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Preservation and thermal alteration of organic matter in the Ortles and Quattervals nappes (Upper Austroalpine, North-Eastern Lombardy, Italy): Preliminary results and implications for regional geology

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Key words: Austroalpine, Triassic, Italy, organic matter petrography, thermal maturity

ABSTRACT

About 150 samples collected in the Triassic sedimentary successions of the Ortles and Quattervals Nappes (Central Austroalpine) have been processed in order to evaluate and compare the thermal history of the two tectonic units. The study of the organic matter preservation based on the optical comparison of the palynofacies components colour (TAI) demonstrated that the Quattervals Nappe (occupying a tectonically higher position) had been subjected to higher diagenetic-metamorphic temperatures (estimated above 300°C) with respect to the Ortles Nappe (few tens of degrees lower). Heating is mainly ascribed to tectonic burial related to higher tectonic units eroded or tectonically displaced after the thermal peak and before the development of the present-day nappe edifice: it occurred before the emplacement of the present thrust nappes which was not followed by a new temperature rise able to overprint previously recorded temperatures. Heating and thrust development of the succession both occurred during the eo-alpine orogenetic stages (post-Turonian).

The presence, in the study area, of a previously documented increasing metamorphic gradient from west to east fits with the hypothesis of a south-eastern provenance of the higher tectonic unit (Quattervals Nappe) with respect to the lower one, as earlier suggested by different authors.

RIASSUNTO

Circa 150 campioni rocciosi provenienti dalle successioni sedimentarie di età triassica delle falde Ortles e Quattervals (Austroalpino Centrale) sono stati analizzati al fine di ricostruire e confrontare la storia termica delle due unità. La valutazione del colore e dello stato di conservazione della sostanza organica (TAI) ha dimostrato che la Falda Quattervals, tettonicamente in posizione superiore, è stata soggetta a temperature diagenetico-metamorfiche più elevate rispetto alla Falda Ortles. Il riscaldamento delle due falde (di poco superiore ai 300°C per la Falda Quattervals e poche decine di gradi in meno per la Falda Ortles) è avvenuto, almeno parzialmente, prima della messa in posto delle unità strutturali attualmente costituenti l'Austroalpino Centrale; questa messa in posto non è stata seguita da un successivo riscaldamento della pila di falde in grado di modificare le evidenze delle temperature raggiunte in precedenza. Sia il riscaldamento che la messa in posto delle falde sono di età cretacica (post-Turoniano). Il riscaldamento precedente alla messa in posto delle falde attuali è principalmente attribuibile al carico litostatico di unità tettoniche superiori non più conservate.

La presenza nel settore studiato di un gradiente metamorfico crescente verso est, si inquadra perfettamente con l'ipotesi, suggerita da tempo, di una provenienza dai quadranti sud-orientali dell'unità superiore più calda (Falda Quattervals) rispetto a quella sottostante.

Introduction

A study of the preservation degree of organic matter (OM) and organic phosphate fragments has been carried out on sediments belonging to the Ortles and Quattervals Nappes (Austroalpine Domain), cropping out in north-eastern Lombardy (Italy) (Fig. 1, 2). The two studied tectonic units, consisting of deformed Mesozoic sedimentary successions, are structurally referred to the Upper Austroalpine of the Central Alps (Central Austroalpine of Trümpy 1980) and geographically belong to the Engadine Dolomites (Fig. 1). The nappes, building up the Engadine Dolomites, structurally lie below the huge basement body of the Ötztal Nappe, which moved for more than 45 Km first towards north-west and then westwards (Schmid & Haas 1989). Movement of these Central Austroalpine tectonic units also occurred from east/south-east to west/north-west, as suggested for years (Spitz & Dyhrenfurth 1914; Dal Piaz 1936; Pozzi 1965; Schmid & Haas 1989; Froitzheim et al. 1994) and recently confirmed by studies on kinematic indicators along the main faults and thrust planes (Conti 1992, 1994).

The Ortles Nappe lies below the Quattervals Nappe (Fig. 3); the tectonic surface dividing the two nappes generally dips northwards and, only in Fraele Valley, becomes almost horizontal. The line representing this surface in outcrop is known as Alpisella Line or Trupchun-Braulio Line and shows a WNW-ESE trend.

Tectonic relationships between the two units are clear in the central part of the study area, whereas both eastwards and

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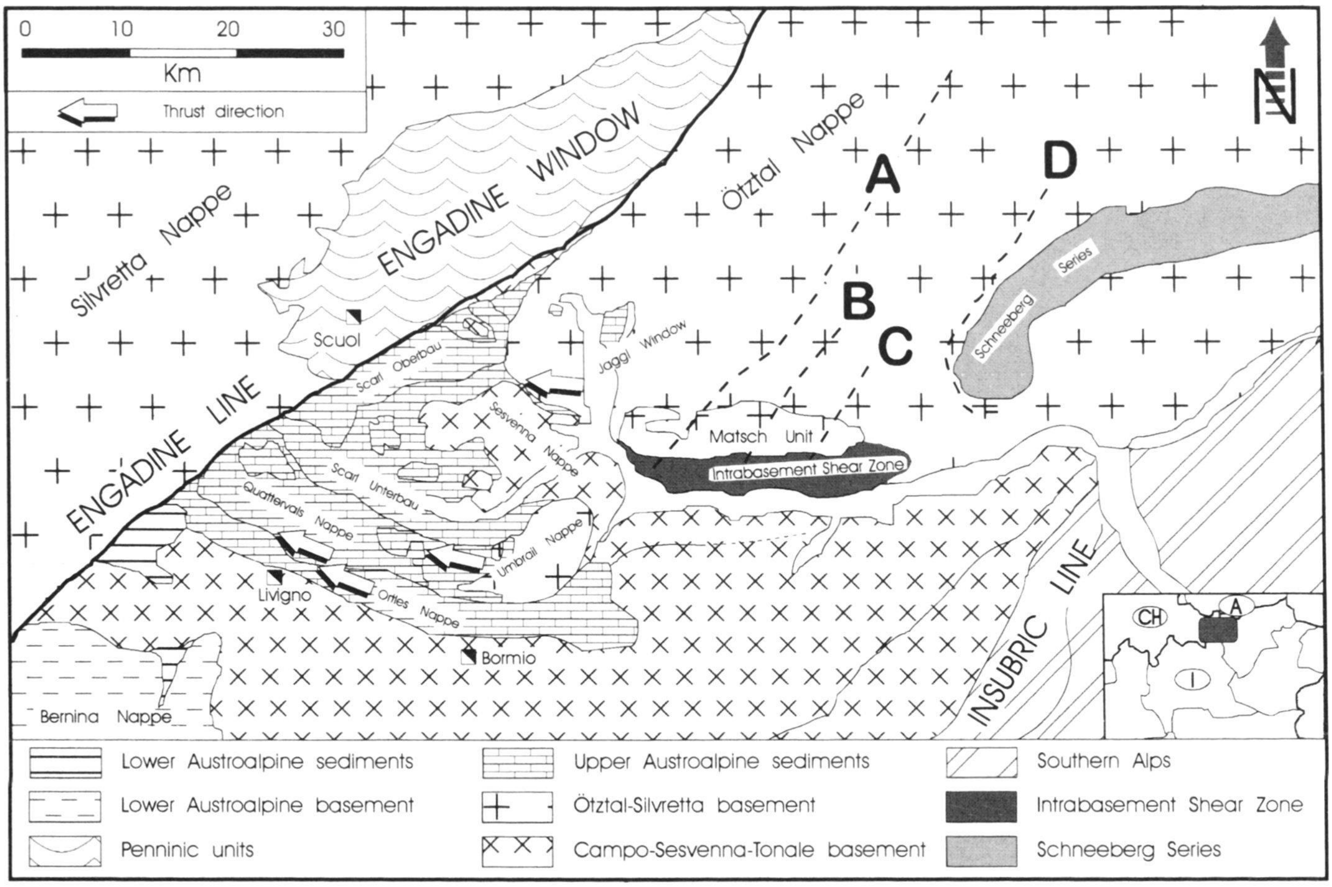


Fig. 1. Tectonic map of the surroundings of the study area (simplified after Spicher 1972 and "Structural Model of Italy 1:500,000" 1990). The distribution of the Eoalpine metamorphism in the Central Austroalpine Units is shown by the mineral zone boundaries in the Ötztal Nappe: a) Chloritoid in (440°C); b) Garnet in (480–490°C); c) Staurolite and chloritoid (520°C); d) Staurolite without chloritoid (550–600°C) (data from Thöni 1980; Frank et al. 1987a; Schmid & Haas 1989). The arrows along the thrust planes represent the direction of movement (from Schmid & Haas 1989; Conti 1992; and personal observations).

westwards different units occur and the Quattervals and Ortles Nappes pinch out, partially (Ortles) or completely (Quattervals): eastwards the Quattervals Nappe wedges out and the tectonically complex thrust body of the Umbrail unit (Umbrail-Chavalatsch Schuppenzone p.p., Schmid 1973) directly lies above the Ortles Nappe.

Geological setting

a) Stratigraphy

Ortles Nappe: the lower boundary of this nappe is represented in outcrop by the E-W trending Zebrù Line, which divides the sedimentary succession of the Ortles Nappe from the Hercynian basement of the Campo Nappe. Along the fault, tectonic slices of Permo-Scythian siliciclastic deposits (Verrucano or Chazforà Fm.), Middle Triassic carbonates, Carnian dolomites and gypsum locally occur: these slices are generally only a few metres thick and discontinuous, but locally (i.e. Alpe Trela) they can reach a thickness of a few hundred metres. The oldest formation widely exposed in the Ortles Nappe is the Hauptdolomit or Dolomia Principale (Dolomia del Cristallo in Bonsignore et al. 1969), consisting of an up to more than 1000 m thick succession of inner platform facies almost completely dolomitised during an early diagenetic phase. Towards the east, metric intercalations of dark thin-bedded limestones are common (Kappeler 1938; Pozzi 1959). The Hauptdolomit/Dolomia Principale forms most of the Ortles Nappe body between the Ortles Massif and Trepalle (east of Livigno); westwards the Hauptdolomit/Dolomia Principale tectonically pinches out against the Zebrù Line. This formation is overlain by shales and limestones of the Fraele Formation (or Kössen Formation), Late Norian-Rhaetian in age (Furrer 1993b; Berra & Cirilli 1997). Beginning at the Rhaetian-Hettangian boundary, sedimentation of cherty and marly limestones (M. Motto or Allgäu Formation) took place during the early Jurassic. Toward the west in Switzerland, younger sedimentary units crop

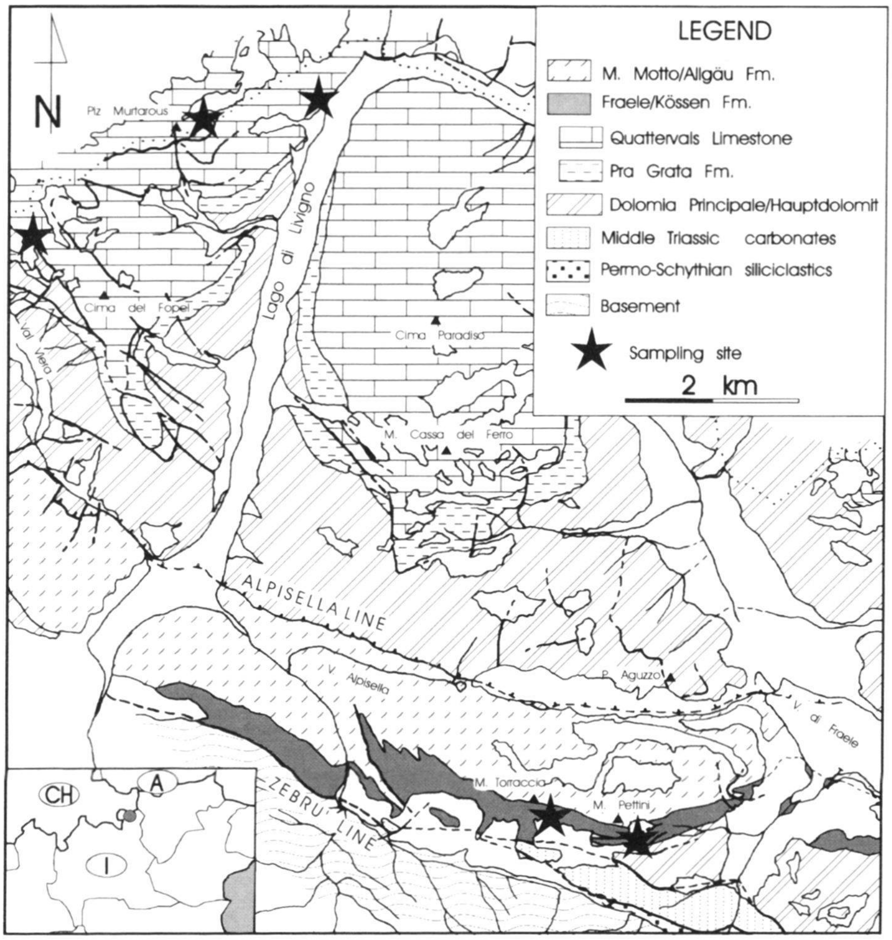


Fig. 2. Geological map of the investigated area, with the locations of sampling sites (stars).

out: the youngest rocks (Chànels Formation; Caron et al. 1982; Dössegger et al. 1982) are preserved in the core of a syncline. The age of the 10 to 20 metres thick Chànels Formation is Late Aptian-Middle Turonian, as documented by foraminifers (Caron et al. 1982). This formation consists of hemipelagic deposits of variegated shales and limestones rich in radiolarians, planktonic and benthonic foraminifers, with intercalation of sandy and bioclastic limestones (Furrer 1985).

Quattervals Nappe: north of the Alpisella Line, the thick Norian carbonate succession of the Quattervals Nappe crops out. In the study area three partly coeval formations are present (Hess 1953; Somm 1965; Berra 1994, 1995). The lower formation is represented by inner platform facies of the Hauptdolomit/Dolomia Principale, passing upward into a calcareous-dolomitic unit (Pra Grata Formation), which is overlain by dark, and generally thin-bedded, basinal carbonates of the Quattervals Limestone. These three Norian formations (more than 1000 m thick) document the evolution from an inner platform to an intraplatform basin related to syndeposi-

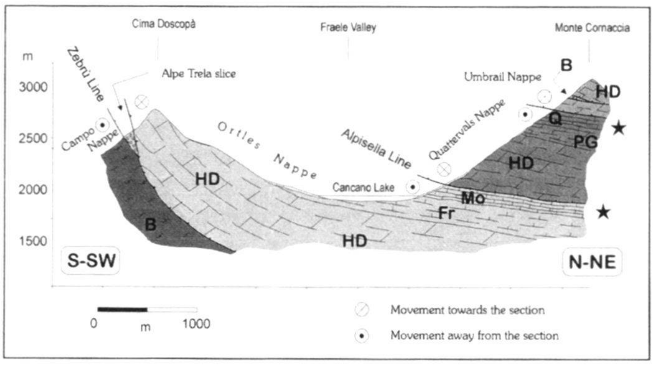


Fig. 3. Schematic geologic section across the nappe pile, with the stratigraphic and structural position (stars) of the sampled horizons. The section is more or less perpendicular to the direction of thrusting. The sample horizons come from the Fraele Formation (Ortles Nappe) and Quattervals Formation (Quattervals Nappe). B: Basement; HD: Hauptdolomit; Fr : Fraele Formation; Mo: Monte Motto Formation; PG: Pra Grata Formation; Q: Quattervals Formation.

tional tectonics (Berra 1995). The intraplatform basin had an east-west length of some tens of kilometres, a north-south width of about ten kilometres and a depth in the depocentre of a few hundred metres. To the west, in the Swiss National Park, younger formations are preserved: above the Quattervals Limestone, Hauptdolomit/Dolomia Principale outcrops document a recovery of the inner platform (Obernorischer Dolomit or Murteret Dolomit; Somm 1965; Dössegger et al. 1982; Furrer 1993a) and, at the top of the succession, the occurrence of the Kössen Formation is documented.

The sedimentary successions of the two considered nappes reflect a different paleogeographic evolution during the Norian. The Quattervals Nappe succession records the development of a Norian intraplatform basin, which was later closed by a progradation of shallow-water carbonate platform facies. Any evidence of intraplatform basin facies is lacking in the underlying Ortles Nappe, where inner platform conditions (Hauptdolomit/Dolomia Principale) persisted until the beginning of the mixed sedimentation of the Fraele Formation (Berra & Cirilli 1997).

b) Metamorphism in the Central Austroalpine: distribution and age

Information about distribution and age of Alpine metamorphism in the Austroalpine units of the Central Alps (generally from anchimetamorphism to greenschist facies) mainly derives from the study of the basement nappe of Ötztal, while recent data are available on most of the tectonic units of the Engadine Dolomites, mainly from the sedimentary covers (i.e. Henrichs 1993; Kürmann 1993). No data instead are available for the Quattervals Nappe. Alpine metamorphism overprinted the Hercynian metamorphism of the basement and affected the Permo-Mesozoic sedimentary cover of the Austroalpine nappes with different intensities. In the Ötztal Nappe, zoning of metamorphism shows a clear trend (Thöni 1980; Thöni 1983, Frank et al. 1987a; Schmid & Haas 1989; Fig. 1): the peak of the alpine metamorphism is documented in the Schneeberg complex area (with alpine temperatures around 550–600°C; Frank et al. 1987a), while temperatures decrease westwards. Data from the Scarl Nappe document lower temperatures with respect to the Ötztal Nappe (250–300°C in the westernmost part of the Ötztal Nappe, according to Schmid & Haas 1989). In the Ortles Nappe, a temperature of around, or slightly above, 300° is recorded in sediments of probably Carnian age by the growth of phengite and biotite (Thöni 1983). Recent studies on the sediments of the Ortles Nappe (Henrichs 1993; Kürmann 1993) document an early alpine anchimetamorphic overprint prior to nappe emplacement, with temperature evaluated around 230–240° (Kürmann 1993; in Permoscythian sediments) or 240–260° (Henrichs 1993; in Late Triassic sediments). Temperatures recorded across the Ortles Nappe show a decrease from east to the west, from more than 300°C in the east to diagenesis conditions westwards (Conti 1994). A similar trend (from epizone in the east to higher anchizone conditions in the west) is also documented for the Scarl Nappe (Kürmann 1993), which recorded higher temperatures with respect to the Ortles Nappe.

Alpine metamorphism can be referred to two main events (Thöni 1980; Frank et al. 1987b): a first metamorphic event dated around 70–100 Ma and a second one mainly dated around 12–20 Ma. The older one (eoalpine metamorphism, Cretaceous in age) is documented all over the Ötztal, Scarl and Ortles Nappes (Thöni 1983; Frank et al. 1987b), while the younger one (Late Alpine Tertiary metamorphism), is restricted to a relatively narrow zone in the area around and south of Vipiteno-Sterzing (near the Tauern Window; Thöni 1980; Frank et al. 1987b). Metamorphism affecting the Engadine Dolomites is related to the eoalpine orogenic event and any evidence for a later heating is not documented. The alpine micas in the Permian sediments of the southern part of the Scarl Nappe document an age of about 75–95 Ma. (white mica K/Ar dating; Thöni 1980) and were interpreted partly as cooling ages and as formation ages (in the north). One sample from of the Ortles Nappe (probably Raibl Beds, Carnian) contains micas which yielded K/Ar ages of 86 ± 6 and 86 ± 4 Ma. (uncorrected Rb/Sr age: 93 ± 19 Ma; Thöni 1983). Thöni (1983) suggests that the age of 86 my "may be interpreted as to trace the end of the progressive part of the Early Alpine metamorphism" and that "the postulation of a 90 ± 5 my T peak is *still valid, although a 90/85 T peak would possibly fit better, if* the most reliable data alone are considered" (p. 231). The youngest sediments of the Ortles Nappe (Chanel Formation) are Aptian to Middle Turonian in age (Caron et al. 1982): according to the geological time scale by Harland et al. (1989), the Turonian is dated from 90.4 to 88.5 Ma., very near to the age of the metamorphism.

Two different models have been suggested to explain the Cretaceous metamorphism of the Central Austroalpine units. Frank (1987) considered the metamorphism to be due to tectonic stacking which involved zones of already elevated heat flow, related to the Jurassic crustal thinning and the subsequent mantle rise. Schmid & Haas (1989) proposed that an important heat source was provided by subduction of very young (and consequently warm) oceanic lithosphere.

Data analyses

All the processed samples came from limestones of the Quattervals Formation (Middle-Late Norian, Quattervals Nappe) and of the Fraele Formation (Late Norian-Rhaetian, Ortles Nappe; Fig. 2, 3). They are taken from stratigraphic sections selected on the basis of two main requirements:

- they belong to relatively undeformed areas in order to avoid the effects of high temperatures related to local tectonics which could modify the thermal index derived from regional tectonics;
- sampling sites in the different nappes were chosen in order to compare the palaeotemperature along a vertical section across the two nappes.

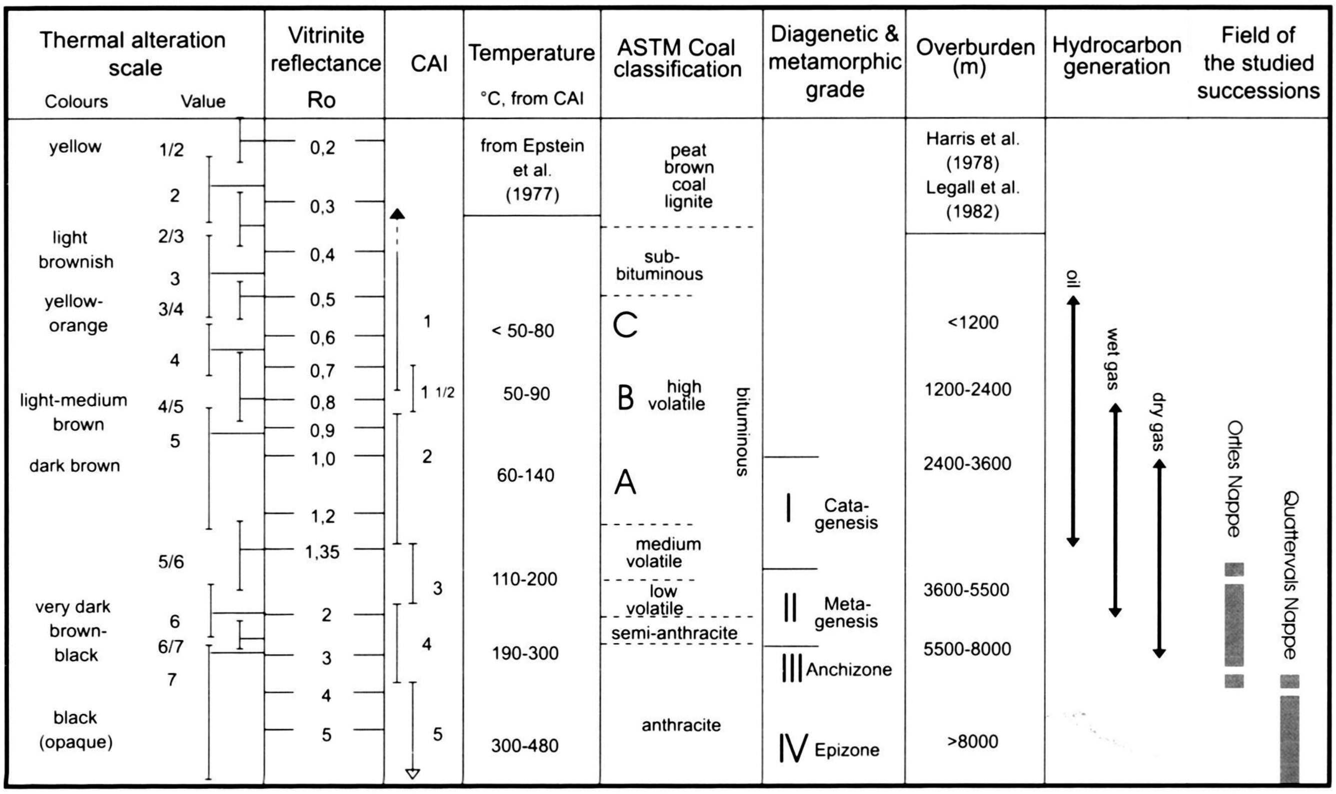


Fig. 4. Tentative comparisons among different scales of OM preservation and alteration, diagenetic and metamorphic grade, temperatures and overburden. The position of the two studied successions with respect to the different scales is represented in the last column.
The presented correlation does not consider the time of the heat exposures, except for the values of the temperature deduced by the CAI values.
Data sources: "Thermal alteration scale" from Gaupp & Batten (1985) (the vertical bars near the values represent the possible errors related to the TAI determination); "Vitrinite reflectance" from Dow (1977); "CAI" from Epstein et al. (1977); "ASTM Coal classification" from Staplin (1977); "Diagenetic and metamorphic grade" from Winkler (1979); "Overburden" from Harris et al. (1978) and Legall et al. (1981) (the thicknesses of the overburden are only examples deriving from studies respectively on the Appalachian Basin-USA and Michigan Basin-Canada); "Hydrocarbon generation" from Batten (1982).

Figure 2 shows the provenance of the processed samples, which were collected along measured stratigraphic sections. Most of the samples come from the Diga del Gallo section (Quattervals Nappe) and the M. Pettini section (Fraele Formation); additional samples were collected from sections in Val Viera and Piz Murtuaruo (Quattervals Formation) and from M. Torraccia (Fraele Formation).

The thermal history of sedimentary basins is controlled by a number of geological and geophysical factors following sedimentation. Special interest in thermal phenomena of sedimentary basins arise because they provide valuable information regarding the origin, development and tectonic history of sedimentary basins and because they have direct influence on the oil potential of source rocks.

Temperature and duration of exposure are the most important factors controlling the thermal maturation of organic material (OM). Most oil and gas present in sedimentary basin is generated when kerogen is converted to hydrocarbons. The chemical reactions are controlled by the nature and the abundance of kerogen, pressure and temperature, the latter being the most sensitive parameter in kerogen conversion (Tissot & Welte 1984; Tissot et al. 1987).

Temperature reached by sediments is reflected by the maturation and preservation degree of the OM.

The large number of analyses, about 150 samples, allowed to recognise two different maximum temperatures recorded in the studied successions; these results were obtained considering the Thermal Alteration Index, the conodont Colour Alteration Index (Fig. 4) and with a qualitative estimate of the recrystallisation degree of more than 110 petrographic thin sections from both the two formations, trying to compare samples with similar lithology. It was observed that the limestones of the Quattervals Nappe clearly show a stronger degree of recrystallisation compared to those of the Ortles Nappe (Fig. 5).

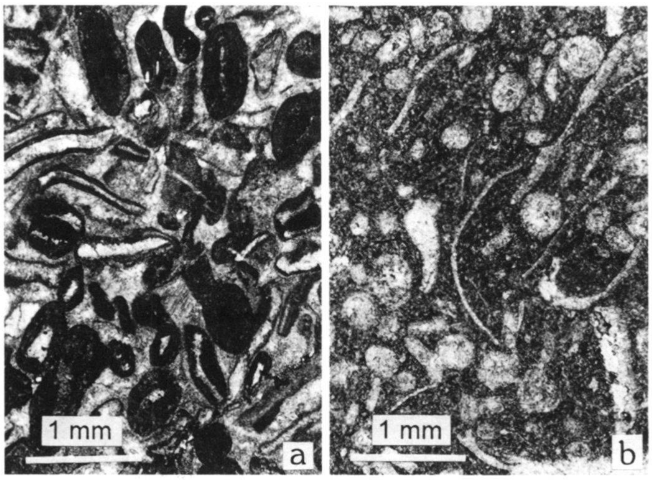


Fig. 5. Examples of microfacies from the sampled units. Note the different recrystallisation degree of the two oo-bioclastic packstones:

a: Fraele Formation, Ortles Nappe
b: Quattervals Limestone, Quattervals Nappe

Thermal alteration index (TAI)

The thermal alteration index is obtained from an analytic technique mostly based on measuring pollen and spore colour in unoxidised macerals in transmitted light (Staplin 1969, 1977). TAI was originally defined on spores and later observed also on liptinitic (i.e. hydrogen-rich) palynomorphs such as pollens and dinocysts (Robert 1988).

Several types of scales have been proposed for the coloration of spores and pollens (Hood et al. 1975; Gray & Bocout 1975). Gutjahr (1966) based his scale on "yellow through brown to black colour scale"; TAI from Staplin (1969) is based on microscopic observations of both colour and structural alteration of organic debris; Correia (1967) considered the preservation degree of palynomorphs. To reconstruct the thermal hystory of the Ortles and Quattervals nappes the TAI method, relatively fast and cheap, was used.

More than 150 samples of limestone from the Fraele and Quattervals formations have been processed in order to obtain a wide representative spectrum of TAI values. The standard procedure for palynological slides has been followed. Crashed samples have been etched with HCl and HF, in order to dissolve respectively carbonates and silicates. After sieving (with 250 μm and 10 μm sieve) the organic residue has been split into two parts: one part has been mounted on covered glass for palynofacies analysis and for studies on thermal alteration; the other part has been oxidised in order to destroy the more labile OM such as amorphous OM (AOM) and mounted on covered glass for studying palynological assemblages. Palynological analyses have been carried out in a transmitted light microscope.

Description of the organic constituents of palynofacies and their state of preservation follows the nomenclature introduced respectively by Whitaker (1984) and Hart (1986).

Accumulation and preservation of organic matter within sediments result from a complex interaction of several factors (Fig. 6; Batten 1982; Huc 1988; Tyson 1987, 1993, 1995). Accumulation is mainly linked to the primary productivity of the biomass, the input of allochtonous terrestrial material, the sedimentation rate and the depth of the depositional environment. The preservation degree of OM dispersed in the sediments commonly results (Fig. 6) from oxidation, transport and reworking processes, and from the sediment texture, which can favour or prevent the circulation of oxygenated pore waters. The sporopollenin degradation involves a large number of processes, some acting simultaneously, others at different times. It is important to distinguish between processes occurring mostly within the depositional environment or during the early stages of diagenesis and those taking place during burial, when heat is the main controlling factor. The former group comprises mainly biological and oxidation processes, mechanical damage due to long transportation and/or reworking: they do not give information about OM thermal maturity, but must be recognised for decoding the effects of diagenetic processes. The early diagenetic degradation may produce a gradual fading of the morphological structures and the partial or total destruction of pollen grains or local degradation of palynomorph walls linked to microbial activity. Instead, the increase of thermal gradients leads to a darkening of palynomorphs. Morphological details are generally slightly affected by heating, unless the anthracite stage is reached; OM thermal alteration, being related to burial and local or regional thermal gradients, gives confident information about the thermal history of the host sediments (Fig. 6).

Sediments of the Fraele Formation and Quattervals Limestone were deposited in poorly oxygenated basins with scarce or no life (Berra 1995; Berra & Cirilli 1997), where OM accumulated without being affected by oxidation or reworking, both biological and mechanical. Subsequently, OM (both marine and terrestrial) only scarcely underwent depositional and early diagenetic degradation: therefore, darkening of OM is mainly due to late diagenetic heating.

Results and interpretation: OM present in the two considered units shows strong differences with respect to the preservation degree, indicating different temperatures reached by the sediments:

- in the Quattervals Limestone, the colour of all the palynofacies components is black. Sometimes it is possible to recognise the nature of the original structured organic components such as palynomorphs, woody and tracheid remains and amorphous organic matter (AOM). Several specimens or palynodebris, composed of very resistant organic tissues, clearly show the original microstructures allowing the species identification (Fig. 7a–g). AOM, representing the most labile portion of OM, is still present, although completely black.

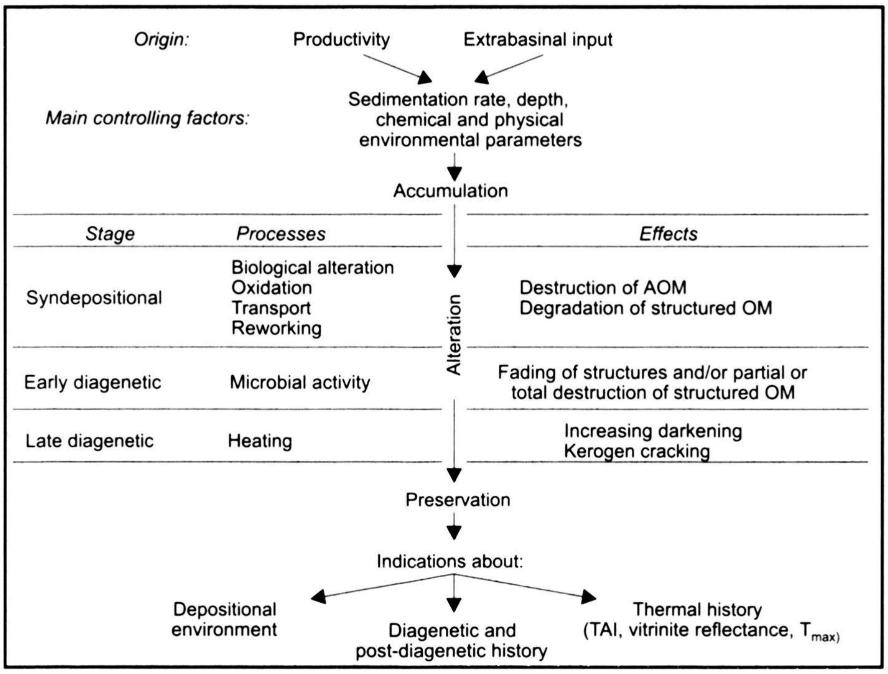


Fig. 6. Schematic diagram showing the factors controlling the production, accumulation and preservation of the organic matter in sediments.

All the constituents of the organic facies throughout the Quattervals Limestone are black: we consider that the present colour of the OM is related to post-depositional heating. We are confident that most of the OM is not of detrital origin or represents older recycled material in younger sediments, because the identified palynomorphs document a Norian age and the sedimentary succession did not record any important extrabasinal input.
By comparison with the thermal alteration scales of Staplin (1969, 1977) and Gutjahr (1966), the approximate TAI is estimated at > 6/7 (theoretically corresponding to a Ro > 2.9), and all OM is definitely overmature (Fig. 4).

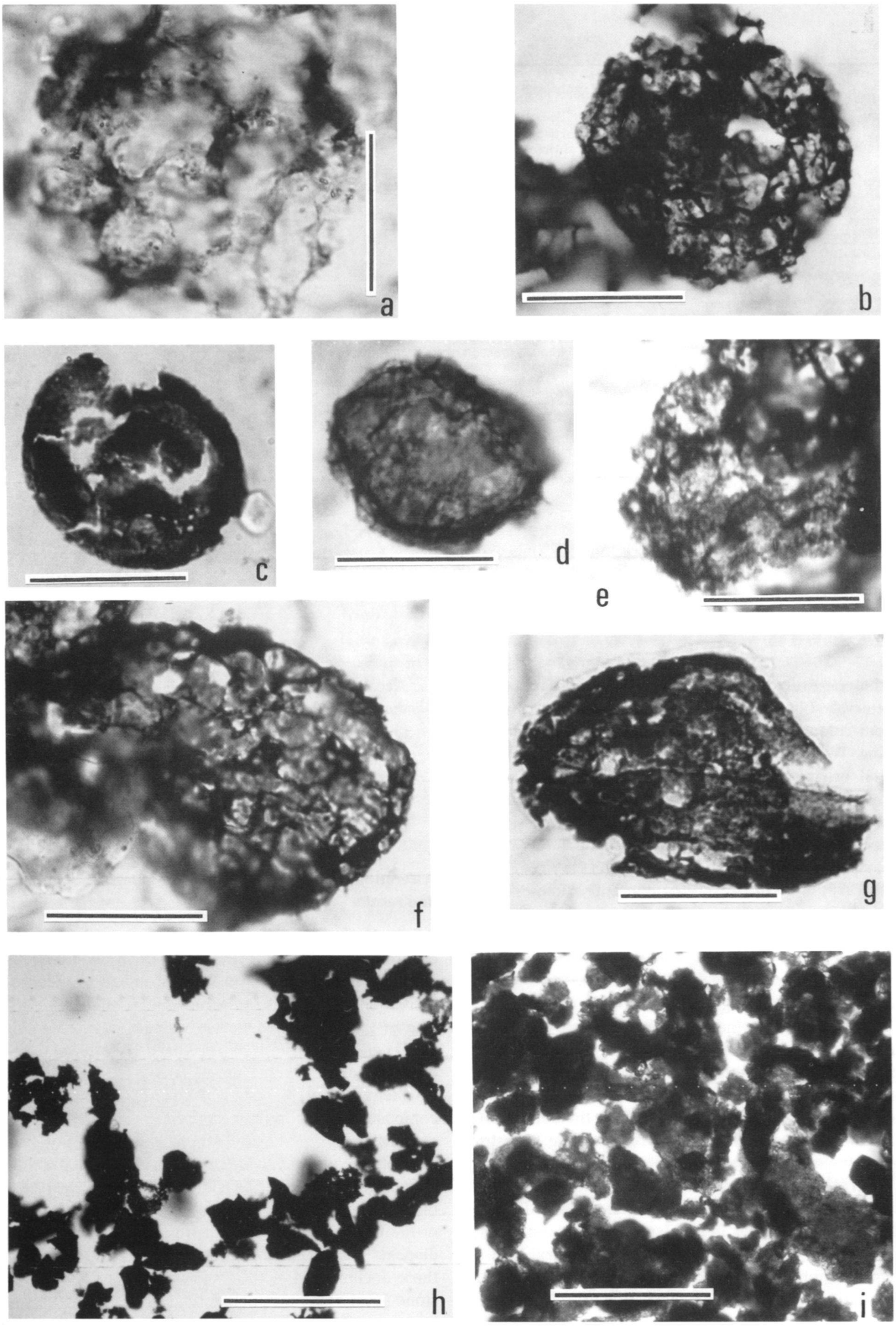
– in the Ortles Nappe (Fraele Formation), the palynomorph colour also indicates high-temperature diagenetic conditions, but the organic matter generally shows a brownish colour (Fig. 7a, c, g, i). Organic facies are mainly composed of dark brown AOM with variable amount of inertinite, vitrinite and palynomorphs. In both cases the variable amount of vitrinite and inertinite reflects the depositional conditions (Berra & Cirilli 1997), representing terrestrial organic fragments more or less recycled and transported basinwards (this situation was observed in the Kössen Formation also in other nappes; Krumm et al. 1988; Ferreiro Mählmann 1994, 1995, 1996; Henrichs 1993). Inertinite, being chemically the most stable palynomaceral, can be transported for long distances, and therefore be present in distal marine sediments as main constituent.

According to the reference scales, the approximate TAI of the Fraele Formation is comprised between 6 and 6/7, corresponding to a mean Ro between 1.5 and 2.9.
By comparing palynomorphs characterised by the same type of organic tissue and/or specimens belonging to the same species (Fig. 5), TAI from the two nappes appears to be clearly different (Fig. 4).

Alteration colour of phosphatic fragments (CAI): methods and results

About 15 calcareous samples were processed with acetic acid according to the standard technique for conodonts. The organic phosphate fragments (fish bones and scales) from the two formations were compared with tables used for the determination of the Colour Alteration Index (CAI) by Epstein et al. (1977) and Rejebian et al. (1987). These tables are generally used for conodonts, but the behaviour of the fish phosphatic fragments and conodonts, which have the same mineralogical composition, may be considered the same (A. Nicora, pers. comm.).

Both the phosphatic fragments from the Quattervals Limestone and the Fraele Formation show dark colours, almost black. Nevertheless, it is possible to recognise in the fragments of the Fraele Formation a brightness which documents lower diagenetic temperatures (CAI from 4 to 5) with respect to those documented by the fragments of the Quattervals Limestone (CAI 5). The colour of the fragments allows some con-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siderations about the temperature reached by the sediments. The boundary between CAI 4 and CAI 5 is considered to be around 300°C (Epstein et al. 1977; Rejebian et al. 1987) which may be the possible temperature recorded in the Fraele Formation. The range of CAI 5 is comprised between 300 and 480 °C (Rejebian et al. 1987): the Quattervals samples show a colour related to this class, but it is impossible to suggest a more precise temperature.

Discussion: working hypothesis

In the sediments of the Austroalpine units, important and abrupt changes in the paleotemperatures and metamorphism among different adjacent units have been observed during the last years (i.e. Krumm et al. 1988; Gawlick et al. 1994; Ferreiro-Mählmann 1994, 1995, 1996).

The method used in this study allowed to collect qualitative data (based on TAI and preservation degree of the OM) about the thermal evolution of the studied succession (this approach is very similar to that followed for CAI, but it can be used in successions where conodonts are missing). Nevertheless, the high number of processed samples and their provenance from different places of the two considered nappes allowed to obtain data which in our opinion are very confident, because the possibility of misinterpretation related to analysis on few samples or to local phenomena are strongly reduced. Therefore, this approach (because fast and relatively cheap) could be useful to point out geologic situations in which a more quantitative approach is worth being used.

The collected data document that the temperature reached by the sediments of the Quattervals Nappe is higher than that of the underlying Ortles Nappe; therefore a metamorphic inversion between Ortles and Quattervals nappes occurred. It follows that heating occurred, at least partially, before the development of the present nappes, whose overburden did not provide a thermal re-equilibration allowing the preservation of the record of former temperatures. Heating of the successions of the considered nappes was likely coeval (the development of the thermal peak for the Central Austroalpine units seems to be isochronous considering the absolute ages obtained from the different nappes; Thöni 1980, 1983) and occurred during the eoalpine orogenetic stages at different structural levels and therefore with different temperatures.

If the evaluated temperatures comprised 200 and 300° for the Ortles Nappe and slightly above 300°C for the Quattervals Nappe are correct and assuming a normal geothermal gradient, an approximated overburden ranging from 7 to 9 km respectively would be needed (Harris et al. 1978; Legall et al. 1981). Even considering lower temperatures (Henrichs 1993; Kürmann 1993) and a gradient of about 40°/km (Henrichs 1993) a minimum overburden of some 6 km is needed above the Fraele succession of the Ortles Nappe. In the Ortles Nappe, sediments above the sampled Fraele Formation up to the Chanels Formation are no more than 1000 m thick; they alone are surely insufficient to explain the heating of the succession, which occurred just after the deposition of the Chanels Formation. The subduction of a young oceanic crust alone (suggested by Schmid & Haas 1989, together with the tectonic overburden) seems insufficient to explain the metamorphism. The model of Frank (1987), who suggested the preservation of heat subsequent to Jurassic crustal thinning during the Cretaceous, does not seem satisfactory, because of the large time span (about 80 Ma) between crustal thinning and collision (Schmid & Haas 1989).

A tectonic overburden is needed to explain temperatures of about 300°C. Metamorphism developed after the deposition of the youngest sediments of the Ortles Nappe: the age of metamorphism must be at least slightly younger than Middle Turonian (see dating from Thöni 1980; Thöni 1983, 1988; Frank et al. 1987b). It is possible that the tectonic overburden acted together with an anomalous geothermal gradient (gradient of 40°/km is suggested by Henrichs 1993), leading to the estimated temperatures with a burial of less than 9 km (but more than about 6 km), partly provided by overlying sediments and partly by overthrust tectonic units. The thermal gradient was higher and/or the overburden thicker towards the Schneeberg complex area, where a stronger metamorphic overprint is recorded (Frank et al. 1987a, Schmid & Haas 1989).

The present framework of the Central Austroalpine may be explained as the result of the two following events. The first one is represented by the overriding of a huge and thick tectonic unit(s) above the Engadine Dolomites. The subsequent heating of the overridden sediments of the Ortles and Quattervals nappes (which still did not occupy the present-day position) was responsible for the development of the temperatures recorded by the organic matter. This stage was followed by another tectonic phase, responsible for the overthrusting of the nappes presently observed in the Central Austroalpine. This second tectonic event occurred after or simultaneously with the cooling, and was not sufficient to produce temperatures higher than those reached during the earlier phase. A relationship between heating and thrusting is observed and it is useful to distinguish the two phenomena, although it does not exclude a continuous evolution during the eoalpine orogenetic stages.

Fig. 7. The different colour and preservation degree of organic matter from the two investigated units outline the different temperatures reached by the host rock:
a) *Tsugapollenites* sp. from the Fraele Formation, Ortles Nappe; b) *Tsugapollenites* sp. from the Quattervals Limestone, Quattervals Nappe; c) *Corollina* sp. from the Fraele Formation, Ortles Nappe; d) *Corollina* sp. and e) *Trachysporites fuscus*, both from the Quattervals Limestone, Quattervals Nappe; f) *Ovalipollis pseudoalatus* from the Quattervals Limestone; g) *Ovalipollis pseudoalatus* from the Fraele Formation; h) palynofacies from the Quattervals Limestone, totally composed of inertinite (black opaque particles of organic matter); i) palynofacies from the Fraele Formation; the colour of the organic matter (included AOM) is brown, documenting a low thermal alteration with respect to the Quattervals Limestone (scale bar is about 50 µm in Fig. a to g; about 170 µm in Fig. h and i)

In the Austroalpine domain, the first tectonic event (gravitational gliding) dates back to the Late Jurassic; subduction of Penninic oceanic crust began during the Neocomian (Tollmann 1987; Frank 1987). Different Cretaceous tectonic events (mostly related to the closure of the Vardar Ocean) are documented in the Northern Calcareous Alps (NCA), both in sediments (e.g. Rossfeld Formation, Valanginian to ?Barremian, with ophiolite fragments; Decker et al. 1987; Pober & Faupl 1988) and tectonic structures. In the frontal part of the Eastern Alps, a first tectonic event is documented during the Albian (Austrian phase; Trümpy 1975), while the culmination of the nappe-forming process occurred during the Turonian (Frank 1987). Within the sedimentary succession of the Ortles Nappe, preserved up to the middle Turonian, no important alpine tectonic events are documented.

Turonian tectonics (pre Gosau) may be related to two different geodynamic mechanisms:

- the closure of the South Penninic ocean (i.e. Trümpy 1975; Frank 1987, Thöni 1988) and the subsequent collision of the Austroalpine domain with the Brianconnais crystalline wedge. The emplacement of the overburden needed to obtain the estimated temperatures was probably due to this tectonic phase (post-middle Turonian). The later development of the nappe edifice as observed now may be ascribed to a subsequent tectonic event which affected the previous nappe edifice. A large-scale crustal detachment and intracrustal fracturing, extensional and thrusting processes (following the compression stage related to the early-Late Cretaceous continental collision) is dated around 75 Ma (deformation ages from mylonitic rocks, coincident with the process of regional cooling) by Thöni (1988) in the Central Austroalpine;
- the final phases of the closure of the Hallstatt trough, located south of the NCA. The existence of this trough, floored at least partly by oceanic crust (probably connected with the Vardar Ocean, Channel et al. 1990, 1992), is documented since the Jurassic by sedimentary (Decker et al. 1987) and magnetostratigraphic evidence (Channel et al. 1990, 1992). This hypothesis suggests that the emplacement of the overburden might be due to a tectonic phase related to the closure of the Hallstatt trough, which was followed by another geodynamic event (related to the closure of the South Penninic domain?) which produced the present nappe organisation.

The latter model suggests that evolution of the Central Austroalpine area may be controlled by at least two Cretaceous tectonic (compressional) events with different geodynamic significance. The suggested possible closure of the Hallstatt trough around 90 Ma ago could have been caused (predating it) by the effects of the closure of the most external Penninic Ocean or to the compressional tectonics geodynamically related to the latter stages (affecting the Hallstatt trough representing the westward continuation of the basins) of the Late Jurassic closure of the Vardar Ocean.

In the Central Austroalpine a metamorphic gradient increasing eastwards from the Ortles-Quattervals area to the Ötztal Nappe is clearly documented. In the latter unit, which moved towards the west/north west (Dal Piaz 1936; Schmid & Haas 1989), the Permo-Mesozoic sediments underwent early-alpine (and locally meso-alpine) metamorphism (Thöni 1980), with increasing temperature from west to east within the nappes.

The occurrence of warmer units above colder ones, seems to point out that post-heating movement occurred from the hotter areas toward the western peripheral parts. This model fits with the tectonic reconstruction of the studied area, which documents a relative westward movement of the Quattervals Nappe with respect to the Ortles Nappe (Spitz & Dhyrenfurth 1914; Conti 1992, 1994).

So far, no vitrinite reflectance measurements have been carried out on the collected samples. Further investigations in this area are in progress, which will use vitrinite reflectance, in order to obtain more quantitative data on an area where qualitative analysis demonstrated different thermal histories in different nappes.

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REFERENCES

BATTEN, D.J. 1982: Palynofacies, paleoenvironments and petroleum. J. Micropaleont. 1, 107–114.

BERRA, F. 1994: Stratigrafia e paleogeografia del Triassico superiore delle falde Ortles e Quattervals (Austroalpino superiore) in Lombardia. PhD-thesis, Università degli Studi, Milano.

– 1995: Stratigraphic evolution of a Norian intraplatform basin recorded in the Quattervals Nappe (Austroalpine, Northern Italy) and paleogeographic implications. Eclogae geol. Helv. 88, 501–528.

BERRA, F. & CIRILLI, S. 1997: Paleoenvironmental interpretation of the Late Triassic Fraele Formation (Ortler Nappe, Austroalpine Domain, Lombardy). Riv. ital. Paleont. Stratigr., 103, 53–70.

BONSIGNORE, G., BORGO, A., GELATI, R., MONTRASIO, A., POTENZA, R., POZZI, R., RAGNI, U. & SCHIAVINATO, G. 1969: Note illustrative della Carta Geologica d'Italia, Foglio 8-Bormio. Serv. Geol. Ital., Roma.

CARON, M., DÖSSEGGER, R., STEIGER, R. & TRÜMPY, R. 1982: Das Alter der jüngsten Sedimente der Ortler-Decke (Oberostalpin) in der Val Trupchun (Schweizerische Nationalpark, Graubünden). Eclogae geol. Helv. 75, 159–169.

CHANNEL, J.E.T., BRANDNER, R., SPIELER, A. & SMATHERS, N.P. 1990: Mesozoic paleogeography of the Northern Calcareous Alps – Evidence from paleomagnetism and facies analysis. Geology 18, 828–831.

CHANNEL, J.E.T., BRANDNER, R., SPIELER, A. & STONER, J.S. 1992: Paleomagnetism and paleogeography of the Northern Calcareous Alps (Austria). Tectonics 11, 792–810.

CONTI, P. 1992: Tettonica delle Falde Austroalpine nelle Dolomiti dell'Engadina: un'ipotesi di lavoro. Atti Tic. Sc. della Terra 35, 61–66.
– 1994: La Falda Austroalpina dell'Ortles e l'evoluzione tettonica delle Dolomiti dell'Engadina (Svizzera, Italia). Boll. Serv. Geol. Ital., in press.
CORREIA, M. 1967: Relations possibles entre l'état de conservation des éléments figurés de la matérie organique (microfossiles palynoplanctologiques) et l'existence de gisements d'hydrocarbures. Rev. Inst. franc. Pétrole 22, 1285–1306.
DAL PIAZ, G.B. 1936: La struttura geologica delle Austridi. Nota III. Il sistema austroalpino nelle Alpi Breonie e Venoste e nel massiccio dell'Ortles. Nuovo schema tettonico delle Austridi della Venezia Tridentina e del Tirolo orientale. Atti r. Accad. Sc. Torino 71, 3–29.
DECKER, K., FAUPL, P. & MÜLLER, A. 1987: Synorogenic sedimentation on the Northern Calcareous Alps during the Early Cretaceous. In: Geodynamics of the Eastern Alps (Ed. by FLÜGEL, H.W. & FAUPL, P.), 126–141, Vienna, Deuticke.
DÖSSEGGER, R., FURRER, H. & MÜLLER, W.H. 1982: Die Sedimentserien der Engadiner Dolomiten und ihre lithostratigraphische Gliederung (Teil 2). Eclogae geol. Helv. 75, 303–330.
DOW, W.G. 1977: Kerogen studies and geological interpretations. J. Geochem. Explor. 7, 79–99.
EPSTEIN, A.G., EPSTEIN, J.B. & HARRIS, L.D. 1977: Conodont colour alteration – An index to organic metamorphism. U.S. geol. Surv. prof. Pap. 995.
FERREIRO MAHLMANN, R. 1994: Zur Bestimmung von Diagenesehöhe und beginnender Metamorphose-Temperaturgeschichte und Tektogenese des Austroalpins und Südpenninikums in Vorarlberg und Mittelbünden. Frankfurter geowiss. Arb., C, 14.
– 1995: Das Diagenese–Metamorphose-Muster von Vitrinitreflexion und Illit-"Kristallinität" in Mittelbünden und im Oberhalstein. Teil 1: Bezüge zur Stockwerktektonik. Schweitz. mineralog. petrogr. Mitt. 75, 85–122.
– 1996: Das Diagenese-Metamorphose-Muster von Vitrinitreflexion und Illit-"Kristallinität" in Mittelbünden und im Oberhallbstein. Teil 2: Korrelation kohlenpetrographischer und mineralogischer Parameter. Schweitz. mineralog. petrogr. Mitt. 76, 23–46.
FRANK, W. 1987: Evolution of the Austroalpine elements in the Cretaceous. In: Geodynamics of the Eastern Alps (Ed. by FLÜGEL, H.W. & FAUPL, P.), Deuticke, Wien, 379–406.
FRANK, W., HOINKES, G., PURTSCHELLER, F. & THÖNI, M. 1987a: The Austroalpine unit west of the Hohe Tauern: the Ötztal-Stubai complex as an example for the Eoalpine metamorphic evolution. In: Geodynamics of the Eastern Alps (Ed. by FLÜGEL, H.W. & FAUPL, P.), Deuticke, Wien, 179–225.
FRANK, W., KRALIK, M., SCHARBERT, S. & THÖNI, M. 1987b: Geochronological data from the Eastern Alps. In: Geodynamics of the Eastern Alps (Ed. by FLÜGEL, H.W. & FAUPL, P.), Deuticke, Wien, 272–281.
FROITZHEIM, N., SCHMID, S. M. & CONTI, P. 1994: Repeated change from crustal shortening to orogen–parallel extension in the Austroalpine units of Graubünden. Eclogae geol. Helv. 87, 559–612.
FURRER, H. (Editor) 1985: Field Workshop on Triassic and Jurassic sediments in the Eastern Alps of Switzerland-Guide Book. With contributions of B. Aemissegger, G. Eberli, U. Eichenberger, S. Frank, H. Furrer, H. Naef & R. Trümpy. Mitt. geol. Inst. ETH u. Univ. Zürich. [N. F.] 248.
– 1993a: Dinosaurier im Schweizerischen Nationalpark. Cratschla-Parc Naziunal Svizzer-Ediziuns Specialas 1, Zernez.
– 1993b: Stratigraphie und Fazies der Trias/Jura-Grenzschichten in den Oberostalpinen Decken Graubündens. Ph. D Thesis, Geol. Inst. Univ. Zürich (1981)
GAUPP, R. & BATTEN, D.J. 1985: Depositional setting of Middle to Upper Cretaceous sediments in the Northern Calcareous Alps from palynological evidence. N. Jb. Geol. Paläont. Mh. 10, 585–600.
GAWLICK, H.J., KRYSTYN, L. & LEIN, R. 1994: Conodont colour alteration indices: Paleotemperatures and metamorphism in the Northern Calcareous Alps – a general view. Geol. Rdsch. 83, 660–664.
GRAY, J. & BOCOUT, A.J. 1975: Colour changes in pollen and spores: a review. Geol. Soc. Amer. Bull. 86, 1019–1033.
GUTJAHR, C.C.M. 1966: Carbonization of pollen grains and spores and their application. Leidse geol. Meded. 38, 1–30.
HARLAND, W.B., ARMSTRONG, R.L., COX, A.V., CRAIG, L.E., SMITH, A.G. & SMITH, D.G. 1989: A geologic time scale 1989. Cambridge University Press.
HARRIS, A.G., HARRIS, L.D. & EPSTEIN, J.B. 1978: Oil and gas data from Paleozoic rocks in the Appalachian Basin: maps for assessing hydrocarbon potential and thermal maturity (conodont colour alteration isograds and overburden isopachs). U.S. geol. Surv. Maps, I–917-E.
HART, G.F. 1986: Origin and classification of organic matter in clastic systems. Palynology, 10, 1–23.
HENRICHS, C. 1993: Sedimentpetrographische Untersuchungen zur Hochdiagenese in der Kössen-Formation (Obere Trias) der westlichen Ostalpen und angrenzender Südalpengebiete. Bochumer geol. u. geotech. Arb. 40.
HESS, W. 1953: Beiträge zur Geologie der südöstlichen Engadiner Dolomiten zwischen dem oberen Münstertal und der Valle di Fraele (Graubünden). Eclogae geol. Helv. 46, 39–142.
HOOD, A., GUTJAHR, C.C.M. & HEACOCK, R.L. 1975: Organic metamorphism and the generation of petroleum. Amer. Assoc. Petroleum Geol. Bull. 59, 986–996.
HUC, A.Y. 1988: Sedimentology of organic matter. In: Humic substances and their role in the environment (Ed. by FRIMMEL, F.H. & CHRISTAN, R.F.), Wiley, New York, 215–243.
KAPPELER, U. 1938: Zur Geologie der Ortlergruppe und zur Stratigraphie der Ortlerzone zwischen Sulden und dem Engadin. Inaug. Diss. Univ. Zürich.
KOTTER, VON, K. 1960: Die Mikroskopische Reflexionsmessung mit dem Photomultiplier und ihre Anwendung auf die Kohlenuntersuchung. Brennstoff-Chemie 9/41, 263–272.
KRUMM, H., PETSCHICK, R. & WOLF, M. 1988: From diagenesis to anchimetamorphism, upper Austroalpine sedimentary cover in Bavaria and Tyrol. Geodinamica Acta, 2, 33–47.
KURMANN, H. 1993: Zur Hochdiagenese und Anchimetamorphose in Permotrias-Sedimenten des Austroalpins westlich der Tauern. Bochumer geol. u. geotech. Arb. 41.
LEGALL, F.D., BARNES, C.R. & MACQUEEN, R.W. 1981: Thermal maturation, burial history and hotspot development, Paleozoic strata of southern Ontario-Quebec, from conodont and acritarch colour alteration studies. Bull. canad. Petroleum Geol. 29, 492–539.
POBER, E. & FAUPL, P. 1988: The chemistry of detrital chromian spinels and its implications for the geodynamic evolution of the Eastern Alps. Geol. Rdsch. 77, 641–670.
POZZI, R. 1959: Studio stratigrafico del Mesozoico dell'Alta Valtellina (Livigno-Passo dello Stelvio). Riv. ital. Paleont. 65, 2–54.
– 1965: Schema tettonico dell'Alta Valtellina da Livigno al Gruppo dell'Ortles. Eclogae geol. Helv. 58, 21–38.
REJEBIAN, V.A., HARRIS, A.G. & HUEBNER, J.S. 1987: Conodont colour and textural alteration: An index to regional metamorphism, contact metamorphism and hydrothermal alteration. Bull. geol. Soc. Amer. 99, 471–479.
ROBERT, P. 1988: Organic metamorphism and geothermal history: microscopic study of Organic Matter and thermal evolution of sedimentary basins. Elf-Aquitaine and D. Riedel Publ. Comp.
SCHMID, S. 1973: Geologie des Umbrailgebiets. Eclogae geol. Helv. 66, 101–210.
SCHMID, S. & HAAS, R. 1989: Transition from near-surface thrusting to intrabasement decollement, Schlinig Thrust, Eastern Alps. Tectonics 8, 697–718.
SOMM, A. 1965: Zur Geologie der westlichen Quattervals-Gruppe im schweizerischen Nationalpark (Graubünden). Ergeb. wiss. Untersuch. im schweiz. Nationalpark, N. 52, Zürich.
SPICHER, A. 1972: Tektonische Karte der Schweiz, 1:500 000. Schweiz. Geol. Komm.
SPITZ, A. & DYHRENFURTH, G. 1914: Monographie der Engadiner Dolomiten zwischen Schuls, Scanf und Stilsiferjoch. Beitr. Geol. Karte Schweiz 44, 1 carta Geol. 1:50 000, Bern, 1–235.
STAPLIN, F.L. 1969: Sedimentary organic matter, organic metamorphism and oil and gas occurrence. Bull. canadian Petroleum Geol. 17, 47–66.
– 1977: Interpretation of thermal history from colour of particulate organic matter – a review. Palynology 1, 1–18. Structural Model of Italy, 1:500 000 (1990). CNR, Progetto Finalizzato Geodinamica.

THÖNI, M. 1980: Distribution of pre-Alpine and Alpine Metamorphism of the Southern Ötztal Mass and the Scarl unit, based on K/Ar Age Determinations. Mitt. österr. geol. Ges. 71/72, 139–165.
– 1983: The thermal climax of the early alpine metamorphism in the Austroalpine thrust sheet. Mem. Sci. Geol. Univ. Padova 36, 211–238.
– 1988: Rb-Sr isotopic resetting in mylonites and pseudotachylites/Implications for the detachment and thrusting of the Austroalpine basement nappes in the Eastern Alps. Jb. geol. Bundesanst 131, 169–201.
TISSOT, B.P. & WELTE, D.H. 1984: Petroleum formation and occurrence. 2nd ed: New York, Springer Verlag.
TISSOT, B.P., PELET, R. & UNGERER, P.H. 1987: Thermal history of sedimentary basins, maturation indices, and kinetics of oil and gas generation. Bull. amer. Assoc. Petroleum Geol. 71, 1445–1466.
TOLLMANN, A. 1987: The Alpidic evolution of the Eastern Alps. In: Geodynamics of the Eastern Alps (Ed. by FLÜGEL, H.W. & FAUPL, P.), Deuticke Wien, 361–378.
TRÜMPY, R. 1975: Peninic-Austroalpine boundary in the Swiss Alps: a presumed former continental margin and its problems. Amer. J. Sci. 275–a, 209–238.
– 1980: Geology of Switzerland. Part A: an outline of the Geology of Switzerland. Wepf & Co., Basel.
TYSON, R.V. 1987: The genesis and palynofacies characteristics of marine petroleum source rocks. In: Marine petroleum Source Rocks (Ed. by BROOKS, J. & FLEET, J.), 26, 47–67.
– 1993: Palynofacies analysis. In: Applied Micropaleontology (Ed. by JENKINS, D.J.), Kluver, Dordrecht, 153–191.
– 1995: Sedimentary Organic Matter. Chapman & Hall.
WHITAKER, M.F. 1984: The usage of palynostratigraphy and palynofacies in definition of Troll Field geology. In: Offshore Northern Seas – Reduction of uncertainties by innovative reservoir geomodelling. Norskpetrol. forening, article G6.
WINKLER, H.G.F. 1979: Petrogenesis of metamorphic rocks., Springer, Heidelberg.

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