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Jurassic tectonic framework of the eastern border of the Lombardian basin

By Alberto Castellarin and Vincenzo Picotti[1])

ABSTRACT

Along the tectonic alignment Ballino-Garda a wide, N-S trending belt between the Po plain and the Tonale Line was affected by extensional tectonics linked to Liassic intracontinental rifting which disintegrated the area of the Southern Alps, i.e. the future southern continental margin of the western Tethys. The structural architecture of this belt is determined by normal master faults (very probably listric and/or domino systems) presently trending in a N-S and NNE-SSW direction and by nearly E-W trending fault systems which can be interpreted as kinematic links (transfer faults) between the different segments of the listric (or domino) major system.

Extensional tectonics prograded from W to E during the Liassic as documented by the drowning age of the peritidal carbonate shelf in the different sectors: Early Liassic (?Hettangian-Early Sinemurian) in the western parts of the belt (Ballino-Gruppo di Brenta and Sebino-Val Trompia areas); mainly Middle Liassic (?Late Sinemurian-Pliensbachian) between the western side of Lake Garda and the hills of Botticino (Brescia); mostly Late Liassic in the easternmost part of the belt. This last event marks the greatest eastward progradation of the Liassic rifting in this area.

The Liassic rifting displays a marked irregularity: to the North of Riva del Garda there is no intermediate block that was foundered around the beginning of the Middle Liassic.

The Liassic evolution of the Ballino Line is strongly different N and S of Riva. To the N this structure is the principal divide between the basinal Lombardian and Venetian platform domains, whilst to the S, the line did not produce a major fault scarp in the Early Liassic and there was one continuous carbonate platform from the eastern Venetian area (Calcari Grigi Formation, lower member) to the Lombardian sector (Corna Formation).

The most characteristic, complete and thick basinal Liassic successions form syntectonic sedimentary prisms which are equivalent in geometry and stratigraphic patterns in the Ballino-Gruppo di Brenta zone and in the Sebino-Val Trompia area. They are not continuous in N-S direction, but are offset along E-W trending faults. This offset runs along a major E-W trending fault system (Vies-Trat, Lenzumo and Dosso del Vento Lines) and presumably has a western prolongation in the Val Trompia Line. These discontinuities are interpreted as parts of a transfer fault system which was the Liassic kinematic link between the two segments of the belt.

RIASSUNTO

Lungo il lineamento tettonico Ballino-Garda è riconoscibile una estesa fascia compresa tra la Pianura Bresciana e la Linea del Tonale, interessata da tettonismo distensivo riferibile ad un rifting continentale liassico. La sua architettura strutturale e' determinata da faglie dirette principali (probabilmente listriche e/o a domino) attualmente secondo allineamenti N-S e NNE-SSW e da faglie trasversali circa E-W, talora particolarmente estese e pronunciate, che rappresentano gli svincoli cinematici («transfer faults») del sistema tettonico maggiore.

La tettonica distensiva si è propagata nel tempo da W ad E come, con buon fondamento, indicano le età di «annegamento» della piattaforma peritidalica nei vari settori: Lias inferiore (Hettangiano(?)-Sinemuriano inf.) nei settori più occidentali (zona Ballino-Gruppo di Brenta e area della Val Trompia e Sebina); Lias medio (Sinemuriano

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sup. (?)-Pliensbachiano) nel settore della Gardesana occidentale fino a Botticino; Lias superiore (Toarciano) nella fascia più orientale (bordo occidentale della Piattaforma Veneta). Quest'ultimo evento segna la massima propagazione verso E del rifting giurassico in questa regione.

Il rifting liassico presenta una spiccata asimmetria:

– nel settore settentrionale manca infatti la zona di annegamento iniziale del Lias medio, ampiamente sviluppata a S di Riva del Garda (dalla Gardesana occidentale a Botticino);

– la Linea di Ballino nel Lias inferiore ha una funzione differente a N e a S di Riva. A N costituiva la scarpata morfostrutturale principale interposta fra i due domini lombardo e veneto; a S probabilmente essa non aveva un apprezzabile risalto morfologico e separava settori a subsidenza differenziata (molto maggiore a W) senza modificare le condizioni batimetriche e paleoambientali che dovevano corrispondere a quelle di una piattaforma carbonatica praticamente continua dal dominio veneto (con le successioni del membro inferiore dei Calcari Grigi) a quello lombardo (con le successioni assai più potenti della Corna).

Le successioni bacinali liassiche più caratteristiche, complete e di maggiore spessore, formano prismi sedimentari sintettonici stratigraficamente e geometricamente omologhi nella zona di Ballino-Gruppo di Brenta e nell'area sebina-Val Trompia, che non risultano allineati in senso N-S, ma appaiono notevolmente distanziati in senso E-W fra loro. Tale asimmetria si localizza in corrispondenza del pronunciato sistema trasversale di faglie liassiche E-W dei dintorni di Riva del Garda e nel loro possibile prolungamento verso W nella fascia corrispondente a quella della attuale Linea della Val Trompia. Si ritiene che questa associazione trasversale costituisca un sistema di «transfer faults» liassico lungo il quale si sarebbe realizzato un raccordo cinematico primario fra le zone bacinali liassiche dei due differenti settori.

1. Introduction

This contribution deals with an area in the central part of the Southern Alps extending from the Trento and western Verona provinces to the area of Lake Garda and Brescia. This sector is part of the Giudicarian fold and thrust belt East of the Southern Giudicarie Line and around the Adamello pluton (Fig. 1). The area forms also the hinge zone between the Lombardian and Venetian regions, two geological provinces with a highly different tectonic and sedimentary evolution (Fig. 1).

In the past, the Southern Giudicarie Line has been interpreted in very different ways (for further references see also Perna et al. 1983):

1) as an Alpine strike-slip fault (Trevisan 1939; Laubscher 1971, 1973, 1988, 1990; Doglioni & Bosellini 1987);

2) as an eastward directed Alpine thrust (Dal Piaz 1942; Vecchia 1957; Boni 1963; Semenza 1974; Castellarin & Sartori 1979, 1983; Castellarin & Vai 1982);

3) as a Mesozoic extensional fault reactivated during Alpine compression (Castellarin 1972; Castellarin et al. 1988).

The present paper deals with the Jurassic sedimentary evolution of this belt, which was affected by extensional movements during rifting of the future southern continental margin of the Alpine Tethys (see also Laubscher & Bernoulli 1977; Bernoulli et al. 1979; Winterer & Bosellini 1981). However, Mesozoic extensional structures in the Giudicarie belt are not easily recognized because they were, as many of pre-existing tectonic elements, structurally inverted during the Neogene compression. During the last two decades, detailed sedimentological, stratigraphical and structural analysis in several key zones less involved in Neogene deformation were carried out by us, in order to reconstruct the paleotectonic evolution. The main results of these studies are summarized here.

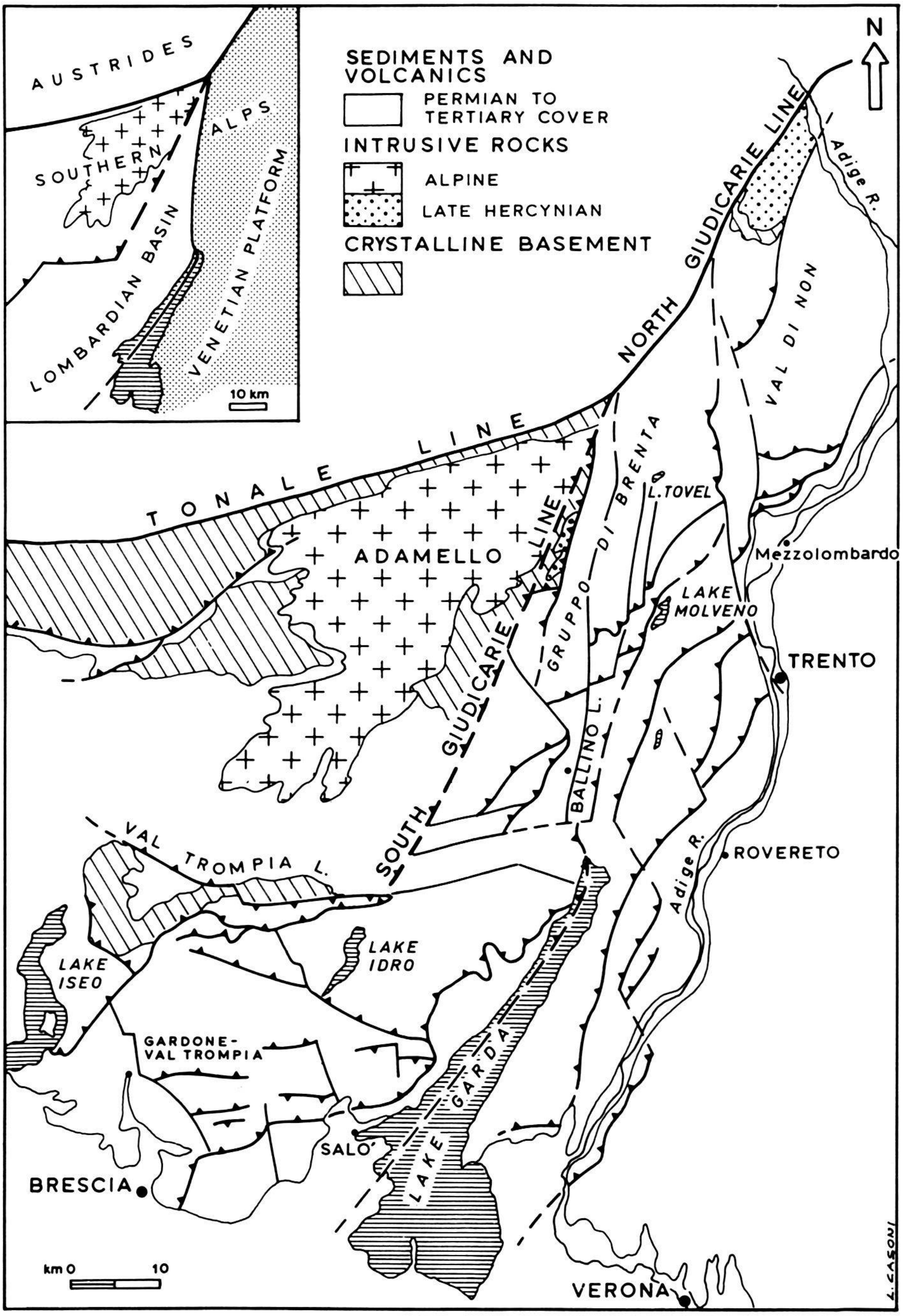

Fig. 1. Synthetic view of the Giudicarie structural belt. The scheme shows the complicated pattern of the thrust system (barbed lines) and its truncation by transfer faults (from CASTELLARIN 1981, modified). The Jurassic divide of the Ballino-Garda alignment, separating different sedimentary realms, is sketched in the inset (upper left).

2. The Ballino Line

One of the most fascinating problems of our area concerns the geometrical relationships between the two different facies realms East and West of Lake Garda: along its eastern border, the so-called Venetian facies is extensively outcropping with a Liassic Bahamian-type carbonate platform succession capped by a deepening upward pelagic limestone sequence including the Rosso Ammonitico Veronese (mainly Upper Jurassic) and the Calpionella limestones of the Biancone Formation (Lower Cretaceous). In contrast, along the western border of the lake, basinal deep water Jurassic deposits are present with thinly bedded cherty limestones (Medolo Formation), radiolarites (Upper Jurassic) and Calpionella limestones (Maiolica Lombarda Formation, Lower Cretaceous) (Fig. 1, inset).

North of Riva del Garda the stratigraphic record of both sectors is well preserved and exposed in the Tenno-Ballino area (Fig. 2), and their contrasting sedimentary evolution was recognized by several European geologists as early as the end of the last century (BITTNER 1881). Different proposals were offered to explain the different stratigraphic evolution. Early workers (SCHWINNER 1918; TREVISAN 1939) proposed that two previously distant areas were juxtaposed by Neogene sinistral strike-slip displacement along N-S trending lines, e.g. the Ballino Line. Alternative interpretations assumed very rapid lateral facies transitions between the two different sedimentary realms whose original setting was considered not to have been drastically changed by Neogene deformation. This latter explanation was mainly sustained by French authors (AUBOUIN 1963; AUBOUIN et al. 1965; CHARVET 1966; BONNEAU 1969).

CASTELLARIN (1972), taking up observations by BITTNER (1881) and suggestions by Italian geologists (DAL PIAZ 1942; CADROBBI 1943; VECCHIA 1957) recognized in the Ballino Line a pronounced, nearly N-S trending, synsedimentary fault scarp which was active and a source area of gravity displaced resediments in the Lombardian basin at least since the Early Jurassic. This results in drastically different facies not only in the Jurassic but also in the Cretaceous, indicating reactivation of previous structures and formation of new normal faults up to the Maastrichtian. The reconstruction of Jurassic faults in the Ballino area matches with the models developed in western Lombardy, where similar Mesozoic structures (Lugano Line and Monte Generoso Basin) were recognized by paleotectonic analysis (BERNOULLI 1964; WIEDENMAYER 1963).

North of Ballino the same paleotectonic situation has been recognized along the western borders of the Brenta Group up to the proximity of the Tonale Line (M. Spolverino, Dimaro zone, unpublished data from SANGUINETTI 1989) along a continuous paleotectonic alignment trending nearly North-South (Figs. 1, 8). The Ballino Line is considered to be a continuous element also to the South of Riva del Garda, as its continuation appears to be necessary in order to explain the facies differences between the sedimentary sequences East and West of the Lake (Fig. 1, inset). The whole alignment has been called Ballino-Garda Line by GAETANI (1975) and Ballino-Garda tectonic escarpement by CASTELLARIN (1982). In several modern studies, this prominent feature of the central Southern Alps is associated with crustal extension in the evolving passive southern continental margin of the Alpine Tethys and interpreted as a normal (listric) fault (BOSELLINI 1973; BERNOULLI et al. 1979; BALLY et al. 1981; WINTERER & BOSELLINI 1981; SARTI et al. 1989).

No direct observations exist to establish the geometry of the Jurassic faults in the Ballino zone, due to their exclusive outcrop in the upper sedimentary cover (i.e. in the Jurassic sequence) and to the Neogene structural inversion. Listric geometries of the Jurassic structures are generally assumed by comparison with the examples of western Lombardy (Bernoulli 1964; Bertotti 1990).

3. Zone of the Vies-Trat and Lenzumo Lines

This area is located to the West and South-West of Ballino, and is dominated by prominent thrusts with Norian to Liassic dolomites overriding Jurassic and Cretaceous basinal deposits (Fig. 2). The major M. Cadria-Doss de la Torta and M. Tofino overthrusts are interrupted by a marked E-W trending dextral strike-slip transpressive fault zone (Vies-Trat Line). The Val Croina and Lenzumo overthrusts are possible continuations of the mentioned northern thrusts, sinistrally displaced by some 2.5–3 km along the line during Neogene compression (Cadrobbi 1943; Bonneau 1969; Laubscher 1973; Silla 1973; Spaggiari 1976; Castellarin 1981; Di Bartolomeo 1988; Castellarin et al. 1988).

The area is part of the Lombardian Basin showing stratigraphic successions of Lower to Middle Jurassic cherty limestones and a thick, mainly Upper Jurassic radiolarite interval. However, there are important stratigraphic differences between adjacent

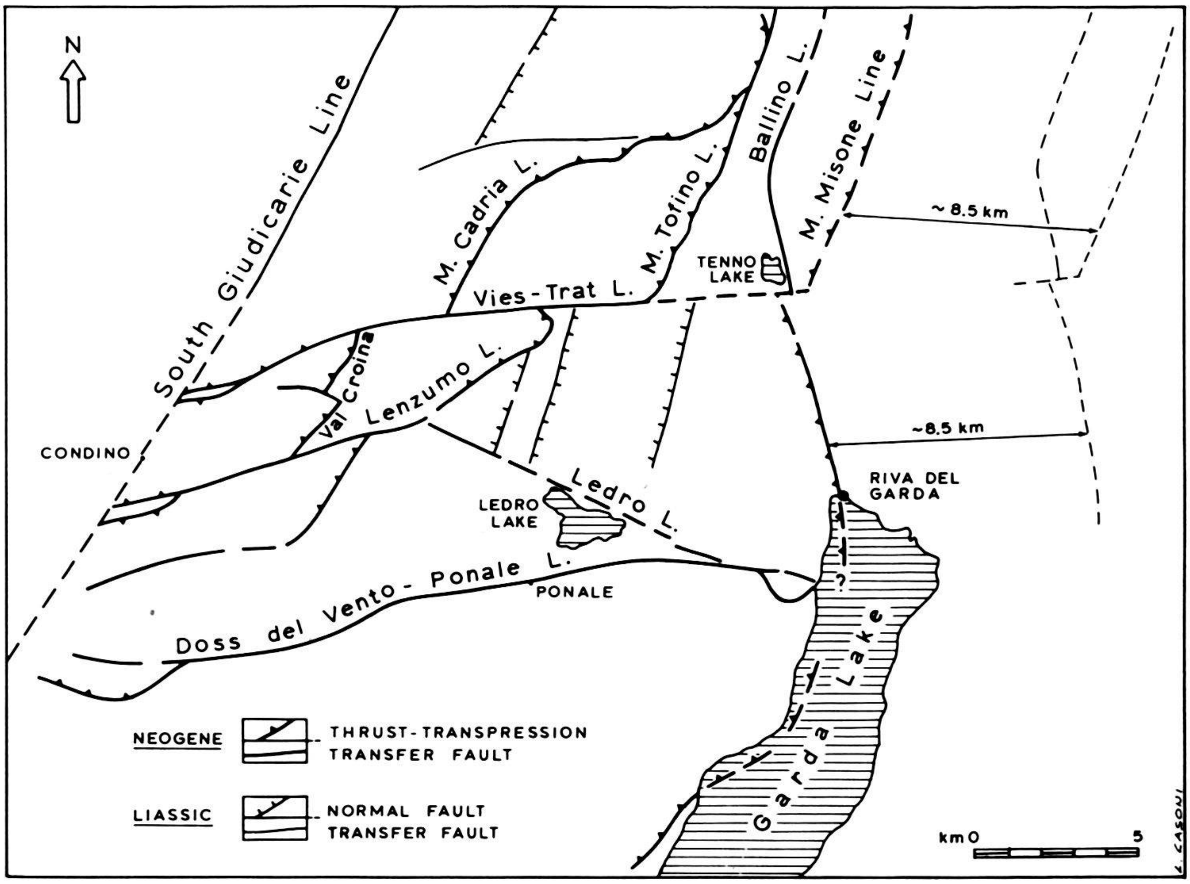

Fig. 2. Simplified tectonic scheme of the area between the Ballino-Garda alignment and the South Giudicarie Line.

tectonic sectors (Fig. 3). The Jurassic succession of the Ballino area, the M. Tofino-Concei overthrust zone and the M. Parì-E block includes thick intercalations of megabreccias and calciturbidites composed of resedimented "Bahamian" calcareous sand and attains a thickness of the order of 1 km. In contrast, in the M. Cadria, M. dei Pini, M. Palone thrust sheets the coeval sequences are reduced (200–400 m) and contain rare or no redeposited coarse calciturbidites at all.

In some areas, located still further West of the Ballino Line and close to the present Southern Giudicarie Line (near Condino), the whole Liassic sequence is no more than 100 m thick. Moreover the M. dei Pini and M. Cadria overthrusted units include up to ten meter thick intervals of Rosso Ammonitico facies (Fig. 3).

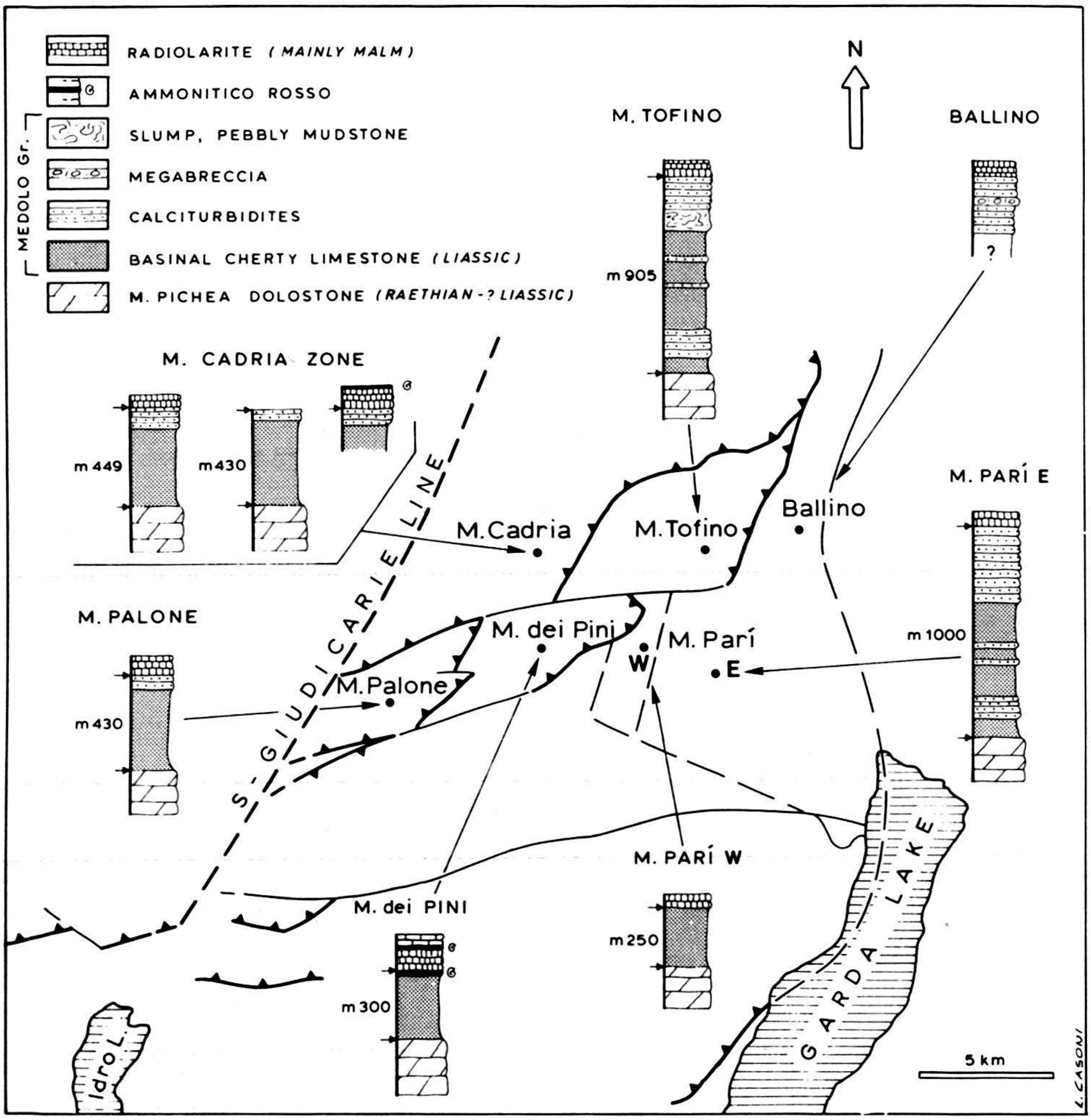

Fig. 3. The Jurassic stratigraphy in the area between the Ballino-Garda alignment and the South Giudicarie Line. Note the marked differences in thickness and lithology between the various tectonic sectors across the Vies-Trat Line. Arrows (in the stratigraphic logs) indicate base and top of basinal syn-rift sediments.

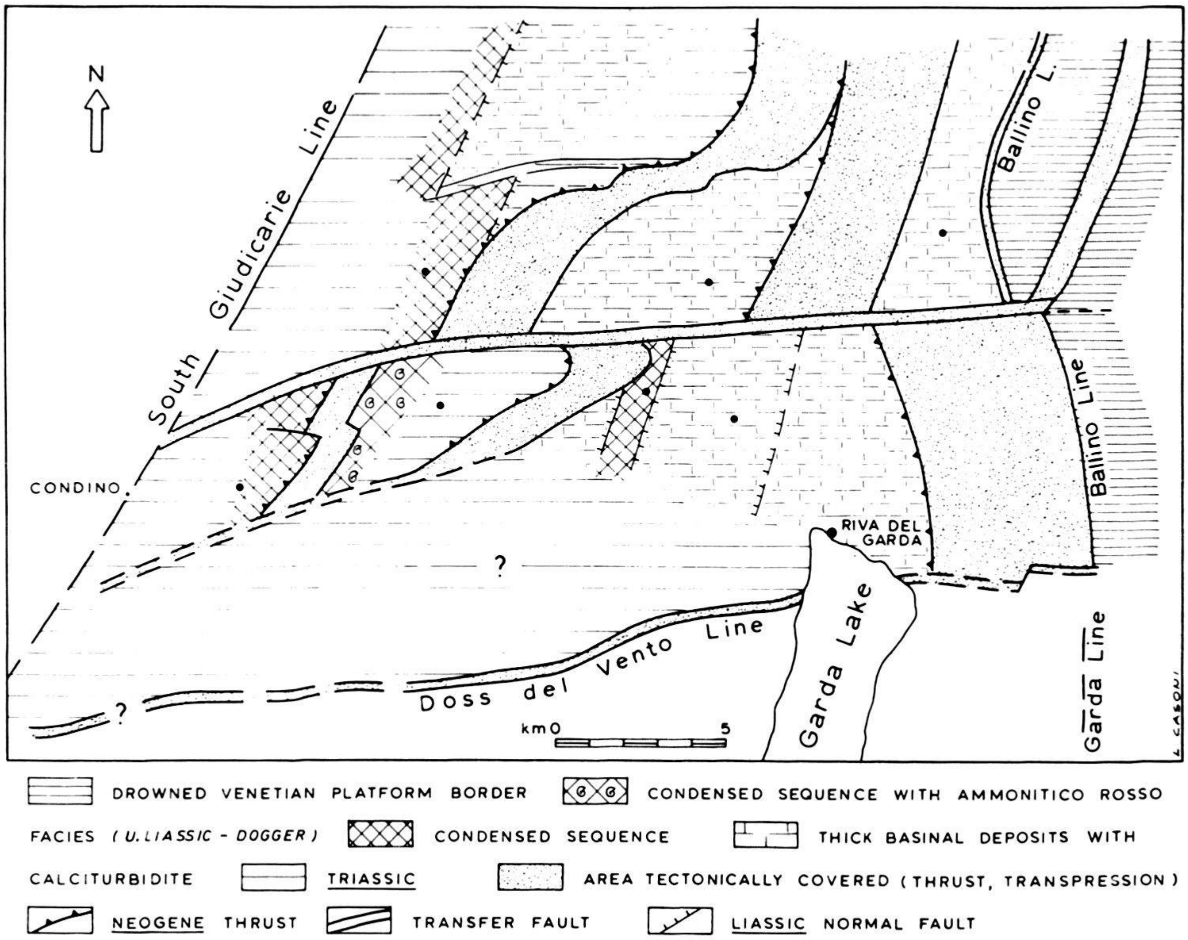

Fig. 4. Palinspastic reconstruction of the Liassic basinal area between the Ballino-Garda lineament and the South Giudicarie Line, obtained from unpublished balanced cross sections by the authors. Points indicate the restored position of the localities of Fig. 3.

There is no correlation of these specific stratigraphic successions across the Vies-Trat Line: the M. Parì-W structural high is unknown opposite of the line and the M. dei Pini Rosso Ammonitico, mainly Aalenian-Bajocian in age, does not continue across the line to the North (Figs. 3–6). Moreover, the depocenters of large basinal areas cannot be correlated. This indicates that the paleotectonic and sedimentary evolution of the area was not only controlled by NNE-SSW faults, but that it was largely dominated by E-W trending ones: the Vies-Trat Line played the role of pronounced E-W discontinuity during Liassic time.

In addition, the area shows other prominent E-W trending Neogene tectonic lines which, like the Vies-Trat Line, most probably also developed from Mesozoic faults, but stratigraphic data are scarce and no sufficient documentation is available due to the erosion of the Jurassic sequence south of the Lenzumo Line. Anyhow, the appearance of the Lower Liassic peritidal limestones (Corna Formation) replacing the Pichea dolostone Formation (Rhaetian-Lowermost Liassic) of the Ballino-Concei zone, closely parallels the southern border of this E-W trending fault system (Vies-Trat, Lenzumo, Doss del Vento-Ponale Lines) (Figs. 2, 4, 5).

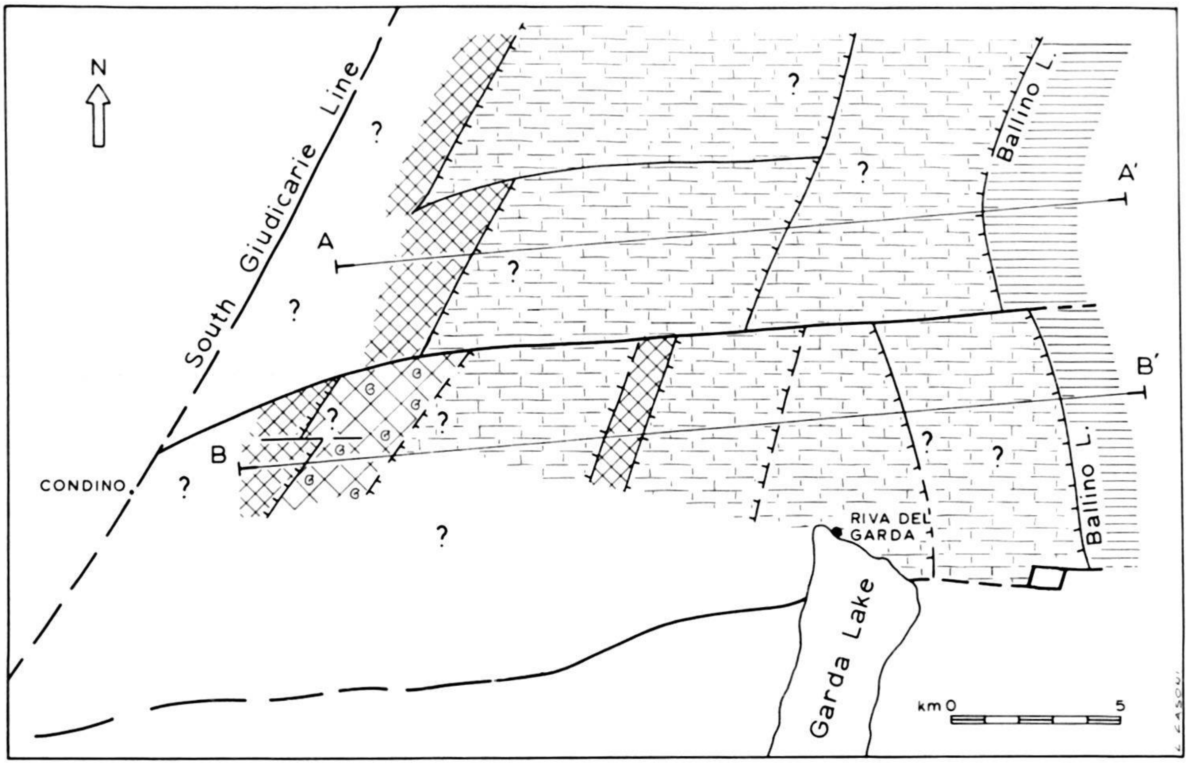

Fig. 5. Interpretative palaeotectonic map of the area between the Ballino-Garda alignment and the South Giudicarie Line for the Liassic (see Fig. 4 also for captions).

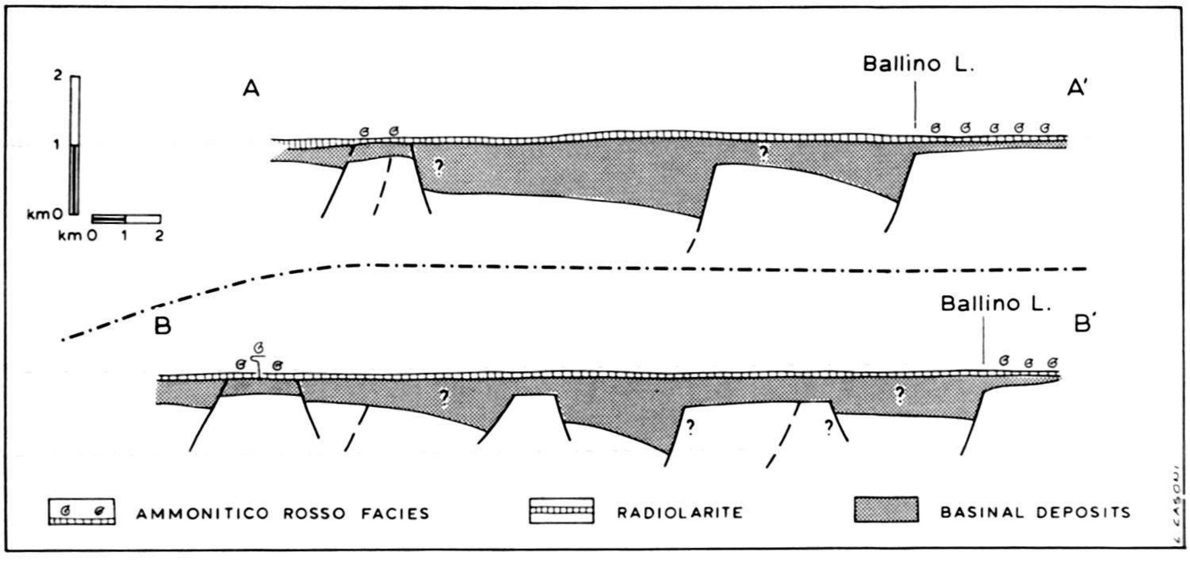

Fig. 6. Interpretative palinspastic cross-sections across the Ballino-Garda Liassic rift zone.

4. The plateau west of Lake Garda

4.1 Northern sector

This area is located between Limone and Salò and extends southwestward to the northern border of the Botticino structural high (Fig. 9). The sequence is dominated by generally thick successions of peritidal limestones of the Corna Formation ranging from a few to several hundred meters in thickness (300–600), and containing Early Liassic dasycladacean assemblages (PICOTTI 1990). The overlying "basinal" Lower to Middle Jurassic successions are mainly made up by cherty micritic pelagic limestones and are, in the Lower to Middle Liassic interval, very poor in calciturbidites of shallow water origin. Oolitic and crinoidal resediments, mostly late Toarcian-Aalenian in age (corresponding to the Oolitico di S. Vigilio Group, according to BARBUJANI et al. 1986) are more frequent and widespread in the uppermost part of the sequence and are derived from the Venetian platform. Megabreccia bodies, including blocks from the Corna Formation, sporadically occur. Exceptions are the thick megabreccia bodies located in Val di Brasa and at Bine, along E-W trending Liassic lines. The thickness of the overlying pelagic sequence is of the order of a few hundred meters and locally strongly reduced to several tens of meters or less (M. Denervo zone, Valle di Campione). Rosso Ammonitico facies are often developed, especially on the top of the most elevated blocks. In particular, Rosso Ammonitico of Pliensbachian age is the most widespread, but the facies also occurs in the Toarcian (M. Denervo), Bajocian (Teglie high zone), Kimmeridgian-Tithonian (M. Denervo zone, T. Toscolano) and in the lowermost Cretaceous (M. Denervo zone, Tignale, PICOTTI 1990). Moreover blocks of Upper Jurassic Rosso Ammonitico are common in the Pregasio or Ballino megabreccias of Early Cretaceous age (CASTELLARIN 1964, 1972), largely widespread in the whole area.

Locally, adjacent to the main, NNE-SSW trending, normal faults, the Liassic pelagic sequence is much thicker. These faults appear to be interrupted and probably transferred by E-W oriented faults.

4.1.1 Campione basin

The Liassic basinal sequence overlies the Corna Formation and consists of medium-bedded micritic cherty limestones; resedimented deposits are represented by decametric massive Corna-like intervals, whose components are both peloidal-intraclastic particles similar to those of the Misone Limestone (CASTELLARIN 1972; see also BECCARELLI BAUCK 1988) and sand from the carbonate platform. Megabreccias with Corna blocks and sporadic isolated olistolithes are present mostly at the base and in the uppermost part of the sequence, whereas thinly bedded calciturbidites are common at its top (M. Cas, Tignale see CASTELLARIN 1964); these latter can be correlated with the Concesio Formation (CASSINIS 1968; BONI & CASSINIS 1973). The thickness of the Campione basinal sequence is over 500 m in the depocenter near the lake and gradually disappears westward (Campiglio), over a distance of about 3.5 km. (PICOTTI 1990) (Fig. 7B).

4.1.2 The Pizzoccolo-Val di Sur basin

The thickness of this basinal sequence attains its maximum value (over 700 m) near Dosso Le Prade-Val di Sur zone (Fig. 7A). The eastern border of the depocenter of this basin is an intrabasinal tectonic fault scarp marked by megabreccias with Corna elements (Dosso Le Prade). The block East of the fault scarp displays peritidal Corna limestone, intensively fractured and with neptunian dikes, reaching several tens of meters depth, and filled with condensed pelagic limestones. To the East, the basin was very probably bounded by an other similar and younger fault scarp, adjacent to which a 300–400 m thick basinal sequence of Late Pliensbachian-Toarcian age was

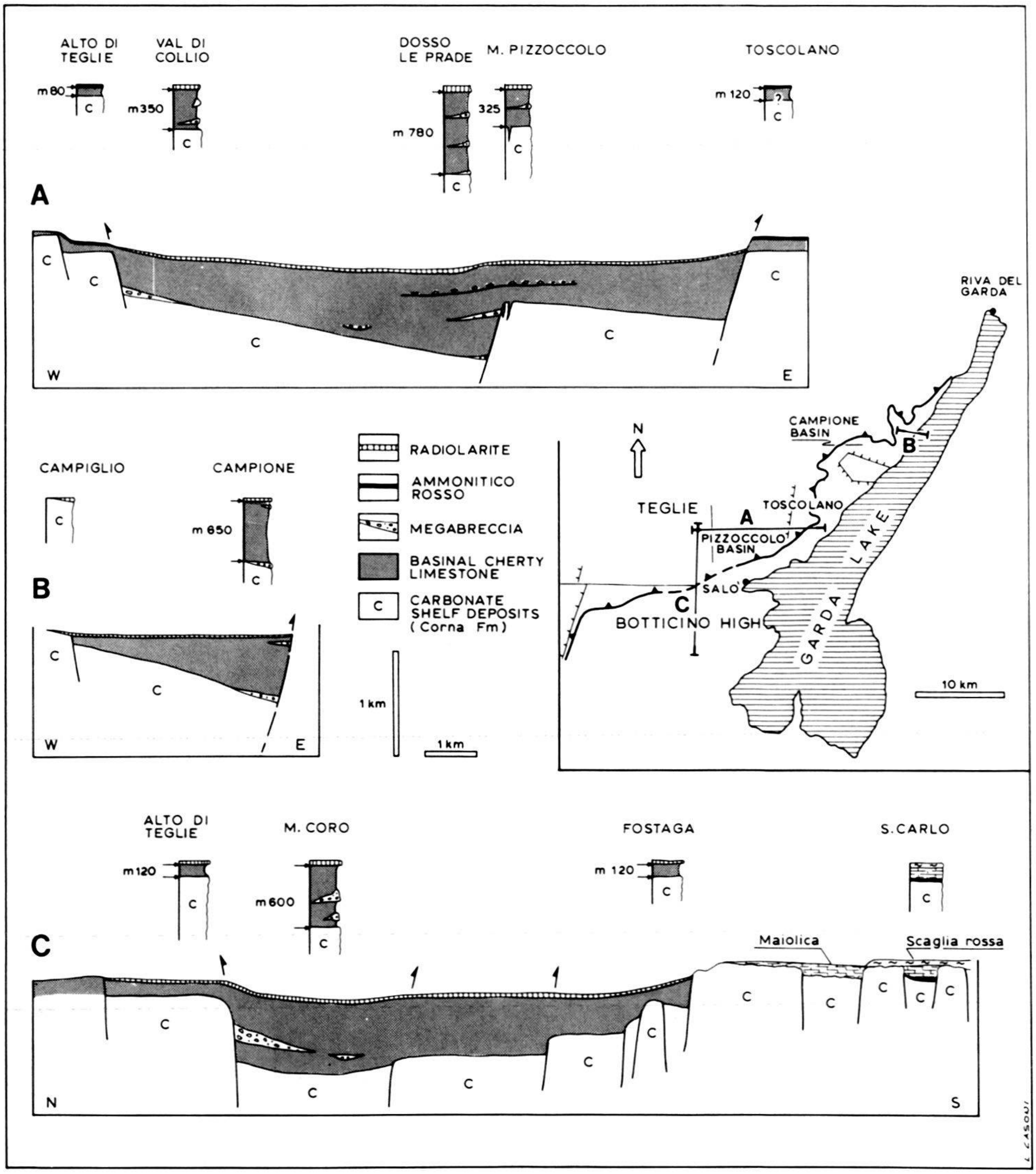

Fig. 7. Geometries and architecture of the Liassic basins West of Lake Garda (from Picotti 1990). Small arrows in the stratigraphic logs indicate base and top of basinal syn-rift sediments. Arrows in the cross sections mark the tectonically inverted structures.
A = M. Pizzoccolo-Val Sur basin (Middle to Late Liassic).
B = Campione basin (?Early, Middle to Late Liassic).
C = Vobarno-M. Coro basinal corridor between the Botticino and Teglie structural highs.

deposited. The western border of the basin is very probably corresponding to the Teglie structural high (Fig. 7A).

In the western part of the basin, the sequence consists of a monotonous succession of thinly bedded cherty limestones with megabreccia bodies and olistoliths (VERCESI & BISSOLATI 1982), presumably derived from the fault scarps bounding the basin to the West. Slumped beds, pebbly mudstones including fragments of the Corso Formation (a condensed facies of the Botticino High) and oolitic and intraclastic calciturbidites occur at different stratigraphic levels (mainly Pliensbachian and Toarcian). The sediments thin westward from the depocenter close to the Pizzoccolo fault scarp, to a minimum of about 100 m or less (Teglie high zone), presently located about 9 km from the depocenter (Dosso Le Prade) (PICOTTI 1990).

4.2 The Botticino High and adjacent basinal areas

Liassic peritidal carbonates (Corna Formation) are widely outcropping in this area with a thickness of some 400 to 500 m. The overlying Liassic pelagic sequences are reduced to intervals of several tens of meters in thickness (up to 100 m) comprising condensed facies similar to the Rosso Ammonitico (Corso Formation, see CASSINIS 1968). These deposits are overlain by thinly bedded cherty limestones with few calciturbidites (Concesio Formation, see CASSINIS 1978), containing ooids derived from the Venetian S. Vigilio Formation. This sequence may be extremely reduced in thickness or totally absent in the eastern part of the Botticino structural high, where the Corna platform limestones are directly overlain by the radiolarites (Selcifero Lombardo Formation) and the Rosso Ammonitico (Upper Jurassic) or by the Maiolica Lombarda Formation (Lower Cretaceous) or finally by the Upper Cretaceous Scaglia Rossa Formation (VERCESI & VISCONTI 1981; CASSINIS & VERCESI 1982) (Fig. 7C).

Thick sequences of cherty limestones, including megabreccias and olistoliths of Corna limestones and calciturbidites with bio- and lithoclastic carbonate sand from the Corna and Calcari Grigi platforms occur close to the northern border of the Botticino High (Vobarno), documenting a pronounced, about E-W trending Liassic fault scarp (CASNEDI 1981). In the depocenter of this basinal corridor, i.e. along the base of the tectonic scarp, the thickness attains its maximum value (about 500 m) (Fig. 7C).

5. Age of Liassic basinal sequences

The onset of basinal deposition to the West of the Ballino-Garda Line occurred during two different time intervals.

In the Ballino-Concei sequence and their northern equivalents, the base of the basinal Jurassic deposits is Early Sinemurian in age or older (?Late Hettangian) as documented in the M. Tofino section (CASTELLARIN 1972). These Lower Liassic sediments are overlain by extended sequences of Middle Liassic and Late Liassic age ranging up to the Aalenian-Bajocian (CASTELLARIN 1972).

South of the Vies-Trat and Ponale fault zones, W of Lake Garda, the peritidal Corna Formation has been dated mainly as Early Liassic (Hettangian-Sinemurian) (CASSINIS & CANTALUPPI 1967; CANTALUPPI & CASSINIS 1970). The basal parts of the overlying pelagic sequence (Corso and Medolo Group) is thus likely to be of Late

Sinemurian-Pliensbachian age, with continued deposition in the Toarcian and Aalenian-Bajocian (see Cassinis 1968, Picotti 1990). The Liassic pelagic sequences thus appear to be more complete and older in the Ballino area. In the southern sector, the pelagic sequences represent a smaller time span. In both areas the sedimentation rates are highest during the Pliensbachian (Picotti 1990).

6. Discussion and conclusive remarks

1) Along the Neogene tectonic alignment Ballino-Garda, a wide belt between the Po plain and the Tonale Line appears to be affected by earlier extension linked to Liassic pre-oceanic rifting, which dissected the future southern continental margin of the western Tethys (Bosellini 1973; Laubscher & Bernoulli 1977; Bernoulli et al. 1979; Bally et al. 1981; Bernoulli & Lemoine 1980; Winterer & Bosellini 1981; Sarti et al. 1989).

The Liassic architecture of this belt is determined by normal master faults (very probably listric and/or domino system) which today trend N-S and NNE-SSW and by nearly E-W fault systems, some of which are in part extensional and which can be seen as the kinematic links (transfer faults) between the different segments of the major system of normal faults (Fig. 8). Listric faults of similar age have been documented, in the Southern Alps, in Ticino (Bernoulli 1964). These faults can be traced downwards into the cristalline basement (Bally et al. 1981), where they flatten with depth and pass into early Mesozoic mylonite zones (Bertotti 1990).

As previously seen, the Jurassic basin development is essentially controlled by rifting, producing fault bounded sedimentary prisms. The main Jurassic global sea level changes (Haq et al. 1987; Vail 1987) are better recognizable in the platform (see Barbujani et al. 1986) and in the marginal areas of sedimentary basins (see Coe et al. 1989). In the examined zone, the Late Toarcian event is the most intense and widespread, appearing largely independent and superimposed to the basin architecture.

2) During the Liassic, the extensional movements prograded from W to E as indicated by the age of drowning of the peritidal carbonate platform along this part of the margin (Fig. 8): Early Liassic (?Hettangian-Early Sinemurian) in the northern and western part of the belt (Ballino-Gruppo di Brenta and Sebino-Val Trompia area); mainly Middle Liassic (Pliensbachian) from Lake Garda to Botticino (Brescia); mostly Late Liassic in the easternmost part of the belt, when the western border of the Venetian platform was incorporated into the Lombardian basin: in this region this last event marks the widest eastward backstep progradation of the Liassic rifting.

However, the onset of extensional tectonics does not necessarily lead to the drowning of the platforms (i.e. deepening upward sequences), as described at point 5.

3) North of Riva del Garda, the Ballino Line is the principal divide between the Lombardian Basin and the Venetian platform. The stratigraphic equivalents of the Ballino-Tofino sequences are documented only in the northern sector, i.e. in the Brenta Group (Val Laone, Val d'Algone, Castello dei Camosci, Cima Forcolotta, I Marugini), extending northward to the Folgarida zone (M. Spolverin), close to the Tonale Line.

South of Riva del Garda the Ballino Line must continue; however, it changes its palaeogeographic and palaeotectonic significance: West of Lake Garda, the Corna Formation forms a very thick carbonate platform sequence of mainly Hettangian to

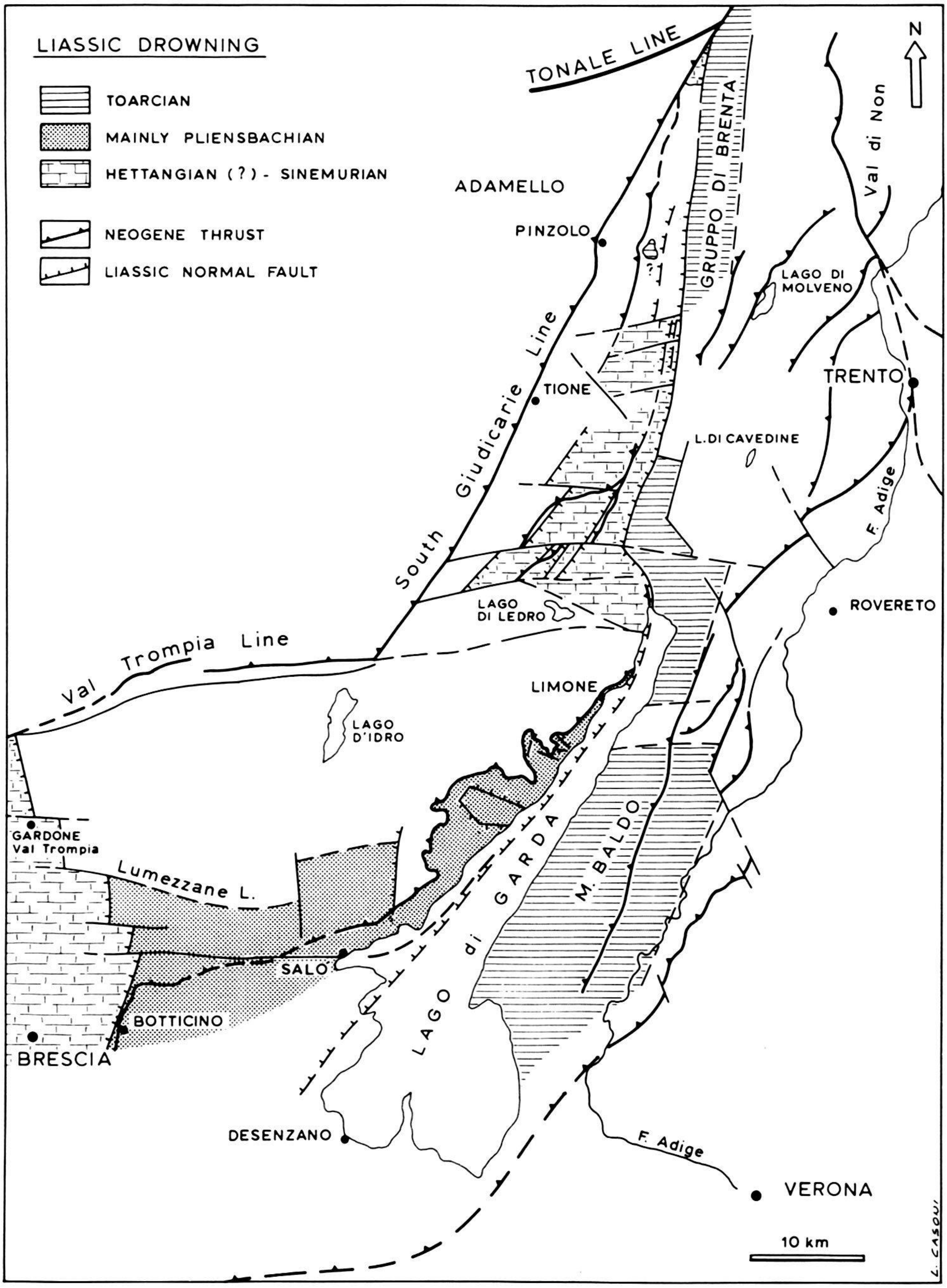

Fig. 8. Scheme of Liassic rifting in the S-Giudicarie and Val Trompia structural belt between the Tonale Line and the Po Plain, showing also the timing of the platform drowning.

Early-Middle Sinemurian age, with a maximum thickness of 600 m close to the presumed prolongation of the Ballino fault scarp. It apparently replaces the Pichea Dolomite of the northern sector. The Corna Formation seems also to be the western counterpart of the Venetian Calcari Grigi Formation, lower member (Bosellini & Broglio Loriga 1971), whose average thickness is much smaller attaining only about 200 m or even less. Liassic block-faulting along the Ballino-Garda Line can explain this thickness difference. Probably the fault separated two shallow water areas with different subsidence rates: to the West, in the future basinal area, the sedimentation rate was at least twice as much than in the adjacent Venetian sector, thus following the previous Late Triassic trend (Picotti & Pini 1988; Picotti 1990). Moreover along this possibly listric fault the displacement obviously was gradual and slow, thus maintaining similar bathymetric and environmental conditions in the two sectors (Fig. 9).

4) The subsequent post-Early Sinemurian history of the Ballino-Garda fault scarp in the southern sector is dominated by the disintegration of the previous Lower Liassic carbonate tidal flat into two different facies domains. Rapid sinking affected the Lombardian side with foundering of the Corna carbonate shelf below the photic zone. In contrast, in the eastern Venetian side, the previous carbonate platform persisted up to the earliest Toarcian. The resulting Jurassic palaeotectonic and palaeogeographic setting of the area West of the Ballino-Garda Line corresponds to a more or less stable sunken Corna plateau, gradually onlapped by stratigraphically reduced and condensed pelagic sequences, with a few zones in which higher subsidence rates resulted in the formation of morphological basins (Campione and Pizzoccolo basins, Botticino northern basinal corridor).

5) The Lower to Middle Liassic sedimentary prisms of the Ballino-Tofino area and of the northern sector linked to the major system of NNE-SSW and N-S striking listric faults and of E-W trending transfer faults, have no exact equivalents to the South of Riva del Garda (Fig. 8). Basinal sedimentary sequences starting with thick intervals of similar age (?Hettangian-Early Sinemurian) are located far to the West of the Ballino-

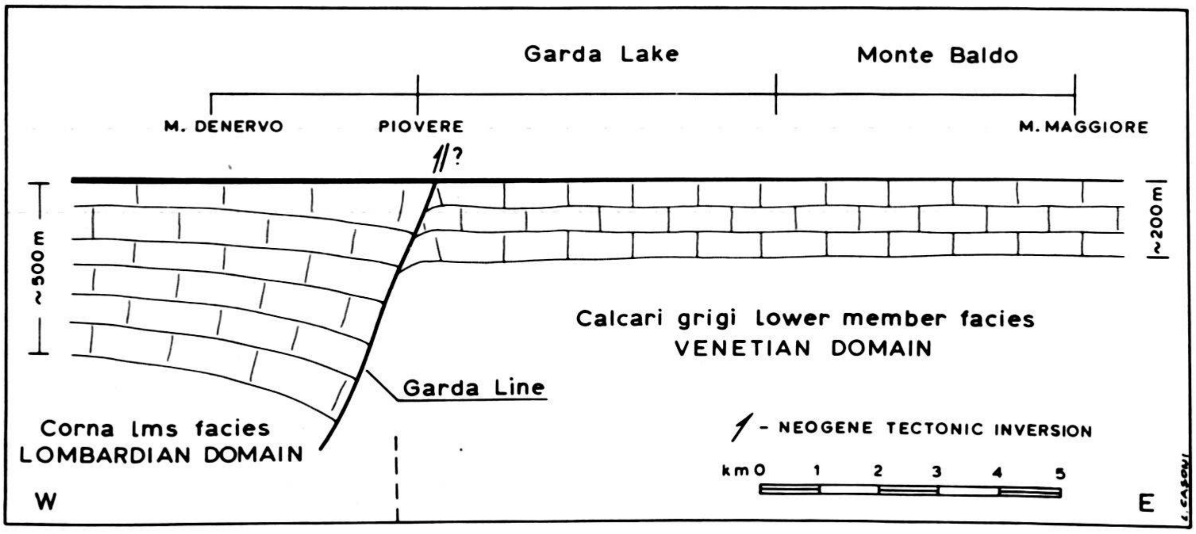

Fig. 9. Scheme showing the hypothetic Lower Liassic tidal flat West of Lake Garda. The arrow indicates Neogene tectonic inversion.

Tofino zone in the Sebino-Val Trompia area and, to the South, at M. Maddalena (vicinity of Brescia). Here very probably Upper Hettangian and well dated Lower Sinemurian (M. Isola, VECCHIA 1946) thick cherty limestones sequences are present: they are followed up-section by Pliensbachian and Toarcian well developed intervals made up by cherty limestones with calciturbidites. The whole sequence attains over 1.5 km in thickness forming a continuous belt from N to S, however repeatedly dissected by E-W trending discontinuities. This belt can be interpreted as a Liassic basinal area created by listric faults along the western border of the Corna platform; moreover the E-W trending discontinuities may be seen as transfer faults, some of which were pronounced morphological scarps (e.g. the western prolongation of N Botticino fault, the Lumezzane fault) (Fig. 8).

Thus, in terms of chronology, thickness of basinal deposits and areal extension of the syntectonic sedimentary prisms, this belt can be compared with the Ballino-Tofino area. If this comparison is correct, the Sebino and Val Trompia Lower Liassic sequence was, during rifting, probably kinematically linked to the Ballino-Tofino area by an East-West transfer zone with the classical fault geometry of continental rift zones (LIGGETT & EHRENSPECK 1974; BALLY 1983; GIBBS 1984 and further references, e.g. in COWARD et al. 1987).

As previously seen the Ballino-Tofino basinal area is separated in the South from the carbonate platform domain of the Corna Formation by a pronounced East-West trending fault system (Figs. 2, 4, 5, 6, 8), i.e. the Vies-Trat system, which must be Liassic in age or older and which was reactivated in the Neogene. This E-W-trending fault zone possibly continued to the West in the area of the Val Trompia Line, a lineament which was active already in the Permian (CASSINIS 1983). However, the Upper Triassic and Jurassic sequence has been largely eroded in this area, and we therefore cannot prove this assumption.

The postulated E-W-trending fault system reaching the Sebino-Val Trompia area may be seen as the kinematic connection to the Ballino-Tofino zone and may correspond to the East-West transfer fault system, required to link the two corresponding segments of the Liassic basinal belt in the studied area (Fig. 8).

This interpretation is difficult to be ascertained because of the lack of stratigraphic and structural continuity, mainly due to erosion. Moreover the studied area shows a complicated Alpine tectonic structure and many geological relationships are buried below folds and thrusts. Moreover, the whole tectonic system is largely detached from the crystalline basement and its older sedimentary cover by the strong Neogene compressional movements. Nevertheless the previous stratigraphic relationships between different sedimentary domains and among the differently displaced blocks were not completely obliterated and many pieces of the Jurassic mosaic maintained their original mutual relationship.

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