Eclogae geol. Helv. 88/3: 827–852 (1995)

0012-9402/95/030827-25 $1.50 + 0.20/0
Birkhäuser Verlag, Basel

The Kalkschieferzone (Upper Meride Limestone; Ladinian) near Meride (Canton Ticino, Southern Switzerland) and the evolution of a Middle Triassic intraplatform basin

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Key words: Kalkschieferzone, Middle Triassic, Monte San Giorgio, Southern Alps, intraplatform basin, vertebrates, invertebrates, plants

ABSTRACT

The Kalkschieferzone (uppermost Meride Limestone; Late Ladinian) in the area of Monte San Giorgio near Meride (Canton Ticino, Switzerland) and Ca' del Frate (Varese, Italy) is known for its excellent preservation of numerous small actinopterygian fishes and rare aquatic reptiles. During small-scale excavations in the Gaggiolo valley near Meride, some actinopterygians, crustaceans and plants have been recovered in the middle Kalkschieferzone. Preliminary studies suggest a seasonally controlled sedimentation in a shallow basin or lagoon with fresh-water influence in the wet season. A high productivity in the surface water and stable density stratification resulted in anoxic bottom water with accumulation of organic matter. Carbonate laminae were deposited under increased salinity in the dry season. Mud-cracked stromatolites and halite crystal casts indicate the presence of evaporitic conditions. The Kalkschieferzone represents a late stage evolution of an intraplatform basin, beginning with open marine influence in Late Anisian time (Grenzbitumenzone) and increasing restriction by growing carbonate platforms during Early Ladinian (Lower Meride Limestone). In Late Ladinian time, the basin was filled progressively by carbonate and siliciclastic mud (Upper Meride Limestone). The shallow lagoon of the Kalkschieferzone with strong seasonal variation of salinity and water level finely was buried by an increasing input of fine siliciclastic material, reaching its maximum with the locally evaporitic Pizzella Marls (Raibl Beds) in the Carnian.

ZUSAMMENFASSUNG

Die Kalkschieferzone (oberste Meride-Kalke; spätes Ladinian) im Gebiet des Monte San Giorgio bei Meride (Kanton Tessin) und Ca' del Frate (Varese, Italien) ist durch die Funde von ausgezeichnet erhaltenen kleinen Knochenfischen und 3 Exemplaren des aquatischen Reptils *Lariosaurus* bekannt geworden. Kleinere Grabungen in der mittleren Kalkschieferzone im Tal des Gaggiolo-Bachs bei Meride im Herbst 1994 haben horizontiertes Fossilmaterial, hauptsächlich kleine Knochenfische, Crustaceen und Pflanzenreste geliefert. Nach taphonomischen Untersuchungen wird zumindest die mittlere Kalkschieferzone als saisonal geprägte Ablagerung eines abgeschlossenen seichten Beckens oder Lagune mit wechselndem Süsswassereinfluss und Austrocknung interpretiert. Während der Regenzeit konnte sich im nähr- und sauerstoffreichen Oberflächenwasser Plankton und der auf solche Nahrung spezialisierte Schwarmfisch *Prohalecites* optimal entwickeln. Dank stabiler Wasserschichtung reicherte sich im salzreicheren, schwereren Bodenwasser unter lebensfeindlichen anoxischen Bedingungen organisches Material an. In der Trockenzeit mit starker Verdunstung wurden bei steigendem Salzgehalt vermehrt Karbonat abgelagert und weite Schlammflächen trockengelegt. Diese Interpretation stützt sich hauptsächlich auf das Vorkommen stromatolithischer Laminae mit Austrocknungserscheinungen, wie sie für heutige Mikrobenmatten im höheren Intertidal und Supratidal von abgeschlossenen Lagunen, hypersalinen

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Tümpeln oder Sabkhas typisch sind. Abdrücke von Steinsalzkristallen und Pseudomorphosen nach deformierten Anhydritlagen dokumentieren evaporitische Bedingungen. Schichtweise massenhaft vorkommende Estherien (Conchostraca, Crustaceen) werden als autochthone Populationen angesehen, die sich nach aussergewöhnlichen Niederschlägen innert weniger Wochen im ausgesüssten Randbereich des Beckens aus eingeschwemmten Eiern entwickeln konnten, bei steigender Salinität und Abnahme des Sauerstoffgehalts in der Trockenzeit aber wieder abstarben. Die Kalkschieferzone bildet den Abschluss in der Entwicklung eines Intraplattform-Beckens, das nach anfänglich offenmarinem Einfluss im späten Anisian (Grenzbitumenzone), im frühen Ladinian immer mehr vom Ozean abgeschnitten wurde (Untere Meride-Kalke). Im späten Ladinian wurde das Becken allmählich mit Karbonat und Ton aufgefüllt (Obere Meride-Kalke). Das seichte Becken oder die Lagune der Kalkschieferzone mit starken saisonalen Schwankungen des Salzgehalts und Wasserspiegels wurde schliesslich im Carnian durch massive siliziklastische Schüttungen eingedeckt und endete als Sabkha der gipsführenden Pizzella-Mergel (Raibl-Schichten).

RIASSUNTO

La Kalkschieferzone (Calcare Superiore di Meride; Tardo-Ladinico) nella regione del Monte San Giorgio (Canton Ticino, Svizzera) e Ca' del Frate (Varese, Italia) è conosciuta per l'eccellente stato di conservazione dei ritrovamenti fossili di numerosi piccoli pesci ossei e di tre esemplari del rettile acquatico *Lariosaurus*. Nell' autunno 1994, durante una campagna di scavi nella Valle del Gaggiolo nei pressi di Meride, sono stati portati alla luce nella Kalkschieferzone media alcuni esemplari di piccoli pesci ossei, crostacei e resti vegetali. Studi tafonomici suggeriscono una sedimentazione controllata dal clima in un bacino o una grande laguna con afflusso di acqua dolce durante la stagione umida. Nelle acque di superficie ricche di nutrimento e ossigeno, potevano svilupparsi organismi planctonici e il pesce *Prohalecites* si diffondeva in condizioni ottimali. La deposizione di materiale organico nelle acque anossiche del fondale è il risultato di un'alta produttività e della stabile stratificazione delle acque. Nella stagione secca l'alto tasso di evaporazione aumentava la salinità favorendo la precipitazione di sedimenti carbonatici e il prosciugamento di piane fangose. Questa interpretazione si basa soprattutto sulla presenza di lamine stromatolitiche simili agli attuali tappeti microbici essicati, tipici della zona intertidale superiore e sopratidale di lagune isolate, pozze ipersaline e sabkha. Impronte di cristalli di salgemma documentano condizioni evaporitiche. La densa popolazione di esterie (Conchostraca, Crustacea) viene interpretata come autoctona: dopo abbondanti piogge, grazie all'afflusso di acqua dolce nel bacino, poteva svilupparsi in poche settimane dalle uova trasportate dalle alluvioni. La popolazione moriva con l'aumento della salinità e la diminiuzione dell'ossigeno nei periodi secchi. La Kalkschieferzone rappresenta l'ultimo stadio nell'evoluzione di un bacino di piattaforma, iniziato in condizioni di influenza di mare aperto nel Tardo-Anisico (Grenzbitumenzone/Strati bituminosi di Besano), via via sempre più isolato dagli inizi del Ladinico (Calcare Inferiore di Meride). Nel Tardo-Ladinico, il bacino era progressivamente riempito da depositi carbonatici e fanghi (Calcare Superiore di Meride). Il bacino o laguna della Kalkschieferzone, con forti variazioni stagionali di salinità e del livello delle acque, terminava poi la sua esistenza nel Carnico, quando veniva riempito e sepolto da materiale siliciclastico (Marna del Pizzella) e condizioni di sabkha andavano localmente instaurandosi.

1. Introduction

The Monte San Giorgio area near the village of Meride in Canton Ticino and the adjoining region on Italian territory near Besano (Fig. 1) is known for one of the World's richest fauna of Middle Triassic marine vertebrates (Rieber & Sorbini 1983, Bürgin et al. 1989, Pinna & Teruzzi 1991). Paleontological studies were started in the middle of the 19th century by Italian scientists (Stoppani 1857, Bassani 1886) and were continued on Swiss territory since 1919 under the direction of the paleontologists B. Peyer and E. Kuhn-Schnyder from the University of Zürich (for a review see Kuhn-Schnyder 1974). The famous vertebrate fauna was collected mainly from the Grenzbitumenzone, but also from four younger calcareous beds in the Meride Limestone: Cava inferiore beds, Cava superiore beds, Cassina beds and Kalkschieferzone (Peyer 1931, Kuhn-Schnyder 1974, Sander 1989a, Rieppel 1993).

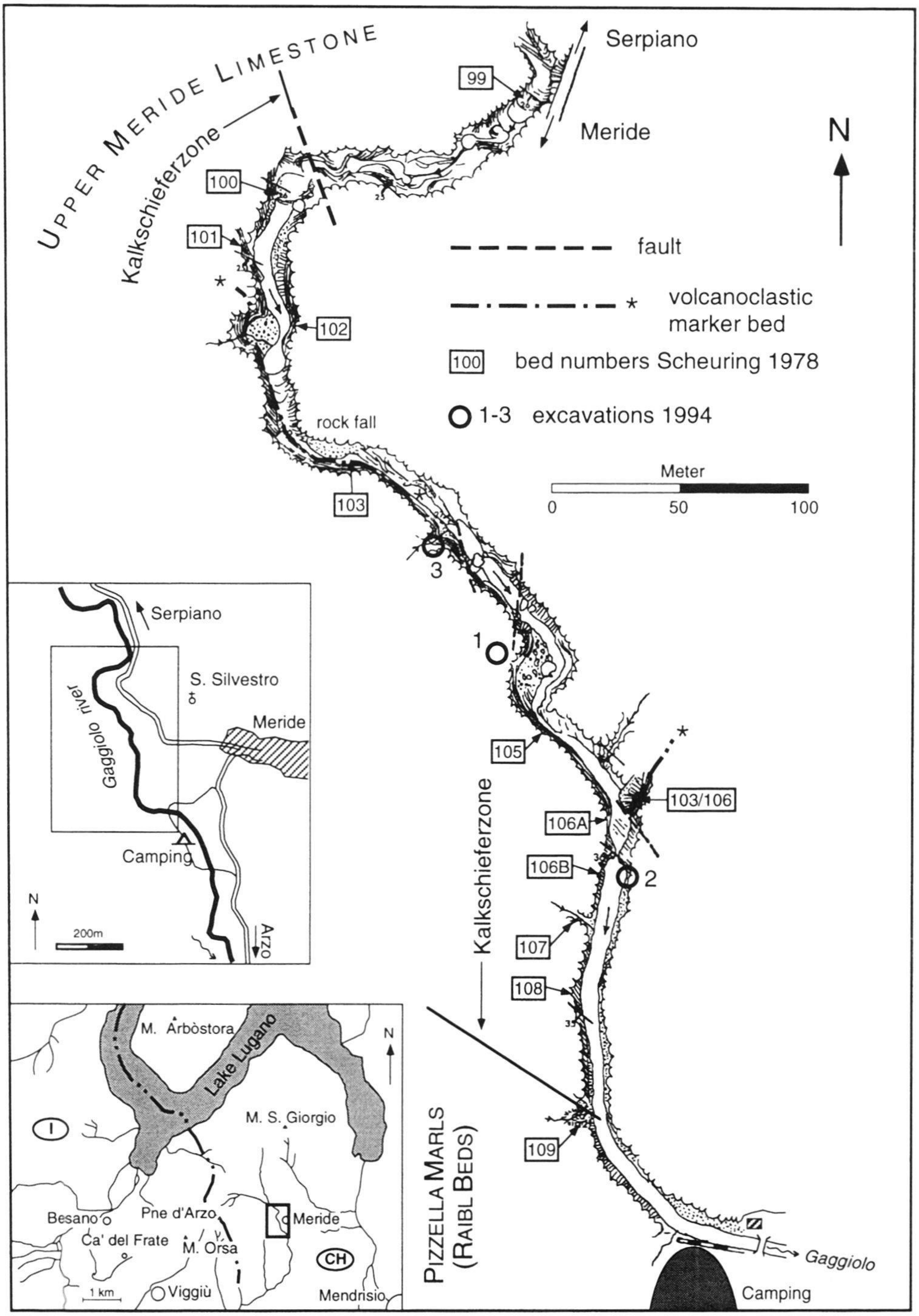


Fig. 1. Map of the Gaggiolo valley near Meride, modified after Scheuring (1978).

Diversity is highest in the Grenzbitumenzone (Fig. 2) with 71 species: 16 reptiles, 3 crossopterygians, 47 actinopterygians, many of them not yet described, and 5 chondrichthyans. The Cava inferiore beds yield 18 species: 16 actinopterygians and only 2 species of the sauropterygian reptiles *Ceresiosaurus* and *Neusticosaurus,* who are also the only reptiles from the Cava superiore beds. 4 reptiles *(Ceresiosaurus calcagnii, Pachypleurosaurus edwardsii, Tanystropheus meridensis* and *Macrocnemus bassanii)* and only 2 actinopterygians have been identified from the Cassina beds.

From the Kalkschieferzone, the youngest vertebrate beds at Monte San Giorgio and the adjoining Italian territory, 2 reptiles and 8 actinopterygians are reported. Two new species of *Lariosaurus, L. lavizzarii* KUHN-SCHNYDER 1987 from the section near Meride and *L. valceresii* TINTORI & RENESTO 1990 from the locality Ca' del Frate near Varese have been described on the base of single specimens (see p. 833). The locality Ca' del Frate has been known since the end of last century, when several fishes were found in a neighbouring small quarry (Tintori 1990a&b). However, the fossils have been erronously considered to be from the same level as the Grenzbitumenzone (Repossi 1909, De Alessandri 1910, Brough 1939, Patterson 1981). Between 1984 and 1990 volunteers from the Museo di Induno Olona explored in collaboration with the University of Milano a fossil-rich horizon of the lower Kalkschieferzone in the neighbourhood of Ca' del Frate. They found two specimens of *Lariosaurus,* about 1700 actinopterygians and many small crustaceans (Tintori & Renesto 1983 & 1990; Tintori et al. 1985; Tintori 1990a & b, 1991 & 1992). However, a detailed lithologic section and a faunal list have not yet been published. A monographic description of the Ca' del Frate fauna is in preparation (A. Tintori, personal communication).

Major parts of the fossil material from the Middle Triassic of Monte San Giorgio in the collection of the Paleontological Museum of the University of Zürich (PIMUZ) have been collected from individual beds and are well documented. 5000 specimens of vertebrate fossils (from complete or fragmented skeletons to disarticulated bones and teeth) and about 1000 invertebrates are registered. Despite numerous studies, only half of the vertebrate fossils have been identified adequately. A catalogue of the published material, open to public at PIMUZ, is in preparation. Most authors also discussed the biostratinomy and palecology (Rieber 1973a, Kuhn-Schnyder 1974, Wild 1974, Sander 1989a, Rieppel 1993) but no complete taphonomical study has been published.

Based on the compiled field data, a taphonomic study on the material from the older excavations, stored in the collection of the PIMUZ is planned. In addition some small excavations are organized in collaboration with the Museo Cantonale di Storia Naturale di Lugano. The first one started 1994 in the Kalkschieferzone in the valley of the river Gaggiolo West of Meride. Detailed sections of 1 to 2 m thickness have been studied at three localities. Aim of the study was to obtain more information about the diversity and taphonomy of the fossils in the Kalkschieferzone. Detailed studies on the stratigraphy, sedimentology, diagenesis and geochemistry are the topics of an ongoing diploma thesis by D. Bionda, in collaboration with the Geological Institute of the ETH Zürich.

The new collected material is deposited at the Museo Cantonale di Storia Naturale di Lugano (abbreviation MCSN), the other at the Paleontological Institute and Museum of the University of Zürich (abbreviation PIMUZ).

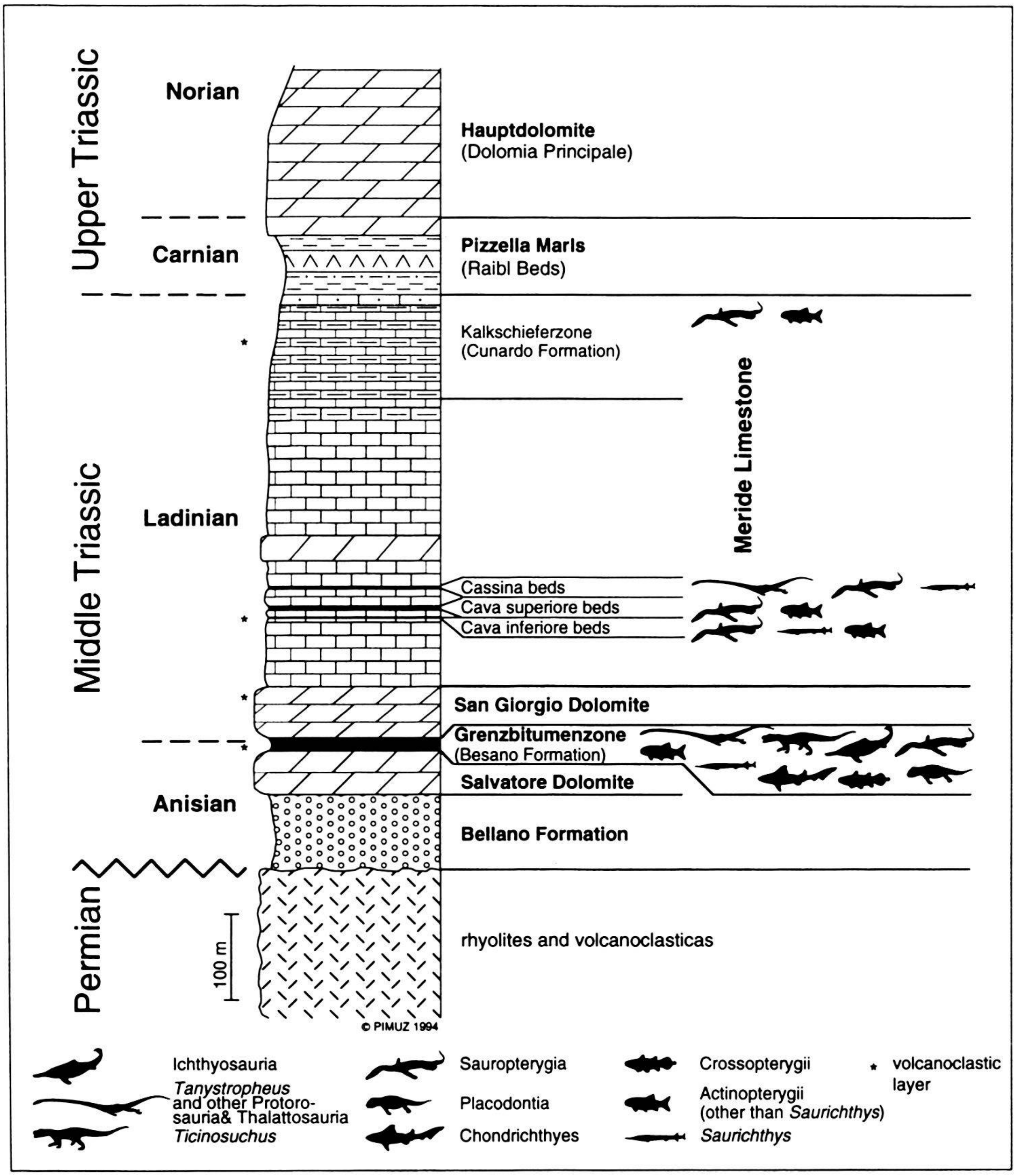


Fig. 2. Stratigraphy of the Triassic sediments in the area of Monte San Giorgio (Canton Ticino) with special reference to the vertebrate beds, studied since 1919 by paleontologists of the University of Zürich.

2. Geology and stratigraphy

The Monte San Giorgio area is part of the Southern Alps, a S-vergent fold and thrust belt. The regional geology and stratigraphy in South Ticino has been described by Frauenfelder (1916), Senn (1924), Wirz (1945), Kuhn-Schnyder & Vonderschmitt (1954) and Bernoulli (1964). The basement consists mainly of gneisses and phyllites. The oldest unmetamorphic sediments are lenses of conglomerates and sandstones of Late Carboniferous (Westphalian) age (Manno Conglomerate) which are exposed northwest and northeast of Lugano. These are followed by a complex of Permian lavas and pyroclastic rocks of andesitic to rhyolitic composition (Fig. 2). Overlying the Permian volcanics are red sandstones, conglomerates and shales of the Bellano Formation. The age of these alluvial sediments is not known. Dolomitic sandstones with scarce bivalves and the transition to sandy dolomites at the base of the Salvatore Dolomite suggest a progressive transgression of a shallow epicontinental sea from the east towards the west. With this Late Anisian transgression, carbonate platforms began to grow and shallow-water carbonate sedimentation with frequent bioclasts of dasycladacean algae, gastropods and bivalves became dominant throughout the Lombardian Alps. Tectonic activity associated with extensive volcanism during the latest Anisian and Ladinian led to the formation of several basins separated by carbonate platforms. In the Lugano region, shallow-water platform sedimentation continued unchanged in the north and west (Monte San Salvatore and Monte Caslano), where the Middle and Upper Salvatore Dolomites were deposited. In the south (Monte San Giorgio – Besano – Pogliana), a basin with restricted circulation and anoxic to disaerobic bottom waters developed in the latest Anisian. The 15–16 m thick sequence of interbedded, finely laminated organic matter-rich dolomites and black shales of the Grenzbitumenzone (Besano Formation) were deposited under permanently anoxic conditions during 2 to 5 Million years (Bernasconi & Riva 1993, Bernasconi 1994). The high supply of organic matter and the anoxic bottom water could explain the extraordinary preservation; the low sedimentation rate of 1 to 5 mm per thousand years the accumulation of vertebrate skeletons. After Brack & Rieber (1986, 1993) the Anisian-Ladinian boundary lies in the upper beds of the Grenzbitumenzone. The 60 m thick San Giorgio Dolomite and the 400 to 600 m thick Meride Limestone were deposited in the same basin, with an E-W extension estimated to have been about 20 km, including the time equivalent Perledo-Varenna subbasin, bordering the Esino carbonate platform East of Lake Como (Gaetani et al. 1992, Bernasconi 1994).

During the latest Ladinian the basins were filled by thinbedded to laminated limestones and marls of the 120 m thick Kalkschieferzone. This informal lithologic unit, introduced by Senn (1924) and described in detail by Wirz (1945), was supposed to be of Carnian age as no index fossil had been found. Scheuring (1978) proved that the Kalkschieferzone and even the lowermost layers of the Raibl Beds yield palynomorphs of the Langobardian stage, comparable to the Keuper facies in Northern Switzerland, and that the Ladinian-Carnian boundary must lie in the lowermost Raibl Beds. Similar lithologies in Western Lombardy have been named Cunardo Formation. An abundant input of clastic material, probably derived from the erosion of a Southern Mobile Belt (Brusca et al. 1981), with local deposition of evaporites, characterized the Pizzella Marls or Raibl Beds. This Carnian phase of high detrital input corresponds to a major regressive phase which caused the emersion of the Esino Platform to the East and can be observed across the entire Southern Alps (Jadoul & Rossi 1982).

3. The Kalkschieferzone section near Meride

The term Kalkschieferzone was introduced by Senn (1924) for the uppermost part of the Meride Limestone sensu Frauenfelder (1916). Wirz (1945) published a detailed description of the best section in the so called "Val Mara", an unusual name for the valley of the river Gaggiolo, some 300 m west of Meride (Fig. 1). From the base of the waterfall northwest of Meride, formed by typical Meride Limestone s. str., a discontinuous section of the Kalkschieferzone is exposed mainly on the Western side of the river, down to the old mill, now used as reception of the small camping place southwest of Meride. The base of the Pizzella Marls or Raibl Beds is drawn with the onsetting of thick marls, 80 m northwest of the old mill house. Beneath the swimmig pool of the camping, a natural looking pond is the relic of an old gypsum pit in the lower Raibl Beds.

Wirz (1945, p. 19–20) noticed some fish remains, coprolites, estherid conchostracans, ostracods, foraminifers and plant fossils in the section, included in the columnar section measured by D. Bionda in 1994 (Fig. 3). Wirz also described many volcanoclastic layers, sedimentological and diagenetic structures, based on numerous samples and thin sections deposited in the collection of the PIMUZ. In 1971 U. Oberli, a member of the PIMUZ team excavating the Cassina beds north of Meride, discovered in the middle part of the Kalkschiefer section a small reptile, some actinopterygian fishes and conchostracan crustaceans. A lithologic section at the locality had been measured by R. Wild (unpublished data). The reptile was described by Kuhn-Schnyder (1987) as a new species *Lariosaurus lavizzarii,* the largest fish as *Perleidus* sp. by Bürgin (1992, Fig. 59). The validity of *L. lavizzarii* as taxon was criticized by Tschanz (1989). According to him, the juvenile specimen lacks specific characters and those used by Kuhn-Schnyder (1987) fall into ontogenetic variation, a view accepted by Tintori & Renesto (1990) when describing another new species *(L. valceresii)* on the base of a single specimen from the locality Ca' del Frate. When describing a second specimen from the locality Ca' del Frate as a juvenile *Lariosaurus* sp., Renesto (1993) even discussed if *L. valceresii* could be the other sex of *L. balsami,* known from the type locality in the higher part of the Ladinian Perledo-Varenna Limestone near Perledo (Curioni 1847, Peyer 1934).

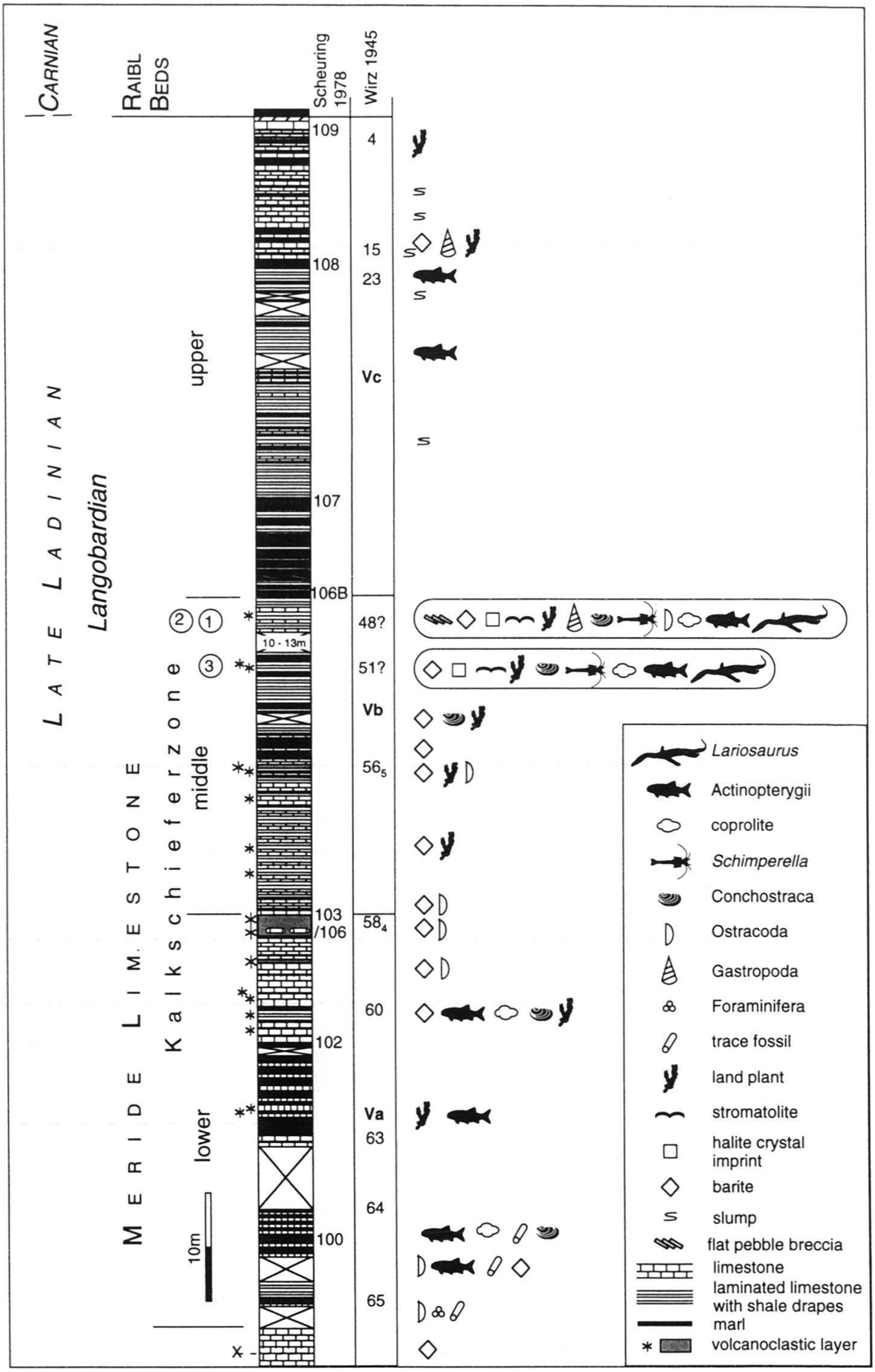
Scheuring (1978, Textfig. 1) studied the microflora and documented first some faults in a detailed sketch and columnar section. He showed that the thickest volcanoclastic layers in the upper and lower part of the valley belong to the same marker bed, displaced by faulting. In this tuffitic layer he also discovered an extraordinarily well-preserved spore assemblage, indicating a Langobardian (Late Ladinian) age of the whole Kalkschieferzone, whereas the first Carnian microflora occurs above the base of the Raibl Beds (Scheuring 1978, Textfig. 2).

Tab. 1 is a synopsis of the fossils known so far from the Kalkschieferzone near Meride. The fish fossils were studied by Bürgin (1995, this volume), who identified seven actinopterygian species.

Wirz (1945) divided the Kalkschieferzone into three subunits (Va, Vb, Vc), herein called the Lower, Middle and Upper Kalkschieferzone.

Lower Kalkschieferzone

The Kalkschieferzone below the volcanoclastic marker bed is characterized by grey micritic limestones, laminated marly limestones and marls. Light grey limestone laminae of 0.05–3.0 mm thickness, sometimes with normal graded bedding, are separated by very thin (0.01 mm) dark shale drapes. Wirz (1945) noted many fossiliferous beds (Fig. 3). All three fish specimens in the collection coming from Wirz's bed Vm 63 and 65 belong to a


CARNIAN
RAIBL BEDS
LATE LADINIAN
Langobardian
MERIDE LIMESTONE
Kalkschieferzone
upper
middle
lower
Scheuring 1978
Wirz 1945
109
108
107
106B
103
/106
102
100
10 - 13m
10m
4
15
23
Vc
48?
51?
Vb
56₅
58₄
60
Va
63
64
65
② ①
③
Lariosaurus
Actinopterygii
coprolite
Schimperella
Conchostraca
Ostracoda
Gastropoda
Foraminifera
trace fossil
land plant
stromatolite
halite crystal imprint
barite
slump
flat pebble breccia
limestone
laminated limestone with shale drapes
marl
volcanoclastic layer

		Kalkschieferzone upper	Kalkschieferzone middle	Kalkschieferzone lower
Plants				
	Voltzia sp.	-	x	x
	Gen indet.	xx	xx	x
Invertebrates				
Foraminifera				
Ammodiscidae	Gen. indet.	-	-	xx
Ophthalmidiidae	Gen. indet.	-	-	xx
Gastropoda				
	Gen. indet.	1	1	-
Crustacea				
	Gen. indet.	-	-	1
Mysidacea	*Schimperella beneckei*	3	-	-
Conchostraca	? *Laxitextella* sp.	-	xxx	xxx
Ostracoda	Gen. indet.	-	xxx	xxx
Vertebrates				
Osteichthyes				
Actinopterygii				
Palaeoniscididae	*Gyrolepis* sp.	-	1	-
Perleididae	*Perleidus altolepis*	-	6	-
Peltopleuridae	*Peltopleurus* sp. A	1	2	3
	Peltopleurus sp. B	1	-	-
Semionotidae	*Archaeosemionotus* sp.	-	3	-
Ophiopsiidae	*Ophiopsis* cf. *lepturus*	-	4	-
Neopterygii inc. sed.	*Prohalecites porroi*	-	70	-
Reptilia				
Sauropterygia				
Lariosauridae	*Lariosaurus lavizzarii*	-	1	-
	Gen. indet.	-	1	-

Occurence: x - rare, xx - few, xxx - common

Tab. 1. Fossils of the Kalkschieferzone (Upper Meride Limestone, Ladinian) from the Gaggiolo valley near Meride (Ticino). The identification of the foraminifers is adopted from Wirz (1945), the conchostracans from Tintori & Brambilla (1991), the actinopterygian fishes from Bürgin (1995, this volume) and the reptile from Kuhn-Schnyder (1987).

Fig. 3. Stratigraphic section of the Kalkschieferzone (Uppermost Meride Limestone, Ladinian) in the Gaggiolo valley near Meride. The columnar section, measured by D. Bionda in 1994, is simplified and correlated with bed numbers and fossil findings of Wirz (1945) and Scheuring (1978).

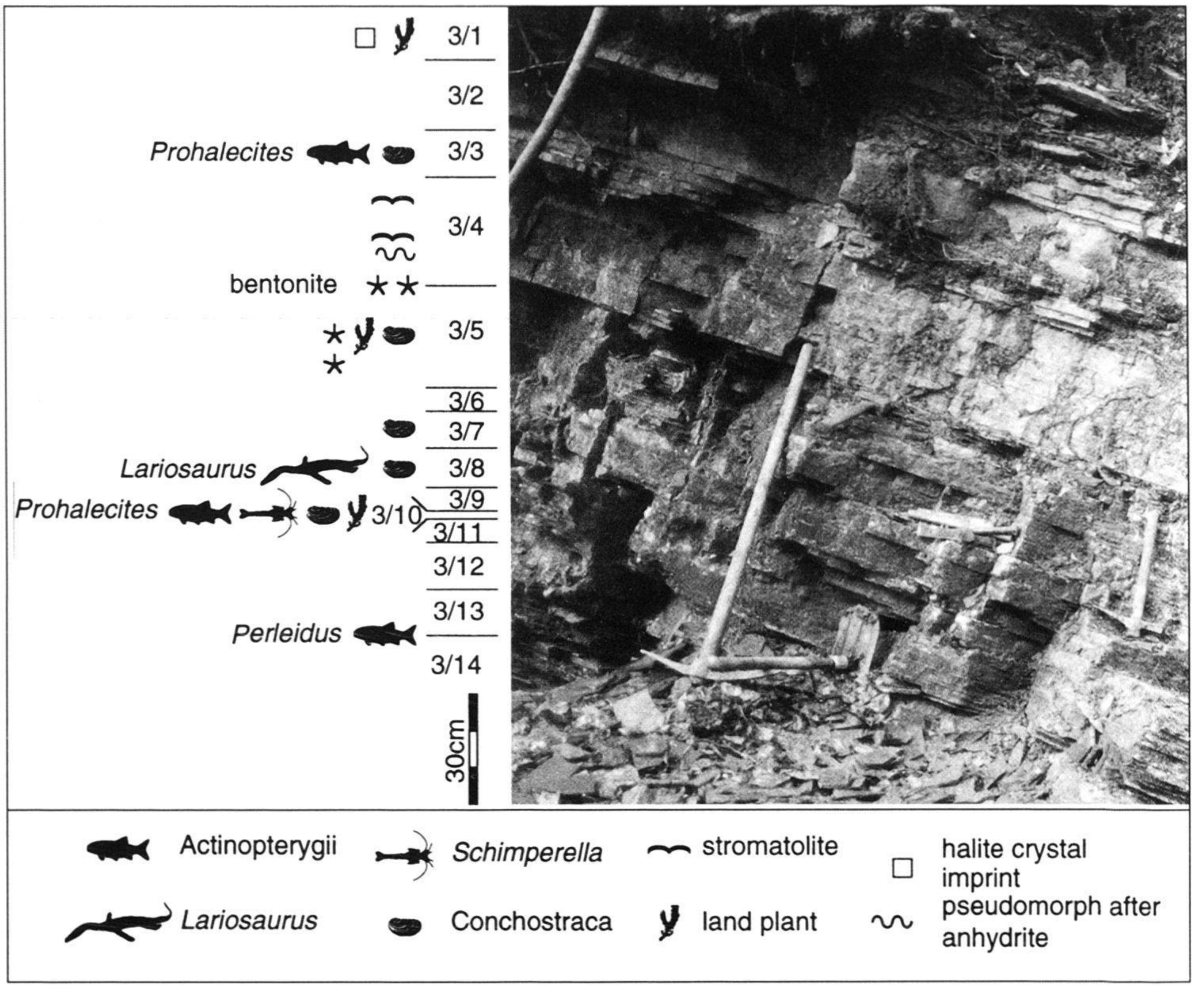


Fig. 4. Section in the middle Kalkschieferzone at locality 3 in the Gaggiolo valley near Meride, with approximate position of the *Lariosaurus lavizzarii* and *Perleidus altolepis* recovered in 1971.

small *Peltopleurus* species A (Bürgin, 1995 this volume). PIMUZ T 4980 is a fragment of an articulated specimen in lateral view. A black ?bituminuous band is visible in the body through the transparent scales. A second specimen (PIMUZ T 4979) is partly disarticulated. The skull elements are shifted 12 mm away from the body, whose fins are also shifted or partly missing. A third specimen (PIMUZ T 4978) is articulated with exception of the skull, that was turned backwards from the lower jaw. It is excellently preserved and embedded in a light limestone lamina above a dark shale drape with a small crustacean and not totally flattened conchostracans of 5–8 mm length, determined by Wirz (1945, Pl. 75, Fig. 55) as *Estheria* sp. Identical forms have been assigned by Tintori (1990c) to the genus *Palaeolimnadia*, then by Tintori & Brambilla (1991) to *Laxitextella.* Ophthalmid foraminifers were reported from the lowermost beds (Wirz 1945, Pl. 74, Fig. 21), whereas ostracods occur in several beds. Two beds with bioturbations (*Planolites* sp.), described by Wirz (1945, Pl. 76, Fig. 36, 38) as "Schlammwülste", and spiral burrows document the short existence of benthic life. Land plants (*Voltzia* sp. and other indeterminate rests) are not rare. Common are also layers with single crystals, bundles or thick

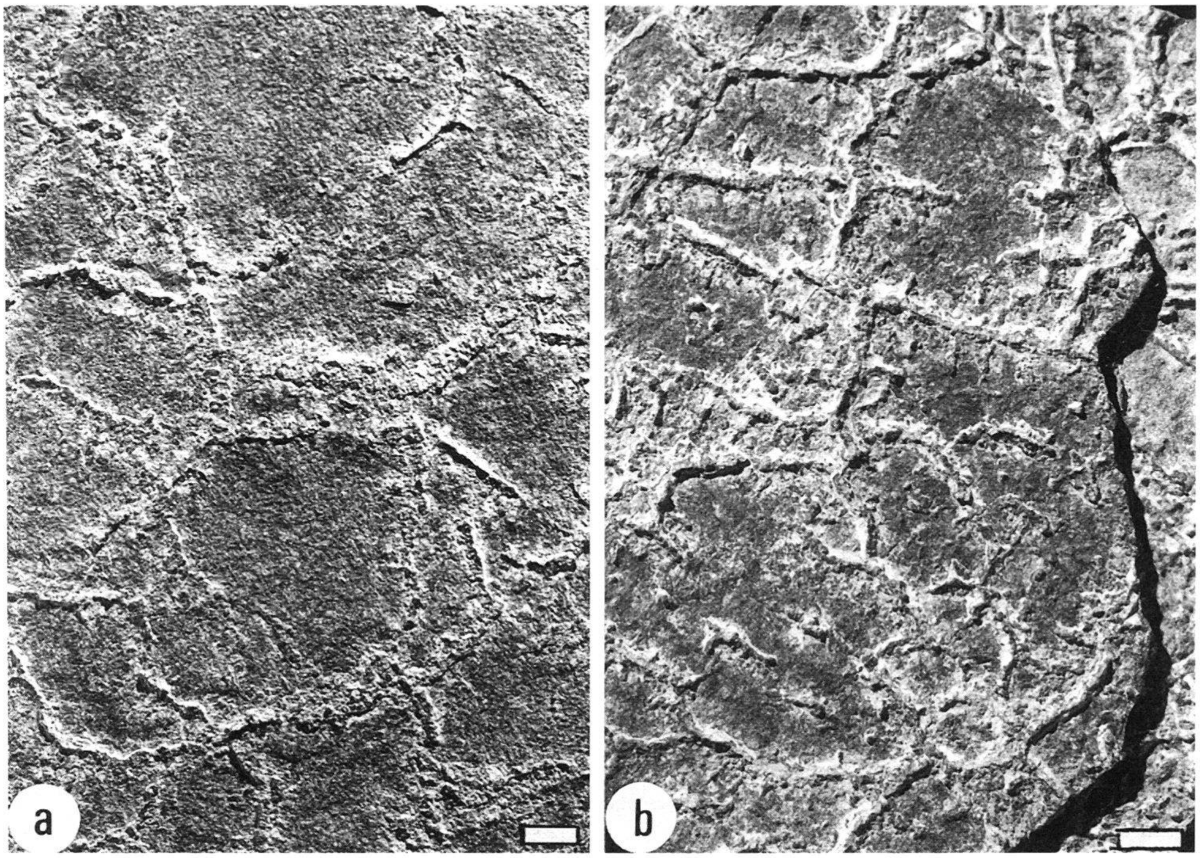


Fig. 5a,b. Upper surfaces of stromatolitic laminae in the middle Kalkschieferzone of the Gaggiolo valley near Meride, locality 3. The polygonal arranged crests formed by dessication of microbial mats. Scale bars = 1 cm.

aggregates of barite (Wirz 1945, Pl. 76, Fig. 42, 47). The volcanoclastic marker bed, noticed by Wirz (1945) to be 0.1 m, by Scheuring (1978, Textfig. 1: bed 103, 106) to be 0.5 m thick, is 2.0 m thick and represents a very important volcanic ash fall event.

Middle Kalkschieferzone

The middle part of the Kalkschieferzone above the volcanoclastic marker bed is dominated by dark thin-bedded and laminated limestones. Locality 3 (Fig. 4) is the place where U. Oberli found in 1971 the articulated skeleton of *Lariosaurus lavizzarii*. The thin-bedded limestones along the small creek on the right side of the Gaggiolo valley consist of 0.1–2 mm thick light grey limestone laminae, separated by very thin (0.01–0.05 mm) black bituminuous shale drapes. The limestone laminae often display a peloid structure, sometimes with normal graded bedding. Some shale drapes are very rich in conchostracans (Fig. 7a). About 500 to 1000 specimens per square meter can be counted together with 2 specimens of the small mysidacean *Schimperella beneckei* Bill 1914. The well-preserved, but flattened conchostracans measure in length from 4 to 9 mm. All specimens are found in lateral view parallel to the bedding plane. The long axis of the bivalved carapaces show random orientation. Characteristic for these beds are flattened calcitic objects, 5 to 30 mm long and 1 to 8 mm broad, with longitudinal ribs and cellular

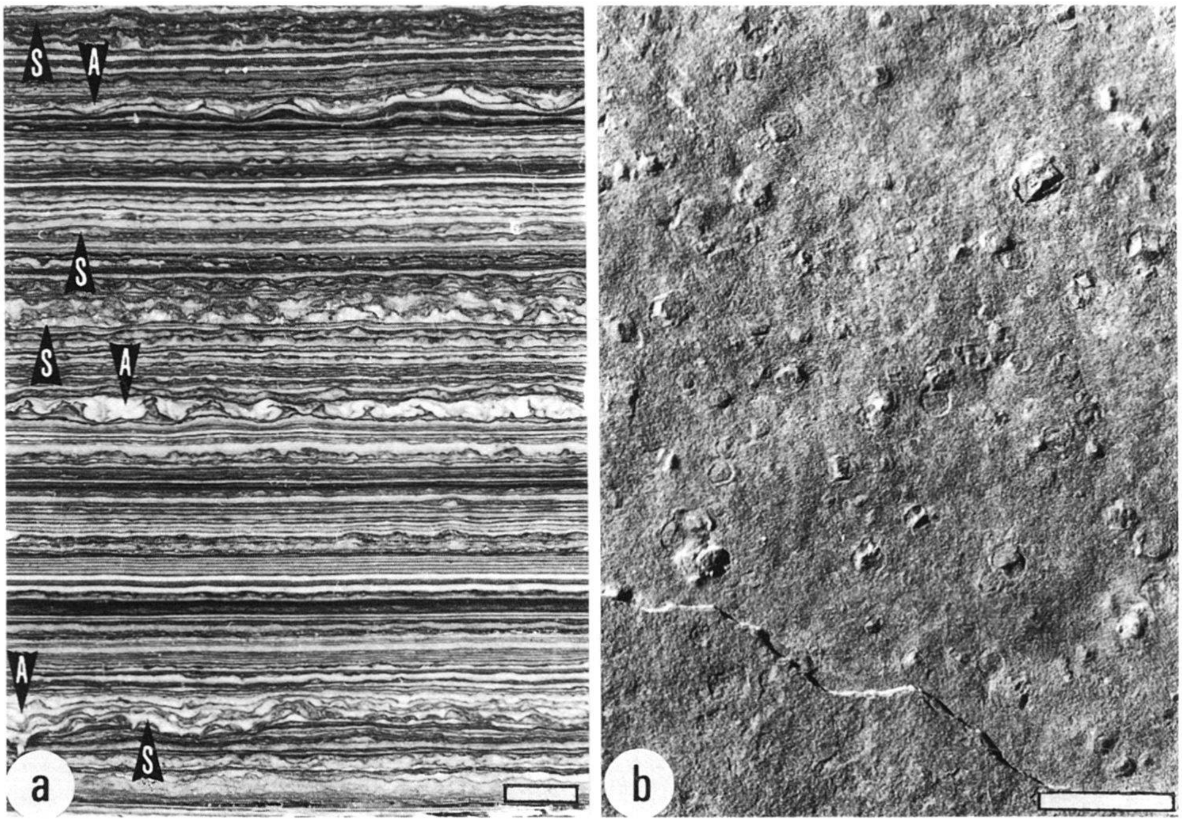


Fig. 6. Laminites in the middle Kalkschieferzone of the Gaggiolo valley near Meride, locality 3. 6a. Polished section of the laminite bed (3/4) just above the thin bentonite layer. Some limestone laminae of the slightly crinkled stromatolite are silicified (S). The three enterolithic laminae of white microcrystalline calcite (A) are interpreted as pseudomorphs after contorted anhydrite layers. 6b. Flattened casts of halite (hopper) crystals at the base of a limestone lamina in bed 3/1. Scale bars = 1 cm.

structures, interpreted as calcified plant material. Etched carefully by acetic acid, cellular structures can be observed, indicating that they are calcified plant material.

The articulated specimen of *Lariosaurus lavizzarii* (PIMUZ T 4288, Kuhn-Schnyder 1987, Fig. 1&2) is embedded with the ventral side on the surface of a limestone lamina and was covered by a shale drape. The light brown bones are mantled by a dark bituminuous film, probably rests of soft parts or skin. All elements of the articulated skeleton, belonging to a juvenile specimen, have been fossilized. All legs point backwards on both sides. The vertebral column is remarkably straight, as it is typical for all lariosaurs (Kuhn-Schnyder 1987, p. 13). The distal part of the neck and the skull are bent backwards to the left side, probably when the carcass hit the ground. The end of the tail was lost before embedding. The specimen of *Perleidus altolepis* (PIMUZ T 4798, Bürgin 1992, Fig. 59) was found 20 cm below the lariosaur, in a bed of very thin laminated limestone. The 13 cm long skeleton is embedded in a shale drape, in excellent preservation with only minor distortion and shifting of the most distal elements of the pectoral, ventral and caudal fins. The small actinopterygian *Prohalecites porroi* is documented by complete specimens, always found in shale drapes without any conchostracans.

Some bedding planes are very smooth, others show a crinkled or wavy surface. They

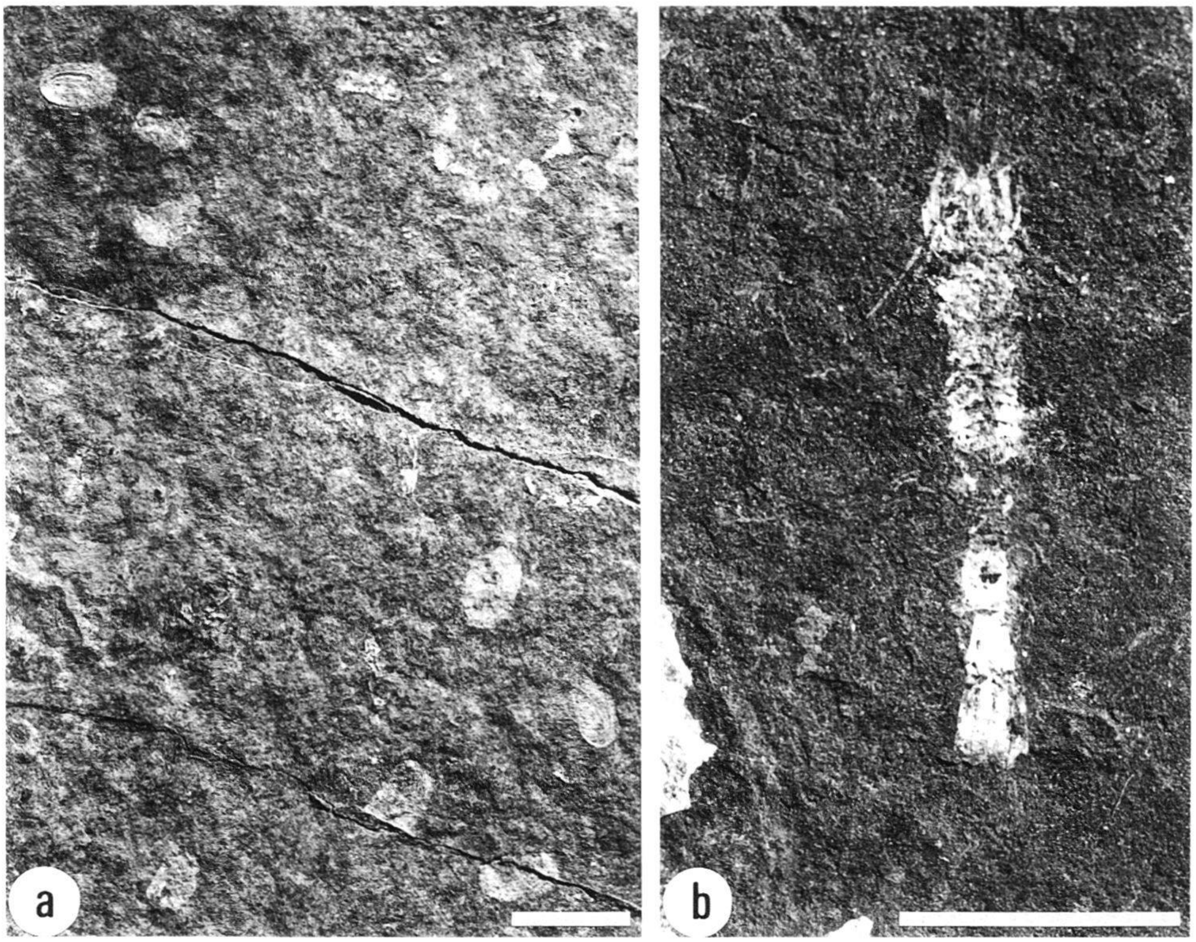


Fig. 7a. Estherid conchostracans in the middle Kalkschieferzone of the Gaggiolo valley near Meride, bed 3/10 (MCSN 3071). 7b. *Schimperella beneckei* from the middle Kalkschieferzone of the Gaggiolo valley near Meride, locality 2. Note the preservation of the antennae on both sides (MCSN 3070). Scale bars = 1 cm.

must have formed as stromatolites (Krumbein 1983) or microbialites (Burne & Moore 1987), as suggested by bedding planes with polygonal patterns of deformed and mud-cracked laminites (Fig. 5). Similar features are observed in modern microbial mats in the higher intertidal or supratidal of tidal ponds on the Bahamas (Shinn et al. 1969) or coastal sabkhas of the trucial coast in the Persian Gulf (Kendall & Skipwith 1969) and Tunisia (own observation). The bed 3/4 just above a 5 mm thick bentonite displays three contorted laminae (Fig. 6a), resembling the enterolithic structure of anhydrite beds in modern and ancient sabkha deposits (Kendall & Skipwith 1969, Shearman 1978). These laminae are interpreted as deformed anhydrite layers, now replaced by microcrystalline calcite. Some of the limestone laminae are partly silicified, probably by diagentic processes related to the underlying volcanoclastic layer. Higher in the section, casts of halite (hopper) crystals at the bottom of a limestone lamina are deformed by compaction of the underlying shale drape (Fig. 6b).

At locality 1, some 10 m above locality 3, thin laminated limestones have been excavated in 1994 bed by bed on a surface of 4 square meters (Fig. 9). As the outcrop was affected by small scale sliding and intense weathering, we were not able to correlate individual laminae and to determine the exact position or orientation of the small fossils,

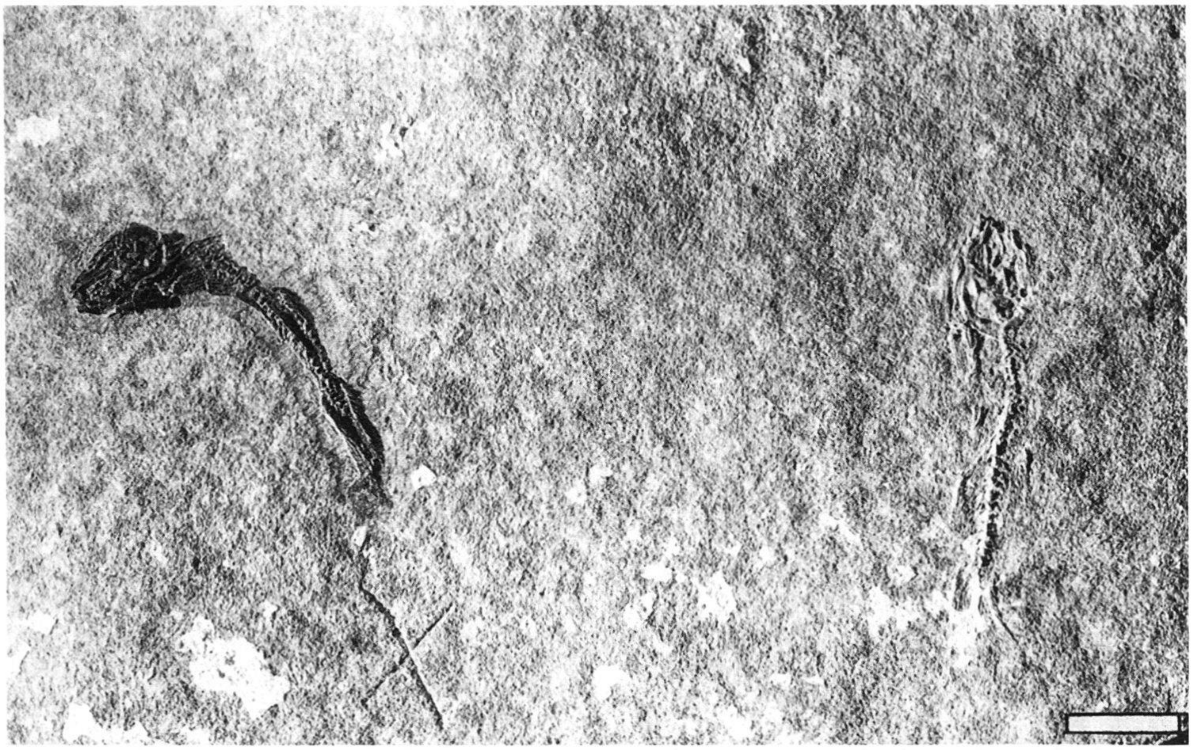


Fig. 8. *Prohalecites porroi* from the middle Kalkschieferzone of the Gaggiolo valley near Meride, bed 1/42. Both articulated specimens are embedded in a dark shale drape, removed from the left specimen by mechanical preparation (MCSN 3033). Scale bar = 1 cm.

which were hardly recognizable in the dark grey shale drapes. In the very fine laminated limestone-shale alternations of bed 1/42 and 1/43, 25 articulated and two disarticulated specimens of *Prohalecites porroi* with isolated skull elements, two articulated specimens of *Archaeosemionotus* sp. and one specimen of *Ophiopsis* cf. *lepturus* have been found. They are always embedded and flattened in very thin black bituminuous shale drapes between the limestone laminae. The *Archaeosemionotus* sp. and the *Ophiopsis* cf. *lepturus* were preserved in lateral position (e.g. MCSN 3012 & 3014, Bürgin 1995, this volume Fig. 11, 12B), as do some *Prohalecites porroi*. But in most specimens of *Prohalecites porroi,* the broad skull and the paired pectoral fins of this species are dorsal-ventrally flattened, whereas the body with the other fins is twisted, lying on the side (e.g. MCSN 3016 & 3017, Bürgin 1995, this volume Fig. 15A, 16). The same observations were made by Tintori (1990a). In about half of the specimens the skull is turned backwards (e.g. MCSN 3033, Fig. 8). In most specimens, the bones are covered by a black film of organic matter, thickest in the orbit of the skull. Some otoliths are present in situ, but their calcite is strongly weathered. Sometimes stomach content is preserved as a light brownish band. There are also flattened coprolites, measuring 5 to 10 mm. Many flattened conchostracans are preserved in four remarkable smooth shale drapes, ostracods in another one, but never together with fish remains. Polygonal structures in laminites, interpreted as deformed microbial mats, are recorded in two limestone laminae. Coaly remains of land plants are rare.

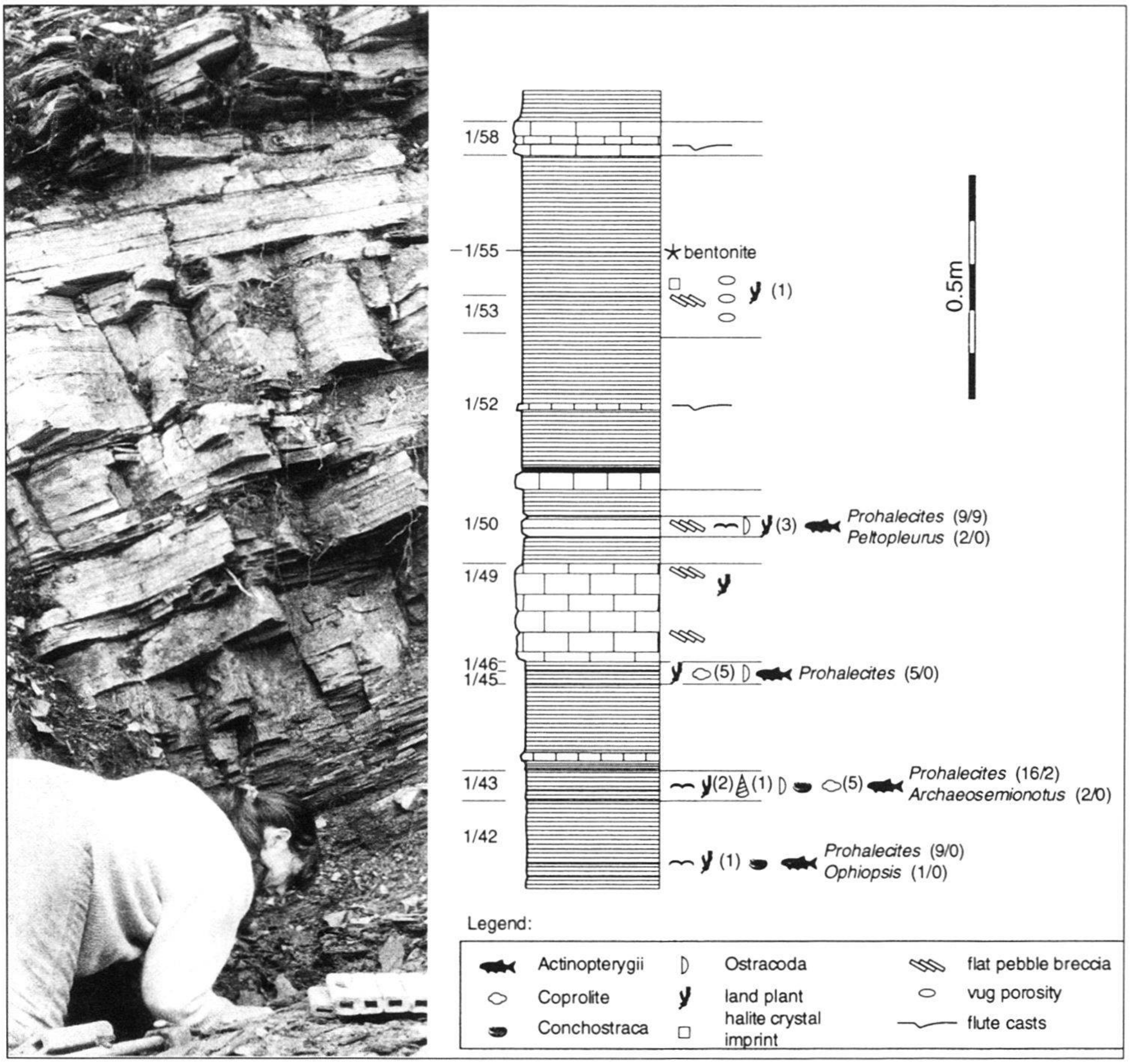


Fig. 9. Section in the middle Kalkschieferzone at locality 1 in the Gaggiolo valley near Meride, studied in 1994. The numbers in brackets behind fossil symbols indicate the articulated/respectively disarticulated specimens, recovered on a excavation surface of about 4 square meters.

In the higher beds 1/45 and 1/46 five well preserved *Prohalecites porroi* have been found in shale drapes together with some coprolites, measuring 5 to 15 mm. The flattened coprolites contain disarticulated skeletal elements of *Prohalecites*. Calcified plant remains are common. The irregular laminated bed 1/49 contains many black shale flakes, only 0.05 mm thick but 10 to 50 mm in diameter. Bed surfaces are similar to modern equivalents of flat pebble breccias, with angular clasts ripped up by storms from dessicated and mudcracked microbial mats on inter- to supratidal flats.

Nine articulated specimens of *Prohalecites porroi* (e.g. MCSN 3015 & 3021; Bürgin 1995, this volume Fig. 15, 17) and two *Peltopleurus* sp. A (e.g. MCSN 3009, Bürgin 1995, this volume Fig. 5A) have been discovered in bed 1/50, composed of grey laminated limestones with minor shaly interfaces. The very well preserved specimens, with black organic material from soft parts (e.g. MCSN 3021; Bürgin 1995, this volume Fig. 15B), are embedded here in limestone laminae or at their boundaries. Nine other specimens are documented by fragmentary axial skeletons, missing head and fins or by fragmented fins and isolated skull elements. A cluster of about 10 ostracods, some coaly and calcified plant remains are the other fossils; deformed and mudcracked stromatolites and flat pebble breccias are the sedimentological features of this bed. In the upper part of the excavation, only one plant remain was found, in a series of laminated limestones with regulary vuggy porosity and a lense of flat pebble breccia, occurring below a 1 mm thick bentonite. This youngest bentonite in the Kalkschiefer section can be used as a marker bed for the correlation with the locality 2, down on the left side of the Gaggiolo river. There some conchostracans and 14 fishes have been discovered in a 0.5 m thick thinbedded series of dark grey limestone laminae and shale drapes: one *Perleidus altolepis* (MCSN 3007; Bürgin 1995, this volume Fig. 2), 11 articulated and two disarticulated specimens of *Prohalecites porroi.* A well preserved specimen of *Schimperella beneckei* (MCSN 3070, Fig. 7b), found in a loose block, must come from these beds.

Upper Kalkschieferzone

The upper part of the Kalkschieferzone section along the river Gaggiolo consist of a 40 to 50 m thick alternation of fine laminated marls, thin-bedded and laminated limestones, sometimes with black shale drapes and slumping. Wirz (1945) noted some indeterminable land plants, a gastropod and fish remains. One complete specimen (PIMUZ T 4966) found in the section by Wirz (1945, Vm 23) is described as *Peltopleurus* sp. A by Bürgin (1995, this volume Fig. 7B). Another specimen (MCSN 3011) found in 1994 by Michèle Septfontaine (Lausanne) in a loose block, belongs to another species (*Peltopleurus* sp. B; Bürgin 1995, this volume Fig. 9). Both are very well preserved specimens in lateral view. The orbit is covered by a black ?bituminuous material, visible also as a black band in the body through the transparent scales.

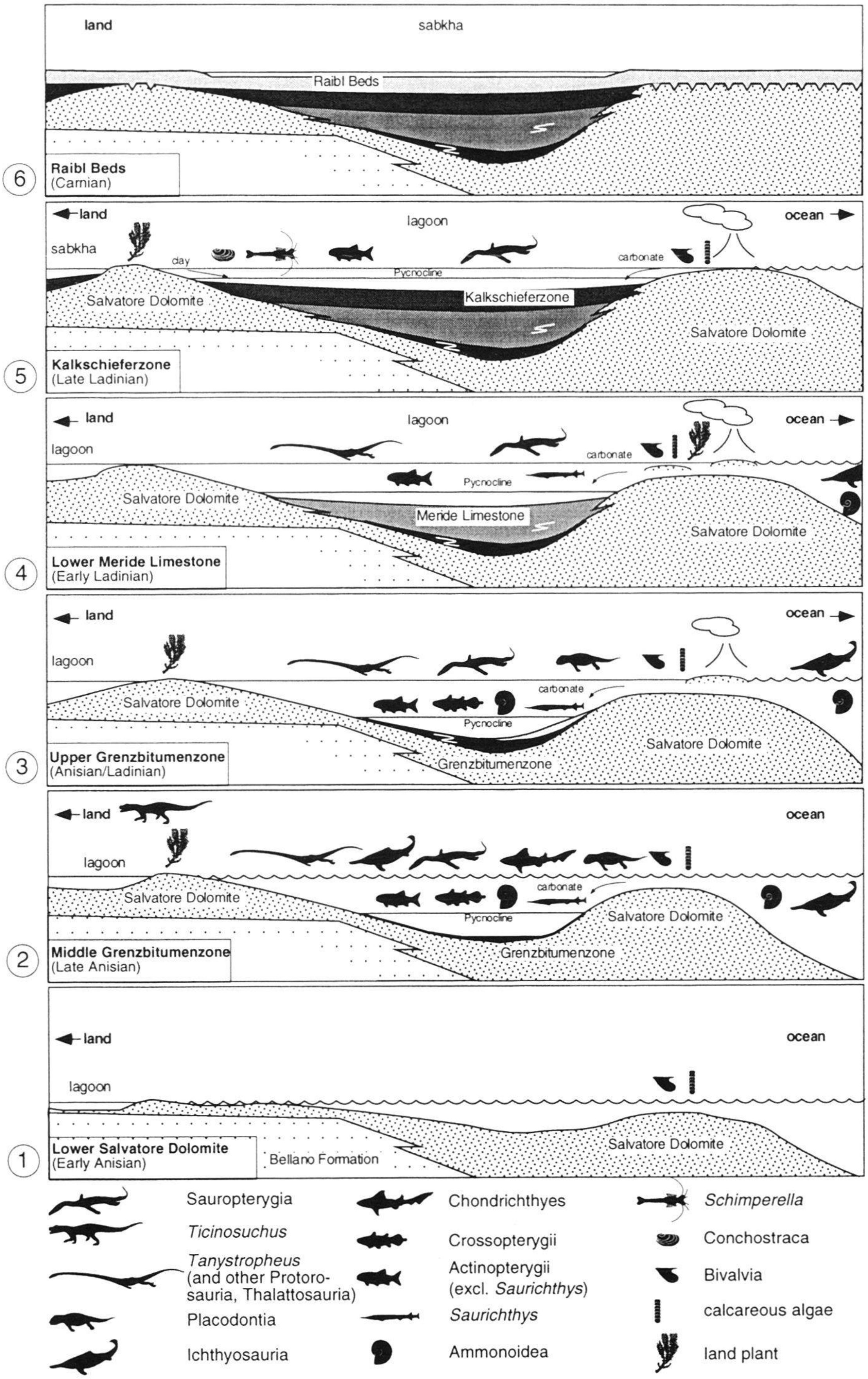
The upper boundary of the Kalkschieferzone is drawn on top of a dolomitic limestone bed, below the first thick marls of the overlying Pizzella Marls (Raibl Beds), cropping out about 100 m northwest of the camping place on the right side of the Gaggiolo river, overlain by a big block of a Pleistocene conglomerate.

4. Evolution of the Middle Triassic Monte San Giorgio basin

Lower Salvatore Dolomite

The transgression of the Tethys ocean in the Western Lombardian Alps is documented by the Lower Salvatore Dolomite, overlying red sandstones, conglomerates and shales of the Bellano Formation of supposed Anisian age. With this Late Anisian transgression,

Fig. 10. Simplified sketches of the environmental evolution of the Monte San Giorgio region from Anisian to Carnian time. Not to scale. Discussion see text.


land
sabkha
Raibl Beds
6
Raibl Beds
(Carnian)
land
lagoon
ocean
sabkha
clay
carbonate
Pycnocline
Salvatore Dolomite
Kalkschieferzone
Salvatore Dolomite
5
Kalkschieferzone
(Late Ladinian)
land
lagoon
ocean
lagoon
carbonate
Pycnocline
Salvatore Dolomite
Meride Limestone
Salvatore Dolomite
4
Lower Meride Limestone
(Early Ladinian)
land
ocean
lagoon
carbonate
Salvatore Dolomite
Pycnocline
Salvatore Dolomite
Grenzbitumenzone
3
Upper Grenzbitumenzone
(Anisian/Ladinian)
land
ocean
lagoon
Salvatore Dolomite
carbonate
Pycnocline
Salvatore Dolomite
Grenzbitumenzone
2
Middle Grenzbitumenzone
(Late Anisian)
land
ocean
lagoon
Salvatore Dolomite
Bellano Formation
1
Lower Salvatore Dolomite
(Early Anisian)
Sauropterygia
Ticinosuchus
Tanystropheus
(and other Protorosauria, Thalattosauria)
Placodontia
Ichthyosauria
Chondrichthyes
Crossopterygii
Actinopterygii
(excl. Saurichthys)
Saurichthys
Ammonoidea
Schimperella
Conchostraca
Bivalvia
calcareous algae
land plant

shallow water carbonate sediments with frequent bioclasts of dasycladacean algae, gastropods and bivalves became dominant (Fig. 10/1). Tectonic activity associated with extensive volcanism during the latest Anisian and Ladinian led to the formation of several basins separated by carbonate platforms. In the Lugano region, shallow-water platform sedimentation continued unchanged in the north and west (Monte San Salvatore and Monte Caslano), where the Middle and Upper Salvatore Dolomites were deposited (Zorn 1971).

Grenzbitumenzone (Besano Formation)

In the south (Monte San Giorgio–Besano–Pogliana), a starved basin with restricted circulation and density stratification developed in the latest Anisian. The finely laminated organic matter-rich dolomites and black shales of the Grenzbitumenzone (Besano Formation) without any bioturbations were deposited under permanently anoxic conditions during 2 to 5 Million years (Bernasconi 1994). Criticism of strictly anoxic bottom water conditions by Tintori (1992) is based on wrong assumptions or not convincing arguments (Etter 1994, p. 227). High supply of organic matter and stagnant anoxic bottom water could explain the extraordinary preservation; the low sedimentation rate of 1 to 5 mm per thousand years the accumulation of vertebrate skeletons. The low sedimentation rate could also be responsible for the early dolomitization of the primary calcitic mud, imported periodically from adjacent platforms by low density turbidites and detached turbidites, initited by storm events (Bernasconi 1994). Organic geochemical studies by Bernasconi & Riva (1993) in the dolomites and black shales with organic carbon contents of up to 10 or 40 wt % respectively, showed that hopanoids are present in very high concentrations in the lower and middle and scarce in the upper Grenzbitumenzone. They suggested that bacteria were a significant contributor to the primary organic matter production in the basin, forming a planktonic "bacterial plate" at the oxic-anoxic boundary in the water column.

The Grenzbitumenzone must be classified as a typical stagnation deposit sensu Seilacher, Reif & Westphal (1985), with minor influence of obrution by turbidity currents and bacterial sealing. The high diversity in vertebrates with aquatic reptiles and fishes documents various habitats and ecological niches as pointed out by Rieppel (1985b, 1993) and Bürgin (1992). Diversity is highest in the middle Grenzbitumenzone (Fig. 10/2): chondrichthyans, crossopterygians, some actinopterygians as the large predator *Birgeria* and most ichthyosaurs are restricted to these beds (Kuhn-Schnyder 1974, Rieppel 1980, 1981, 1985b, Sander 1989b), suggesting best connections to the open sea and normal marine surface water during this time. The same trend can be observed in the occurrence of thin shelled bivalves of the genus *Daonella* (Rieber 1968), ammonoids (Rieber 1973b) and conodonts (Rieber 1980) requiring stenohaline surface water. Very rare benthic organisms as dasycladacean algae, one echinoid spine and doubtful brachiopods (Rieber 1976), thylacocephalan crustaceans (Bürgin et al. 1991, Teruzzi & Dal Sasso 1995), only three specimens of decapod crustaceans (Pinna & Teruzzi 1991), one of them described by Etter (1994) as a new species *Antrimpos mirigiolensis,* and rare specimens of *Halicyne* (Pinna & Teruzzi 1991), also found in the Middle Salvatore Dolomite by Zorn (1971), are explained as allochthonous elements, swept into the basin by storms and currents from adjacent platforms. The existence of small islands and even larger terrestrial areas are indicated by the presence of well preserved twigs and fruit cones of the conifer *Voltzia*

(Sordelli 1857, Kuhn-Schnyder 1974, Pinna & Teruzzi 1991) and terrestrial reptiles as the small *Macrocnemus bassanii* (Rieppel 1989b) and the 2.5 m long *Ticinosuchus ferox* (Krebs 1964).

The small pachypleurosaur *Serpianosaurus mirigiolensis* (Rieppel 1989a) and three species of the long snouted actinopterygian *Saurichthys* (Rieppel 1985a, 1993) dominate the less diverse fauna in the upper Grenzbitumenzone (Fig. 10/3). It is possible, that the Grenzbitumenzone basin was separated progressively from the open sea by growing carbonate platforms, developing into a lagoonal environment. That is in contrast to the results of Wirz (1945) and Bernasconi (1994) who found increasing numbers of radiolarians in the upper Grenzbitumenzone, suggesting better connections to the ocean.

The Grenzbitumenzone basin itself measured in minimum 10 km in diameter and was 100 to 150 m deep (Zorn 1971, Rieber 1973a). Based on tectonic studies of Bertotti (1991), Bernasconi (1994) and Bernasconi & Riva (1993) suggested that the Grenzbitumenzone belonged to the same basin as the Perledo-Varenna Formation east of Lake Como, interfingering with the Esino platform (Gaetani et al. 1992). Such a basin would measure about 20 km in E-W direction. The dark, well bedded limestones, marls and dolomites of poorly oxic to anoxic environment are the time equivalent of the higher parts of the Grenzbitumenzone and the Meride Limestone. Most of the classical vertebrate fauna from Perledo originate from the Late Ladinian Perledo Member (Gaetani et al. 1992).

Meride Limestone

The 60 m thick San Giorgio Dolomite and the 400 to 600 m thick Meride Limestone were deposited in the same basin. The lower Meride Limestone is characterized by an alternation of micritic limestones and marls. Some ammonoids, pelagic bivalves and radiolarians were found in the lower part of the Meride Limestone below the thickest volcanoclastic marker beds (Airaghi 1912, Senn 1924, Wirz 1945), suggesting periods with stenohaline surface waters. *Rhizocorallium* is a trace fossil known from some beds.

Vertebrates were excavated in three intercalations of finely laminated organic matter-rich black shales, marls and limestones. 16 actinopterygian species (Bürgin 1992 & in prep.) are known from the Cava inferiore beds, discovered between two volcanoclastic layers (Wirz 1945, Textfig. 7; Sander 1989a, Fig. 5). The largest predating fish was *Saurichthys macrocephalus* (Rieppel 1985a), in competition with the small pachypleurosaur *Neusticosaurus pusillus* (Sander 1989a) and the large sauropterygian *Ceresiosaurus calcagnii* (Peyer 1931). *C. calcagnii* and *Neusticosaurus peyeri* are the only reptiles from the Cava superiore beds (Peyer 1931, Sander 1989a). Two sauropterygians *(C. calcagnii, Pachypleurosaurus edwardsii)* and two protorosaurs *(Tanystropheus meridensis, Macrocnemus bassanii)* and only two actinopterygians *(Saurichthys curionii, S. macrocephalus)* have been identified from the Cassina beds (Kuhn-Schnyder 1974, 1994, Wild 1980, - Carroll & Gaskill 1985, Rieppel 1985a, 1989b, Sander 1989a).

The only invertebrate fossil from these vertebrate beds in the Lower Meride Limestone is one specimen of a regular sea urchin, preserved with all spines (Jeannet 1933), probably washed in from the shallow water platform. Sedimentological and paleontological observations indicate a deeper basin environment for the Lower Meride Limestone with deposition of fine grained carbonate mud and clay below normal wave base (Fig.

10/4). Slumping and graded bedding document the instability of the margins, influenced by turbidity and storm currents. The few cephalopods and pelagic bivalves came into the lagoon during short periods with better connections to the open sea. The rare bioturbated horizons document few events with benthic life in the normally disoxic to anoxic bottom water, possibly also triggered by extraordinary storms (Föllmi & Grimm 1990).

In Late Ladinian time the lagoonal basin was filled progressively by the 200 to 300 m thick alternation of limestones and marls of the Upper Meride Limestone ending with the Kalkschieferzone.

Kalkschieferzone

The 120 m thick Kalkschieferzone has been thought to be deposited in a wide restricted lagoon with increasing input of fine siliciclastic detritus from the land (Wirz 1945, Scheuring 1978, Kuhn-Schnyder 1987). This interpretation was based on the low diversity fauna, the common fossils of land plants and the widespread barite and gypsum crystals. In his study on *Prohalecites porroi* from an isolated outcrop of the supposed lower part of the Kalkschieferzone near the locality Ca' del Frate, Tintori (1990a) recognized in the finely laminated beds a seasonal alternation at the anoxic bottom of a marine basin influenced by continental areas. After Tintori (1990a & b) light layers yield smaller specimens of *Prohalecites,* believed to be young specimens of "summer" schools, hatched in spring and killed by a mass mortality event in "summer". Dark layers yield larger ones, died in "winter" when these small fishes reached their maximum size of about 40 mm.

Some hundred specimens of the small mysidacean crustacean *Schimperella* have been found in the locality Ca' del Frate (Tintori & Brambilla 1991, Tintori et al. in prep.). During field work in 1994 only three specimens have been found, two of them together with conchostracans. They are attributed to *Schimperella beneckei* Bill 1914, a well known species from the Grès à Voltzia (Uppermost Buntsandstein) of the Vosges in France (Gall 1971), interpreted as deltaic sediments in a fresh to brackish water environment. The species was recently found in the mainly marine Prosanto Formation (Ladinian) of the Swiss Alps in Canton Graubünden (Bürgin et al. 1991). The mysidaceans today occupy different habitats, but commonly live as epibenthic or endobenthic "shrimps" in fresh, brackish and marine water (Schram 1986).

Tintori (1990c) excluded the autochthony of the most abundant fossils, the conchostracans, in these anoxic sediments. After Tasch (1969) and Schram (1986) all modern conchostracans live in fresh or slightly brackish water, generally dwelling in temporary or perennial pools. They are active filter feeders, lying in the mud with open valves and upturned appendices (Frank 1988). By analysing 600 specimens, Tintori & Brambilla (1991) suggested a sexual dimorphism of smaller females and slightly larger males, not differing in shape. About half of the specimens bear traces of their soft parts and about 20% are undoubtly female, because eggs of about 0.04 mm in diameter are preserved. Based on the relatively few growth-lines (7–10) on the carapaces with lengths between 4.1 to 8.9 mm, Tintori & Brambilla (1991) suggest that these conchostracans lived only one or two months during the wet season in the Triassic monsoon-type climate. In their hypothesis 1, these small crustaceans dwelled in freshwater seasonal ponds along the shore and were transported by overflows during the rain season into the marine or brackish basin. In hypothesis 2, the conchostracans are thought to have lived on high areas inside the basin reaching the superficial, almost fresh water during the rainy season. Weak superficial currents could carry the organisms into the deeper part of the basin, where the thin carapaces and even soft parts and eggs were preserved in the anoxic bottom water.

I am not convinced by the allochthony of the conchostracans, found in some dense populations in the dark shale laminae, lacking any signs of currents. I agree with Tintori (1990c) that the fine lamination is due to seasonal change in a monsoon-type climate as suggested for the northwestern Tethys coast in Triassic time by Frakes (1979) and Pollard & Schulz (1994). The light limestone laminae most probably are the product of the dry season with low water level and high salinity, whereas the dark shale laminae document the wet season with high water level and low salinity in the surface water. With the begin of the wet season the remaining hypersaline lagoon on the carbonate platform was flooded by lighter freshwater, that renewed the density stratification with anoxic bottom water below a pycnocline (Fig. 10/5) or anoxic conditions at the water/sediment interface, also excluding any larger endobenthic organisms.

The resulting large lagoon with warm brackish surface water, rich in oxygen and nutrients from the weathered continental areas gave rise to fast growth of microorganisms as base of a food chain with small crustaceans (ostracods and mysidaceans), fishes and aquatic reptiles migrating thanks to the high water level from neighboured open lagoons. According to the dentition, *Prohalecites porroi,* the dominating actinopterygian species, presumably was a schooling fish (Tintori 1990a) feeding on small, planktonic invertebrates (Bürgin 1995, this volume). A similar diet is presumed of *Peltopleurus* sp. *Ophiopsis* cf. *lepturus* shows larger and more pointed teeth suggesting invertebrate picking and piercing from substrates. The large and stout teeth of *Perleidus altolepis* and *Dipteronotus olgiatii* would allow crushing of hard-shelled prey (Bürgin 1995, this volume).

The dense populations of conchostracan crustaceans are here interpreted as autochthonous populations, that developed during extraordinary strong rainy seasons in shallow areas of the lagoon, flooded by almost fresh surface water. Growing in a few weeks, these small benthic organisms were killed by the increasing salinity and decreasing oxygen in the dry season. The strong evaporation lowered the water level, increased the salinity and killed progressively most of the other organisms, especially in extreme dry years. The preservation of half of the specimens of *Prohalecites porroi* with the skulls bent backwards can be explained by subaqueous dehydration, known from other localities, as the Late Jurassic Solnhofen Limestone (Viohl 1993). The carcasses were covered quickly by microbial mats and embedded in the organic-rich mud. Suffering no damage by scavengers, often articulated skeletons with soft parts are preserved. Only carcasses floating some time in the superficial water disarticulated and were embedded as fragmentary rests or isolated skeletal elements. Such a preservation is more common in the light limestone laminae (bed 1/50), favoured by increasing salinity and temperature in the dry season. Probably most of the lime mud was settled in form of fecal pellets, well known today from crustaceans living in salt lakes.

The very regular, partly cyclic lamination must be controlled by microbial communities. Though no filaments are observed in these stromatolites, the beds with crinkly laminations and polygonal surface structures document dessicated and partly mudcracked microbial mats, known today from inter- to supratidal marshes or coastal sabkha deposits. Also characteristic for such environments are flat pebble breccias with ripped up clasts of microbial mats or early diagenetic lithified laminites, observed several times in the section. The enterolithic structure of the white calcitic layers can be best explained as pseudomorphs after anhydrite layers with diapiric deformation, formed today in the mud of sabkhas. The anhydrite was leached and replaced by calcite after lithification of the laminite. The natural casts of crystals at the base of limestone laminae preserved the imprints of halite crystals in the clay. The original hopper crystals precipitated in brines of salinas and were leached during early diagenesis before lithification of the overlying lime mud. Few informations are available in the literature about the formation of barite in sediments. After Puchelt (1972), Ba^{2+} is enriched in anoxic pore water compared to seawater and could crystallize by contact with meteoric water.

An actualistic model for the depositional environment of the Kalkschieferzone could be the Lagoa Vermelha, one of a string of lagoons situated along the Brazilian coast east of Rio de Janeiro (Oliveira Vasconcelos 1994). This very shallow coastal lagoon is controlled by wet and dry seasons, a semi-arid microclimate and salinity fluctuations between brackish and hypersaline. A laminated mud facies composed of white fine-grained carbonate interbedded with dark organic carbon-rich layers and a pelletal carbonate mud facies are permanently anoxic with the anoxic/oxic boundary just above the sediment/water interface.

Based on lithostratigraphic correlation, the Kalkschieferzone could be time equivalent of the Cunardo Formation and the Lierna Formation east of Lake Como, a series of well bedded limestones and dolomites, marls and volcanoclastic layers (Gaetani et al. 1992), overlying the Perledo-Varenna Formation. Their uppermost part, the Perledo Member, yielding most of the classical vertebrate fauna from Perledo (Gaetani et al. 1992), possibly has the same age as the lower Kalkschieferzone (Tintori 1990c) or could be slightly older. That would explain the similarity of the vertebrate fauna, as mentioned by Tintori & Renesto (1990).

Pizzella Marls (Raibl Beds)

In latest Ladinian time an increasing input of fine siliciclastic material, probably derived from the erosion of a Southern Mobile Belt (Brusca et al. 1981), influenced the carbonate sedimentation of the upper Kalkschieferzone. The maximum was reached by the Pizzella Marls or Raibl Beds with local deposition of evaporites in coastal salinas or a sabkha environment (Fig. 10/6). This Carnian phase of high detrital input corresponds to a major regressive phase which caused the emersion of the Esino Platform to the east and can be observed across the entire Southern Alps (Jadoul & Rossi 1982).

Acknowledgements

This study was possible thank the collaboration of the Paleontological Institute and Museum of the University of Zürich (director H. Rieber), the Natural History Museum Lugano (M. Felber), T. Bürgin, who described the fossil fishes and D. Bionda, student of the Geological Institute of the ETH Zürich under direction of D. Bernoulli and J. McKenzie. Financial support for field work and publication was granted by the Dipartimento del Territorio del Canton Ticino. U. Oberli (St. Gallen) provided information on his findings in 1971 and A. Tintori (Milano) was very helpful by many informations and stimulating discussions during field trips to the localities near Meride and Ca' del Frate. I would like to thank for the help of D. Bionda, W. Brinkmann, D. Cook, M. Hebeisen, J. Huber, H. Lanz, E. Premru and S. Sägesser during the field work. The fossils were prepared by M. Hebeisen and H. Lanz, who also provided the photos. W. Schatz drew the illustrations. The manuscript was improved by corrections and critical comments of J.-P. Beckmann, S. Bernasconi, D. Bionda, H. Rieber (Zürich) and A. Tintori (Milano).

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Manuscript received April 28, 1995
Revision accepted August 17, 1995