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The boundary between the metamorphic and non- to anchi-metamorphic domains in the Southalpine basement *s.l.* of the eastern southern Alps: a review

RAFFAELE SASSI[1]*, CORRADO VENTURINI[2] and PÉTER ÁRKAI[3]

[1] Dipartimento di Mineralogia e Petrologia, Università di Padova, C.so Garibaldi 37, 35137 Padova, Italy
[2] Dipartimento di Scienze della Terra e Geologico-Ambientali, Università di Bologna, via Zamboni 67, 40127, Bologna, Italy
[3] Laboratory for Geochemical Research, Hungarian Academy of Sciences, H-1112, Budapest, Budaörsi út 45, Hungary.

ABSTRACT. — The Southalpine basement in the Eastern Alps consists of thick metamorphic mainly phyllitic sequences which formed within greenschist facies conditions, and unmetamorphosed to very-low grade Paleozoic sequences in its easternmost part (Palaeocarnic Chain).

Many authors tried to localize the boundary between the metamorphic and non-metamorphic domains. Recent studies demonstrated, by means of KI (Kübler Index) data, that the locations of this boundary given in the maps are uncorrect, and that the boundary occurs more eastwards than previously suggested, mainly in correspondence of the Val Bordaglia Line.

The present review critically summarizes all data existing in the literature (Kübler Index, Árkai Index, vitrinite reflectance, Colour Alteration Index of Conodonts, fluid inclusions) concerning the location of the eastern boundary of the Hercynian metamorphism, and discusses the occurrence and possible significance of a local Alpine overprint to the east of the Val Bordaglia Line.

RIASSUNTO. — Il basamento Sudalpino delle Alpi Orientali è formato da una spessa sequenza metamorfica prevalentemente filladica, in facies degli scisti verdi, e nella sua parte più orientale da una sequenza Paleozoica da non- fino ad anchi-metamorfica (Catena Paelocarnica).

Molti autori hanno provato a localizzare il limite tra il dominio metamorfico e quello non metamorfico. Studi recenti, basati sul KI (Kübler Index) hanno dimostrato che la localizzazione del limite, generalmente riportata sulle carte è errata, e deve essere spostata più a est, in corrispondenza della Linea della Val Bordaglia.

La presente revisione critica riassume tutti i dati presenti in letteratura (*Kübler Index, Arkai Index, vitrinite reflectance, Colour Alteration Index of Conodonts, fluid inclusions*) riguardanti il limite orientale del dominio metamorfico Ercinico nel basamento Sudalpino, e la locale sovraimpronta metamorfica Alpina riscontrata ad est della Linea della Val Bordaglia.

KEY WORDS: *Southalpine basement of the Eastern Alps; Palaeocarnic Chain; metamorphic/anchi-metamorphic; Kübler Index; Árkai Index; Vitrinite reflectance; Color Alteration Index; Fluid inclusions.*

INTRODUCTION

In eastern sectors of the Southern Alps the Alpine succession (Upper Palaeozoic-

* Corresponding author, E-mail: raffaele.sassi@unipd.it

Mesozoic-Tertiary) unconformably overlies the non (to anchi-) metamorphic Palaeozoic sequences to the east (in Carnia) and the greenschist facies metamorphic rocks to the west (in Pusteria and Comelico). Earlier, before the last decade of the XXth century, the location of the boundary between the metamorphic and non-metamorphic domains was considered as shown in Fig. 1 (Metamorphic Map of the Alps, 1973; Structural Model of Italy and Gravity Map, 1990). The new metamorphic map of the Alps (Frey *et al.*, 1999) did not plot this boundary, and reports the whole region as a domain of Hercynian (*sensu* Ziegler, 1989) metamorphism of «greenschist facies or lower grade», although it also shows an area of Alpine overprint (Hoinkes *et al.*, 1999). The explanatory texts (papers) published simultaneously to this map summarize very briefly the available main results on Hercynian metamorphism and possible Alpine overprint (Neubauer *et al.*, 1999; Hoinkes *et al.*, 1999). (Incidentally, it is worthy to be pointed out that a big mistake is shown in this map, where the basement area of the Valsugana – Cima d'Asta is related to the amphibolite facies).

However, recent studies based on illite and chlorite «crystallinity» (here reported respectively as Kübler Index, KI, and Árkai Index, AI, according to a recent international recommendation: Guggenheim *et al.*, 2002), reflectance of vitrinite and graptolite fragments, and microthermometry on fluid inclusions data, demonstrate the boundary location, as shown in the above mentioned maps of 1973 and 1999, is uncorrect. New research works (Árkai *et al.*, 1991; Sassi *et al.*, 1995; Rantitsch, 1997; Läufer *et al.*, 2001; Brime *et al.*, 2003) show that this boundary is indeed complex and located more eastwards than before assumed.

Moreover, in the eastern Southern Alps the metamorphism of the basement commonly appears as only related to the Hercynian event. However, the existence of Alpine recrystallization effects have also been admitted locally. Fault bounded blocks with Alpine metamorphism are well proven in the Carnic Alps (Läufer *et al.*, 1997).

The present review critically summarizes the data concerning the location of the eastern boundary of the Hercynian metamorphism, and discusses the occurrence and possible significance of a local Alpine overprint.

Work in progress by Brime *et al.* (pers. comm. by C. Venturini) will add some new data about the Hercynian structural evolution

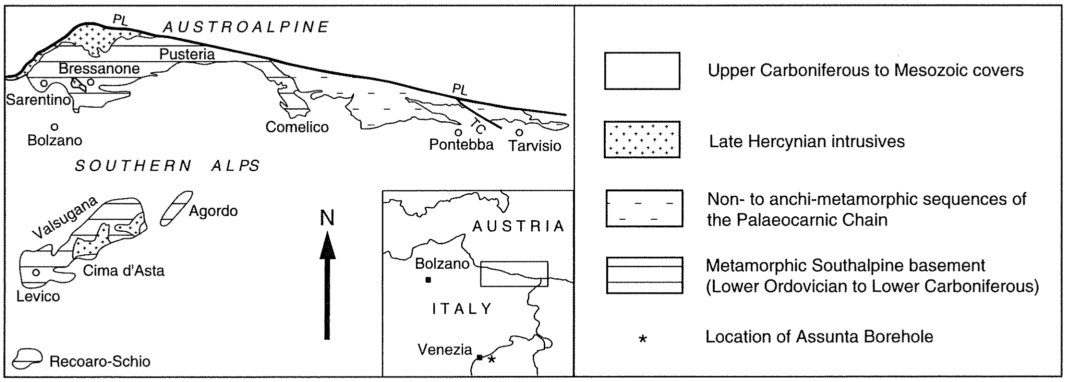

Fig. 1 – The simplified geological sketch shows the boundary between the metamorphic Southalpine Basement and the assumed «non-metamorphic» sequence of the Carnic Chain taken from the Metamorphic Map of the Alps (1973), the Structural Model of Italy and Gravity Map (1990) and Frey *et al.* (1999). The asterisk close to Venezia roughly indicates the location of the Assunta Borehole in which Ordovician granitoids uneffected by any metamorphism was reached at 4711 m below the sea floor. PL = Pusteria Line (Periadriatic Lineament); TC = Tröpolach-Camporosso Line.

of the Carnic Alps. They concern the CAI value (Colour Alteration Index of conodonts) and the KI of illite content, both measured in the Ordovician-Carboniferous sequence and the relevant Upper Carboniferous-Triassic covers.

Geological setting

The metamorphic basement (basement for short) of the eastern Southern Alps outcrops, underneath the Upper Carboniferous to Mesozoic and Tertiary stratigraphic covers, in three main areas (inset of Fig. 1): *i)* a northern, approximately west-east trending belt, from the Sarentino Valley through Bressanone-Pusteria up to Comelico (i.e. the westernmost Carnic Alps); *ii)* an intermediate, approximately southwest-northeast trending belt, from Valsugana through Cima d'Asta to Agordo; *iii)* a southern sector, the Recoaro-Schio area. The basement only records a metamorphism of Hercynian age (Del Moro *et al.*, 1980, 1984; Vai and Cocozza, 1986; Dallmeyer and Neubauer, 1994; Meli, 2004). The main structures are Hercynian in age, but Alpine, mostly gentle folding and brittle deformation also occur. The mineral assemblages occurring in the basement reveal greenschist facies conditions, with a metamorphic zoning ranging from the almandine zone (mainly localized in the north-western part of the basement), a biotite zone, and, in the southernmost and easternmost parts, a chlorite zone.

The basement passes eastwards to the anchizonal and even non-metamorphic Palaeozoic sequences of the Carnic Alps, in which a Hercynian Palaeocarnic Chain has been recognized (Spalletta *et al.*, 1982; Vai *et al.*, 1984). The structural relationship between the basement and the non-metamorphic Palaeozoic sequence of the Carnic Alps is rather complex due to the overlapping effects of complicated Hercynian and Alpine tectonics.

The Palaeocarnic Chain (PCC for short) is the ancient Hercynian core of the Carnic Alps. It consists of a narrow, west-east elongated belt outcropping in Comelico and Carnia. Its deformational history records strong, multistage, Hercynian shortening. Furthermore, it experienced the Alpine north-south shortening producing a mainly S-verging thrust and fold belt (Venturini, 1990a; Carulli and Ponton, 1992; Bressan *et al.*, 1998, 2003). The Hercynian stages of deformation have been distinguished from the Alpine ones in several, Lower Palaeozoic, sedimentary nuclei (Venturini, 1990b; Venturini and Delzotto, 1992; Venturini *et al.*, 2001-2002). In spite of all available data, the location of the boundary between the Hercynian metamorphic rocks of the basement and the non- (to anchi-) metamorphic domain of Carnia is still debated.

Metamorphic effects, where present in the PCC, display a low- to very low-grade, and by the authors are considered Hercynian in age. The Alpine tectonic reworking of the PCC is generally regarded free of metamorphism. The PCC can be subdivided into two adjacent areas (western and eastern), each characterized by a specific Hercynian rock sequence (see Sassi *et al.*, 1994 and references quoted therein): *i)* the western PCC is made of solely metamorphic rocks (they are part of the basement); a metamorphic gap between the pre-Upper Carboniferous sequence and the post-Hercynian cover is manifest (Menegazzi *et al.*, 1991); *ii)* the rock succession of the eastern PCC (Carnia) is almost entirely non- or anchi-metamorphic, except some small stripes along the Periadriatic line (Eder unit and similars) which show greenschist facies metamorphism (Läufer, 1996), and gave K/Ar and Ar/Ar Alpine ages (Läufer *et al.*, 1997). The rock sequence of the eastern PCC (Carnia) is described in Spalletta *et al.* (1982), Läufer *et al.* (1993), Vai (1998), Venturini and Spalletta (1998) and Läufer *et al.* (2001), and has been mapped in detail by Venturini *et al.* (2001-2002). The non-metamorphic rock sequence of the PCC is believed to have come off from its pre-Upper Ordovician metamorphic basement due to the Hercynian compressions.

The western area experienced two Hercynian deformation phases respectively at about 350 Ma and 320 Ma (Del Moro *et al.*, 1980;

Hammerschmidt and Stöckhert, 1987); they both yielded a metamorphic imprint. On the opposite side, the eastern area (Carnia) underwent only the younger phase (about 320 Ma).

The rock succession making up the whole PCC (Comelico and Carnia, Fig. 1) is dismembered in several tectonic units, due to the combined effects of the Hercynian and the Alpine tectonics (Menegazzi *et al.*, 1991; Venturini, 1990b; Bressan *et al.*, 2003). Therefore, the thermal zone (*i.e.* epizone, anchizone, diagenetic zone) inferred for a specific locality cannot be extrapolated in a simplistic, off-hand manner. Thus, the many constraints imposed by the complicated structure of the area need to be taken into due consideration. For this reason, some pieces of information are given here on the tectonics of the PCC.

The Hercynian orogeny produced in the PCC a complex structural pattern mainly trending N120°E at present. The folded and thrust edifice can be considered a foreland fold-thrust belt uplifted in a short time span (not before Namurian and not after the early Westfalian C). This deformation phase, named as «Carnic phase» by Vai (1976), reflects the Leonian movements related to the Asturian phase. Field evidence confirms that the eastern area of the PCC only underwent this youngest Hercynian deformational phase. It produced three different deformation styles (Venturini, 1991), which overprinted each other and are characterized by the same N120°E trend with south-southwestern vergence. Each system of structures is to be referred to a shallower crustal depth of burial supported by the accreting belt during its deformation history (Fig. 2).

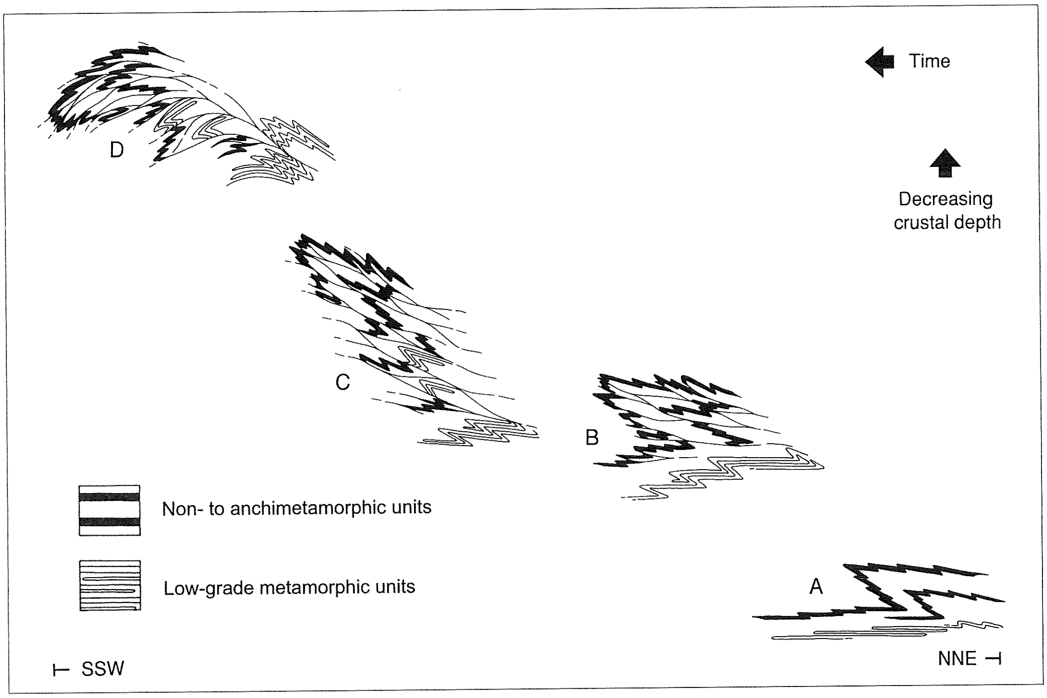

Fig. 2 – Effects of the three deformation stages of the Carnic event (A to D) in the Carnic Alps, east of the Val Bordaglia Line (see text). This interpretation tries to explain the mixture between non- to anchimetamorphic and low-grade metamorphic units (from Venturini, 1991, modif.) A = 1st stage; B, C = 2nd stage; d = 3rd stage.

The first deformation stage developed a multi-km, asymmetric, close fold as wide as the almost entire north-south section of the presently outcropping belt (Fig. 2a). The second and shallower deformation stage produced many ramp and flat structures which intersected and shifted the previous map-scale folds producing a thick system of tectonic slices (Fig. 2b, c). It corresponds to the «imbricated tectonic slices» recognized by Selli (1963), Vai (1979) and Spalletta *el al.* (1982) as the only Hercynian structures of the PCC. The third and shallowest deformation stage took place after a further uplift of the belt. A series of km-sized, open antiforms developed in the hangingwall of newly-formed thrust surfaces. All the previous structures were refolded during the last stage (Fig. 2d).

Palaeomagnetic data from the overlying Permo-Carboniferous beds, which uncorformably rest on the Hercynian folded belt, indicate the Hercynian basement has been rotated counterclockwise of about 40° since Late Carboniferous (Manzoni *et al.*, 1989). The rotation is quite similar to that measured in the Comelico and Dolomites (Manzoni, 1970). Therefore, both the Carnia and Comelico structural trends rotated together since the end of the Hercynian orogeny.

The Val Bordaglia Line (VB, Fig. 4) is one among the the major tectonic elements of the PCC. At present it consists of a N50°E trending bundle of sub-vertical faults. First it was active in the Late Carboniferous times and experienced intense strike-slip and pure compressive movements during the Alpine orogeny (Venturini, 1990b; Bressan *et al.*, 2003; Venturini *et al.*, 2001-2002). According to Läufer *et al.* (2001), VB is a late Alpine left-lateral fault conjugated to the Gailtal Line.

To better understand the relationship existing between the metamorphic and non (to anchi-) metamorphic Hercynian successions of the whole PCC, it is basic to discuss the born of the VBL, as it is assumed by the authors. Selli (1963) and Zanferrari and Poli (1992) refer it to the Hercynian orogeny and generally admit it was a thrust surface yielding the overlap of the Hercynian Basement (western PCC, Comelico) onto the not (to anchi-) metamorphic succession (eastern PCC, Carnia).

Cassinis *et al.* (1997) and Venturini and Spalletta (1998) agree on this interpretation but point out that the first activation of the Val Bordaglia thrust has occurred at the very end of the Hercynian orogeny, during the early Late Hercynian wrench tectonics, controlled by the dextral strike-slip offset of a hypothetical palaeo- Gailtal Line. In this view, the VB is interpreted as a contractional duplex developed in restraining overstep conditions. As a consequence, in the PCC the western limb of the VB (Comelico), made of metamorphic units, translated over the non- (to anchi-) metamorphic succession of the eastern limb (Carnia). The two tectonic domains, west and east of the VB, correspond to the two Hercynian «zones» distinguished by Venturini and Spalletta (1998).

Similarly, the Hercynian zonation was reported by Hubich and Läufer (1996, 1997), who in turn interpreted the two zones as Hercynian tectonic nappes, by means of modern structural analyses and studies concerning the metamorphic evolution of the region.

Besides, it is to note that the present VB bundle of close faults, reactivated in the Alpine times, is made of both the Val Bordaglia Late Hercynian thrust and a system of normal faults sub-parallel to it and born in front of it during the Late Carboniferous-Early Permian times (Venturini and Spalletta, 1998).

The Hercynian thermal zoning

The large scale regional pattern

As concerns the regional metamorphic zoning of the whole eastern Southern Alps, Sassi and Zirpoli (1968) and Sassi *et al.* (1974) pointed out an increase in metamorphic grade from the east (Comelico area: chlorite zone) to the west (Sarentino, Sarntal Alps: almandine zone), and from the south (Recoaro area: mainly chlorite zone) to the north (Sarentino, Sarntal Alps). However, such a pattern is only a rough general indication, which cannot be directly related to the palaeogeothermic situation. In fact, every time it is used to estimate the metamorphic thermal gradient, unbelievably low values are obtained due to the great thickness of each mineral zone, in sharp contrast with the relatively high thermal gradient value estimated on petrologic base. Thus, the above mentioned regional pattern should be a combined result of regional folding of the isothermal surfaces from one hand, and different depths of erosion on the other (Fig. 3) (Mazzoli and Sassi, 1988). Moreover, this metamorphic zonation is disturbed by dextral NW-trending and sinistral NE-trending faults genetically linked as Riedel and Antiriedel shears to the Alpine dextral strike-slip of the Periadriatic Lineament (Schmidt *et al.*, 1993).

It is worth pointing out here that the vanishing southwards of the Hercynian metamorphism is also proven by the lack of Hercynian metamorphic effects in the Venice granodiorite (Vai and Cocozza, 1986; Meli and Sassi, 2003).

The boundary between the very low-grade and low-grade metamorphic domains in Carnia: evidence from KI (Kübler Index)

According to Sassi *et al.* (1995), the boundary coincides with the Val Bordaglia Line. In fact, as shown in Fig. 4, the epimetamorphic realm, based on KI data, lies to the west of the Val Bordaglia Line (VB) and the anchi-metamorphic conditions, ascertained by means of KI data, prevail to the east of it. The above authors, who used scattered samples, find only a few epimetamorphic rocks to the east of VB. They preliminarily interpreted the KI data as confined within tectonic slices which they speculatively considered as exumed portions of the deep core of the Hercynian belt («eastern zone»). More specifically they are the tectonic slice of the Valentintal and the Frassenetto tectonic slice, near Forni Avoltri. A third epimetamorphic band defined by KI values is reported by Selli (1963), Rantisch (1997) and Läufer (1996) to the east of the Tröpolach-Camporosso Line (TC in Figs. 1 and 4). This line is also known as Schwartzwipfel Line, and is a Late Variscan strike-slip fault, conjugated to the paleo-

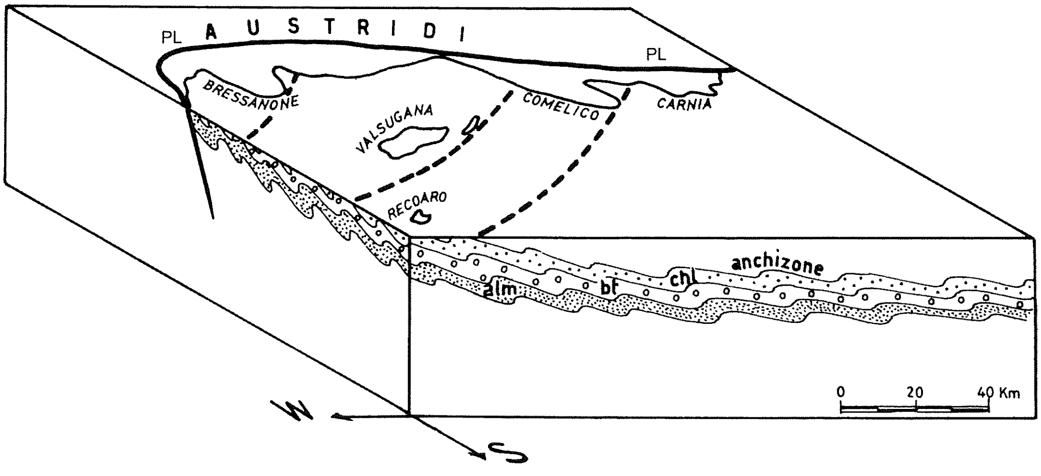

Fig. 3 – Schematic representation of the general pattern of the mineral zones (chl = chlorite; bt = biotite; alm = almandine) in the Southalpine Basement of the Eastern Alps (from Mazzoli and Sassi, 1988). Folding is symbolically shown.

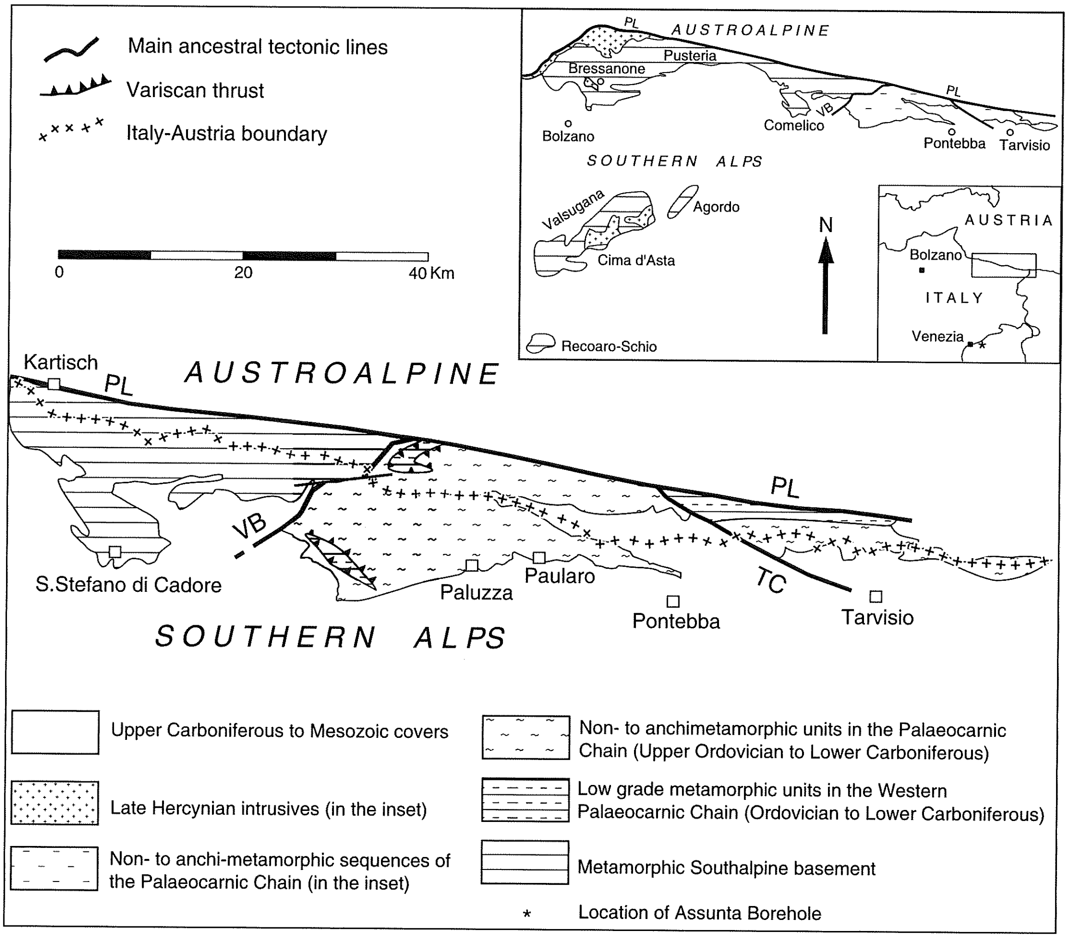

Fig. 4 – Northeastern boundary of the metamorphic Southalpine Basement as turns out from the results of literature data (taken from Sassi *et al.*, 1995). VB = Val Bordaglia Line; PL = Pusteria Line (Periadriatic Lineament); TC = Tröpolach-Camporosso Line.

Periadriatic Lineament and responsible for the opening of the Pramollo pull-apart basin in Late Carboniferous times (Venturini, 1991). Läufer *et al.* (1997) report in this band Alpine K/Ar and Ar/Ar age data. However, the several tectonic lines and thrust planes which dismembered this area in several tectonic units, obliterated the original regular metamorphic zoneography. Anyway, notwithstanding this structural complexity, the above mentioned KI data show that the block to the east of the VB was located at cooler and shallower crustal levels within the Hercynian thermal structure, than the western block.

Rantitsch (1997) published new KI data along three traverses crossing perpendicularly the general strike of the Carnic Alps. These KI data are consistent with the results of Sassi *et al.* (1995). Furthermore, Rantitsch (1997) evidenced the decrease of metamorphic grade to the tectonic hangingwall: the epizonal values were found at the deepest position. On the contrary, the KI data in the post-Hercynian strata of the Auernig Group show an inverse correlation with the altitude of the sample location.

KI data presented by Läufer *et al.* (2001) are also consistent with previous results of Sassi *et al.* (1995) and confirm the presence of the two above mentioned epimetamorphic tectonic slices within the anchimetamophic zone east to the VB.

Brime *et al.* (2003) confirm the widespread anchimetamorphic conditions east of VB established by Sassi *et al.* (1995). Furthermore, Brime *et al.* (2003) evidence a «late diagenetic» area west of Paularo.

The boundary between the very low-grade and low-grade metamorphic domains in Carnia: evidence from the AI (Árkai Index)

Illite (KI) and chlorite «crystallinity» indices (AI) (Árkai *et al.*, 1995) were simultaneously measured in the same samples. The AI data demonstrate that the changes of AI may be used for monitoring metamorphic grade in the same way as the changes of KI. However, the AI range of the anchizone is somewhat smaller than that of the corresponding KI range, and consequently, the AI method is slightly less sensitive than KI method. Nevertheless, in prograde pelitic to silty sequence, it is equally reliable in monitoring the changes from the diagenetic zone through the anchizone up to the epizone.

The boundary between the very low-grade and low-grade metamorphic domains in Carnia: evidence from reflectances of the vitrinite and graptolite fragments

Regional variation of coal rank results obtained by Sassi *et al.* (1995) are in a fairly good agreement with the KI data obtained by the same authors, with the exception of anomalously high R_{max}, low R_{min} and high ΔR values for the group *FR* (near Frassenetto), which conflict with KI data of the same rocks showing low-T anchizone (near to the anchizone/diagenetic zone boundary). This discrepancy may be interpreted differently: i) the overwhelming part of the organic matter grains in *FR* could be derived as thermally matured detritus from higher-grade metamorphic rocks; ii) it may have suffered a short-term magmatic heating, which did not affect KI; iii) it may have suffered a short-term tectonic heating and deformation, which did not affect KI.

Rantitsch's (1997) coalification data confirm the above mentioned metamorphic zoneography (Sassi *et al.*, 1995) and are in agreement with the reflectance of graptolite fragments obtained by Rantitsch (1992, 1995).

The boundary between the very low-grade and low-grade metamorphic domains in Carnia: evidences from Colour Alteration Index (CAI) of conodonts

CAI in carbonatic rocks was measured by Brime *et al.* (2003) in combination with KI in pelitic rocks. CAI results obtained by Brime *et al.* (2003) mirror the KI values, and evidence the presence of a «late diagenetic» area west of Paularo.

The boundary between the very low-grade and low-grade metamorphic domains in Carnia: evidences from microthermometry on fluid inclusions

Rantitsch (1997) studied fluid inclusions from anchizonal terrains north to Lake Zollner distinguishing mainly two fluid inclusion populations. The first one, related to the Hercynian event, indicates a trapping between 170°C and 270°C. The highest possible pressure in the diagenetic to anchizonal fluid regime of 1.6 kbar is given by the intersection of the steepest methane isochore (calculated after Grevel, 1991) with the 270°C isotherm. Pressures lower than 0.9 kbar are explained by local pressure drops in the fluid regime.

The second fluid inclusion population, which gives homogenisation temperatures between 300°C and 360°C, is interpreted as the expression of a later hydrothermal event (2 to 4 km overburden load) Rantitsch (1997).

In conclusion, the fluid inclusion microthermometry gave indications which are important as regards the thermal history of the Carnic Alps, but are irrelevant for the location of the discussed boundary, because all microthermometric data come from the anchimetamorphic area.

Alpine metamorphic overprint

Metamorphism in the Southalpine basement of the Eastern Alps has been commonly referred to the Hercynian event (e.g. Bögel, 1975; Sassi and Zirpoli, 1989; Sassi and Spiess, 1993). All geochronological data available in literature confirm such a view. They indicate a two-episode Hercynian metamorphic event, consistently with previously detected petrological evidences (Sassi and Zirpoli, 1965; Sassi, 1969; Mazzoli and Sassi, 1988). The older episode has been dated at about 350 Ma in the Bressanone area (Del Moro *et al.*, 1980), the younger one at 320 Ma in the Plan de Corones area (Del Moro *et al.*, 1984; Hammerschmidt and Stöckhert, 1987). $^{40}Ar/^{39}Ar$ radiometric ages obtained by Dallmeyer and Neubauer (1994) from Ordovician sandstones in the Lake Zollner area have been related to a Hercynian rejuvenation of Cadomian micas, at values close to the muscovite-argon retention temperature of 300° to 350°C. Läufer *et al.* (1997) report also Alpine ages.

Läufer *et al.* (2001) report the preliminary age results of geochronological studies still in progress: approximately 340 Ma for metamorphism in the Fleons nappe and 320-300 Ma for the younger Cellon-Kellerwand and Hochwipfel nappes (K/Ar on white mica and clay fractions).

More recently, Meli (2004) confirms the two-episode development of the Hercynian metamorphism, at 345-353 Ma and 331-335 Ma (Ar/Ar on white micas), finding between the two Hercynian metamorphic episodes a smaller time gap than previously reported, and not detecting any effect of Alpine overprint in Sarentino and Levico areas.

Therefore, no radiometric evidence of an Alpine metamorphic overprint exists in the Comelico-Carnia area as well as in the whole metamorphic basement of the Eastern Southern Alps. In spite of this, some hypotheses on an Alpine metamorphic heating in the Carnic Alps have been put forward recently.

Rantitsch (1997) indeed pointed out the lack of a metamorphic gap across the Hercynian unconformity: the higher formations of the pre-Hercynian strata show, according to coal rank and KI data of this author, the same metamorphic grade as that detected in the lowermost level of the post-Hercynian strata. In particular, Rantitsch (1997) reports an anchizonal Alpine metamorphism in the post-Hercynian Auernig Group. In any case, according to this author, during Alpine times «Permian to Triassic boundary sediments remained at temperature below 150°C and therefore unmetamorphic». The lack of any metamorphic overprint in the Permian rocks of the Carnic Alps is also reported by Schramm (1991).

Therefore, some Alpine metamorphic imprint seems to exist and be confined within the lowest levels of the post-Hercynian sequence. The epizone metamorphism and ductile deformation shown by the Eder unit and similars, mainly distributed north of the TC Line, was strictly related with the emplacement of an Oligocene plutonic mass (Rantitsch, 1997). The K-Ar ages (Läufer, 1996; Läufer *et al.*, 1997) and tectonics confirm a Late Oligocene heat flow along the Periadriatic Line (Sassi and Zanferrari, 1973; Laubscher, 1983) followed by the Late Miocene exumation by transpression (Läufer, 1996).

The peak conditions of the Alpine heating event are shown by the diagenetic to anchizonal fluid inclusions: a temperature of max. 270°C and a burial of 4 to 6 km (Rantitsch, 1997). However, the basin modelling of Rantitsch (1997) «confirms the burial depth and reveals a "normal" heat flow as obtained by the methodical correlation».

In other words, the above mentioned basin modelling does not confirm «in an exact way»the supposed post-Hercynian hyperthermal anomaly, «but taken into account it requires an extreme heat flow» (155 mW/m^2). Such a heat flow regime is related by the above mentioned author to «a hyperthermal anomaly *sensu* Robert (1988)», and to a «diastathermal metamorphism *sensu* Robinson (1987)».

An enhanced Palaeogene heat flow is also reported by Sachsenhofer (1992), as inducing an extremely high rank of coalification of Slovenian coals near the Periadriatic Lineament. Rantitsch and Rainer (2003) confirm the interpretation reporting Alpine very-low grade metamorphism from the Palaeogene sediments of the Southern Karawanke, and refer it to Oligocene.

It is worth mentioning that, according to the basin modelling of Rantitsch (1997), the geothermal gradient of the Hercynian metamorphism was of 30-40°C/km, i.e. the same value range estimated basing on the muscovite-illite 060-33$\bar{1}$ cell parameter by Árkai *et al.* (1991) in the same area, and by Sassi and co-workers (e.g. Sassi and Spiess, 1993) in the whole Southalpine metamorphic basement of the Eastern Alps.

In conclusion, there are some pieces of evidence of Alpine thermal effect (Middle Triassic? Oligocene?) detected at the base of the post-Hercynian sedimentary sequence, but further work is needed for its interpretation.

CONCLUDING REMARKS

1) The epimetamorphic realm within the Southalpine basement of the Eastern Alps only records Hercynian metamorphism and is confined to the west of the Val Bordaglia Line (VBL). The main structures are Hercynian in age, but Alpine structures also occur (mostly gentle folding and brittle deformation).

2) Non- to anchimetamorphic conditions are recorded to the east of VB. The structural relationship between the basement and the non-metamorphic Palaeozoic sequence of the Carnic Alps is rather complex due to the overlapping effects of complicated Hercynian and Alpine tectonics.

3) The original, regular metamorphic zoneography of the Hercynian event is not yet recognizable, due to the several tectonic lines and thrust planes which dismembered it in several tectonic units. Anyway, notwithstanding the structural complexity, the above data show that the block to the east of the VB was located at cooler crustal levels within the thermal Hercynian structure, than the western block.

4) Only Hercynian metamorphism is extensively supported by geochronological data. Alpine ages are limited to relatively small, fault-bounded blocks.

5) There is evidence of local Alpine epimetamorphic overprint. It is present solely in tectonic blocks (Eder unit and similars) located close to the Periadriatic Lineament and bounded by Alpine faults. Geochronological data are in accordance with a release of hypertermal fluids from Oligocene intrusives; in Late Miocene the metamorphosed rocks were exhumated in the present setting by transpressive tectonics.

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