92	13.52	8.53	0.14	10.13	7.49	0.09	7.07	0.86	0.18	1.89	99.8	792	633	261	125
1085	688.384	147.415	50.00	13.76	7.88	0.14	9.46	8.47	0.24	6.58	0.84	0.25	2.20	99.8	897	578	231	117
1090	688.373	147.414	49.38	14.41	8.11	0.14	9.69	7.66	0.01	7.48	0.89	0.26	1.79	99.8	1042	584	273	128
1091	688.372	147.414	49.65	13.35	8.25	0.14	10.00	8.10	0.14	6.98	0.86	0.25	2.09	99.8	866	628	260	134
1092	688.372	147.414	50.43	14.20	7.42	0.13	9.14	8.21	0.24	7.34	0.89	0.21	1.59	99.8	1113	557	242	128
1094	688.372	147.409	50.75	13.36	8.51	0.14	9.85	7.50	0.11	6.30	0.84	0.22	2.26	99.8	792	621	259	125
1097	688.372	147.409	49.54	13.85	7.98	0.14	10.10	7.95	0.28	7.07	0.85	0.22	1.81	99.8	1025	590	260	122
1098	688.372	147.409	49.72	13.54	7.91	0.14	9.99	8.52	0.14	6.96	0.85	0.20	1.83	99.8	987	588	250	117
1099	688.372	147.409	49.47	13.79	7.89	0.14	9.81	8.45	0.25	6.94	0.85	0.26	1.96	99.8	1057	591	258	123
1100	688.381	147.409	48.82	14.05	7.81	0.14	9.99	8.26	0.10	7.11	0.91	0.28	2.32	99.8	1032	565	265	123
1104	688.381	147.415	49.58	13.71	8.43	0.14	9.90	8.15	0.33	6.16	0.85	0.26	2.29	99.8	848	617	255	129
1105	688.381	147.413	49.97	14.57	8.09	0.15	9.75	7.15	0.45	6.79	0.90	0.26	1.71	99.8	872	557	229	111