Rivista Italiana di Paleontologia e Stratigrafia	volume 101	numero 1	pagine 17-36	Maggio 1995

ANATOMY OF A SEMIARID COASTAL SYSTEM: THE UPPER CARNIAN OF LOMBARDY (ITALY)

EDUARDO GARZANTI, MARIO GNACCOLINI & FLAVIO JADOUL

Key-words: Semi-arid Fan, Coastal Plain, Sabkha/Lagoon, Salina, Carbonate Platform, Sandstone Petrography, Climate, Late Carnian, Southern Alps.

Riassunto. Il Carnico Superiore in Lombardia è rappresentato dalla Lingua di Campolungo (parte superiore della Fm. di Breno) e dalla Fm. di San Giovanni Bianco. Lo studio di dettaglio di questa successione, potente da 200 a 300 m, ha consentito di identificare 10 litosomi, caratterizzati da differente litologia, strutture sedimentarie e composizione mineralogica, e di ricostruirne la geometria e il significato ambientale. La Fm. di San Giovanni Bianco viene qui suddivisa in due parti (SGB1 e SGB2), separate da una discontinuità maggiore, interpretata come dovuta a un abbassamento relativo del livello del mare (limite di sequenza).

Nella parte inferiore della Fm. di San Giovanni Bianco (SGB1) sono stati riconosciuti sei litosomi. Arenarie e peliti da verdi a rosse, accumulatesi a sud-ovest e a sud-est, passano verso nord a sedimenti costieri misti terrigeni-carbonatici e infine a dolomie deposte in piane carbonatiche peritidali. Una significativa attività tettonica è testimoniata, nelle sezioni più prossimali delle Prealpi bresciane, dalla progradazione verso nord-ovest di facies rosse continentali con intercalati livelli lentiformi di conglomerati ricchi di frammenti di rocce carbonatiche. Un netto aumento di quarzo detritico rappresenta un marker regionale, che può essere correlato attraverso le Prealpi lombarde e documenta l'approfondimento dell'erosione a intaccare il basamento dell'arco magmatico posto a meridione. Una lacuna importante al tetto dell' SGB1 è documentata, nell'area della Presolana, da un paleosuolo siliceo che ricopre direttamente il Membro dell'Annunciata della Formazione di Breno, di età Julica. In Val Brembana, la discontinuità cade all'interno di una successione clastica di piana costiera, e viene tracciata al tetto di un livello guida caratterizzato da arenarie e siltiti rosse.

La parte superiore della Fm. di San Giovanni Bianco (SGB2) comprende quattro litosomi. Arenarie e siltiti verdi, accumulatesi in piane costiere a sud-ovest, fanno transizione verso nord a peliti e dolomie. In Val Camonica meridionale, alle peliti sono intercalate calcareniti fossilifere di mare aperto che contengono anche litoclasti perforati da organismi e pedogenizzati, strappati alla sequenza sottostante durante la rapida trasgressione. In seguito, notevoli spessori di gesso si accumularono in saline costiere sbarrate a nord da piattaforme carbonatiche spesso oolitiche. Alla sommità della formazione in Val Brembana, rare lenti di arenaria contengono detrito riolitico esclusivo, documentando l'erosione di ignimbriti più antiche o, in alternativa, una fase terminale di vulcanismo esplosivo.

Abstract. The mixed terrigenous-carbonate-evaporitic S.Giovanni Bianco Formation and dolomitic Campolungo Tongue (upper part of the Breno Formation), generally 200 to 300 m thick, are assigned to the Late Carnian. They respectively overlie lagoonal limestones (Gorno Fm.) and peritidal carbonates (Annunciata Member of the Breno Fm.), and underlie intraformational breccias and recrystallized limestones (Castro Fm.). Recognition of an unconformity, ascribed to a relative fall of sea-level (sequence boundary), allowed us to subdivide the Upper Carnian succession into two parts.

In the *lower part* (SGB1), six lithosomes were recognized. Red to green alluvial clastics in the south-east and south-west pass northward to mixed terrigenous-carbonate coastal sediments and finally to dolostones deposited in carbonate tidal flats. In the proximal sections of the Brescia Prealps, renewed north-westward progradation of alluvial redbeds with intercalated calclithite conglomerates points to a stage of tectonic uplift. A distinct increase in quartz, representing a regional petrographic marker followed all across Lombardy, indicates deepening of erosion into the metamorphic wallrocks of the volcanic belt. A major hiatus at the top of the SGB1 is best documented in the northern Presolana area by a silcrete crust directly overlying the Julian Annunciata Member of the Breno Formation. In the Brembana Valley area, the discontinuity occurs within a greenish siliciclastic coastal plain succession, and may be traced at the top of a marker interval of interbedded reddish siltstones and sandstones.

The *upper part* (SGB2) consists of four lithosomes. Greenish sandstones and siltstones, accumulating in coastal plains in the south-west, passed northward to mudrocks and dolostones. In the southernmost Camonica Valley area, mudrocks are locally interbedded with calcarenites containing bored or pedogenized lithoclasts ripped from the underlying sequence and varied bioclasts, testifiying to relatively open shallow-marine conditions during transgression. Next, thick gypsum accumulated in coastal salinas barred by locally oolitic platform carbonates to the north. Rare sandstone lenses occurring in the Brembana Valley at the top of the unit contain exclusive rhyolitic detritus, indicating either a terminal phase of explosive volcanism or erosion of older felsic volcanic products.

Introduction.

The Carnian Stage in the Lombardy Southern Alps is represented by several terrigenous to carbonate units deposited in deltaic, lagoonal and carbonate peritidal environments (Garzanti & Jadoul, 1985; Gnaccolini, 1987; Gnaccolini & Jadoul, 1988). The upper part of the Carnian succession, underlain by lagoonal

- Dipartimento di Scienze della Terra, Università degli Studi, Via Mangiagalli 34, 20133 Milano, Italy.

limestones (Gorno Formation) or by peritidal carbonates (Annunciata Member of the Breno Formation; Gnaccolini & Jadoul, 1990) and overlain by the intraformational breccias and recrystallized limestones of the Castro Formation (Jadoul et al., 1992b), is characterized by largely unfossiliferous, mixed terrigenous-carbonate deposits and locally by evaporites. These rocks, reaching a maximum thickness around 350 m (average 170 m), and tentatively ascribed to the Late Carnian according to their stratigraphic position (Allasinaz, 1968a), are known in the geologic literature as S. Giovanni Bianco Formation and Campolungo Tongue of the Breno Formation after the work of Assereto & Casati (1965).

Only local sedimentological or petrographic features have been analyzed in these rocks (Assereto, 1965; Casati & Gnaccolini, 1967; Garzanti, 1985 a,b, 1986, 1988). A detailed regional analysis has never been completed so far, also due to discontinuous outcrops and alpine deformations, which are concentrated in this incompetent décollement horizon (De Sitter & De Sitter Koomans, 1949; Gaetani & Jadoul, 1979; Laubscher, 1985).

The purpose of the present paper is to provide for the first time a detailed and up-to-date physical stratigraphic framework for the Upper Carnian succession, and to reconstruct the paleogeographic evolution of Lombardy through facies and microfacies analysis.

Stratigraphic framework

The 550 up to 900 m thick Carnian succession of central Lombardy (Southern Alps), arranged in east-west trending belts (Brusca et al., 1982), has been recently subdivided into four depositional sequences (Gaetani et. al., 1995). The first sequence (C1), represented by peritidal carbonates (Breno Fm. and Calcare Metallifero Bergamasco; Assereto et al., 1977), is overlain by the Gorno Fm. marly limestones, passing laterally to the Val Sabbia deltaic sandstones in the south (Gnaccolini, 1983, 1986) and to the Breno Fm. peritidal carbonates in the north (second sequence, C2). After a bio-oo-calcarenitic tongue documenting a major event of carbonate platform progradation in the middle part of the Gorno Fm. (Gnaccolini & Jadoul, 1990), open lagoonal limestones to mixed terrigenous-carbonate shallow-bay sediments continued to be deposited in the third sequence (C3), which is capped by peritidal dolostones in the north-east (Campolungo Tongue at the top of the Breno Fm.), and by prograding alluvial fan to coastal plain and lagoonal sediments in the south-east and south-west (lower S. Giovanni Bianco Fm.).

In the present paper, we will focus on this upper part of sequence C3 (lower S. Giovanni Bianco Fm. - uppermost Gorno Fm. - Campolungo Tongue; SGB1), and on sequence C4 (upper S. Giovanni Bianco Fm.; SGB2). The SGB1/SGB2 sequence boundary occurs in the Camonica Valley area at the top of the Campolungo Tongue peritidal dolostones (Fig. 1). In Val Supine (section 7 in Fig. 1), it corresponds with sharp transition to richly fossiliferous calcarenites. In the southeast, the boundary is thought to occur at the top of the 150 to 200 m thick lower part of the S. Giovanni Bianco Fm., characterized by red mudrocks (Zone; section 15 in Fig. 1) and sandstones with intercalated pebbly conglomerates (Val Nozza; section 16 in Fig. 1) and corresponds to a strong decrease in grain size of largely dolomitized sandstones interbedded with poorly exposed mudrocks. In the west, in the Brembana Valley area, the discontinuity has been traced at the top of a reddish silty to sandy interval in the middle part of the S. Giovanni Bianco Formation.

This unconformity can be traced also north of the study area, in the Presolana thrust sheet (Fig. 1). Here a carbonate platform succession corresponding to the Annunciata Member of the Breno Fm., containing several tepee horizons and yielding cephalopod faunas ascribed to the Julian (Allasinaz, 1968a), is capped by a silcrete profile (Rodeghiero, 1977) documenting a prolonged hiatus. This emersion surface is overlain by dark pelites passing upward to alternating grey peritidal dolostones and greenish pelites, considered as Gorno Fm. by previous authors but here ascribed to the upper S. Giovanni Bianco Fm. (SGB2).

The SGB2 sediments are overlain by a unit of thick recrystallized limestones and collapse breccias, pointing to carbonate deposition on a very unstable substratum (Castro Fm. of Jadoul et al., 1992b), finally transgressed by the Dolomia Principale carbonate platform.

Physical stratigraphy and lithofacies description.

Within the two depositional sequences represented in the Upper Carnian succession of Lombardy, 10 intertonguing lithosomes have been recognized and traced laterally, in order to reconstruct their geometrical relationships. Lithosomes are physically expressed by characteristic lithofacies associations, which will be described in detail here below. Overall, 21 lithofacies have been recognized; their concise description and sedimentological interpretation are given in Table 1.

Lower S. Giovanni Bianco Fm. - Campolungo Tongue (SGB1).

Six lithosomes have been recognized within this interval (Fig. 1). These are described below from bottom to top.

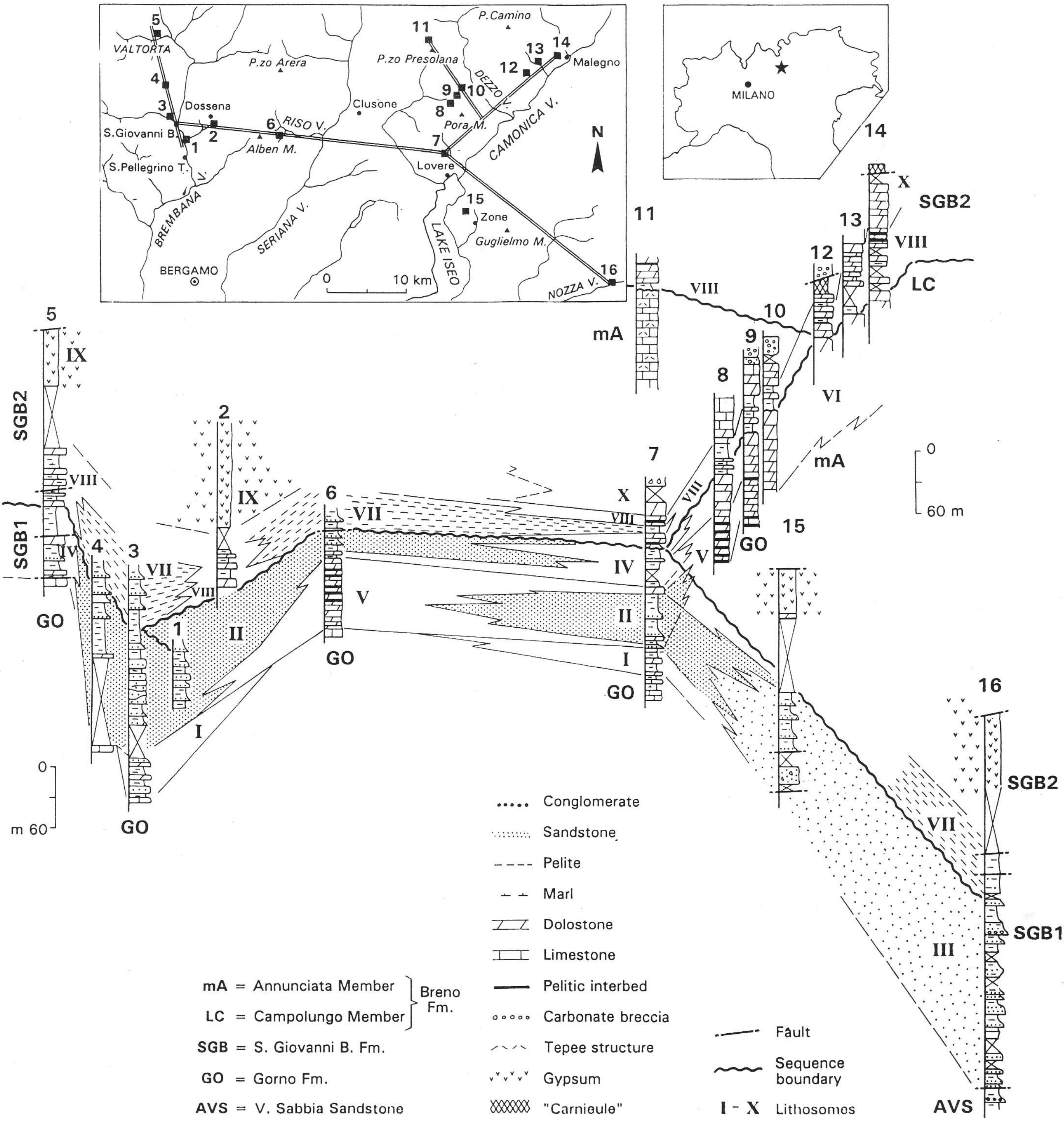

Fig. 1 - Fence diagram showing vertical and lateral relationships between lithosomes recognized in the Upper Carnian succession (upper part of sequence C3: SGB1; sequence C4: SGB2) of the Lombardy Southern Alps. Location of measured stratigraphic sections is shown in inset (1 = S. Pellegrino; 2 = Dossena; 3 = S. Giovanni Bianco/Val Taleggio; 4 = Brembella; 5 = Valtorta; 6 = Val Riso; 7 = Val Supine; 8, 9 = Colle di Vareno; 10 = Castello Orseto; 11 = Rifugio Albani; 12 and 13 = Ossimo inferiore; 14 = Malegno; 15 = Zone/Casere; 16 = Val Nozza). Lithofacies characterizing Lithosomes I to X are summarized in Tab. 1.

Lithosome I (transition with the underlying Gorno Fm.).

Alternating sandstones, mudrocks and subordinate dolostones represent the transition with the underlying Gorno Fm (Fig. 2); thickness ranges from 25 m (Val Supine; section 7) to about 36 m (Brembana Valley; section 3). Lithosome I passes laterally to topmost Gorno Fm. lagoonal deposits and is overlain by terrigenous Lithosome II (Brembana Valley).

Lithofacies:

S3) up to upper fine-grained, grey-green, parallel to cross-laminated sandstones locally with scoured base (up to 2 m thick intervals);

LITHOFACIES CODE	DESCRIPTION	DEPOSITIONAL SETTING
C1	Channellized extraformational conglomerates.	Channel deposits; oximal fan.
C2	Red to grey-greenish intraformational conglomerates, with rough cross-bedding.	Channel, bank failure; alluvial fan.
S1	Medium to coarse-grained red sandstones, mostly with scoured base and trough cross-lamination, locally with epsilon cross-stratification.	Channel; alluvial fan.
S2	Fine-grained reddish sandstones, locally channellized and with low-angle or parallel lamination.	Crevasse to levee; distal alluvial fan.
S3	Fine to medium-grained grey-green sandstones, with trough to low-angle or parallel lamination, locally with scoured base.	Channel; distal alluvial fan to coastal plain.
S4	Thin-bedded, very fine-grained grey-green sandstones with parallel to current ripple laminations.	Overbank, flash flood; coastal plain.
S5	Greenish-grey, very fine to fine-grained sandstones with wave ripples.	Wave-reworked delta front.
P1	Reddish siltstones to shales, locally containing nodular caliches.	Floodplain.
P2	Grey to bright green siltstones to shales, locally with parallel to ripple lamination and dolomitic concretions.	Interchannel; coastal plain.
P3	Dark grey mudrocks, locally with fine laminations.	Prodelta.
D1	Dark grey dolostones (dolomitized mudstone to intra-bioclastic packstone).	Restricted shallow lagoon.
D2	Light grey dolostones in thin single beds intercalated in prevailing P2 lithofacies (dolomitized mudstone to oo-intra-bioclastic grainstone).	Ephemeral pond to storm layers; coastal plain.
D3	Light grey dolostones and marly dolostones, locally fossiliferous and/or bioturbated, in thin to medium beds separated by pelitic drapes (mudstone to bio-intraclastic packstone).	Shallow lagoon.
D4	Grey stromatolitic dolostones, locally displaying fenestrae and/or small tepees (bindstone to intraclastic packstone).	Carbonate tidal flat.
D5	Grey dolostones with vugs locally filled by reddish internal sediment and white sparry dolomite (wackestone to intra-bioclastic packstone).	Shallow hypersaline lagoon, possible local emersions.
D6	Grey, thick-bedded oolitic dolostones, locally with cross-lamination (dolomitic to oo-intraclastic grainstone).	Oolitic bars; shallow carbonate platform.
D7	Thin-bedded, dark-grey dolostones with dark chert nodules (bindstone to fine packstone).	Restricted shallow lagoon.
LD1	Dark-grey biocalcarenites, locally with scoured base and containing pedogenized lithoclasts; locally dolomitized (mainly bio-lithoclastic packstone to rudstone).	Shallow marine, transgressive.
LD2	Grey limestones, locally dolomitized (bio-intraclastic wackestone to packstone).	Subtidal carbonate platform.
G	Laminated gypsum, with discontinuous dolostone drapes, locally intercalated with stromatolitic dolostone. Frequently deformed and recrystallized.	Salina.
Ca	Diagenetic and tectonic microbreccias, with dolomitic and subordinately pelitic clasts.	

Tab. 1 - Brief description and sedimentological diagnosis for the 21 lithofacies recognized in the Upper Carnian succession of the Lombardy Southern Alps.

S4) very fine to fine-grained, faintly laminated grey-green sandstones in beds a few cm thick, intercalated with predominating siltstones;

S5) thin beds of very fine to fine-grained greenish-grey sandstones, locally separated by drapes of dark mudrocks, displaying small symmetrical ripples and rarely dark mudclasts (intervals up to over 2 m thick);

P2) grey to bright green siltstones to shales, locally with faint lamination;

P3) dark grey mudrocks (from a few cm to over 1 m thick), locally laminated or containing plant material;

D1) dark grey fossiliferous dolostones in 5 to 60 cm thick beds, commonly associated with lithofacies P3. Wholly dolomitized intrabioclastic packstones, locally bioturbated, showing prism cracks and containing pelecypods (*Myophoria* sp.), crinoids, gastropods, ostracods, foraminifers, dasycladacean algae and coated grains, predominate.

Depositional environments.

Sedimentological features testify to a deltaic environment. Terrigenous lithofacies document deposition by fluvial currents (S3, S4) entering a lagoon and locally interacting with waves and tidal currents (S5). Lagoonal lithofacies are represented by dark mudrocks and carbonates with faunal assemblages typical of the Gorno Fm. (P3, D1).

Lithosome II (sandstones and mudrocks of the Brembana Valley).

This up to 100 m thick clastic wedge is best developed in the middle Brembana Valley (sections 1

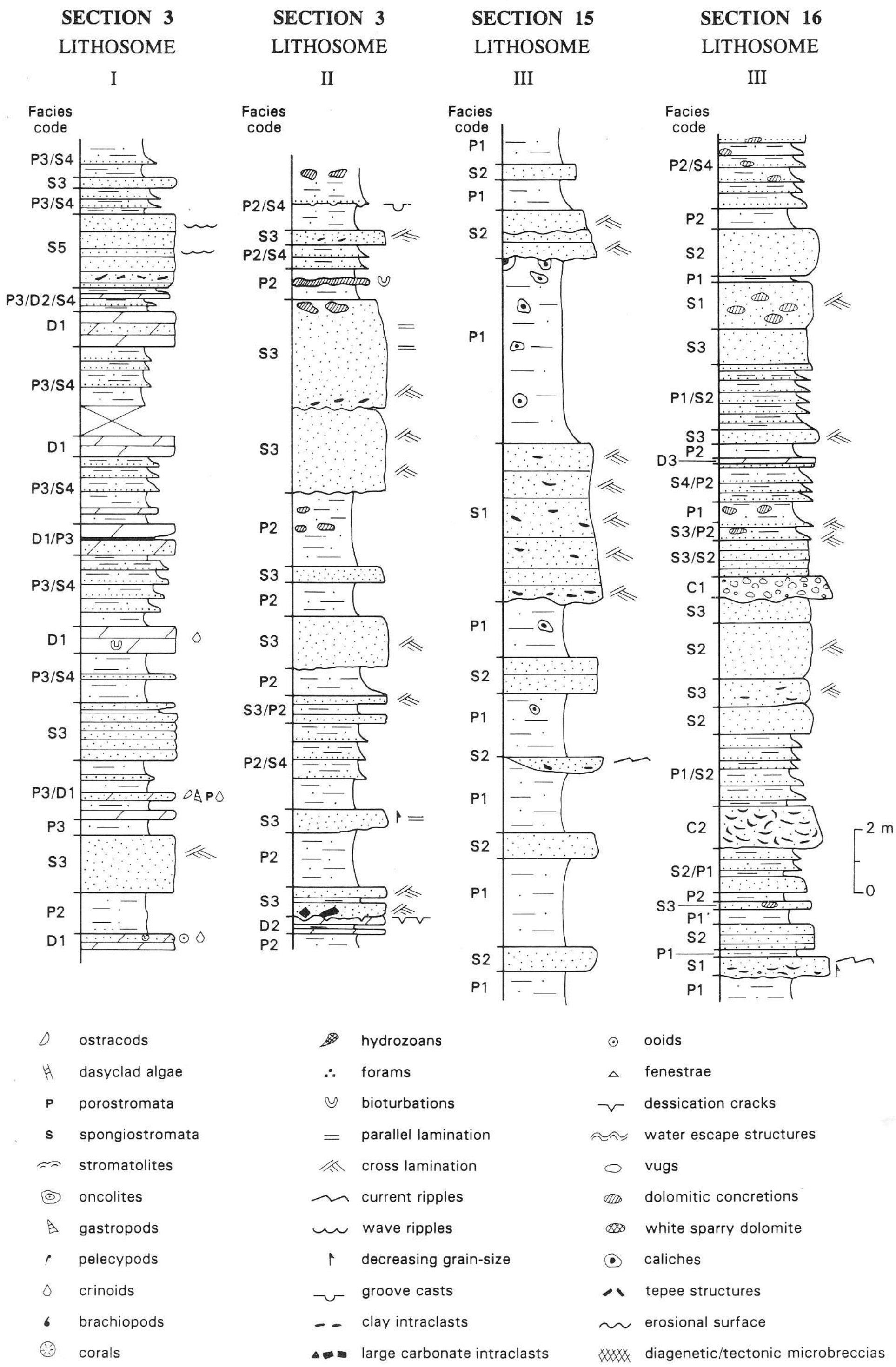

Fig. 2 - Key sedimentologic logs show typical lithofacies associations for Lithosomes I, II and III. For location of sections 3, 15 and 16 see Fig. 1.

and 3). It gradually thins to 40 m towards the north and north-east, where finer-grained lithofacies prevail (upper Brembana Valley: section 4; Val Riso: section 6). Some 80 m of alternating sandstones and mudrocks, passing rapidly to 0 northward, also occur in Val Supine, where they represent the distal part of Lithosome III (Fig. 1). Lithosome II is bracketed between the underlying Lithosome I and the SGB1/SGB2 sequence boundary at the top, and is laterally replaced north-eastward by dolostones and mudrocks of Lithosomes IV and V.

Lithofacies:

C2) grey-greenish intraformational microrudites with rough cross-bedding and oversized mudclasts, associated with up to coarse sand-sized siliciclasts (up to 1 m thick lenses). Reworked caliche nodules are locally abundant;

S3) fine to rarely medium-grained grey-green sandstones with faint trough to subordinately low-angle and parallel lamination (up to 3 m lenses, locally with scoured base). One bed intercalated within mudrocks shows flute casts. Carbonaceous fragments, leaves and up to decimetric plant logs are locally found associated with clay chips. Paleocurrents are mostly towards the ESE (100 to 130°N) in the Brembana Valley (Fig. 3C). Pelitic or rarely dolomitic intraclasts up to 10 cm in size were locally observed; dolomitic concretions up to some dm in size occur;

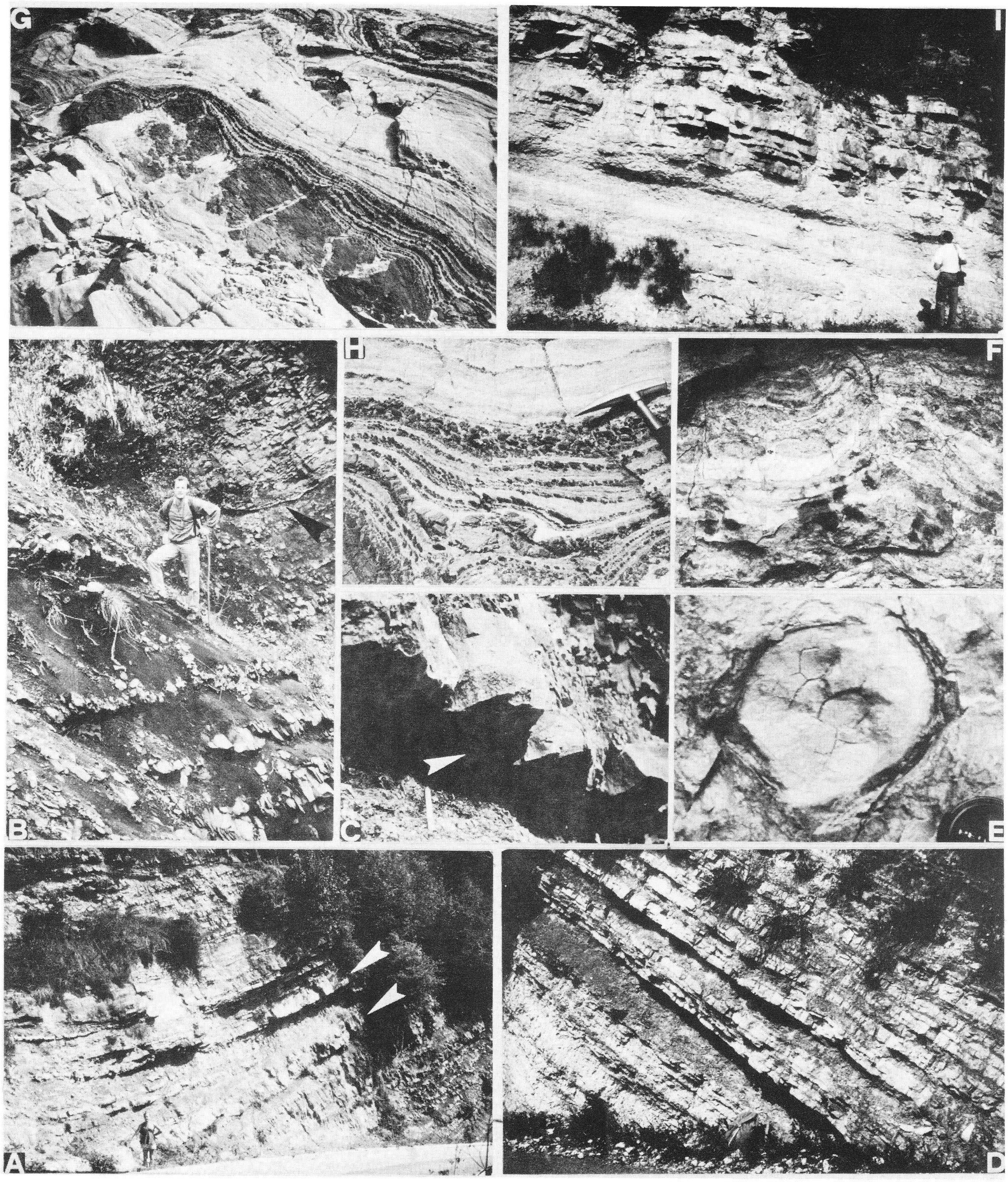

Fig. 3 - Proximal to distal lithofacies associations in the Upper Carnian. Photos arranged from SGB1 alluvial redbeds (A,B), to SGB1 - lower SGB2 sabkha/lagoons (C to F), to upper SGB2 salinas (G,H) and oolitic shoals (I). A) Lenticular channellized conglomerates and cross-bedded sandstones (arrows; Lithosome III, section 16; L. Crepaldi stands by C1 bed in Fig. 2); B) red overbank mudrocks with thin crevasse-splay? sandstones (Lith. III, sect. 15; black arrow points to scoured base of thick S1 interval in Fig. 2); C) sharp-based green sandstone with sole casts (arrow; base of Lith. II, sect. 3; rule for scale); D) green siltstones cyclically alternating with grey dolostones (Lith. VIII, sect. 12; rucksack for scale); E) septaria-like dolomitic concretions within green siltstones (Lith. IV, sect. 5; lens cap for scale); F) stromatolitic dolostones with centimetric embryo tepees (Lith. V, sect. 8); G) deformed white gypsum layers interbedded with dark grey stromatolitic bindstones. Boundary between D4 and G lithofacies in lower right corner enlarged in H) (Lith. IX; Lovere quarry; hammer for scale); I) sharp boundary between Lith. VIII and thickening-upward carbonate cycles of Lith. X (sect. 14 in Fig. 1).

S4) mainly fine-grained grey-green sandstones, with parallel to current ripple lamination and local groove casts, in thin (1 to 10 cm) beds intercalated with predominating siltstones;

P1) reddish siltstones to shales (top SGB1 marker interval increasing westward in thickness from 9÷13 m between S. Pellegrino and S. Giovanni Bianco to over 30 m in Val Taleggio; sections 1 and 3), with rarely interbedded fine-grained sandstones and abundant dolomitic concretions up to 40 cm in diameter;

P2) grey to bright green siltstones to shales, locally with faint laminations or plant material (intervals from a few cm to 15 m). Coalescent dolomitic concretions up to 40 cm in size are common, as well as authigenic pyrite;

D2) light grey dolostones in thin to medium beds (a few to 30 cm) intercalated within lithofacies P2, locally with well-developed mudcracks or chert nodules. Oo-intraclastic packstones with rare pellets, foraminifers (lagenids), ostracods and relatively common siliciclasts prevail over rarely bioturbated mudstones. Authigenic bipyramidal quartz or feldspars grew in small cavities or replaced carbonate to evaporitic minerals.

Depositional environments.

Most common in the Brembana Valley are lithofacies S3 and P2, which alternate in 1 to 5 m thick fining-upward cyclotems, locally with sharp scoured base (Fig. 2). Mudrocks prevail in several sections. Lithofacies distribution points to semi-arid coastal plain environments, representing the distal toe of alluvial fans passing northward to paralic and marginal-marine tidal settings. Channel areas are documented by fining-upward (S3+P2) cyclothems, whereas mudrocks are predominant to exclusive in interchannel areas.

In the lower part of the lithosome, thin-bedded and up to lower fine-grained sandstones intercalated with mudrocks and locally displaying flute or groove casts are interpreted as flash floods in coastal plain to paralic environments (Fig. 3C; these structures were ascribed to turbiditic flows by Assereto, 1965). Abundant plant material (Equisetaceae and conifers; A. Paganoni, pers. comm. 1994), found both in the Brembana Valley (between S. Pellegrino and S. Giovanni Bianco; Assereto, 1965) and in Val Supine (north of Lovere), indicate that vegetated emerged lands existed in the south when deposition of the S. Giovanni Bianco Fm. began. Rare and thin cherty dolostone intercalations (D2) point to temporary tidal flat to sabkha sedimentation on the coastal plain.

In the middle part of the lithosome between S. Pellegrino and S. Giovanni Bianco (Fig. 4), large-scale, wedge-shaped and up to lower medium-grained channel-fills are ascribed to scouring of the coastal plain by ephemeral streams. Intraformational caliche-arenite lenses are particularly abundant at S. Pellegrino. Reddish lithofacies P1 found at the top of the lithosome was seemingly the result of prolonged subaerial exposure.

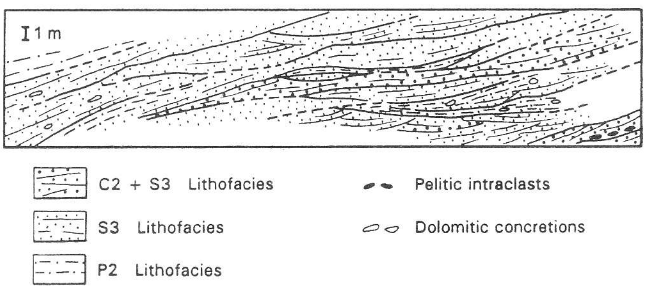

Fig. 4 - Channel-fill deposits ascribed to wadi-type ephemeral streams migrating periodically on a coastal plain (coarser middle part of Lithosome II; SGB1 in type section 3 at S. Giovanni Bianco). Direction of sediment transport is away from the observer. Drawing from photo.

Lithosome III (redbeds of Val Nozza).

About 180 m thick reddish sandstones and mudrocks yielding caliche and/or dolomitic concretions with intercalated conglomerates crop out in the eastern part of the study area (Zone to Sabbia Valley). The base of Lithosome III lies in Val Nozza (section 16; Fig. 3A) within a thick wedge of continental redbeds, and can be detected mostly on petrographic grounds (see paragraph on sandstone petrography); at Casere (section 15; Fig. 3B) the lithosome follows (stratigraphically?) 30 m thick dacitic pyroclastics and extraformational microbreccias with angular dolomitic pebbles, in turn overlying, with faulted and covered contact, the karstified top of Ladinian Esino dolostones. The top of Lithosome III, poorly exposed or somewhat faulted, would correspond with the SGB1/SGB2 sequence boundary overlain by widely dolomitized siltstones and very fine-grained sandstones (Lithosome VII). North-eastward of Zone, Lithosome III interfingers with the top of the Gorno Fm. and with greenish sandstones and mudrocks alternating with yellow dolostones on both sides of the Camonica Valley (Toline and Val Supine; Lithosome II).

Lithofacies:

C1) channellized extraformational conglomerates containing light to dark grey subrounded carbonate cobbles (median diameter 3 cm; maximum diameter up to 13 cm) and subordinate red chert and green volcanic pebbles (0.4 to 1 m thick; Fig. 3A);

C2) lenticular intraformational microrudites with reworked caliche and red to greenish mudclasts up to 20 cm in size (thickness 0.2 to 1.3 m);

S1) medium to coarse-grained red sandstones, mostly with scoured base and trough cross-lamination indicating WNW-ward paleocurrents in the Nozza section, commonly containing dolomitic clasts, reworked caliche and red to greenish mudclasts up to 9 cm in size (thickness from 0.7 to 3.5 m, exceptionally reaching 6 to 10 m);

S2) commonly dolomitized fine-grained reddish sandstones, locally channellized and with low-angle to parallel lamination, in medium beds (5 to 25 cm) intercalated with reddish siltstones (P1) (intervals up to 3.3 m thick);

S3) grey-green sandstones with grey mudclasts;

S4) thin-bedded very fine-grained greenish sandstones, locally with concretions, interbedded with greyish pelites (P2);

P1) red siltstones, commonly containing caliche nodules (paleosoil profiles may be up to 1 m thick) or dolomitic concretions up to 60 cm in size (intervals, 0.15 to 2 m thick in Val Nozza, reach up to 6 m and may be burrowed at the top at Casere; Fig. 3B);

P2) grey to greenish pelites;

D3) impure grey calcareous dolostone (0.15 cm).

Depositional environments.

Main lithofacies are S2 and P1 (Fig. 2). Commonly channellized lithofacies S1 (replaced or underlain by C1 or C2) marks the base of poorly-defined fining-upward cyclothems, mostly 4 to 6 m thick (better defined and reaching 12 m at Casere). Only one thin dolostone intercalation (D3) was observed at Malpaga. Much coarser-grained deposits with respect to Lithosome II, abundant red colours and widespread caliche nodules testify to deposition in semi-arid alluvial fan settings.

Lithosome IV (mudrocks and dolostones of the Camonica Valley).

Lithosome IV, characterized by greenish mudrocks (P2) with intercalated grey dolostones (D3) and thin layers of (tectonic?) carbonate microbreccias with pseudomorphs of evaporites ("carnieules"; Ca), is

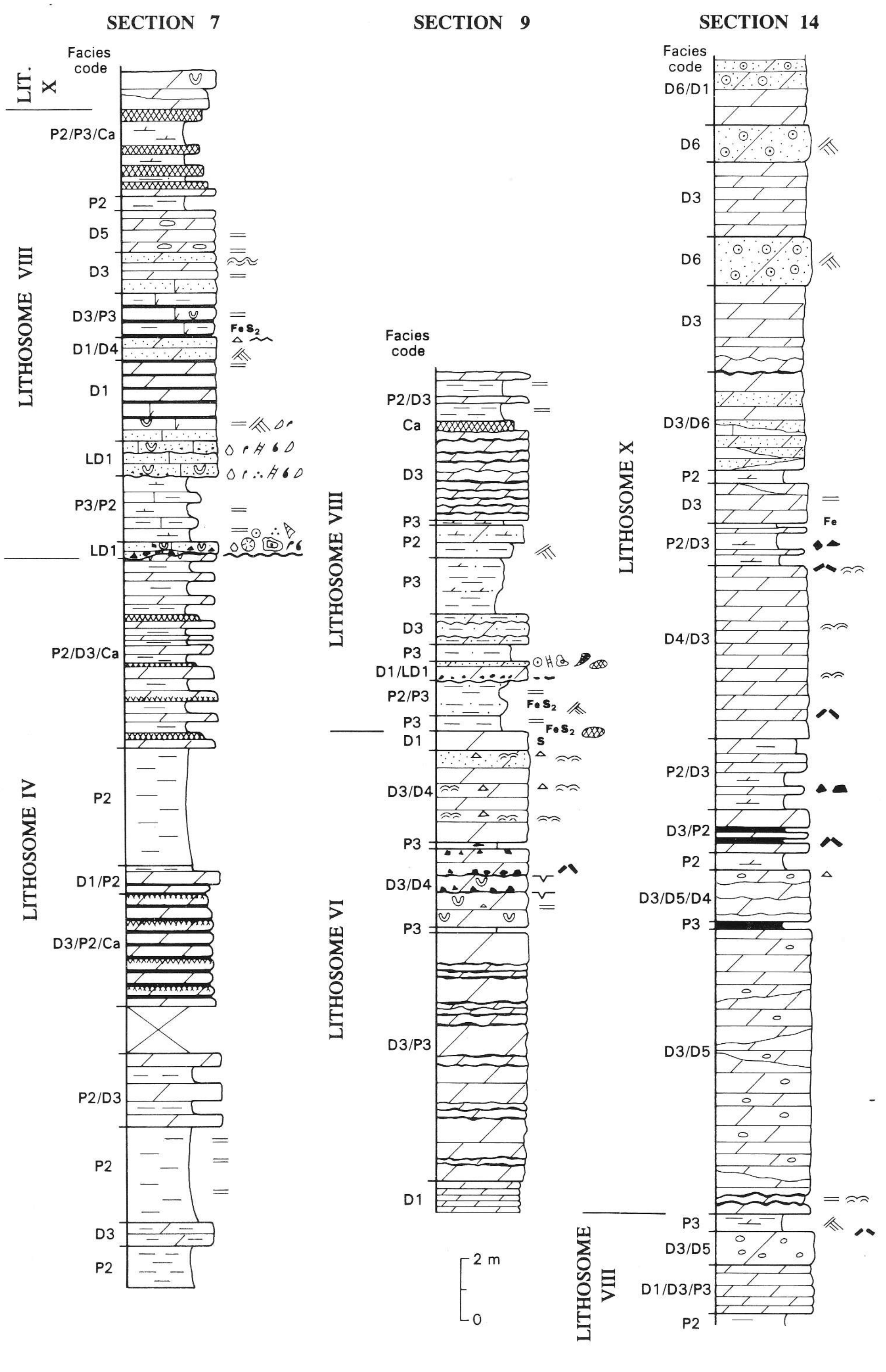

Fig. 5 - Key sedimentologic logs show typical lithofacies associations for Lithosomes IV, VI, VIII and X. For location of sections 7, 9 and 14 see Fig. 1.

poorly exposed from Val Riso (7 m; section 6) to Val Supine (36 m; section 7) (Fig. 5). In Valtorta (about 60 m; section 5), thin sandstones (S3, S4) and greenish mudrocks (P2) with septaria-like dolomitic nodules (Fig. 3E) are intercalated with vuggy or concretionary grey dolostones (D5) in 2 to 6 m thick cyclothems.

Lithosome IV, which is capped by the SGB1/SGB2 sequence boundary, was probably deposited in coastal sabkha/lagoons interfingering with alluvial fans (Lithosomes II and III) to the south, and with the Campolungo Tongue peritidal dolostones (Lithosome VI) to the north.

Lithosome V (dolostones with thin mudrock intercalations).

Lithosome V, reaching a maximum thickness in Val Riso (70 m; section 6) and at Colle di Vareno (40 m; sections 8 and 9), consists of thin-bedded (a few to 20 cm) dolostones cyclically alternating with greenish-grey to dark grey siltstones and shales in generally thin (but exceptionally up to 70 cm) intervals. It overlies Lithosome I and is replaced laterally by Lithosomes II and IV p.p.; it underlies arenaceous Lithosome II to the south and dolomitic Lithosome VI in the north (Fig. 1).

Lithofacies:

P2) light grey to green siltstones and shales in a few mm to 70 cm thick beds, locally laminated or containing dolomitic concretions;

P3) dark grey to black mudrocks in a few mm to 20 cm thick beds;

D3) mainly light grey dolostones in thin to medium beds (a few to 30 cm) separated by mudrock drapes. Wholly dolomitized packstones with intraclasts, bioclasts and pellets prevail; Porostromata, Spongiostromata, ostracods, rare dasycladacean algae and locally foraminifers are common. Bioturbation is frequent. Authigenic quartz and feldspars grew in fractures and cavities, possibly at the expense of carbonate to evaporitic minerals;

D4) grey stromatolitic dolostones in medium beds (15 to 25 cm), locally displaying centimetric embryo-tepees (Fig. 3F). Bindstones alternate with burrowed intraclastic packstones, rarely yielding ostracods and Porostromata. Both early and late fractures are commonly filled by authigenic quartz and felspars;

D5) grey dolostones in up to 30 cm thick beds with abundant vugs, locally filled by reddish internal sediments and white coarse dolomite spars. Microfacies are similar to D3.

Depositional environments.

Dolostones prevail (mainly D3), with greenish mudrocks (P2) rhythmically intercalated. Up to 90 cm thick lenticular intervals containing gypsum and dolomitic or pelitic clasts (Ca) may be interpreted as early diagenetic evaporitic-collapse breccias, even though they are commonly associated with along-bed tectonic deformation. Lithofacies associations point to a sabkha/shallow lagoon, passing laterally to carbonate supratidal-intertidal flats only episodically reached by fine-grained terrigenous detritus from the south.

Lithosome VI (dolostones).

Lithosome VI (Campolungo dolomitic Tongue of the Breno Fm.; sections 8 to 14) decreases in thickness along the middle Camonica Valley from a maximum of about 90 m in the north, where it overlies the calcareous Annunciata Member of the Breno Fm., to 0 in the south, where it both overlies and passes laterally to the more pelitic Lithosomes IV and V (Fig. 1). Lithosome VI is capped by the SGB1/SGB2 sequence boundary.

Lithofacies:

P3) dark grey dolomitic mudrocks mainly in up to 15 cm thick beds;

D1/D3/D4) grey to locally dark grey dolostones, in up to 1 m thick beds. Wholly dolomitized intrabioclastic packstones yielding ostracods, Porostromata, Spongiostromata, dasycladacean algae and subordinately foraminifers, prevail over locally intercalated fenestral stromatolitic bindstones. Authigenic quartz occurs in both early and late cavities and fractures.

Depositional environments.

Dominating lithofacies D3 (Fig. 5) indicates the seaward part of the shallow lagoons to tidal flats also represented by Lithosome V.

Upper S. Giovanni Bianco Fm. (SGB2).

Four lithosomes have been recognized (Fig. 1). This sequence can be in turn subdivided in a basal part characterized by mixed carbonate-terrigenous sedimentation (Lithosomes VII and VIII) and a carbonate-evaporite upper part (Lithosomes IX and X), which marks a sharp reduction in terrigenous detritus recorded all over the Lombardy Prealps.

Lithosome VII (mudrocks and sandstones of the Brembana Valley).

In the Brembana Valley (sections 3 and 4), Lithosome VII mainly consists of green to greenish-grey mudrocks (P2). Up to lower medium-grained greenish grey sandstones with oblique to parallel lamination and pelitic to dolomitic intraclasts (S3, S4; up to 50 cm thick intervals, exceptionally reaching 3 m) locally occur at the base of fining-upward cyclothems. Dolomitic concretions up to 35 cm in size grew in greenish siltstones (P2) full of pyrite in well-developed pentagonal dodecahedrons. In Val Nozza (section 16), at least 40 m thick altered reddish dolomitized sandstones (S2), alternating with reddish to grey-greenish siltstones with yellowish concretions (P1, P2), impure dolostones (D3) and intraformational conglomerates (C2), pass upward to poorly exposed weathered mudrocks and finally to the evaporites of Lithosome IX.

Lithosome VII, about 50 m thick, occurs only in southernmost sections, where it overlies reddish clastics capping the SGB1 (Lithosomes II and III); laterally it passes to mudrocks and dolostones (Lithosome VIII). The upper boundary is never well exposed.

Lithofacies are, in order of decreasing abundance, P2, S3, S4, P1, S2 and C2, suggesting deposition on an arid coastal plain passing northwards to marginal marine environments.

Lithosome VIII (mudrocks and dolostones of the Seriana-Camonica Valleys).

Grey-greenish to locally dark grey siltstones and shales (a few cm to 9 m thick intervals) alternate with thin beds of light to dark grey dolostones, locally amalgamated in up to 8 m thick intervals (sections 7 to 14; Fig. 3D). Locally bioclastic dolostones gradually become prevalent northward (Val Supine: section 7), whereas they are replaced by the terrigenous Lithosome VII in Val Nozza and Brembana Valley (Fig. 1). Bioturbated marls and dolostones are dominant in Valtorta, where rare beds of very fine-grained carbonatic sandstones display north-dipping cross-laminae.

Along the Camonica Valley, Lithosome VIII overlies Lithosome IV in the south (Val Supine) and Lithosome VI in the north; where the upper boundary is exposed, it is overlain by evaporitic Lithosome IX or calcareous Lithosome X. Maximum thickness is about 35 m (Colle di Vareno; sections 8 and 9).

Lithofacies:

P2) grey to green siltstones and shales, locally with large dolomitic concretions;

P3) dark grey marls and siltstones with ripples or parallel lamination;

D1/D3/D4/D5) dark to light grey dolostones. Wholly dolomitized, burrowed intraclastic packstones, rarely containing ooids and bioclasts, prevail over stromatolitic bindstones locally with small tepees;

D7) dark grey dolostones in thin (2 to 20 cm) beds separated by black clay drapes and clayey micritic dolostones locally with up to 30 cm thick bands and nodules of black chert; small concordant sedimentary dykes with brownish internal sediments occur. Typical microfacies are bindstones with Spongiostromata and fine-grained burrowed packstones with ostracods. Lithofacies D7 occurs only in the northern part of the Camonica Valley (and further to the north-east in the Brenta Dolomites);

LD1) locally dolomitized bioclastic calcarenites in lenticular beds with scoured base, locally showing fining-upward grain size and parallel to ripple lamination. Bio-intraclastic packstones and wackestones yielding crinoids, brachiopods, foraminifers (*Aulotortus praxoide*, *Aulotortus* gr. *sinuosus*; determinations by R. Rettori, 1994; Involutinidae), corals (*Isastrea*), sponges, hydrozoans?, dasycladacean algae and ostracods predominate; bioclastic rudstones with locally pedogenized or bored lithoclasts, mudclasts, phosphates, quartz and micas occur in Val Supine (section 7);

Ca) up to 50 cm thick carbonate microbreccias are locally intercalated. Several of these, occurring in even metric horizons containing large clasts and associated with thrust surfaces, are tectonic in origin.

Depositional environments.

Lithosome VIII represents the distal part of the Val Nozza and Brembana Valley coastal plain (Fig. 5).

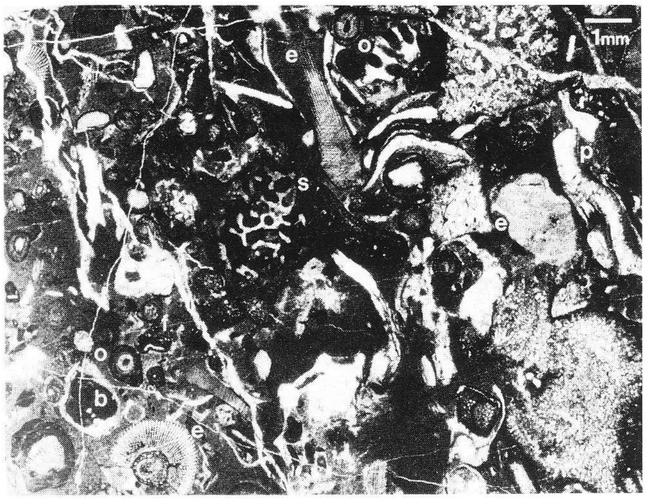

Fig. 6 - Coarse bioclastic packstone with scattered radial to concentric ooids (o) and coated grains. Open marine fossils include abundant echinoderms (e), sponges (s), brachiopods (b), pelecypods (p), sessile and benthic foraminifers (f) (lithofacies LD1; base of Lithosome VIII at Valle dell'Orso, Val Riso area).

Layers rich in varied bioclasts occurring at its base in Val Supine and Valle dell' Orso (Val Riso area; LD1) locally document storm events in more open and relatively deeper environments with normal salinity (Fig. 6). Even a few halobids were observed at Dossena and, further to the west, nautiloids (*"Nautilus" brembanus*; identification by M. Balini, 1993) were found in Valsassina at Moggio, in beds presumably belonging to Lithosome VIII.

Lithosome IX (evaporites).

Up to 100-200 m thick evaporitic successions crop out from the southeastern (Auro: section 16; Lovere and Toline: between sections 7 and 15) to the northwestern (Dossena: section 2; S. Brigida: section 5) parts of the study area. In the rare relatively continuous exposures, Lithosome IX is seen to overlie Lithosome VIII and to pass laterally to carbonatic Lithosome X. Post-depositional deformation, due not only to alpine tectonics but probably also to dehydration during burial, is extensive.

Lithofacies:

D3/D4) light to dark grey dolostones in up to 1 m thick beds. Wholly dolomitized packstones with ostracods and Porostromata, locally thin laminae of burrowed mudstones and bacterial stromatolitic bindstones occur (Fig. 3G);

G) gypsum in mm-thick deformed micronodular laminae alternating with discontinuous dark grey limestone to dolostone drapes (Fig. 3H); anydrite was observed in a core drilled by ANAS at S. Pellegrino (and as relict in the Lovere quarry).

Depositional environments.

Thick gypsum was deposited in a strongly subsident evaporitic lagoon, extending from east to west across the study area and barred to the north by the locally oolitic carbonates of Lithosome X.

Lithosome X (limestones and calcareous dolostones of the Camonica Valley).

Lithosome X widely crops out in the north-eastern part of the study area (sections 7 to 14), where it overlies Lithosome VIII (Fig. 3I) and passes upward to the commonly tectonized intraformational limestone breccias of the Castro Fm. (Jadoul et al., 1992b). Due to extensive cover, lateral transition to Lithosome IX can only be hypothesized according to stratigraphic position.

Lithosome X consists of irregularly alternating limestones to dolomitic limestones, in a few cm to about 2 m thick beds locally separated by thin pelitic intercalations. Dolomitization is more extensive in the north-east (northern Camonica Valley to Adamello Group; Gaetani, 1986). Maximum observable thickness is about 30 m.

Lithofacies:

P2/P3) dark to greenish-grey dolomitic mudrocks, locally with parallel lamination or pyrite, in a few to 60 cm thick beds intercalated with carbonate lithofacies;

D3/D4/D5) light grey, locally stromatolitic dolostones (similar to those of Lithosome V);

D6) grey dolostones (oolitic to oo-intraclastic grainstones) in up to 2 m thick beds, locally displaying megaripple cross-lamination;

LD2) grey recrystallized limestones and dolomitic limestones in dm- to m-thick beds. Bioclastic wackestones yielding ostracods, foraminifers, Spongiostromata and dasycladacean algae are locally associated with intraclastic to bioclastic (pelecypod) packstones.

Depositional environments.

Lithofacies D3 and D5 prevail at the base of Lithosome X, whereas lithofacies LD2 e D6 gradually become predominant in the upper part; dolostones prevail in the northern part of the study area (Fig. 5). Tectonized breccias containing large clasts of various underlying lithofacies are associated with thrust surfaces at the top of the S. Giovanni Bianco Formation. Lithosome X is inferred to represent a mainly subtidal carbonate platform.

Sandstone petrography

In the eastern part of the study area (Sabbia Valley to Zone; Brescia alluvial fan), the Carnian succession is mostly represented by continental redbeds. At about 500÷550 m from the base of the Val Sabbia Sandstone, detrital modes show a subtle change, with transition to slightly more quartzose compositions (from Q6 F33 L62 n= 16 in sequence C2, to Q9 F31 L60 n= 7). In Val Nozza this change is recorded above an about 20 m thick interval of olivine basalts, in red sandstones and siltstones with interbedded channellized calclithitic conglomerates and thick paleosoils with caliche to ferriferous nodules (30 to 45 m). A much sharper break occurs in the overlying dolomitized redbeds, about 180 m thick, where consistently more quartzose compositions are recorded (proximal part of Lithosome III: Q15 F23 L62). If the latter of these two petrologic intervals (both mapped as Val Sabbia Sandstone in the Foglio "Breno" of the geologic map of Italy) can be ascribed safely to the S. Giovanni Bianco Fm. (SGB1) on both sedimentologic and petrographic grounds, correlation of the former with the Gorno Fm. remains tentative.

The over 100 m thick redbed succession exposed at Casere/Croce di Marone is similarly ascribed to the S. Giovanni Bianco Fm. (distal part of Lithosome III: Q13 F37 L50). To the west, a similar trend is documented in Val Supine, where the Gorno Fm. (Q10 F59 L31 n= 1) passes gradually upward to the S. Giovanni Bianco Fm. (distal part of Lithosome II: Q15 F43 L42).

In the western part of the study area (Brembana Valley; Bergamo alluvial fan), detrital quartz increases from the Val Sabbia Sandstone (Q6 F36 L59 n= 39; sequence C2) to the Gorno Fm. (Q10 F44 L45 n= 3). These sandstones are already markedly enriched in pumiceous lithics and in basement-derived quartz grains (Garzanti, 1985b, fig. 6, 7). Quartz increases further from the transition with the S. Giovanni Bianco Fm. (Lithosome I: Q11 F36 L53) to the prograding coastal plain green sandstones of the SGB1 (proximal part of Lithosome II: Q15 F32 L53), and reaches a maximum in green sandstones interbedded up to the top of the SGB2 (Lithosome VII: Q18 F25 L57; Lithosome VIII: Q22 F50 L27). Petrographic data for the S. Giovanni Bianco Fm. are resumed in Table 2.

Depositional setting

Detailed three-dimensional reconstruction of previously described lithosomes, their lateral relationships and environmental significance, allowed us to envisage a sequence of varied depositional scenarios.

Lower S. Giovanni Bianco Fm. - Campolungo Tongue (SGB1).

The proximal southern areas of the Lombardy Prealps were characterized by alluvial fans, prograding towards the ESE in the west and towards the WNW in the east. They are best documented in the Brescia area, where continental redbeds, up to conglomeratic at Nozza, extend for 20 km toward the north-west

Lithosome	Environment	Locality	N	Q	F	L	F/F+L
SGB2							
VIII	Prodelta/Lagoon	Valtorta	2	22	50	27	0.65
VII	Coastal plain	S. Pellegrino	2	18	37	45	0.45
VII toe of	Alluvial fan	Val Taleggio	5	18	21	62	0.25
SGB1							
IV	Prodelta	Val Supine	4	15	43	42	0.51
II	Alluvial fan	San Pellegrino	7	14	31	54	0.36
II	(green beds)	S. Giovanni Bianco	11	15	32	53	0.38
III distal	Alluvial fan	Casere	1	13	37	50	0.42
III proximal	(redbeds)	Val Nozza	7	15	23	62	0.27
I	Coastal plain	S. Giovanni Bianco	1	11	36	53	0.40

Tab. 2 - Sandstone petrography for the clastic lithosomes recognized in the S. Giovanni Bianco Formation (methods and parameters after Dickinson, 1970, and Zuffa, 1985; data after Garzanti, 1985a; Crepaldi, 1990; Tosoni, pers. comm., 1994). Detrital quartz increases primarily with time, from Q = 11 at the base of the SGB1 to Q = 22 in the SGB2. F/F+L ratio is instead largely controlled by depositional environments, increasing laterally both in the SGB1 and SGB2 from proximal to distal settings.

(Lithosome III). The eastern toe of a second fan, probably represented by redbeds poorly exposed around Lecco, is recognized in the middle Brembana Valley (Lithosome II), where it rapidly passes eastward to paralic and shallow lagoonal settings (Fig. 7).

These semi-arid fans reached a coastal plain episodically scoured by ephemeral streams, forming an at least 7 km (Camonica Valley) to about 10 km (Brembana Valley) wide belt extending from east to west across the Bergamasc and Brescian Prealps. Dolostone beds document local deposition in sabkha-type ephemeral ponds.

The coastal plain passed northward to marginal marine environments with mixed terrigenous-carbonate sedimentation, including shallow sabkha/lagoons (Lithosomes IV and V p.p.) and tidal flats (Lithosome V p.p.). This facies belt extended southward to form an at least 10 km wide embayment centered along the present Seriana Valley and separating the Bergamasc from the Brescian clastic wedges. The microtidal coast was protected from waves by a carbonate platform characterized by continuous peritidal sedimentation in the north (Lithosome VI).

These facies belts evolved in time. During deposition of the SGB1, lagoonal environments were gradually confined by progradation of both alluvial fans (towards the east, west and north) and peritidal carbonate platforms (towards the south). The SGB1 in the Brembana Valley in fact displays an overall regressive trend, indicated by vertical transition from very fine-grained paralic clastics with sole marks and intercalated dolostones to up to medium-grained cross-laminated alluvial sandstones, capped in turn by finer-grained subaerial redbeds. Paleocurrent directions as well as decreasing thickness and maximum grain size consistently document lateral transition from proximal environments in the west (Val Taleggio to S. Giovanni Bianco; section 3) to distal settings in the east (S. Pellegrino to Dossena; sections 1 and 2) and north (Valtorta; section 5). Deposition of coarsening- and then fining-upward regressive alluvial facies (Garzanti, 1986, fig. 3) took place landward of the bayline during the late highstand stage, when the rate of accomodation development decreased and the equilibrium point moved seaward (Posamentier & Vail, 1988). Prolonged subaerial exposure eventually characterized the coastal plain at the top of the SGB1 (marker horizon of red mudrocks in the Brembana Valley). Local emergence is indicated even in areas where lagoonal sediments were previously accumulated (extrasequential clasts with borings or pedogenized in the biocalcarenites at the base of the SGB2 in Val Supine; section 7), and is particularly well-documented in less subsiding northern carbonate platform areas (silcretes of the Presolana; Rodeghiero, 1977).

Upper S. Giovanni Bianco Fm. (SGB2).

Poorer exposures and widespread alpine tectonic deformation hamper accurate reconstruction of the less competent uppermost part of the Carnian succession.

Sedimentation resumed in coastal plains (Lithosome VII), which passed northward to cyclic carbonate-siliciclastic shallow lagoonal environments (Lithosome VIII). The latter facies belt was at least 8 km wide and extended north of Val Supine. Biocalcarenites rich in open marine fossils (Fig. 6) form a distinct horizon at the base of the SGB2 from Val Supine to Val Riso (possibly represented by beds bearing thin-shelled pelecypods at Dossena and *Nautilus* in Valsassina); these document the persistence of a shallow trough connected with the open sea in the north during the basal transgression (Fig. 8).

Next, terrigenous detritus from the almost peneplaned emerged lands to the south was drastically reduced, probably also due to progressively dryer cli-

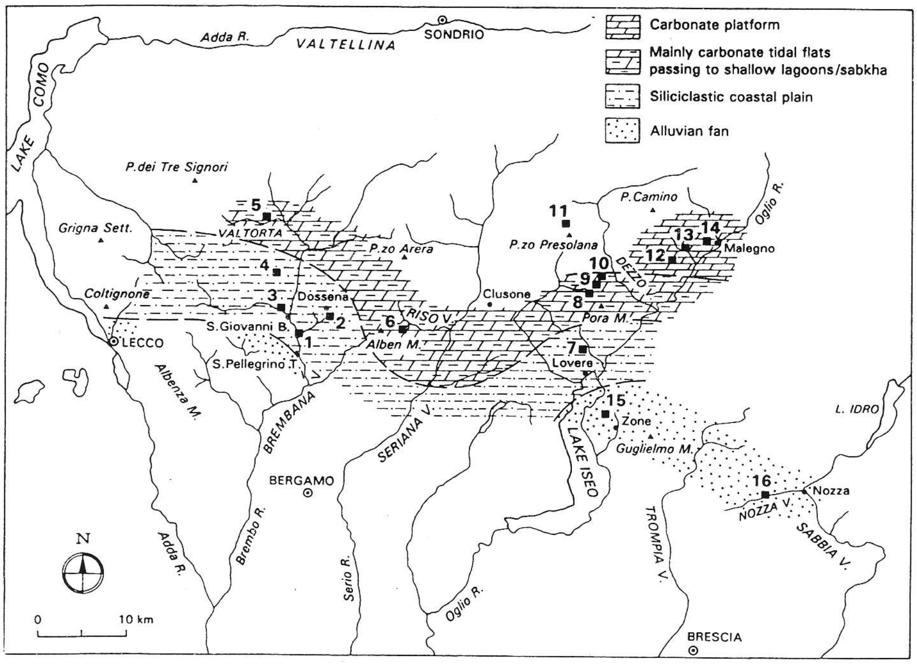

Fig. 7 - Paleogeographic sketch map of the Lombardy Southern Alps during SGB1 time. Location of stratigraphic sections 1 to 16 is shown. Note that a shallow-lagoon centered along the Seriana Valley still separates, as earlier in Val Sabbia Sandstone times, the Bergamasc from the Brescian clastic system.

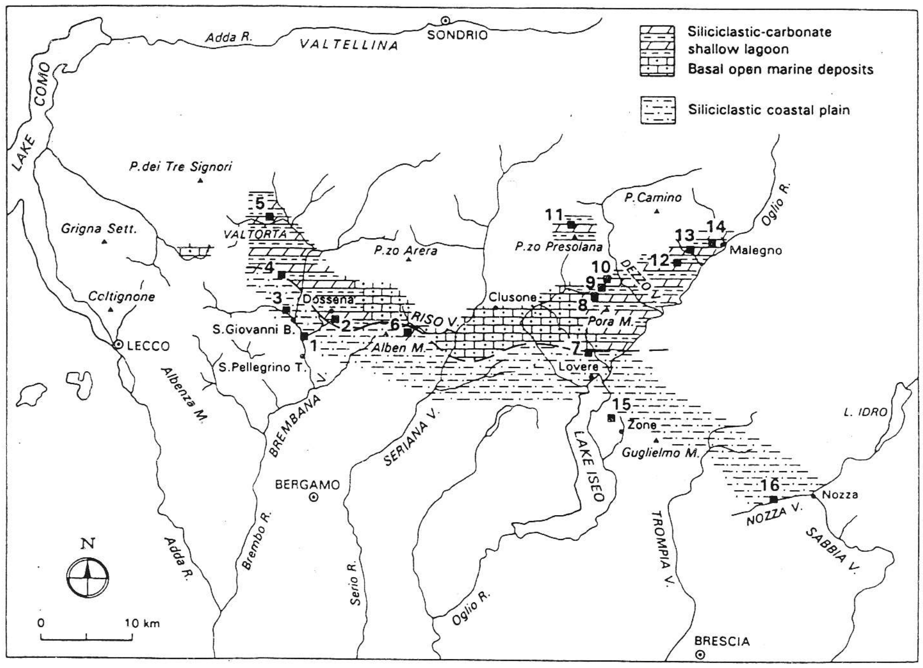

Fig. 8 - Paleogeographic sketch map of the Lombardy Southern Alps during early SGB2 time. Location of stratigraphic sections 1 to 16 is shown. Note persistence of a shallow trough, still centered along the Seriana Valley and connected with the open sea during transgression.

matic conditions. Thick evaporitic successions (Lithosome IX) in fact rapidly accumulated in salt pans characterized by strong subsidence, through repeated cycles of surface evaporation and flood recharge supply of marine waters. These salinas were delimited to the north-east by mainly subtidal carbonate platforms (Lithosome X), which developed in shallow-marine environments where mixed terrigenous-carbonate deposits had previously accumulated (Fig. 9).

Modern analogues.

Actualistic models for the depositional setting of the S. Giovanni Bianco Fm. may be found in the tropical zone of the northern emisphere. Similar distribution of siliciclastic to carbonate-evaporite facies belts, with alluvial fans passing laterally to outwash plains crossed by wadis, in turn grading seaward to coastal sabkhas, lagoons, algal flats and biogenic reefs or oolitic shoals, is observed around the Arabian Plate margins north of the Tropic of Cancer, from the Persian Gulf (Purser, 1973) to the gulfs of the northern Red Sea (Roberts & Murray, 1988). More significant discrepancies are accounted for by differences in geodynamic setting and topographic relief (estimated as 500 m at most for the SGB1; Garzanti, 1986, tab. 4) and in climatic conditions. Salina evaporites (Warren & Kendall, 1985; Warren, 1991) were in fact accumu-

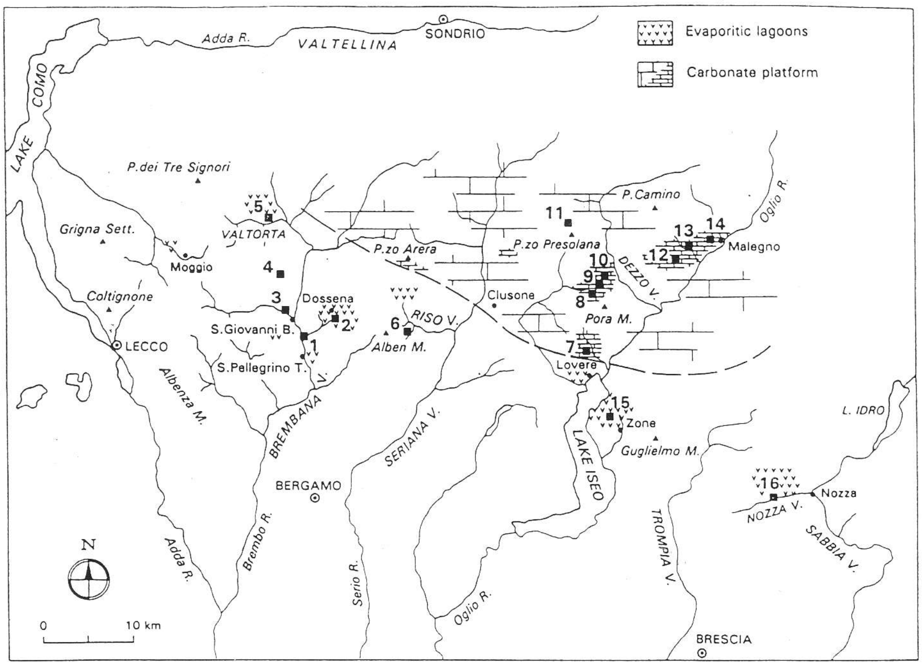

Fig. 9 - Paleogeographic sketch map of the Lombardy Southern Alps during late SGB2 time. Location of stratigraphic sections 1 to 16 is shown. Clastic influx has ceased and coastal salinas are barred by oolitic shoals in the north.

lated extensively only in the SGB2, whereas sporadic coastal sabkha deposits (*sensu* Purser, 1985) suggest more humid conditions for the SGB1.

Sequence stratigraphy and regional correlations

The S. Giovanni Bianco Fm. documents two third-order depositional sequences (upper part of C3 and C4 of Gaetani et al., 1995), which can be tentatively traced eastward across the Southern Alps, through the Dolomites (sequences Car3 and Car4 of De Zanche et al., 1993) to Carnia and the Julian Alps. Due to lack of age-diagnostic fossils, correlations with sequences recognized in other sedimentary basins (i.e. Canadian Arctic: Skjold et al., 1992; Barents Sea: Embry, 1988, 1993) or with the global eustatic chart (Haq et al., 1988) are unfortunately very poorly constrained.

Lower S. Giovanni Bianco Fm. - Campolungo Tongue (SGB1).

In the upper part of sequence C3, highstand progradation of peritidal carbonate platforms is observed from the Lombardy Prealps (Campolungo Tongue of the Breno Fm.; Lithosome VI) to the Brenta Group in Trentino ("tepee"-bearing topmost part of the "Dolomia Ladino-Carnica") and the Dolomites (upper part of the Dürrenstein peritidal platform). In Carnia, the Dürrenstein Fm. contains siliciclastic intercalations ("Violet Sandstone Member" of Pisa et al., 1979). In the Julian Alps, the Conzen carbonate platform may belong to the underlying sequence, and the SGB1 probably correlates instead with the terrigenous horizon in the lower part of the overlying Tor Fm. (Allasinaz & Assereto, 1968). The latter includes volcaniclastic sandstones derived from the south (Fella Valley, Dogna), and a thin carbonate platform at the top ("Orizzonte di Mestri e Dordolla" of Bianchin et al., 1979).

Upper S. Giovanni Bianco Fm. (SGB2).

Sequence C4 is characterized by more homogeneous facies associations. In the Dolomites it is represented by mixed siliciclastic-carbonate-evaporite deposits (Raibl Fm.); at places, localized coastal sandstones probably equivalent to Lithosomes VII and VIII p.p. (Falzarego fm.; Bosellini et al., 1978) pass upward to multicoloured mudrocks with intercalated shallow-water carbonates and local gypsum lenses (equivalent to Lithosomes VIII p.p., IX and X of SGB2). In eastern Carnia, the SGB2 would correlate with the Monticello Fm. and the underlying gypsum lenses occurring in the west and south (Bianchin et al., 1979). In the Julian Alps, green to black mudrocks are intercalated within dolomitized peritidal platform deposits in the Carnizza Fm. (Lieberman, 1978a, b; upper part of the Tor Fm. of Allasinaz & Assereto, 1968).

Upper Carnian successions in other nearby areas.

Upper Carnian successions are only a few to several tens of metres thick in western Lombardy, south-eastern Switzerland and north-western Slovenia.

In the Varese area, the highly lacunose Carnian succession is capped by reddish-greenish dolomitic mudrocks, overlain in turn by marls, micritic supratidal dolostones and local gypsum lenses (Pizzella Fm., 40 to 60 m thick; Allasinaz, 1968b).

In the Austroalpine domain, a 5 to 10 m thick horizon at the base of the Fanez Fm. (Cluozza Member of S. Frank, in Furrer, 1985, pp. 58-60) consists of impure dolostones containing mid?-Carnian pelecypods and locally very abundant ganoid fish scales, passing upward to reddish arkosic sandstones with plant remains (Q25÷45 F35÷50 L20÷30; samples kindly provided by S. Frank, ETH Zürich, 1985). At this stage, which probably corresponds to the SGB1, exclusively very fine-grained detritus, including abundant K-feldspar, some felsitic and very few microlitic volcanic rock fragments, was largely derived from Hercynian Europe in the north, possibly with subordinate supply from the Southern Lombardy volcanic belt (Garzanti, 1988). The overlying stromatolitic dolostones, possibly correlatable with the Campolungo Tongue of the Lombardy Southern Alps, pass upward and laterally to lagoonal mudrocks containing interbedded siltstones, dolostones and oolitic fossiliferous limestones with abundant echinoderms (Mezdi Member). The latter unit, along with the overlying polymict dolostone breccias and "carnieules", would represent the SGB2 sequence. Reddening of siliciclastics in the Engadine Dolomites and local lateritic horizons in the Ducan Chain (Furrer, 1985, p. 23) might be correlative with the SGB1/SGB2 unconformity.

In northern Slovenia, sedimentary facies similar to the Julian Alps are still found in the Mezica area (Jurkovsek, 1978), where shales and marls (about 15 m thick) pass upward to thick-bedded unfossiliferous limestones with marly intercalations (40 to 60 m thick). A facies change is observed along the upper Sava Valley towards the south-east, where cherty limestones with pelagic faunas (ammonoids, conodonts, fishes) become progressively more abundant throughout the Upper Carnian, documenting progressively deeper-water conditions (Kolar-Jurkovsek, 1991).

Paleogeographic evolution

Climatic framework.

The wide range of climatic indicators found at successive stratigraphic intervals within the Carnian succession of the Lombardy Southern Alps documents overall warm tropical conditions. In the lower part of the Carnian climates were semiarid, probably with a wet monsoonal season characterized by significant rainfall (Garzanti, 1986; Parrish, 1993), as suggested by continental redbeds containing widespread caliche and interbedded evaporite lenses, but locally also caliche-hematite to ferriferous pedogenic concretions and hematitized quartz grains. Mature lateritic-type soils developed during prolonged exposure, along with iron-manganese concretions formed on wood particles, document a warm humid stage at the top of the Val Sabbia Sandstone in the Brescia Prealps (M. Cremaschi, pers. comm, 1991). Also, *terra rossa* paleosoils with iron pisoids are observed at the top of the Conzen platform in the Julian Alps (Jadoul & Nicora, 1986).

The mid-Carnian sedimentary succession of the Southern Alps thus seemingly records a climatic episode such as that hypothesized for the whole Europe and North America (Simms & Ruffell, 1990); existence of such Carnian "pluvial events" has however been recently challenged (Visscher et al., 1994).

About at the time the main body of the Gorno Fm. was deposited, southern landmasses were mantled at least in part by forests with Equisetaceae and conifers, remains of which are locally found in abundance in the lower part of the prograding SGB1 clastic wedge (Lithosome I to II). Semiarid tropical conditions resumed in the upper part of the SGB1, as documented by widespread caliche paleosoils. Next, climates became progressively dryer, until salina evaporites were deposited in the upper part of the SGB2.

After a relatively humid event represented by the Castro Fm. (see Jadoul et al., 1992b), climate turned again to arid in the Early Norian, during deposition of the Dolomia Principale (Jadoul et al., 1992a). Finally, palynological data document another more humid episode in the Late Norian (Riva di Solto Shale), gradually followed by warmer semiarid climates in the Rhaetian (Zu Limestone; Jadoul et al., 1994).

This cyclic climatic evolution is consistent with tropical position of the Lombardy Southern Alps in the Late Triassic. Preliminary paleomagnetic analysis of the S. Giovanni Bianco Fm. in the Brembana Valley type-area suggests in fact paleolatitudes of about 15°N (Muttoni, 1994).

Subsidence and paleogeographic belts.

In the Upper Carnian, volcanic-derived clastic wedges followed by mixed siliciclastic-carbonate-evaporite sequences reach up to 400 m in thickness both in the western (Lombardy) and eastern (Carnia) Southern Alps. The largely carbonatic successions deposited in the central part (Brenta Group to Dolomites) are instead only 150 to 200 m thick.

Geometry and lateral relationships of lithosomes recognized in the study area document remarkable persistence of paleogeographic belts through time. Both in the lower and upper parts of the Carnian (Val Sabbia Sandstone to S. Giovanni Bianco Fm.), two major prograding clastic wedges in the east (Brescia) and west (Bergamo) show a marked increase in thickness in southern proximal sectors, whereas carbonate platform deposits document limited subsidence in northern sectors.

Such paleogeographic scenario was inherited from the mid-Triassic, when volcaniclastics accumulated closer to the Southern Mobile belt (Brusca et al., 1982, fig. 1), whereas carbonate buildups preferentially grew in cleaner waters to the north. Differential compaction during subsequent burial may explain the much greater subsidence of southern sectors during the Carnian.

Provenance of siliciclastics and geodynamic setting.

The source area of terrigenous detritus was the Southern Mobile Belt (Brusca et al., 1982). Detailed quantitative petrographic analysis allowed recognition of five petrologic intervals within the Carnian siliciclastic succession of Central Lombardy, documenting progressive stepwise increase in detrital quartz from the base to the top (Garzanti, 1985a, b, 1986, 1988; Crepaldi, 1990; Garzanti et al., 1995).

Although volcanic rock fragments and feldspars still predominate (Garzanti, 1985b, fig. 5), detrital quartz nearly doubles at the base of the S. Giovanni Bianco Formation. This significant change represents a regional petrographic marker which can be followed across the Bergamasc and Brescian Prealps, and therefore cannot be ascribed to local factors such as shifting drainage patterns. Since polycrystalline and monocrystalline quartz with undulose extinction both increase, and a few metamorphic lithics (phyllite to paragneiss) are recorded, deepening of erosion into the metamorphic wallrocks and basement of the volcanic belt is indicated. Much greater abundance in quartz and occurrence of perthitic K-feldspar are recorded already in the Val Sabbia and Gorno Formations of the Lake Como area ("Lierna lobe" of Garzanti & Pagni Frette, 1991), reflecting local provenance from Hercynian crystalline rocks and sedimentary cover exposed on basement highs to the west.

Abundance of monocrystalline quartz with straight extinction, bipyramidal outlines or embayments due to magmatic resorption, along with spherulitic to axiolitic vitric rock fragments, increases throughout the S. Giovanni Bianco Fm. and reaches a maximum at the top of the unit. Either a terminal phase of explosive activity or erosion of older felsic volcanic products is thus indicated.

Neovolcanic origin of rhyolitic detritus at the close of the Carnian cannot be ruled out. Although it is widely held that mid-Triassic magmatism evolved from rhyolitic to latitic-andesitic and eventually basaltic products during its terminal phase, and ended generally by the mid-Carnian (Bosellini et al., 1982), in the Giudicarie area to the east rhyolitic pyroclastic layers are interbedded within the lower part of the upper member of the Benna Fm., possibly Late Carnian in age (Castellarin et al., 1982).

In the studied area, the youngest volcanic rocks are vesicular lava flows of olivine basalts interbedded east of Malpaga in the uppermost Val Sabbia Sandstone. Clasts from these basalts are found in the overlying redbeds (possibly lateral equivalent to the main body of the Gorno Fm., which is absent in Val Nozza), and microlitic lithics derived from similar mafic volcanic products reach a relative maximum at the top of the SGB1 to decline rapidly in the SGB2.

Circumstantial evidence favouring a paleovolcanic origin of rhyolitic detritus in the S. Giovanni Bianco Fm. includes the appearance of vitric rock fragments along with hypabissal grains at the top of the Val Sabbia Sandstone. This fact suggests that the latitic to dacitic volcanic pile was already dissected before the mid-Carnian transgression of the main body of the Gorno Fm. (Garzanti & Jadoul, 1985, fig. 7). Chessboard-albite, a typical component of the Upper Anisian to Ladinian "Pietra Verde" rhyolitic tuffs (Callegari & De Pieri, 1966), is particularly abundant in the SGB2 (Garzanti 1985a, fig. 4b). Also, a few chert grains locally bearing radiolarians and presumably derived from the mid-Triassic Buchenstein Fm. occur in the Val Sabbia and Gorno Fms. of the Lierna area (Garzanti & Pagni Frette, 1991, fig. 5d) and sporadically also in the Bergamasc and Brescian Prealps. Paleovolcanic origin could thus be claimed even for the Val Sabbia Sandstone, which might have been fed by erosion of andesitic to latitic and dacitic volcanic rocks largely erupted during the Ladinian (Barbieri et al., 1982). This hypothesis would explain why interbedded pyroclastic layers are present only in the basal part of the Gorno Fm., correlative with the Val Sabbia Sandstone.

In the Brescian Prealps (e.g., Sabbia Valley), the fluvio-deltaic Val Sabbia Sandstone locally overlies directly Ladinian volcaniclastic turbidites (Wengen Fm.; Brusca et al., 1982, fig. 1), documenting a major tectonically-enhanced regression probably associated with uplift and basin inversion around the Ladinian/Carnian boundary. On local structural highs (Recoaro: De Zanche & Mietto, 1977; Croce di Marone: Cassinis & Zezza, 1982; Barghe: Picotti, 1991), largely Middle Triassic sedimentary rocks were eroded, thus

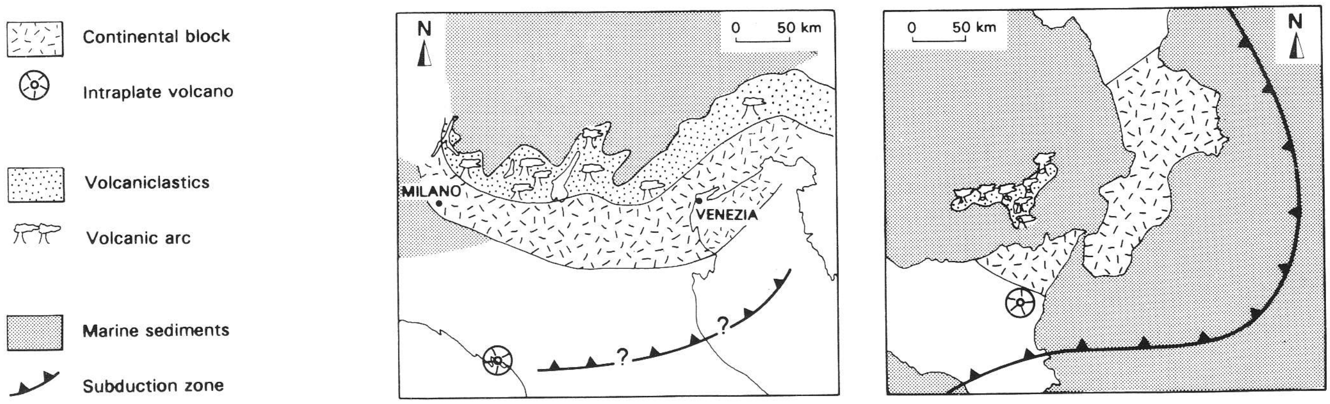

Fig. 10 - Differences and similarities between modern and ancient small-sized volcanic arcs formed due to confined subduction: a provocative comparison between the present day Calabrian accretionary prism and the Triassic Southern Mobile Belt (mod. after Brusca et al., 1982; De Zanche & Mietto, 1985), where volcanism was active at least until the mid-Carnian. Reduced mid-Triassic sedimentary successions from the Varese area to the Po Plain (Turbigo and Battuda Wells: Brugora, 1977) may have been deposited in "forearc" settings, with the Punta Bianca alkalic volcanics (Lucchini et al., 1982) possibly representing a Triassic analogous of Mt. Etna today.

providing throughout the Carnian carbonate pebbles, paleosoil clasts and other sedimentary and volcanic detritus to the Val Sabbia and S. Giovanni Bianco alluvial redbeds. Tectonic uplift associated with emergence took place locally even in the north (Brenta Group; Peloso & Vercesi, 1985).

To the south, a southward-convex arcuate basement-high can be prolonged from the Lake Como area (Garzanti & Pagni Frette, 1991) to the south-east beneath the Po Plain (as documented by subsurface data from the Monza, Malossa and Rodigo Wells: Brugora, 1977; Mattavelli & Margarucci, 1992) and as far as the Adriatic Sea (Villaverla, Legnaro and Assunta Wells: Brugora, 1977). According to the model of Marinelli et al. (1980; Garzanti, 1985b), the Southern Alpine and Austroalpine domains in the mid-Triassic may be envisaged as a retroarc basin on thinned continental crust, dominated by transtensional to locally transpressional tectonics (Doglioni, 1984; Castellarin et al., 1988; Garzanti, 1988). If a back-arc rifting interpretation is accepted (e.g., Stampfli et al., 1991, fig. 2 and 3), the mid-Triassic geodynamic scenario might be compared with that of southern Italy today (Fig. 10), where the Thyrrhenian back-arc basin (i.e. Southern Alpine-Austroalpine) is bordered to the south by the Eolian volcanic arc and by the southward-convex Calabria basement arc (i.e. Southern Mobile Belt of Brusca et al., 1982).

A major change in paleogeography is documented in the Norian by widespread transgression of the Dolomia Principale, which onlapped paraconformably the underlying succession and disconformably to non conformably the Southern Mobile Belt. This new tectono-sedimentary cycle, triggered by renewed tectonic extension, will lead to rifting and spreading of the Piedmont-Ligurian Ocean in the Jurassic (Jadoul et al., 1992a; Bertotti et al., 1993; Gaetani et al., 1995).

Conclusions

Integrated stratigraphic, sedimentologic and petrographic analysis of the Upper Carnian succession exposed in the Lombardy Southern Alps allowed us to reconstruct the evolution in time of a mixed terrigenous-carbonate-evaporitic coastal depositional system (Fig. 11).

During deposition of the lower part of the S. Giovanni Bianco Fm. (SGB1), two alluvial fan systems prograding towards the east in the Brembana Valley and towards the north-west in the Brescia area passed northwards to a siliciclastic coastal plain. They were separated and delimited seaward by a mixed siliciclastic-carbonate lagoon, which formed an embayment centered in the Seriana Valley and was protected from waves by a mainly peritidal carbonate platform in the north (Campolungo Tongue of the Breno Fm.). Major paleogeographic features, such as the Bergamasc and Brescian clastic wedges or the Breno carbonate platform, thus persisted throughout most of the Carnian (depositional sequences C1 to C4 of Gaetani et al., 1995).

The regressive trend at the top of the SGB1 is capped by an unconformity associated with local emergence and development of soil profiles.

During deposition of the overlying SGB2, sedimentation resumed in coastal plains, which passed northward to mixed carbonate-siliciclastic shallow lagoonal environments. A distinct horizon of calcarenites rich in open marine fossils locally marks the transgressive surface (Fig. 6). Next, terrigenous detritus from emerged lands in the south was drastically reduced, and gypsum accumulated in subsident coastal salinas barred to the north-east by mainly subtidal carbonate platforms.

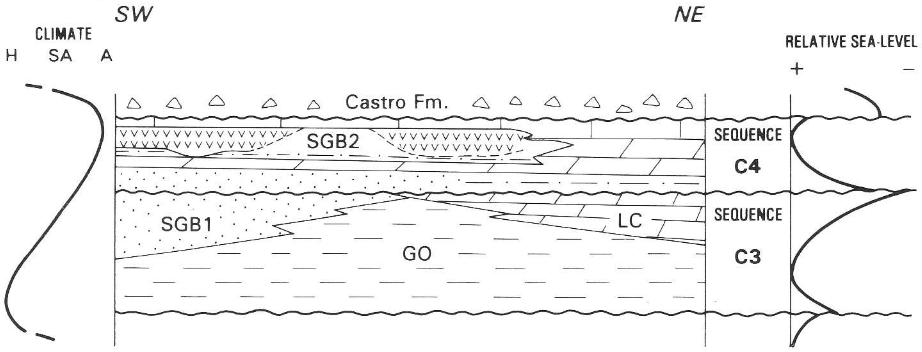

Fig. 11 - Simplified stratigraphic framework for the Upper Carnian of Lombardy (profile from the Brembana Valley in the SW to the Camonica Valley in the NE; Fig. 1). Long-term eustatic and climatic changes are schematically shown. H = humid; SA = semiarid; A = arid. GO = Gorno Fm.; LC = Campolungo Tongue.

Sedimentary evolution is partly related to changing climatic conditions, which passed from relatively humid in the mid-Carnian to tropical semiarid in the SGB1 and finally to arid in the upper part of the SGB2 (Fig. 11). Sedimentation at tropical latitudes is consistent with recently obtained paleomagnetic data. Also, best actualistic models for the depositional setting of the S. Giovanni Bianco Fm. are found in the tropical belt of the northern emisphere, as around the Arabian Plate margins. Several discrepancies may be accounted for by topographic relief, more subdued for the S. Giovanni Bianco Fm., and different geodynamic setting.

Petrology of sandstones from the Austroalpine and Southern Alpine domains, lateral distribution of facies belts and available geological information are not inconsistent with deposition in a retroarc basin formed on thinned continental crust and dominated by transtensional to locally transpressional tectonics. Evolution of detrital modes, however, is anomalous with respect to typical trends observed in Pacific-type active margin basins (Garzanti, 1985b, fig. 8). Since observations from areas south of the Po Plain are scarce, all possible scenarios should be taken into account in order to shed further light on the strongly debated geodynamic evolution of the Southern Alps during the Triassic.

Acknowledgments.

Luca Crepaldi and Natascia Tosoni point-counted a number of thin sections, all carefully made by Curzio Malinverno. Paolo Bruni, Mauro Cremaschi and Silvia Frisia gave precious advice on volcanic, pedogenetic and diagenetic processes. Anna Paganoni and Roberto Rettori helped in determination of plant remains and benthic foraminifers. "*Nautilus brembanus*" was found by Paolo Biffi and identified by Marco Balini. Stephan Frank (ETH Zürich) and Giovanni Muttoni kindly provided sandstone samples with field descriptions and information on paleolatitudes respectively. The manuscript has benefitted from careful reviews by Carla Rossi Ronchetti, Maurizio Gaetani, Franco Ricci Lucchi and an anonymous geologist. Photographs printed by Giovanni Chiodi; drawings made by Magda Minoli. The project was supported by MURST 40% to M. Gnaccolini, Milano.

REFERENCES

Allasinaz A. (1968a) - Il Trias in Lombardia. Studi geologici e paleontologici. XXIII. Cefalopodi e Gasteropodi dello Julico in Lombardia. *Riv. It. Paleont. Strat.*, v. 74, pp. 327-400, Milano.

Allasinaz A. (1968b) - Il Trias in Lombardia. Studi geologici e paleontologici. XXIV. Il Carnico della Lombardia occidentale. *Riv. It. Paleont. Strat.*, v. 74, pp. 1007-1056, Milano.

Allasinaz A. & Assereto R. (1968) - Formazione di Tor. *Studi Illustr. Carta Geol. Italia.* Formazioni geologiche, n. 1, pp. 3-8, Roma.

Assereto R. (1965) - Sulla presenza di torbiditi nei sedimenti del Carnico nei dintorni di Dossena (Val Brembana). *Riv. It. Paleont. Strat.*, v. 71, pp. 839-852, Milano.

Assereto R. & Casati P. (1965) - Revisione della stratigrafia Permo-Triassica della Val Camonica meridionale (Lombardia). *Riv. It. Paleont. Strat.*, v. 71, pp. 999-1097, Milano.

Assereto R., Jadoul F. & Omenetto P. (1977) - Stratigrafia e metallogenesi del settore occidentale del distretto a Pb, Zn, fluorite e barite di Gorno (Alpi Bergamasche). *Riv. It. Paleont. Strat.*, v. 83, pp. 395-532, Milano.

Barbieri G., De Vecchi G., De Zanche V., Mietto P. & Sedea R. (1982) - Stratigrafia e petrologia del magmatismo triassico nell' area di Recoaro. In Castellarin A. & Vai G.B. (Eds.) - Guida alla geologia del Sudalpino centro-orientale. *Guide Reg. Soc. Geol. It.*, pp. 179-187, Bologna.

Bertotti G., Picotti V., Bernoulli D. & Castellarin A. (1993) - From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the Early Cretaceous. *Sedim. Geol.*, v. 86, pp. 53-76, Amsterdam.

Bianchin G., Carulli G.B., Frizzo P., Longo Salvador G., Mantovani F., Masé G., Mezzacasa G. & Semenza E. (1979) - Carta Geologica della zona tra il T. Chiarzò e il Fella (Alpi Carniche), scala 1:20.000, Grafica Ferrares.

Bosellini A., Castellarin A., Doglioni C., Guy F., Lucchini F., Perri M.C., Rossi P.L., Simboli G. & Sommavilla E. (1982) - Magmatismo e tettonica nel Trias delle Dolomiti. In Castellarin A. & Vai G.B. (Eds.) - Guida alla geologia del Sudalpino centro-orientale. *Guide Reg. Soc. Geol. It.*, pp. 189-210, Bologna.

Bosellini A., Dal Cin R. & Gradenigo A. (1978) - Depositi litorali raibliani nella zona del Passo Falzarego

(Dolomiti Centrali). *Annali Univ. Ferrara,* Geol. Paleont. 5, pp. 223-237, Ferrara.

Brugora C. (Ed.) (1977) - Temperature sotterranee. V. of 1390 pp., AGIP, Segrate (Milano).

Brusca C., Gaetani M., Jadoul F. & Viel G. (1982) - Paleogeografia Ladino-Carnica e metallogenesi nel Sudalpino. *Mem. Soc. Geol. It.*, v. 22, pp. 65-82, Roma.

Callegari E. & De Pieri R. (1966) - Un interessante fenomeno di albitizzazione del feldspato potassico osservato nella "Pietra verde" della Regione Dolomitica. *Studi Trent. Sc. Nat.*, v. 43, pp. 218-232, Trento.

Casati P. & Gnaccolini M. (1967) - Strutture diagenetiche nella Formazione di S. Giovanni Bianco della Val Taleggio (Bergamo). *Riv. It. Paleont. Strat.*, v. 73, pp. 1143-1148, Milano.

Cassinis G. & Zezza U. (1982) - Dati geologici e petrografici sui prodotti del magmatismo triassico delle Prealpi Bresciane. In Castellarin A. & Vai G.B. (Eds.) - Guida alla geologia del Sudalpino centro-orientale. *Guide Reg. Soc. Geol. It.*, pp. 157-171, Bologna.

Castellarin A., Lucchini F., Rossi P.L., Selli L. & Simboli G. (1988) - The Middle Triassic magmatic-tectonic arc development in the Southern Alps. *Tectonophysics*, v. 146, pp. 79-89, Amsterdam.

Castellarin A., Perri M.C., Resenterra L. & Sartori R. (1982) -Vulcaniti triassiche della zona delle Giudicarie (area di Roncone e dintorni). In Castellarin A. & Vai G.B. (Eds.) - Guida alla geologia del Sudalpino centro-orientale. *Guide Reg. Soc. Geol. It..*, pp. 173-177, Bologna.

Crepaldi L. (1990) - Rilevamento di un'area delle Alpi Bergamasche e petrografia delle arenarie carniche della Lombardia. Tesi di Laurea, v. of 132 pp., Milano.

De Sitter L.U. & De Sitter Koomans C.M. (1949) - The geology of the Bergamasc Alps, Lombardia, Italy. *Leid. Geol. Med.*, v. 14B, pp. 1-257, Leiden.

De Zanche V., Gianolla P., Mietto P., Siorpaes C. & Vail P.R. (1993) - Stratigraphic sequence stratigraphy in the Dolomites (Italy). *Mem. Sc. Geol.*, v. 49, pp. 1-27, Padova.

De Zanche V. & Mietto P. (1977) - Il Carnico nelle Prealpi vicentine. *Boll. Soc. Geol. It.*, v. 94, pp. 1573-1593, Roma.

De Zanche V. & Mietto P. (1985) - Il Gruppo di Raibl in Valsugana e nei dintorni di Trento. *Mem. Soc. Geol. It.*, v. 30, pp. 293-299, Roma.

Dickinson W.R. (1970) - Interpreting detrital modes of greywacke and arkose. *Journ. Sedim. Petrol.*, v. 40, pp. 695-707, Tulsa.

Doglioni C. (1984) - Tettonica triassica transpressiva nelle Dolomiti. *Giorn. Geol.*, v. 46, pp. 47-60, Bologna.

Embry A.F. (1988) - Triassic sea-level changes: evidence from the Canadian Arctic Archipelago. In Wilgus C.K. et al. (Eds.) - Sea-level changes - an integrated approach. *Soc. Econ. Paleont. Min.*, Spec. Publ. 42, pp. 249-259, Tulsa.

Embry A.F. (1993) - Triassic T-R sequence analysis, Sverdrup Basin, Canadian Arctic archipelago. Carboniferous to Jurassic Pangea Meeting. Abstract volume, p. 89, Calgary.

Furrer H. (Ed.) (1985) - Field workshop on Triassic and Jurassic sediments in the Eastern Alps of Switzerland. *Mitt. Geol. Inst. ETH Univ.*, n. 248, v. of 81 pp., Zürich.

Gaetani M. (1986) - Il Triassico dell'Adamello Meridionale. *Mem. Soc. Geol. It.*, v. 26, pp. 105-118, Roma.

Gaetani M., Garzanti E., Gnaccolini M. & Jadoul F. (1995) - Multiorder sequence stratigraphy in the Triassic of the western Southern Alps. *Soc. Econ. Paleont. Min.*, in press.

Gaetani M. & Jadoul. F. (1979) - The structure of the Bergamasc Alps. *Rend. Acc. Naz. Lincei*, v. 66, pp. 411-416, Roma.

Garzanti E. (1985a) - Petrography and diagenesis of Upper Triassic volcanic arenites (Val Sabbia, Gorno and S. Giovanni Bianco Formations; Bergamasc Alps). *Boll. Soc. Geol. It.*, v. 104, pp. 3-20, Roma.

Garzanti E. (1985b) - The sandstone memory of the evolution of a Triassic volcanic arc in the Southern Alps, Italy. *Sedimentology*, v. 32, pp. 423-433, Oxford.

Garzanti E. (1986) - Source rocks versus sedimentary control on the mineralogy of deltaic volcanic arenites (Upper Triassic, Northern Italy). *Journ. Sedim. Petrol.*, v. 56, pp. 267-275, Tulsa.

Garzanti E. (1988) - Ambienti sedimentari fluvio-deltizi e composizione petrografica: le arenarie del Trias superiore lombardo. In Ori G.G. & Cremona M. (Eds.) - I depositi continentali. *Giorn. Geol.*, v. 50, pp. 163-175, Bologna.

Garzanti E. & Jadoul F. (1985) - Stratigrafia e paleogeografia del Carnico lombardo (Sondaggio S. Gallo, Valle Brembana). *Riv. It. Paleont. Strat.*, v. 91, pp. 295-320, Milano.

Garzanti E. & Pagni Frette M. (1991) - Il Carnico di Lierna (Como): stratigrafia e paleogeografia. *Riv. It. Paleont. Strat.*, v. 96, pp. 407-426, Milano.

Garzanti E., Sciunnach D. & Confalonieri M. (1995) - Discriminating source rock and environmental control from detrital modes of Permo-Triassic sandstones (Lombardy Southern Alps). In Basu A. & Valloni R. (Eds.) - Quantitative sandstone petrography. *Mem. Serv. Geol. It.*, in press.

Gnaccolini M. (1983) - Un apparato deltizio triassico nelle Prealpi Bergamasche. *Riv. It. Paleont. Strat.*, v. 88, pp. 599-612, Milano.

Gnaccolini M. (1986) - La Formazione di Gorno nei dintorni di Dossena e di Gorno (Prealpi Bergamasche): analisi di una laguna Triassica. *Riv. It. Paleont. Strat.*, v. 92, pp. 3-32, Milano.

Gnaccolini M. (1987) - Arenaria di Val Sabbia e Formazione di Gorno: un sistema deposizionale delta-laguna nel Trias superiore delle Prealpi Bergamasche. *Riv. It. Paleont. Strat.*, v. 93, pp. 329-336, Milano.

Gnaccolini M. & Jadoul F. (1988) - Un sistema deposizionale delta-laguna-piattaforma carbonatica nel Carnico lombardo (Triassico superiore, Alpi Meridionali, Italia). *Riv. It. Paleont. Strat.*, v. 93, pp. 447-468, Milano.

Gnaccolini M. & Jadoul F. (1990) - Carbonate platform, lagoon and delta "high-frequency" cyclothems from the Carnian of Lombardy (Southern Alps, Italy). *Sedim. Geol.*, v. 67, pp. 143-159, Amsterdam.

Haq B.U., Hardenbol J., & Vail P.R. (1988) - Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In Wilgus C.K. et al. (Eds.) - Sea-level changes - an integrated approach. *Soc. Econ. Paleont. Min.*, Spec. Publ. 42, pp. 71-108, Tulsa.

Jadoul F., Berra F. & Frisia S. (1992a) - Stratigraphic and paleogeographic evolution of a carbonate platform in an extensional tectonic regime: the example of the Dolomia Principale in Lombardy (Italy). *Riv. It. Paleont. Strat.*, v. 98, pp. 29-44, Milano.

Jadoul F., Berra F., Frisia S., Ricchiuto T. & Ronchi P. (1992b) - Stratigraphy, paleogeography and genetic model of Late Carnian carbonate breccias (Castro Formation, Lombardy, Italy). *Riv. It. Paleont. Strat.*, v. 97, pp. 355-392, Milano.

Jadoul F., Masetti D., Cirilli S., Berra F., Claps M. & Frisia S. (1994) - Norian-Rhaetian stratigraphy and paleogeographic evolution of the Lombardy Basin (Bergamasc Alps). 15 IAS Regional Meeting, Excursion B1, pp. 5-38, Ischia (Napoli).

Jadoul F. & Nicora A. (1986) - Stratigrafia e paleogeografia ladinico-carnica delle Alpi Carniche orientali (versante nord della Val Canale, Friuli). *Riv. It. Paleont. Strat.*, v. 92, pp. 201-238, Milano.

Jurkovsek B. (1978) - Biostratigraphy of the Carnian beds in the Mezica area. *Geol. Razpr. Poroc.*, v. 21, pp. 173-208, Ljubliana.

Kolar-Jurkovsek T. (1991) - Microfauna of Middle and Upper Triassic in Slovenia and its biostratigraphic significance. *Geol. Razpr. Poroc.*, v. 33, pp. 21-170, Ljubliana.

Laubscher H.P. (1985) - Large-scale, thin-skinned thrusting in the Southern Alps: kinematic models. *Geol. Soc. Am. Bull.*, v. 96, pp. 710-718, Boulder.

Lieberman H. (1978a) - Carnitza Formation, ein neuer Begriff für oberkarnische Beckenkalke der südlichen Kalkalpen bei Raibl (Cave del Predil, Italien). *Mitt. Ges. Geol. Bergbaustud.*, v. 25, pp. 35-62, Wien.

Lieberman H. (1978b) - Das Raibler Becken: eine paläogeographische Rekonstruktion aus dem südalpinen Karn von Raibl (Cave del Predil, Italien). *Geol. Paläont. Mitt.*, v. 7, pp. 7-20, Innsbruck.

Lucchini F., Rossi P.L., Simboli G. & Cristofolini R. (1982) - Confronto geochimico fra i prodotti magmatici basici del Trias-Giura nell' area Tetidea. In Castellarin A. & Vai G.B. (Eds.) - Guida alla geologia del Sudalpino centro-orientale. *Guide Reg. Soc. Geol. It.*, pp. 33-141, Bologna.

Marinelli M., Viel G. & Farabegoli R. (1980) - Il Permo-Trias delle Alpi Meridionali: evoluzione tardo-ercinica di un bacino marginale di retroarco sialico. *Ind. Miner.*, v. 6, pp. 1-14, Roma.

Mattavelli L. & Margarucci V. (1992) - Malossa Field (Po Basin, Italy). In Beaumont E.A. & Foster N.H. (Eds.) - Structural traps VII. Treatise of petroleum geology - Atlas of oil and gas fields. *Am. Ass. Petr. Geol.*, pp. 119-137, Tulsa.

Muttoni G. (1994) - Analisi paleomagnetica di sezioni stratigrafiche significative del Triassico Inferiore e Medio della Tetide. Tesi di Dottorato, v. of 173 pp., Milano.

Parrish J.T. (1993) - Climate of the supercontinent Pangea. *Journ. Geol.*, v. 101, pp. 215-233, Chicago.

Peloso G.F. & Vercesi P.L. (1985) - Brecce intraformazionali nella piattaforma carbonatica carnica a N di Tione (Brenta): interpretazione e significato paleogeografico. *Mem. Soc. Geol. It.*, v. 30, pp. 285-292, Roma.

Picotti V. (1991) - Ladinian-Carnian evolution of the Barghe structural high (Val Sabbia, Southern Alps). *Rend. Soc. Geol. It.*, v. 14, pp. 101-106, Roma.

Pisa G., Marinelli M. & Viel G. (1980) - Infraraibl Group: a proposal (Southern Calcareous Alps, Italy). *Riv. It. Paleont. Strat.*, v. 85 (1979), pp. 983-1002, Milano.

Posamentier H.W. & Vail P.R. (1988) - Eustatic controls on clastic deposition. II. Sequence and systems tract models. In Wilgus C.K. et al. (Eds.) - Sea-level changes - an integrated approach. *Soc. Econ. Paleont. Min.*, Spec. Publ. 42, pp. 125-154, Tulsa.

Purser B.H. (Ed.) (1973) - The Persian Gulf. Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. V. of 471 pp., Springer Verlag, Berlin.

Purser B.H. (1985) - Coastal evaporite systems. In Friedman G.M. & Krumbein W.E. (Eds.) - Hypersaline ecosystems: the Gavish Sabkha, pp. 72-102, Springer Verlag, Berlin.

Roberts H.H. & Murray S.P. (1988) - Gulfs of the northern Red Sea: depositional settings of abrupt siliciclastic-carbonate transitions. In Doyle L.J. & Roberts H.H. (Eds.) - Carbonate-clastic transitions. *Developm. Sediment.*, v. 42, pp. 99-142, Amsterdam.

Rodeghiero F. (1977) - Le mineralizzazioni a Pb-Zn, fluorite e barite nel Carnico della zona del Pizzo della Presolana (Prealpi Bergamasche). *Boll. Ass. Min. Subalpina*, v. 14, pp. 453-474.

Simms M.J. & Ruffell A.H. (1990) - Climatic and biotic change in the late Triassic. *Journ. Geol. Soc.*, v. 147, pp. 321-327, London.

Skjold L.J., van Veen P.M., Kristensen S.-E. & Rasmussen A.R. (1992) - Triassic sequence stratigraphy in the Barents Sea. Sequence stratigraphy of European Basins. Abstract volume, pp. 86-87, Dijon.

Stampfli G., Marcoux J. & Baud A. (1991) - Tethyan margins in space and time. *Palaeogeogr. Palaeoclim. Palaeoecol.*, v. 87, pp. 373-409, Amsterdam.

Visscher H., Van Houte M., Brugman W.A. & Poort R.J. (1994) - Rejection of a Carnian (Late Triassic) "pluvial event" in Europe. *Rev. Palaeobot. Palynol.*, v. 83, pp. 217-226, Amsterdam.

Warren J.K. (1991) - Sulfate dominated sea-marginal and platform evaporative settings: sabkhas and salinas, mudflats and salterns. In Melvin J.L. (Ed.) - Evaporites, petroleum and mineral resources, pp. 69-187, Elsevier, Amsterdam.

Warren J.K. & Kendall C.G.ST.C. (1985) - Comparison of sequences formed in marine sabkha (subaerial) and salina (subaqueous) setting - modern and ancient. *Am. Ass. Petr. Geol. Bull.*, v. 69, pp. 1013-1023, Tulsa.

Zuffa G.G. (1985) - Optical analyses of arenites: influence of methodology on compositional results. In Zuffa G.G. (Ed.) - Provenance of arenites. *NATO-ASI Series*, pp. 165-189, Reidel, Dordrecht.

Received February 13, 1995; accepted February 20, 1995