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STRATIGRAPHY, PALEOGEOGRAPHY AND GENETIC MODEL OF LATE CARNIAN CARBONATE BRECCIAS (CASTRO FORMATION, LOMBARDY, ITALY)

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Riassunto. L'analisi stratigrafico-paleogeografica della successione al limite Carnico-Norico affiorante nel settore centrale del Bacino Lombardo ha permesso di riconoscere una nuova unità litostratigrafica proposta con il nome di Formazione di Castro. Si tratta di una unità esclusivamente carbonatica costituita da brecce calcaree e da subordinati calcari. L'analisi stratigrafica delle facies ha permesso di riconoscere due litozone: l'inferiore, è caratterizzata da prevalenti calcari dolomitici grigio-scuri con subordinate intercalazioni di brecce; la superiore è essenzialmente massiccia e costituita da brecce calcaree intraformazionali amalgamate e calcari ricristallizzati grigi e grigio-scuri. La litozona inferiore è verosimilmente eteropica con la Formazione di S. Giovanni Bianco.

Gli spessori della Formazione di Castro variano da circa 100 a oltre 250 m.

Le associazioni di microfacies riconosciute nei calcari e nei clasti delle brecce della Formazione di Castro sono generalmente poco differenziate, sempre molto ricristallizzate e caratterizzate da mudstones e wackestone-packstones finemente intraclastici e pellettiferi, sovente con addensamenti di Ostracodi articolati e disarticolati. Nell'ambito delle litofacies a brecce intraformazionali sono state riconosciuti vari tipi di brecce monogeniche e poligeniche.

Le litofacies sedimentarie e diagenetiche della Formazione di Castro sono spesso associate a tettofacies, connesse soprattutto a fenomeni di sovrascorrimento di età alpina, molto diffusi in corrispondenza del limite stratigrafico tra questa unità e la Formazione di S. Giovanni Bianco. Localmente sono diffusi fenomeni erosivi, di risedimentazione, pedogenetici e carsici di età ancora incerta, alcuni sembrano sindeposizionali, la maggior parte appare di età più tardiva, verosimilmente compresa tra il Neogene e il Pleistocene.

Le analisi geochimiche effettuate sulla Formazione di Castro hanno permesso una caratterizzazione di questa unità rispetto alle successioni sopra e sottostanti; esse hanno evidenziato in particolare una diagenesi precoce con influssi di acque meteoriche.

Il modello deposizionale proposto per la Formazione di Castro prevede ambienti caratterizzati da bacini, laghi effimeri non sempre in diretto contatto con il mare aperto e con influssi di acque meteoriche in un regime climatico verosimilmente monsonico. Emersioni periodiche, fenomeni erosivi e di dissoluzione-collasso controllati da tettonismo sinsedimentario e da variazioni volumetriche di sottostanti corpi evaporitici della Formazione di S. Giovanni Bianco, hanno contribuito alla messa in posto di potenti accumuli di brecce intraformazionali.

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Abstract. The stratigraphic and paleogeographic analysis of the Carnian-Norian boundary succession in central Lombardy allows the recognition of a new unit, the Castro Formation.

This unit, 100-250 m thick, is represented by carbonatic intraformational breccias and associated limestones. Two lithozones have been recognized in the Castro Fm.: the lower one, heteropic with the S.Giovanni Bianco Fm., with dark dolomitic limestones and breccias intercalations, and the upper lithozone, massive, with amalgamated calcareous breccias. Microfacies, recrystallized and often tectonized, consist of mudstones, wackestones and fine packstones, locally rich in ostracods.

Geochemical analyses show differences between the Castro Fm. and the overlying and underlying units, possibly because of early diagenetic meteoric imprint.

The Castro Fm. depositional setting is represented by coastal ephemeral lakes with periodic emersions and erosional, tectonically controlled phenomena in a monsoonal regime.

Introduction.

The Late Carnian stratigraphy in Lombardy has been poorly understood up to now because of the insufficient fossil record and tectonic thrusting occurring between the uppermost carnian deposits and the overlying norian Dolomia Principale. This Upper Carnian succession consists, at the bottom, of predominant medium-fine grained siliciclastics (lower San Giovanni Bianco Formation), making transition to pelites, carbonates and evaporitic lenses (upper San Giovanni Bianco Formation). The upper S. Giovanni Bianco Fm. is considered Tuvalian by Allasinaz (1968), in the Presolana and Gorno-Dossena areas, on the basis of the presence of *Neomegalodon triqueter* (Wulfen).

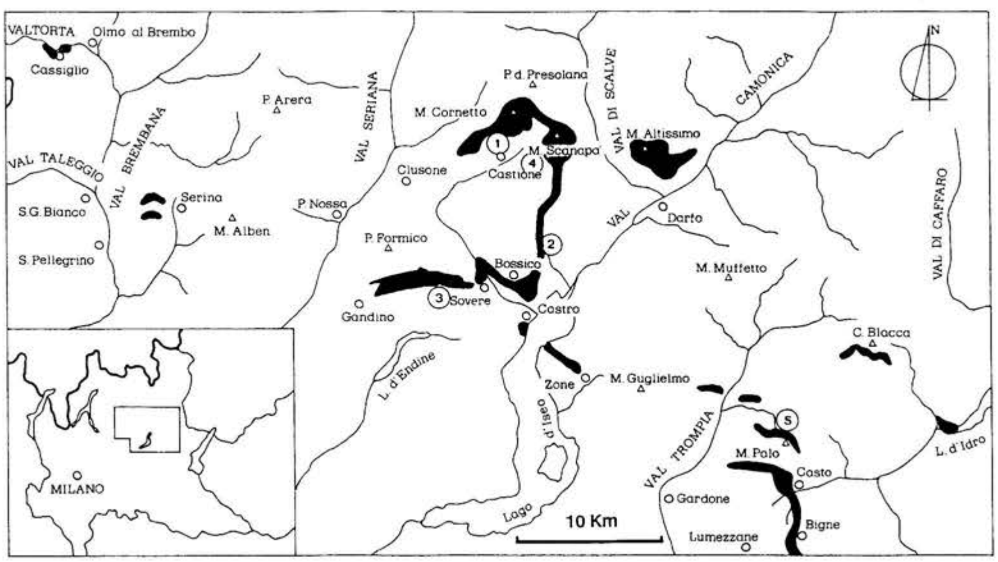


Fig. 1 - Map showing the location of the studied area and of the most important outcrops of the Castro Fm. as well as of Upper Carnian dolomitic breccias. Location of stratigraphic sections is labelled with numbers.

Carbonates and carbonate breccias (Basal Breccias of the Dolomia Principale Auct.) follow (Fig. 1, 2), which have never been the object of detailed studies up to now. These breccias were described in 1877 by Curioni, who found it difficult to distinguish sedimentary from associated tectonic breccias. The far-reaching extent of the breccias in Lombardy was mentioned in several geologic and stratigraphic studies (De Sitter & De Sitter Koomans, 1949; Pollini, 1958; Assereto & Casati, 1965; Rossetti, 1966; Boni & Cassinis, 1973; Gaetani, 1985; Gaetani et al., 1987). Breccias with the same stratigraphic position were described by Renevier (1879), Lehner (1952), Gianotti (1984), Bertotti (1990, 1991) (Ligomena Breccias west of the northern Como Lake) as well as by Gwinner (1971), Fürrer et al. (1985) in the Upper Austroalpine sediments of the Graubunden (Switzerland). Similar lithotypes, of probable Upper Carnian age, were also observed in the Apennines of Tuscany (Ciarapica & Passeri, 1978). However, only a few genetic interpretations have been attempted: Assereto & Casati (1965) hypothesized that the formation of the Upper Carnian breccias was due to a transgressive event occurred at the base of the Norian; Jadoul & Rossi (1982) related brecciation phenomena with a Late Carnian tectonic phase. In particular, the Ligomena Breccias have been recently considered as alpine tectofacies consisting of dedolomitized Dolomia Principale clasts (Bertotti, 1990, 1991). Preliminary studies on the diagenesis of the "Basal Breccias" Auct. have been carried out by Frisia & Jadoul (1988), who infer the influence of fresh water on the basis of geochemical and cathodoluminescence analyses.

Object of the present study is both the lithostratigraphy of the Upper Carnian carbonates and the genetic interpretation of intercalated breccias. We also attempt a detailed reconstruction of the paleogeographic evolution at the Carnian-Norian boundary in the western Southalpine and in particular of the area comprised between Val Seriana and Lake Idro, where the breccias are common and show thicknesses up to hundreds of meters.

In this work we do not discuss problems about the Carnian-Norian boundary because of the lack of significant fossils. However, we suggest that this boundary could be placed at the top of the lower Dolomia Principale on the basis of paleontological data from Conti (1954) and our determinations on *Dasycladaceae*. In fact, in the studied area (Dolomia Principale of lower Val Taleggio) we found the carnian *Clypeina besici* Pantic in the first 150-200 m of succession, just above the Lower Member of the Dolomia Principale. We also found problematic assemblages of dasycladacean Algae, very similar to the "middle triassic" Algae, in the middle-upper Dolomia Principale (E. Fois determinations) (*Phisoporella* cf. *pauciforata* and *Teutloporella* cf. *peneculiformis*, *Macroporella* cf. *alpina* and *Diplopora* cf. *annulata*). These Algae are present in stratigraphic sections of Dolomia Principale in Val Brembana (Val Taleggio-Pizzo Grande) and Iseo Lake (Corna Trenta Passi), where typical upper triassic dasycladaceans are also present (*Griphoporella* sp., *Gyroporella vesiculifera, Phisoporella heraki, Macroporella humilis).* Nevertheless, Algae biostratigrapy of the Upper Triassic is not well calibrated and needs more detailed biostratigraphic studies.

Stratigraphy.

The uppermost Carnian of the studied area (Fig. 1) is characterized by massive calcareous breccias and subordinate limestones. In the past these lithofacies were considered part of the Dolomia Principale and given the informal name of "Basal Breccias of the Dolomia Principale" (Assereto & Casati, 1965; Jadoul & Rossi, 1982). However, the "Basal Breccias" lithofacies are remarkably different both from the underlying evaporites and siliciclastics of the San Giovanni Bianco Formation and from the peritidal and subtidal dolomites of the overlying Dolomia Principale. Furthermore, the breccias and associated limestones always occur at the same stratigraphic level and show conspicuous thicknesses. In fact, they form abrupt cliffs at the base of the Dolomia Principale, which can be observed over a wide area. On the basis of these considerations, we promote the institution of a new formation: the Castro Formation. Type-area is north of Iseo Lake (Lower Camonica Valley; Fig. 1). Outside the type area the unit outcrops, though not continuously, from Idro to Como lakes. The easternmost and westernmost outcrops show intense dolomitization phenomena, and a gradual transition to the lower Dolomia Principale which provided some of the clasts of the breccias (Fig. 2). Frequent detachments at the base of the breccias hinder a detailed observation of the lower stratigraphic limit with the San Giovanni Bianco Fm. When visible, both lower and upper limits are transitional.

The Castro Formation can be divided into two lithozones according to lithologic and stratigraphic criteria:

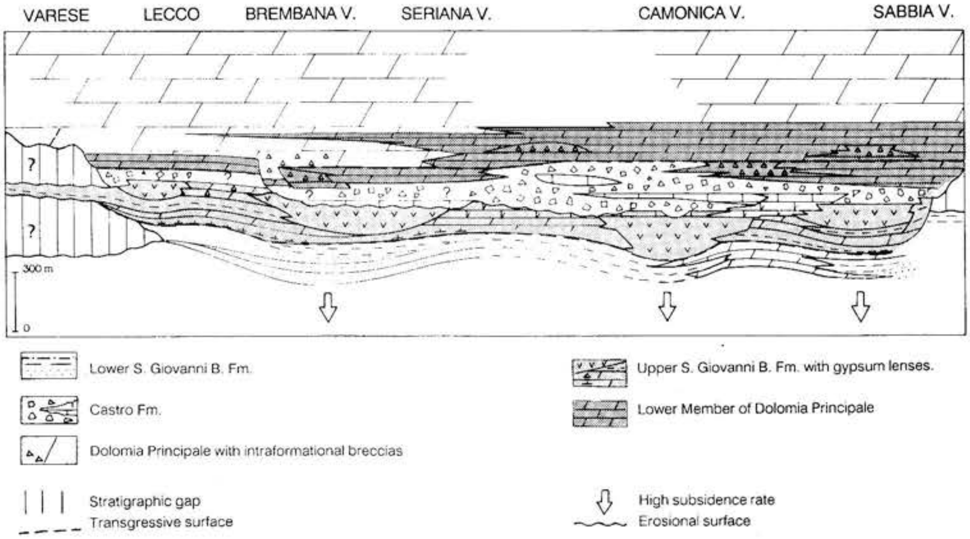


Fig. 2 - Stratigraphic scheme of the Late Carnian succession of Lombardy.

1) Lower Lithozone; representing the transition between evaporites and siliciclastics of the San Giovanni Bianco Fm. and carbonates of the typical Castro Fm.

2) Upper (typical) Lithozone; with limestones and polygenic breccias. This lithozone gradually makes transition to the overlying dark and well bedded dolomites of the lower Member of the Dolomia Principale.

Thicknesses of the Castro Formation are quite variable. In the type-area maximum thickness is about 300 m, average thicknesses are in the range 100-150 m (Fig. 3, 5 and 9c). Maxima can be due to overthrusts which double the sequence.

The Late Carnian, Carnian-Norian boundary lithofacies.

The stratigraphic and paleogeographic evolution of the succession that we suggest as Late Carnian-Early Norian can be better understood considering both the sediments which overlie and underlie the Castro Fm. and the two lithozones characterizing this formation.

Upper San Giovanni Bianco Formation.

The upper lithozone of the San Giovanni Bianco Formation consists (Gnaccolini, Jadoul & Garzanti, in prep.) of well bedded, grey, vuggy dolomites and limestones with grey, green or reddish shale partings. Fossiliferous or bioturbated marly dolomites and biocalcarenites rich in crinoids are locally present at the base. The top of the formation shows, in some areas, sulphate lenses (up to 200 m thick) alternating with subordinate dark and laminated dolomites, probably stromatolitic bindstones. In the upper San Giovanni Bianco it is also possible to observe vuggy dolomites and/or grey limestones locally with collapse breccias, small sedimentary dikes and widespread tectonic-diagenetic cellular dolomites. These lithofacies are considered transitional to the Castro Formation.

Castro Formation lithofacies (Tab. 1).

1. Lower Lithozone.

It does not occur in the whole studied area because of tectonics or possible lateral transition to the upper San Giovanni Bianco Formation.

The lower lithozone of the Castro Formation consists of grey to light brown dolomitic limestones (mudstones and packstones; L1 and L3, Fig. 3, 4), white in alteration, and intercalated breccias (B1a, B1b, Fig. 3, 4) with intraformational clasts (size can be up to a few decimeters) of dolomitic limestones. Breccias are poorly sorted, both clast-supported and matrix-supported, with rare sedimentary structures mostly represented by reverse grading and, subordinately, normal grading (Fig. 4). The matrix consists both of comminute rock fragments of the same nature of the clasts and of a mixture of micrite and clay.

Lithofacies	Description
B1	Polygenic to monogenic intraformational carbonate breccias, well bedded (decimetric to metric bed thickness). Both matrix and clast-supported. Fine, detrital, carbonate matrix. B1a: fine grained breccias with angular clasts consisting of grey to light brown limestone and dolomitic limestone (less than 4 cm). Poor sorting. B1b: medium to coarse grained polygenetic breccias with dark grey, grey and light brown limestone and dolomitic limestone clasts (from a few centimeters up to 40 cm in size). Matrix supported with carbonate matrix.
B2	Massive polygenic carbonate breccias organized in amalgamated meter-thick beds. Clast sizes from 1 to 5 cm (locally up to a decimeter). Grain supported, conspicuous compaction with developmet of intergranular stylolites and accumulation of residual brown-reddish clay. Textural maturity is low. In some cases the clasts consist of fine grained breccias. B2a: predominant limestones. B2b: predominant dolomites.
B3	Autoclastic grey to light brown calcareous breccias. Tension fractures are filled by non-luminescent sparry calcite. The original lithotypes are represented by L3.
B4	Monogenic carbonate breccias with dark clasts (ripped-up strata, a few centimeters to a few decimeters in size) consisting of dolomitic limestones and, locally, dolomites.
B5	Carbonate breccias with dissolution phenomena.
B6	Polygenic breccias with reddish-brown marly-clayey matrix which is locally abundant, mostly in connection with fractures and pockets where they show pedogenetic structures. Clasts belong to the L and B lithofacies, may be subrounded and may show pedogenetic alteration. Within fractures-cavities as well as in "terra rossa" filled pockets, some calcite cement crusts can be observed, which show luminescent zones in CL. This particular lithofacies is typical of the most weathered part of the Castro Fm.
B7	Polygenic dolomitic breccias with platform-derived and dark, laminated dolomite clasts (Valtorta) possibly deriving from the Dolomia Principale.
L1	Grey and dark grey limestones with parallel laminations, locally stromatolitic. Thickness of beds of the order of the decimeter, often amalgamated. Locally calcarenites intercalate with these limestones. Strongly recrystallized microfacies.
L2	Vuggy, grey dolomitic limestones.
L3	Grey to ligth brown limestones organized in beds from a few centimeters to a few decimeters thick. Intraclastic-peloidal packstones, bioclastic mudstones with ostracods. Rare bioclasts and possible presence of *Spongiostromata*. Frequent tension fractures filled by sparry calcite may give rise to monogenic breccias.
L4	Lithofacies similar to L3, but characterized by dark-grey to black color.
D1	Dark grey, well bedded (thickness of beds of decimeter scale) with planar bedding micritic dolomites, locally showing laminites which may be of stromatolitic original. Recrystallized microfacies (pseudosparites).
D2	Dark grey, intraclastic doloarenites with graded structure and erosive base. Locally bioclasts may be present, mostly represented by: bivalves, ostracods and dasycladaceans.
T	Carbonate tectofacies. These are characterized by breccias with clasts of centimeter-scale dimensions. Several generation of fractures mostly affecting lithofacies B (TB in the sections). This peculiar lithofacies is widespread in all the studied stratigraphic sections and can be partially ascribed to the tectonic thrusting at the base of the Castro Fm.

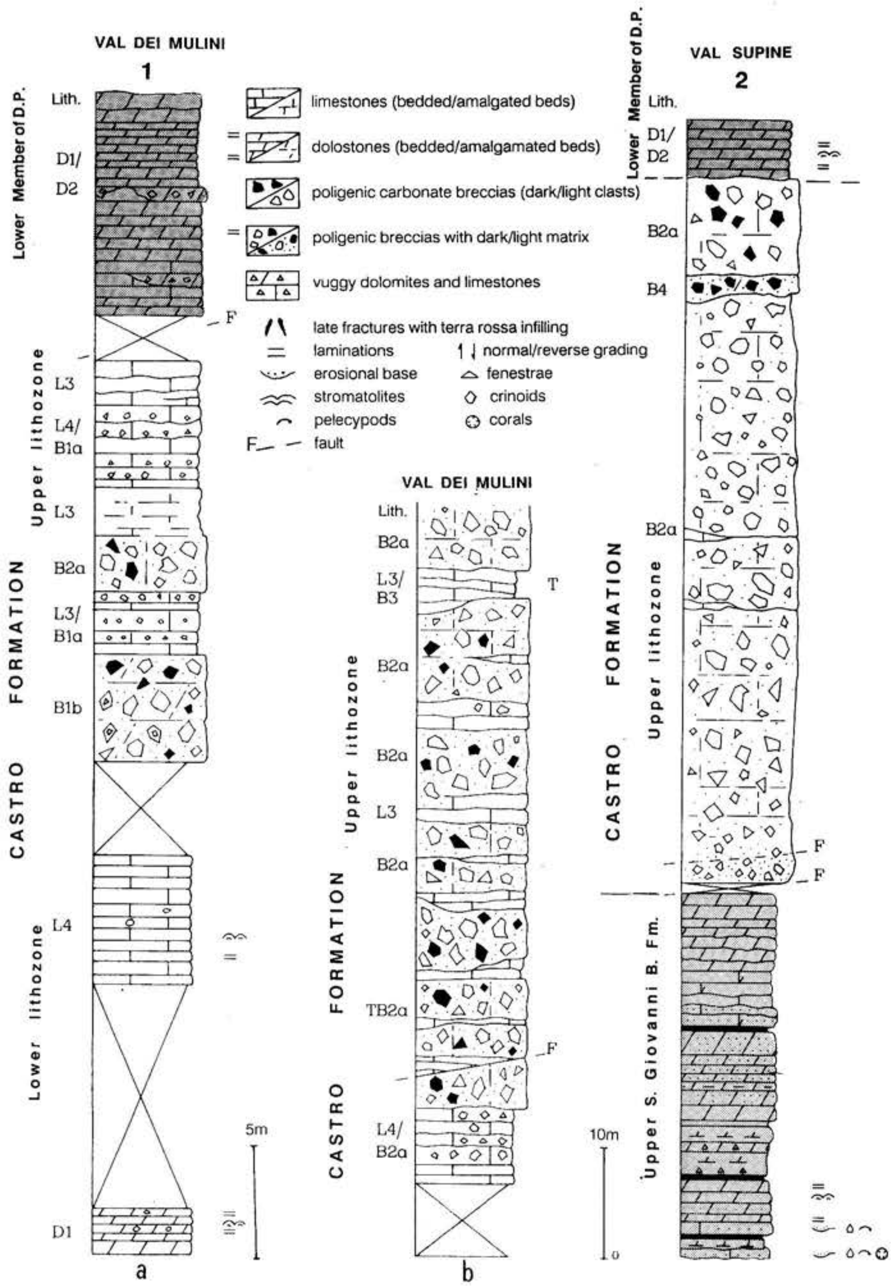


Fig. 3 - Stratigraphic sections of Castro Fm. of Valle dei Mulini and Val Supine. For lithofacies code explanation see Tab. 1.

Tab. 1 - Lithofacies recognized in the Castro Formation and lower Dolomia Principale.

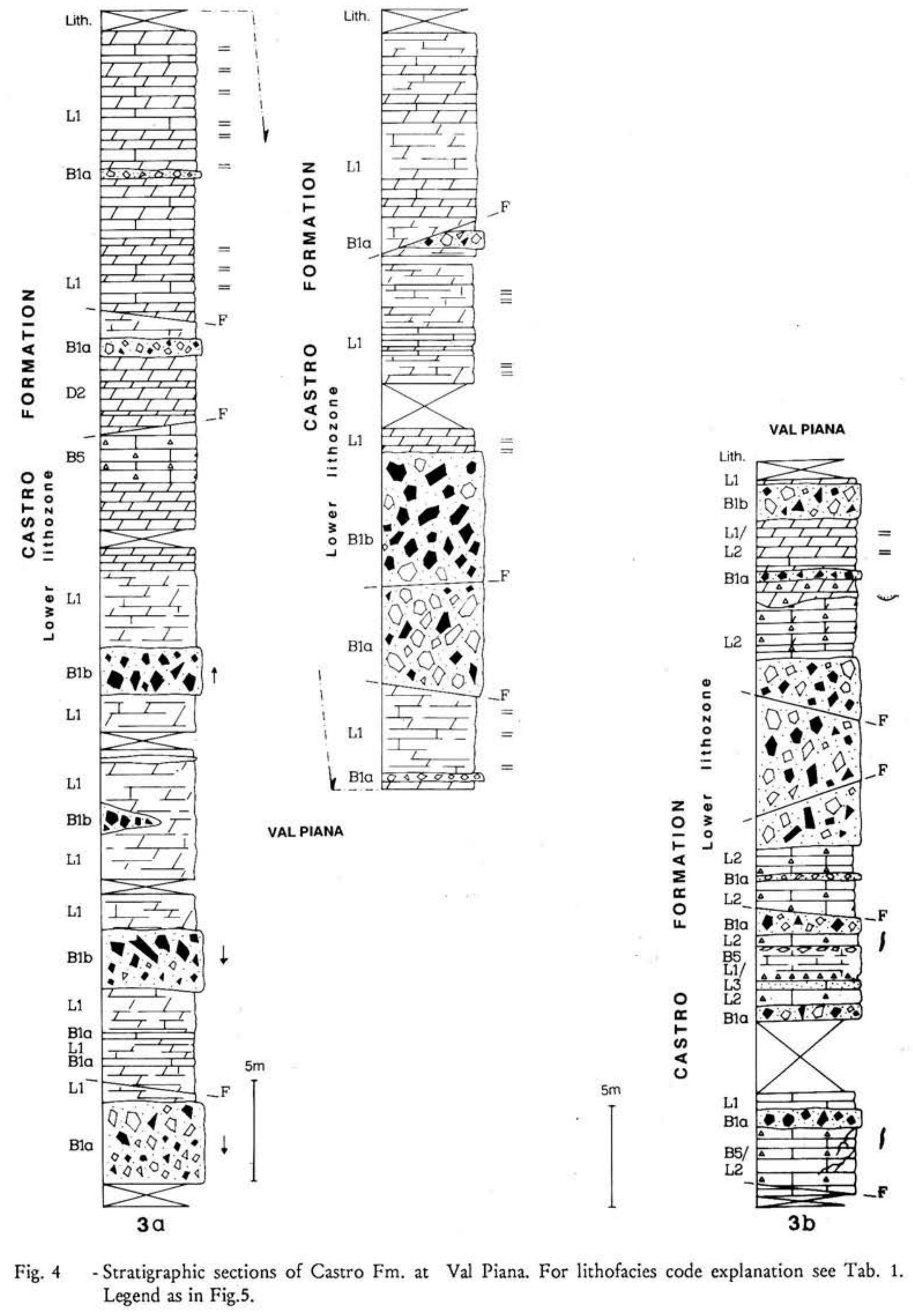


Fig. 4 - Stratigraphic sections of Castro Fm. at Val Piana. For lithofacies code explanation see Tab. 1. Legend as in Fig.5.

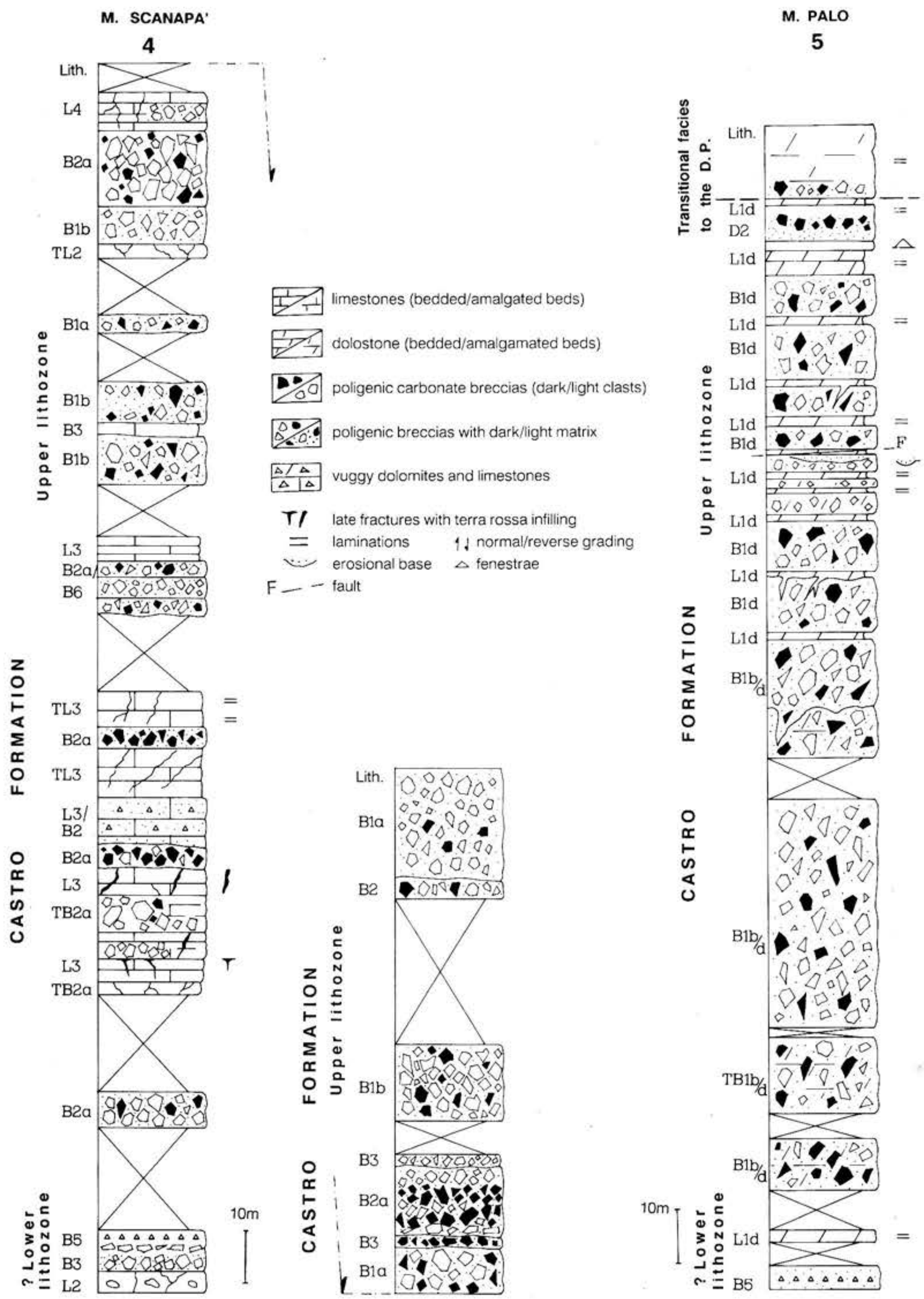


Fig. 5 - Stratigraphic sections of Castro Fm. at Monte Scanapà and Monte Palo.

In the lower part of this lithozone thin beds of dolomite and limestones (L2) and subordinate layers, 1-2 cm thick, of yellow-ochre clay (transitional facies to the San Giovanni Bianco Formation) are present. The microfacies of the dolomitic limestones consist almost exclusively of intraclastic packstones and wackestones as well as ferriferous-clayey micrites. Microfacies of the breccia clasts are the same as those of the lithotypes from which they derive: intraclastic packstones, wackestones and mudstones. Rare oolites and ostracods can be found within packstones and mudstones.

Limestones are characterized by penecontemporaneous fractures indicative of an early phase of brecciation (B3). Tension fractures, both due to syndepositional and late phenomena are also present. A last phase of stylolitization follows.

Recrystallization is generally strong and translates into widespread microsparites and pseudosparites microfacies. Among the rare authigenic minerals we observed: quartz, feldspars, pyrite and small dolomite rhombs. Chalcedony is very rare. Dissolution cavities are not very common and are filled by non-luminescent, clear sparite. The margins of the cavities may show local micritization phenomena.

Maximum thickness of the lower lithozone is about 50-80 m.

2. Upper Lithozone.

The upper lithozone is the most characteristic and common of the Castro Fm. It consists of both monogenic and polygenic breccias, the prevalent type of which consists of intraformational, relatively fine grained, carbonates (clast size from 2 to 5 cm) (B2). Grey to light brown limestone beds (L3), from a few centimeters up to a few decimeters thick, intercalate with and make lateral transition to the breccias (Fig. 3, 5).

Three different lithofacies have been recognized:

a) Typical Breccias of the Castro Formation. Grain supported breccias with angular clasts consisting of grey to light brown limestones (Fig. 6 a, d) which may show micritization surfaces and loss of the original colour. Intergranular stylolites are common. The scanty matrix is calcareous with subordinate clay. In the lower part of this lithozone, small clasts of yellow-ochre to reddish siltites and shales have been observed, the probable provenance of which is from the San Giovanni Bianco Formation. Altered porphyrite clasts are also present (M. Scanapà). The microfacies of limestone clasts are generally poor: intraclastic and peloidal mudstone-packstone and subordinate ferroan-clayey mudstones and wackestones. Recrystallization to microsparites and pseudosparites is common. Packstones and wackestones may show rare ooids and lumps. Rare fossil content, mostly represented by ostracods (Fig. 7 c) and small bivalves. Stromatolitic and problematica (*Spongiostromata*) bindstones are also present. Clasts are cross-cut by several generations of syndepositional tension fractures, prism-cracks and late fractures filled by calcite spar and, less frequently, micrite (Fig. 7 a, b, d). Cements are non-luminescent in cathodoluminescence (CL). Fracture-cavities filled by coarse sparry calcite mosaics and subordinate columnar calcites, cross-cut both sedi-

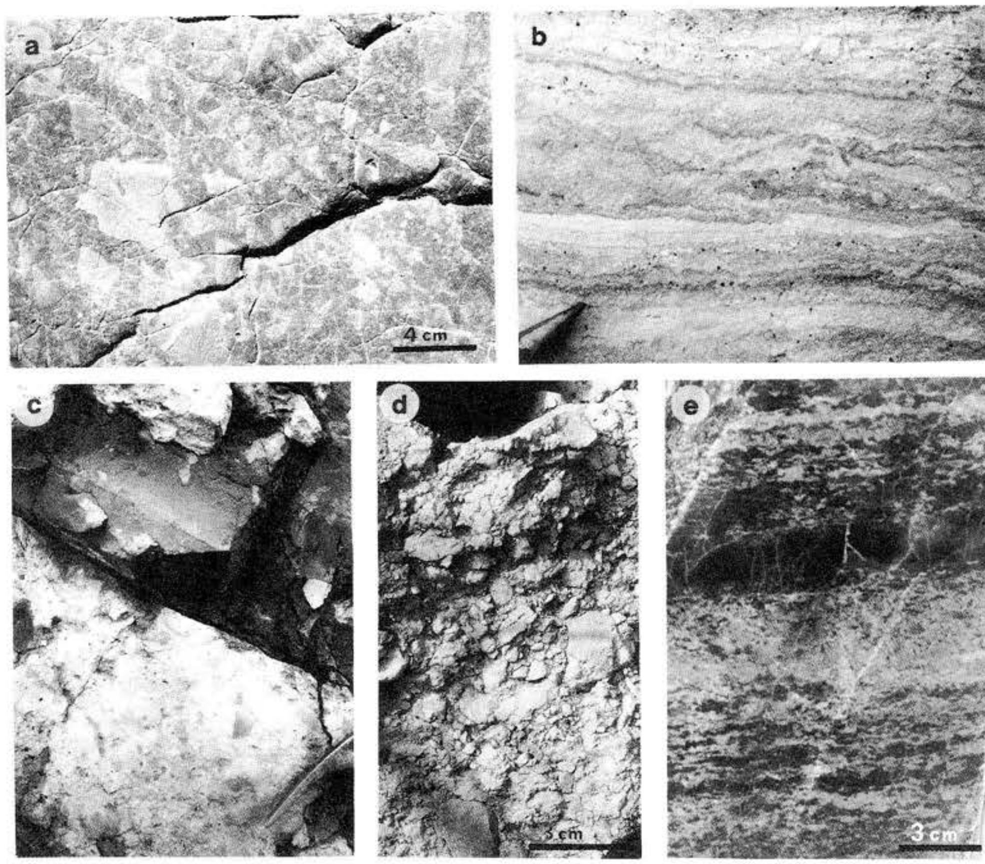
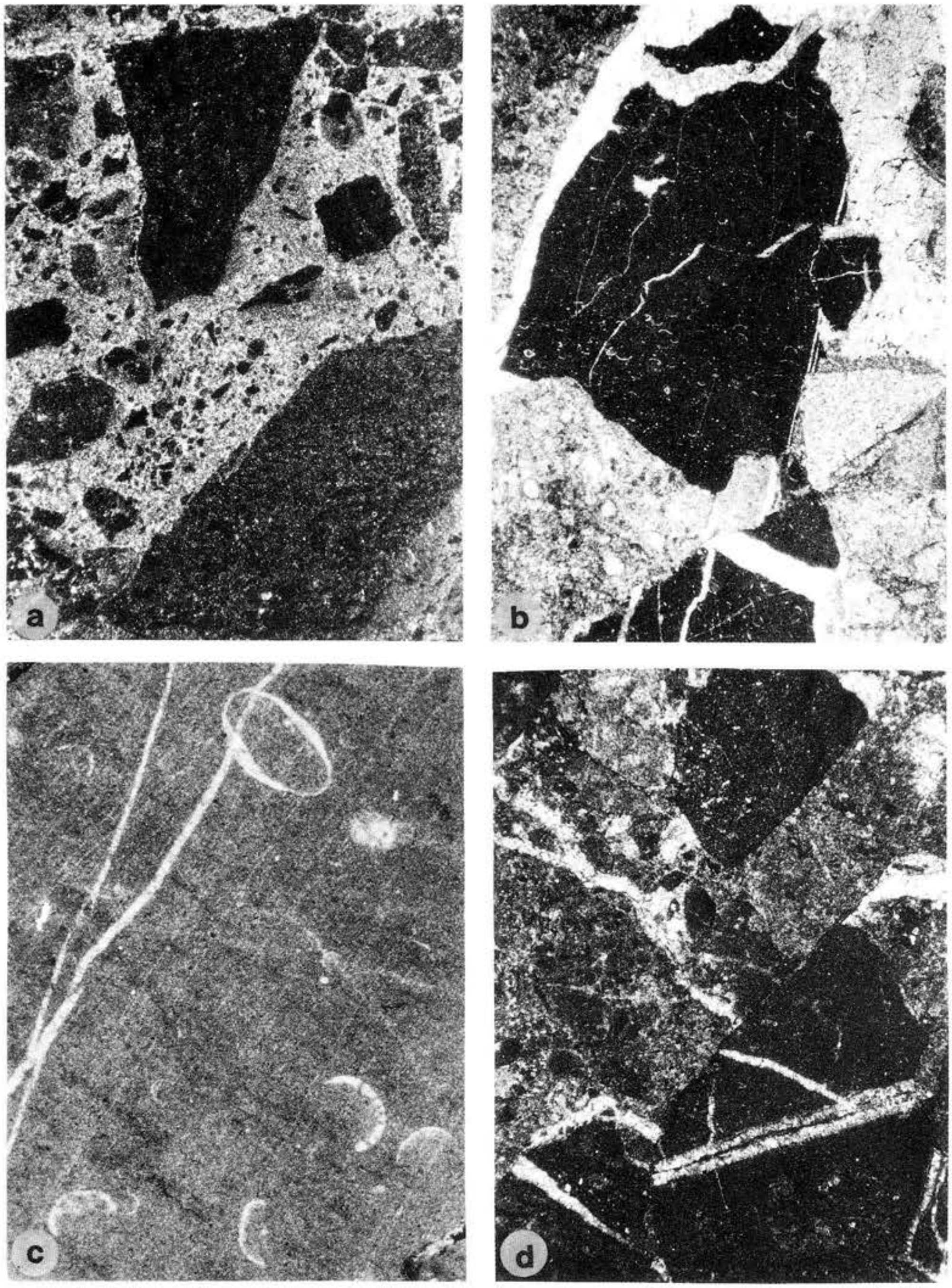


Fig. 6 - Castro Formation breccias and limestones lithofacies. a) Intraformational calcareous monogenic breccia, note clasts showing tension fractures filled by sparry calcite (Castro, upper lithozone). b) Laminated dolomitic limestones showing the development of incipient brecciation (Val Piana, lower lithozone). c) At the bottom polygenic breccias and intercalated dark azoic marly limestones. At the top of the latter irregular pockets of polygenic breccia (Val Piana, lower lithozone). d) Poorly sorted calcareous breccia with good compaction and affected by tectonics (Castro, base of upper lithozone). e) Pseudolaminated dark micrite with alternating light pseudosparitic "layers" with small dark intraclasts probably due to recristallization phenomena (Val Piana, upper lithozone).

mentary and early diagenetic structures. Therefore, they are to be considered late diagenetic. The fracture-cavities filling cements show a thin orange luminescent (CL) central zone. Stylolites are always subsequent to fractures and may affect even fractures/cavities filled by sparry calcite.

Authigenic minerals are represented by: quartz with carbonate inclusions, pyrite, feldspars, clays and rare, small dolomite rhombs.

b) Limestones. Grey to dark grey, well bedded limestones with faint parallel lamination (Fig. 6e), which intercalate with the carbonatic breccias. Locally (Nozza


a
b
c
d

Valley), dark limestones characterize the uppermost Castro Fm. Microfacies are represented by intraclastic-peloidal mudstones and wackestones, often recrystallized into microsparites and pseudosparites. Rare ostracods (Fig. 7 c), small bivalves, biogenic laminites (*Spongiostromata?*) and extremely rare ooids can be present.

Intergranular vugs filled by non-luminescent late sparry calcites occur in the packstones. Syndepositional tension fractures, fractures/cavities, dissolution cavities and late stylolites are common. Authigenic minerals are almost exclusively represented by quartz and dolomite.

c) Transitional lithofacies and lower Dolomia Principale. The typical Castro Formation lithofacies is overlain by rocks which mark the transition to the dark and well bedded dolomites of the lower member of the Dolomia Principale. In some areas the transition may be abrupt, because of the occurrence of well bedded (thickness of beds up to a few decimeters) dark doloarenites (D2) and laminated dolomicrites (D1).

When well developed, the transitional lithofacies are represented by dark, well bedded dolomitic limestones intercalating with lenses of calcareous to dolomitic, monogenic and polygenic breccias with dark coloured clasts. In Valtorta, the transitional lithofacies intercalate with the carbonate platform sediments of the lower Dolomia Principale. Associated breccia bodies consist of clasts derived both from the typical Dolomia Principale (light colour) and from its lower member (dark colour). The upper limit of the Castro Formation is set where the dark dolomites become prevalent.

Polygenic breccias of uncertain age associated with the Castro Formation.

The lithofacies of the Castro Formation are often associated with polygenic breccias with angular to subrounded clasts which differ from the typical Castro Fm. breccias because of the more abundant yellow-ochre, calcareous-marly matrix, the lower compaction, the less intense diagenetic overprint and the presence of rounded clasts.

In this lithofacies, two types of breccias have been distinguished:

I Breccias and conglomerates at the base of the Castro Formation.

II Breccias and conglomerates associated with the upper Castro Formation lithofacies.

I) In some areas (from M. Scanapa' to M. Altissimo) breccia bodies, a few tens of meters thick, consist of marly limestone clasts. Pockets of hybrid arenites rich in

Fig. 7 - Typical microfacies of the Castro Formation. a) Intraformational breccia with clasts consisting of intraclastic packstones supported by a recrystallized carbonate matrix (upper lithozone, Monte Cornetto); x 25. b) Polygenic carbonate breccia with: dark wackestones with small ostracods and tension fractures, light bio-intraclastic packstones and strongly recrystallized limestones. Rare interstitial carbonate matrix (upper lithozone, Monte Cornetto); x 20. c) Wackestones with ostracods (upper lithozone, Monte Cornetto); x 50. d) Polygenic recrystallized and tectonized breccia with stylolites at the grain boundaries which cross cut several generations of tension fractures (upper lithozone, Monte Scanapà); x 25.

carbonates with normal grading and parallel laminations are also present (? internal sediments). Polygenic breccias-conglomerates with erosional base and blocks deriving from the Castro Formation can be observed. The breccias are frequently associated with alpine tectofacies having a marly yellow-ochre coloured matrix support. This particular lithofacies contains altered porphyritic clasts, green and reddish shales, and white chips of sparry calcite. These breccias are stratigraphically set between a tectonically reduced San Giovanni Bianco Formation succession (at the bottom) and the typical Castro Formation (at the top).

Age and nature of these lithofacies are uncertain, mostly because of the presence of porphyry clasts (Tertiary or Carnian?) and tectofacies showing some sedimentary structures. In fact, this unit could represent: a) a tectofacies ; b) a sedimentary succession with a tectonic imprinting. At the present state of knowledge we prefer to consider a prevalent tectonic origin for these lithofacies connected with alpine thrusting (Berra et al., 1991).

II) Breccias with reddish to yellow-ochre calcareous matrix, characterized by intense pedogenesis and low compaction are locally associated with the upper lithozone of the Castro Fm. These polygenic breccias with subrounded grey to dark grey clasts (B6) form lenses, pockets and dyke-type structures.

The clasts derive from the Castro Formation and show pedogenetic and alteration phenomena towards the margins (Fig. 8). In some cases, pedogenesis alters the

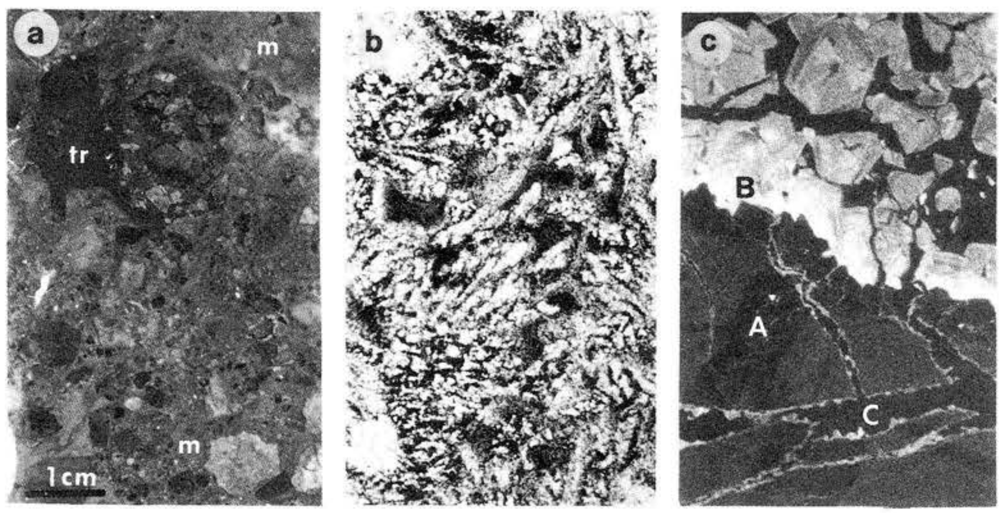


Fig. 8 - Macro and microfacies of Castro polyphasic breccias affected by karst phenomena of uncertain age (Corni Capreni). a) Dark and light grey recrystallized and fractured clasts with matrix (m) and late "terra rossa" filling (tr). b) Acicular pedogenetic structures as relicts within terra rossa pockets; x 35. c) CL micrograph showing different generation of fractures (1,2) and related cements (A non luminescent, B zoned yellow-orange luminescent, C late non luminescent calcite); x 25.

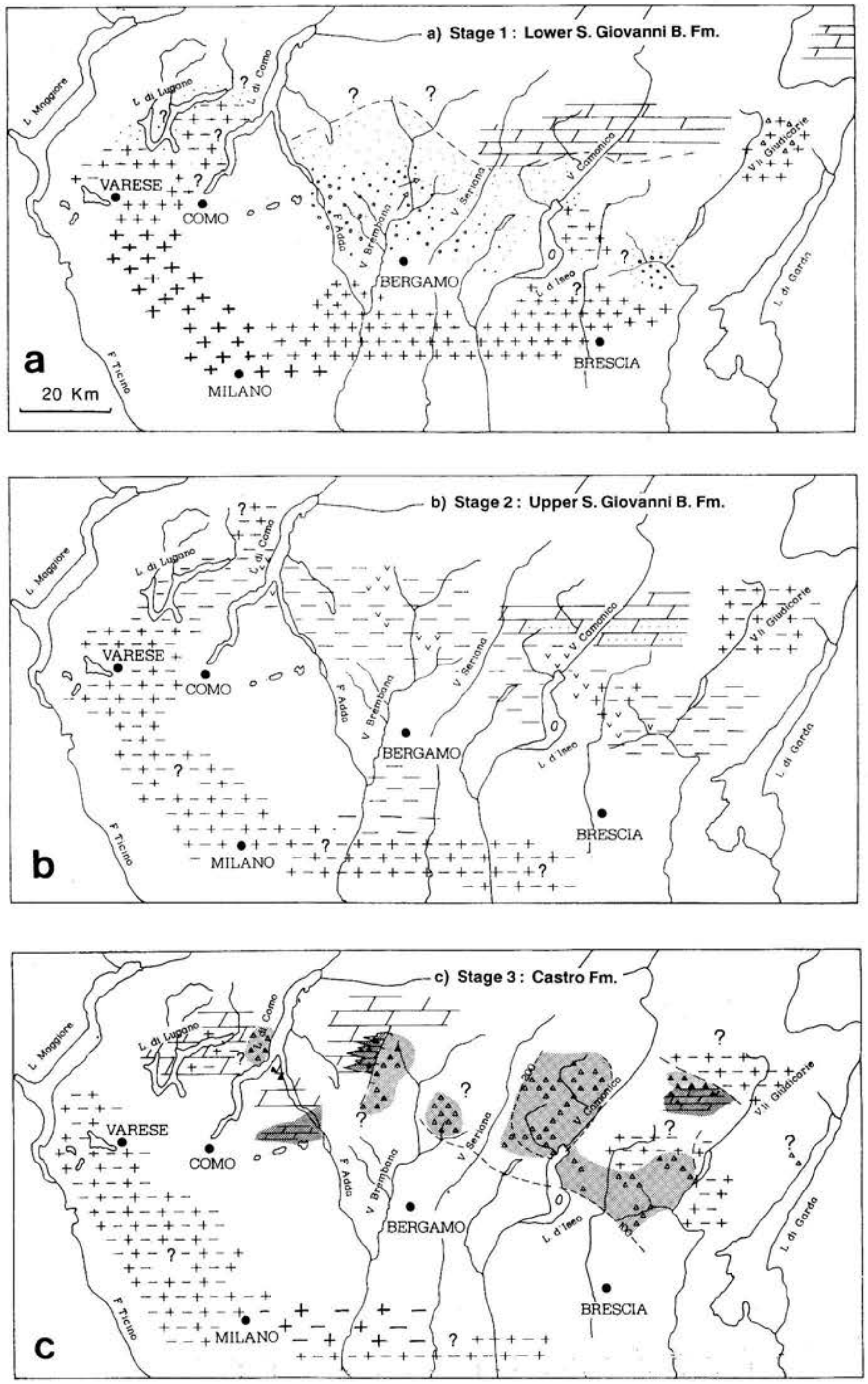
clasts into a pseudomatrix. The microfacies of the clasts are similar to those already described for the typical lithofacies: laminated microsparites, intraclastic-peloidal mudstones, wackestones and packstones with rare ostracods. Authigenic minerals are: quartz crystals (sometimes chalcedony), dolomite and iron oxydes. Tension fractures are frequent.

Microfacies analysis allowed the recognition of a prolonged diagenetic history with at least two types of matrix filling the fractures/cavities. The first type consists of yellow-ochre marls and the second of reddish clay. The first type shows laminites due to filling phenomena, while the second type bears acicular calcite crystals due to pedogenesis. At the margins of the clasts some fractures/cavities, filled by columnar and sparry calcite can be seen. Cathodoluminescence (Fig. 8 c) shows a first non-luminescent zone followed by some yellow-orange to dull to non-luminescent zones (Frisia & Jadoul, 1988). Within the reddish matrix some trace-fossils of uncertain nature have been observed. Coarse calcite spar fragments, with the same CL zonation as the fractures/cavities filling cements, are locally abundant in the matrix.

The origin of these breccias can be related to pedogenesis and subaereal erosion of uncertain age.

Lower Member of the Dolomia Principale.

In the whole studied area the base of the Dolomia Principale is characterized by dark, well bedded dolomites similar to the Dolomie Zonate (Jadoul, 1986) and the "heteropic facies of the Dolomia Principale", Lumezzane Member (Boni & Cassinis, 1973). Because lithofacies association is very different from that of the typical Dolomia Principale, the dark dolomites are considered a member of this formation, at least in Lombardy. The Lower Member outcrops in the Brescia province (Val Trompia, Val Sabbia), in the metamorphosed carbonate rocks of the Southern Adamello (the "euxinic facies" of Gaetani, 1985) and in the Bergamasc Alps (Jadoul & Rossi, 1982). In some part of the Brescia province and in Val Camonica the absence of the basal member may be due to tectonics. The outcropping area of the Lower Member coincides with that of the Castro Formation (Fig. 1). Thicknesses are variable, however mean thickness is about 80-100 m. The passage to the overlying Dolomia Principale occurs gradually: well bedded dark dolomites intercalate with peritidal, massive, grey to dark grey dolomites. Typical microfacies coinsist of dolomitic mudstones and intraclastic packstones, which may show laminations. Doloarenites with normal grading and erosional base, containing ooids, ostracods, dasycladacean Algae and micritic-clayey chips are also present. Small slumpings and synsedimentary faults with associated breccias several meters thick (eastern Iseo Lake) have been observed. Towards the top, doloarenites and dolosiltites may show abundant bioclasts represented by thin-shelled bivalves.


a) Stage 1 : Lower S. Giovanni B. Fm.
L. Maggiore
L. di Lugano
L. di Como
VARESE
COMO
F. Adda
V. Brembana
V. Seriana
V. Camonica
V. Giudicarie
BERGAMO
L. d'Iseo
L. di Garda
BRESCIA
MILANO
F. Ticino
a
20 Km
b) Stage 2 : Upper S. Giovanni B. Fm.
L. Maggiore
L. di Lugano
L. di Como
VARESE
COMO
F. Adda
V. Brembana
V. Seriana
V. Camonica
V. Giudicarie
BERGAMO
L. d'Iseo
L. di Garda
BRESCIA
MILANO
F. Ticino
b
c) Stage 3 : Castro Fm.
L. Maggiore
L. di Lugano
L. di Como
VARESE
COMO
F. Adda
V. Brembana
V. Seriana
V. Camonica
V. Giudicarie
BERGAMO
L. d'Iseo
L. di Garda
BRESCIA
MILANO
F. Ticino
c

Late Carnian paleogeography in Lombardy.

The paleogeographic evolution within a time interval comprised between the deposition of the San Giovanni Bianco Formation and that of the Lower Member of the Dolomia Principale is here considered. Fig. 9 and 10 show the four most significant scenarios.

Stage 1 - Siliciclastics of the lower S.Giovanni Bianco Formation (Fig. 9a, 10a).

This first phase corresponds to the deposition of the lower part of the San Giovanni Bianco Formation, represented by a sedimentary prism of siltites and sandstones bound by dry lands westwards (Varese zone), eastwards (Brescia zone) and southwards (our interpretations: Fig. 9 a, 10 a). Terrigenous clastics probably derived from the breakdown of an area corresponding to the present-day southern margin of

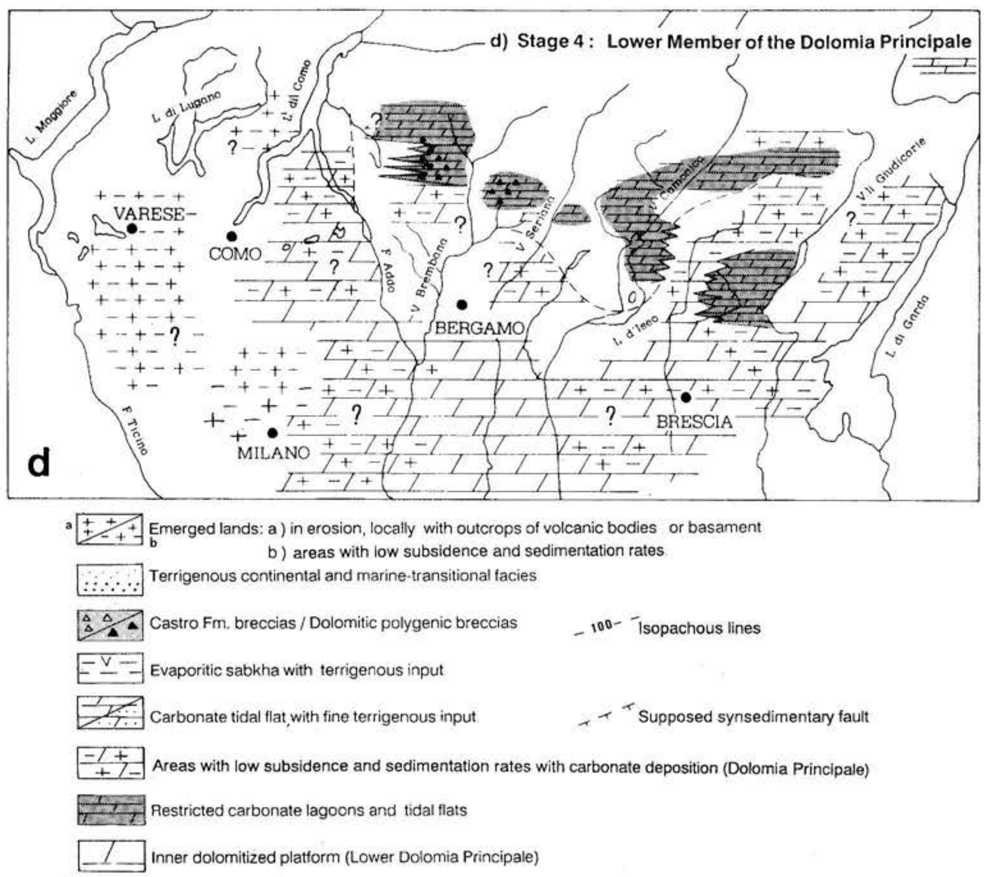


Fig. 9 - Late Carnian paleogeographic interpretative schemes (a,b,c,d), not palinspastic, from the deposition of the S. Giovanni Bianco Fm. to the sedimentation of the Lower Member of the Dolomia Principale. Palaeogeographic evolution of the southern areas (Po plain) is an extrapolation of our data of the Prealps outcrops and Agip data (Errico et al.,1979; Bongiorni, 1987).

the Po plain (Southern Mobile Belt, Brusca et al., 1982; Garzanti, 1985).

Northwards, terrigenous sediments make transition to lagoonal carbonates and mixed carbonatic-terrigenous deposits (upper Gorno Formation). Towards north-east, the upper part of the examined lithofacies is transitional with tidal flat carbonates (Campolungo Member of the Breno Formation). The lower San Giovanni Bianco Formation represents deltaic, alluvial plain and, more rarely, sabkha deposits. The depocenter is probably located in the present-day Val Brembana, where the coarser deposits outcrop. These latter decrease in thickness and show progressively finer particles north-eastwards and westwards (Fig. 9 a, 10 a).

The basal part of the sequence has been ascribed by Gnaccolini and Jadoul (1990, fig. 2) to the 3.2 cycle of Haq et al. (1988).

Stage 2 - Evaporites and carbonates of the upper San Giovanni Bianco Formation (Fig. 9 b, 10 b).

Phase 2 lithofacies make up the upper part of the San Giovanni Bianco Formation, which is characterized by shales, rare siltites and intercalated dolomites. Upwards, evaporite lenses (gypsum and anhydrite) up to 200 m thick become dominant and seem to indicate an increasing of subsidence. At the bottom of the sequence, the presence of bioclastic calcarenites with corals, crinoids, echinoderms, forams, bivalves and small patch-reefs is indicative of normal salinity and open circulation, related to a marine transgression possibly connected with a regional increasing of subsidence and relative sea level changes.

The lithofacies of the upper San Giovanni Bianco Formation are more widespread than those of phase 1, because sedimentation took place in areas which were previously subaerially exposed (Fig. 9 b, 10 b). Evaporites show millimeter-thick, laterally continuous, rithmic laminations, putting to evidence a dominant chemical precipitation in small, isolated subsiding basins with constant recharge of sea water in a low-energy regime. Deposition of evaporites in sabkhas seems less probable. In fact, in that case sulfate crusts should be present instead of thick laminated sediments (Tucker, 1981). Sabkhas possibly developed at the margins of the evaporitic basins.

The depositional basin of the upper San Giovanni Bianco Formation was bound by peneplains characterized by moderate subsidence and sedimentation. Small peritidal and shallow subtidal carbonate platforms were present both within and towards the

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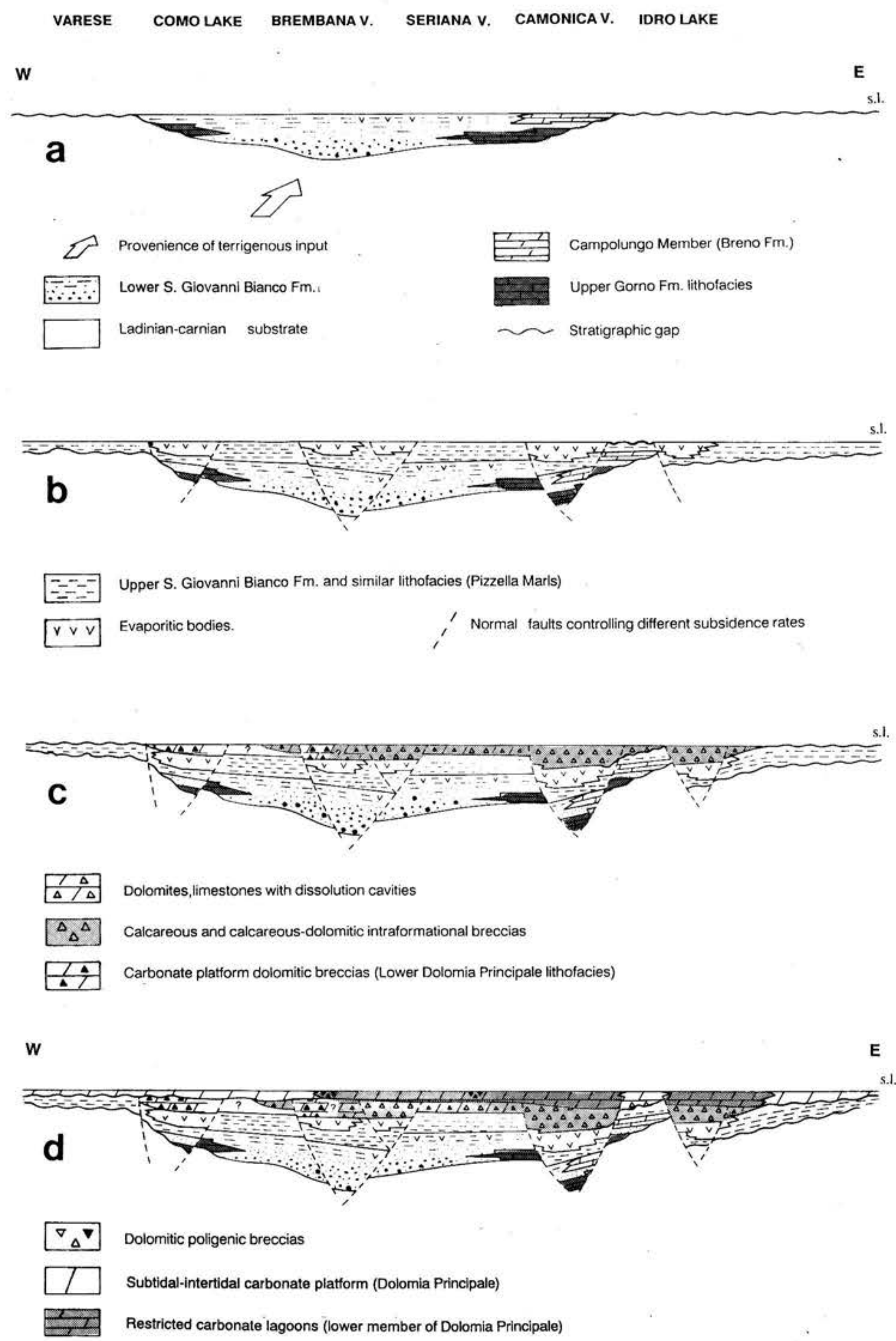
Fig. 10 - Paleogeographic interpretative profiles of the main evolutionary stages of the Late Carnian in Lombardy (an early stage of the Norian ensialic rifting). a) Stage 1. Regression at the top of the II carnian third order cycle, terrigenous, continental deposits of Lower S. Giovanni Bianco Fm. b) Stage 2. Regional transgression in the lower part of the upper S. Giovanni Bianco Fm. Fine marine-transitional terrigenous sedimentation conquires previous emerged lands, development of small depressions infilled by evaporites.

c) Stage 3. Deposition of the Castro Fm. in a large, subsiding and tectonically controlled depression. Local emersions in correspondence of structural highs with pedogenetic phenomena. d) Stage 4. Transgressive sequence of the lower Dolomia Principale with subsident lagoons overlying the structural depressions of the Castro Fm.


VARESE
COMO LAKE
BREMBANA V.
SERIANA V.
CAMONICA V.
IDRO LAKE
W
E
s.l.
a
Provenience of terrigenous input
Lower S. Giovanni Bianco Fm.
Ladinian-carnian substrate
Campolungo Member (Breno Fm.)
Upper Gorno Fm. lithofacies
Stratigraphic gap
s.l.
b
Upper S. Giovanni Bianco Fm. and similar lithofacies (Pizzella Marls)
Evaporitic bodies.
Normal faults controlling different subsidence rates
s.l.
c
Dolomites, limestones with dissolution cavities
Calcareous and calcareous-dolomitic intraformational breccias
Carbonate platform dolomitic breccias (Lower Dolomia Principale lithofacies)
W
E
s.l.
d
Dolomitic poligenic breccias
Subtidal-intertidal carbonate platform (Dolomia Principale)
Restricted carbonate lagoons (lower member of Dolomia Principale)

margins of the depositional system of the San Giovanni Bianco Fm. The local development (Val Supine, Ponte Nossa) of patch reefs and a more open and diversified marine sedimentation can be inferred from the presence of oolites, rarely ferruginous ooids and bioclastic calcarenites, with corals, crinoids, echinoids and pelecypods in the upper San Giovanni Bianco Fm.

Extensional tectonics may have controlled subsidence and facies distribution, small scale sinsedimentary and diagenetic dykes are frequent in carbonates near the top of the S. Giovanni Bianco Formation.

These upper S. Giovanni Bianco Fm. with tidal flat siltites, shales and subtidal carbonates of stage 2 represent the base of a third Carnic cycle, which has not been recorded by Haq et al. (1988). The presence of a third Carnic cycle has been recognized in other parts of the eastern Southern Alps (Doglioni et al., 1990). The correlation of these cycles is still problematic.

Stage 3 - Deposition of the Castro Formation (Fig. 9 c, 10 c).

This phase, corresponding to the deposition of the Castro Fm., was controlled by synsedimentary tectonics as indicated by the fact that this formation has the maximum thicknesses in correspondence of the subsiding evaporitic basins (Fig. 9 c, 10 c) with depocenter north of Iseo Lake. Environmental factors also controlled the sedimentary evolution causing the end of terrigenous input and the beginning of restricted bay carbonate sedimentation followed by deposition of breccias and associated limestones. For the depositional model see discussion in "Genetic Models".

The lower lithozone of the Castro Formation may again represent environments which laterally pass to the carbonate platform and evaporitic basins of the upper San Giovanni Bianco Fm. In the western and eastern areas, dolomitization of the Castro Formation breccias may be linked with the passage of dolomitizing saline fluids formed on carbonate platforms at the margins of the basin (Fig. 9 c) and driven through lagoonal sediments by density differences. The forementioned platforms may represent the first nuclei of the Dolomia Principale. Pedogenesis possibly affected temporarily subaerially exposed areas.

The sedimentary basin of the Castro Formation was probably bound towards the open sea by areas where the lower Dolomia Principale was being deposited. The presence in the Late Carnian of this platform was suggested for the Lugano zone (Conti, 1954) and confirmed by our data referred to the Val Brembana area (the Dasycladacea *Clypeina besici*).

Evolution of the platform sedimentation pattern was, at least in Valtorta, structurally controlled as indicated by thick deposits of dolomitic breccias with polygenic clasts (B7) both of platform and lagoonal provenance. Synsedimentary faults were probably active at the western margin of the Castro Formation depositional basin (Fig. 10 c).

Stage 4 - Development and expansion of the lithofacies of the Lower Member of the Dolomia Principale (Fig. 9 d, 10 d).

This phase is connected with a regional marine transgression which brought forth the rapid expansion of platform dolomites. These are progradational on the depositional basin of the Castro Formation. Dark, well bedded dolomites (D1, D2) at the base of the Dolomia Principale were deposited in restricted lagoons, which correspond to the more subsiding sectors developed during phases 2 and 3 (Fig. 9 d, 10 d). The basal lithofacies intercalate with subtidal and intertidal platform dolomites. This fact and the pervasive dolomitization indicate that the platform was already widespread over most of Lombardy. The restricted lagoonal facies make gradual transition to the typical Dolomia Principale which, by prograding all over the area, levels the former paleogeography and covers the structural highs of western Lombardy and the Southern Mobile Belt (Errico et al., 1979; Brusca et al., 1982; Bongiorni, 1988).

Stratigraphic unit	Lithofac.	C org.	Ca	Mg	Li	Na	K	Sr	Mn	Sr/Ca	Mg/Ca
		ppm			ppm	ppm	ppm	ppm	ppm		
Middle Dol. Princip.	dolom.	200	21.7	13.1				94	23	0.43	0.60
" "	dolom.	100	21.7	13.1				63	21	0.29	0.60
" "	dolom.	400	21.7	13.1				50	26	0.23	0.60
" "	dolom.	200	21.7	13.1				71	20	0.32	0.60
Lower Member D.P.	dolom.	300	21.7	13.1				30	126	0.14	0.60
Lower Dol. Princip.	dolom.	100	21.7	13.1				55	43	0.25	0.60
Castro Fm.(Bergam.)	breccia		39.4	0.2	5	22	31	127	25	0.32	0.005
" "	breccia		38.2	0.2	3	21	73	155	34	0.4	0.005
" "	breccia		34.2	3.8	8	64	80	95	74	0.27	0.11
" "	breccia		39.4	0.1	4	59	66	267	18	0.67	0.002
" "	breccia		38.6	0.6	4	41	70	242	23	0.62	0.015
" "	breccia		34.1	0.7	117	53	1300	139	158	0.41	0.02
" "	breccia	200	21.3	12.7	10	330	61	90	38	0.41	0.60
Castro Fm. (W.Idro L.)	breccia							90			0.98
" "	breccia					200		60			0.96
" "	breccia					200		500			0.01
S.Giovanni B. Fm.	marl		14.1	5.7				81	>600	0.67	0.04
Campolungo Member	dolom.	200	21.3	12.3				112	122	0.52	0.57
Campolungo Member	dolom.	200	22	11.8				167	168	0.67	0.54

Tab. 2 - Chemical analysis of samples of carnian-norian units of Lombardy.

Geochemical analyses.

Major and trace elements, as well as stable isotope analyses have been carried out in order to better characterize the Castro Formation lithofacies.

Major and trace elements (Tab. 2).

The Castro Formation is formed by a variety of lithotypes, ranging from dolomites to pure limestones. However, dolomitic limestones are frequent and, as a consequence, major and trace elements content change accordingly to the degree of dolomitization. A strong decrease in Mg content has been observed in the typical lithofacies. Dolomitization phenomena occur again at the limit with the Dolomia Principale.

Lower lithozone of the Castro Formation.

a) The clasts of the breccias consist of limestones, dolomitic limestones and dolomites. These latter have a Mg/Ca ratio from 0.96 to 0.98 (Tab. 2), therefore are calcian to slightly calcian. Sr content ranges from 60 to 90 ppm (Frisia, 1991) (which are values consistent with the predicted ones for slightly calcian dolomites; Vahrenkamp & Keuning, 1990), and Na ranges from 200 to 90 ppm. Limestone clasts have Mg/Ca ratio of 0.1 when not dolomitized; Sr content is up to 500 ppm and Na varies from 150 to 200 ppm.

b) Al and Si traces are mostly present in the matrix, along with traces of Na, S and Fe.

Upper lithozone of the Castro Formation.

a) The upper lithozone consists of almost pure limestones, with Mg/Ca ratio 0.05. However, in the areas of Valtorta and Lake Idro (margin of the sedimentary basin of the Castro Fm.), dolomitic breccias are common, with Mg/Ca ratio of 0.96 (calcian dolomites). Sr content in limestones averages less than 300 ppm, while in dolomites drops to about 100 ppm. Na content is similar both in dolomites and limestones, with values of about 200 ppm (up to 330 ppm).

b) Low Al and Si content.

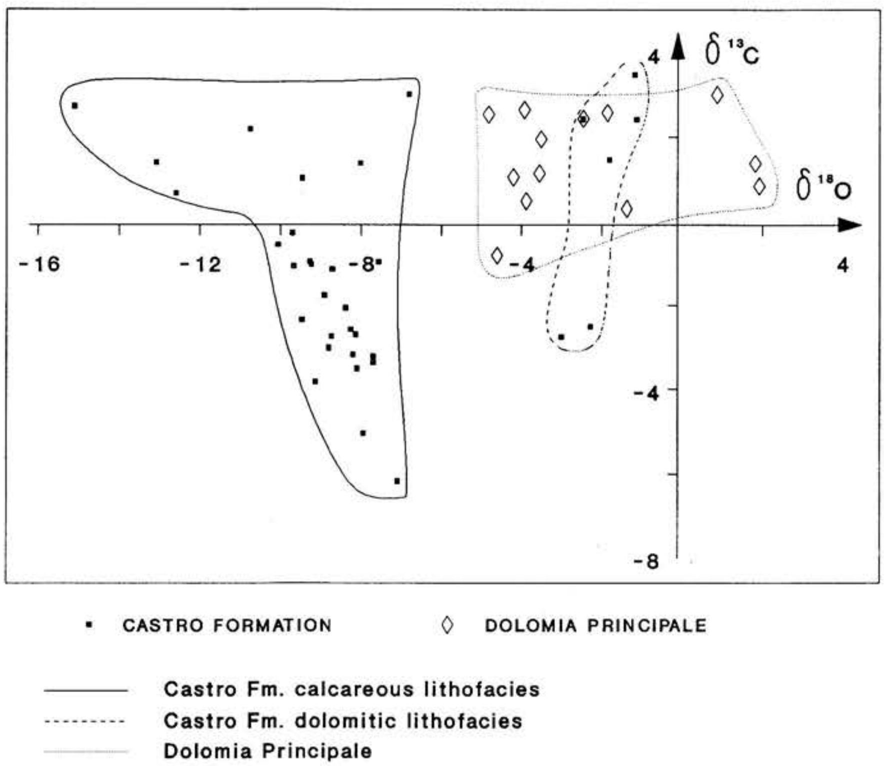


Fig. 11a - $\delta^{18}O$ and $\delta^{13}C$ isotopic values of the Castro Formation and overlying-underlying units.

c) Fe is present in traces, mostly in the matrix. Traces of Cl and K have also been detected.

The observed trace elements values are similar to those of the overlying Dolomia Principale, though Sr is generally lower for this latter (the Lower Member has 30-50 ppm Sr) (Frisia, 1991). Castro Fm. limestones Sr content appears to be comparable with triassic shallow water marine limestones; it is lower with respect to the marine limestones of the heteropic facies of the Dolomia Principale, where Sr can be in the range of 2000 ppm (Spezzi Bottiani pers. com.). This may be due to a possible higher recrystallization of the Castro Formation in early diagenetic environments controlled by freshwater (Veizer, 1983). To understand if meteoric diagenesis occurred, it is necessary to confront major and trace elements data with stable isotope values.

Stable isotopes analyses.

Over 50 stable isotope analyses on whole rock were carried out at AGIP Geochemical Laboratories on samples representative of different lithotypes of the Castro Fm. In addition, some Dolomia Principale and San Giovanni Bianco Formation samples were analyzed for comparison (Fig. 11 a, b).

Samples from the Castro Formation show $\delta^{18}O$ values ranging from -6 to -11 ‰ (PDB), with some extremely depleted values (-13 to -15 ‰). Dolomitized samples of the same formation are characterized by $\delta^{18}O$ values from -1 to -3.5 ‰ (PDB), while $\delta^{13}C$ values range from -4 to -6 ‰ (PDB). In the Idro Lake the $\delta^{13}C$ is more

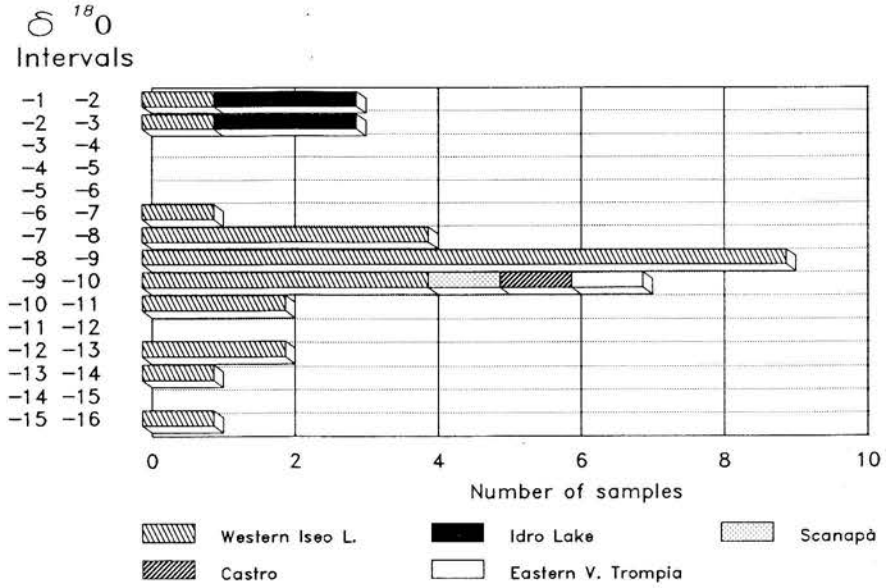


Fig. 11b - Geographical distribution of $\delta^{18}O$ in the Castro Formation lithofacies.

positive both in limestones and dolomites (values up to 2 ‰).

The Dolomia Principale samples show $\delta^{18}O$ values from -5 to +2 ‰, where the most depleted ones pertain to the lower part of this formation. Dolomites from the underlying San Giovanni Bianco Formation and transitional dolomitic limestones (lower lithozone of the Castro Formation) give $\delta^{18}O$ values of about -1/-2 ‰. Some breccias of the lithofacies B6, from the most weathered parts of the Castro Formation, with calcite (karst?) cements, paleosoils, pedogenetic phenomena, and of uncertain age, have values similar to those of the typical lithofacies ($\delta^{18}O$ from -5 to -9 ‰).

Stable isotopes data discussion.

The distribution of isotopic data (Fig. 11 a, b) puts to evidence that the Castro Formation shows values generally different from both these of the dolomites of the San Giovanni Bianco Fm. and those of the overlying Dolomia Principale. In particular, the limestones of the Castro Fm., though characterized by variable values within the same specimen (i.e. differences between matrix and clasts) fall in a separated field of the diagram, with a shift of $\delta^{18}O$ of 5-6 ‰. Towards negative values (which is considerably greater than the expected difference in fractionation between co-precipitated dolomite and calcite; McKenzie, 1981) with respect to the Dolomia Principale dolomites. The Castro Fm. limestones are depleted in $\delta^{18}O$ and $\delta^{13}C$ also with respect to the calcareous heteropic facies of the Dolomia Principale, which have mean values between +2 and -4 ‰ $\delta^{18}O$ and about 1‰ $\delta^{13}C$ (Frisia, 1991). Negative $\delta^{18}O$ values similar to those of the Castro Fm. limestones ($\delta^{18}O$ to -6 ‰ and even lower) have been observed in Rhaetian limestones of the Brenta Dolomites with evidences of meteoric diagenesis (cf. Mazzullo et al., 1990; Frisia, 1991). However, the Castro Fm. samples show more negative $\delta^{13}C$ with respect to these latter, possibly indicative of more open diagenetic systems.

The most depleted $\delta^{18}O$ values of the Castro Fm. fall in the field of precipitation from high temperature fluids (over 100° C; cf. Morse & MacKenzie, 1990).

Stable isotopic values similar to those of the Castro Fm. were observed for the Ligomena Breccias (Bertotti, 1990), which have the same stratigraphic position. In that case, the geochemical data have been interpreted as indicative of tectonic origin for the breccias, with subsequent circulation of hydrothermal fluids. If this was the case also for the Castro Fm., any primary signal may have been cancelled by tectonics. However, the marked difference between the Castro Fm. isotope values and those of both the Dolomia Principale and the San Giovanni Bianco Fm., and the variability between different elements within the same Castro Fm. breccia sample (matrix, limestone clasts, dolomitized clasts) may indicate the preservation of an early diagenetic isotopic signature. In fact, a tectonic isotopic imprint should have affected the same way all the rocks involved in deformation processes, and this does not seem the case. Furthermore, some limestone and breccia samples do not show evidence of tectonic deformation, therefore exclusive tectonic-hydrothermal isotopic imprint may be ruled out.

A primary imprint may be referred to early freshwater diagenesis of the carbonates. Negative values of $\delta^{18}O$ and $\delta^{13}C$ may reflect an original deposition of the Castro Fm. carbonates within hyposaline environments under direct influence of meteoric waters. In fact, meteoric systems are characterized by modifications of $\delta^{18}O$ and $\delta^{13}C$ composition linked with fluid circulation in open systems and presence of soil-gas CO_2 at water recharge surface (Lohmann, 1988). The "meteoric calcite trend" (Fig.11a) is associated with another, less evident, trend with positive $\delta^{13}C$ and extremely negative $\delta^{18}O$ values. This latter may reflect recrystallization during deep burial diagenesis (Veizer, 1983) or influence of hydrothermal fluids connected with tectonics.

Isotope data for the Castro Fm. do not fit into the scenario proposed for the depositional environment and diagenetic evolution of the overlying Dolomia Principale (Frisia, 1991) where evaporative phenomena are very important. On the basis of geochemical consideration, it seems also improbable that the Castro Fm. breccias formed by solution of former interbedded evaporites and subsequent collapse. In fact, there is no evidence of the presence of evaporites in the Castro Fm.

In conclusion, the Castro Fm. may preserve some early diagenetic imprints of meteoric diagenesis which took place in an open system. Clear evidences of vadose diagenesis have not been detected, therefore it is possible that limestones (possibly consisting of metastable phases) spent much of their time in the phreatic meteoric zone. The less depleted $\delta^{18}O$ values may be indicative of alteration by mixed freshwater and seawater in the proximity of developing carbonate platforms or coastlines. The relatively light $\delta^{13}C$ values imply alteration in an open system where soil carbon dioxide was a source of carbon for replacement reactions. As for the original mineralogy of the limestones, trace elements and stable isotopes do not allow a straight forward interpretation. The presence of some positive "marine" isotope values, and of Sr and Mg traces may be indicative of an original admixture of aragonite and Mg-calcite as in modern marine and transitional environments. The original limestones altered through time in a freshwater-controlled phreatic system and changed into a low-Mg calcite microsparite depleted in trace elements. Subsequently the rocks were modified by late deep burial and tectonic phenomena.

Genetic models discussion.

The Castro Formation lithofacies are difficult to interpret with one or the other of the models utilized to explain conspicuous breccia deposits. Post-diagenetic modification due to alpine tectonics, which caused detachment phenomena in correspondence with the evaporites of the San Giovanni Bianco Fm., further complicates the scenario.

Stratigraphic and sedimentological analysis of the recognized lithofacies allowed us to propose a model which takes into consideration the following characteristics of the Castro Formation:

1) abundance of intraformational calcareous breccias, with clasts ranging in size from a few millimeter to a few decimeters (average around 3-7 cm) intercalating with well bedded limestones;

2) rare fossils preserved, mostly ostracods;

3) monotonous microfacies, different from those of the Dolomia Principale;

4) facies distribution restricted to the Lombardy basin. Possible correlation of the Castro Formation with other units characterized by breccias set at the base of the Dolomia Principale in the Austroalpine (Fürrer, 1985; Gwinner, 1971) and in the Apennines (Ciarapica & Passeri, 1978) has still to be demonstrated;

5) lithology, mostly represented by limestones. In the underlying and overlying formations dolomites are predominant. Dolomitic breccias outcrop only at the margins of the depositional basin;

6) in the lower Castro Formation limestones and dolomitic limestones (lithofacies L1 and L2, Tab. 1, Fig. 4) alternate with mass flow breccias characterized by sedimentary structures indicative of short-distance transport from subaerially exposed areas;

7) extremely rare sedimentary structures (irregular, discontinuous laminations, chaotic breccias) in thick, massive or amalgamated beds of the upper Castro Fm. The imprint of alpine tectonics (tectofacies TB9) makes the recognition of sedimentary and early diagenetic structures in the Castro Fm. breccias difficult. Therefore, the distinction between tectonic and sedimentary-diagenetic derived breccias is not straightforward.

The interpretation of the typical lithofacies of the Castro Fm., with its prevalent calcareous lithofacies and chaotic setting, rare matrix, penetrative clasts sutures and lack of clear sedimentary structures, must take into account diagenetic and tectonic modifications. In any case, before considering a depositional model for the Castro Fm., it is useful to examine some of the models already proposed to interpret extensive breccia bodies.

Review of the models proposed for the genesis of conspicuous calcareous breccia deposits.

The most common phenomena for the genesis of conspicuous bodies of carbonatic intraformational breccias are those connected with the followings: karst processes; solution-collapse in evaporitic-carbonatic successions, mechanical erosion (emersions, synsedimentary tectonics, storms) of carbonate platform followed by sedimentation of the debris along the slope or within depressions.

These processes are here reviewed considering the possible genetic aspects of the Castro Fm. breccias.

a) Karst phenomena in carbonate rocks. One of the genetic models proposed in literature to explain the formation of breccias is that of karst solution of carbonates not associated with evaporites (James & Coquette, 1988). Breccias due to subaerial exposure and karst dissolution are generally associated with stratigraphic discontinuities at the top of the formation. An exclusively karst-related genesis for the breccias of the Castro Fm. seems improbable because of the followings:

- The Castro Fm. is characterized by lateral continuity over a wide area, considerable thicknesses and gradual lateral transitions. Breccia deposits inequivocally ascribed to karst phenomena show limited areal extension, extreme thickness variability and lack of lateral continuity. Rare exception have been observed, such as the Famennian collapse paleokarst breccias developed in a phreatic environment described by Quinif (1989) in Belgium.

- At the top of the Castro Fm. there is no a clear evidence of the presence of a discontinuity surface, which should be expected in the case of karst-related origin for the breccias.

- Karst-related collapse breccias are associated with vadose calcite cements, internal sediments and marked dissolution structures. These features are only locally present in the Castro Fm. Furthermore, karst breccias are generally subordinate with respect to the original lithotype; this is not the case for the Castro Fm., where breccias are dominant over the associated limestones.

The only paleokarst model that may partially explain the characteristics of the Castro Fm. is that of karst solution under cover in the phreatic zone followed by collapse phenomena (Quinif, 1989). However, because of the forementioned considerations, this model is not entirely satisfactory.

In the Castro Fm., thin levels of breccias with altered clasts, pockets and clastic-dykes filled by "terra rossa" (with acicular carbonates) are indicative of pedogenesis (Fig. 6). The presence of these lithofacies indicates that parts of the Castro Fm. underwent subaerial exposure in a relatively wet environment at a certain time of their history. The age of the paleosoils is uncertain: pedogenesis may have been syndepositional, but the bulk of the phenomenon seems to be much younger, possibly even Neogenic. Most of the pedogenetic structures are characterized by a diagenesis (Frisia & Jadoul, 1988) different from that of the typical facies of the Castro Fm.: presence of recrystallized and tectonically deformed clasts associated with paleosoils should rule out a Triassic age.

b) Karst solution and collapse brecciation in connection with the presence of evaporites. This model can explain the presence of thick intraformational breccia deposits which extend over wide areas. For example, breccias 150-200 m thick outcrop for thousands of km in South Dakota (Ford, 1989). Other examples from the United States are the Mississippian Madison Limestone (Sando, 1987) and Phasapa Limestone and from Belgium is the Belle Roche breccia (Swennen et al., 1990). In this latter there are unmistakable evidences of clasts pried upwards from undisturbed bedrock, a result of solution and recrystallization of sulfate prior to Mississippian paleokarst development (Palmer & Palmer, 1989).

Collapse breccias due to dissolution of evaporites show structures and lithofacies similar to those observed in the Castro Fm.: i.e. angular and subrounded clasts, matrix consisting of clay and detrital carbonates, sutured and interpenetrating clast boundaries indicative of brecciation phenomena occurred before the complete induration of the limestone (dolomite?). However, sulphate-related breccias are characterized by: cavities and cellular dolomites connected with hypersaline environments (Ford, 1989); dedolomitization phenomena; "zebra rocks" derived from interlaminated gypsum and carbonates; lens-shaped bodies with outer calcite shells indicative of isolate ponds of sulphates within limestone; correlative gypsum/anhydrite beds.

The sulphate-related brecciation model shows some discrepancies when we try to apply it to the Castro Fm. because of the followings:

1) Within the studied breccias we did not observe intercalated evaporites or cellular dolomites as well as carbonate pseudomorphs after sulphates. Even if we hypothesize a complete dissolution of these minerals due to karst-related phenomena, it would be difficult to explain why in the underlying San Giovanni Bianco Fm. anhydrite and gypsum sabkha deposits are still preserved. These latter are associated with pseudomorphs after sulphates and dedolomitization. Furthermore, in the San Giovanni Bianco Fm. some intraformational breccias, a few meters thick, with cellular-dolomite can be locally observed and fit into the sulphate solution-collapse model.

2) The pure limestones of the typical lithozone of the Castro Fm. (Tab. 2) seem to contradict the hypothesis of chemical precipitation of the carbonates in a hypersaline environment controlled by strong evaporation, as it is the case for most intercalated evaporite and carbonate deposits. Because of the preservation of the original microfacies with ostracods, the lack of dolomite inclusions in the most of sparites, massive (texturally destructive) dedolomitization phenomena seem also improbable.

3) Dolomitic limestones and dolomites of the lower lithozone of the Castro Fm. (probably heteropic with the carbonates and evaporites of the San Giovanni Bianco Fm.) do show intercalated breccias that may be due to solution-collapse. However, some of these breccias can be ascribed to limited mass and debris-flow phenomena on the basis of facies analysis. The recrystallized and monotonous facies of the analyzed samples (peloidal packstones, micrites and microsparites with rare ostracods) are indicative of environment with anomalous salinity. Yet, it is still to be understood whether hyper or hyposalinity prevailed.

On the basis of the forementioned characteristics, we believe that the environment of deposition had either variable salinity or was hyposaline and therefore, not suitable to the precipitation of evaporites.

c) Tectonic brecciation. At least two cases of tectonic brecciation may be distinguished:

I) syndepositional tectonics, which originated fault-escarpment brecciation;

II) late tectonics brecciation. In this case we may have either real tectofacies, connected with mechanical action during thrusts phenomena or breccias deposited within intramontane basins genetically linked with the development of alpine overthrusts.

I) Breccias due to Late Carnian synsedimentary tectonics.

Volcanism and tectonics were common in Lombardy at the Ladinian-Carnian boundary and during the Early Carnian. These phenomena can be ascribed to the presence of a subduction zone as postulated by Marinelli et al. (1980), Garzanti and Jadoul (1985), or to activity along transcurrent faults (Doglioni, 1987). In the Late Carnian the same phenomena could have occurred, but they are not well documented. However, regression, rejuvenation and erosion of structural highs located to the south and to the west (Fig. 9 a, 10 a) may be indicative of tectonics. Terrigenous sediments derived from erosion of these structural highs can be observed in the lower lithozone of the San Giovanni Bianco Fm. in Val Brembana (Garzanti, 1985). As it has been already mentioned, Jadoul and Rossi (1982) interpreted the breccias of the Castro Fm. as due to Late Carnian tectonics. The tectonic-paleogeographic evolution of the Late Carnian of west Sudalpine, seems to present analogies with the Lower Keuper of Central Europe (Ziegler, 1982).

Field and laboratory data for the present study do not allow the unequivocal attribution of the analyzed breccias to synsedimentary tectonics. In fact, breccias connected with fault escarpments and having thicknessess comparable to those of the Castro Fm. are generally more heterogeneous, contain elements of the underlying units (Mustard & Donaldson, 1990) and are characterized by a wedge shape. Furthermore, their distribution is controlled by the trend of the paleofaults. These conditions do not occur for the Castro Fm.

II) Tectonic breccias due to late tectonics.

The Castro Fm. breccias show frequently intense tectonic deformations. This may lead to the conclusion that they are exclusively connected with cataclastic phenomena in correspondence of alpine overthrusts and faults often present at the base and within the unit. Such origin is proposed by Bertotti (1990, 1991) for the Ligomena breccias, which show dedolomitization phenomena starting from Dolomia Principale lithofacies. A similar interpretation has been proposed for the Cordillera Betica rauhwackes (Leine, 1968).

The thickness of the breccias, the locally observed transitional-stratigraphic boundary with the Dolomia Principale, the undisturbed intercalated limestones and the microfacies of the breccia clasts, which differ from these of the underlying and overlying formations, seem to rule out an exclusive late tectonic origin. Nevertheless, alpine deformation has locally strongly affected the Castro Fm. and its boundary with the S. Giovanni Bianco Fm. With respect to this problem we consider the polygenic breccias and tectofacies of uncertain age mainly located at the base of the Castro Fm. (more details in Forcella & Jadoul, 1990; Berra et al., 1991). These particular lithofacies are very similar to the tectonic breccia of the Lugano area (Bertotti, 1991, tab. 10, fig. 3). Furthermore, late tectonic brecciation as the only mechanism producing the Castro Fm. brecciation is improbable because of the constant stratigraphic position of the formation, even in different tectonic units (Berra et al., 1991), and because of the thickness of the breccia deposits.

IIa) A second hypothesis to explain the Castro breccias as tectonically related could be linked to large scale detachments, occurred along listric faults, of the overlying Dolomia Principale during the upper triassic-liassic crostal thinning and rifting (cf.

the Lugano Fault, Bertotti, 1990, 1991). At the present state of knowledge there are no data supporting this hypothesis. However, the observed correspondence between breccia outcrops and the overlying upper triassic carbonate platform tectonic margins should be taken into consideration.

IIb) Breccias deposited in alpine intramontane basins. The Castro Fm. breccias may also be syntectonic breccias deposited within intramontane basins, the development of which was controlled by thrusts with southwards vergence. In fact, the Castro Fm. breccias can occur with, and make lateral transition to continental breccia deposits with paleosoils, ascribed (Forcella & Jadoul, 1988) to thrust-related debris deposits. Comparisons between petrographic characteristics of the two deposits put to evidence a stronger recrystallization, tectonic deformation and compaction for the clasts of the Castro Fm. breccias. "Tertiary" breccias are more heterogeneous and show more abundant matrix.

Therefore, we do not consider intramontane breccia deposits as a satisfactory model to be proposed for the Castro Fm. breccias, mostly because of their well documented stratigraphic position.

Proposed model.

On the basis of the forementioned premises, we propose a complex model (Fig. 12) to explain the development of the Castro Fm. breccias, which includes some of the reviewed ones. These latter may explain only partially the formation of the breccias. However, they do not explain the presence of undisturbed intercalated limestones and dolomites representing the sources of the clasts.

The proposed model is based on the following considerations:

1) the Castro Fm. lithofacies can be observed over a wide area (from W Lombardy to the Brescia province) (Fig. 1);

2) the Late Carnian evolution of this area seems to be characterized by local changes in the subsidence rate with presence of widespread evaporite deposits (Fig. 2, 9 b, 10 b);

3) the lithologic characteristics of the Castro Fm. lithotypes are indicative of the de elopment of peculiar environmental conditions.

The first phase of our model envisages the presence of transitional environments where marine conditions prevail. This translates in the passage from evaporites and limestones-dolomites of the upper San Giovanni Bianco Fm. to limestones and dolomitic limestones with intercalated intraformational breccias of the lower Castro Fm. The origin of these breccias, which may be interpreted as debris-flows will be discussed later. The depositional environment of these Castro Fm. lithofacies comprises tidal flats, lagoons and isolated basins characterized by hypo- to hypersaline (schizohaline, Folk & Siedlecka, 1974) conditions.

The change in environmental characteristics documented by the different sedimentation may be ascribed to several causes: a marine regression and subsequent isolation of some areas from sea water flooding; increased meteoric water influx; climatic

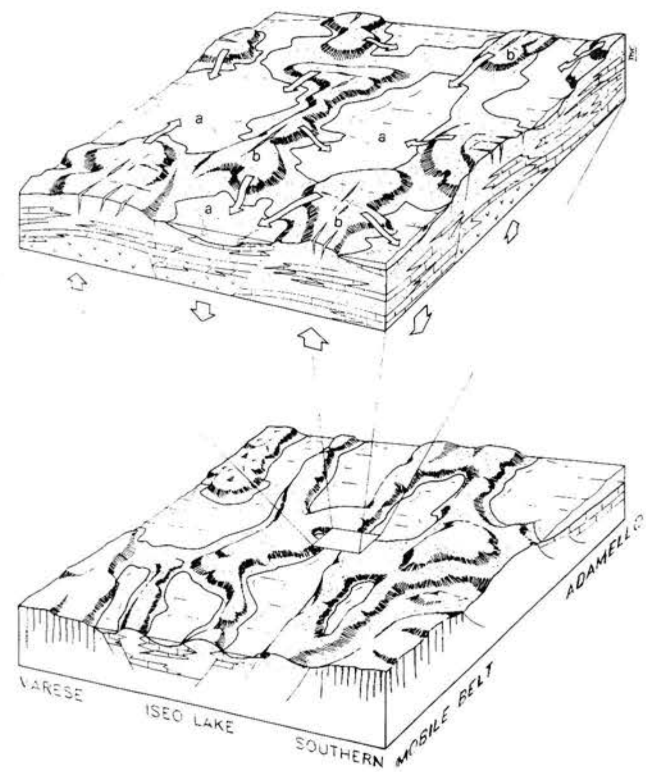


Fig. 12 - Depositional system proposed for the Castro Fm. a) Ephemeral, subsident lakes with fine limestones, intraformational breccias and dissolution-collapse breccias related to underlying evaporitic bodies. b) Mounds and ridges temporarily emerged related to dissolution-collapse and uplift-deformation phenomena into the underlying evaporites, desiccation of limestone muds. Tectonics may be an important element controlling subsidence in the central Lombardy depression and locally its paleogeographic setting.

variations. A climatic change probably occurred in the Late Carnian (Simms & Ruffel, 1990), possibly connected with changes in atmospheric circulation regime. As a consequence, monsoonal climates developed and rainfall increased with respect to the deposition period of the S. Giovanni Bianco Fm. Increased rainfall may explain the lack of dolomite precipitation in the Castro Fm. In fact, annual precipitation over 700 mm rain (typical of monsoon climate) seems unfavorable to the formation of dolomites (Warren, 1990).

It is probable that hyposaline environments developed locally at that time in the western Tethys as documented by paleontological data (*Estheria minuta* faunas in successions of the Late Carnian of Southern Italy; De Castro, 1988). The middle and upper parts of the Castro Fm. (massive breccias, lithofacies B2) seem to represent this climatic regime in a subsiding depositional environment. Ephemeral basins created by marine regression migrated laterally through time and were subject to seasonal rainfalls and marine influx during times of prevalent evaporation, which caused sea water to flow through the sediment landwards (cf. Rosen et al., 1989 and Warren, 1990). The presence of marine environment subject to freshwater influx, constraining both sedimentation and subsequent diagenesis, can be inferred from geochemical analyses of the Castro Fm. lithotypes (presence of Sr and Mg as well as Cl and Na traces, indicative of marine precursors (Tab. 2), while stable isotopes recorded freshwater diagenesis) (Fig. 11).

The monotonous ostracod-bearing, rare stromatolitic and problematica bindstones microfacies are indicative of ecologic niches unfavorable to the development of a rich fauna, further evidence for strong salinity variations. Facies were subject to lateral migration that caused subaerial exposure of areas which had been the site of carbonate deposition. The sediments of these dry lands deformed by dessiccation structures (mud cracks and prism cracks) and tension fractures evolved to intraformational breccias. In the zones where subaerial exposure was prolonged, erosion, karst dissolution and evaporite solution-collapse may have generated in situ a great quantity of clasts (Fig. 12).

An increase in energy connected with strong rainfalls may have caused a short transport of the clasts towards small depressions and ephemeral basins. Subaerial exposure of some areas could have been tectonically controlled as a consequence of two factors: a) prosecution of Late Carnian extensional tectonics, already active at the time of deposition of the San Giovanni Bianco Fm. sulphates; b) geometric and volumetric changes occurred within the underlying evaporite bodies which may have had influence on the surface morphology. These changes can be ascribed to surface waters circulation and subsequent dissolution and mineralogic transformations (anhydrite to gypsum).

The proposed model explains in part the genesis of the breccias at the top of the upper lithofacies, characterized by the presence of "terra rossa" (B6). In fact these latter may be due to syndepositional pedogenetic alteration. However most of these breccias show a different diagenetic history and tectonic deformation less pronounced than the typical Castro Fm. lithofacies (Frisia & Jadoul, 1988). Therefore, "terra rossa" bearing breccias may be "relict paleokarst" (Jennings, 1971; Wright, 1982) connected with Neogenic pedogenetic phenomena.

Conclusions.

The present study proposes a lithostratigraphic reconstruction of for the Late Carnian in Lombardy. In particular, sedimentological analysis of the sequence comprised between the San Giovanni Bianco Fm. and the Lower Member of the Dolomia Principale has put to evidence that sedimentation was predominantly carbonatic. This succession, in our opinion, may represent a third order cycle not envisaged in the curve of Haq et al. (1988). This cycle, which can be tectonically controlled, begins with the upper San Giovanni Bianco Fm. and ends with the disappearance of breccias at the top of the Castro Fm. At present we have not enough data to support physical correlations through the Late Carnian-Early Norian successions of Sudalpine. The presence of the third Carnian sedimentary cycle, however, can be observed in other areas of the Southalpine (Doglioni et al., 1990), with different thicknesses and lithofacies. Recognition and correlation of the carnian cycles in the Southern Alps is problematic because of the lack of a detailed biostratigraphy. In respect to the physical stratigraphy of Upper Carnian-Norian sequences, it is interesting to consider the presence of a "base norian unconformity" (Ziegler, 1983) in Central Europe interpreted by Beutler (1979) as related to combined effects of differential subsidence, regional relief warping and temporary eustatic lowering.

The subsequent norian cycle starts with dark, well bedded, lagoonal dolomites of the Lower Member of the Dolomia Principale, followed by the progradation of subtidal-peritidal Dolomia Principale.

Facies analysis of the Castro Fm. has put to evidence that this formation deposited in environments which were partially isolated from direct marine flooding under the control of meteoric waters in a monsoonal climate regime. Deposition of the Castro Fm. possibly took place in coastal zones subject to different subsidence rates in the presence of subaerially exposed areas representing the "factories" of the breccia clasts. These latter were subsequently transported into small depressions and ephemeral lakes. Subaerial exposures were possibly controlled by relative water level fluctuations in the ephemeral lakes and by extensional tectonic phenomena at the margins of the depositional basin where small fault escarpments can be hypothesized.

Alpine tectonics locally modified the original lithotypes and yielded tectonic brecciation. Often, karst and pedogenetic phenomena as well as neogenic brecciation superimpose on the Castro Fm. lithotypes. Therefore, the geochemical data of the analyzed formation, which we considered as indicative of freshwater influx in its earlier depositional/diagenetic history, may also reflect post-depositional events and tectonic inprint.

The Late Carnian stratigraphic and paleogeographic evolution seems to point out the presence of a subsident tectonic depression in central Lombardy controlling also the deposition of the Lower Member of Dolomia Principale. This tectonic depression is an ancestral precursor of Late Norian intraplatform basins, and may be considered as the earliest rifting episode of the alpine orogenic cycle.

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