The new metamorphic map of the Alps : introduction

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The new metamorphic map of the Alps: Introduction

by *Martin Frey*[1], *Jacqueline Desmons*[2] and *Franz Neubauer*[3]

Abstract

Two new maps describing the pre-Alpine metamorphism (1:1'000'000) and the Alpine metamorphism (1:500'000) of the Alps are presented. The legends are discussed and some comments and conclusions on both maps are given.

Keywords: metamorphic evolution, pre-Alpine metamorphism, Alpine metamorphism, Alps, map, review article.

General remarks

For many years, small scale metamorphic maps have been published by the Subcommission for the Cartography of the Metamorphic Belts of the World, affiliated to the International Union of Geological Sciences (IUGS). Such maps provide an excellent means of obtaining information on the distribution of metamorphic rocks and facies of entire continents and orogenic belts. The metamorphic map of Europe at a scale of 1:2'500'000 was published 25 years ago (ZWART, 1973). This map included an additional sheet at a scale of 1:1'000'000 displaying the Alps, an area where more extensive knowledge allowed a larger scale (NIGGLI and ZWART, 1973). An explanatory text was published five years later (ZWART et al., 1978). This first map has been an incentive for further research in metamorphic petrology.

In 1983 a proposal, by one of the authors (MF), to compile a new metamorphic map of the Alps was met with enthusiasm. Progress reports were made public at various meetings (DESMONS, 1987; FREY, 1987 b, c; FREY et al., 1989; FRANK et al., 1993; DESMONS et al., 1995, 1996; FREY et al., 1997; FREY et al., 1999). More than 50 collaborators, whose names are listed on the new map, contributed substantially to this long-term project which started at a first meeting in Basel in 1984. Meanwhile, some synthetic cartographic data have been published (e.g. Geological map of France at 1:1'000'000, CHANTRAINE et al., 1996).

Metamorphic maps rely on high-quality topographic and tectonic maps. To this end we have chosen the Structural Model of Italy (BIGI et al., 1990), modified and completed to the W and SW.

On the first metamorphic map of the Alps (NIGGLI and ZWART, 1973), information on the pre-Alpine and Alpine metamorphism was contained in a single sheet. However, the abundance of facts to be displayed led to a map which was, at least in part, difficult to read. For this reason the editors of the present study decided to print two maps, i.e. a map of pre-Alpine metamorphism at 1:1'000'000 and a map of Alpine metamorphism at 1:500'000.

The legends of the maps

The map of ZWART (1973) was a facies map, and the timing was indicated by letters corresponding to orogenic cycles (Alpine, Variscan, etc.). Following a proposal by our Austrian colleagues, the emphasis in the new maps is put on the chronology and different colour strengths are used according to the general geological colouring (green for Cretaceous, yellow for Cainozoic, etc.). On the map of pre-Alpine metamorphism we have distinguished between "older than Variscan",

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"Variscan" and "Permian" ages of metamorphism, on the map of Alpine metamorphism between the "Cretaceous peak" and the "Tertiary peak" of metamorphism. However, the maps are being completed just when the timing of metamorphic imprints in the Western Alps is being reevaluated. Therefore, on the map of Alpine metamorphism, we added "high-pressure metamorphism of partly uncertain, Cretaceous or Tertiary, age".

A simple scheme of metamorphic facies was adopted, following the example of some recent textbooks (e.g. YARDLEY, 1989, Fig. 2.8.; BUCHER and FREY, 1994, Fig. 4.2.). On the map of Alpine metamorphism, "very low-grade metamorphism" is defined mainly on the basis of illite crystallinity data because critical mineral assemblages are rare. Areas containing mineral assemblages in the pumpellyite-actinolite facies are included in "greenschist facies metamorphism". In addition to eclogite, HP/LT metamorphism is subdivided into three facies, namely "lawsonite + albite + chlorite facies" at relatively low pressure, "glaucophane + lawsonite + jadeite facies" at high pressure and low temperature, and "glaucophane + epidote facies" at high pressure and slightly higher temperatures. The nomenclature of the two latter facies follows the proposal of EVANS (1990). This use of four different HP/LT facies turned out to be especially useful in the Western Alps for displaying variations in P and P/T.

Minerals characteristic of a facies shown have not been indicated (e.g., kyanite in medium-pressure amphibolite facies). However, index minerals are indicated if their presence provide additional information on metamorphic grade (e.g., the pressure character of a facies, by indicating the presence of minerals such as andalusite or coesite), or if their presence is exceptional (e.g. relic of an earlier period of the evolution which could not be shown on the map).

This issue of the Swiss Bulletin of Mineralogy and Petrology (SMPM/SBMP) contains 12 articles summarizing our present knowledge on the metamorphism of the Alps. These articles will serve also as explanatory text for the two maps enclosed in this issue. The first five articles are devoted to the pre-Alpine metamorphism of the Alps whereas the following seven contributions focus to the Alpine metamorphism. In these papers, the number of references had to be limited and preference was given to papers with extensive reference lists. Mineral abbreviations are according to BUCHER and FREY (1994).

Some comments on the map of pre-Alpine metamorphism

Metamorphic imprints are indicated according to facies and orogenic cycles. In the literature the term "Variscan" is used in a variety of meanings. The term originally designated the Carboniferous orogenic paroxysm within the Central European orogens. Early stages were considered to represent precursor stages, e.g., Early Variscan for Devonian events and those that occurred at the Devonian/Carboniferous boundary.

It has long been known that the Variscan orogeny, which was of continent-continent collision type, is well-constrained by the presence of Early Carboniferous synorogenic flysch sequences which were deposited on the southern, lower plate (e.g., MATTE, 1986; NEUBAUER, 1988; FLÜGEL, 1990; and references cited therein). No pre-Carboniferous and no Silurian to Devonian orogenic events have been observed in the southern, lower continental plate (now Austroalpine and Southalpine units). In contrast, Silurian to Devonian tectonic, magmatic and metamorphic events occurred at the margin of the northern, upper continental plate (now the External units). These events are interpreted as indicating the accretion of units to the northern margin (e.g., VON RAUMER, 1998; and references cited therein). Consequently, we restrict the term "Variscan" to the Carboniferous continent-continent collisional orogeny. This is corroborated by the age of granitoids which show a syn-orogenic group (ca 360–320 Ma) and a post-orogenic group (ca 320–260 Ma) (see also FINGER et al., 1997).

Permian metamorphism is only shown in a few places, but recent radiometric dating indicates that it may have been more widespread, as explained in several papers of this issue.

"Older than Variscan" includes Pan-African metamorphism. This event is shown as being widespread in the Internal Western Alps, although a consensus has not yet been attained on the age of the pre-Alpine metamorphism in all basement units.

Some comments on the map of Alpine metamorphism

"Folded, non-metamorphic sequences" are shown as light beige coloured areas and their appearance on the map enhances the understanding of the overall metamorphic zonation.

The terms "Eo-, Meso- and Neo-Alpine" were introduced by TRÜMPY (1973) and subsequently have been used by some authors (e.g., HUNZIKER

et al., 1989). In our opinion these terms have to be re-defined and we have preferred not to use them here. Instead, wherever possible, we have distinguished between a Cretaceous and a Tertiary peak of metamorphism.

In the Central Alps, two isograds are shown, the pyrophyllite isograd within the Helvetic zone (FREY, 1987c) and the staurolite isograd bordering the Lepontine area (NIGGLI and NIGGLI, 1965). Within the Lepontine area, some selected isotherms and isobars are shown according to TODD and ENGI (1997). Selected isotherms, mainly according to oxygen isotope thermometry (HOERNES and FRIEDRICHSEN, 1974) were also added to the Tauern window area.

Conclusions

1. In some tectonic units, e.g. within the Southalpine and some Austroalpine basement units, the pre-Alpine metamorphism is well-constrained because it has not been, or has been only slightly, overprinted by Alpine metamorphism. In these areas, several stages of pre-Alpine metamorphism are recognized including high-pressure and ultrahigh pressure metamorphism interpreted as subduction-related. However, there is often uncertainty with some of the age information.

In the Western and Central Alps, the pre-Alpine map displays a contrast between the External Crystalline Massifs with their strong Variscan Barrovian-type metamorphism, and the Internal basement units. There is clear evidence of only pre-Variscan, probably Pan-African, metamorphism in the western Briançon basement. The age of the metamorphism is still debated for the Ligurian Briançon zone and the other Internal basement units, where Late Variscan granitoids are present which may have altered the isotopic ratios in their country rocks.

Furthermore, both geochronological and petrological work has revealed a major metamorphic imprint during Permian time. As explained in the following papers, it is interpreted in the Eastern Alps as being related to the extension due to ongoing post-Variscan lithospheric stretching, and in the Western Alps as accompanying the Ivrea magma underplating related to ocean consumption.

2. On the Alpine map it is shown that there appear to have been three main metamorphic imprints:

(i) In the Eastern Alps the Cretaceous Barrovian facies imprints in the Austroalpine units. This is a striking contribution to the new edition of the map: the contrast of the metamorphic evolution in the Eastern and the Western-Central Alps during the Cretaceous and Palaeocene. Such a contrast in the T-P regime points to a lithospheric discontinuity such as a transform fault separating both domains at the time. General tectonic and palaeogeographic interpretations of the Alps will have to take this into account.

(ii) High-pressure facies imprints in the Western Alps and also in part of the Central and Eastern Alps. These imprints were considered as partly Cretaceous in age at the time of the first edition of the map. There is now strong radiometric evidence pointing to an Eocene age for all of them, including the eclogite and the lower-grade HP associations, except those of the Sesia zone which are from the Cretaceous-Palaeocene boundary. This is a major difference of the present map with respect to the first edition.

(iii) The thermal culmination of the Central Alps and the Tauern, which are the centers from which low- to very low-grade imprints widely spread in the Western Alps, and in a more limited way in the Eastern Alps. The boundary between domain (ii) and domain (iii) has been transported westward along the Simplon shear zone. Also in the Eastern Alps, breaks in metamorphic grade often coincide with large-scale tectonic boundaries, mainly ductile low-angle normal faults. Along these faults in the Eastern Alps, higher-grade metamorphic units in the footwall were juxtaposed with low-grade to nearly non-metamorphic units in the hangingwall.

Very low-grade areas are related to all three imprints, from the Cretaceous anchimetamorphic areas in the Eastern Alps to the Cainozoic anchimetamorphic areas in the Central and Western Alps, with possibly a Late Cretaceous imprint in the External zones of the Western Alps. In the Southern Alps the Alpine metamorphism has been weak or locally absent.

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METAMORPHIC MAPS OF THE ALPS

Map of Alpine

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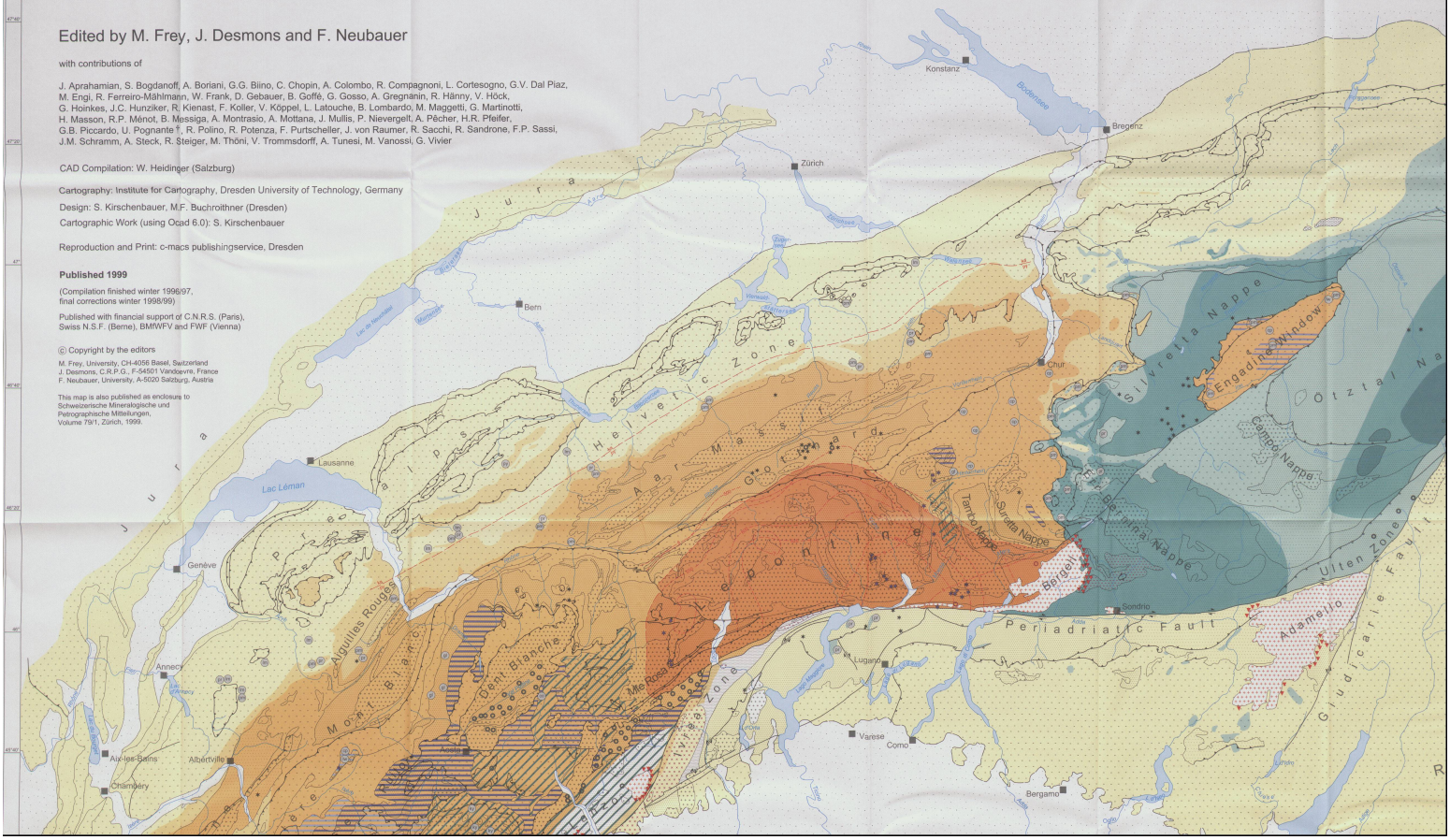
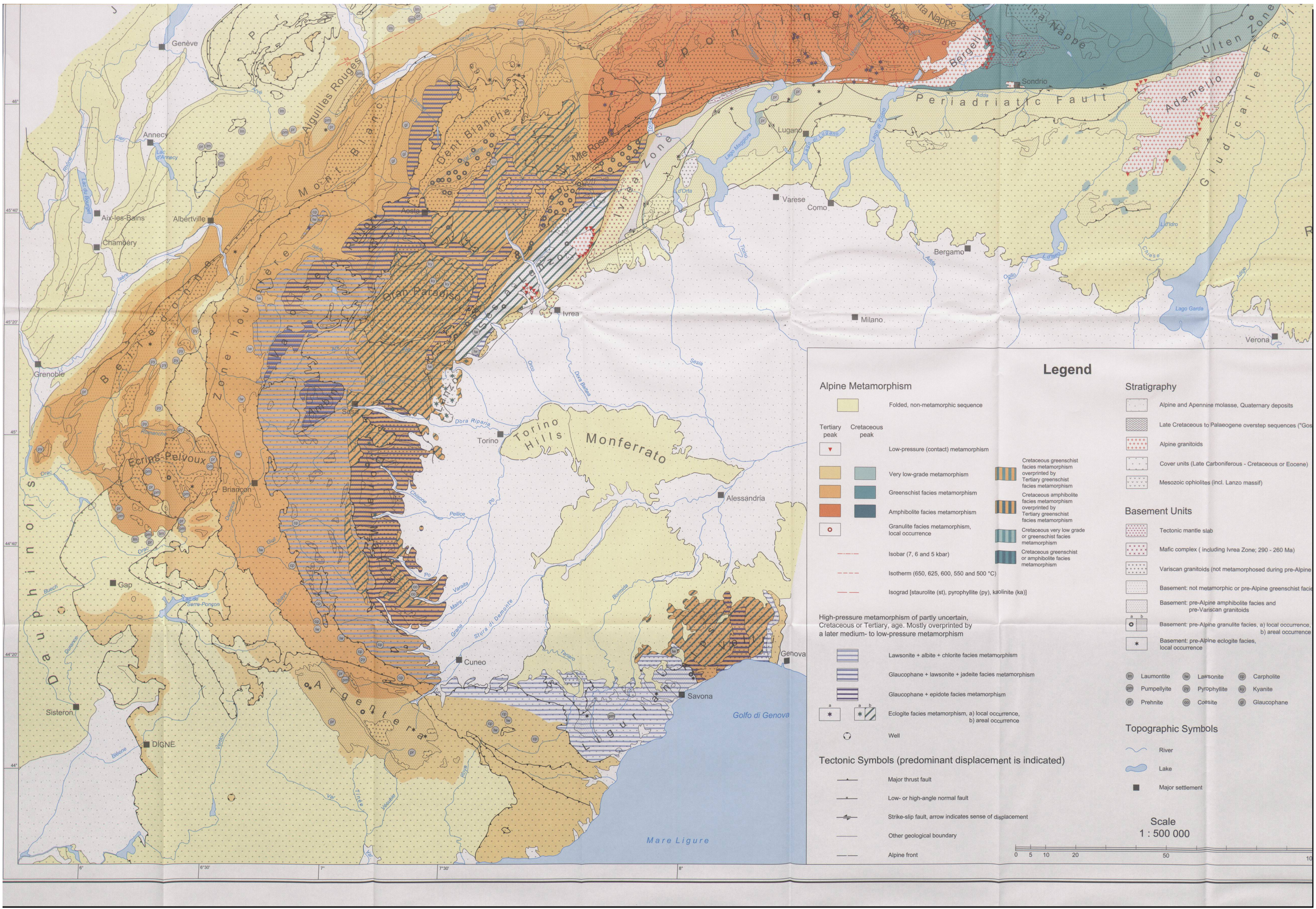
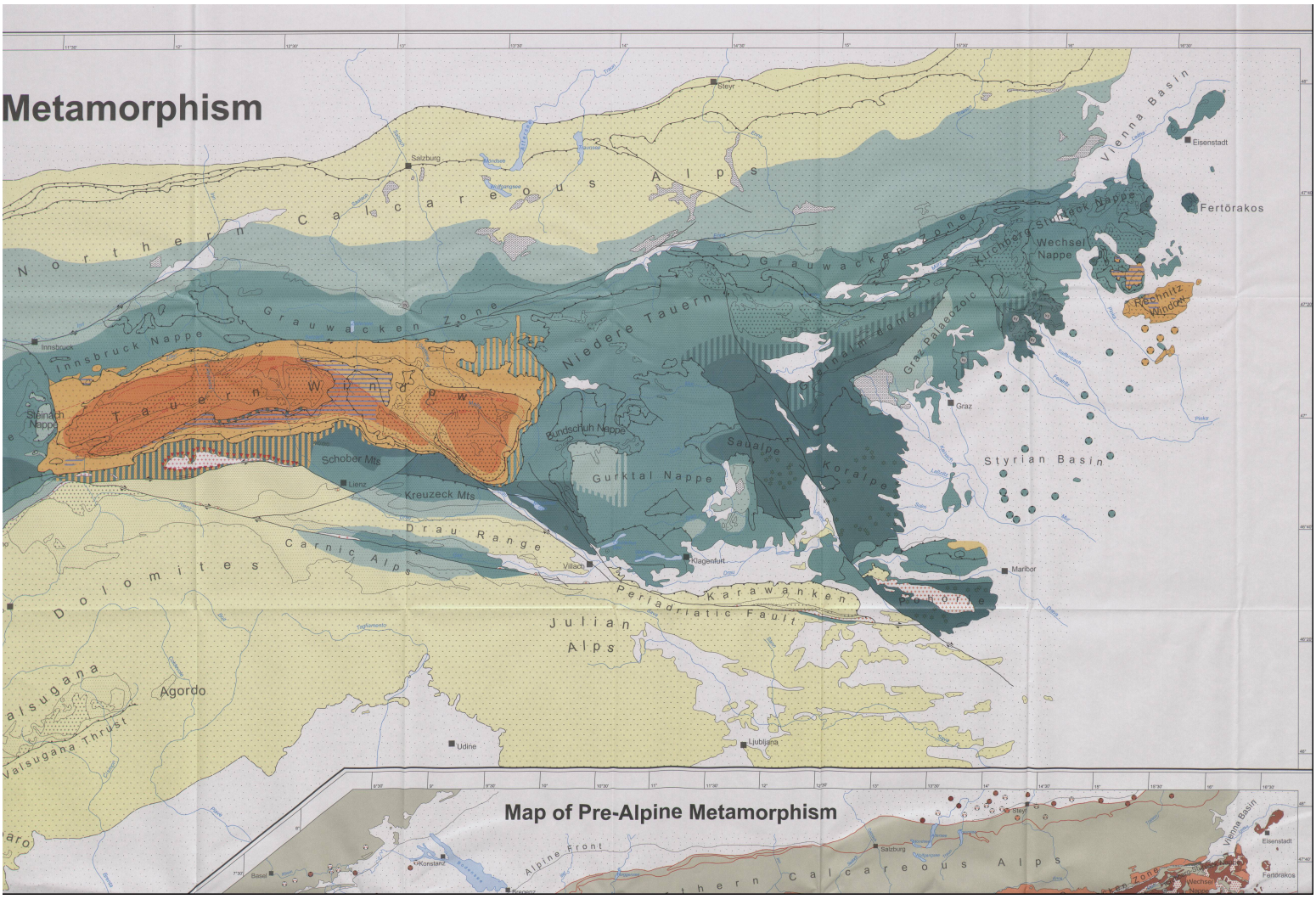
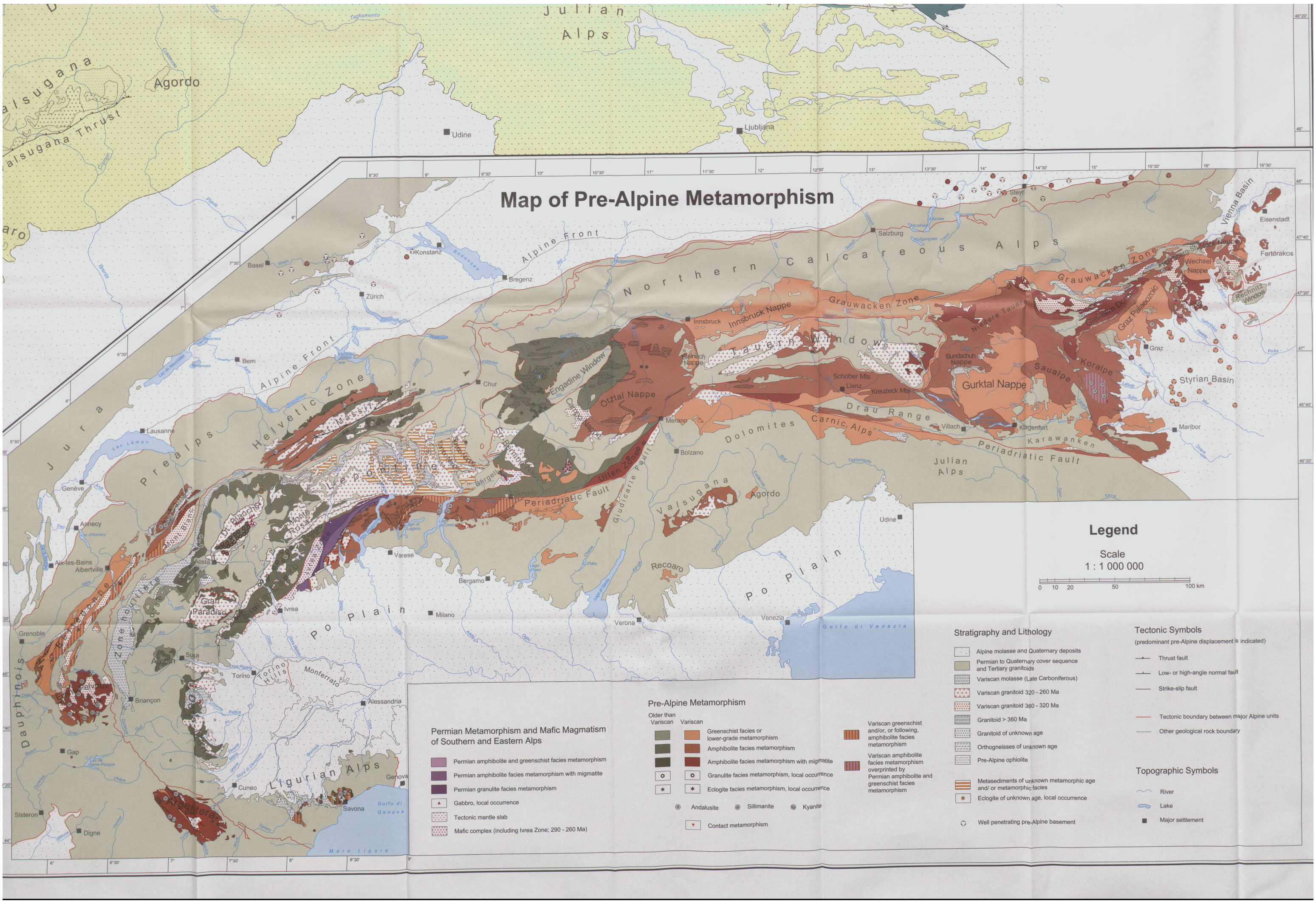
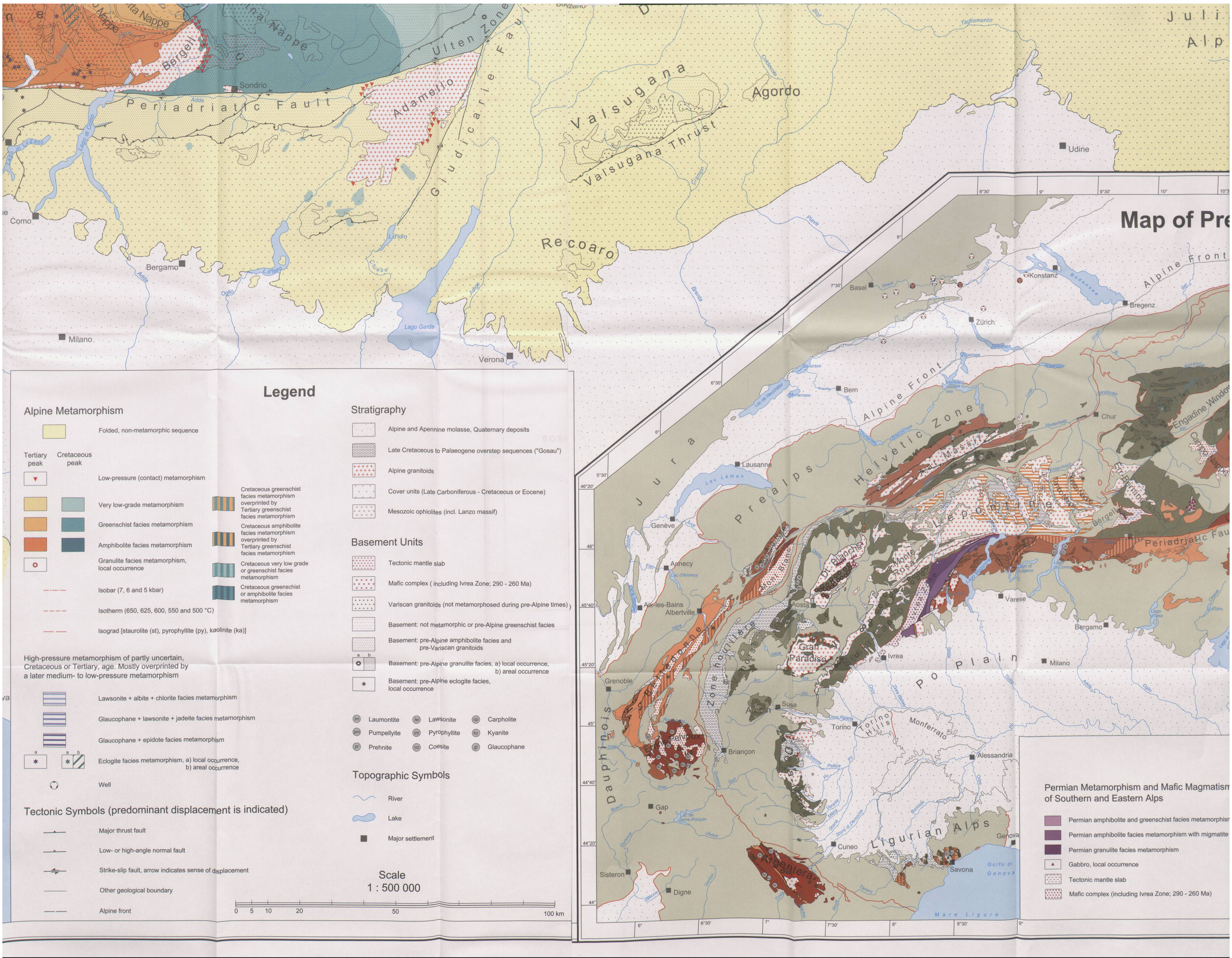




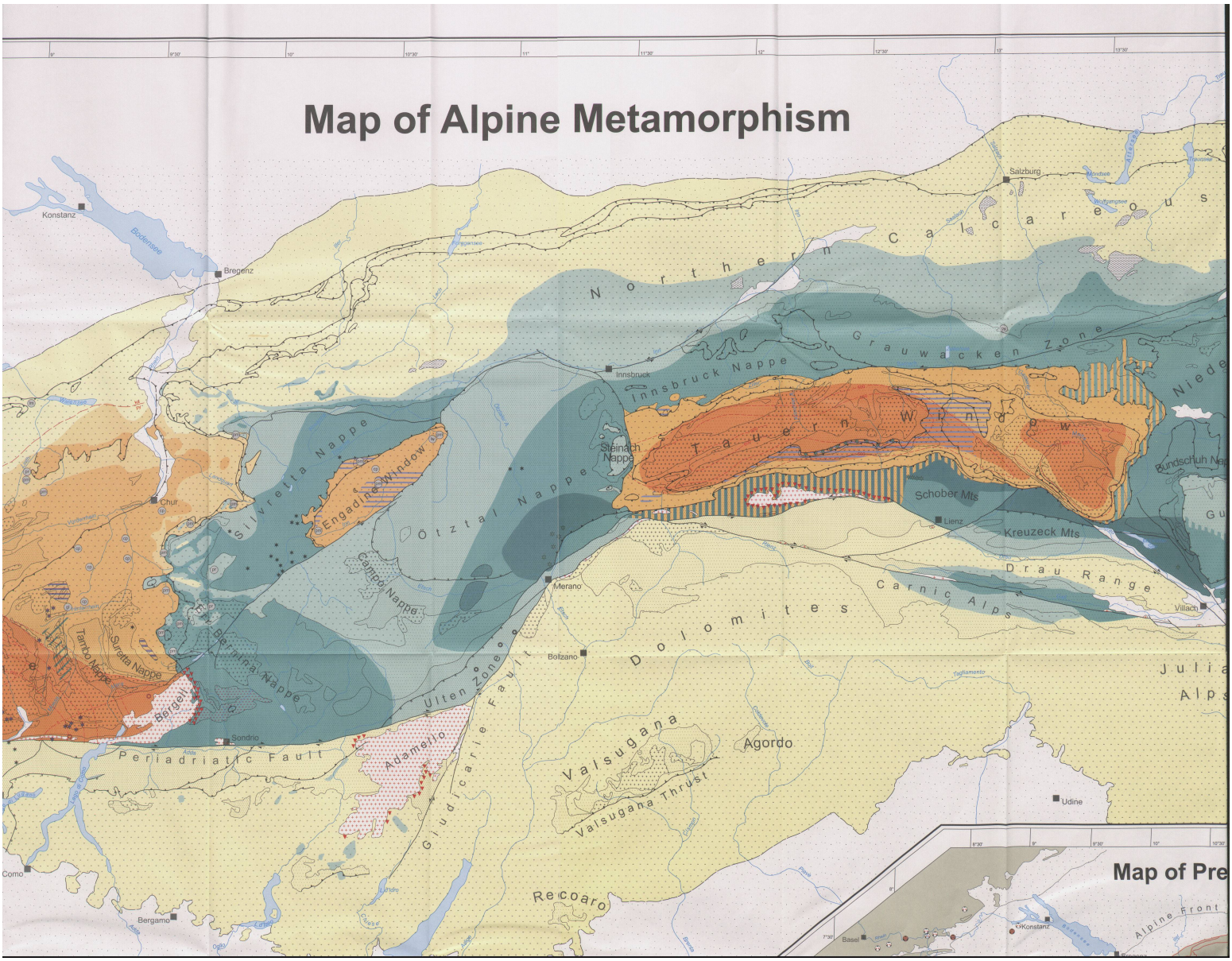
Genève
Annecy
Aix-les-Bains
Chambéry
Albertville
Grenoble
Briançon
Gap
Sisteron
DIGNE
Aosta
Ivrea
Torino
Cuneo
Savona
Genova
Alessandria
Milano
Varese
Como
Lugano
Bergamo
Sondrio
Verona
Aiguilles Rouges
Mont Blanc
Dent Blanche
Gran Paradiso
Belledonne
Zone houillère
Ecrins-Pelvoux
Argentera
Dauphinois
Torino Hills
Monferrato
Ivrea Zone
Periadriatic Fault
Bergell
Adamello
Ulten Zone
Giudicarie Fault
Lago Maggiore
Lago di Como
Lago Garda
Golfo di Genova
Mare Ligure
Legend
Alpine Metamorphism
Folded, non-metamorphic sequence
Tertiary peak
Cretaceous peak
Low-pressure (contact) metamorphism
Very low-grade metamorphism
Greenschist facies metamorphism
Amphibolite facies metamorphism
Granulite facies metamorphism, local occurrence
Cretaceous greenschist facies metamorphism overprinted by Tertiary greenschist facies metamorphism
Cretaceous amphibolite facies metamorphism overprinted by Tertiary greenschist facies metamorphism
Cretaceous very low grade or greenschist facies metamorphism
Cretaceous greenschist or amphibolite facies metamorphism
Isobar (7, 6 and 5 kbar)
Isotherm (650, 625, 600, 550 and 500 °C)
Isograd [staurolite (st), pyrophyllite (py), kaolinite (ka)]
High-pressure metamorphism of partly uncertain, Cretaceous or Tertiary, age. Mostly overprinted by a later medium- to low-pressure metamorphism
Lawsonite + albite + chlorite facies metamorphism
Glaucophane + lawsonite + jadeite facies metamorphism
Glaucophane + epidote facies metamorphism
Eclogite facies metamorphism, a) local occurrence, b) areal occurrence
Well
Tectonic Symbols (predominant displacement is indicated)
Major thrust fault
Low- or high-angle normal fault
Strike-slip fault, arrow indicates sense of displacement
Other geological boundary
Alpine front
Stratigraphy
Alpine and Apennine molasse, Quaternary deposits
Late Cretaceous to Palaeogene overstep sequences ("Gos
Alpine granitoids
Cover units (Late Carboniferous - Cretaceous or Eocene)
Mesozoic ophiolites (incl. Lanzo massif)
Basement Units
Tectonic mantle slab
Mafic complex (including Ivrea Zone; 290 - 260 Ma)
Variscan granitoids (not metamorphosed during pre-Alpine
Basement: not metamorphic or pre-Alpine greenschist facie
Basement: pre-Alpine amphibolite facies and pre-Variscan granitoids
Basement: pre-Alpine granulite facies, a) local occurrence, b) areal occurrence
Basement: pre-Alpine eclogite facies, local occurrence
Laumontite
Lawsonite
Carpholite
Pumpellyite
Pyrophyllite
Kyanite
Prehnite
Coesite
Glaucophane
Topographic Symbols
River
Lake
Major settlement
Scale
1 : 500 000
0 5 10 20 50


Metamorphism
Northern Calcareous Alps
Grauwacken Zone
Innsbruck Nappe
Tauern Window
Steinach Nappe
Schober Mts
Lienz
Kreuzeck Mts
Drau Range
Carnic Alps
Dolomites
Agordo
Valsugana Thrust
Udine
Niedere Tauern
Rundschuh Nappe
Gurktal Nappe
Graz Paleozoic
Graz
Styrian Basin
Sausalpe
Koralpe
Klagenfurt
Villach
Periadriatic Fault
Karawanken
Julian Alps
Ljubljana
Maribor
Vienna Basin
Eisenstadt
Fertörakos
Kirchberg-Stuhleck Nappe
Wechsel Nappe
Rechnitz Window
Map of Pre-Alpine Metamorphism
Alpine Front
Salzburg
Steyr
Basel
Konstanz


Map of Pre-Alpine Metamorphism
Northern Calcareous Alps
Alpine Front
Grauwacken Zone
Tauern Window
Innsbruck Nappe
Ötztal Nappe
Engadine Window
Gurktal Nappe
Koralpe
Saualpe
Drau Range
Carnic Alps
Karawanken
Periadriatic Fault
Julian Alps
Dolomites
Valsugana
Agordo
Recoaro
Helvetic Zone
Prealps
Jura
Po Plain
Ligurian Alps
Dauphinois
Vienna Basin
Styrian Basin
Legend
Scale
1 : 1 000 000
0 10 20 50 100 km
Stratigraphy and Lithology
Alpine molasse and Quaternary deposits
Permian to Quaternary cover sequence and Tertiary granitoids
Variscan molasse (Late Carboniferous)
Variscan granitoid 320 - 260 Ma
Variscan granitoid 360 - 320 Ma
Granitoid > 360 Ma
Granitoid of unknown age
Orthogneisses of unknown age
Pre-Alpine ophiolite
Metasediments of unknown metamorphic age and/ or metamorphic facies
Eclogite of unknown age, local occurrence
Well penetrating pre-Alpine basement
Tectonic Symbols
(predominant pre-Alpine displacement is indicated)
Thrust fault
Low- or high-angle normal fault
Strike-slip fault
Tectonic boundary between major Alpine units
Other geological rock boundary
Topographic Symbols
River
Lake
Major settlement
Permian Metamorphism and Mafic Magmatism of Southern and Eastern Alps
Permian amphibolite and greenschist facies metamorphism
Permian amphibolite facies metamorphism with migmatite
Permian granulite facies metamorphism
Gabbro, local occurrence
Tectonic mantle slab
Mafic complex (including Ivrea Zone; 290 - 260 Ma)
Pre-Alpine Metamorphism
Older than Variscan
Variscan
Greenschist facies or lower-grade metamorphism
Amphibolite facies metamorphism
Amphibolite facies metamorphism with migmatite
Granulite facies metamorphism, local occurrence
Eclogite facies metamorphism, local occurrence
Andalusite
Sillimanite
Kyanite
Contact metamorphism
Variscan greenschist and/or, or following, amphibolite facies metamorphism
Variscan amphibolite facies metamorphism overprinted by Permian amphibolite and greenschist facies metamorphism



Nappe
Bergell
Sondrio
Periadriatic Fault
Ulten Zone
Adamello
Giudicarie Fault
Valsugana
Valsugana Thrust
Agordo
Julian Alps
Udine
Como
Bergamo
Recoaro
Lago Garda
Milano
Verona
Legend
Alpine Metamorphism
Folded, non-metamorphic sequence
Tertiary peak
Cretaceous peak
Low-pressure (contact) metamorphism
Very low-grade metamorphism
Greenschist facies metamorphism
Amphibolite facies metamorphism
Granulite facies metamorphism, local occurrence
Isobar (7, 6 and 5 kbar)
Isotherm (650, 625, 600, 550 and 500 °C)
Isograd [staurolite (st), pyrophyllite (py), kaolinite (ka)]
Cretaceous greenschist facies metamorphism overprinted by Tertiary greenschist facies metamorphism
Cretaceous amphibolite facies metamorphism overprinted by Tertiary greenschist facies metamorphism
Cretaceous very low grade or greenschist facies metamorphism
Cretaceous greenschist or amphibolite facies metamorphism
High-pressure metamorphism of partly uncertain, Cretaceous or Tertiary, age. Mostly overprinted by a later medium- to low-pressure metamorphism
Lawsonite + albite + chlorite facies metamorphism
Glaucophane + lawsonite + jadeite facies metamorphism
Glaucophane + epidote facies metamorphism
Eclogite facies metamorphism, a) local occurrence, b) areal occurrence
Well
Tectonic Symbols (predominant displacement is indicated)
Major thrust fault
Low- or high-angle normal fault
Strike-slip fault, arrow indicates sense of displacement
Other geological boundary
Alpine front
Stratigraphy
Alpine and Apennine molasse, Quaternary deposits
Late Cretaceous to Palaeogene overstep sequences ("Gosau")
Alpine granitoids
Cover units (Late Carboniferous - Cretaceous or Eocene)
Mesozoic ophiolites (incl. Lanzo massif)
Basement Units
Tectonic mantle slab
Mafic complex (including Ivrea Zone; 290 - 260 Ma)
Variscan granitoids (not metamorphosed during pre-Alpine times)
Basement: not metamorphic or pre-Alpine greenschist facies
Basement: pre-Alpine amphibolite facies and pre-Variscan granitoids
Basement: pre-Alpine granulite facies, a) local occurrence, b) areal occurrence
Basement: pre-Alpine eclogite facies, local occurrence
Laumontite
Lawsonite
Carpholite
Pumpellyite
Pyrophyllite
Kyanite
Prehnite
Coesite
Glaucophane
Topographic Symbols
River
Lake
Major settlement
Scale
1 : 500 000
0 5 10 20 50 100 km
Map of Pre
Basel
Konstanz
Alpine Front
Bregenz
Zürich
Bern
Chur
Engadine Window
Lausanne
Jura
Prealps
Helvetic Zone
Genève
Annecy
Aix-les-Bains
Albertville
Periadriatic Fau
Varese
Bergamo
Milano
Ivrea
Po Plain
Grenoble
Gran Paradiso
Susa
Torino
Torino Hills
Monferrato
Briançon
Alessandria
Dauphinois
Gap
Cuneo
Ligurian Alps
Genova
Savona
Sisteron
Digne
Argentera
Mare Ligure
Permian Metamorphism and Mafic Magmatism of Southern and Eastern Alps
Permian amphibolite and greenschist facies metamorphism
Permian amphibolite facies metamorphism with migmatite
Permian granulite facies metamorphism
Gabbro, local occurrence
Tectonic mantle slab
Mafic complex (including Ivrea Zone; 290 - 260 Ma)


Map of Alpine Metamorphism
Konstanz
Bodensee
Bregenz
Salzburg
Northern Calcareous
Grauwacken Zone
Innsbruck Nappe
Innsbruck
Tauern Window
Steinach Nappe
Silvretta Nappe
Engadine Window
Ötztal Nappe
Chur
Schober Mts
Lienz
Kreuzeck Mts
Campo Nappe
Merano
Drau Range
Carnic Alps
Villach
Dolomites
Julia
Alps
Bolzano
Tambo Nappe
Suretta Nappe
Err-Bernina Nappe
Bergell
Sondrio
Ulten Zone
Giudicarie Fault
Periadriatic Fault
Adamello
Valsugana
Agordo
Valsugana Thrust
Udine
Como
Bergamo
Recoaro
Map of Pre
Basel
Konstanz
Alpine Front