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EXPLANATORY NOTES TO THE MAP: METAMORPHIC STRUCTURE OF THE ALPS INTRODUCTION

by

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Abstract

Two new maps describing the Mesozoic-Cenozoic, Alpine metamorphic structure (1:1’000’000) and metamorphic ages (1:2’000’000) are presented. A short discussion of the map units used is provided to introduce some key papers summing up new ideas, lines of thought, the data used and the problems encountered.

General remarks

These maps and notes are based on studies of Austrian, French, Italian and Swiss earth scientists who worked in the Alps for the last 30 years, trying to understand the Mesozoic and Cenozoic evolution of the orogen. We investigated the Cretaceous and Tertiary closing of the Tethyan realm, subduction related processes, and the exhumation of the Alps. Most data have been published in specialized journals, others are the result of recent investigations of our working groups.
Concise compilations of recent geophysical data have been published from ECORS-CROP (ROURE et al., 1990; DAL PIAZ et al., 2003) and NRP20 (BLUNDELL et al., 1992; PFIFFNER et al., 1997) for the Western and the Central Alps. Results from the Eastern Alps are about to be published (TransAlp, 2002). A new compilation is given by SCHMID et al. (2004b). These studies resulted in a better knowledge of the present deep structure documenting subducted remains of passive margins and a distinct variation along strike in the deep structure of the Alpine orogen. These results added substantially to the pioneering ideas of geologists during the last century (ARGAND, 1911, 1916, 1924, 1934; AMPFERER, 1906; BERTRAND, 1884; FRANCHI et al., 1908; HEIM, 1919-22; LUGEON, 1902; LUGEON & ARGAND, 1905; STEINMANN, 1905; TERMIER, 1904) who conceived and developed the nappe theory from the cover to the basement nappes throughout the Alps (historical review in DAL PIAZ, 2001).

ELLENBERGER (1958), TRÜMPY (1960) and TOLLMANN (1963) gave further advances in stratigraphy, regional tectonics and paleogeographic reconstructions. DAL PIAZ (1928) gave one of the earliest modern works on Alpine eclogites and glaucophane-bearing rocks. ERNST (1971), DAL PIAZ (1971) and DAL PIAZ et al. (1972) innovated the interpretation of HP metamorphism in the Alps. Further compilation were presented by SPALLA et al., (1996) and GODARD (2001).
As the map of the distribution of metamorphic rocks of the Alps compiled by the late Martin Frey and co-workers did not account for tectonic setting and geodynamic evolution, our initial objective was to show differences in the geodynamic evolution of various parts of the Alpine orogen. To do so, we should have included kinematic information based on structural and paleomagnetic data, as well as the age and distribution of flysch sequences, much of which has been published over the last thirty years. The regional distribution of such data, however, is quite uneven and would have hampered the readability of the map, hence we decided to concentrate on the type and grade of the metamorphism. To the extent that metamorphism is related to geodynamic processes, our new maps show which units underwent which process, approximately at what time and to what depth. We made the choice to refer to conditions where pressure and temperature peak were reached simultaneously or where a temperature peak was reached at lower pressures after a significant temperature increase during the decompression path (hatched areas). These choices at the first glance clearly show what type of process is linked the main metamorphic structure: subduction process as for the Western Alps or collision process for Central Alps, and complex metamorphic structures as in the Eastern Alps being due to a complex geodynamic and metamorphic history involving the succession of the two types of process. The new maps show where subduction-, collision-, exhumation-related types of metamorphism are found in the Alps. The FREY et al. (1999) map was an obvious and excellent starting point for this task.

In addition we are working on an interactive CD version of the maps, presenting information on the data used for this compilation. Our working philosophy is explained in the chapter Extended Legend and in the regional compilations that follow.

Since the aim of these maps is to address the Mesozoic-Cenozoic evolution of the Alps, all pre-Alpine metamorphic features have been omitted. Highlighting domains overprinted by Alpine "peak" metamorphic reactions typical for certain geotectonic settings results in a picture much easier to read than previous maps of the metamorphic evolution of the Alps published by NIGGLI & NIGGLI (1965), NIGGLI & ZWART (1973), ZWART et al. (1973, 1978) and FREY et al. (1974, 1999), which all strive to emphasize polymetamorphic and/or plurifacial complexities. Our new map shows Alpine metamorphic peak conditions irrespective of when these were attained. The age information is given in a separate map shown as inset (1:2'000'000). We also added new data, notably compiled from high-pressure metamorphic metapelites. Thus the wide distribution of subduction related metasediments of the Valais ocean domain have brought forth new geodynamic aspects and paleogeographic reconstructions.

Fig. 1 shows local names used in the text but partly omitted on the metamorphic map and the position of the main Jurassic paleogeographic elements within the Mid- to Late Tertiary structure of the present Alps; it also indicates major metamorphosed fault zones. Although our metamorphic map tries to show a general picture of the Alpine thermo-mechanical evolution, this could not be done without reference to local names. To maintain clarity on the metamorphic map and as thesaurus for the "non-Alpine" reader we used a modified version of the tectonic map by SCHMID et al. (2004a). The map of SCHMID et al. (2004a) is based on the structural model of Italy (BIGI, et al., 1989, 1990a, 1990b, 1992).

The metamorphic map clearly shows a relatively simple picture for the Western Alps with an internal high-pressure dominated part thrust over an external greenschist to low grade domain, although both metamorphic domains are structurally very complex (GOFFÉ et al., 2004 this volume; BOUSQUET et al., 2004, this volume). Such a metamorphic pattern is generally produced by subduction followed by exhumation along a cool decompression path. In contrast, the Central Alps document conditions typical for subduction (and partial accretion) followed by an intensely evolved collision process resulting to an heating event during the decompression path of the early subducted units (hatched units in the map) (ENGI et al., 2004, this volume). Subduction-related relics and (collisional/decompressional) heating phenomena in different tectonic edifices characterize the Eastern Alps (Schuster et al., 2004, this volume). This complex picture is due to a dual Cretaceous and Tertiary metamorphic evolution related to a complex tectonic history. For the Tuscan and Corsica parts of the map the reader is invited to see the synthetic work of JOLIVET et al. (1998) that was used as reference to draw this part of the map.

Legend of the metamorphic structure map

The following divisions were used as legend on the map

LGM Low grade metamorphism

DIA: Diagenesis / sub-anchizone (T < 200°C; P < 0.3 GPa)

zeolite / illite – kaolinite

SGS: Sub-greenschist facies (T 200–300°C; P < 0.5 GPa)

laumontite – prehnite – pumpellyite / kaolinite – chlorite – illite – interlayered illite – smectite

GS Greenschist facies

LGS: Lower greenschist facies (T 300–450°C; P < 0.7 GPa)

albite – chlorite – epidote ± actinolite / albite – chlorite – phengite / pyrophyllite – chlorite–illite – phengite – paragonite ± chloritoid

UGS: Upper greenschist facies (T 420-500°C; P < 0.8 GPa)

actinolite / biotite – chlorite – kyanite ± chloritoid

HPGS: High-pressure greenschist facies (T 300–450°C; 0.6 < P < 1.0 GPa)

albite – lawsonite – chlorite ± crossite / phengite – chlorite ± chloritoid ± kyanite

GAT Greenschist- amphibolite transitional facies (T 450–600°C; 0.8 < P < 1.2 GPa)

albite – epidote – amphibole / biotite – garnet – chloritoid / phengite – chloritoid – kyanite

AM Amphibolite facies (T 500–650°C; 0.5 < P < 1.3 GPa)

plagioclase – hornblende – garnet / biotite – garnet – staurolite – phengite ± kyanite

BS **Blueschist facies**

BS: Blueschist facies **(T 250–400°C; 0.8 < P < 1.5 GPa)**

glaucophane – lawsonite – jadeite – quartz /Fe-Mg-carpholite – phengite ± pyrophyllite ± chloritoid

UBS:Upper blueschist facies **(T 380–5s50°C; 1.0 < P < 1.5 GPa)**

glaucophane – epidote – garnet / chloritoid – glaucophane – phengite ± garnet

BET **Blueschist to eclogite transitional facies** **(380–550°C; 1.3 < P < 1.8GPa)**

blue amphibole – zoisite – garnet ± clinopyroxene / garnet – Mg–rich chloritoid – phengite

ECL **Eclogite facies** **(T 450–750°C; 1.3 < P < 2.5 GPa)**

garnet – omphacite – zoisite – quartz ± amphibole ± phengite / garnet – Mg–rich chloritoid – kyanite – phengite / garnet – lawsonite

UHP **Ultrahigh-pressure facies** **(T 600–800 °C; 2.5 < P < 4.0 GPa)**

garnet – omphacite – coesite – zoisite / Mg–rich chloritoid – talc – phengite – kyanite – pyrope – coesite

VT **Variegated HT facies** **(T 600–800°C; 0.7 < P < 2.5 GPa)**

Tectonic mélange with relics of ECL, AM, and local granulite facies, interpreted as tectonic accretion channel (TAC); in the Southern Steep Belt evidence of partial melting is widespread

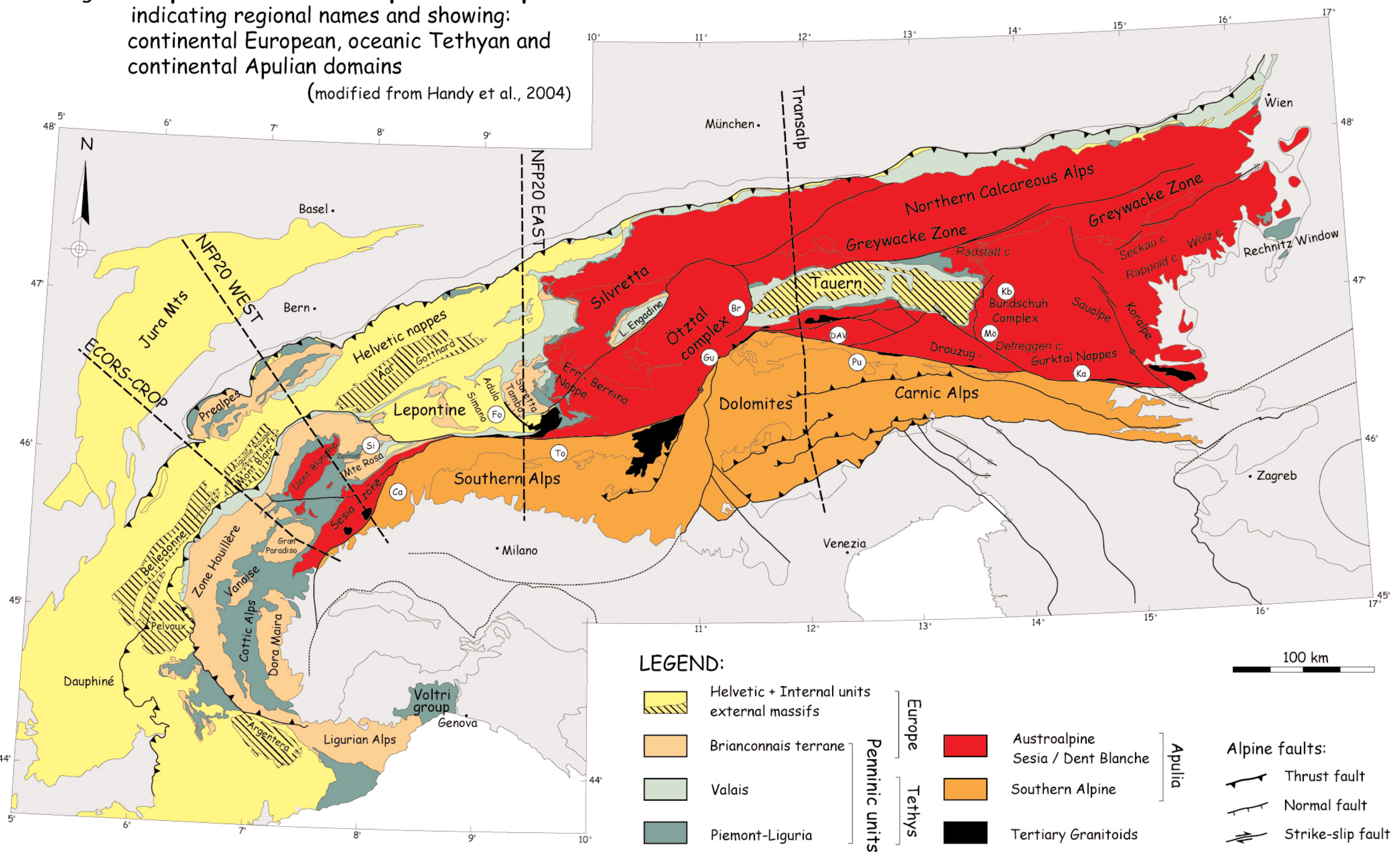
These divisions are based on metamorphic assemblages identified in mafic and in pelitic compositions. Temperature and pressure limits for different facies are far from being precisely defined but represent a compromise for different rock compositions. Sketches of P-T grids give the P-T pathes used to define the P-T grid shown in the map..

Large parts of the Austroalpine unit consist exclusively of pre-Alpine metamorphic rocks over-printed during the Eo-Alpine event at various grade. In these rocks the prograde assemblages defined above can not be recognised, but the following criteria have been used to cover the area:

LGM	(low grad metamorphism)	
	diagenesis / sub anchizone	illite cristallinity and coalification data
	sub greenschist facies	illite cristallinity and coalification data
LGS	~ 300 °C	total reset of Rb-Sr isotopic system in biotite
UGS	~ 400 °C	total reset of K-Ar isotopic system in muscovite
GAT	~ 500 °C	garnet-in, assemblage Ms + Ca-amphibole
AM	~ 600 °C	staurolite-in

As far as sub-anchi facies (DIA), sub-greenschist facies (SGS), lower greenschist facies (LGS), upper greenschist facies (UGS) and high-pressure greenschist facies (HPGS) are concerned, these facies terms as well as the corresponding P and T conditions can be considered as standard. The transitional greenschist amphibolite facies (GAT) accounts for the fact that different bulk rock compositions either produce greenschist or amphibolite facies mineral assemblages within this pressure and temperature realm.
No Eo-Alpine blueschist facies rocks are reported from the Austroalpine units.

Fig. 1: **Simplified tectonic map of the Alps**
indicating regional names and showing:
continental European, oceanic Tethyan and
continental Apulian domains
(modified from Handy et al., 2004)



Mylonitic amphibolite - greenschist facies fault zones

(Ca) Canavese (To) Tonale (Gu) Giudicaria (Pu) Pustertal (Ka) Karawanken
(Si) Simplon (Fo) Forcola (Br) Brenner (DAV) Deferregen-Antholz-Vals (Mö) Mölltal (Kb) Katschberg

Instead the collision-related pressure-dominated rocks between greenschist facies and eclogite facies re-equilibrated in the GAT field. For some areas clear amphibolite facies (AM) conditions are evident in the field. Blueschist facies rocks can be divided into normal blueschist facies (BS) rocks and garnet-bearing blueschists that experienced somewhat higher temperatures and are classified as upper blueschist facies (UBS) rocks. For the transition from blueschist to eclogite facies, where all intermediate stages can be found in various tectonic units, we chose to lump the different rock types in a blueschist to eclogite transitional facies (BET). The eclogite facies is subdivided into eclogite facies (ECL) and ultrahigh-pressure facies (UHP), based on the quartz – coesite phase transition. In the southern part of the Central Alps rocks occur that apparently underwent different metamorphic conditions within coherent tectonic units. As these outcrops are to small to be mapped, the composite zone has been interpreted as remnant of a tectonic accretion channel (see below). In order to avoid a tectonic term in the legend, we summarize all rocks exhibiting amphibolite, eclogite or granulite facies metamorphism, as well as migmatization (in the Southern Steep Belt) under the term variegated high temperature facies (VT).
The colour code applied to the metamorphic facies domains indicates subduction-related metamorphic conditions by blue, pink and violet tints. Yellow, green to red colours indicate conditions related to continental collision. Red to orange tints suggest high temperature conditions, which appear to be related to exhumation (e.g. TAC, see ENGI et al., 2004.).

Legend of the Alpine tectono-metamorphic age map

The choices made for the presentation of metamorphic ages is discussed by HANDY & OBERHÄNSLI (2004, this volume).
High-retentivity isotopic systems such as Sm-Nd, Hf-Lu of HP assemblages and U-Pb SHRIMP data of zircon were used to assess ages of high-pressure metamorphism. Rb-Sr, Ar-Ar and K-Ar biotite and white mica cooling ages were used to separate areas dominated by cooling ages from areas where mixed ages are observed. For some areas biotite cooling ages were contoured to show the cooling pattern of the thermal overprint.
Green and yellow-orange colours indicate, respectively, the Cretaceous and Tertiary metamorphic cycle. Dotted areas show tectonic units that experienced high-pressure metamorphism.

Conclusions

These maps include information based on recent data from high-pressure metasediments that yields new aspects of the geodynamic evolution of the Alps. The fact that subduction-related high-pressure metamorphism can be identified all along the Valais ocean domain calls for adapted paleogeographic reconstructions.
The compilation of this new map resulted in two aspects. In our opinion, the Mesozoic and Tertiary evolution of the Alps has been depicted in a way permitting an easier approach to a geodynamic understanding of this orogen.

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