# The lithostratigraphy of the pre-Mesozoic basement of the Gotthard massif: a review

by *Ivan Mercolli*[1], *Giuseppe G. Biino*[1,2] and *Jürgen Abrecht*[1,3]


## Abstract

The Gotthard massif shows a coherent lithostratigraphy and can be subdivided into units, which can be traced across the entire massif. Indications of possible protholiths, relics of metamorphic parageneses, and magmatic events permit to classify the units chronologically and to distinguish major orogenic cycles. We propose the following revised lithostratigraphic subdivision of the Gotthard massif:

- Uppermost Carboniferous, Permian and Mesozoic sedimentary covers (with some outcrops of Permo-Carboniferous volcanic rocks)
- Late Variscan granitoids (divided into two cycles by a deformation phase)
- Middle Paleozoic metasedimentary rocks
- Late Ordovician metagranitoids
- Proto Gotthard (pre-Late Ordovician):
  - Migmatitic gneisses
  - Metagabbros, with island arc affinity
  - Metabasalts, metagabbros and meta-ultramafics, with ophiolitic affinity
  - Metasedimentary gneisses


*Keywords:* basement, granitoid, orogenic cycle, pre-Mesozoic, Gotthard massif, Central Alps.

## Introduction

The Gotthard pass, one of the privileged North-South connections across the Alps, has been crossed by many famous naturalists during the past centuries. Many of them report geological descriptions of the area (Cotti et al., 1991). The gigantic venture of the railroad tunnel at the end of the 19th century led to the remarkable geological description by Stapff (1880) along the railway cross section.

At the beginning of the 20th century, the petrography school of Zürich guided by Paul Niggli, started a long tradition of detailed geological investigations in the Gotthard massif which ended in the sixties. An exhaustive bibliography was presented by Labhart (1977) and Cotti et al. (1991). These works were mainly done in times when fossils were the only chronological support to geologists, and geophysics was an unknown discipline. Nevertheless, earlier authors clearly recognized in the Gotthard massif (Fig. 1 and Tab. 1), despite its Alpine deformation and metamorphism (greenschist to lower amphibolite facies), some records of at least two major pre-Alpine tectonometamorphic (orogenic) events.

The purpose of this paper is to review the literature on the Gotthard massif. The review is not based on a rigorous literature survey but on the authors' subjective selection of papers that, in the their opinion, are of broad interest, that were particularly novel, or that represented substantial advances in the knowledge of the lithostratigraphy and tectonometamorphic relationships between the different rocks making up the Gotthard massif. In this sense, the so called geological field evidences provided by the old authors (but not only...) are useful and important. Nevertheless

[1] Mineralogisch-petrographisches Institut, Universität Bern, Baltzerstrasse 1, CH-3012 Bern, Switzerland.
[2] Present address: Institut de Minéralogie et de Pétrographie, Université de Fribourg, Pérolles, CH-1700 Fribourg, Switzerland.
[3] Present address: GEOTEST AG, Birkenstrasse 15, CH-3052 Zollikofen, Switzerland.

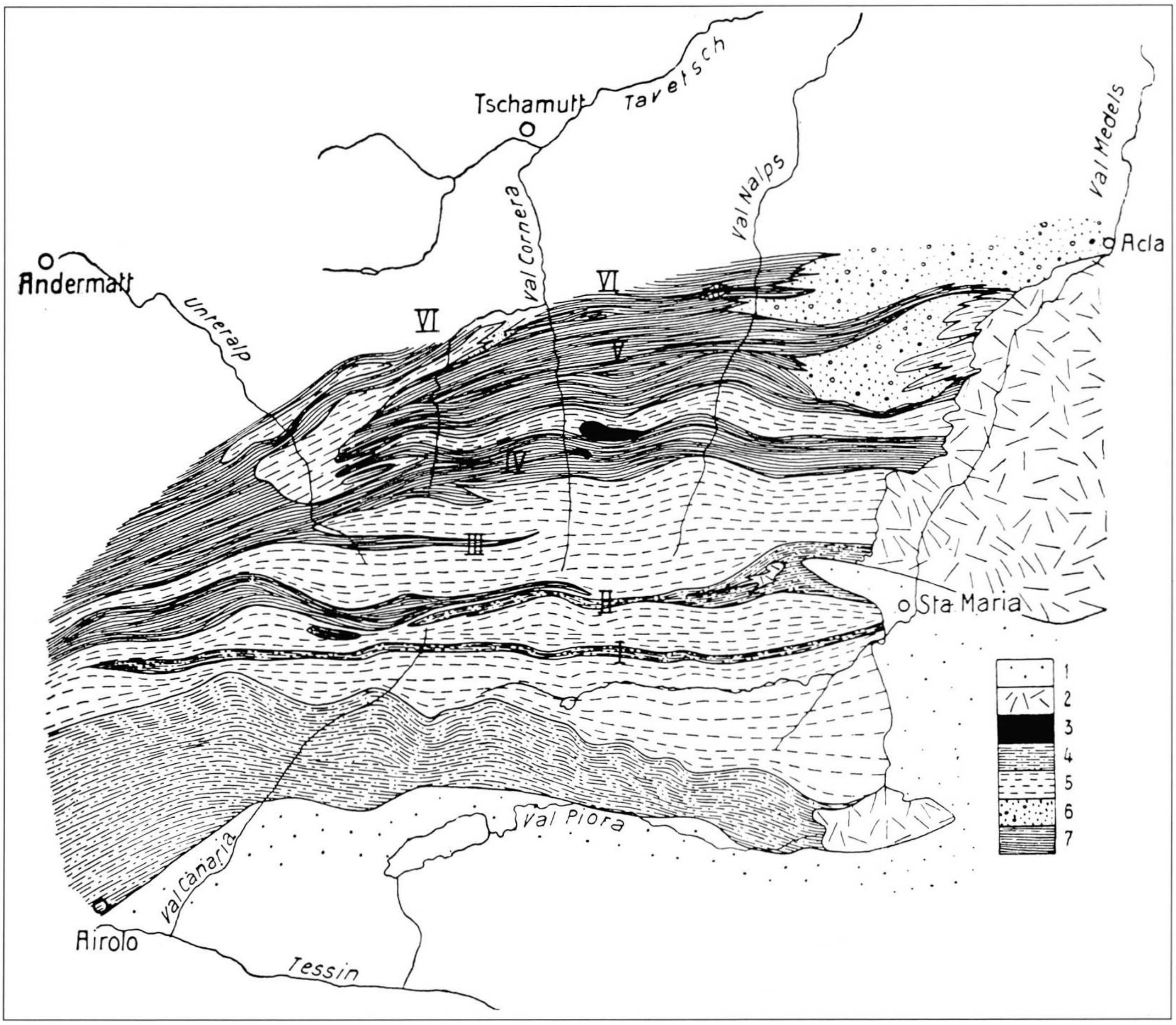


*Fig. 1* Tectonic subdivision of the south-eastern Gotthard massif. 1. Mesozoic schists; 2. Late Paleozoic granite bodies; 3. peridotite bodies; 4. younger trough zones (Tremola-Tenelin-Borel); 5. "Streifengneise"; 6. "Mischgneise"; 7. older trough zones with basic layers. Reproduction of the original figure of HUBER 1943, figure 6, page 93.

some caution must always be applied since the dominant theory at that time could considerably have conditioned the field observations: many of the earlier authors described thermal effects produced by the serpentinite magma (considered a Late Paleozoic intrusive), and the contact between Streifengneis and migmatitic gneiss is always quite controversially described (the dominant theory at the beginning of the century suggested migmatitization by lit-par-lit intrusion).

In this contribution we summarize in a coherent model (at a regional scale) the observations of previous authors. This model may represent a simplification in many respects, and misinterpretation of former authors' interpretations cannot be excluded. However, despite or because of such shortcomings we hope to stimulate a discussion of this important chapter of the geology of the Central Alps.

## Rock types and lithostratigraphy

The pre-Mesozoic basement of the Gotthard massif is made up by paragneiss and micaschist with embedded mafic, ultramafic and calc-silicate rocks. This sequence was intruded during Late Ordovician and Late Carboniferous by granitoids.

A characterization of the rock types and the used formational names are presented in tables 1 and 2.

HUBER (1943) and NIGGLI (1944) have proposed to use two major magmatic events as lithostratigraphic markers for the evolution of the

*Tab. 1* Rock series belonging to the sedimentary portion of the crystalline basement of the Gotthard massif. Translated from NIGGLI (1944), table V, page 128.

| | Series I | Series II | Series III | Series IV | Series V | Series VI |
|---|---|---|---|---|---|---|
| Typical localities in the central Gotthard massif | Garves da Nual Piz Cavradi Six Madun Piz Tegliola Unteralptal (Spannmatt, Glockenspitz) | Eastern Val Nalps Piz Paradis Guspistal | Motta Naira zone (H.M. HUBER) central Val Curnera and Val Nalps | Tremola series southern border of the massif | Piz Tenelin Piz Borel Val Rondadura | Northern and ? eastern border of the massif |
| Main rock type | **Andesine/labradorite gneisses** (Bt, Hbl, Grt), with inclusion of calc-si-licate and Bt-Act-fels; Sil gneiss; associated with albite/oligoclase gneiss and rare amphibolite | **Mica albite/oligoclase gneiss** (Bt, Ms, Grt), hornfelsitic or fine banded or fine "augig"; associated with minor amphibolite | Amphibolite; minor mica-albite/oligoclase gneiss and andesine/labradorite gneisses | Grt-mica schist; Hbl-garben schist; Cal-mica schist; amphibolite; Zo amphibolite; quartzitic gneis; quartzite; coal bearing schist; Bt quartzite; cross-Bt gneiss | Mica gneiss; Hbl-Grt-mica schist; Hbl-Cal-mica schist; quartzite; amphibolite | Sericite-Bt gneiss; phyllite; quartzite; graphitic schist |
| Guide rock | Calc-silicate | | | Quartzite | Quartzite | Quartzite |
| Pre-Alpine metamorphic grade | Meso to catazone | | | Meso to epizone | | |
| Age refered to the Streifengneis and Hercynian granite | Pre Streifengneis | | | Post Streifengneis but pre-Hercynian granite (? ± coeval) | | |
| Likely primary sedimentary facies | Shale to carbonaceous marl, partly sandy; layers of calcareous sandstone in the shale | Sandy shale; minor dolomitic marl; relatively monotonous sedimentation | Dolomitic marl, sandy shale; with intercalatons of ? "ophiolite"; deep basin? | Shale to dolomitic marl with single quartz sandstone layers | Shale to dolomitic marl with thick quartz sandstone layers | Shale ? and sandy shale quartz sandstone |

massif. The first marker of the basement evolution is the intrusion of the Streifengneis (Late Ordovician granitoids), the second is represented by the Late Variscan intrusives (Tab. 1 and 2).

In the central part of the massif (Fig. 2) HUBER (1943) and NIGGLI (1944) proposed the following subdivision of the crystalline basement:

- Pre Streifengneis gneisses and amphibolites
- Streifengneis
- Middle Paleozoic metasedimentary rocks, mainly mica schists and quartzites (post-Streifengneis sedimentation age, first metamorphism and deformation pre-Upper Paleozoic granitoids ?)
- Late Variscan granitoids (Upper Carboniferous-Permian)
- Permo-Carboniferous and Mesozoic sediments.

In this review we used the remarkable lithostratigraphic synthesis of NIGGLI (1944, Tab. V, page 128, here reported as Tab. 1) as starting point for our reconstruction. We reorganized them (Tab. 2) according to the evolution model proposed by ABRECHT et al. (1991a) and summarized in table 3. Table 2 reports further a synopsis of the geological terms occurring in the past literature.

Pre-Streifengneis gneisses and amphibolites are in the following considered as being a member of a unit called Proto Gotthard (Tab. 2).

In order to simplify matters for the readers, we have subdived the Gotthard massif in three geographical areas. This subdivision has no geologic ground.

## The central part of the Gotthard massif

### THE MAFIC AND ULTRAMAFIC ROCKS

The mafic and ultramafic rocks are embedded in metasedimentary rocks. As already suggested by NIGGLI (1944), some of the amphibolites in series I, II, and III (Tab. 1) show an ophiolitic affinity and belong to the oldest part of the basement (Proto Gotthard). Isotopic and chemical investigations show that part of the mafics derived from former MOR basalts (ABRECHT et al., 1991a; BIINO and MEISEL (1993) have suggested that the meta-ultramafics are mainly abyssal peridotites. The mafics and ultramafics are clearly associated in the field. Therefore, mafics and ultramafics can be related to an ophiolitic sequence. The Sm–Nd isotope systematics suggest a formation age of approximately 950 Ma (BIINO et al., 1994). The

*Tab. 2* Characterization of the lithostratigraphic units of the pre-Mesozoic basement of the Gotthard massif.

| | Proto Gotthard | | | Late Ordovician granitoids | Palaezoic metasedimentary unit | Late Carboniferous granitoids |
|---|---|---|---|---|---|---|
| | Metasedimentary meta-ophiolitic unit | Metagabbro unit | Migmatic gneiss unit | | | |
| Correlation with unit names already existing in the literature | "Nördliche Paragneise", "Gurschengneise", Guspisgneise", "Prato Serie", "Distelgrat Zone" Series I, and II of NIGGLI | | "Mischgneise", "Homogene Mischgneise", "Injektionsgneise", "Schmitzengneise", "Paradisgneis", "Sorescia gneis", wester part of the "Giubine Serie" Series II of NIGGLI | "Streifengneis", "Orthogneis" | "Tremola Serie", "Zone des Piz Borel", "Zone des Piz Tenelin", eastern part of the "Giubine Serie" Series IV, V and VI of NIGGLI | Medelser granite, Cristallina granodiorite, Uffien diorite, "Gamsboden-Granit-gneis", "Fibbia-Granit-gneis", "Winterhorn-Granitaplit", Cacciola granite, Rotondo granite, Prosa granite, Sedelhorn diorite |
| Guide rocks | Bio-andesine/ labradorite gneiss, Grt-amphibolite, serpentinite and calc silicate | Metagabbro | migmatite, banded gneiss, chorismatic and stromatic gneisses | Two mica gneiss | Quartzite, Hbl-Grt-mica schist, Hbl garben schist, Sericite-phyllite | Undeformed to weak foliated granitoid |
| Protholith | Clastic sediment and dismembered ophiolitic rocks | Gabbros with island arc affinity | Clastic sediments | Granite | Clastic sediments | Calc-alkaline granitoid |
| Age of the protholith | Proterozoic to Cambrian | Proterozoic to Lower Ordovician | Proterozoic to Cambrian | Late Ordovician (440 Ma) | Silurian to Devonian | Late Carboniferous |
| Pre Late Ordovician metamorphisms | Eclogite facies Granulite facies | Eclogite facies Granulite facies | Eclogite facies Granulite facies anatexis | | | |
| Variscan metamorphism | Amphibolite facies | Amphibolite facies | Amphibolite facies | Amphibolite facies | Greenschist facies ? | |

metasedimentary and meta-ophiolitic rocks are interpreted by ABRECHT et al. (1991a) as an accretionary prism.

Until recent (ABRECHT et al., 1991a,b; ABRECHT and BIINO, 1994), metagabbros were not recognized in the Gotthard massif. The Kastelhorn metagabbro was only dubiously considered a former orthogenic rock of upper Carboniferous age (AMBÜHL, 1929). Two generations of gabbros can be defined. Some metagabbros (e.g. Fuorcla Paradis) clearly belong to the ophiolite sequence, but other metagabbros (e.g. Kastelhorn, Unteralptal) are intrusive into the metasedimentary and meta-ophiolitic series. These younger metagabbros, possibly of Lower Ordovician age (OBERLI et al., 1993), show island arc affinities.

All these rocks have suffered at least two major metamorphic overprints prior to the intrusion of the Streifengneis (Late Ordovician granitoids); the first one at eclogite facies conditions and the second one at granulite facies conditions (ARNOLD, 1970).

## THE PRE-STREIFENGNEIS BASEMENT AND THE MIGMATITE PROBLEM

The wedge sequence is made up by a variety of gneisses. Some of these gneisses show, to different degrees, migmatitic-looking textures ("Mischgneise", "chorismatische Gneise", "Injektionsgneise", "feldspatreiche Gneise", "Migmatitgneise" and "Paradisgneis" according to AMBÜHL, 1929; HUBER, 1943; NIGGLI, 1944; ARNOLD, 1970).

The interpretation of the relationship between these gneisses, the Streifengneis, and the evolution of the older basement is quite controversial. AMBÜHL (1929), HUBER (1943) and NIGGLI (1944) used different names for these gneisses, such as "Mischgneise", "Homogene Mischgneise", "chorismatische Gneise", "Injektionsgneise", "feldspatreiche Gneise", but never explicitly called them migmatites. Nevertheless, they always used the classical migmatite terminology (chorismatic, micro chorismatic, stromatic, nebulitic, phlebitic) in their descriptions. It is important to keep in mind that ptygmatic folds or melt migration in axial planes are seldom described (in contrast to the migmatitic terrains outcropping in the Aar massif). All these authors describe the rocks as neither clearly paragenetic nor orthogenetic. They stressed the non homogeneous character at microscopic and hand specimen scale, but the relative homogeneity at megascopic scale.

HUBER (1943) observed that the "Mischgneise" were always cropping out along the contact of Late Ordovician granitoids to the basement. He pointed out the close spatial relationships, and

*Tab. 3* Schematic summary of the geological history of the Gotthard massif, after ABRECHT et al. (1991a).

| *Time* | *Tectonic event* | *Process of crustal growth* | *Metamorphism* |
|---|---|---|---|
| ~ 1000 Ma | – Opening of an oceanic basin | | |
| | | – Formation of oceanic crust | |
| | | | – Sea water-rock reaction |
| ~ 900 ? Ma | – Subduction of the oceanic crust | | |
| | | – Formation of an accretionary prism | |
| | | – Juxtaposition of oceanic and continental series | |
| | | – Intrusion of gabbros in the accretionary prism | |
| ~ 470 Ma | – Subduction of the accretionary prism due to collision | | |
| | | | – Eclogite facies (Ky) |
| | | | – Granulite facies (Ky) |
| | | | – Anatexis (Sil) |
| | | | – Grt-amphibolite facies |
| ~ 440 Ma | – Uplift | – Intrusion of granitoid (Streifengneis) | |
| | – Erosion | – Sedimentation of clastic series | |
| ~ 350 Ma | – Compression | | – Amphibolite facies |
| 315–300 Ma | | – Intrusion of the first generation of granitoids | |
| ~ 300 Ma | – Deformation phase | | |
| 300–250 Ma | – Uplift | – Intrusion of the second generation of granitoids | |
| | | – Formation of volcanic and volcanoclastic series | |

interpreted the "Mischgneise" as the product of the impregnation of the metasedimentary gneisses by melt or fluids during the intrusion of the Late Ordovician granitoids. NIGGLI (1944) partly agreed with Huber's interpretation. However, he

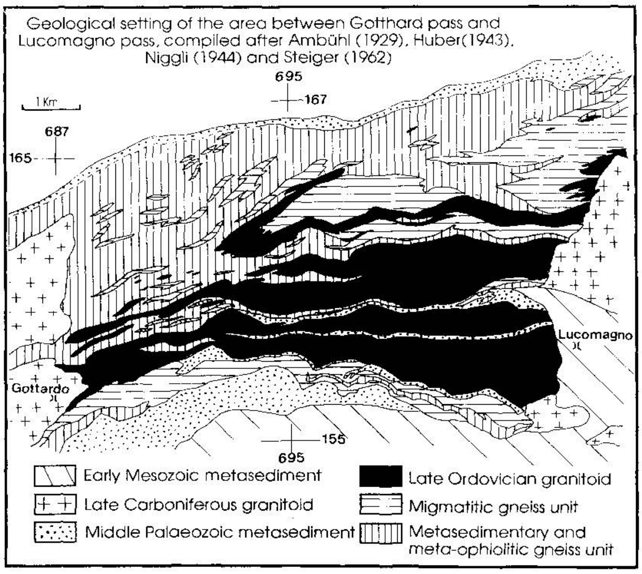


*Fig. 2* Geological setting of the area between Gotthard pass and Lucomagno pass, compiled after AMBÜHL (1929), HUBER (1943), NIGGLI (1944) and STEIGER (1962).

observed "Mischgneise" with no obvious spatial relationship with the Late Ordovician granitoids. AMBÜHL (1929) described sharp contacts between ortho- and paragneisses, and he observed discordant dikes cutting the country rocks. ARNOLD (1970) described true migmatites occurring mainly as border facies of the "Mischgneise" along the contact either with the Late Ordovician granitoids or the metasedimentary gneisses. He could not establish a precise age relationship between migmatites, "Mischgneise" and Late Ordovician granitoids, but he supported the conclusion of HUBER (1943) that the anatectic phase was related to the intrusion of the granitoids at least in time.

In the following, we propose to consider the "Mischgneise", "chorismatische Gneise", "Injektionsgneise", "feldspatreiche Gneise" and "Migmatitgneise" of AMBÜHL (1929), HUBER (1943), NIGGLI (1944) and ARNOLD (1970) as a single complex of rocks of sedimentary origin having been transformed to different degrees by migmatitic processes. We will refer to these rock types as migmatitic gneisses (Tab. 2, Fig. 2).

A particular type of gneiss, associated with the migmatitic gneisses has been reported by HUBER (1943) as "Paradisgneis". It is a rather massive mica-plagioclase gneiss, showing only a weak foliation and containing centimetric to decimetric inclusions of gneisses, amphibolites, quartz nodules and calc-silicate rocks. Similar rock types are described by AMBÜHL (1929) and NIGGLI (1944, 1948) in Val Maighels. In contrast to the syn-Streifengneis impregnation hypothesis proposed by HUBER (1943), ARNOLD (1970) has suggested a pre-Streifengneis anatectic origin of this rock (pp. 41, 44). The mica-plagioclase gneiss represents the anatectic melt and the inclusions are considered to be restites. The presence of granulite-facies assemblages in the "Schollen" clearly indicates an anatectic event between the high temperature metamorphic event and the intrusion of the Streifengneis (Late Ordovician in age). Whether the "Mischgneise" were formed during this anatectic event is still a matter of debate. A continuous transition from the non migmatitic paragneiss to "Paradisgneis" is shown in HUBER (1943), NIGGLI (1944), and ARNOLD (1970), and the transitional contact is discordant to older structures (e.g. lineaments of mafic lenses). A similar observation is also true for the transition between the non migmatitic paragneiss and the migmatitic gneiss. The contact between Paradisgneis and migmatitic gneiss is described by HUBER (1943) as transitional and by ARNOLD (1970) as tectonic. All these authors point out the difficulty of establishing clear field relationships between migmatitic gneiss and Paradisgneis.

Thus, two different scenarios may be proposed:

1. The "Mischgneise", "chorismatische Gneise", "Injektionsgneise", "feldspatreiche Gneise", "Migmatitgneise" and the Paradisgneis were formed by the same anatectic event. In this case the anatexis must be pre-Streifengneis but younger than granulite facies metamorphism.

2. Two separate anatectic events have occurred. As a consequence, a first migmatization phase of unknown age has to be assumed for the migmatitic gneisses, while a second one of presumably Lower Ordovician age is responsible for the Paradisgneis. In this case the migmatitic gneisses represent the oldest rocks of the basement and are relics of a continental crust on which the protolith of the Paradisgneis has been deposited or overthrusted. The second event (Paradisgneis) is considered to be only a minor one with local geological importance.

The first scenario would indicate a widespread migmatitic event of at least Late Ordovician age, which affected large masses of the older metasedimentary to meta-ophiolitic series. The field relationships between paragneiss-migmatitic gneisses and between paragneiss-Paradisgneis strongly support this interpretation, and the tectonic contact between Paradisgneis and migmatitic gneisses may be due to a local and minor event. On the other hand, several arguments are not fitting the second scenario. Paradisgneis and Migmatitgneis show the same type of inclusions (mafics, ultramafics, calc-silicate fels), and it was not possible to demonstrate any difference in the metamorphic evolution. At present, this second scenario must be only considered as a working hypothesis. Hence we propose to consider the Paradisgneis as part of the migmatitic gneiss. New field observations led us to conclude that the contact between Streifengneis and metasediments (already migmatitized) is discordant and intrusive. Dikes and apophyses emanating from the Late Ordovician metagranitoids discordantly cut the metamorphic structures of the Upper Proterozoic metasedimentary and metaophiolite rocks, indicating an Ordovician to Upper Proterozoic tectonometamorphic event (or events) recorded only in the oldest part of the basement. A post migmatite deformation in garnet amphibolite facies occurred before the Streifengneis intrusion (BIINO, unpubl. data), while Streifengneis and migmatitic gneisses were deformed together during the Variscan (Schlingen phase).

The term Streifengneis is well established in the Alpine literature. Nevertheless, it contains ambiguities since it is constrained by a peculiar texture more than by genetic or chronological criteria. The Streifengneises are locally less deformed and, therefore, are not banded orthogneisses but augengneisses, or even at outcrop scale they have preserved igneous textures. Another quite common feature is the presence of a finer grained marginal facies that is transitional to the augengneisses. These clearly plutonic textural and structural variations are not easily integrated in a classification based on a later tectonic fabric. In the present review as in the older literature the chronological criteria seem to be the overwhelming characteristic. These rocks yield an absolute chronological age of ca. 440 Ma (ARNOLD, 1970; BOSSART et al., 1986; SERGEEV and STEIGER, 1993), and we therefore suggest to replace the term Streifengneis by Late Ordovician metagranitoids, although they consist of granites, granodiorites, quartz monzodiorites and quartz monzonites.

## MIDDLE PALEOZOIC METASEDIMENTS

An interesting rock unit, including sericite-biotite-gneisses, phyllites, quartzites and graphitic schists, borders the northern margin of the crystalline basement in the central and eastern part of the massif. NIGGLI (1944) considers these rocks to be Middle Paleozoic metasediments (series VI in Tab. 1). According to AMBÜHL (1929) the sericite-

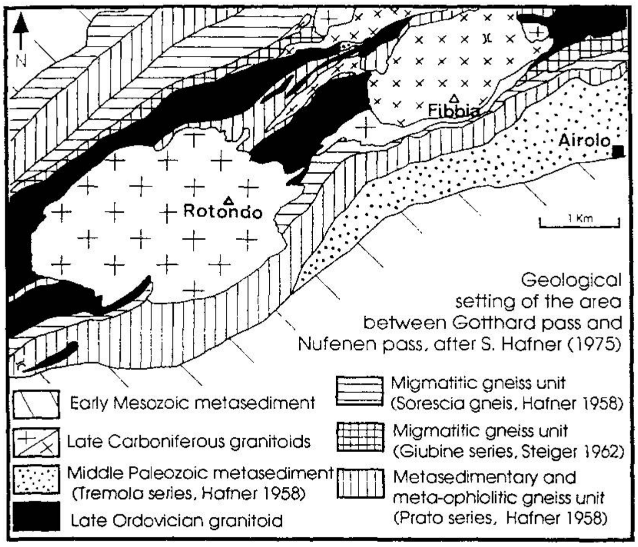


*Fig. 3* Geological setting of the area between Gotthard pass and Nufenen pass, modified after HAFNER (1975, 1:25 000 Swiss Geological map, Val Bedretto, Blatt 68, LK1251).

biotite-gneisses and phyllites are formed due to retrograde alteration of the paragneisses along the contact with the Permo-Carboniferous sediments.

Although admitting a strong Alpine (or Late Variscan) deformation and recrystallization, in accordance with ARNOLD (1970), we prefer Niggli's interpretation of a Middle Paleozoic sedimentary sequence and consider it to be a separate lithological unit (Fig. 2). Similar rocks outcrop in the Piz Tenelin and Piz Borel slices (Fig. 4). AMBÜHL (1929) clearly described "Garbenschiefer" identical with those from the Tremola zone (see below) in the Piz Borel zone (Pizzo Centrale, Fig. 4). In the western termination of the massif, OBERHOLZER (1955) reports an alignment of quartzitic rocks of several kilometers in length interlayered with the "Zweiglimmer-Na-K-Feldspatgneise" (Fig. 5). We tentatively assign these rocks to the same Middle Paleozoic metasediments.

## The southern and western parts of the Gotthard massif

HAFNER (1958) and STEIGER (1962) have investigated the southern margin of the massif (Figs 2 and 3). From the descriptions of the units mapped by these authors we can derive the following relationships with the previously defined units.

The "Prato Serie" (HAFNER, 1958, p. 277) is an unequivocal equivalent of the metasedimentary gneisses (accretionary wedge sequence) with embedded ophiolitic metabasalt and meta-ultramafic rocks. In this series HAFNER (1958) observed migmatitic structures.

The "Soresciagneis" (HAFNER, 1958, p. 274) is described as biotite-plagioclase gneiss. The contact with the "Streifengneis" is a pre-Late Variscan thrust plane (HAFNER, 1958, p. 273). The gneiss is very homogeneous and with seldom stromatic, ophthalmitic and microchorismatic structures. STEIGER (1962, p. 482) considered the "Soresciagneis" as a sedimentary cover of the Prato series. HAFNER (1958, p. 315) pointed out a possible correlation between "Soresciagneis" and "Mischgneis". In our reconstruction, the "Soresciagneis" is considered as migmatitic gneiss and, therefore, belongs to the Proto Gotthard.

The "Giubine Serie" (STEIGER, 1962, p. 506 and so forth) contains three lithotypes:

– The "Schmitzengneis". From Steiger's descriptions and from a comment by ARNOLD (1970, p. 38) the "Schmitzengneis" appears to be identical with the Paradisgneis.

– The stromatic gneiss seems to correspond to the "Mischgneise".

– The garnet micaschist, as already stated by STEIGER (1962, p. 515), shows a clear affinity to the micaschists of series IV, V, VI of NIGGLI (1944; Tab. 1).

STEIGER (1962) pointed out the possible age differences of the rocks of the "Giubine Serie" and the difficulties to map the contact between "Schmitzengneis", stromatic gneiss and "Soresciagneis". Steiger's observations suggest that only one migmatitic event occurred (but at different degrees of partial melting).

The garnet micaschists are intruded by the Late Variscan granitoids (e.g.: north of the Passo dell'Uomo after STEIGER, 1962).

The "Giubine Serie" is composed of poly- and mono(Variscan)-metamorphic rocks, but it is not an independent nappe. Hence we propose to discard the unit name "Giubine serie" (Tab. 2 and Fig. 2) and to assign the "Schmitzengneis" and stromatic gneiss to the migmatitic gneisses and the garnet micaschist to the Middle Paleozoic metasediments.

The "Tremola Serie" is formed by marine metasediments (shales, carbonates with minor sandstone), and in only one locality metaconglomerate layers crop out (HEZNER, 1909, pp. 164, 186). HAFNER (1958) described discordant contacts between Prato and Tremola series (p. 321). The "Tremola Serie" and its subunits have been studied in detail by HEZNER (1909) and STEIGER (1962). This unit shows neither the high-grade pre-Alpine metamorphism nor any intrusive contact with the Late Ordovician granitoids. Apparentely, it is not refolded by the Variscan Schlingen tectonic. A separate slice of "Tremola Serie" (map by HAFNER, 1:25 000 Swiss Geological map, Val Bedretto, Blatt 68, LK1251) is possibly intruded by the Gamsboden granite (Fig. 3). Therefore, the "Tremola Serie" has been deposited or tectonically juxtapposed on the Gotthard basement during the Middle Palaeozoic. In accordance with the subdivision by NIGGLI (1944) and with the field observations of AMBÜHL (1929), we assign the "Tremola Serie" to the Middle Paleozoic metasediments.

The western Gotthard massif has been investigated by OBERHOLZER (1955). His lithological classification permits a correlation with our proposed lithostratigraphic subdivision. Mica-plagioclase gneisses, amphibolites, garnet amphibolites and serpentinites represent the metasedimentary gneisses, ophiolitic metabasalt and metaultramafics unit (Series I, II, III, NIGGLI 1944; reported in Tab. 1). The "Mischgneise" belong to the migmatitic gneisses and the "Zweiglimmer-Na-K-Feldspatgneise" to the Late Ordovician metagranitoids. OBERHOLZER discussed the possible correlations of these rocks with the central part of the massif and arrived, despite of some local lithological differences, at similar conclusions.

## The eastern part of the Gotthard massif

Somewhat more problematic is the extrapolation of our lithostratigraphic subdivision to the eastern end of the massif. WEBER (1924) distinguishes on his map two main units, the "Paragesteine" and the "Ältere kristalline Schiefer (teils Ortho-, teils Paragesteine)". The main part of the "Paragesteine" clearly belongs to the Proto Gotthard, while some lithotypes such as "Konglomeratgneiss, Serizitgneisse, -schiefer -phyllite und -quarzite" could be assigned to the Middle Paleozoic metasediments. The "Ältere kristalline Schiefer (teils Ortho-, teils Paragesteine)" include migmatitic gneisses and Late Ordovician granitoids.

WINTERHALTER (1930) did not map the "Orthogneiss" (Late Ordovician granitoids) and the "Injektionsgneis" (migmatitic gneisses) separately. It was, therefore, impossible to define on figure 5 the limits of these two units in the area north of the Medelser-Cristallina granitoid complex. In WINTERHALTER'S map (1930) a phyllite zone marks the Late Ordovician granitoids-paragneiss contact. He interprets these phyllites as strongly deformed paragneisses and discusses a possible link with the wedging of Permo-Carboniferous sediments within the paragneisses. On the other hand, the mineralogy of these phyllites is the same as the sericite-phyllite that NIGGLI (1944) assigned to series VI (Tab. 1). Lacking new facts on this subject, it is impossible to decide if these phyllites belong to the Middle Palezoic metasediments or to the Proto Gotthard.

FEHR (1956) has tried to distinguish different gneiss domains at the eastern end of the massif. Unfortunately, it is difficult to relate his gneiss nomenclature to our subdivision, this concerns particularly the distinction between Late Ordovician granitoids and migmatitic gneisses. Further, the map by FEHR (1956) differs in some points from the one by WEBER (1924) preventing clear correlations.

It is, nevertheless, evident that the eastern end of the massif does not show any important lithological changes. Rocks only present in this area, are meta-rhyolitic volcanics and rhyolitic dikes ("Quarzporphyre") of Late Paleozoic age (frequentely associated with black schists and tourmaline fels) which crop out within the crystalline basement. Together with the abundant Permo-Carboniferous sediments on top of the crystalline basement (Verrucano of Ilanz), the presence of the these volcanics indicates that at least this part of the massif was denuded in Late Paleozoic times.

## Structural evolution

The polyorogenic tectonic reworking of the Gotthard massif and the lack of systematic modern structural studies, presently prevent a clear assignment of structures to single deformation events. As the emphasis of our study was clearly on the petrographic characterization of the rock units, it was beyond its purpose to summarize in a modern and coherent frame the structural observations dispersed in the literature. Nevertheless, some general remarks can be made. The best way to investigate the main structures is by establishing the structural evolution within the three major intrusive bodies: the Late Ordovician granitoids, the first and the second suites of Late Variscan granitoids, and to compare them with the structures in the old basement. This same strategy has been followed by earlier geologists but the theoretical progress in structural geology will lead to new results. The help of isotope geology is also decisive in order to geometrically distinguish similar but diachronous phases of deformation, and to better constrain the age of the structural markers. A good example of such strategy is found in the central Gotthard massif. The Rotondo granite

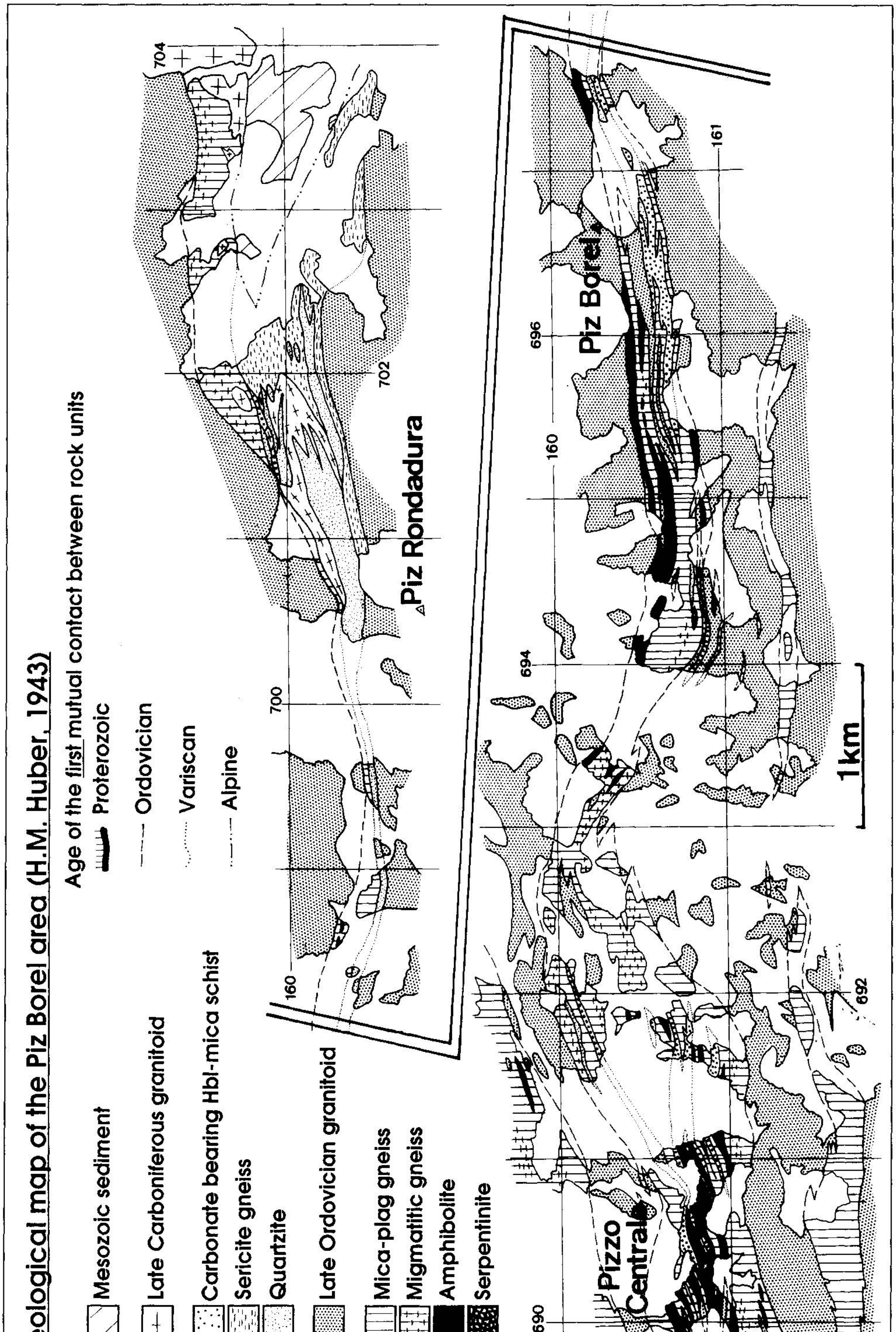


*Fig. 4* Geological map of the Piz Borel zone, after HUBER (1943).

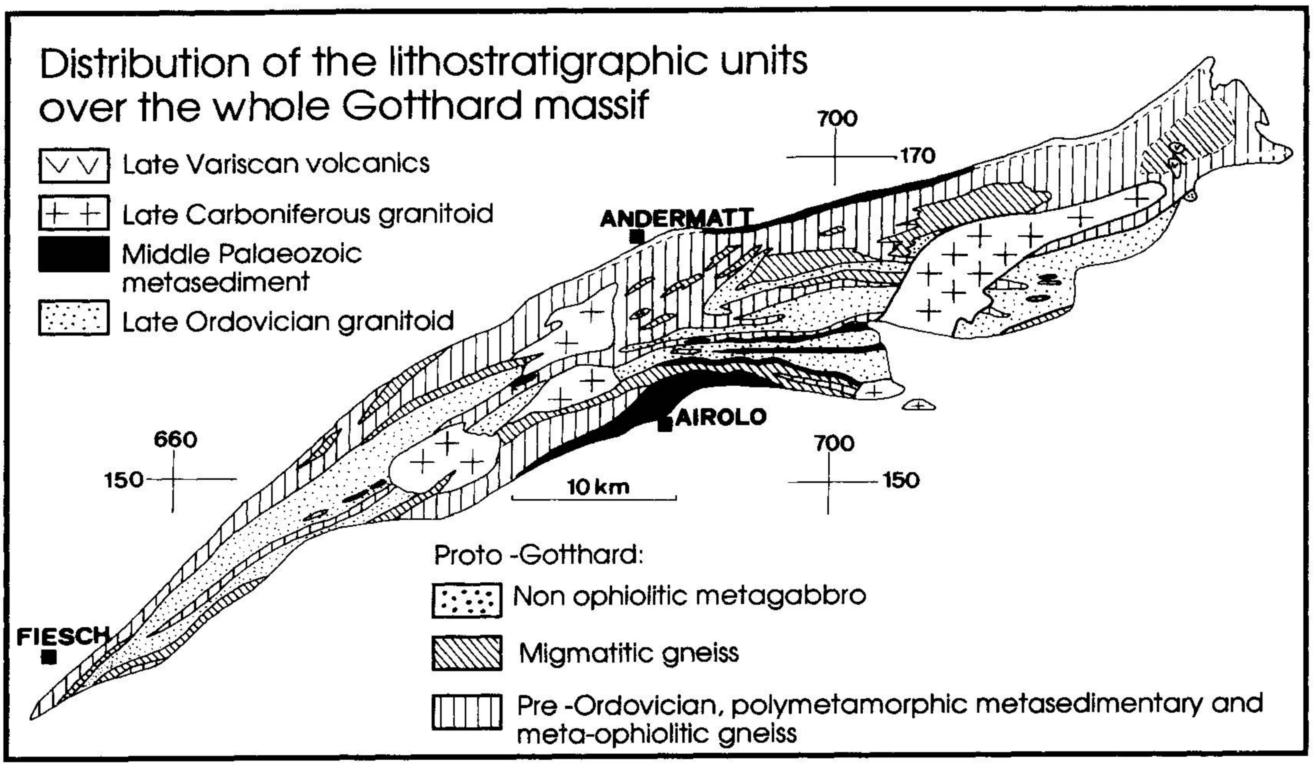


*Fig. 5* Distribution of the lithostratigraphic units over the whole Gotthard massif. Drawn after the Geological Map of Switzerland 1:500 000, 1980.

shows significant differences in deformation patterns when compared to the Fibbia-Gamsboden orthogneisses (Hafner, 1958; Steiger, 1962; Grünenfelder and Hafner 1962; Kvale, 1966; Marquer, 1990). New chronological data suggest that a phase of deformation occurred within a relatively limited time span at the end of the Variscan cycle (Guerrot and Steiger, 1991; Sergeev and Steiger, 1993). This phase is probably responsible for the differences in deformation of the Variscan plutons. A Late Variscan tectonic phase was also suggested for the Aar massif by Oberhänsli et al. (1988).

## Conclusions and open problems on the Gotthard massif structuration

The proposed lithostratigraphy helps us to understand the structuration of the Gotthard massif, but poses new questions too. In the following, some of these problems are briefly outlined.

### THE VARISCAN PALEOGEOGRAPHY

The pre-Triassic evolution is a good criteria in order to understand the old structuration of the Alpine basement. The Gotthard massif shows a pre-Alpine metamorphic evolution similar to that of the Tavetsch (Biino, 1994), Silvretta (Maggetti and Flisch, 1993) and Strona Ceneri (as already suggested by Niggli, 1944). They possibly formed a coherent basement, later on disrupted by Alpine tectonics.

More problematic is the correlation with the Aar massif (Abrecht, 1994). Some differences (lack of extensive Ordovician intrusion, presence of "Schollenamphibolite", widespread occurrence of low pressure migmatites, and strong retrogression of the high temperature assemblages) suggest a different Paleozoic evolution. The presence in both terranes of slightly diachronous and, in a wider sense, cogenetic intrusives (Late Carboniferous granitoids) may help to constrain the timing of the Late Variscan rearrangement of the different blocks.

### THE NATURE OF THE CONTACT BETWEEN THE BASEMENT AND THE MIDDLE PALEOZOIC METASEDIMENTS

The Late Ordovician granitoids were themselves folded together with the older basement, as indicated by their pervasive foliation and the large scale open fold ("Schlingen" tectonic, Fig. 2). The time of this deformation is loosely constrained by the Upper Devonian – Lower Carboniferous

(Variscan) tectonics. If the Middle Paleozoic metasediments represent the cover of the basement, then they should be folded with the basement during this tectonic stage. From the literature it is hard to prove such a conclusion. The other possibility is that the Middle Paleozoic metasediments may represent a Variscan nappe from a higher structural level, tectonically juxtaposed with the basement after the Schlingen tectonic phase. In any case the Middle Paleozoic metasediment-basement contact must be of Carboniferous age. In fact, the Upper Carboniferous intrusives clearly crosscut these structures and locally produced a contact metamorphism in the Middle Paleozoic metasediments (e.g. Medel intrusive in the Rondadura Valley, Fig. 4).

In the Tremola series, STEIGER (1962) described two metamorphic events. The first prograde event is characterized by a metamorphic grade increasing towards the north. The later metamorphic phase is responsible for the formation of the garben texture, and the metamorphic grade increases towards the south. The thermal gradient of the first event is quite problematic and difficult to explain in terms of the Alpine metamorphic evolution only. The correlation of the first metamorphism with a Late Variscan event, presumably the phase of deformation observed in the older Late Variscan plutons (Fibbia, Gamsboden and Medelser), would coherently explain STEIGER's observations.

## THE COVER SYNCLINES

The Piz Borel zone (HUBER, 1943) is a small east-west trending complex slice between two bodies of Late Ordovician metagranitoids, and is well developed between the Pizzo Centrale and the Lucomagno pass (Fig. 4). From west to east it contains: Upper Proterozoic metasedimentary and meta-ophiolitic rocks, Middle Paleozoic metasediments (truncated and metamorphosed by the intrusion of a Late Variscan granitoid which was itself deformed by Alpine tectonics) and finally Mesozoic metasediments. Accordingly, three orogenic events are superimposed in this small zone. In pre-Late Ordovician times the ophiolitic material (metabasalt and meta-ultramafic) was folded and metamorphosed together with metasedimentary gneisses. After the intrusion of the Late Ordovician granitoids the active folding during the Variscan orogeny was superimposed on the pre-existing structures. The juxtaposition of the Middle Paleozoic metasediments predates the intrusion of the Upper Carboniferous granitoids. Finally, in Alpine times, the Mesozoic sedimentary cover was itself folded into the same previously folded structures (LAMBERT et al., 1992). It can, therefore, be expected that also other ancient structures have consecutively been reused during different tectonic phases from the Proterozoic until the present.

A logic continuation of the Piz Borel zone can be traced eastwards between the Fibbia and Gamsboden bodies and, after the break of the Rotondo granite, until the Rappental (Fig. 5).

Similar zones represent intrabasement (both Alpine and older) thrust planes. Without sedimentary markers, the importance of these thrust planes may be underestimated. Metamorphic petrology points out a complex tectonic setting with imbrication of basement slices in the Gotthard massif as suggested by anomalous Alpine pressure gradients (Lucomagno pass after RIDLEY, 1989) and Alpine temperature gradient (Nufenen pass after KAMBER, 1993).

## Summary

The Gotthard massif shows a coherent lithostratigraphy and can be subdivided into units (Tab. 2), which can be traced across the entire massif (Fig. 5). We propose the following revised lithostratigraphic subdivision of the Gotthard massif:

- Uppermost Carboniferous, Permian and Mesozoic sedimentary covers (with some outcrops of Permo-Carboniferous volcanics)
- Late Variscan granitoids (divided into two cycles by a deformation phase)
- Middle Palaeozoic metasediments
- Late Ordovician metagranitoids
- Proto Gotthard (pre Late Ordovician):
  - -- Migmatitic gneisses
  - -- Metagabbros, with island arc affinity
  - -- Metabasalts, metagabbros and meta-ultramafics, with ophiolitic affinity
  - -- Metasedimentary gneisses.

Within the pre-Mesozoic basement of the Gotthard massif, indications on possible protholiths, relics of metamorphic parageneses and magmatic events, permit to classify the units chronologically and to distinguish major orogenic cycles. The geological history proposed by ABRECHT et al. (1991a) is summarized in table 3.

## Acknowledgements

We are grateful for comments made by E. Niggli and W. Oberholzer. This study was supported by the Swiss National Science Foundation grants Nos 21-29901.90 and 20-25282.88.

## References

ABRECHT, J. (1994): Geological units of the Aar massif and their pre-Alpine rock associations: A critical review. Schweiz. Mineral. Petrogr. Mitt. 74, 3–25.

ABRECHT, J., BIINO, G.G,. MERCOLLI, I. and STILLE, P. (1991a): Mafic-ultramafic rock-associations in the Aar, Gotthard and Tavetsch Massifs (Helvetic domain, Central Switzerland): marker of a ophiolitic pre-Variscan suture, reworked by polymetamorphic events? Schweiz. Mineral. Petrogr. Mitt. 71, 295–300.

ABRECHT, J., BIINO, G.G., MERCOLLI, I. and STILLE, P. (1991b): Multireaction path of the coronitic Kastelhorn gabbro in the Gotthard Massif (Helvetic domain, Central Switzerland). Terra abstracts 3 : 97.

ABRECHT, J. and BIINO, G.G. (1994): The metagabbros of the Kastelhorn area (Gotthard massif, Switzerland): Their metamorphic history inferred from mineralogy and texture. Schweiz. Mineral. Petrogr. Mitt. 74, 51–66.

AMBÜHL, E. (1929): Petrographisch-geologische Untersuchung im zentralen Gotthardmassiv südlich Andermatt. Schweiz. Mineral. Petrogr. Mitt. 9, 265–441.

ARNOLD, A. (1970): Die Gesteine der Region Nalps-Curnera im nordöstlichen Gotthardmassiv, ihre Metamorphose und ihre Kalksilikatfels-Einschlüsse (Petrographische Untersuchungen im Bereich der Anlagen der Kraftwerke Vorderrhein). Beitr. Geol. Karte Schweiz N.F. 138. Lfg., 128 p.

BIINO, G.G. (1994): The pre Late Ordovician metamorphic evolution of the Gotthard-Tavetsch massifs (Central Alps): from lawsonite to kyanite eclogites to granulite retrogression. Schweiz. Mineral. Petrogr. Mitt. 74, 85–102.

BIINO, G.G. and MEISEL, T. (1993): Geochemistry of polymetamorphic ultramafics (major, trace, noble and rare earth elements): an example from the helvetic basement (Central Alps, Switzerland). Mineralogy and Petrology, 49, 189–212.

BOSSART, P.J., MEIER, M., OBERLI, F. and STEIGER, R.H. (1986): Morphology versus U–Pb systematics in zircon: a high-resolution isotopic study of a zircon population from a Variscan dike in the Central Alps. Earth and Planetary Science Letters 78, 339–354.

COTTI, G., FELBER, M., FOSSATI, A., LUCCHINI, G., STEIGER, E. and ZANON, P.L. (1991): Introduzione al paesaggio naturale del Canton Ticino: 2. Materiali per una bibliografia. Locarno, Dip. Ambiente. 1–500.

FEHR, A. (1956): Petrographie und Geologie des Gebiets zwischen Val Zagragia–Piz Cavel und Obersaxen-Lumbrein. Schweiz. Mineral. Petrogr. Mitt. 36, 349–453.

GRÜNENFELDER, M. and HAFNER, ST. (1962): Über das Alter und die Entstehung des Rotondogranites. Schweiz. Mineral. Petrogr. Mitt. 42, 169–208.

GUERROT, C. and STEIGER, R.H. (1991): Variscan granitoids of the Gotthard massif, Switzerland: U–Pb single zircon and Sr–Nd data. Terra abstracts 3, 35.

HAFNER, S. (1958): Petrographie des südwestlichen Gotthardmassivs (zwischen St. Gotthardpass und Nufenenpass). Schweiz. Mineral. Petrogr. Mitt. 38, 255–362.

HEZNER, L. (1909): Petrographische Untersuchung der Kristallinen Schiefer auf der Südseite des St. Gotthard (Tremolaserie). N. J. Miner. Geol. und Paläont. 27, 157–218.

HUBER, H.H. (1943): Physiographie und Genesis der Gesteine im südöstlichen Gotthardmassiv. Schweiz. Mineral. Petrogr. Mitt. 23, 72–260.

KAMBER, B.S. (1993): Regional metamorphism and uplift along the Southern margin of the Gotthard "massif"; results from the Nufenenpass area. Schweiz. Mineral. Petrogr. Mitt., 73, in press.

KVALE, A. (1966): Gefügestudien im Gotthardmassiv und den angrenzenden Gebieten. Schweiz. Geotech. und Schweiz. Geol. Komm., pp. 86.

LABHART, T.P. (1977): Aarmassiv und Gotthardmassiv. Sammlung geol. Führer – Berlin-Stuttgart, 63. Gebr. Bornträger. 173 p.

LAMBERT, P., MARQUER, D. and PERSOZ, F. (1992): Structures sur la bordure sud du socle du Gotthard: histoire cinématique tertiare du Val Rondadura (Alpes centrales suisses). Schweiz. Mineral. Petrogr. Mitt. 72, 325–334.

MAGGETTI, M. and FLISCH, M. (1993): Evolution of the Silvretta nappe. In: VON RAUMER, J. and NEUBAUER, F. (eds), Pre-Mesozoic basement in the Alps. Springer Verlag, Berlin, in press.

MARQUER, D. (1990): Structures et déformation alpine dans les granites hercyniens du massif du Gothard (Alpes centrales suisses). Eclogae geol. Helv. 83/1, 77–97.

NIGGLI, E. (1944): Das westliche Tavetscher Zwischenmassiv und der angrenzende Nordrand des Gotthardmassivs. Schweiz. Mineral. Petrogr. Mitt. 24, 58–301.

NIGGLI, E. (1948): Zur zeitlichen Abfolge der magmatischen und metamorphosierenden Vorgänge im Gotthardmassiv. Schweiz. Mineral. Petrogr. Mitt. 28, 165–177.

OBERHÄNSLI, R., SCHENKER, F. and MERCOLLI, I. (1988): Indications of Variscan nappe tectonics in the Aar massif. Schweiz. Mineral. Petrogr. Mitt. 68, 509–520.

OBERHOLZER, W. (1955): Geologie und Petrographie des westlichen Gotthardmassivs. Schweiz. Mineral. Petrogr. Mitt. 35, 320-409.

OBERLI, F., BIINO, G.G. and MEIER, M. (1993): Early polymetamorphic evolution of a Central Swiss Alpine terrain examinated by single-crystal U–Th–Pb dating tecniques. Terra abstracts, 5, 392.

RIDLEY, J. (1989): Vertical movement in orogenic belts and timing of metamorphism relative to deformation. Evolution of metamorphic belts, LONDON, J.S., DALY CLIFF, R.A. and YARDLEY, B.W.D. Geological Society Special Publication. 103–115.

SERGEEV, S.A. and STEIGER, R.H. (1993): High-precision U–Pb single zircon dating of Variscan and Caledonian magmatic cycles in the Gotthard Massif, Central Swiss Alps. Terra Abstracts 5, 394–395.

STAPFF, F.M. (1880): Geologisches Profil des St. Gotthard in der Achse des grossen Tunnels. Bern.

STEIGER, R.H. (1962): Petrographie und Geologie des südlichen Gotthardmassivs zwischen St. Gotthard- und Lukmanierpass. Schweiz. Mineral. Petrogr. Mitt. 42, 381–577.

WEBER, F. (1924): Geologische Karte des Tödi-Vorderrheintal-Gebietes: Ostende des Aarmasivs und der Wurzelregion der helvetischen Decken, 1:50 000.

WINTERHALTER, R.U. (1930): Zur Petrographie und Geologie des östlichen Gotthardmassivs. Schweiz. Mineral. Petrogr. Mitt. 10, 38–116.

Manuscript received June 1, 1993; revised manuscript accepted November 18, 1993.