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Stratigraphic evolution of a Norian intraplatform basin recorded in the Quattervals Nappe (Austroalpine, Northern Italy) and paleogeographic implications

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Key words: Austroalpine, Norian, carbonate platform, intraplatform basin, syndepositional tectonics, paleogeography

ABSTRACT

The Quattervals Nappe (Central Austroalpine) consists of a thick Norian succession which records a stratigraphic evolution from inner carbonate platform to intraplatform basin facies (Quattervals Basin).

This evolution is recorded by three partly coeval formations (from bottom to top): 1-Hauptdolomit or Dolomia Principale (up to 400–500 m thick), mainly represented by dolomitized inner platform facies; 2-Pra Grata Formation (thickness from 200 m southward to 20–30 m northward), characterized by alternations of dark thin-bedded limestones and dolomitic breccias and dolarenites; 3-Quattervals Limestone (more than 600 meters thick, the top being not preserved in the study area), mainly consisting of dark calcarenites and fine grained limestones.

Facies association and distribution allowed the reconstruction of the geometry and paleogeography of the basin with a width in N-S direction of at least 8 km. The preserved E-W length is about 30 km. Facies distribution and sedimentologic features, such as orientations of slump overfolds and submarine erosional surfaces, clearly document the asymmetry of the basin. The existence of two different margins can be inferred: a flexural type northern margin with a low angle slope and a fault-controlled southern one with a steeper slope.

The orientation of the synsedimentary faults of the southern margin was probably W-E or WNW-ESE: the Norian faults are likely to have been reactivated during the alpine orogenic phases. The development of the Quattervals Basin is related to extensional/transtensional tectonics. A Norian tectonic phase is documented almost all over the alpine realm and is usually related to the first stages of the extension responsible for the Jurassic opening of the Penninic Ocean. The characteristics of the Quattervals Basin suggest that its origin could be related not directly to the opening of the Penninic Ocean (Neotethys), but to the evolution of the Hallstatt basin (Paleotethys).

RIASSUNTO

La Falda Quattervals (Austroalpino Centrale) è costituita da una successione carbonatica di età norica, che documenta l'evoluzione stratigrafica da una piattaforma carbonatica interna intersubtidale ad un bacino intrapiattaforma (Bacino di Quattervals).

Questa evoluzione è registrata da tre formazioni parzialmente eteropiche, rappresentate, dalla base al tetto, da: 1-Dolomia Principale (potente circa 400–500 metri; la base non è conservata per motivi tettonici), principalmente rappresentata da facies di piattaforma interna completamente dolomitizzate; 2-Formazione di Pra Grata (con spessore compreso tra 200 m a sud e 20–30 m a nord), caratterizzata da alternanze di calcari scuri in strati sottili e brecce dolomitiche e doloareniti derivate dallo smantellamento della piattaforma carbonatica; 3-Calcare di Quattervals (spessore di almeno 600 metri, la sommità non è conservata nel settore studiato), rappresentato principalmente da calcari fini (calcareniti e calcilutiti) di colore scuro in strati sottili.

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La distribuzione delle facies all'interno dell'area bacinale, ha consentito la ricostruzione della geometria del Bacino di Quattervals, caratterizzato da una larghezza in senso N-S di almeno 8 km e da una lunghezza in senso E-O di almeno 30 km. La presenza di strutture sedimentarie (slumpings, superfici erosionali sottomarine) e la distribuzione delle facies (paraconglomerati, brecce) documentano un apporto di sedimenti fini sia dal margine settentrionale che meridionale del bacino, mentre la distribuzione dei corpi di breccia dolomitici evidenzia un apposto da sud di materiale derivato dallo smantellamento di porzioni della piattaforma. Il bacino mostra una evidente asimmetria, ed è possibile ipotizzare l'esistenza di due differenti margini: uno settentrionale, caratterizzato da un pendio inclinato di pochi gradi, ed uno meridionale di natura tettonica.

L'orientazione (dedotta sulla base della distribuzione delle facies) delle paleofaglie sinsedimentarie che bordavano a sud il Bacino di Quattervals era W-E o WNW-ESE: l'area in cui doveva svilupparsi la paleofaglia norica non è attualmente preservata a causa della tettonica alpina, che probabilmente ha riattivato tale faglia durante le fasi orogenetiche. Lo sviluppo del Bacino di Quatervals è legato ad una fase tettonica distensiva (o transtensiva). Una importante fase tettonica Norica è documentata ovunque nel dominio alpino e riferita alle prime fasi di sviluppo dell'Oceano Pennidico. Le caratteristiche del Bacino di Quattervals permettono di ipotizzare che la sua origine possa non essere direttamente legata geodinamicamente allo sviluppo dell'Oceano Pennidico (Neotetide) ma all'evoluzione del Bacino di Hallstatt (Paleotetide).

Introduction

The reconstruction of the relationships between the tectonic units ascribed to the Austroalpine of the Central Alps (Fig. 1) is one of the still unsolved problems affecting the alpine chain. The intense shortening due to the strong polyphasic alpine tectonics, the lateral wedging of the tectonic units and the erosion of a large part of the original sedimentary cover heavily complicates the paleogeographic reconstructions: the relationships among the sedimentary successions belonging to different nappes or even within a single nappe are often difficult to understand. The Quattervals Nappe succession, entirely represented by upper Triassic carbonates, shows a relatively weak alpine tectonic overprint, allowing a stratigraphic study. The sedimentary succession of the Quattervals Nappe (Upper Austroalpine) was studied between the Swiss-Italian border and the Fraele Valley in North-eastern Lombardy (Italy) (Fig. 2). The analysis of the facies distribution, together with sedimentary observations, led to the reconstruction of the paleogeography of the sedimentary basin and suggested possible relationships with coeval successions of nearby nappes.

Regional and geological setting

The Austroalpine Domain and the Southern Alps belong to the northern margin of the Adria or Apulian Plate, which represented the southern passive margin of the Jurassic Tethys. During the Norian, before the opening of this oceanic seaway (the rifting phase began in the Early Jurassic), the Alps and surrounding areas (Apennine, Hungary etc.) were characterized by the presence of a completely dolomitized inner carbonate platform extended for many thousands of km^2 (Hauptdolomit or Dolomia Principale). This platform developed in the westernmost termination of the Tethys ocean opened toward the east (Bosellini 1973; Kovacs 1982; Furrer 1985; Lein 1987; Ziegler 1988; Dercourt et al. 1990; Haas 1991; Tollmann 1990; Marcoux et al. 1993). Toward the continent, this widespread inner carbonate platform passed into the transitional facies of the Alpine Keuper (today partly preserved in the Helvetic domain), whereas a buildup margin (Dachstein Limestone) bordered the part of the platform facing the open sea (Paleotethys), where the basinal Hallstatt Limestone has been deposited.

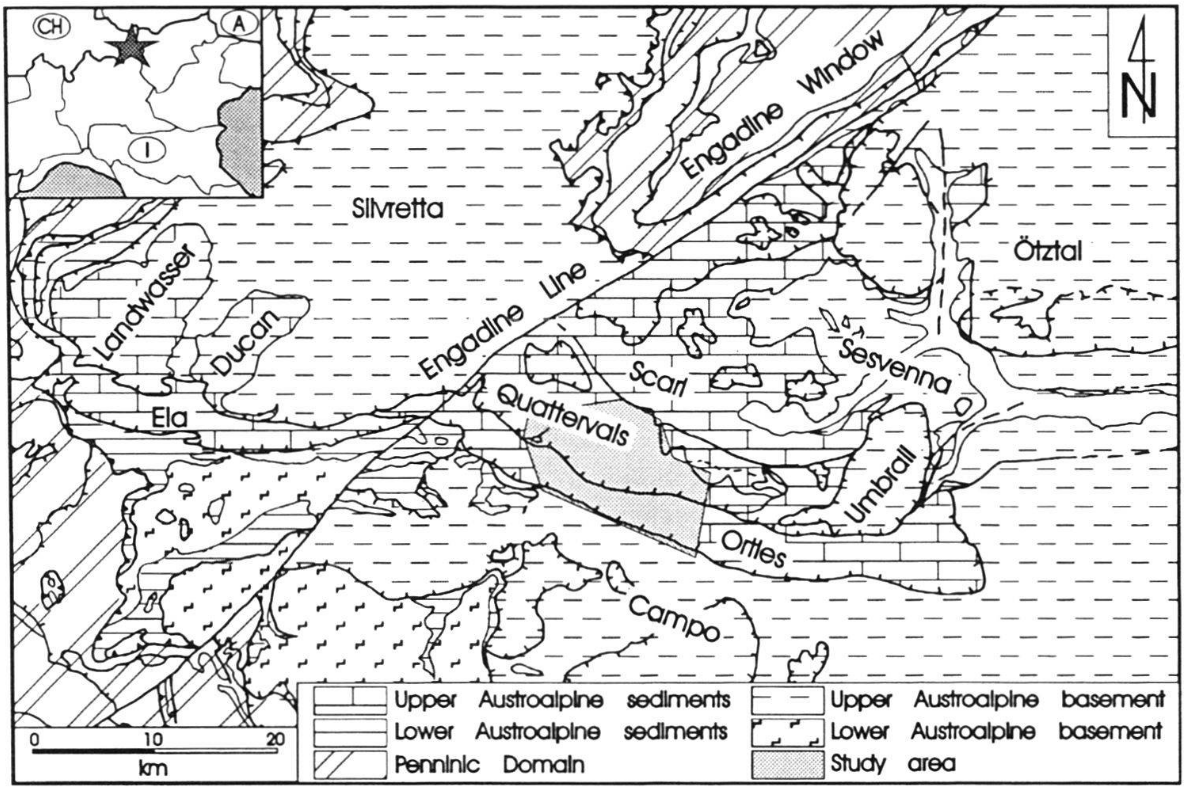

Fig. 1. Tectonic map of the Engadine Dolomites (simplified after Spicher 1972 and "Structural Model of Italy 1 : 500,000", 1990).

The deposition of the Hauptdolomit-Dolomia Principale platform facies occurred in hypersaline shallow water (only a few meters deep), due to the strong evaporation and scarce water exchanges with open seas. This situation led to the development of environmental conditions responsible for the complete early dolomitization of the platform facies.

Within this inner platform the occurrence of intraplatform basins and deep lagoons is documented, both in the Southern (Jadoul 1985; Cirilli & Tannoia 1988; Picotti & Pini 1989; Jadoul et al. 1992; Trombetta 1992) and Northern Calcareous Alps (Müller-Jungbluth W.U. 1968; Czurda & Nicklas 1970; Czurda 1973; Fruth & Scherreiks 1984; Brandner & Poleschinski 1986). The development of these troughs is ascribed to a Norian extensional-transtensional tectonic phase (Norian aborted rifting; Jadoul 1985). Facies distribution (occurrence of breccia wedges at the borders of the basins is typical), the development of intraplatform basins in areas previously characterized by inner platform facies and strong thickness variations (from few hundreds to 2,000 meters for the Hauptdolomit-Dolomia Principale), indirectly point out the existence of a differential subsidence due to synsedimentary tectonics. The Norian syndepositional tectonics are ascribed to the first stages of the opening of the Penninic Ocean, geodynamically related to the Central Atlantic.

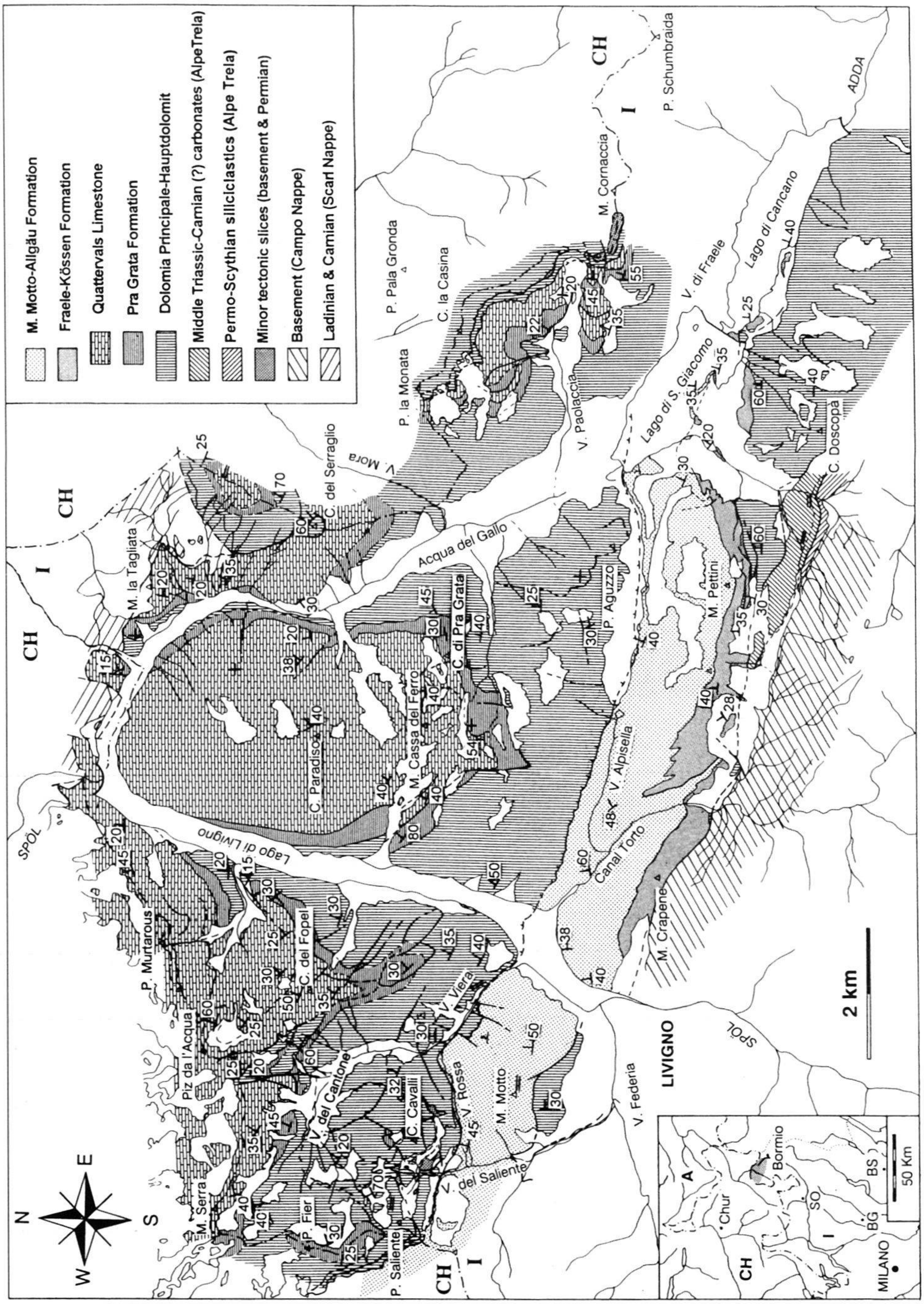

Fig. 2. Geological map of the study area (from Berra 1994).

<table>
<tr><th rowspan="2">Main Nappes / Authors</th><th colspan="7"></th><th colspan="4">Engadine Dolomites</th><th colspan="5"></th></tr>
<tr><th>Carungas</th><th>Err</th><th>Bernina</th><th>Ela</th><th>Dolomiti di Arosa</th><th>Languard</th><th>Campo</th><th>Ortles</th><th>Quattervals/ Terza</th><th>Umbrail</th><th>Scarl</th><th>Silvretta</th><th>Öztal</th><th>Allgäu</th><th>Lechtal</th><th>Inntal</th></tr>
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<tr><td colspan="10">CAA (Central Austroalpine)</td><td colspan="3">NCA (Northern Calcareous Alps)</td></tr>
<tr><td>Froitzheim et al. (1994)</td><td colspan="4">LOWER</td><td colspan="12">UPPER</td></tr>
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Fig. 3. Subdivisions of the Austroalpine units of the Central Alps.

Alpine tectonics strongly affected the pre-alpine paleogeography and the original stratigraphic successions are now preserved in different tectonic units. In the surroundings of the study area, nappes derived from different paleogeographic domains are present: Penninic units cropping out toward south-west are overthrust by strongly deformed Lower Austroalpine nappes which represented, during the Jurassic, the outermost part of the passive continental margin of Adria. These units are covered by Central Austroalpine nappes, separated by north-dipping or flat-lying thrust surfaces. The Central Austroalpine units may in turn consist of basement rocks, sedimentary rocks or both of them.

The Quattervals Nappe is one of the tectonic units of the Engadine Dolomites (Fig. 1). The Engadine Dolomites consist of nappes (mainly represented by carbonate rocks) referred to the Central Austroalpine (Trümpy 1980), which belongs, together with the Northern Calcareous Alps, to the Upper Austroalpine (Fig. 3). The alpine movement of the tectonic units in this area occurred from east/south-east to west/north-west (Spitz & Dyhrenfurth 1914; Dal Piaz 1936; Schmid & Haas 1989; Conti 1992, Froitzheim et al. 1994; Conti et al. 1994).

The Quattervals Nappe crops out from the Engadine Line to the west to the Umbrail unit to the east, for a distance of about 30 km. It lies above the Ortles Nappe and the tectonic surface between the two units is represented in outcrop by the Alpisella or Trupchun-Braulio Line. Northward, the Quattervals Nappe is bordered by the east-west trending Gallo Line, whose nature is still not clear. To the east, the Quattervals Nappe wedges out at the contact with the Umbrail unit. The relationships between these two units are not clear: Hess (1953) suggests a position of the Quattervals Nappe below the Umbrail unit, whereas Schmid (1973), Schmid & Haas (1989) and Froitzheim et al. (1994) consider the Quattervals Nappe as a slice of the Umbrail Nappe (Umbrail-Chavalatsch zone; Schmid 1973).

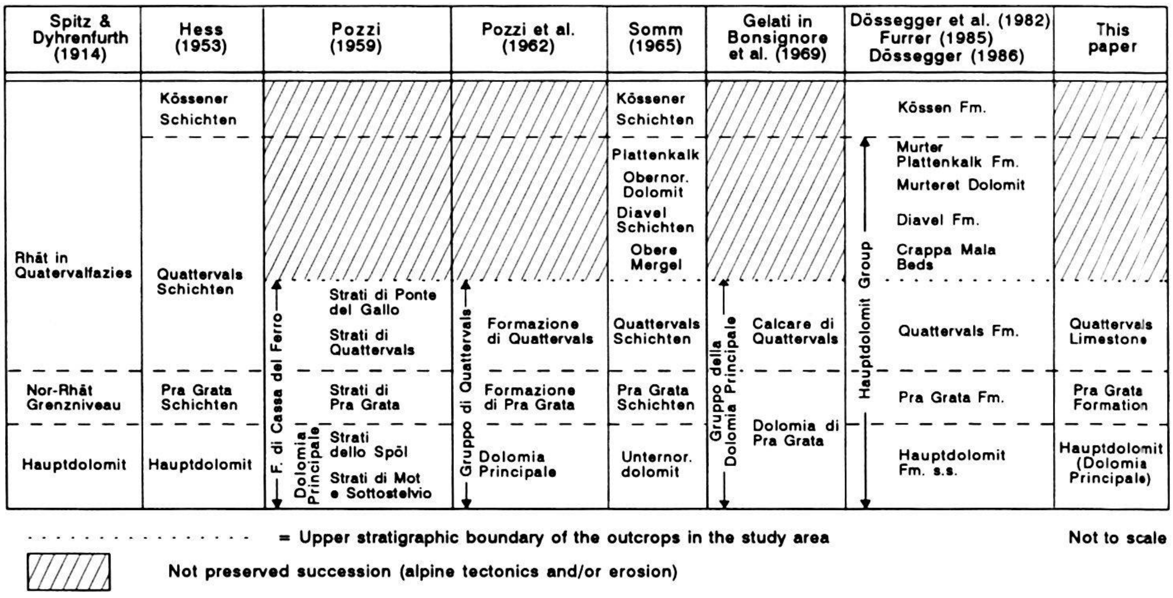


Fig. 4. Stratigraphy of the Quattervals Nappe according to different authors. The uppermost formations of the Hauptdolomit Group and the Kössen Formation are missing in the Italian part of the Quattervals Nappe due to alpine tectonics and erosion.

Bedding in the Quattervals Nappe is characterized by a general northward dip, with an average angle around 20–30°. Frequently minor faults and folds affect the sedimentary succession of this unit, but their effect is generally not so strong to avoid a stratigraphic investigation (Somm 1965).

Stratigraphy

Previous works

The Quattervals Nappe consists of an upper Triassic (mainly Norian, up to 1200 m thick) carbonate succession (Hess 1953; Somm 1965). The youngest sediments of the nappe are preserved in the Swiss territory (Swiss National Park). In the study area only the lower-middle part of the succession crops out, due to alpine tectonics and erosion: nevertheless it is well-exposed, allowing to detect the evolution and meaning of this Norian sedimentary basin.

Different stratigraphic subdivisions of the Quattervals Nappe succession have been proposed (Fig. 4). It is possible to recognize two main classifications: one derived from Hess (1953), who first dated the Norian Pra Grata and Quattervals Schichten, and the other derived from the "Note illustrative della Carta Geologica d'Italia – Foglio Bormio" (Bonsignore et al. 1969). The subdivision proposed by Hess (1953) was followed by Martina (1958) and generally shared by Pozzi (1959), Pozzi & Giorcelli (1960) and Pozzi et al. (1962). The nomenclature proposed by Hess (1953) was also followed by Somm (1965), who distinguished, in the upper part of the Quattervals Nappe succession (in the Swiss National Park), new stratigraphic units: this nomenclature has been followed, slightly modified, by Dössegger et al. (1982), Furrer (1985) and Dössegger (1986).

In this paper, the subdivision proposed by Hess (1953) is followed, even if the boundary of the units are revised and redefined in the light of the stratigraphic meaning of the three formations cropping out in the study area.

The lower formation is represented by the dolomitized inner carbonate platform facies of the Hauptdolomit. Only locally Carnian slices (Somm 1965) are present along the Alpisella Line. This formation passes upward into the Pra Grata Formation (Hess 1953), characterized by alternations of limestones and dolostones, then into the dark Quattervals Limestone, with at its top some 60 meters of marls (Crappa Mala Beds; Furrer 1985). Above a recovery of the carbonate platform is recorded by the Diavel Formation (with dinosaur footprints; Furrer 1993a) and the Murteret Dolomit. At the top of the Norian succession the subtidal facies of the Murtèr Plattenkalk occurs. The occurrence of Rhaetian sediments (Kössen Formation) in stratigraphic contact with the Norian succession is documented by Somm (1965) both in the Quattervals Nappe and in the Terza Unit (Furrer 1993b). In the study area, only the lower-middle part of the Quattervals Nappe succession is preserved, from the Hauptdolomit to the upper Quattervals Limestone.

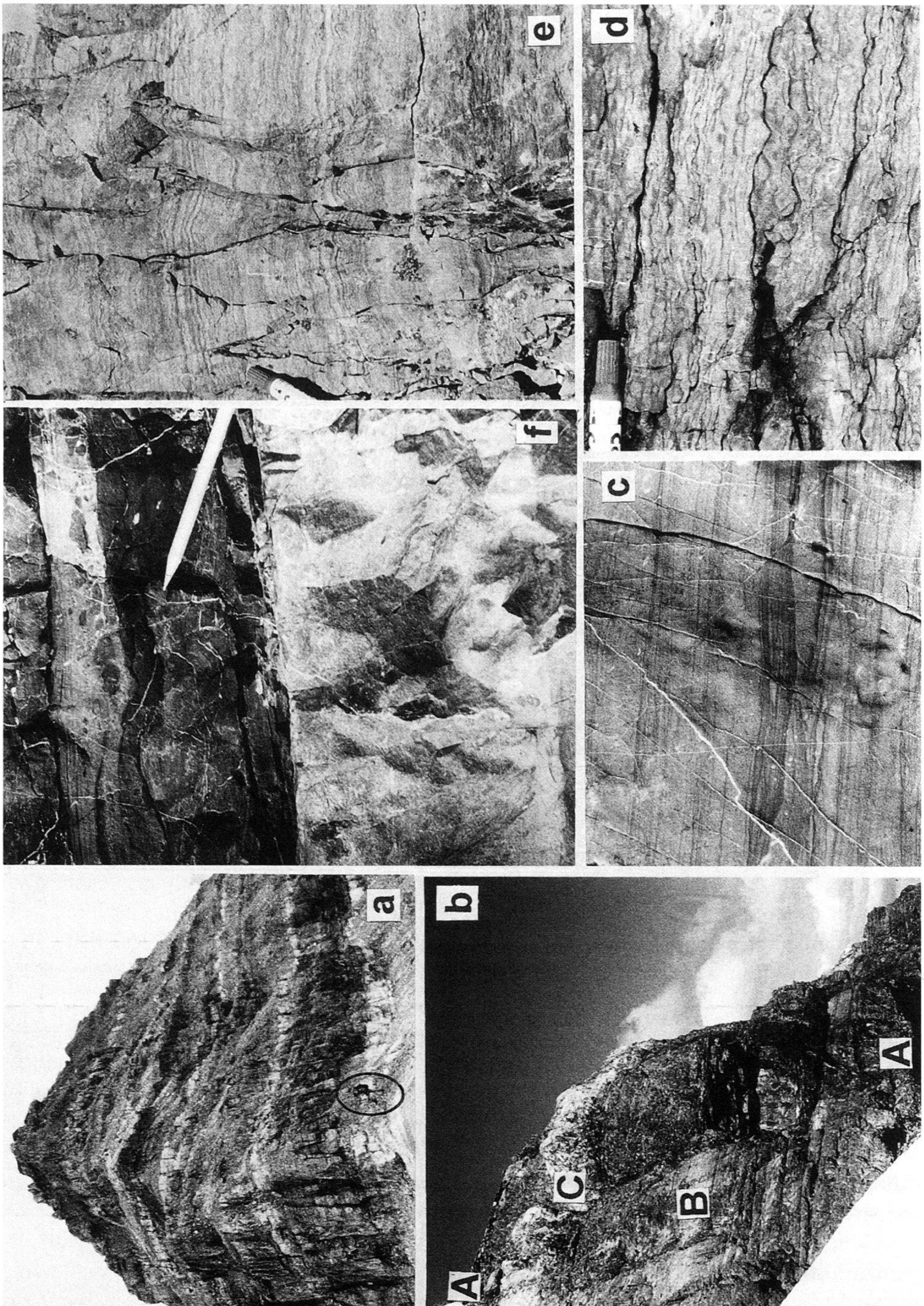
The presence of the thick Quattervals Limestone or its equivalents, is documented only in the Quattervals Nappe: in the bordering tectonic units, intercalations of limestones are documented within the Hauptdolomit, but they reach a thicknesses of a few tens of meters only (Ortles Nappe, Pozzi 1959; Pozzi & Giorcelli 1960; Dössegger et al. 1982; Scarl Nappe, Aemissegger in Furrer 1985; Umbrail Nappe, Hess 1953).

a) Hauptdolomit-Dolomia Principale

The Hauptdolomit crops out in the southern part of the Quattervals Nappe (Fig. 2). The stratigraphic base is never preserved in the study area; the lower boundary is represented by a thrust surface.

The Hauptdolomit of the Quattervals Nappe (Figs. 5, 6, 7) is mainly represented by irregular alternations of fine grained dark-grey dolostones and doloarenites both in centimetric and plurimetric layers locally with intraformational breccias. Infrequently limestones and dolomitic limestones are intercalated. Breccia beds are generally lenticular and a few centimeters thick, both clast- and matrix-supported. Doloarenites mainly consist of intraclastic packstones, rarely bioclastic or oolitic, often with normal grading (tempestites); ripples and cross laminations are also frequent. Original sedimentary structures are locally destroyed by burrowing. Stromatolitic horizons (up to more than 1 m thick) are common. Fine grained dolomites are often dark and strongly recrystallized: parallel laminations are the most common features in these facies. Emersions are documented by mud cracks, pseudomorphs after authigenic evaporitic crystals (Fig. 7) and fenestrae in the stromatolitic layers.

Generally these lithofacies are randomly distributed, nevertheless a cyclic facies organization was recognized in part of the succession. The ideal cycle shows a shallowing upward trend and is characterized by three facies (Fig. 6). The lower ("A" in Fig. 6) is represented by dark thin bedded (5–20 cm) laminated dolostones, with generally thin marly joints. Up in the cycle ("B") the colour becomes lighter, strata are amalgamated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and locally lenticular. Doloarenitic facies and bioclasts become more common. Often, intensive bioturbation affects the "B" portion of the cycle. The top of the cycle ("C") is commonly represented by dolomitized stromatolitic bindstones. The alteration colour is light grey; fenestrae, sheet and prism cracks are common. Some cycles may be only partially developed: facies "A" can be strongly reduced or completely lack, whereas the stromatolitic horizon ("C") can be replaced by 30–40 cm of light-coloured bioclastic dolostones.

The thickness of each cycle ranges from 0,5 to 8 meters, with an average from 4 to 6 meters. Within the formation, a vertical evolution of the facies has been detected. In the lowermost Hauptdolomit (near the Alpisella Line) breccia bodies with clasts up to 50 cm occur ("Basal Breccias of the Dolomia Principale" Auct.). The middle part of the Hauptdolomit is characterized by the common occurrence of cyclic facies. In the upper Hauptdolomit, the occurrence of sedimentary dykes (Fig. 7) and breccia bodies with lithified clasts documents the beginning of the tectonically induced platform drowning, which will lead to the development of the Quattervals Basin.

The upper boundary of the Hauptdolomit with the overlying Pra Grata Formation is marked by the first occurrence of plurimetric and frequent limestones intercalations.

The thickness of the Hauptdolomit is around 400–500 meters; the strong alpine tectonics do not allow a precise evaluation.

Depositional environment

The facies and microfacies analysis document that the deposition of the Hauptdolomit of the Quattervals Nappe occurred on an inner carbonate platform with mainly intertidal to upper subtidal conditions, with local and short-term emersions. The generally dark colour of the subtidal facies, documents low-oxygenated bottoms and a reducing environment, where the organic matter was not completely oxidized.

Events of higher energy and better oxygenation are documented by light grey doloarenites with current structures and by burrowed sediments. The scarce paleontological differentiation (both biomass and taxonomic diversity) within the formation is another indi-

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Fig. 5. Aspects and lithofacies of the Hauptdolomit of the Quattervals Nappe:

a) Cyclic organization of the Hauptdolomit (light layers are stromatolitic beds). Geologist (circled) for scale. Stratigraphic section north of the Corna dei Cavalli.

b) Typical aspect of a shallowing upward cycle, bordered at the top by a light stromatolitic layer. Note at the base of the picture the top of the underlying cycle. Letters refer to Fig. 6. Stratigraphic section north of the Corna dei Cavalli (the depicted cycle is 6.5 m thick).

c) Fine grained laminated dolostones of the lower part of the cycle. Lago di Livigno section.

d) Fine grained burrowed dolostones in the central part of the cycle. Stratigraphic section north of the Corna dei Cavalli.

e) Detail of the stromatolites at the top of the cycles. The thickness of the depicted stromatolitic layers is more than one meter. Stratigraphic section north of the Corna dei Cavalli.

f) Detail of a cycle boundary, where the sharp contact between the light lower part (C, consisting of intertidal stromatolitic dolostone) and the dark top (A, represented by fine grained laminated doloarenites) is extremely evident. Note the thin intraformational breccia layer (above the pencil), with erosional base and laminations. Lago di Livigno section.

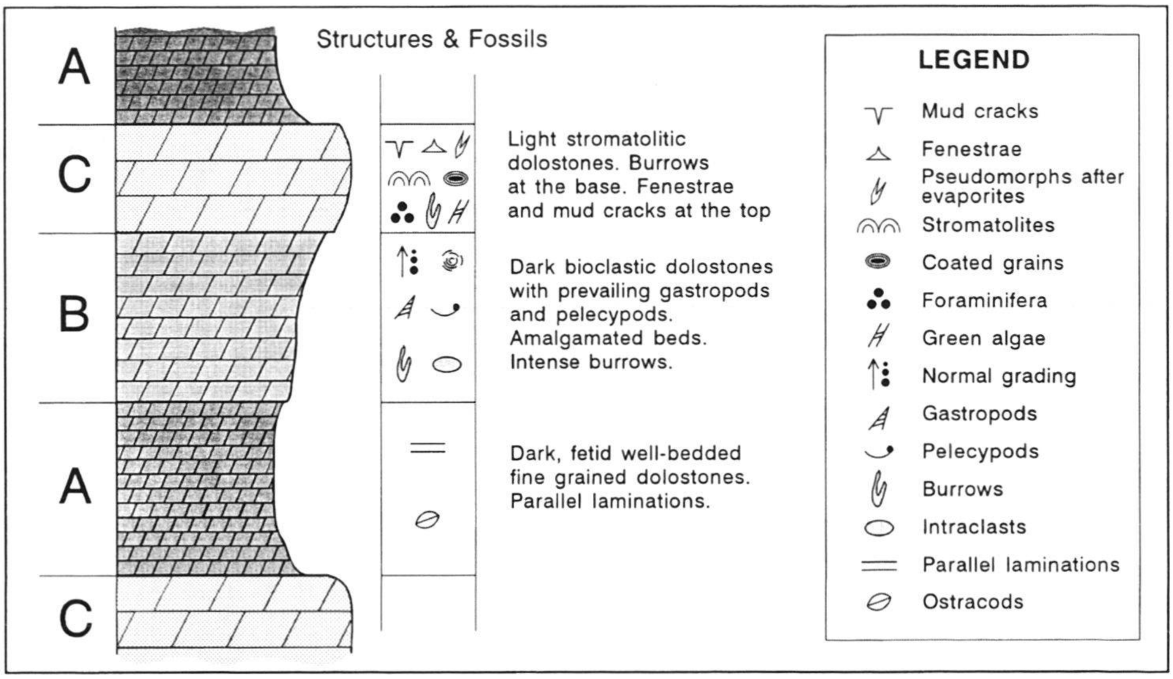
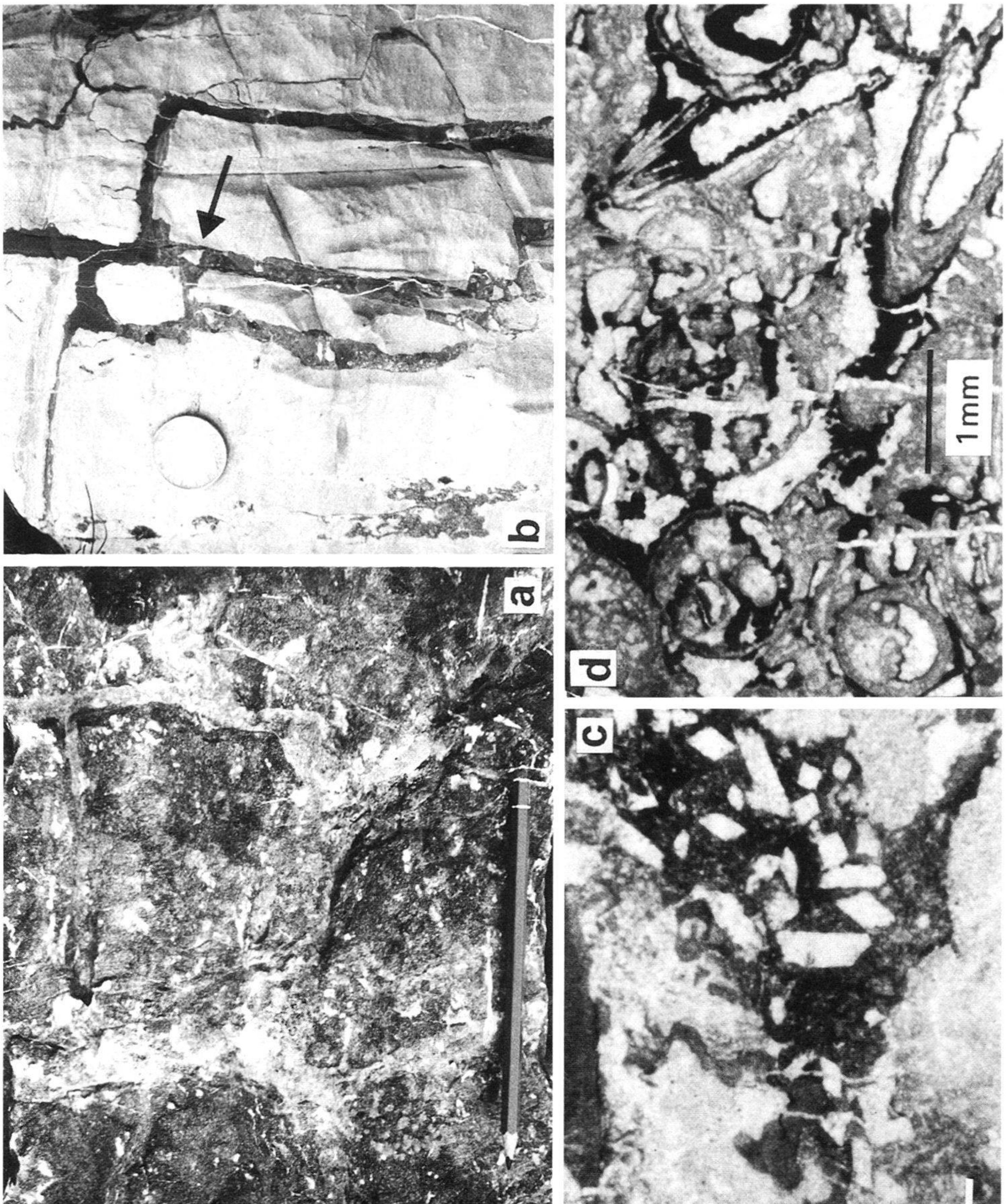


Fig. 6. Sketch of an ideal shallowing upward cycle of the Hauptdolomit of the Quattervals Nappe (thickness from 0.5 to 8 m).

rect indicator of unfavourable environmental conditions: fossils are mainly represented by pelecypods and gastropods (mainly as fragments in the doloarenites) and only rarely by dasycladaceans and benthic foraminifera (mainly oligotypic assemblages of specimens belonging to the genera *Glomospirella, Glomospira, Agathammina* and *Earlandia*). In the subtidal facies, ostracods are locally present. The fact that the organisms of the margin facies of the Dachstein Limestone (i.e. Zankl 1971) did not manage to conquer the inner platform (Hauptdolomit-Dolomia Principale) can only be ascribed to an environmental barrier: the inner platform waters did not have the same characteristics as the normal marine water. Probably the insufficient water exchange and the strong evaporation changed the water salinity, leading to the development of poorly differentiated communities as those observed in the investigated area, which were able to survive in hypersaline waters (Furrer 1993b).

Fig. 7. Lithofacies and microfacies of the Hauptdolomit:
a) Mud cracks on the bed top. Eastern side of the Lago di Livigno.
b) Tensional dykes filled with dark fine material in the upper part of the Hauptdolomit. The arrow points at an angular clast within the dyke, documenting that the host rock was lithified when the dyke developed. Valle del Cantone.
c) Dolomite pseudomorph after sulphates (gypsum?) at the top of a shallowing upward cycle. Lago di Livigno section.
d) Bioclastic packstone rich in dasycladacean algae, with micritized borders, at the top of an incomplete shallowing upward cycle. Lago di Livigno section.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Considerations about the Hauptdolomit cycles

The occurrence of cyclic sedimentation in the Triassic carbonate platforms related to sea-level changes is commonly observed, as the studies of Sander (1936), Schwarzacher (1948, 1954) and Fischer (1964) have pointed out. The allocyclic nature of the carbonate platform cycles is difficult to prove, because carbonate platforms generally lack biostratigraphic tools and because of the strong lateral facies variations and frequent emersions, which made carbonate platforms particularly hiatus-prone. Nevertheless, cycles in carbonate platforms have been interpreted as allocycles (i.e. Goldhammer et al. 1987, 1990, in the middle Triassic Latemar Platform, Dolomites).

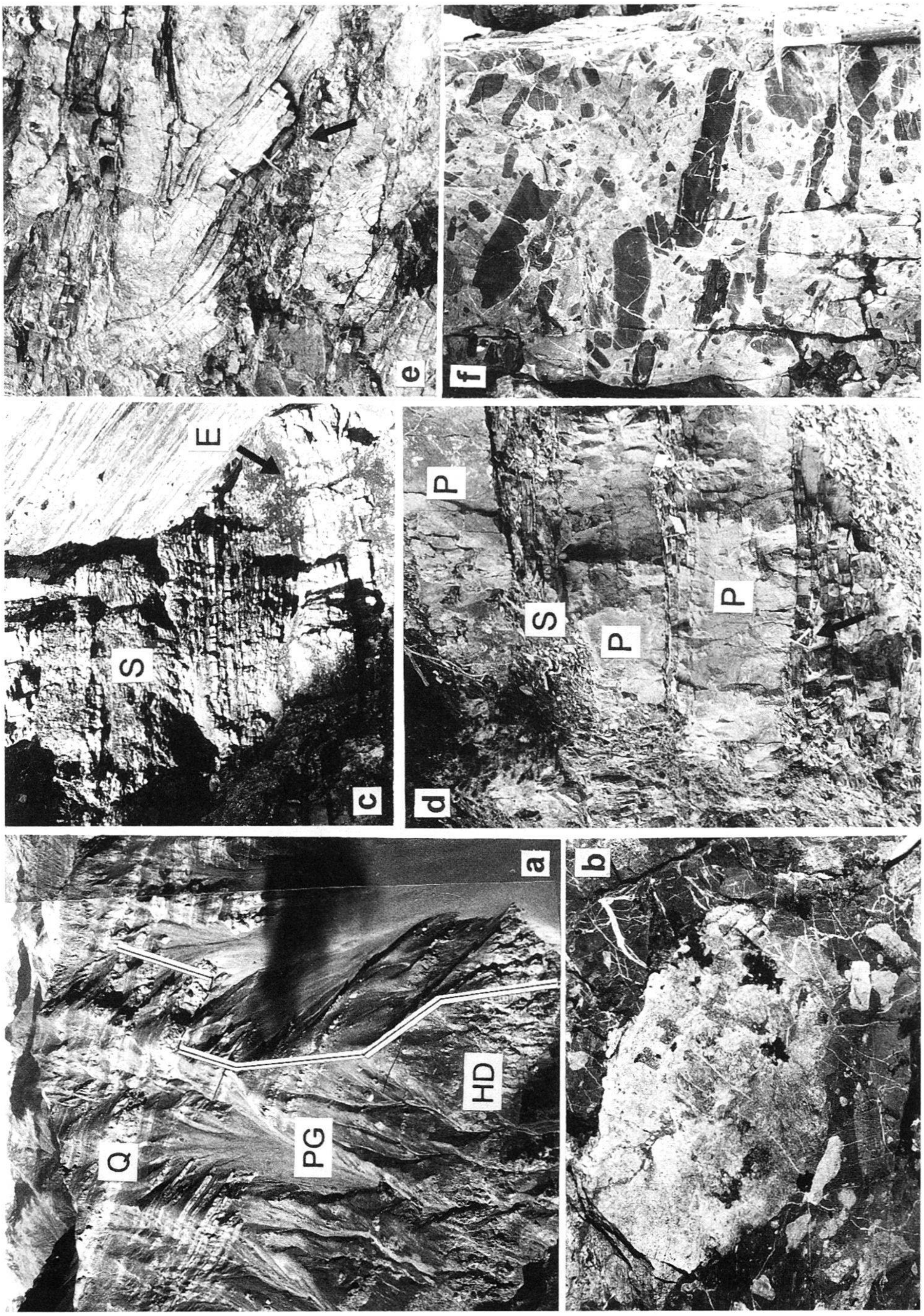
The cycle thickness variations and the occurrence of non-cyclic portions exclude a continuous record of a cyclic signal in the studied Hauptdolomit sections. Nevertheless the existence, in some parts of the succession, of a strong cyclic control during the Hauptdolomit deposition is recorded. The available data do not allow to recognize if the shallowing upward cycles of the Hauptdolomit are controlled by autocyclic or allocyclic phenomena, mainly because of the strong alpine tectonics which do not permit the study of long undisturbed sections and also because of the missing biostratigraphic control.

The facies organization of the Hauptdolomit can be explained with the interaction of two phenomena, sometime prevailing one on the other: a cyclic one (allocyclic?) and an aperiodic one. They are of different intensity and discontinuous (probably related to local and random phenomena, i.e. changes in the subsidence rate). It is possible to suggest that a cyclic signal could have existed during all the Hauptdolomit deposition, but that it was periodically covered by aperiodic phenomena: cyclic control is recognizable only when the aperiodic signal disappears or acts as background noise.

b) Pra Grata Formation

The Pra Grata Formation crops out in the southern-central part of the Quattervals Nappe, along a more or less E-W belt, from Val Viera to Cima di Pra Grata (Fig. 2). Northwards it is less developed, mainly due to the decreasing thickness of the formation.

Fig. 8. Aspect and lithofacies of the Pra Grata Formation and of the Quattervals Limestone:
a) View of the Valle del Cantone section, one of the best preserved and more complete of the Quattervals Nappe in the study area (HD = Hauptdolomit; PG = Pra Grata Formation; Q = Quattervals Formation). The line follows the trace of the measured section (simplified in Fig. 13).
b) Typical aspects of the dolomitic breccias intercalated with limestone in the Pra Grata Formation. Val Trenzeira.
c) Submarine erosional surface in the lowermost Quattervals Limestone, interpreted as slump scar. Note the thin bedded limestone onlapping the erosional surface (E). S: slump. Val Trenzeira, 2080 m asl.
d) Paraconglomerate beds (P) with intraformational clasts alternating with thin bedded limestone (locally slumped, S) in the lower part of the Quattervals Limestone. Hammer (arrow) for scale. Diga del Gallo section (simplified in Fig. 12).
e) Large meter-scale slump in thin bedded limestones, lower Quattervals Limestone (hammer for scale, arrow). The vergence of the slumping is toward the south. Diga del Gallo section (simplified in Fig. 12).
f) Detail of a paraconglomerate bed: among the clasts, it is possible to note both slope (dark, calcareous) and platform derived (light, dolomitized) clasts in a calcareous matrix. Northern side of Cima del Fopel, 2655 m asl.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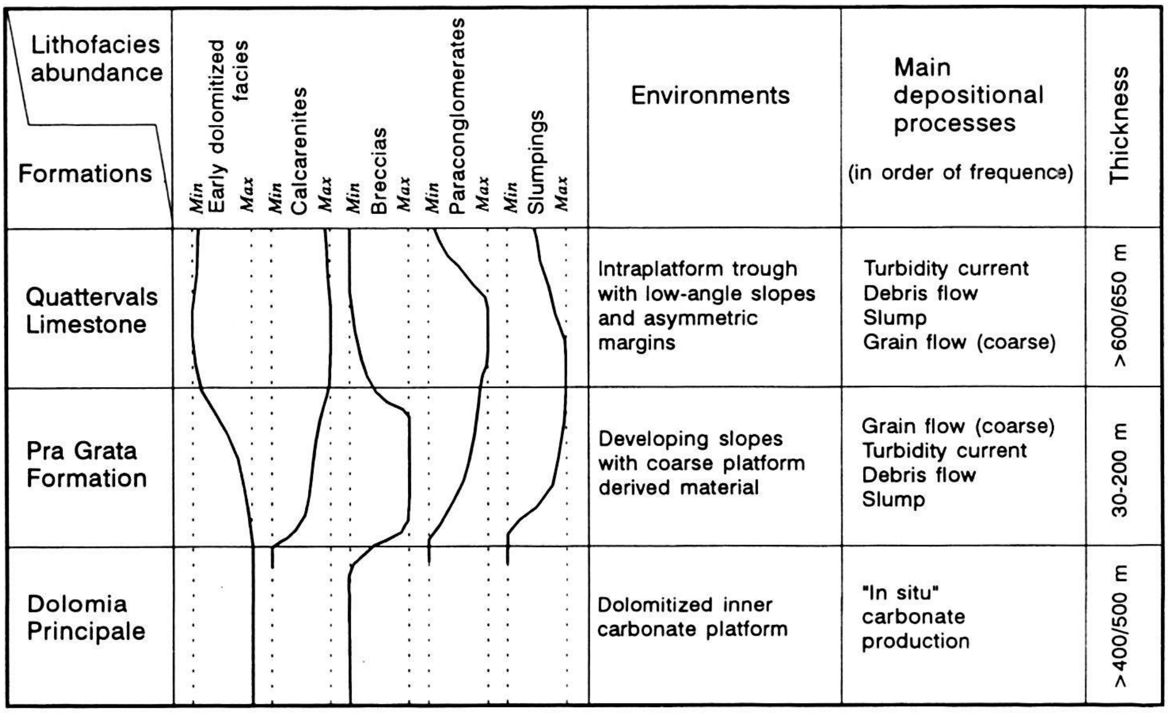


Fig. 9. Facies distribution and abundance, environmental interpretation and depositional processes of the studied succession (nomenclature of sediment gravity flows from Lowe 1979).

This formation is characterized by irregular alternations of limestones and dolostones, with different facies and sedimentologic features (Fig. 8a, b). The two prevailing lithologies ratio changes from base to top: the dolomitic material (considering only early diagenetic dolomites) prevails at the base, whereas limestones become predominant towards the top (Fig. 9).

Limestones consist of generally thin-bedded (meanly around 5–30 cm) dark beds, locally with marly joints. They are mainly represented by fine grained calcarenites, often bioclastic; in the coarser horizons normal grading has been observed. Locally, limestone beds show deformations related to slumps, both at centimetric and metric scale. In the upper part, intercalations of paraconglomerate beds up to 3 meters thick are often present: clasts derive from not completely lithified thin bedded limestones (the term "paraconglomerate" is used according to Pettijohn 1957, to describe a conglomerate that is not a product of normal aqueous flow but is deposited by such modes of mass transport as subaqueous turbidity slides and is characterized by a disrupted gravel framework with clasts not generally in contact, is often unstratified and is notable for containing more matrix than gravel-sized fragments).

The dolomitic portions present completely different characteristics. They mainly consist of generally light-grey breccia bodies (up to 10 meters thick) sometimes amalgamated, whose clasts generally show carbonate platform facies, identical to those of the Hauptdolomit. Rounding is scarce; the occurrence of sharp corners demonstrates that clasts were lithified at the moment of the breccia forming. Sorting is generally low, and the aspect of the breccia bodies is always chaotic, documenting a deposition due to mass flow phenomena. Centimetric to decimetric doloarenitic beds are common.

Both the lower and upper limits of the Pra Grata Formation are transitional. The boundary with the underlying Hauptdolomit is considered the first occurrence of metric limestone intercalations, generally with associated breccia bodies. Locally the base of the Pra Grata Formation is characterized by calcarenitic layers rich in gastropods *(Worthenia* sp.). The upper limit is marked by the sudden decrease of dolomitic breccias with clasts derived from the carbonate platform (Fig. 9).

Southward the formation reaches a maximum thickness of about 200 meters, decreasing northward to 20–30 meters (Alpe del Gallo area).

Depositional environment

Alternation of dolostones (early dolomitized) and limestones documents an environmental change with respect to the underlying Hauptdolomit. The occurrence of well- and thin-bedded limestones outlines a deepening of the environment, preventing dolomitization phenomena.

Sedimentation occurred in dysaerobic to anaerobic conditions (as documented by the black colour and by the absence of burrows in laminated facies), where rare benthic foraminifera and specially ostracods were the only autochthonous fauna.

Limestones represent the normal basinal sedimentation: the calcareous material is represented by mud and fine calcarenites exported mainly by currents or storms from the surrounding carbonate platforms and deposited as turbidites. Its derivation from a neighbouring carbonate platform is documented by microfacies, often rich in platform derived shallow water components (mainly bioclasts). Dolomitic breccias, whose origin is related to episodic phenomena, directly derive from the dismantling of early dolomitized and lithified carbonate platform sediments, probably exposed along scarps. The large amount of breccia bodies and the occurrence of slumps outline that the Pra Grata Formation deposition occurred on a developing slope.

c) Quattervals Limestone

This formation crops out in the central-northern part of the Quattervals Nappe, from Cima del Fopel-Cassa del Ferro toward the north (Fig. 2). Toward the east, the outcrop area of the Quattervals Limestone is reduced due to tectonics (overthrust of the Umbrail Nappe).

The Quattervals Limestone (Fig. 8, 10, 11) is almost entirely represented by dark limestones, in thin beds or banks. Locally, horizons (up to 30 cm thick) of millimetric laminites are present. In these facies the well-preserved laminations are sometimes deformed around coprolites up to some centimeters in size.

The thin bedded limestones (calcarenites and fine-grained limestones, mean strata thickness around 5–25 cm), with marly joints, mainly consist of mudstone and wackestone, with less frequent intercalations of graded packstones, rich in platform derived grains (bioclasts, oolites, intraclasts etc.). Locally, in the lower part of the formation, thick beds (up to 2 meters) of fine grained limestones (mudstone and wackestones) occur. Late silicification often affects the calcarenites; pseudomorphs after authigenic crystals celestite and barite, have been observed within the mudstones.

Lithofacies	Thickness (cm) max-min, av.	Sedimentary structures	Microfacies	Main components	Diagenetic structures
1 Calcarenites	5-100, 25		Pk		S
2 Fine-grained limestones	3-200, 10		Fine grained Pk, Ms, Ws		
3 Thin laminated limestones	0.1-1, 0.5		Ms, Wk		
4 Paraconglomerates	20-350, 100		M: Ms, Wk C: see 1 & 2		S
5 Breccias	20-150, 60		M: Wk, Ms, Pk C: Lms: see 1 & 2; Dol: Pk, Wk, Bs, Ms		

Normal, reverse grading; Parallel, cross lamination; Slumping; Pelecypods; Gastropods; Forams; Ostracods; Filaments; Echinoids; Green algae; Red algae; Radiolarians (?); Coated grains; Spiculae; Problematicae; Ammonoids; Stromatolites; Vertebrates; Intraclasts; Oolites; Pellets; S Silicification; Late diagenetic dolomitization; Authigenic crystals; M: Matrix C: Clasts Lms: Limestone Dol: Dolostone
Pk: Packstone Wk: Wackestone Ms: Mudstone Bs: Bindstone

Fig. 10. Simplified description of the Quattervals Limestone lithofacies organization.

Slumpings at centimetric and plurimetric (5–7 meters) scale are common (Fig. 8e). Submarine erosional surfaces (slump scars) were observed in the lower part of the Quattervals Limestone (Fig. 8c).

Paraconglomerates in banks up to 3–4 m thick and more rarely breccias are intercalated. (Fig. 8d). Paraconglomerates consist of a dark, generally calcarenitic, matrix with not completely lithified centimetric and decimetric intraformational clasts. Normal grading was observed, whereas reverse grading and concentration of the bigger clasts in the middle of the bed are less frequent; commonly, more episodes are amalgamated in banks with morphologic evidence. Selective silicification along the rims of the paraconglomerate clasts is often present. The scattered occurrence of early dolomitized clasts of carbonate platform facies, lithified at the moment of the paraconglomerate formation, is quite common.

The less common breccia bodies, up to 2 meters thick, present a matrix (both calcareous and dolomitic) generally less abundant with respect to the paraconglomerates. The clasts, from angular to rounded, are mainly dolomitic with inner carbonate platform facies. Breccia bodies are more common in the lower part of the Quattervals Limestone (Fig. 9).

In the Quattervals Limestone, it is possible to recognize a background sedimentation represented by well bedded limestone and two other, more episodic, signals: thin laminated limestones (interpreted as rhythmites) on one side, and paraconglomerates and breccias on the other. The deposition of undisturbed, millimetric rhythmites is probably linked to a reduced sedimentary supply in the basin or in some of its parts. Paraconglomerates document instability of the slope and are interpreted as the results of slumps transformed into highly viscous sediment gravity flows. Breccias with lithified dolomitic platform clasts outline the presence, at the borders of the basin, of scarps where these facies were exposed.

The distribution of the lithofacies is characterized by vertical and lateral changes. In particular, the paraconglomerate horizons are more common in the lower part of the formation (just above the limit with the Pra Grata Formation), where also dolomitic breccia bodies occur (Fig. 9). Paraconglomerates are more abundant and thicker in the southern part of the basin, in the Piz da l'Acqua area. Slumps, although prevailing in the lower part of the formation, are common in all the section and have been observed all over the Quattervals Basin, documenting a tectonic instability during the deposition of the Quattervals Limestone.

In the study area, only the lower, transitional boundary of the Quattervals Limestone (with the Pra Grata Formation) is preserved.

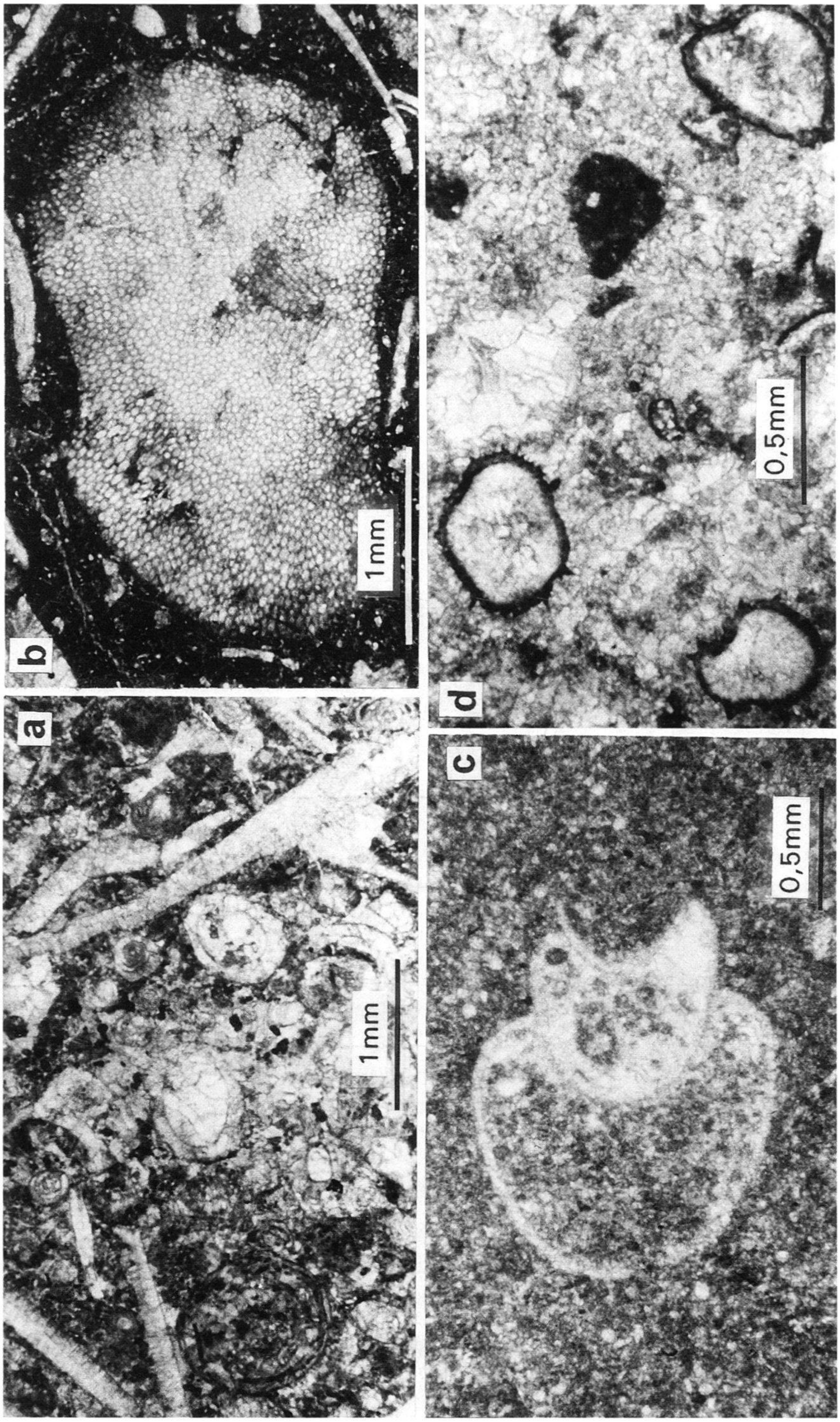
The upper limit, with the Crappa Mala Beds (corresponding to the "Obere Mergel" of Somm 1965), has not been observed in the study area. It is therefore impossible to give a precise thickness of the formation: nevertheless it is possible to evaluate a thickness of at least 600–650 meters.

Depositional environment

The Quattervals Limestone records the full development of the intraplatform basin. The decreased occurrence of dolomitic breccias outlines a minor coarse input from the surrounding carbonate platforms, probably related to a wider extension of the intraplatform basin or to a minor tectonic activity.

The carbonate sediments of the Quattervals Limestone did not deposit on perfectly flat-lying bottoms, as pointed out by sedimentary structures: slump overfolds and slump scars (more common in the lower-middle part of the formation) document deposition on a low angle slope. Also the occurrence of paraconglomerates with slope-derived clasts document this situation. An environmental setting similar to that recorded by the Quattervals Limestone was described by Cook & Taylor (1977) and Cook (1979) in the Upper Cambrian-Lowest Ordovician of Nevada (Hales Limestone), even if in a different paleogeographic setting.

The carbonate material of the Quattervals Limestone must have come from a carbonate platform, because planktonic production was scarce during the Triassic. Microfacies analysis of limestones allowed to distinguish two genetically different deposits (Fig. 11): limestones directly derived from resedimentation of platform material and limestones mainly from decantation of fine grained material. The deposition of packstone and wackestone was clearly linked to mass transport, as documented by sedimentary structures. Also some fine grained deposits (mudstones) in thick beds can derive from mud directly exported from the platform. Other lithofacies, generally more marly and thin-bedded, are probably related to decantation of platform mud in protected areas. Mudstones and fine grained wackestones often contain ostracods, abundant small benthic foraminifera and sponge spiculae, extremely rare juvenile ammonoids and probably radiolarians. Irregular laminations are common mainly in the ostracod-bearing facies: some of them may be interpreted as deep water bacterial mats. These slope facies can frequently be observed as clasts within resedimented deposits (paraconglomerates, calcarenites). The dark colour of the sediments and the absence of bioturbations document unfavourable conditions for the development of a rich benthic community at the bottom of the Quattervals Basin. Nevertheless, in the higher levels of the water column, oxygen was more


a
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abundant: planktonic and nektonic communities are documented also by the occurrence of filaments and vertebrate fragments (mainly fish scales). Articulated fish skeletons were reported from the Quattervals Limestone in the Piz Murtarous (Somm & Schneider 1962; Pozzi et al. 1962) and in the Val Tantermozza (Kuhn 1947) areas. Facies analysis documents that the Quattervals Basin was a partly isolated sea-way; water exchanges with a wider marine basin occurred only for the superficial water and the bottom water was almost stagnant (from dysaerobic to anoxic). Black laminated rhythmites outline sediment by-pass or starvation episodes of part of the basin, probably due to a lower carbonate production on the platform or to the basin morphology.

The production of dolomitic clasts can be ascribed to two main phenomena: subaerial erosion and transport toward the deeper parts of the basin (breccias related to relative sea-level changes) or syndepositional tectonics. The absence of karstic features in the clasts and their predominantly poor sorting and rounding, denote a scarce transport and absence of in situ alterations. Therefore, the breccia bodies are mainly related to syndepositional tectonics, responsible for the development of fault scarps along which lithified and dolomitized inner platform facies were exposed (likely in a submarine environment). Only rarely, breccias with rounded clasts and reddish matrix have been observed: in this case an origin related to subaerial erosion and transport (due to relative sea level falls) can be suggested.

Paleogeography of the Quattervals Basin

The study of the stratigraphy and facies distribution together with the analysis of the sedimentary structures and microfacies of the Pra Grata and Quattervals formations allowed the reconstruction of the slopes orientation and the transport directions of the platform derived materials within the basin. The most significant structures were represented by slump scars and slump overfolds. Slump scars (observed in the northern part of the basin) show a clear N-S trend, which is the same recorded by cross laminations within resedimented calcarenites.

The analysis of the orientation of slump overfolds from the Diga del Gallo section (Fig. 12), where these sedimentary structures are particularly abundant and well exposed, demonstrated an original mean dip of the axial planes toward N-NNE (today the axial planes dip northward due to alpine deformation, with angles slightly higher with respect to that of the beds): it follows that the deepening of the basin occurred toward S-SW, with a sedimentary input from a northern carbonate platform. The scarce (with respect to

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Fig. 11. Microfacies of the Quattervals Limestone:
a) Bioclastic packstone with prevailing pelecypods, foraminifera and probably serpulids. In spite of the strong recrystallization, the nature of allochems is recognisable. Summit of Cima del Fopel.
b) Bioclastic packstone-wackestone. The large bioclast (probably a red algae) is contained in a matrix with small pelecypods fragments. Valle del Cantone section.
c) Small ammonoid fragment in a fine grained packstone containing sponge spiculae. Diga del Gallo section.
d) Strongly recrystallized wackestone with dispersed organisms (ostracods ?), with structures interpreted as shell spines.

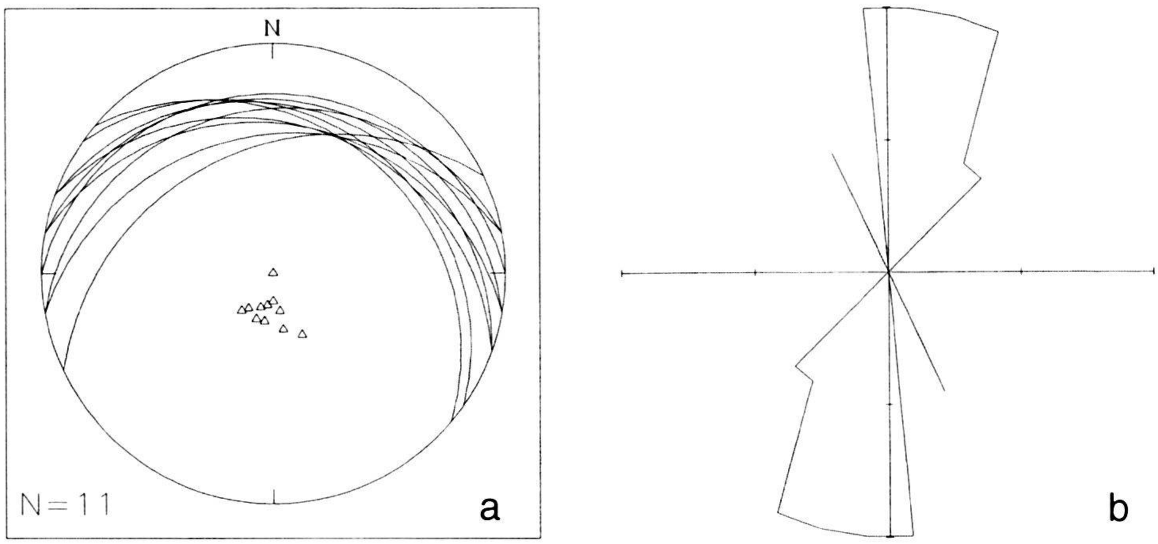


Fig. 12. Present-day distribution of slump overfolds axial planes in the Quattervals Limestone in the Diga del Gallo section. Bedding in the Diga del Gallo section is mainly toward the north with an average dip of 20°: a) Stereographic projection of 11 axial planes; b) Distribution diagram.

the southern part of the basin) occurrence of platform derived breccias suggests a low-angle platform-basin slope, with a dip of a few degrees and the absence of important syn-sedimentary faults.

Thickness and facies changes of the Pra Grata Formation give important information about the basin geometry. This formation is thicker in the southern part of the Quattervals Nappe, where it is rich in dolomitic breccia bodies (directly derived from the dismantling of a carbonate platform) which wedge out northward (Fig. 13). This distribution documents an input from south, where, during the deposition of the Pra Grata Formation, a carbonate platform was still present. The occurrence and the distribution of the breccias suggest the existence of a southern fault-controlled steep basin margin. This tectonic margin, placed near the present Alpisella (or Trupchun-Braulio) Line, is not preserved, due to alpine tectonics. The presence of a developing tectonic margin, can also be detected by the occurrence of sedimentary dykes and breccia bodies (with clasts up to more than one meter) in the upper Hauptdolomit of the southern part of the Quattervals Nappe.

The analysis of the collected data allowed the reconstruction of a intraplatform basin controlled by syndepositional extensional tectonics with the following characteristics (Fig. 14):

- shape and size of the basin: north-south width of at least about 8 kilometers; east-west length unknown (at least some tens of kilometers)
- double sedimentary input: breccias mainly from south/south-west (as documented by areal distribution) and limestones from sweeping of the two margins (probably mainly from north)

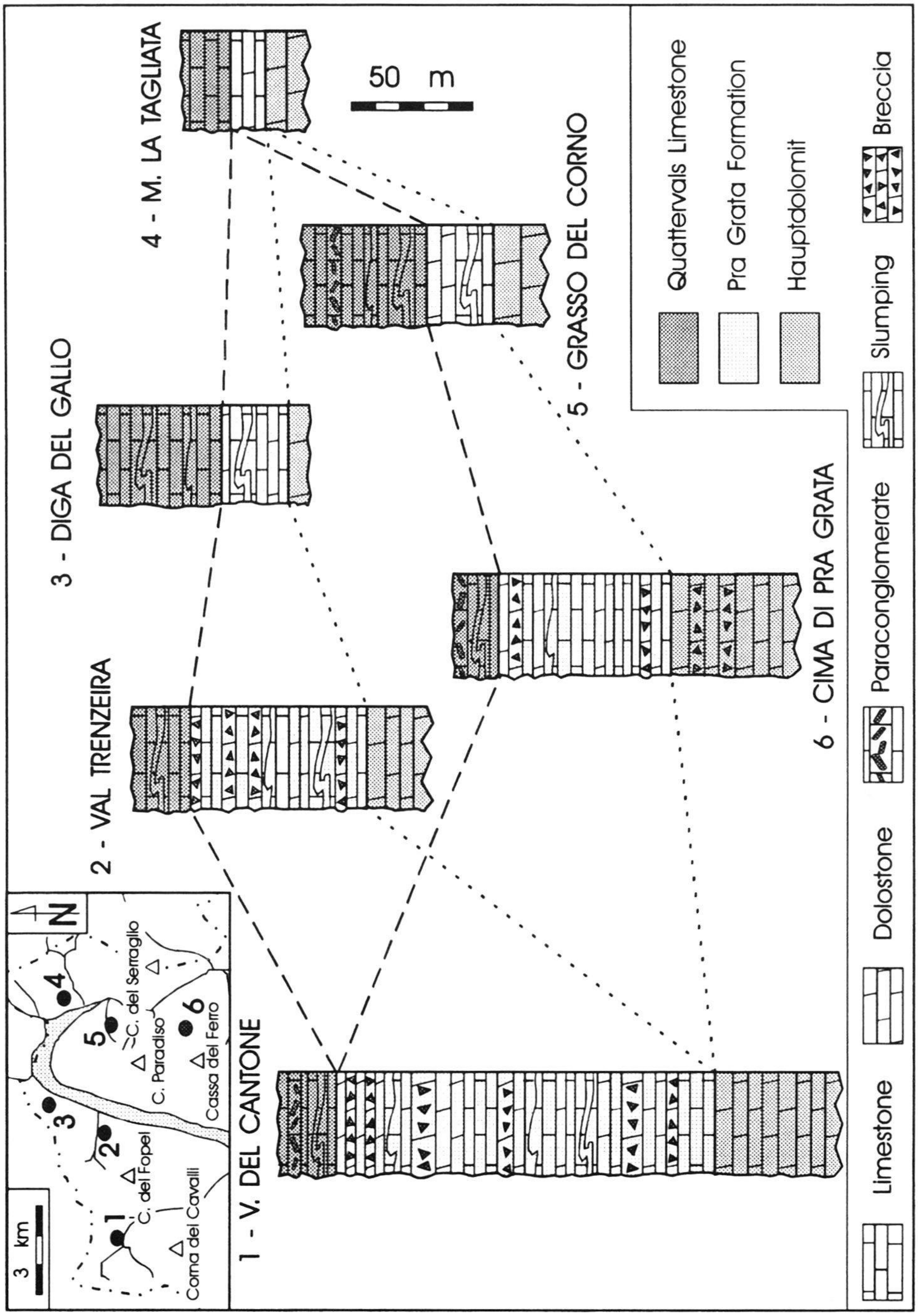


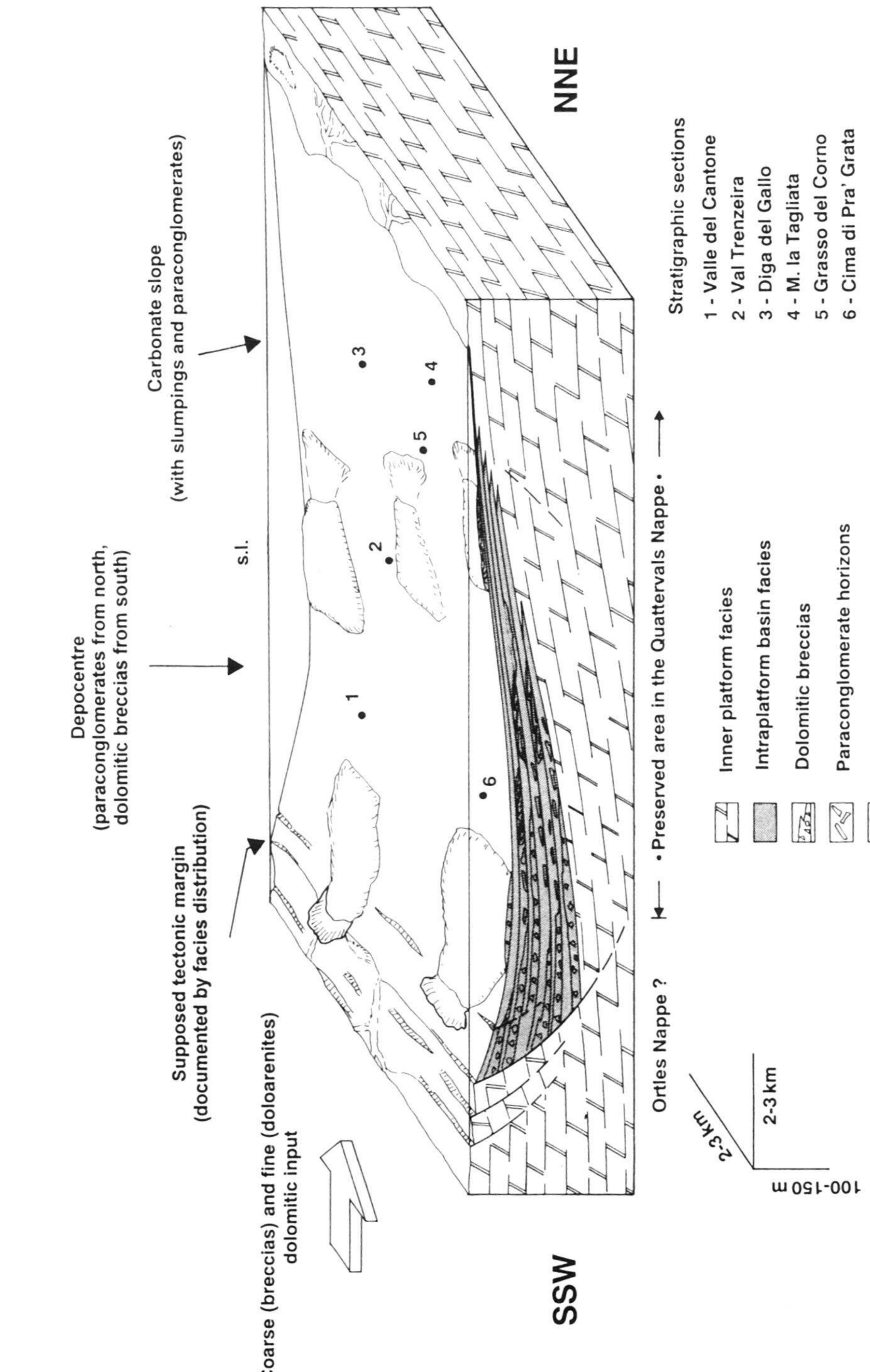
Fig. 13. Facies distribution of the Pra Grata Formation in the study area: note the decreasing thickness of the unit toward north/north-east and the prevailing breccia bodies toward the south.

- asymmetric depocentre: placed near the south/south-western limit of the Quattervals Nappe
- asymmetric margins: a tectonic margin southward and a flexural-type margin northward
- existence of a low-angle slope: occurrence of slumpings all over the basin during the deposition of the Pra Grata Formation and Quattervals Limestone document the absence of flat lying bottoms
- mainly dysaerobic to anaerobic bottom waters, documenting a scarce water exchange with the open sea (probable presence of a topographic threshold)
- gradual increase of the basinal area, with diminishing breccia bodies and development of the Quattervals Limestone.

A tentative evaluation of the basin depth is possible, mainly on the basis of the occurrence of a northern slope with a length of about 6–7 km, along which slumpings with similar orientation are common. Slumps development, request the presence of a slope with a mean dip of a few degrees (4° have been used by Evans & Kendall 1977, to evaluate the depth of a Jurassic basin in Morocco). Even considering the occurrence of uneven slopes, it is possible to evaluate a minimum depth of at least 200 meters in the basin depocentre during the deposition of the lower Quattervals Limestone. This depth is in agreement with the model proposed by Byers (1977), which suggests the pycnocline base (passage from dysaerobic to anaerobic conditions) at about 150 m depth for carbonate basins. The occurrence of biofacies indicative of anaerobic conditions (shelly fauna and bioturbation lacking, laminated sediments) common in the Quattervals Limestone indicates, according to Byers (1977), a paleodepth of more than 150 meters.

The persistence of a quite deep basin within an inner carbonate platform as the Hauptdolomit implies the existence of a strong subsidence, able to permit first the individualisation of the basin and later to keep the pace with the carbonate production in order to avoid a quick filling of the depression. The occurrence of shallow water facies above the Quattervals Limestone (Diavel Formation; Somm 1965; Furrer 1993a) documents the final filling of the Quattervals Basin by platform derived material: this situation can probably be related to a decrease of the basin subsidence rate with the successive recovery of shallow water facies in an area previously characterized by basinal sedimentation. The less frequent occurrence of slumpings and paraconglomerates in the upper Quattervals Limestone documents a decrease of the slope angles and probably the beginning of the filling of the basin.

Fig. 14. Proposed paleogeographic reconstruction for the first stages of the Norian Quattervals Basin development.


NNE
SSW
Carbonate slope
(with slumpings and paraconglomerates)
Depocentre
(paraconglomerates from north,
dolomitic breccias from south)
s.l.
Supposed tectonic margin
(documented by facies distribution)
Coarse (breccias) and fine (doloarenites)
dolomitic input
Ortles Nappe ?
• Preserved area in the Quattervals Nappe •
1
2
3
4
5
6
Stratigraphic sections
1 - Valle del Cantone
2 - Val Trenzeira
3 - Diga del Gallo
4 - M. la Tagliata
5 - Grasso del Corno
6 - Cima di Pra' Grata
Inner platform facies
Intraplatform basin facies
Dolomitic breccias
Paraconglomerate horizons
Slumpings
2-3 km
2-3 km
100-150 m

Conclusions

The development of the Quattervals Basin documents the existence of a Norian extensional-transtensional tectonic phase in the Central Austroalpine, well documented within the huge Hauptdolomit-Dolomia Principale carbonate platform both in the Southern and Northern Calcareous Alps (Jadoul 1985; Brandner & Poleschinski 1986; Picotti & Pini 1989; Jadoul et al. 1992; Trombetta 1992 etc.). This tectonic phase has been referred to the beginning of the Central Atlantic rifting (at least in the Southern Alps, Jadoul et al. 1992), which shows a gradual diffusion in space, from west to east, and time, from the Carnian in Northern America (Newark Basins, Manspeizer 1988) to the Lias in the Southern and Northern Calcareous Alps (Dössegger et al. 1982; Furrer 1985, 1993b; Eberli 1987, 1988; Bernoulli et al. 1990). It is important to notice that the morphologic and sedimentologic characteristics of the Quattervals Basin show some differences with other Norian intraplatform basins described in the Southern and Northern Calcareous Alps. The stratigraphic position of the Quattervals Limestone is similar to the subtidal "Bituminous Hauptdolomit" of the Northern Calcareous Alps (but the latter is only from 10 to 60 m thick and richer in organic matter; Müller-Jungbluth 1968), which passes upward to a new reprise of the Hauptdolomit. On the contrary, the thickness of the Quattervals Limestone is comparable with the Southern Alps intraplatform basins sediments ("Gruppo dell'Aralalta"; Jadoul 1985), but the facies and sedimentary structures are different. The stratigraphic position of the Southern Alps Aralalta Group can be better compared with the Plattenkalk (developed at the top of the Hauptdolomit) than with the "Bituminous Hauptdolomit". Morphologically, the Quattervals Basin is controlled by a WNW-ESE trending fault system, similar to that controlling the Seefeld Basin (oriented W-E; Brandner & Poleschinski 1986) but different from that controlling the Southern Alps basins (generally oriented N-S; Jadoul et al. 1992; Stefani et al. 1992).

The original extension of the Quattervals Basin today is not valuable because its borders are not preserved. Nevertheless it is possible to exclude a continuation of this basin both northward and southward. Actually, the Ortles Nappe, placed south of the Quattervals Nappe, does not present any evidence of southward continuation of the Quattervals Basin. In the eastern part of the nappe, metric limestone intercalations within the Hauptdolomit (Pozzi 1959) may document the original proximity with the Quattervals Basin. A similar situation is present northward: the Norian sediments of the Scarl Nappe do not record the development of any important intraplatform basin corresponding to the Quattervals Basin. Nevertheless, also in this nappe, limestone intercalations within the Hauptdolomit are interpreted as the possible northern closure of the Quattervals Basin (Aemissegger in Furrer 1985). If the northern and southern borders of the Quattervals Basin are represented by the inner platform successions of the Ortles and Scarl nappes, eastward and westward the situation is different. Westward, the Quattervals Nappe ends against the Engadine Line: on the western side of this fault, only in the S-canf Dolomite, between the Ela Nappe and the Silvretta basement, quite typical Quattervals and Diavel Beds are found (R. Trümpy, written comm.). The reduced occurrence of Norian intraplatform facies can be related to the western closure of this basin. Toward the east, the situation is different: the Umbrail and Ötztal nappes only rarely preserve their original sedimentary cover, and stratigraphic observations are strongly incomplete. Therefore, two possibilities can be suggested: the Quattervals Basin was isolated within the Hauptdolomit-Dolomia Principale or it was connected with an open marine basin, which could be located east of the Quattervals Basin. Sedimentary evidence and faunal associations suggest a partial link between the Quattervals Basin and an open basin, even if a threshold was present.

The occurrence of an east-west trending marine seaway related to the Tethys between the Southern Alps and the Northern Calcareous Alps has been suggested by Channel et al. (1990, 1992) and more recently by Neubauer et al. (1995). This basin, corresponding to the Hallstatt-Meliata ocean, is the nearest open marine basin east of the Engadine Dolomites (and, consequently, north of the Southern Alps and south of the Northern Calcareous Alps): the Quattervals Basin might therefore be linked to the western termination of the Hallstatt trough.

Geodynamically, the Norian tectonics responsible for the development of the Quattervals Basin could be tentatively related to two different settings: the first stages of the Jurassic opening of the Atlantic Ocean or the evolution of the Triassic Hallstatt-Meliata Ocean.

The probable orientation of the fault bordering the Quattervals Basin is about WNW-ESE, whereas the faults bordering the Liassic basins preserved in the underlying Ortles Nappe show a north-south trend (Eberli 1987, 1988). Because no evidence of a rotation between the Quattervals and Ortles nappe has ever been documented, it is supposed that fault orientation reflects the original relationships. These data do not permit to affirm if the two tectonic trends (different in time but affecting more or less the same area) can be related to two different geodynamic mechanisms; nevertheless, if the two synsedimentary fault systems are related to the same geodynamic event, it is necessary to suppose a different stress orientation in two different stages. Alternatively, the development of the Quattervals Basin could be related to a mechanism different from the one responsible for the opening of the Atlantic Ocean. The syndepositional tectonic phase documented in the Quattervals Basin could be due to the Late Triassic evolution of the Triassic Tethys (Hallstatt-Meliata basin) and not exclusively to the first extensions related to the opening of the Central Atlantic.

A relationship between the Norian syndepositional tectonics and the Alpine deformations can also be suggested. Alpine tectonics strongly reduced (by shortening) the original area occupied by the basinal sediments and partly destroyed the original paleogeographic relationships. It is possible that the Alpisella Line could, at least in some places, represent an alpine reactivation of the Norian fault bordering the southern margin of the Quattervals Basin. This fault today divides two nappes with different Norian evolution: a basin northward and a relative high to the south. This situation could easily be explained suggesting an old paleogeographic meaning for the present alpine lineament.

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