Upper Triassic Tethyan Carbonates off Northwest Australia (Wombat Plateau, ODP Leg 122)

RÖHL, Ursula, *et al.*

Abstract

Leg 122 of the Ocean Drilling Program (ODP) recovered Upper Triassic (Carnian to Rhaetian) sediments at the sediment-starved passive continental margin off Northwestern Australia. The early-rift series at the Wombat Plateau, a northern sub-plateau of the Exmouth Plateau, consists of Upper Triassic fluviodeltaic siliciclastics and shallow-marine carbonates including reefal facies. Twenty-five microfacies types could be distinguished. These sequences are capped by an erosional "post-rift unconformity" with a 70 m.y. hiatus during the Jurassic. The Wombat Plateau bears only a thin post-rift sedimentary cover of Cretaceous to Cenozoic age. The Carnian and Norian sequences are dominated by fluviodeltaic sediments that contain many carbonate intercalations. Their frequency and the kind and amount of allochems allow the reconstruction of a storm-influenced deltaic to prodeltaic environment with restricted estuarine (intradeltaic) lagoons and high-energy carbonate sand shoals in front of the delta lobes. The presence of the foraminifers Triasina berhauseri and Triasina hantkeni in Sites 761 and 764 indicate a Norian to Rhaetian [...]

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Upper Triassic Tethyan Carbonates off Northwest Australia (Wombat Plateau, ODP Leg 122)

Obertriassische Karbonate der Tethys vor Nordwest-Australien (Wombat Plateau, ODP Leg 122)

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KEYWORDS: MICROFACIES – FORAMINIFERS – REEF – FACIES MODEL – CARBONATE RAMP – SEQUENCE STRATIGRAPHY – RIFT-TECTONICS – SEA-LEVEL CHANGES – PASSIVE CONTINENTAL MARGIN – TETHYS –WOMBAT PLATEAU – EXMOUTH PLATEAU – NW AUSTRALIA – UPPER TRIASSIC (CARNIAN-RHAETIAN)

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SUMMARY

Leg 122 of the Ocean Drilling Program (ODP) recovered Upper Triassic (Carnian to Rhaetian) sediments at the sediment-starved passive continental margin off Northwestern Australia.

The early-rift series at the Wombat Plateau, a northern sub-plateau of the Exmouth Plateau, consists of Upper Triassic fluviodeltaic siliciclastics and shallow-marine carbonates including reefal facies. Twenty-five microfacies types could be distinguished.

These sequences are capped by an erosional 'post-rift unconformity' with a 70 m.y. hiatus during the Jurassic. The Wombat Plateau bears only a thin post-rift sedimentary cover of Cretaceous to Cenozoic age.

The Carnian and Norian sequences are dominated by fluviodeltaic sediments that contain many carbonate intercalations. Their frequency and the kind and amount of allochems allow the reconstruction of a storm-influenced deltaic to prodeltaic environment with restricted estuarine (intradeltaic) lagoons and high-energy carbonate sand shoals in front of the delta lobes.

The presence of the foraminifers *Triasina oberhauseri* and *Triasina hantkeni* in Sites 761 and 764 indicate a Norian to Rhaetian age. The reefal platform can be differentiated in a lagoon to patch reef environment with abundant Aulotortidae, and a patch reef to shelf zone with smaller foraminifers.

The 'Rhaetian' starts with a global sequence boundary. Several shallowing-upward cycles from bioturbated wackestones to dolomitic algal bindstones suggest a shallow-subtidal to intertidal environment at Site 761. Typical reef development was observed at the more 'distal' Site 764. The limestone-marl alternations of the open marine shelf grade into local bioclastic and oolitic grainstones, which are the base for the incipient carbonate buildup. Calcisponge patch reefs developed into

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coral reefs. Several cycles characterize a 'catch-up' system grading into a 'keep-up' carbonate system. The reef growth ended abruptly with the second sequence boundary (211 Ma after HAQ et al., 1987), coinciding with the worldwide latest Rhaetian sea level fall, followed by renewed transgression.

By comparison with Upper Triassic carbonates of the western Tethys (e.g., the Northern Calcareous Alps), several microfacies types could be combined to characteristic facies units: biolithite facies, different reef talus types, grapestone-oncoid facies, and calcareous algae-foraminifera detritus facies showing the reef-backreef/fore-reef-lagoon transitions.

Detailed investigations of microfacies, wireline logs and high-resolution seismics allow the determination of depositional sequences (sequence stratigraphy). We distinguish influences of regional or global tectonics and/or eustatic sea-level changes. The results show that regional tectonic movements are of minor importance in the Rhaetian and that the HAQ et al. (1987) cycle chart could also be used at the passive margin of Northwest Australia.

1 INTRODUCTION

The Wombat Plateau is a small tilted horst at the NW Australian continental margin, which is separated from the northern Exmouth Plateau by a half graben (Figs. 1 and 2). We investigated sediment material from Ocean Drilling Program (ODP) Sites 759, 760, 761, and 764, with the objective to study Upper Triassic facies evolution during the early rift history of this northeast Gondwanan continental margin (VON RAD et al., 1989).

The discovery of a 200-m-thick Rhaetian reef complex at Site 764 is the first discovery of Upper Triassic reefal material offshore Northwest Australia. This gives us the opportunity to compare this sequence with other time-equivalent (non-reefal) Tethyan sections deposited north of Gondwanan continental fragments, such as the Tethyan Himalaya (cf. GRADSTEIN et al., 1989) and the Timor-Papua-New Guinea microplates (cf. KRISTAN-TOLLMANN, 1986).

According to the DNAG-GSA (Decade of North American Geology - Geological Society of America) scale, the Rhaetian is no longer seen as a 'stage', because it represents only one ammonite zones (*Choristoceras marshi*). In the HAQ et al. (1987) cycle chart the Rhaetian represents two ammonite zones (*C. marshi* and *Rhabdoceras suessi*). But because there is no unambiguous definition for the European Triassic (see WIEDMANN et al., 1979), the use of the term 'Upper Norian' for our 'Rhaetian' strata become mixed up with the former Upper Norian. Since an important aspect of the Wombat Plateau investigations is the comparison with the Triassic of the western Tethys areas, we prefer to retain the term 'Rhaetian' with the proviso that it is used as loosely defined stratigraphic term for the uppermost part of the Norian stage.

The four drillsites recovered a 900 m thick composite sequence of Carnian to late 'Rhaetian' age (HAQ, VON RAD, O'CONNELL et al., 1990). Sites 759 and 760 contain Carnian to Norian fluviodeltaic to shallow-marine sequences. Intertidal to subtidal sediments with incipient calcisponge patch reefs characterize the Rhaetian of Site 761. The interfingering between lagoonal and reefal facies is reflected in the Rhaetian of Site 764. The term 'reefal' in this paper summarizes the environmental areas with corals and calcisponges: coral/calcisponge reefs, patch reefs, isolated coral buildups and coral biostromes. The main objectives of the present paper are (1) the analysis of microfacies, (2) the reconstruction of the paleoenvironment, as controlled by tectonics, climate and sea-level changes, and (3) western - eastern Tethys relationships. This study attempts to expand and synthesize several individual papers which are in press in the Scientific Results of the Proceedings of the Ocean Drilling Program: DUMONT (in press) studied the wireline logs and the tectonic evolution of the Wombat Plateau in detail, RÖHL et al. (in press) the diagenesis of the Triassic Wombat Plateau limestones, von RAD et al. (in press) the rift-to-drift history of the Wombat Plateau, and ZANINETTI et al. (in press) the Triassic foraminifers.

2 STRUCTURAL AND STRATIGRAPHIC SETTING

The small Wombat Plateau horst has a water depth of about 2000 m. It is a northward tilted fault block, situated at the northern edge of the Exmouth Plateau (Fig. 1).

The N - S profile across Wombat Plateau shows a conspicuous 'post-rift unconformity' (PRU), which cuts out the Jurassic section. The PRU is underlain by block-faulted Permian to Triassic sediments, which due to the northward tilt of the fault block, become progressively younger northward (Fig. 2). The four ODP sites penetrated a composite thickness of 900 m of Upper Triassic series.

The more than 270 m-thick section of Carnian sediments consists of prodelta mudstones, deltaic marginal-marine mudstone, coal, and associated by shallow-water carbonate intercalations. Norian sediments are 330 m to almost 1000 m thick and consist of several shallowing- upward sequences deposited in shallow-marine, paralic, and coastal plain environments (ITO et al., in press). The northward thickening wedge of fluviodeltaic sediments shown in the seismic profiles suggests a progressively more distal (prodelta) character between Sites 760 and 761 (SARTI, in press). The Rhaetian shallow-water carbonates and part of the Norian strata were eroded south of Site 761 (Figs. 2 and 9). Their thickness ranges from about 170 m in Site 761 to 240 m in Site 764. High-resolution seismic reflection data calibrated by Sites 761 and 764, detected several reef complexes indicated by low-reflectivity and blanking of seismic energy (WILLIAMSON et al., 1989, WILLIAMSON, in press). Associated lagoonal or reef-detritus facies was recognized by downlapping reflectors around the seismically detected slender reef cores.

The Wombat Plateau is a tectonic horst that was faulted by various Permian to Late Triassic rift phases. The horst was then uplifted and subaerially eroded during a major post-Rhaetian (probably Mid-Jurassic, Callovian - Oxfordian) rift phase (von RAD et al., in press). A thin sequence of 250 m post- breakup sediments overlies the post-rift unconformity: A condensed hemipelagic 'juvenile ocean

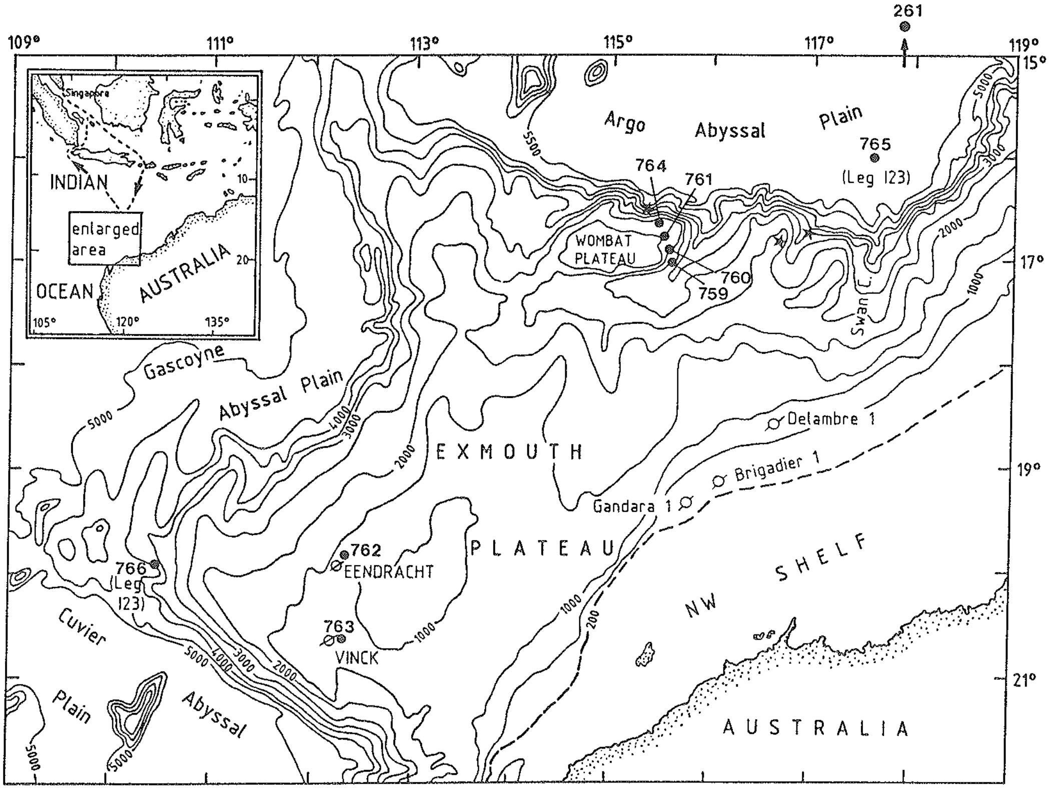


Fig. 1. Location map of ODP sites on Exmouth Plateau and vicinity. The stars show the location of SO-8 and RS-56 dredge samples discussed in text

section' of Early Cretaceous age is overlain by eupelagic carbonates of Late Cretaceous to Cenozoic age.

3 LITHOSTRATIGRAPHY OF THE UPPER TRIASSIC CARBONATES

3.1 Carbonates in the Carnian and Norian of Sites 759 and 760

Sites 759 and 760 are 5 km apart and located at the southeastern flank of Wombat Plateau (Fig. 1). The Upper Triassic section is 268 m thick at Site 759, and 420 m thick at Site 760.

Claystones, siltstones, sandstones, and several shallow-water carbonate intercalations characterize the Carnian and Norian of both sites. The ages of these delta-dominated sequences were determined by palynomorphs, nannofossils, ostracodes and foraminifers (Brenner et al., in press). The frequency and percentage of allochems in the limestones increase from bottom to the central part of each site, indicating an upward shallowing of the depositional environment. The upper Norian section is dominated by sandstone/siltstone alternations without carbonate intercalations. This sequence is described in detail by Haq, von Rad, O'Connell et al. (1990), Röhl et al. (in press), Ito et al. (in press), and summarized by Fig. 3.

We distinguish three main genetic limestone types: (1) Algal mats and patch reefs occurred within areas that were protected from siliciclastic dilution. (2) The second most important limestone types are bioclastic sands (grainstones), which contain fragments of calcareous algae, oncoids and ooids, interpreted as components washed together on shoals. (3) Limestones showing erosive bases and grading of allochems, are interpreted as storm deposits (Fig. 4). These limestones often contain a large amount of quartz grains, large, broken pelecypod shells and crinoid fragments.

3.2 Stratigraphic evolution of the Rhaetian carbonates at Sites 761 and 764

Site 761 penetrates the central part of Wombat Plateau, approximately 20 km south-southeast of Site 764, located near the northeastern flank of the plateau. The Rhaetian section at Site 761 is 180 m thick, that at Site 764 240 m thick. A satisfactory chronostratigraphic subdivision of this interval is difficult due to poor core recovery (5-10 %) and to a lack of suitable zonal markers. The limestones contain *Megalodon* shells and *Triasina hantkeni* Majzon. The sediments are determined as Rhaetian by Brenner et al. (in press), Bralower et al. (in press), and Dèpêche & Crasquin-Soleau (in press).

The early Rhaetian transgression is documented in Site 761 by the change from fluviodeltaic claystones to marine marl/limestone alternations. This site developed into an intertidal carbonate flat to lagoon environment, which graded into a sand shoal facies associated with patch reefs in a lagoonal setting. Site 764 contains typical features of reef development with several lagoonal/reefal cycles.

3.2.1 Site 61

We retained the shipboard lithological units (Haq et al., 1990) shown in Fig. 5A, left column, VI to IV.

Unit VI (422.4 - 436.7 meters below sea floor (mbsf))

The Norian of Site 761, Core 33R consists of black silty

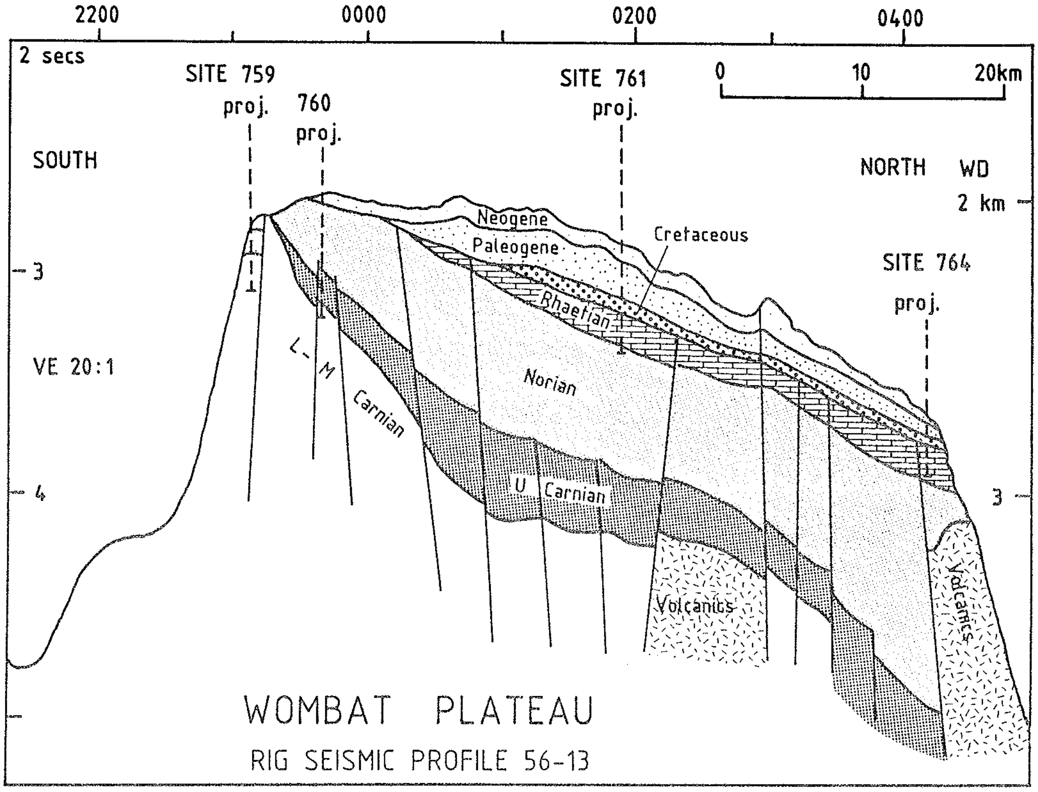


Fig. 2. Interpreted multichannel seismic section across Wombat Plateau and location of ODP Sites 759, 760, 761 and 764. The Wombat Plateau is a tectonic horst that was uplifted, tilted, and eroded during a major Jurassic rifting phase. Time marks are given in the upper scale

claystone with coal. These sediments were probably deposited in a fluviodeltaic environment with coal swamps ('coal-measure sequence').

Unit VB (399.3 - 422.4 mbsf)

The Rhaetian section at Site 761 starts with a sandstone, overlying claystone and coal of the Norian delta plain facies (Fig. 5). It is overlain by dark, laminated claystone with intercalations of crinoidal limestone. The allochems were derived from areas where a rich benthonic and sessile fauna flourished. We found grainstone, packstone, and floatstone with pelecypod shells, foraminifers, coated grains and calcisponge fragments. This facies association suggests shallow-subtidal water depths. The association with dark, laminated claystones suggests a restricted, oxygen-depleted environment with allochthonous limestone intercalations. The incipient development of a patch reef in a lagoonal environment is shown in the upper part of Unit VB (Core 122-761C-30R). There we found coral-algal (corallinacean) and sponge boundstone to floatstone. This drill site is characterized by strong dolomitization, accompanied by the typical iron oxide enrichment (reddish color).

Unit VA (338.3 - 399.3 mbsf)

The lower limestone-dominated part of the marl/limestone alternation of this unit consists of wacke- to packstone with echinoderm (mostly crinoid) fragments. Grainstones at the top of this sub-unit lead to of the middle part of Unit VA, where mudstone and marlstone alternate with partly bioturbated wackestone and packstone.

The uppermost section of Unit VA contains wackestone to floatstone with calcareous algae fragments and oolitic packstone to grainstone.

Unit IV (259.5 - 338.3 mbsf)

This section consists of wackestone to packstone. Peloids and foraminifers are more abundant than in the underlying unit. Besides the dominance of different foraminifers and peloids, the amount of pelecypod and echinoderm fragments is less.

We found several shallowing-upward cycles from bioturbated wackestone to foraminiferal peloidal wackestone and dolomitic algal bindstone in Cores 122-761C-16R to 15R (Fig. 5). The overlying part consists of foraminiferal packstone, wackestone, and grainstone. This section documents the repeated shifting between the intertidal and shallow-subtidal (lagoonal) depositional settings.

3.2.2 Site 764

Unit VII (280.15 - 294.5 mbsf)

The lowermost unit consists of an alternation of highly bioturbated marl, dark clayey carbonate mudstone, and mud- to wackestone (Fig. 5). Because dolomitization of limestones is very common, most components in the wackestone were destroyed, although some residual pelecypod and echinoderm fragments could be identified.

Unit VI (79.5 - 280.15 mbsf)

The upward increase of allochems from Unit VII to Unit

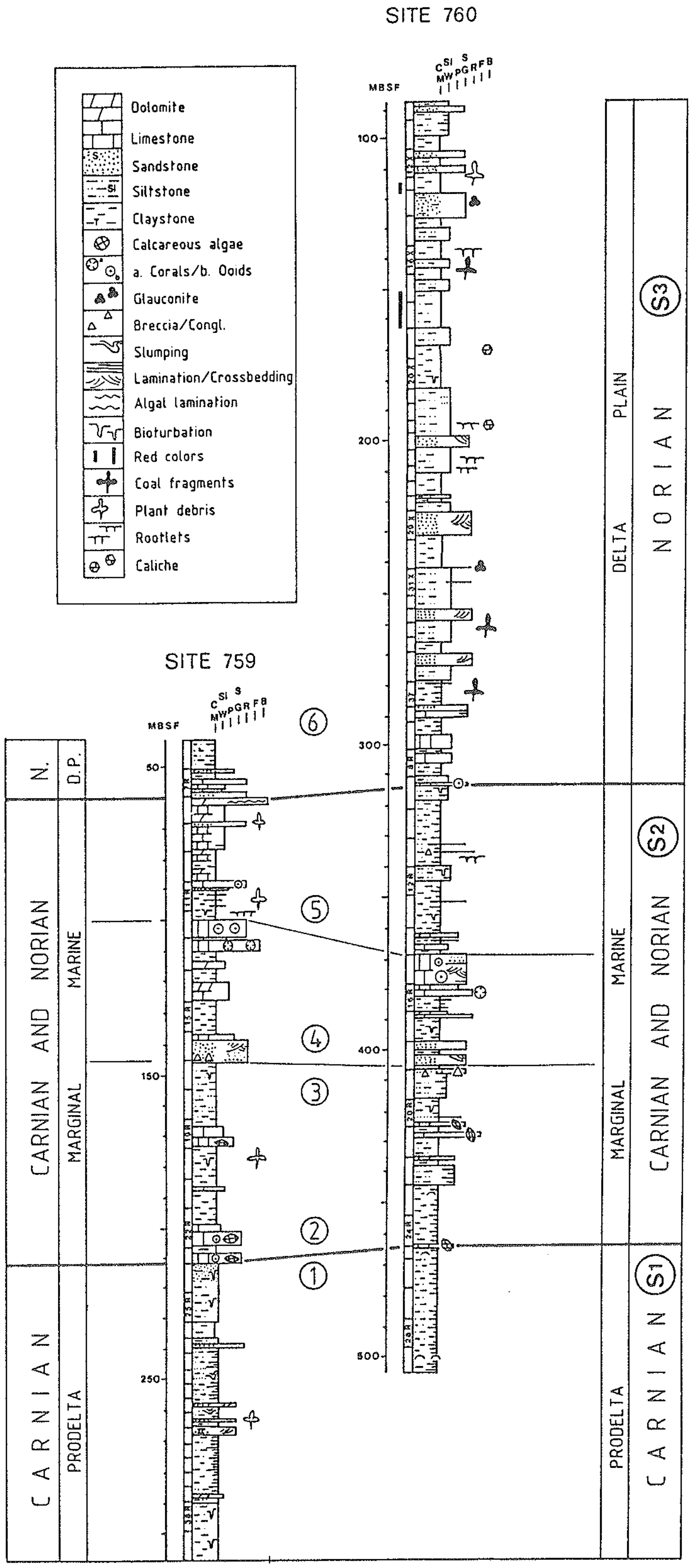


Fig. 3. The Carnian and Norian in Sites 759 and 760. Several limestones are intercalated within the siltstone-claystone-sandstone background of the lower (prodeltaic), and middle (marginal-marine) parts. Note the conglomerate beds at 145 mbsf (meters below sea floor) in Site 759

VI and the occurrence of oolites created a relatively firm substrate favorable for the development of reefs.

The first patch reefs (Core 122-764B-30R to 29R) were formed by calcisponges and interfinger with skeletal pack- to floatstone. Reef cycles that are defined as grainstone-floatstone-boundstone transitions, were found at four intervals in Cores 122-764B-24R to 122-764B-11R (Fig. 5). Back-reef (shelf-lagoonal) and fore-reef sediments are intercalated between the reefal facies.

Unit V (55.9 - 79.5 mbsf)

Alternations of marl and limestone characterize this unit. The limestones of Unit V consist of skeletal packstone with crinoid and brachiopod fragments and sponge spicules, and of peloidal, bioturbated wackestone with foraminifers (including *Triasina hantkeni* Majzon).

Unit IV (50.0-55.9 mbsf)

Triasina hantkeni Majzon and crinoid fragments are very abundant in the uppermost Rhaetian sequence. Due to the high recrystallization, it is difficult to recognize the primary fabric and to determine depositional microfacies types. Unit IV is capped by a major disconformity, the 'post-rift unconformity' (PRU).

Several decimeters to meters below the top of the Rhaetian we observed a few decimeter thick horizon characterized by iron and manganese oxide lamination, a few decimeters thick, which reflects a post-sedimentary reduction/oxidation boundary. Together with increasing porosity, chalkification and dedolomitization to the top of the sites this lead us to interprete this horizon as a fossil water-table/groundwater level produced by a fresh-water lens (Röhl et al., in press). During the Jurassic the whole sediment pile was affected by meteoric-phreatic (to vadose?) diagenesis (Röhl et al., in press). These observations add important arguments in favor of a post-Rhaetian uplift of Wombat Plateau and of erosion/nondeposition conditions during the Jurassic.

The Rhaetian sequence was subsequently buried by the overlying post-rift deposits. Tentatively, we assume a maximum burial depth of less than 500 m (Lower Jurassic? sediments, now eroded, plus 250 m of Cretaceous to Recent sediments).

4 MICROFACIES AND PALEOENVIRONMENT

4.1 Microfacies types of Upper Triassic shallow water carbonates (Carnian to Rhaetian)

Although carbonates were affected by strong diagenetic alteration, we were able to distinguish 25 main microfacies types which are documented in about 354 samples. This was possible by studying all transitions between preserved and totally disturbed biogenic structures and sedimentary textures (Fig. 6).

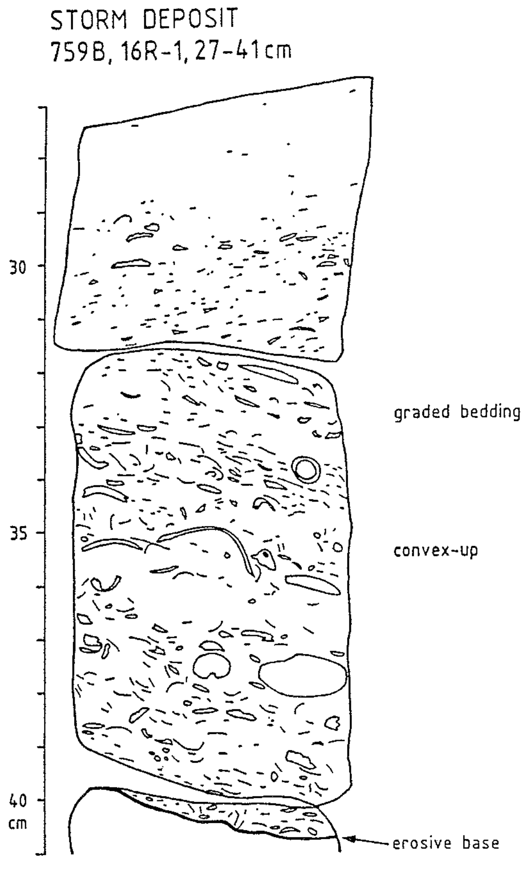


Fig. 4. Line drawing of a core photograph of a Norian storm deposit or tempestite (sample 122-759B-16R-1, 25-40 cm). The short duration of the event is shown by the erosional base, overlain by chaotic bedding, and then the convex-upward position of pelecypod and brachiopod shells. The indistinct grading of components reflects a short, high-energy event with upward-wanning transport velocities.

Based on depositional textures, grain size and biota, we describe each microfacies type briefly and interprete its depositional environment. We used, according to the content of allochems, an extented version of the DUNHAM (1962)-classification and the methods described by FLÜGEL (1982) and WILSON (1975).

MFT 1: Mudstone

This microfacies type consists of micrite with some detrital quartz grains. It is extremly rare and occurs mainly in the Carnian and Norian of Sites 759 and 760. These sediments were deposited in a low-energy, estuarine-lagoonal environment. In Sites 761 and 764 their association with other microfacies types suggests a more open-marine environment.

MFT 2: Bioturbated Wackestone

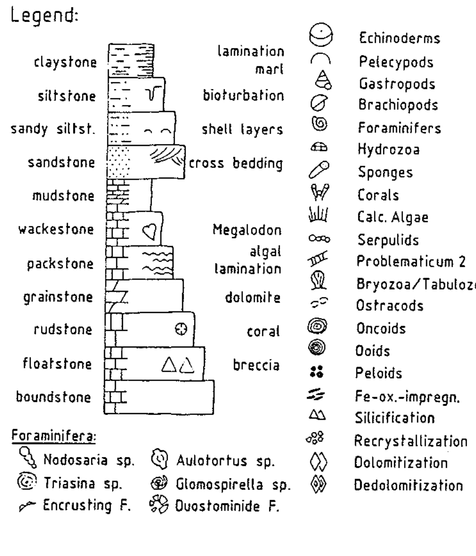
The allochems consist of large (up to 2.5 mm), thin-walled, unbroken shells of pelecypods, nodosariid foraminifers (10-15%), small echinoderm fragments (5-10%) and some pyrite framboids. About 10 - 40% of the components are formed by peloids (150 µm, probably fecal pellets). The primary fabric was strongly disturbed by bioturbation (Pl.60/8). The bioturbated areas contain more thin-shelled pelecypods (40%) and ostracodes (40%) than the non-bioturbated ones. Due to diagenetic recrystallization of micrite to microspar, porosity values rise to 40% by volume (Pl. 56/2). This microfacies type is similar to the standard microfacies type (SMF) 9 of WILSON (1975) and characterizes a restricted depositional environment within a shelf-lagoonal setting. If sponge spicules occur, a more open shelf environment might be possible.

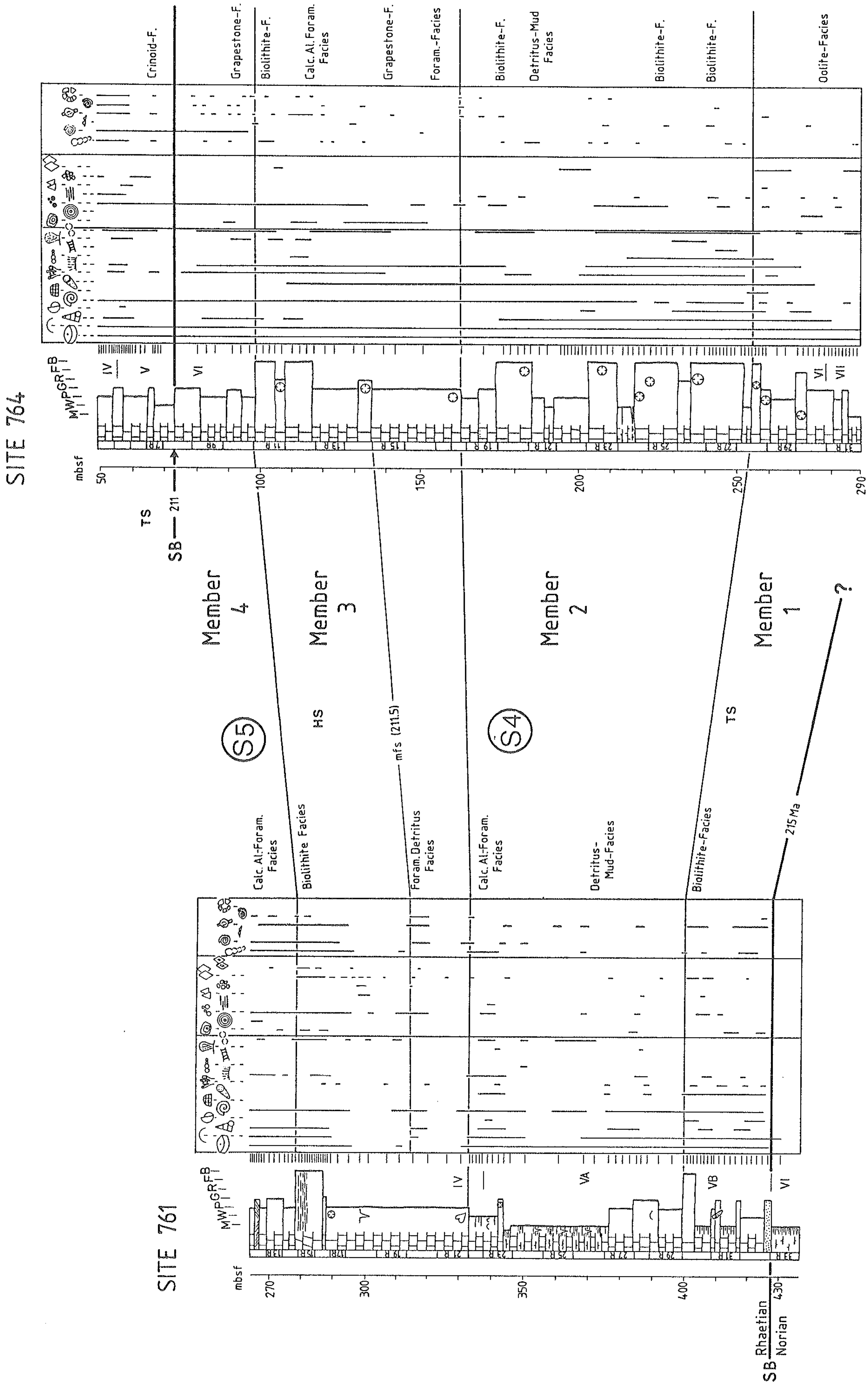
MFT 3: Foraminiferal Wackestone

Within the micritic matrix, large, recrystallized shell fragments and peloids (30% of the allochems) form the main constituents; echinoderm fragments are minor elements. Foraminifers of late Triassic age were found in large numbers and high diversity (see Chapter 5). Due to the predominance of the groups '*Triasina*', 'Involutinidae' and 'Duostominidae/Lagenidae' we distinguish the sub-microfacies types 3a, b und c (Pl. 61/5-10; Pl. 62). Accessory allochems are ostracodes. Dependent on the interfingering with other microfacies types, ooids, fragments of codiaceans and up to 10% quartz may be present; bioturbation is common. The allochems, mainly the foraminifers are moderately to well sorted. Similar foraminiferal limestones were described from the Rhaetian at the Steinplatte (Northern Calcareous Alps) by STANTON & FLÜGEL (1989; their Plates 47 to 50), from the Salzburg area by SCHÄFER & SENOWBARI-DARYAN (1981; their Fig. 6), and from the Calcare di Zu (Southern Alps) by LAKEW (1990; his Plates 39 and 40).

Depositional environment: The large amount of foraminifers, the massive to weakly bioturbated fabric, the mostly small particle size and close spatial relation to other typical microfacies types suggest a lagoonal depositional setting.

Fig. 5. >>>
Correlation of Sites 761 and 764 according to their microfacies and sequential evolution. The biogenic and abiogenic allochems and some diagenetic features are plotted against the lithological column. Further explanations, see text. SB = Sequence boundary S4, S5 = Rhaetian sequences, TS = Transgressive systems tract, HS = Highstand systems tract, mfs = maximum flooding surface, mbsf = meters below sea floor (modified after DUMONT, in press, and RÖHL et al., in press).




SITE 764
mbsf
50
100
150
200
250
290
MWPGRFB
IV
V
VI
VII
Crinoid-F.
Grapestone-F.
Biolithite-F.
Calc. Al. Foram. Facies
Grapestone-F.
Foram.-Facies
Biolithite-F.
Detritus-Mud Facies
Biolithite-F.
Biolithite-F.
Oolite-Facies
SB
TS
211
Member 4
Member 3
Member 2
Member 1
S5
HS
mfs (211.5)
S4
TS
215 Ma
?
SITE 761
mbsf
270
300
350
400
430
MWPGRFB
IV
VA
VB
VI
Calc. Al.-Foram. Facies
Biolithite Facies
Foram. Detritus Facies
Calc. Al.-Foram. Facies
Detritus-Mud-Facies
Biolithite-Facies
SB
Rhaetian
Norian

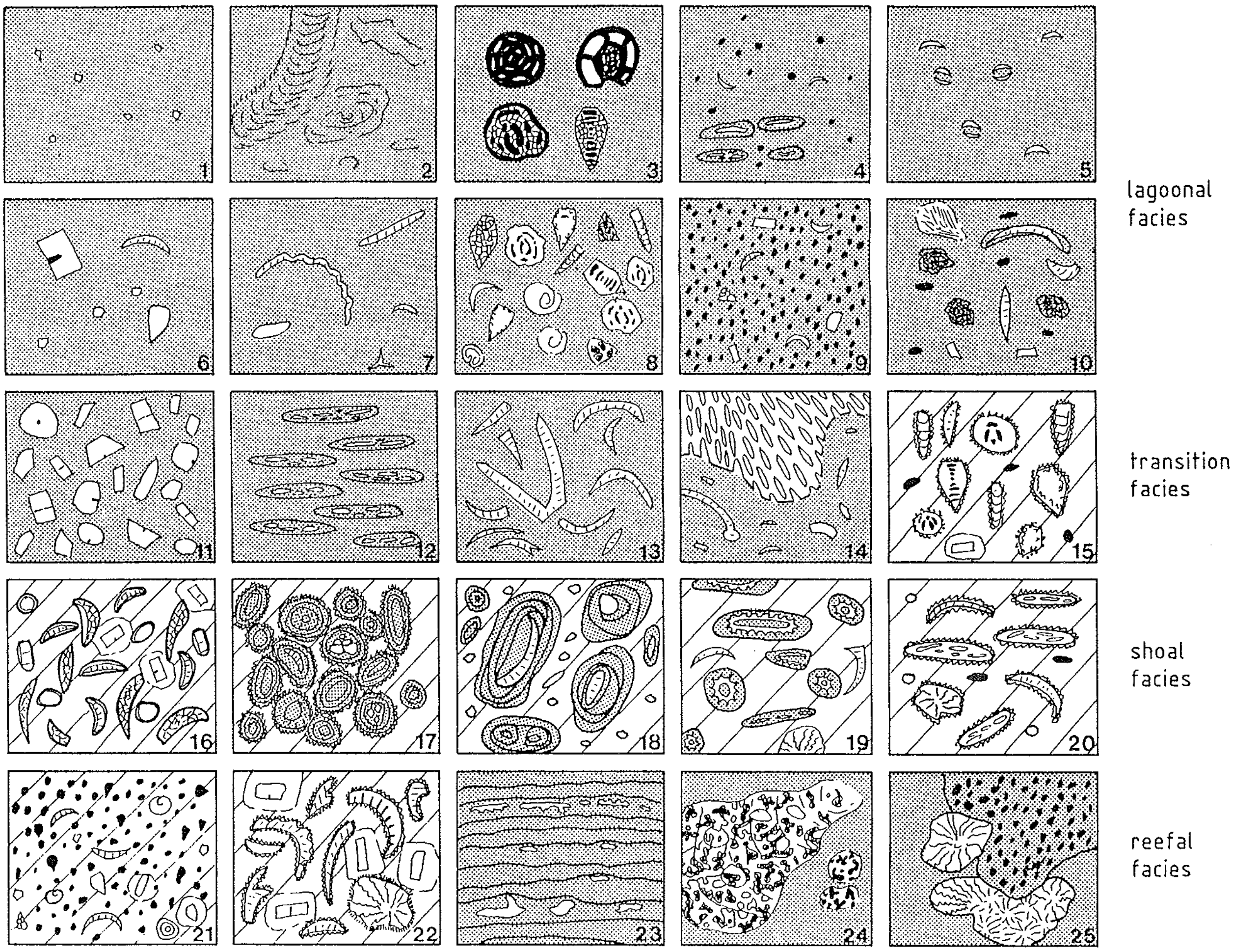


Fig. 6. Sketch of the 25 Upper Triassic microfacies types (MFT) observed in the Wombat Plateau drillsites. Not to scale

MFT 4: Wackestone

Due to the close spatial relationship, we combine two microfacies in this group: the facies of the peloidal (4a) and coated grain wackestones (4b).

MFT 4a: Peloidal Wackestone

The allochems (20 to 30%) consist of up to 70% peloids with diameters between 40 and 80 µm. The peloids are very well sorted and concentrated in mm-fine parallel laminae that were probably produced by bottom currents. The peloids are interpreted as 'micro-intraclasts', i.e., products of resedimentation (cf. Tucker & Wright, 1990). Due to recrystallization of the matrix, there is a gradual transition to the surrounding micrite. Subordinate biogenic components are strongly recrystallized coral fragments, ostracodes, foraminifers (see MFT 3), small fragments of pelecypod shells, and very small echinoderm fragments. Dolomitization is rare to absent, porosity less than 2%.

The composition of this wackestone suggests deposition in a lagoonal environment with episodic influence of bottom currents, similar to the protected parts of the Bahama platform (e.g., Bight of Abaco; Neumann & Land, 1975).

MFT 4b: Coated Grain Wackestone

This wackestone contains coated, rounded bioclasts ('cortoids', Flügel, 1982) (Pl. 60/7). They consist of echinoderm fragments and highly altered, elongated fragments of codiaceans. Minor amounts of mollusc fragments and subrounded quartz grains (300-600 µm) were also observed.

This microfacies type was deposited in a restricted depositional environment, into which quartz and biogenic allochems were transported from nearby shallow-water areas. It is comparable to the standard microfacies type (SMF) 10 of Wilson (1975).

MFT 5: Ostracode Wackestone

Allochems making up 20 to 30% of the rock float in a micritic matrix. They consist of 40% ostracodes, 10% coral debris, and 10% echinoderm fragments and pelecypod shells (thin-shelled and fragmented, filaments).

Foraminifers (*Aulotortus* sp.) are rare. Some inhomogenities in the fabric are due to bioturbation. This type shows no cementation and rare porosity.

The depositional environment was a restricted area behind a reef or sand shoal.

MFT 6: Echinoderm Wackestone

Allochems form about 20 to 40% of the whole rock. They consist mainly (50 to 70%) of poorly sorted echinoderm fragments ranging from 150 to 1200 µm. The second group

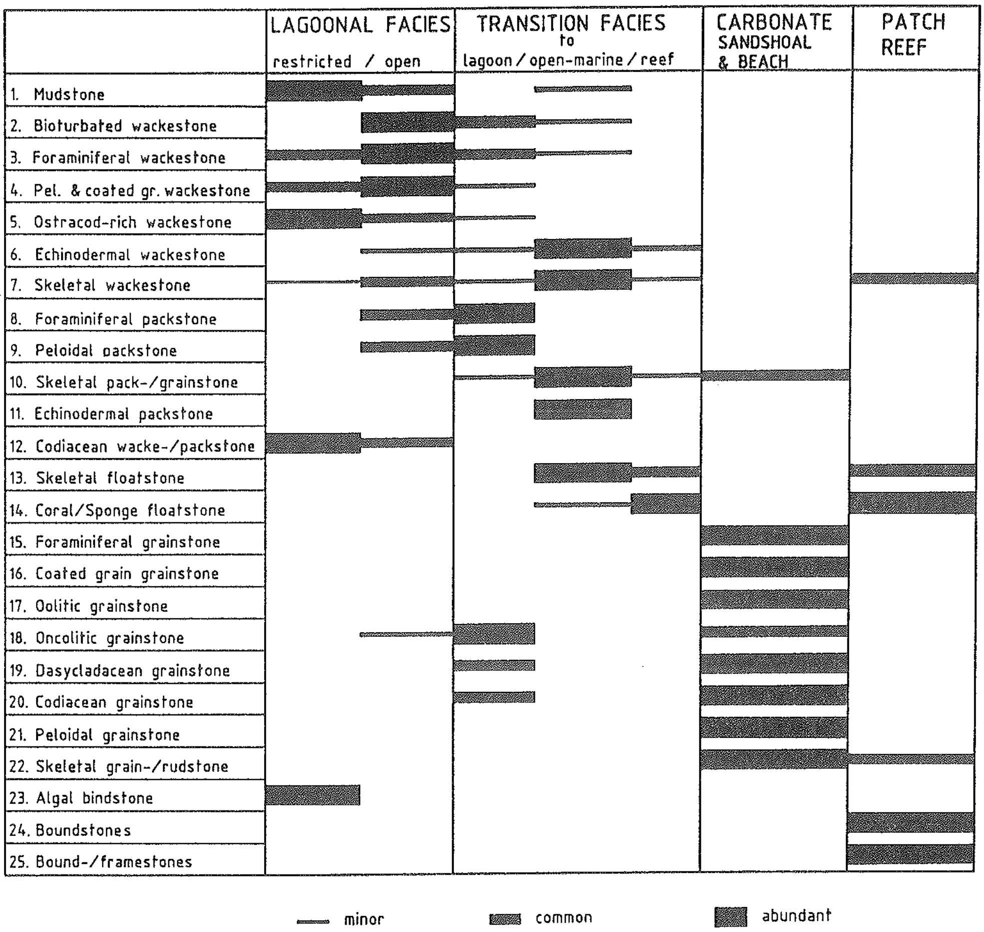


Fig. 7. Microfacies types (MFT) and their distribution in different facies zones.

of allochems consists of sponge fragments, which were strongly altered (sparitized or dissolved). Whole gastropods, pelecypod fragments and duostomid foraminifers form the remaining allochems in equal amounts. Ostracodes are rare.

Due to the abundance of large skeletal and sponge fragments, we assume a depositional environment close to a reef, either in a fore-reef or back-reef setting.

MFT 7: Skeletal Wackestone

The amount of allochems ranges from 15 to 40%. Allochems consist mainly of bioclasts (Pl. 56/6): pelecypod and brachiopod shells, coral, calcisponge and crinoid fragments, sponge spicules, ostracodes, serpulids, calcareous algae, and foraminifers. Additionally, poorly sorted peloids occur. Terrigenous quartz is rare. The biogenic allochems were sparitized or dissolved. Depending on the amount and primary composition of components, the porosity (mostly moldic) ranges from 2 to 20%. Cementation is restricted to the molds and is made up of even-rim, scalenohedral and blocky calcite crystals. Dolomitization is largely restricted to a few scattered rhombs, but strong patchy dolomitization within the matrix was also observed. Intercrystal porosity developed during late dolomitization. In some cases dolomite crystals have dissolved nuclei (dedolomitization), because of the variations in chemical composition of central and outer zones of the rhombs.

On the basis of the lack of predominance of distinct groups of biogenic allochems, we assume that these skeletal wackestones were deposited in a range of shallow, but calm-water environments, mainly in a lagoonal setting. If crinoid fragments, sponge spicules and brachiopod fragments predominate, the sediments may have formed in the open shelf.

MFT 8: Foraminiferal packstone

Up to 60% by volume consists of foraminifers. We distinguish three sub-types. Besides peloids, pelecypods and brachiopod shells, gastropods and ostracodes are present. The foraminiferal packstone forms a transition between MFT 4 (foraminiferal wackestone) and MFT 15 (foraminiferal grainstone). The kind and the roundness of the biogenic allochems is responsible for the degree of sorting.

The paleoenvironment of this microfacies type is a depositional setting at a shoal.

MFT 9: Peloidal packstone (to partly grainstone)

The moderately sorted allochems (60%) consist of 50% peloids and 50% biogenic components (echinoderm fragments, pelecypod shells, and some foraminifers). Normally, the matrix consists of micrite, which was partly washed out (Pl. 58/6). The interparticle pores were closed by several generations of carbonate cements.

This microfacies type is restricted to highly agitated water environment transitional from a sand shoal to the open shelf. The sorting, roundness, and fine lamination suggest reworking of the sediment in a high-energy environment,

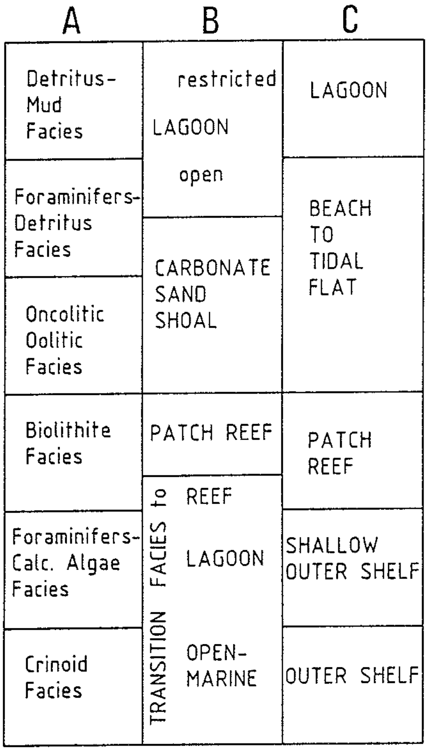


Fig. 8. Facies units and environmental interpretations (cf. DUMONT, in press (C); RÖHL et al., in press (B)) compared with the classification of facies zones (A), which we found in Wombat Plateau Triassic and which are first described by SENOWBARI-DARYAN & SCHÄFER (1981; Salzburg area, Western Tethys).

possibly a foreshore beach accretion. However, cements, that are in general typical for this environment and suggest meteoric-vadose conditions (e.g., meniscus cement and micro-stalactitic cement), were not observed.

MFT 10: Skeletal packstone to grainstone (partly grapestone facies)

About 40 to 60% of the particles, i.e. peloids, pelecypod shells, echinoderm fragments, foraminifers, algae (dasycladaceans, *Thaumatoporella*?) float in a micritic matrix or form a grain-supported fabric. The interstices between the particles are filled by micrite or cemented by spar. Invariably, the allochems show coatings or were cemented by algal activity. Moldic porosity is present up to 20% by volume. Diagenetic phenomena such as even-rim cement and scalenohedral cement, which are partly dissolved, are present in the molds.

The depositional environment was the windward side of a sand shoal. There are all transitions to both lagoonal and open marine skeletal wackestone (e.g., MFT 7). These sediments can be compared to the modern grapestone lithofacies of the Bahamas (TUCKER & WRIGHT 1990).

MFT 11: Echinodermal packstone

These rocks contain 40 to 60% allochems that consist mainly of echinoderm fragments (especially crinoids) and pelecypod shells (Pl. 60/1). Foraminifers, ostracodes, sponge fragments, and some quartz grains are also present. Porosity is commonly high. The molds are cemented by scalenohedral calcite. Dolomitization of the matrix and components is common. In some cases only the echinoderm fragments resisted this neomorphism. The lack of luminescence of the syntaxial cements in the Leg 122 grainstones suggests a meteoric-phreatic origin for these rims (RÖHL et al., in press).

This microfacies type is thought to have been deposited in a shallow and agitated marine environment above wave base. The echinoderm fragments, perhaps could also have been deposited below wave base from suspensions, which were produced by strong storm events. Storm deposits or 'tempestites' are characterized by an erosional base and graded bedding.

MFT 12: Codiacean wacke- to packstone

Up to 5 mm-long, elongated codiacean (udoteacean) fragments (*Boueina hochstetteri* TOULA 1883 and *B. hochstetteri* var. *liasica* LE MAITRE 1937) form about 50% of the allochems. Two types of preservation of codiaceans can be observed: either the branches were replaced by micrite, the area between the branches being microcrystalline spar, or the branches and the space between the branches were replaced by spar (Pl. 57/1). All codiacean fragments were surrounded by a dark micrite rim.

Large, thick-shelled mollusc fragments and echinoderms make up about 20% of the allochems, large oolitic extraclasts make up 15% by volume. All ooids in extraclasts were dolomitized. Peloids are well rounded and sorted; coral fragments and terrigenous quartz are also present.

The high percentage of large codiacean fragments in the micrite matrix suggests an environment within a lagoon or protected bay without detrital influx. Large extraclasts were derived from a high-energy environment with early dolomitization and high terrigenous influx and occur now within storm layers.

MFT 13: Skeletal floatstone

Up to 30% of the allochems are composed of sponge and echinoderm fragments and pelecypod shells (Pl. 60/2). Minor allochems are punctate brachiopod shells, some porostromate blue-algae (*Cayeuxia*?), red algae (*Solenopora*?) and rare foraminifers (*Nodosaria* sp.) and ostracodes; quartz grains are extremely rare. The large fragments float in a biomicritic matrix that contains small bioclasts (Pl. 60/3). Most sponges and pelecypods were recrystallized. Cements are restricted to cavities with geopetal fillings: the clear crystals are up to 600 µm across and have slightly serrated boundaries. Dolomite only occurs as scattered rhombs along fractures.

Based on the composition of the allochems and the homogeneous fabric, this microfacies type is believed to have been deposited in a lagoonal setting close to a patch reef or genuine reef.

MFT 14: Coral and calcisponge floatstone

The allochems (between 30 to 60%; mainly 40 to 50%) of the allochems float in a micrite matrix. Therefore, the porosity is restricted to molds created by dissolution of fossils (fabric-selective secondary porosity), which resulted in a progressive destruction of fossils. In the molds even-rim or scalenohedral cementation occur. The allochems are dominated by *Retiophyllia-* and *Astraeomorpha*-type coral fragments (SARTI et al., in press) and calcisponges (*Paradeningeria* sp.?, *Cryptocoelia* ?), which are rarely affected by strong diagenetic alteration (Pl. 61/1-4). The septae are coated by micrite envelopes, and the sclerites are dissolved. The spaces between the sclerae are filled by micrite, which is commonly totally recrystallized (clotted texture). In some specimens this microfacies type contains encrusting *Bullopora*-type foraminifers, which according to SENOWBARI-DARYAN (1980), are common in central reef areas. Calcareous algae (*Cayeuxia*?) encrust sponges; serpulids are also present. A microproblematicum, called 'Problematicum 2' by SCHÄFER (1979) is restricted to this microfacies type (Pl. 59/8).

This sediment is also characterized by differing amounts of pelecypod shells (5 to 30%, up to 1-2 cm long), echinoderm fragments (spines, crinoids, 10 to 30%), rare ostracodes and some quartz debris. The percentage of the allochems varies in both sites from bottom to top in a characteristic manner according to their facies association. Usually it is difficult to distinguish between allochthonous and authochthonous biogenic allochems.

MFT 14 interfingers with the boundstones of MFT 24 and 25 and is thought to be part of the reefal debris facies.

MFT 15: Foraminiferal Grainstone

Within this microfacies type, 40 to 60% by volume consists of allochems, and the interparticle space is filled by blocky calcite cement (Pl. 61/5). Porosity is restricted to molds. Biogenic components are foraminifers (see MFT 3), pelecypod shells and echinoderm fragments. Coral fragments, ostracodes, serpulids and algal lumps are rare. The trimodal size distribution of the allochems is due to the different sizes of foraminiferal species in the fractions. *Aulotortus sinuosus* and *A. tumidus* has its maximum size distribution between 0.6 mm and 1 mm together with a *Glomospira*-type foraminifer. *Triasina hantkeni* MAJZON is dominant in the coarser fraction (2-4 mm; Pl. 61/6). In this fraction, echinoderm fragments are also common. The small foraminifers are often strongly altered (dissolved, sparitized, or micritized). They were identified by their shape and size.

PURSER & SCHROEDER (1986) and MUSSMANN et al. (1988), suggest that dissolution may have been associated with decomposition of organic matter and organic maturation. According to MOORE (1989) the resulting pore types are generally solution-enlarged intergranular pores evolving into vugs. Moldic porosity, which is the main porosity type on Wombat Plateau, would be rare. The solution mechanism described by MUSSMANN et al. (1988) can nearly be excluded for Leg 122 carbonates.

Abiogenic components are peloids (40 to 60%), coated grains, intraclasts and some quartz debris. The moderately sorted and rounded components have indistinct outlines due to strong postdepositional diagenesis (recrystallization and neomorphism). The origin of the peloids is not clear. They are of spherical to elliptical micritic, well rounded particles with a diameter of 150-600 µm. The peloids are probably micritized allochems, which were later dolomitized.

The foraminiferal grainstone was deposited in a high-energy setting, e.g., on a shoal or beach, into which the lagoonal foraminifers were reworked.

MFT 16: Coated Grain Grainstone

Up to 5-mm-large bioclasts form a grain-supported fabric (Pl. 60/4). They consist of large, thick-walled shell fragments, some of which were heavily recrystallized, with micrite envelopes and drusy mosaic cements (Pl. 58/8). Large echinoderm fragments (50% of the bioclasts) are dominant. Possibly codiacean algae are also present.

Depositional environment: Sand shoal near a lagoonal setting, where the coated grains were derived from.

MFT 17: Oolitic Grainstone (Pl. 58/1-4)

About 60% of the allochems of this microfacies type consist of ooids with several types of nuclei. Eighty percent of the biogenic nuclei are echinoderm fragments ranging in size from 200 to 900 µm. The remaining nuclei of the ooids consist of gastropods and mollusc fragments and some foraminifers. The micritic coatings are up to 50 µm thick. In most cases we observed up to six concentric laminae within the rim. The thicker laminae show (diagenetic) radial fabrics, but the ooids are commonly strongly micritized. In some ooids we found evidence of compaction, such as outer concentric layers splitting from the central part, or distorted ooids.

The rock is almost completely cemented with two generations of cement (Pl. 60/6). Most probably, even-rim and blocky cement were strongly altered during a later diagenetic (meteoric?) phase, possibly associated with the formation of oomolds (Pl. 58/1, 4). Moldic pores are partly filled by dolomite cement with rhombs of 60 µm diameter. In some samples scalenohedral-type crystals were also observed. They consist of clear, columnar 'dogtooth' crystals that display unit extinction under crossed nicols. RÖHL et al. (in press) interprete scalenohedral crystals in Leg 122 samples as products of meteoric diagenesis.

The depositional environment of the oolitic grainstone was a high-energy shoal or sand bar with tidal currents similar to the modern submarine oolitic dunes of the Arabian Gulf (PURSER 1973), whereas an additional aeolian transport cannot be proved for the Wombat Plateau ooids. As indicated by quartz nuclei in ooids of Carnian-Norian age, these shoals were close to the shoreline.

MFT 18: Oncolitic Grainstone (Pl. 57/2)

Two different types of oncoids, up to 2 mm in diameter, form the main constituents of this microfacies type. The oncoids are characterized by different types and symmetries of the individual coatings (Pl. 58/7). Other allochems are fragments of brachiopods, echinoderms, pelecypods, gastropods, and corals which commonly form the cores of the oncoids. Terrigenous quartz makes up about 10% of the allochems. There are also some ooids, which have additional oncolitic layers. The allochems are surrounded by sparite, which has a more or less uniform grain size, but does not display several cement generations. Possibly, the sparite is due to recrystallization of a former micrite matrix (pseudosparite), or the cement was recrystallized (neosparite). This is supported by the presence of 'dirty' calcite crystals (Pl. 58/7).

Oncoids form in protected, shallow-water areas (lagoon or bay) with little water movement. The depositional environment may have been a back-reef lagoon, as indicated by coral debris and the low diversity of the fossils.

MFT 19: Dasycladacean Grainstone

This microfacies type is a poorly sorted grainstone with 15% dasycladaceans (Pl. 59/1), large coral fragments, intraclasts, and micritized ooids. Large elongate codiacean fragments, mostly completely altered, and coated mollusc shells form the remaining bioclastic allochems. Gastropods and echinoderms are rare.

The sediments were deposited in a high-energy environment close to a lagoon with codiacean and dasycladacean plants. Limestones with similar textures and biogenic allochems were described of the *Rhaetavicula contorta* beds in the Tuscanian Triassic by COCOZZA & GANDIN (1990: 23).

MFT 20: Codiacean Grainstone

Up to 1.2-cm-long, elongate, rounded fragments of codiaceans, are the major constituents that form a grain-supported fabric (Pl. 56/3). The codiaceans are of the Udotea-type (*Boueina hochstetteri* TOULA 1883 or *B. hochstetteri* var. *liasica* LE MAITRE 1937). The remaining allochems consist of well rounded, elongated peloids (fecal pellets?), surficial ooids, and former normal ooids (now as oomolds). Allochems are surrounded by even-rim cement with a rim thickness up to 20 µm.

This microfacies type was found only in the Carnian and Norian sections of Sites 759 and 760. The spatial association with siliciclastics suggests that the sediments were deposited in channels, that dissected the shallow-marine, fluviodeltaic-dominated platform. Allochems were derived and redeposited from nearby codiacean plants.

MFT 21: Peloidal Grainstone

About 60% of allochems form a very dense, grain-supported fabric. Fecal pellets and well rounded and sorted peloids (100 to 300 µm, 30% each) are the main constituents. The remaining 40% consist of foraminifers, echinoderms, gastropods, pelecypods, and algae. Because of their shape, at least some of the peloids probably originated from foraminifers by micritization or sparitization. The remaining peloids have a wide range of sizes and consist of micrite or microspar. Sometimes ooids are present, concentrated in up to 5 mm thick layers. Clastic allochems are mainly quartz grains. Volcanic rock fragments are rare. High porosity (up to 20% per volume) is due to interparticle (50%), intraparticle (5%), shelter (15%), and keystone vugs (Pl. 58/5).

As depositional environment we assume a setting in the shoal-lagoon transition. Sedimentary structures (e.g., current lamination) point toward phases of varying water energy. Therefore, shallow-marine sand shoals are a possibility. The association with other features or facies types of an intertidal environment (e.g., vuggy porosity and MFT 23 algal bindstone) suggests 'spit' or 'levee crest' sediments.

MFT 22: Skeletal Grainstone to Rudstone

This sediment contains 50% allochems, which consist of all biogenic and abiogenic particles described above (Pl. 56/5). Pelecypod and brachiopod shells and their fragments, as well as of algal lumps and aggregate grains (grapestone- and bahamite-facies) are predominant, however (Pl. 57/3). Early glauconitization and phosphatization (as rims) can also be observed. The grains are cemented by strongly recrystallized even-rim cement and clear, blocky cement (equant-shaped), with calcite crystals up to 120 µm. Syntaxial cement occurs around echinoderm fragments (Pl. 59/6). Shelter porosity and keystone vugs were also observed.

The composition and structure of this sediment suggest a high-energy environment, e.g., on a sand shoal (reef debris facies). This microfacies type grades into all other grainstone microfacies types and partly into some floatstone types.

MFT 23: Algal Bindstone

The irregular lamination was caused by the activity of cyanophycean algae (stromatolitic fabric) (Pl. 56/4). It contains thin shell fragments (ostracodes?), a few foraminifers, and mm-thin layers with concentrations of pseudomorphs of goethite/limonite to framboidal pyrite. Vuggy and fenestral porosity are also present.

The depositional environment was an intertidal, low-energy mud flat with anomalous salinity (low diversity of organisms). Modern but spectacular sediments with algal bindstones are known from the Shark Bay, Western Australia (TUCKER & WRIGHT, 1990).

MFT 24: Bafflestone and MFT 25: Framestones

Scleractinian corals, hydrozoans, calcisponges and tabulozoans/bryozoans contribute to the reef framework, which is formed by baffle- and framestones (Pl. 61/1-4). The modified DUNHAM-classification of EMBRY & KLOVAN (1971) was used to describe the reef fabric. Detailed paleontological and paleoecological studies of Leg 122 corals and calcisponges by SARTI et al. (in press) showed that the coral community assemblage constitutes the main core of a pinnacle reef complex. The lower part is dominated by *Retiophyllia* (Pl. 61/1) and the upper part by *Astraeomorpha* associations (Pl. 61/2). Most of the reef-builders act as important sediment-trapping and sediment-binding organisms. The interspaces between individuals or colonies were filled by micrite or biomicrite. Framebuilders (MFT 25) are less common in the Leg 122 cores. However, there exists a relationship between these two microfacies types, and therefore, also between their frame-building or sediment-baffling functions. Beneath the corals, calcisponges and the associated reef-organisms (see MFT 14), there are hydrozoans (*Disjectopora*?, *Spongiomorpha*?) (Pl. 57/4). The corals exhibit different stages of preservation, ranging from local sparitization to almost complete recrystallization. Sponges tend to be strongly recrystallized and partly dissolved. Therefore, it is difficult to determine the species. The biogenic allochems may be encrusted by serpulids or coated in place by a dark, micritic layer, presumably from cyanobacterial activity. Locally corals are the substrate for sponges that grew on them. Between individual coral branches, *Baccinella*

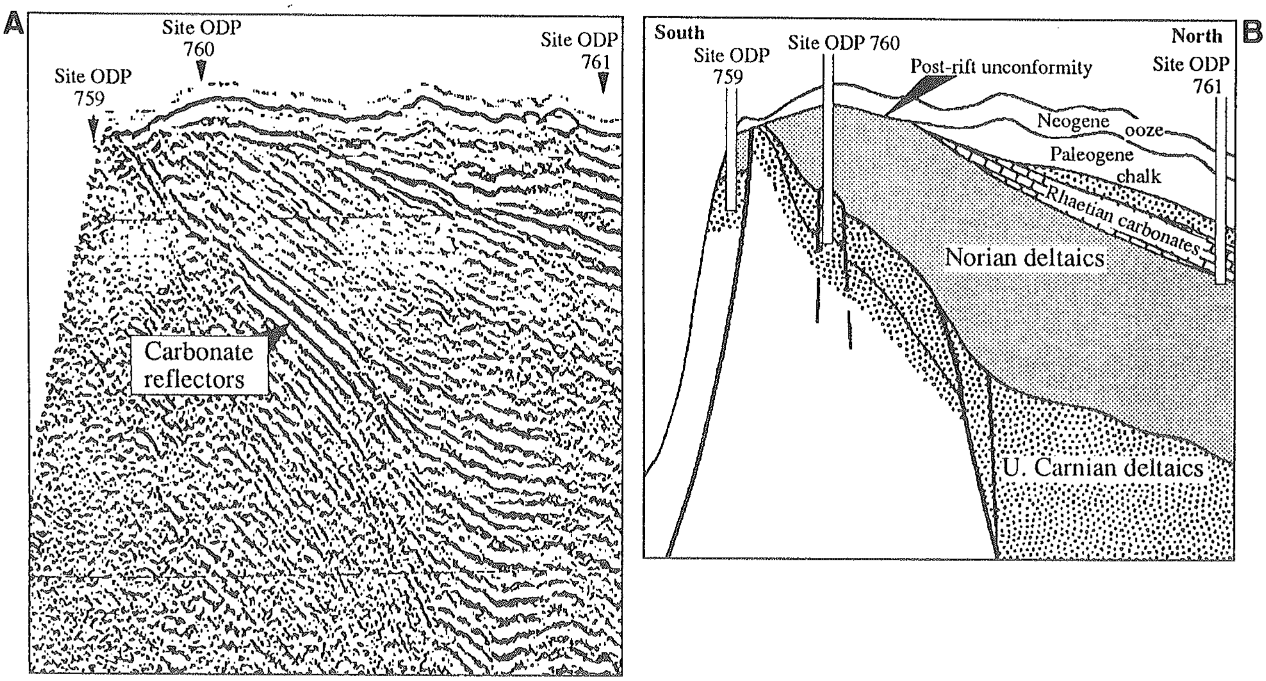


Fig. 9. The southern Wombat Plateau and the Upper Triassic series recovered during the ODP Leg 122 (Sites 759, 760 and 761). Note the strong erosional unconformity overlying the Triassic beds (Post-rift unconformity). A = seismic line BMR 56-13, B = Interpretation (line drawing) after Shipboard Scientific Party (1990).

irregularis may develop. This leads to an additional stabilization of the framework. The biomicritic matrix between the coral fragments contains peloids, some echinoderm fragments, and ostracodes, whereas the biomicrite of the sponge boundstone shows an association with gastropods, red algae (Pl. 59/5), and serpulids. Foraminifers are rare. Based on their internal structure and their outer shape, several types of sponges can be differentiated. A cylinder-shaped type contains very irregular sclerites, the wall thickness of which is up to 900 µm. The second type is a sponge with irregular outlines and a dense network of small spicules.

The abundance of corals, as well as the presence of other large skeletal particles point to a reefal environment. The micrite, which has partly peloidal textures, might have been deposited (or partly formed) within reef cavities.

The described twenty-five microfacies types have been grouped according to their distribution and frequency into several facies units, which are shown in Fig. 7. In Fig. 8 different environmental interpretations are compared with the classification of facies of the western Tethys (cf. Schäfer & Senowbari-Daryan, 1981). It could be shown that similar facies units were found in Western and Eastern Tethys paleoenvironments (Chapter 6).

4.2 Correlation of the drillsites and sequence stratigraphy

4.2.1 Correlation of the drillsites

The age of the youngest Triassic beds recovered in Sites 759, 760, 761 and 764 decreases from south to north along the Jurassic post-rift unconformity (Fig. 9). The analysis of the facies evolution and of seismic reflection profiles shows that there are overlaps between the sections of Sites 759 and 760, and between those of Sites 761 and 764. Tentative correlations are given by Röhl et al. (in press) and Sarti (in press) for the 759/760 correlation, and by Dumont (in press), von Rad et al. (in press), Röhl et al. (in press), and Sarti (in press) for the 761/764 correlation. Biostratigraphic data from Brenner et al. (in press) and Zaninetti et al. (in press) were taken into consideration. They are, however, not sufficient to make detailed correlations, since they are sometimes inconsistent with each other. Detailed microfacies analysis was also used, together with a study of wireline logs. The proposed correlations are in general agreement, but some differences do exist:

The 759/760 correlation is mainly based on microfacies analysis (Fig. 10, after the interpretation of Röhl et al., in press, and von Rad et al., in press). It is in agreement with the palynological zonation of Brenner et al. (in press). Several shallow-marine carbonate layers, which are interbedded with the Carnian and Norian deltaics, were recovered in Sites 759 and 760 and are used for the correlation. These carbonate layers were actually identified as prominent and continuous seismic reflectors in some seismic lines (Fig. 9). Contrary to the siliciclastic facies the deposition of which was influenced by the migration of delta lobes, the carbonate facies is more likely to represent a signature of relative sea-level changes. Our correlation suggests a time gap in the upper Carnian to lower Norian section (Fig. 10). At both sites we found a conspicuous conglomerate bed which indicates an erosional surface (top of core 122-760B-19R).

Several 761/764 correlations were proposed (by Dumont, in press, Röhl et al., in press, and Sarti, in press) which are

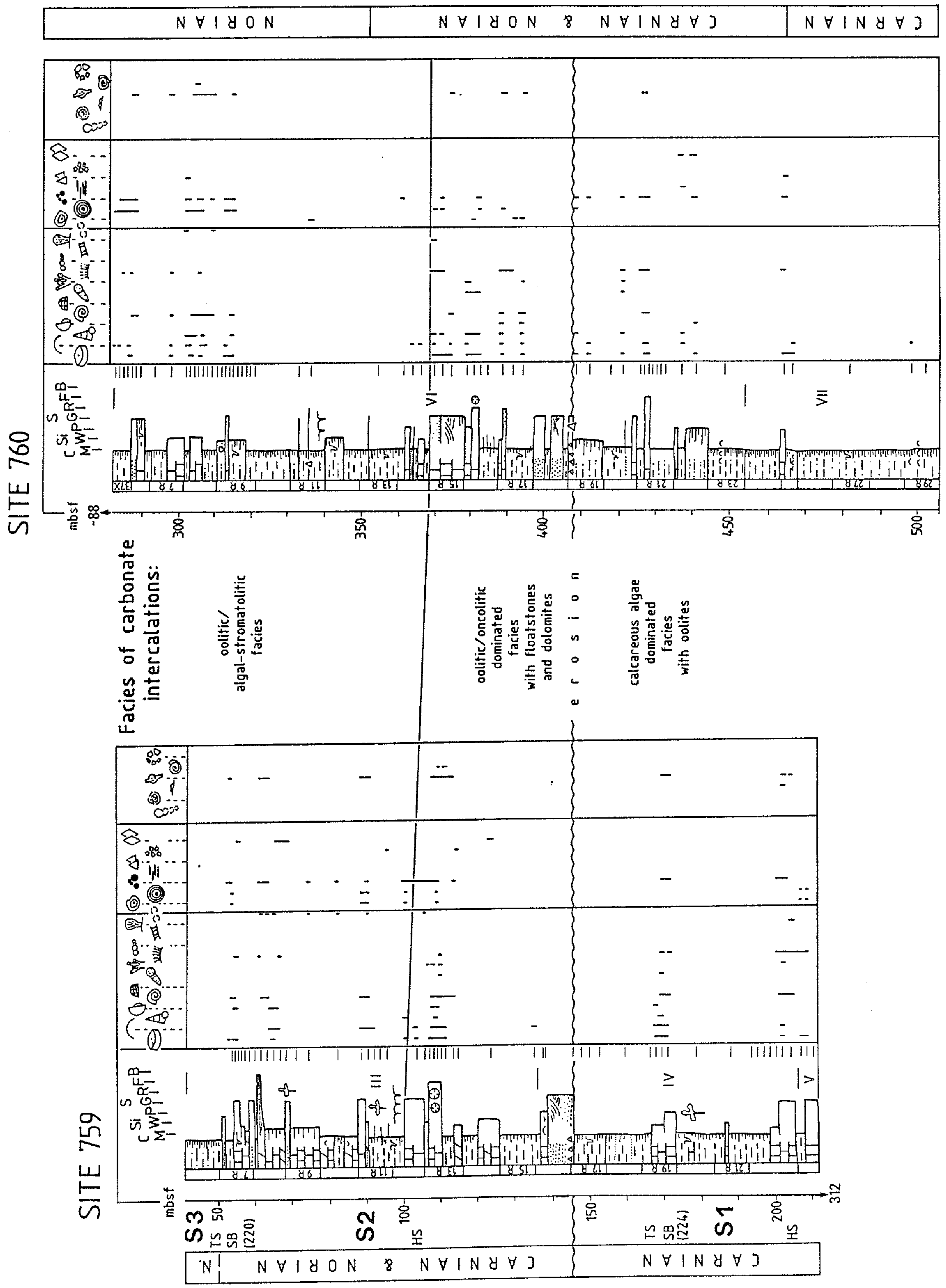


Fig. 10. Parallelization of the carbonate-bearing parts of Sites 759 and 760 according to microfacies and sequential evolution of limestones. The biogenic and abiogenic allochems, as well as some diagenetic features are plotted against the lithological column. For further explanations, see text. The letters M - B refer to rock types mudstone to boundstones, C = claystone, Si = siltstone, S = sandstone; mbsf = meters below sea floor. HS = Highstand Systems Tract, TS = Transgressive Systems Tract, SB = Sequence Boundary (modified after RÖHL et al., in press).

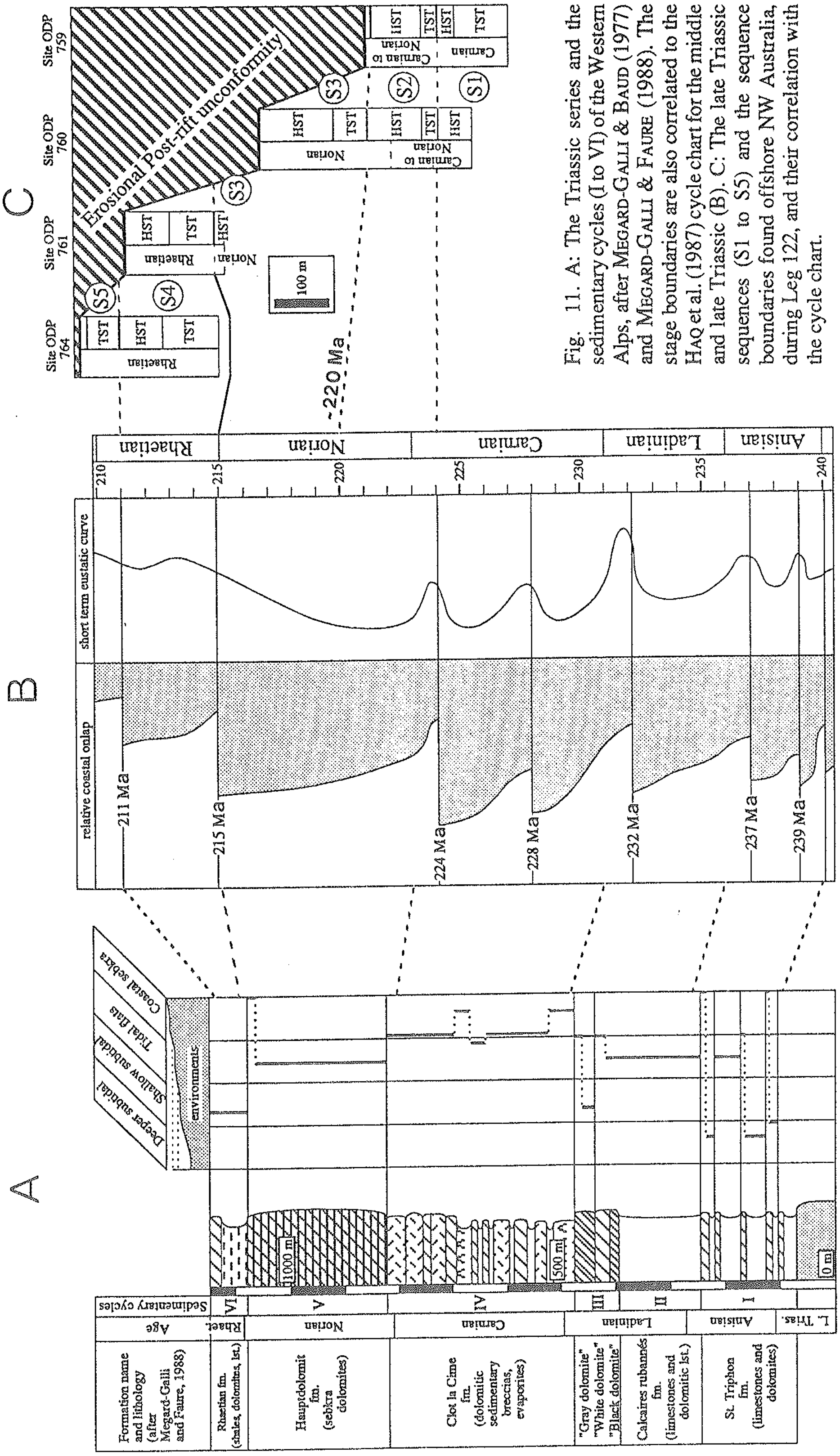


Fig. 11. A: The Triassic series and the sedimentary cycles (I to VI) of the Western Alps, after MEGARD-GALLI & BAUD (1977) and MEGARD-GALLI & FAURE (1988). The stage boundaries are also correlated to the HAQ et al. (1987) cycle chart for the middle and late Triassic (B). C: The late Triassic sequences (S1 to S5) and the sequence boundaries found offshore NW Australia, during Leg 122, and their correlation with the cycle chart.

consistent with palynomorph data (Norian/Rhaetian boundary) and foraminiferal data (dating of Rhaetian carbonates). These correlations were made by microfacies, biostratigraphic, and wireline log analysis. Our interpretation is summarized in Fig. 5. The main difference to the interpretation of SARTI (in press) is noticed in the uppermost part of the Rhaetian series in Site 761, which this author interpreted as a time equivalent of the top of the Rhaetian sequence at Site 764. This interpretation is not supported by any paleontological or microfacies data, and poorly supported by log analysis.

It is our opinion that the top of the Rhaetian sequence at Site 764 is younger than at Site 761 because of the Jurassic tilting and erosion of the Wombat Plateau. This interpretation is consistent with some paleontological data (nannofossils, BRALOWER et al., in press), and with seismic data which indicate a southward truncation of the upper Rhaetian beds between Sites 761 and 764 (WILLIAMSON, in press). Following this interpretation, we assume that the uppermost part of the Rhaetian series is missing at Site 761, and possibly also at Site 764, although it is more complete there.

4.2.2 Sequence stratigraphy

Sequence stratigraphy and the testing of eustatic models was one of the major objectives of Leg 122. In particular we attempted to test the validity of the cycle chart of HAQ et al. (1987) for long-distance correlations, and of the concept of global sea-level changes in the Triassic. Concerning the Triassic series, several interpretations have been proposed (DUMONT, in press; VON RAD et al., in press; SARTI in press). One must distinguish three steps in this analysis : (1) the identification of the unconformities, the sequence boundaries (SB), and of the systems tracts (the sequences between the SBs are called S 1, 2), (2) the comparison of the identified sequences with the cycle chart of HAQ et al. (1987), and (3) the identification of the major causal factor: sediment supply, tectonics, or eustasy (global sea level changes).

Identification of the unconformities and systems tracts.

The interpretations quoted above are more or less con-

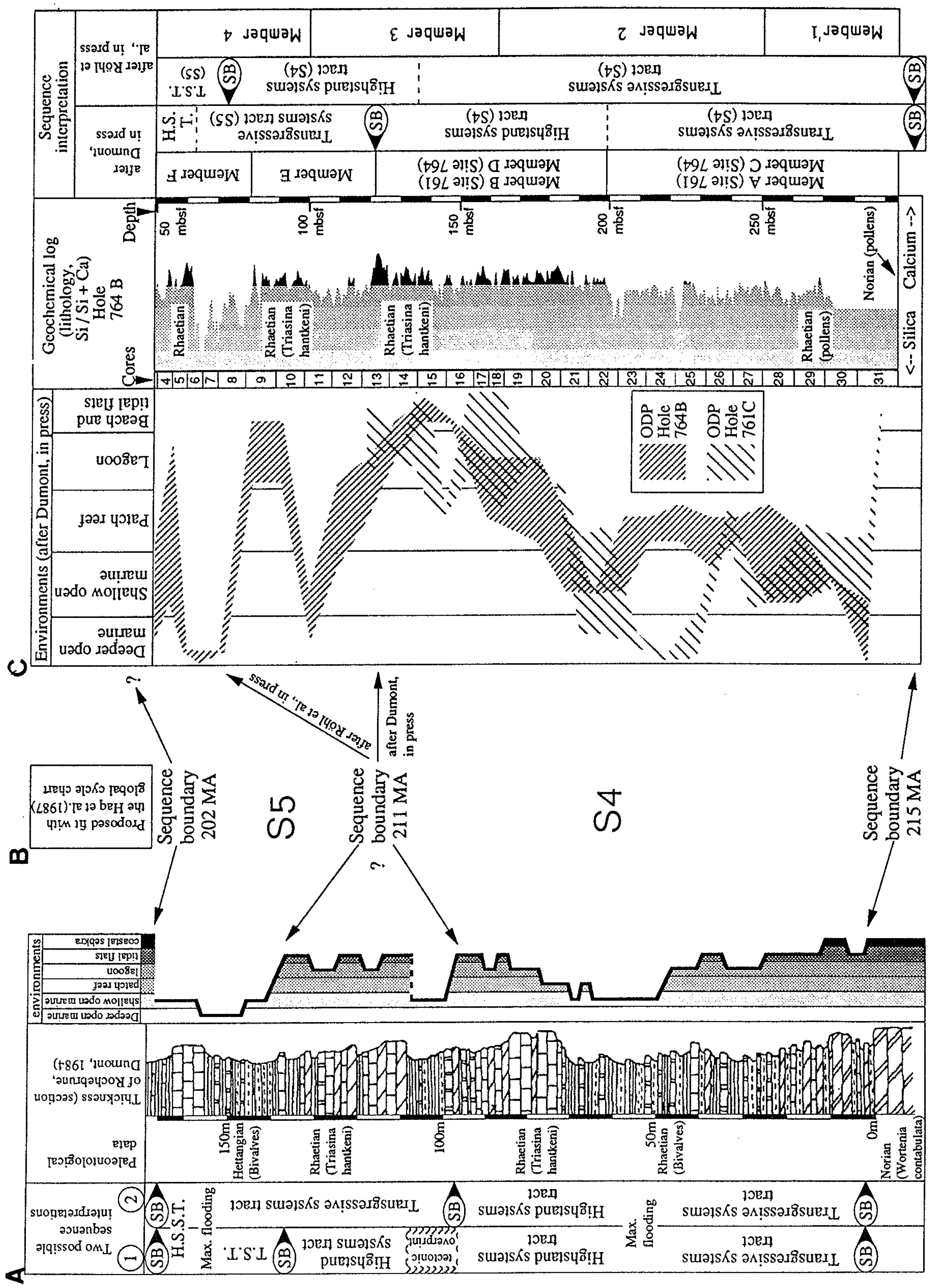


Fig. 12. A comparison of the Rhaetian series of NW Australia and of the Western Alps. A: Rhaetian series of the internal Alpine nappes (Piemont zone) after DUMONT (1984 and unpublished data). B: The proposed correlation with the HAQ et al. (1987) cycle chart. C: Some features of the Rhaetian series of the Wombat Plateau and a summary of the sequence-stratigraphic interpretations of DUMONT (in press) and RÖHL et al. (in press).

sistent with each other concerning the identification of unconformities and systems tracts. Our interpretations are summarized in Fig. 11C, and more detailed explanations are given in Fig. 12C. The Carnian-Norian series shows three sequences after RÖHL et al., in press (Sites 759 and 760; Fig. 3). The basal part of both sites (cores 122-759B-39R to 20R and 122-760B-29R to 19R) is regressive, and is interpreted as the upper transgressive systems tract (TST) and the highstand systems tract (HST) of a sequence of Carnian age (S1). Its maximum flooding surface (MFS) is placed by VON RAD et al. (in press) at the base of the first occurrence of carbonates (oolitic limestone, core 122-759B-23R). The TST of the next sequence is drastically reduced at Site 760 (VON RAD et al., in press). This reduction, together with the occurrence of a conglomerate layer (top of Core 122-760B-19R and Core 122-759B-16R) led to the identification of an

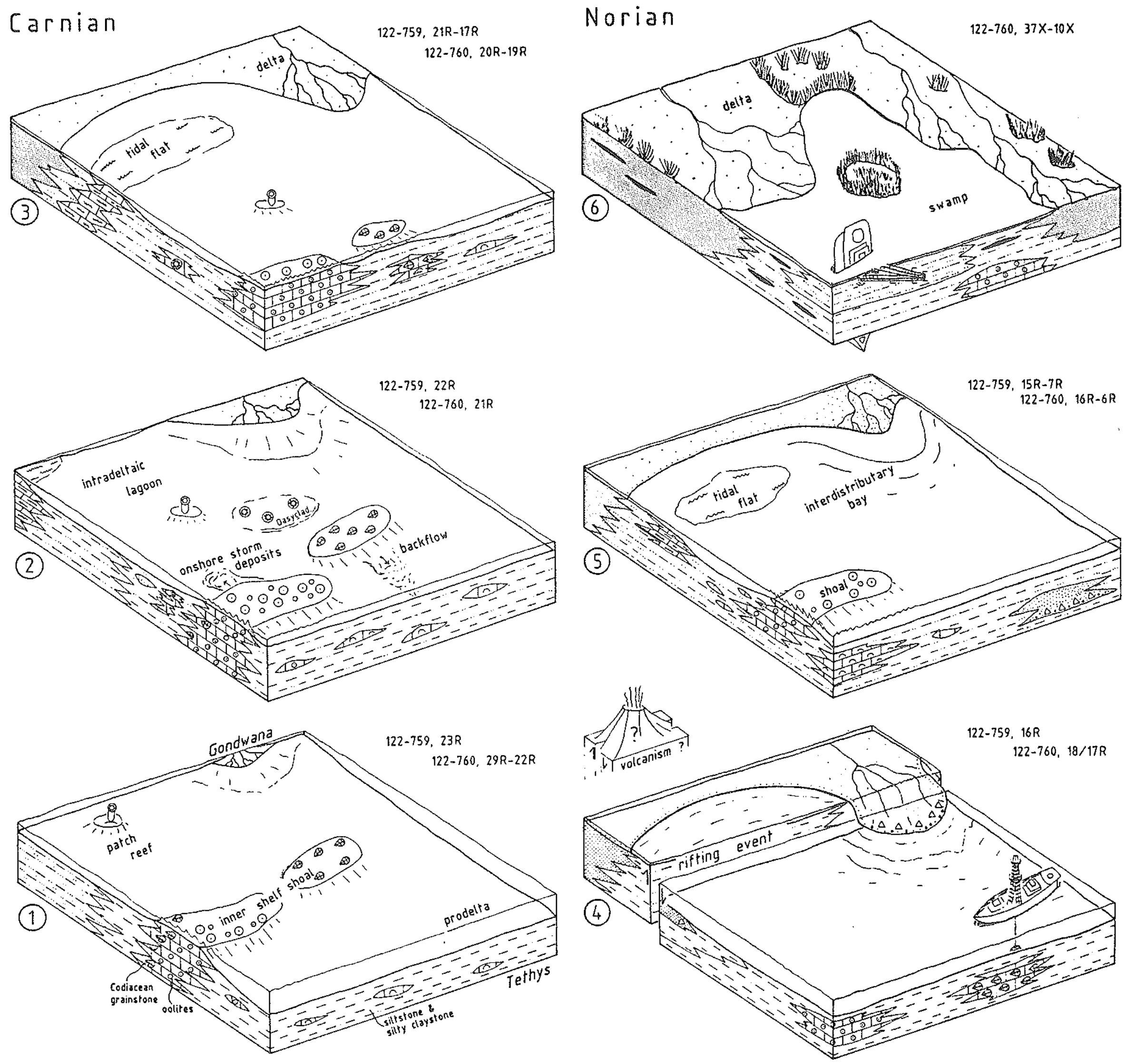


Fig. 13. Six stages were selected to represent the facies development in Sites 759 and 760 during the Carnian and Norian. Site 759 represents the back, Site 760 the frontal part of each block. Note that in each case, Site 760 shows a more distal position compared with Site 759. This agrees with the general paleogeographic situation of the Wombat Plateau area.

erosional surface. The age of S2 is Carnian to Norian, and its top is Norian after Brenner et al. (in press). The next SB (S2/S3) is identified by von Rad et al. (in press) at the transition from limestone-bearing to limestone-poor sequences (Fig. 3), but is not identified by Sarti (in press). The upper part of S3 (cores 122-760B-10X to 30X) is markedly regressive (late HST, increasing development of coal seams and paleosols). Its top is truncated by the PRU. The age of S3 is (late?) Norian.

The seismic profile of the Wombat Plateau (Fig. 9) suggests that there is no overlap of any Triassic beds between Site 760 and Site 761. At the base of Site 761 a prominent transgressive surface underlain by emergent fluviodeltaic siliciclastics was recovered. These sediments are overlain by marine marls and crinoidal limestones. The marked SB coincides with the Norian-Rhaetian boundary (Fig. 5; Brenner et al., in press). The underlying HST is assigned to S3, since the facies is very similar to that of the uppermost Triassic beds of Site 760.

The overlying, Rhaetian sequence (S4) may be interpreted in different ways (see Fig. 12). At Site 761, it has a transgressive, marly lower part (TST; Fig. 12), and a regressive, carbonate-dominated upper part (HST; Fig. 12). Reefal carbonates, which are mainly developed at Site 764, appear in the late TST and the HST. At Site 764, S4 is overlain by transgressive beds which are interpreted as the TST of the next sequence (S5; Fig. 12). These beds are also Rhaetian in age, and are truncated by the post-rift unconformity. According to von Rad & Thurow (in press), a thin claystone horizon can be inferred from the gamma-ray log at the very top of the Triassic series of Site 761 (interval 122-761C-11R), which could correspond to the lateral equivalent of S5. But this interval had no core recovery and its age is unknown.

Comparison with the Haq et al. (1987) cycle chart

Unfortunately, the accuracy of most of the paleontological data does not exceed the resolution of a stage (Brenner et al., in press). However, it is possible to correlate our Wombat Plateau sequences with those of the cycle chart (Fig. 11): the

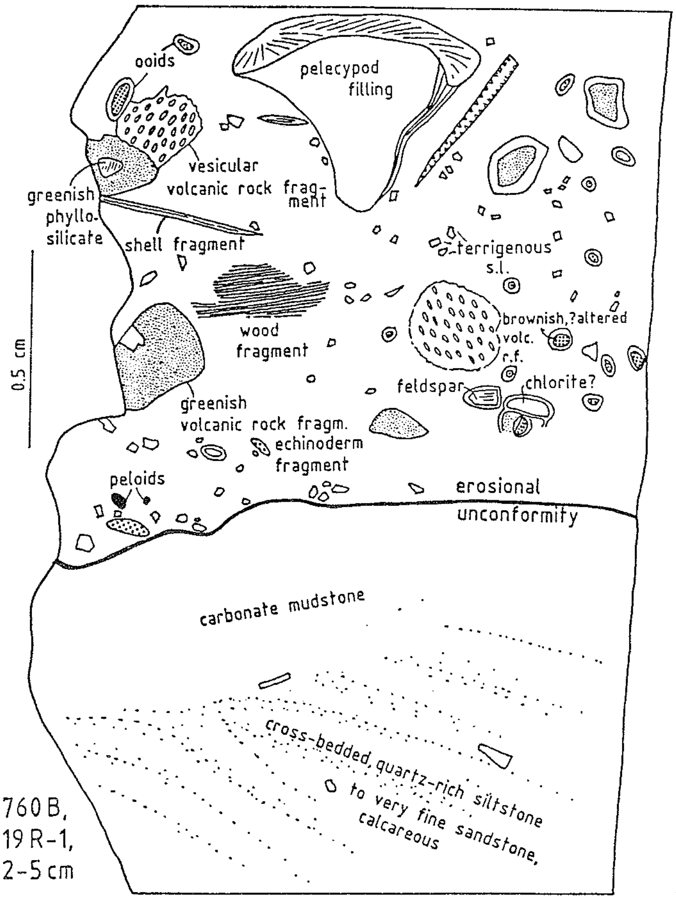


Fig. 14. Intra- and extraclast-rich conglomerate to breccia (sample 122-760B-19R-1, 2-5 cm). From base to top: quartzose and cross-bedded siltstone grading upward into silty calcareous mudstone. The latter was strongly eroded during a regional tectonic event, probably near the Carnian/Norian boundary in both sites (122-759B-17R to 16R, 122-760B-19R; see Figures 3 and 10). A chaotic mixture of carbonate peloids/intraclasts derived from the underlying mudstone, wood, as well as echinoderm and pelecypod fragments are associated with volcanic rock fragments, which usually exhibit ooid cortices and different types and stages of alteration. Terrigenous quartz and (volcanogenic?) feldspar are also present. The large pelecypod at the top is filled by micrite derived from the mudstone below the erosional unconformity.

S1/S2 SB may correspond to the late Carnian (224 Ma) SB. The 'tectonically enhanced' MFS of sequence S2 is thought by von Rad et al. (in press) to correspond to the 223 Ma condensed section of the cycle chart. The S2/S3 SB (estimated to about '220 Ma') is intra-Norian, and is overlain by a thick Norian sequence. It is not shown in the Haq et al. (1987) cycle chart. Thus it has to be tested in some other localities before being considered as a global event (for example, it is not identified in the Dolomite Mountains of the southern Alps, according to Doglioni et al., 1990). The S3/S4-sequence boundary is well dated, and coincides with the Norian-Rhaetian boundary. It corresponds to the 215 Ma SB of the cycle chart, and is also recognized in areas far from Australia, e.g. in western Europe. Therefore it probably represents the signature of a global event. The S4/S5 SB is intra-Rhaetian. It may correspond to the 211 Ma SB of the cycle chart, but we do not know how much of the upper Rhaetian might be missing due to the truncation and erosion along the post-rift.

The sequence-stratigraphic results of the Wombat Plateau sites off NW Australia are generally consistent with the global cycle chart (von Rad et al., in press), but only one SB is unambiguously correlated with the chart (S3/S4, 215 MA). The absolute ages of the other SBs are determined only with respect to those of the cycle chart, and thus they will not be helpful for testing the accuracy of this chart.

Identification of the causal factors.

The observed sequences were generated by relative sea level changes, in agreement with the depositional models of Posamentier & Vail (1988) and Sarg (1988). Relative sea level changes may in turn have been produced either by eustasy, or by tectonic subsidence, or by a combination of both factors. Concerning the Triassic series of the Wombat Plateau, a tectonic explanation was favored by Sarti (in press), whereas according to our interpretaton eustasy played a significant role in producing the depositional sequence boundaries. In fact, the Carnian-Norian series (mainly Carnian) experienced significant extensional tectonics, as shown by the seismic profile (Fig. 9). In addition, volcanic clasts have been found near the Carnian/Norian boundary and in the lower Norian (von Rad et al., in press) and some layers were eroded in the sequence S2. Furthermore, the ages of the sequence boundaries of the Carnian-Norian series are rather poorly constrained, and hence the fit with the global events of the Haq et al. (1987) cycle chart is ambiguous. One can assume that the eustatic signal was significantly altered by tectonic factors during the deposition of the Carnian-Norian series in the Wombat Plateau area. We cannot separate the relative influence of both factors with the available data.

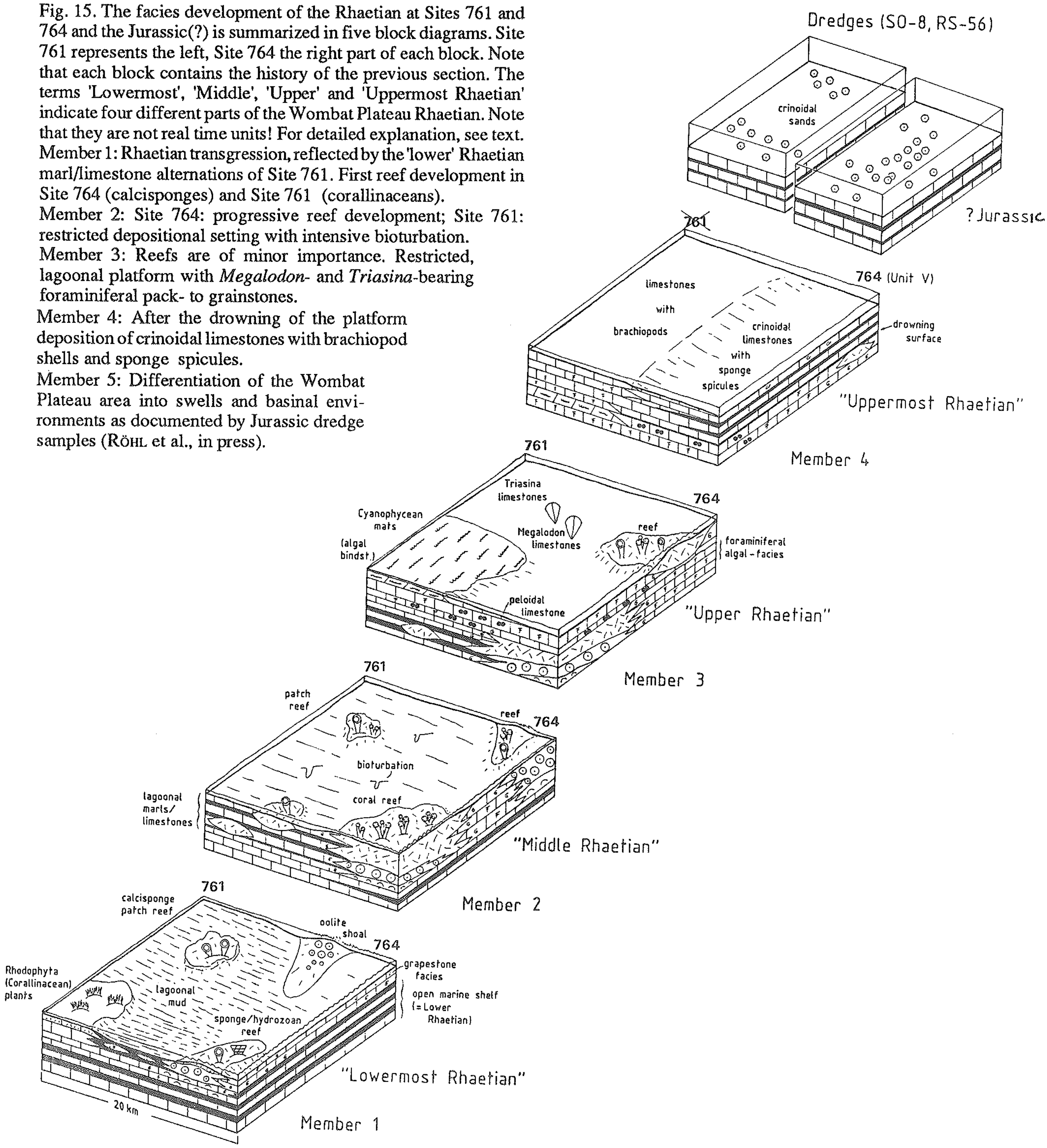
On the contrary, there is very little evidence for Rhaetian extensional tectonics (only small normal faults which are sealed by the base of the Rhaetian sequence S4; Williamson et al., 1989). The basal Rhaetian sequence boundary (S3/S4) is well correlated to the global 215 Ma sequence boundary, overlain by the 'early Rhaetian transgression' (Fig. 19). Thus eustasy is likely to have been the major causal factor during the deposition of the Rhaetian sequences of the Wombat Plateau.

4.3 The facies model

4.3.1 Carnian-Norian evolution

On the basis of microfacies analysis (Röhl et al., in press), the carbonate intercalations of Sites 759/760 are divided into three main facies groups (Fig. 10): (1) The calcareous algae-dominated facies with oolites (Cores 122-759B-23R to 19R; 122-760B-22R to 20R) is overlain by an (2) oolitic/oncolitic dominated facies including dolomites and floatstone-bearing coral or sponge fragments (Cores 122-759B-16R to 12R; 122-760B-17R to 15R). (3) The uppermost facies group is the oolitic/algal-stromatolitic dominated facies (Cores 122-759B-11R to 7R; 122-760B-14R to 7R). Following the general paleogeographic conception of a more nearshore position of Site 759 if compared with Site 760, the lime-

Fig. 15. The facies development of the Rhaetian at Sites 761 and 764 and the Jurassic(?) is summarized in five block diagrams. Site 761 represents the left, Site 764 the right part of each block. Note that each block contains the history of the previous section. The terms 'Lowermost', 'Middle', 'Upper' and 'Uppermost Rhaetian' indicate four different parts of the Wombat Plateau Rhaetian. Note that they are not real time units! For detailed explanation, see text.
Member 1: Rhaetian transgression, reflected by the 'lower' Rhaetian marl/limestone alternations of Site 761. First reef development in Site 764 (calcisponges) and Site 761 (corallinaceans).
Member 2: Site 764: progressive reef development; Site 761: restricted depositional setting with intensive bioturbation.
Member 3: Reefs are of minor importance. Restricted, lagoonal platform with *Megalodon*- and *Triasina*-bearing foraminiferal pack- to grainstones.
Member 4: After the drowning of the platform deposition of crinoidal limestones with brachiopod shells and sponge spicules.
Member 5: Differentiation of the Wombat Plateau area into swells and basinal environments as documented by Jurassic dredge samples (Röhl et al., in press).



stones of Site 760 indicate better ventilated areas than those of Site 759. The calcareous algae dominated facies with oolites consists of codiacean float- and grainstones (MFT 20), dasycladacean grainstones (MFT 9) coated grain grainstones (MFT 16), and subordinate skeletal wacke- and floatstones with codiaceans (MFT 12 and 13). The oolitic-oncolitic-dominated facies contains coated grain grainstones (MFT 16), oolitic grainstones (MFT 17), and oncolitic grainstones (MFT 18). In Site 759, the oncolitic grainstones interfinger with dolomitic mudstones. In both drillsites we observed a characteristic skeletal wacke- to floatstone (Cores 122-759B-13R and 122-760B-14R) with large coral fragments (MFT 14). The oolitic/algal-stromatolitic facies of the third limestone group includes from bottom to top skeletal to oolitic grainstone (MFT 17 and 22), dolomitic wackestone, and quartz-bearing oolitic grainstone (MFT 17).

The limestones in the fluviodeltaic to marginal marine Carnian and Norian series are intercalated between thin and evenly laminated siltstones. Some limestones are interpreted as allochthonous storm deposits (tempestites), reworked from nearby shallow-water carbonates. Autochthonous or parautochthonous carbonate sands are deposited in restricted areas within interdistributary bays as migrating sand waves. Alternatively, these sands might have formed on the top of barrier island arcs in front of an abandoned delta lobe with the development of spits, tidal inlets, and subaerially exposed sand bars. Similar facies relationships were observed in modern carbonate environments of the Bahamas (TUCKER & WRIGHT 1990).

Fig. 13 summarizes the evolution of the Wombat Plateau area during Carnian and Norian times in six time slices. The members characterize time slices. Member 1 to 3 reflect the Carnian history, member 4 to 6 the Norian history. Member 1 represents the calcareous algae-dominated facies with oolites of the lowermost Carnian section in Sites 759 and 760. Biogenic allochems were swepted together on inner shelf shoals. In restricted areas calcisponge patch-reefs developed. The predominant 'normal' sediments consist of siliciclastic silt- and claystones, deposited in a prodelta environment.

The transition of Member 1 to Member 2 reflects the increasing regressive trend. The shoals had water depths close to sea level, and oolites were deposited. Several carbonate intercalations occur within the siliciclastic clay-/siltstone sequence. We interprete them as onshore storm deposits or as results of backflow. Within intradeltaic lagoons calcisponge patch-reefs and dasycladaceans florished. Phase 2 characterizes the oolitic/oncolitic dominated facies of the Carnian.

Member 3 shows tidal flats, where algal laminites occur. General the fluviodeltaic environment moved closer to the Wombat Plateau Sites. The amount of intercalated limestones decreased.

During a 'rifting event', the sea floor relief and the relative sea-level increased (Member 4), resulting in a conspicuous input of coarse siliciclastics and volcanic rock fragments (heterogeneous 'rift conglomerate', Fig. 14).

During Member 5 we observe a renewed balance of sediment buildup with the rising sea-level: oolitic shoals, interdistributary bays with tidal flats occurred again. Finally, regression transformed the area into a non-marine to lagoonal environment with coal swamps, paleosols etc. (Member 6).

4.3.2 Rhaetian evolution

Changes of the paleolatitude of the Wombat Plateau area by latitudinal plate-tectonic movements, as derived from paleomagnetic analysis played a major role in the regional facies development (VON RAD et al., in press).

In Fig. 15 we tried to sketch the spatial relationship between Sites 761 and 764 during Rhaetian/early Liassic(?) times in five time slices. The terms 'Lowermost', 'Middle', 'Upper' and 'Uppermost Rhaetian' are chosen to indicate four different parts of the Wombat Plateau Rhaetian. They are not real time units! We used the correlation of the sites described above. In Member 1 ('Lowermost' Rhaetian to lower 'Middle' Rhaetian, Fig. 15) sedimentation is characterized by open-marine shelf marl/limestone alternations (Site 761). These alternations were caused by periodic changes of terrigenous supply or energy (storm/fair weather) conditions. In the area of Site 764 the first reef development ('catch-up', Member 2) followed an oolitic shoal phase (Member 1). Multichannel seismic stratigraphic studies by WILLIAMSON (1990) suggest that the position of reefal buildups is related to elevated fault blocks in the underlying beds. The slim shape of the reef structures recognized in the seismic reflection lines across Wombat Plateau (WILLIAMSON et al., 1989) may indicate rapid growth of the reef-related organisms, which tried to balance the rising sea level (Member 2/3). This represents the typical situation of a 'keep-up carbonate system' (KENDALL & SCHLAGER, 1981; SCATURO et al., 1989).

A schematic diagram of reef development as represented in the lower part of Site 764 (Core 122-764B – 30R to 27R) is shown in Fig. 16. This section is 45 m thick. On randomly distributed bioclastic accumulations ('basal pile') we found oolitic shoals ('stabilization stage'). 'Normal' oolites occur

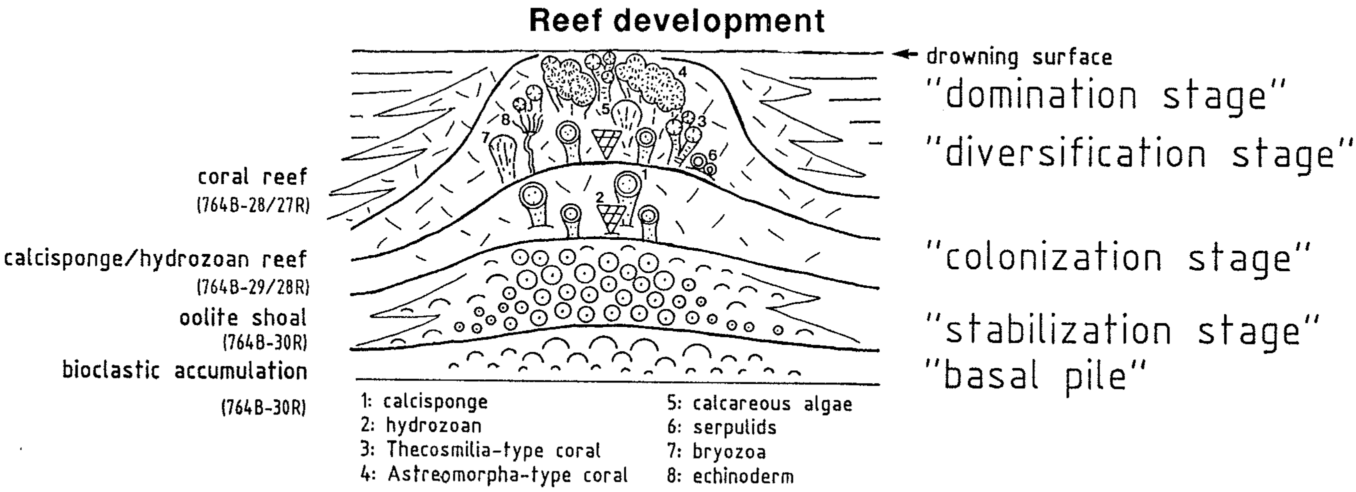


Fig. 16. Schematic sketch of the typical reef development as represented in Site 764 (Core 122-764-30R to -27R, ca. 45 m; cf. WALKER & ALBERSTADT, 1975).

only in the lower part of the Site 764 (Core 122-764B-30R), where reef development had not yet started to shelter the lagoon from the open sea. Calcisponges and hydrozoans formed the first patch reefs that interfinger with skeletal pack-to floatstones. In the 'diversification stage' different corals, calcareous algae, serpulids, bryozoa and echinoderms could be added. In the 'domination stage' *Retiophyllia* and *Astraeomorpha*- type corals predominate. This stage is capped during the next sea-level rise (TST, 'drowing surface', 'give-up' situation).

The biolithite facies of the central reef areas consists of several microfacies types. Like many fossil and recent reefal series, it shows a characteristic association of several microfacies types. In the Rhaetian of the Wombat Plateau, ostracode-rich (MFT 5), echinoderm-rich (MFT 6), and foraminifer-rich limestones (MFT 3, MFT 8, MFT 15) are intercalated between the individual reef structures. The reefal facies is characterized by boundstones with *Retiophyllia* and *Astraeomorpha*-type corals, calcisponges and hydrozoans (MFT 24 and MFT 25). Partly stromatolitic limestones (MFT 23) occur. Peloidal pack- to grainstones (MFT 9 and MFT 21) are typical fillings of reef-growth cavities.

The grapestone/oncoid facies of the uppermost, mostly leeward reef slope is made up of skeletal grainstone to packstone (MFT 10), and coated-grain grainstone (MFT 16).

The lagoonal area is characterized by restricted conditions, created by barriers formed by the reef development. Site 761 shows the development of calcisponge patch reefs and corallinacean buildups. During the deposition of the 'middle' Rhaetian Member 2 the reefal facies continued in the area of Site 764 (MFT 14, 7, 10). The area of Site 761 was dominated by marl/limestone alternations. Biogenic allochems and bioturbation indicate a more restricted intrashelf lagoon setting (MFT 1, 6, 13), if than during the deposition of the marl/limestones cycles of the 'Lower Rhaetian' (Member 1; MFT 1, 6, 13). An algal-foraminiferal-detritus facies was deposited in a lower reef slope to lagoon setting. It shows a wide variety of microfacies types (MFT 15 to MFT 7) with reef debris (coral and sponge fragments, larger mollusc shells) decreasing towards the lagoonal environment.

The 'upper' Rhaetian Member 3 was on the one hand characterized by the dominance of grapestone or foraminiferal-algal facies (Site 764); on the other hand, Site 761 developed regressive cycles from lagoonal foraminifer- and Megalodon-bearing wackestone (shallow subtidal) to algal bindstone.

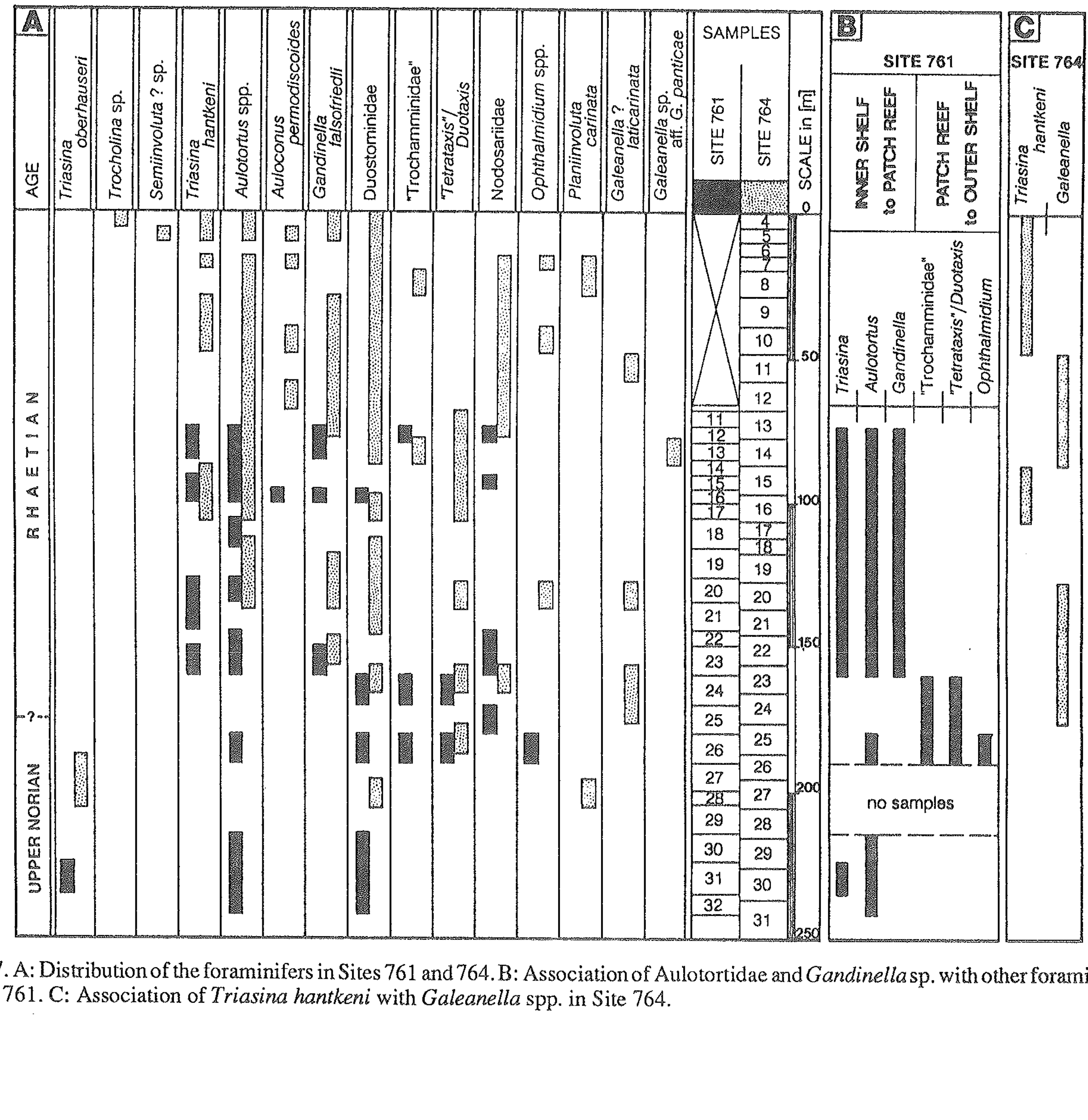


Fig. 17. A: Distribution of the foraminifers in Sites 761 and 764. B: Association of Aulotortidae and *Gandinella* sp. with other foraminifers in Site 761. C: Association of *Triasina hantkeni* with *Galeanella* spp. in Site 764.

In the upper part of the Rhaetian of both sites we found a dominance of the mud/foraminifers facies, characterized by an increase of foraminiferal genera and species (especially of *Triasina hantkeni* MAJZON). Besides peloids and foraminifers in the mud-dominated foraminiferal-mud facies small pelecypod fragments occur. Bioturbation is more common in this member. Even a few quartz grain may be present. In Fig. 5 distinct groups of foraminifers (Nodosariidae, *Triasina*, *Aulotortus*, *Glomospirella*, Duostominidae and encrusting foraminifers) and the other biogenic and abiogenic allochems are plotted against the lithological column. SCHÄFER & SENOWBARI-DARYAN (1981) subdivide the facies zones according to different associations of foraminifer groups (their Fig. 6). Their results agree very well with the distribution of foraminifers in the Rhaetian of the Wombat Plateau. The upward increase of the amount and diversity of foraminifers in Site 764 reflects the replacement of the biolithite facies (Member 2) by the grapestone/reefal-debris facies (Member 3), and then by the algal-foraminiferal facies (Member 4).

The 'uppermost' Rhaetian transgressive pulse (TST) results in renewed sedimentation of marl/limestone alternations at Site 764 (Member 4) that includes crinoids, brachiopod shells, and some sponge spicules. The uppermost block in Fig. 15 represents the relatively deeper water crinoidal sands, which we observed only in dredge samples (KRISTAN-TOLLMANN & GRAMANN in press, QUILTY, 1990). These sediments may be of Rhaeto-Liassic age and document the structuring of the carbonate platform into swells and basinal areas (VON RAD et al., 1990, RÖHL et al., in press).

In summary, we propose continuing uniform tectonic subsidence during Member 1-3 of the Rhaetian, which resulted in a slow relative sea level rise. The reefal facies shows first 'catch-up' deposits grading into 'keep-up' cyclic deposits (cf. SCATURO et al., 1989; KENDALL & SCHLAGER, 1981). Rapid regression at the '211 Ma' SB, followed by the transgression (TST, S5) killed the reefal facies ('give-up') and ended the buildup of reefal carbonates (KENDALL & SCHLAGER 1981) during latest Rhaetian times.

Using a sequence-stratigraphic approach (SARG, 1988), the Rhaetian sequence of the Wombat Plateau can be described as a sequence (S4) starting with a 'transgressive systems tract' ('lower' Rhaetian) to a 'highstand systems tract' (lagoonal and reefal facies of the Upper Rhaetian). A SB is overlain by the next sequence (S5) starting with a 'transgressive systems tract' (uppermost Rhaetian).

5 MICROFAUNAL ANALYSIS

The stratigraphic distribution of the Triassic foraminifers has been studied in ODP Sites 761 and 764 (ZANINETTI et al., in press). On the basis of the Aulotortidae (Triasininae), the sediments of the lower portion can be regarded as upper Norian (*Triasina oberhauseri* Biozone) and as Rhaetian (*Triasina hantkeni* Biozone) for those of the upper portion, up to the contact with the post-rift series (Cretaceous to Holocene).

According to the foraminifers, the Triassic section can be subdivided into three intervals.

5.1 Foraminiferal biostratigraphy of Site 761

1. In the basal interval (Cores 122-761-32R to 30R, Fig. 17 A), the foraminifers are mainly represented by Aulotortidae, (Triasininae and Aulotortinae) commonly associated with Duostominidae (Fig. 17 B). The identified species are *Triasina oberhauseri* (Pl. 62/3), which we consider of upper Norian age (*Triasina oberhauseri* Biozone), and several representatives of the genus *Aulotortus* (*Aulotortus communis*, *Aulotortus* ex gr. *sinuosus*, *Aulotortus friedli*, and *Aulotortus* spp.). The palynological results of BRENNER (in press) give Norian ages only for the lowermost core (122B-761-33R) of Site 761.
2. The intermediate interval (Cores 122-761-26R to 24R, Fig. 17 A) is characterized by a marked change in the microfaunal association. The Aulotortidae are either rare or completely absent. The diagnostic foraminifers are '*Tetrataxis*', *Duotaxis birmanica* (see BRÖNNIMANN et al., 1975) (Pl. 62/16), and *Ophthalmidium* spp.. These species are associated with Lituolidae?, 'Trochamminidae', Textulariidae?, and Endothyridae. Duostominidae, probably represented by different genera, which are not identifiable in thin-sections, are common in this interval. The stratigraphic position of this intermediate interval between cores containing *Triasina oberhauseri* (Interval 1) and cores containing *Triasina hantkeni* places it in the Upper Norian to Lower Rhaetian.
3. The upper interval (Cores 122-761-23R to 11R; Fig. 17 A) is characterized by a rich and varied microfauna. *Triasina hantkeni* is common (Pl. 62/1-2), and the main species of *Aulotortus* have been recorded (*Aulotortus communis, Aulotortus friedli, Aulotortus* ex gr. *sinuosus, Aulotortus impressus, Aulotortus tumidus, Aulotortus* spp.; Pl. 62/7, 8, 10). Rare *Auloconus permodiscoides, Glomospirella* spp., *Gandinella falsofriedli* (SALAJ et al., 1983, *Gandinella*? sp.), are associated with Lituolidae, 'Trochamminidae', Duostominidae and Nodosariidae (Fig. 17 A).

5.2 Foramininferal biostratigraphy of Site 764

As in Site 761, Site 764 contains also cores with abundant Aulotortidae. They alternate with cores in which only smaller foraminifers occur. These alternations, however, are less obvious than in Site 761 (Fig. 17 C). In both sites they are due to the variation in carbonate content: in limestones Aulotortidae (*Aulotortus* spp., *Auloconus permodiscoides*) are predominant, and in less carbonate-rich rocks smaller foraminifers. Site 764 is also characterized by the appearance of *Galeanella? laticarinata*, associated with '*Tetrataxis*', *Duotaxis birmanica, Ophthalmidium* spp. and by Duostominidae and Nodosariidae.
1. In Site 764, the following intervals can be distinguished: The occurrence of *Triasina oberhauseri* in Core 122-764-31R to 27R suggests an upper Norian age, or lower Rhaetian as the stratigraphic range of *Triasina oberhauseri* is not well established. *Aulotortus* spp. and Duostominidae, occasionally associated with *Planinvoluta carinata*, also occur. Palynological investigations by BRENNER (in press) and BRENNER et al. (in press), however, found only Rhaetian

palynomorphs (especially the dinoflagellate *Rhaetogonyanlax*) in this interval. These results lead to the assumption that the lowermost section of Site 764 is Rhaetian, age which has to be applied also to the foraminifers.

2. The intermediate interval, which extends from Core 122-764-26R to 21R (Fig. 17 A), is characterized by smaller foraminifers. These are represented by Nodosariidae, Ataxophragmiidae?, Duostominidae, 'Trochamminidae', Miliolidae?, '*Tetrataxis*' sp., *Duotaxis birmanica*, *Ophthalmidium* spp., *Gandinella falsofriedli* and by *Galeanella? laticarinata*, which first appears in Core 122-764-24R (Pl. 62/17, 18; Fig. 17 A). The age of this intermediate interval cannot be precisely established, it is (upper Norian ? to) lower Rhaetian.

3. The upper interval extends from Core 122-764-20R to 4R (Fig. 17 A). This interval is dominated by the Aulotortidae *Aulotortus sinuosus*, *Aulotortus communis*, *Aulotortus* spp., *Auloconus permodiscoides*, and *Triasina hantkeni*.

The Aulotortidae often occur together with Nodosariidae, Duostominidae (Pl. 62/14, 15), and particularly with *Gandinella falsofriedli* (Pl. 62/5, 6) and *Galeanella* sp. aff. *G. panticae*. Interruptions in the vertical distribution of *Triasina hantkeni* and sometimes also of *Aulotortus* spp. and *Aulotortus permodiscoides* are characterized by the presence of smaller foraminifers with microgranular or porcelaneous walls. These include 'Trochamminidae', Endothyridae, small miliolids, "*Tetrataxis*' *inflata*, *Duotaxis birmanica*, *Ophthalmidium* spp., *Planiinvoluta carinata*, *Planiinvoluta? irregularis*, and *Galeanella? laticarinata* (Pl. 62/12, 13, 19). At the top of the Rhaetian of Site 764, we observe the first occurrence of *Trocholina* sp.. A doubtful form, tentatively placed into *Semiinvoluta* , is also present at this level.

5.3 Micropaleontological comparison between Sites 761 and 764

The microfaunal analysis shows similarities between the two sites, with the predominance of the Aulotortidae at the base and, particularly, at the top of the sections. Duostominidae and Nodosariidae occur in both sites. They are, however, more common in Site 764. Also the group '*Tetrataxis*' - *Duotaxis*, and especially *Miliolina*, represented in Site 761 only by *Ophthalmidium* spp., are more common in Site 764. *Galeanella*? and *Planiinvoluta* were observed in Site 761. This is perhaps an indication of a more external reefal sedimentation in Site 764. We further observe in Site 764 a regular alternation of cores with *Triasina hantkeni* and cores with *Galeanella? laticarinata* (Fig. 17 C). This clearly indicates that these species are restricted to paleoecologically different environments. Apparently *Triasina hantkeni* occurs in more quiet muddy subenvironments of the reefal platform, whereas *Galeanella? laticarinata* appears to be restricted to the bioconstructions itself or to their immediate vicinity.

5.4 Micropaleontological comparison with other Triassic Tethyan localities

The Northwestern Australian Triassic foraminiferal fauna shows the closest affinity with that of the Indonesian locality of Seram (Al-Shaibiani et al 1984).

The more important species of the Rhaetian of Seram are *Triasina hantkeni*, which is abundant, several species of *Aulotortus*, then Duostominidae, and 'Trochamminidae'. Other species also occur, which are biostratigraphically significant, but up to now less often recorded in the Upper Triassic of the Tethys; they are '*Tetrataxis*" *inflata*, *Duotaxis birmanica*, which was originally recorded in the Upper Triassic of Burma, and especially *Galeanella*? *laticarinata*. This species was first described from Seram (Al-Shaibani et al., 1983) and seems to be paleogeographically restricted to the eastern Tethys. In fact, the occurrence of the species, though mentioned in Sicily (di Stefano et al., 1990) remains doubtful in the Alps and Western Tethys.

Obviously the micropaleontological similarities between the Indonesian and Australian localities should be supported by further stratigraphic information in order to establish the paleogeography of the Upper Triassic carbonate platforms in the eastern Tethys. However, the presence of *Triasina*

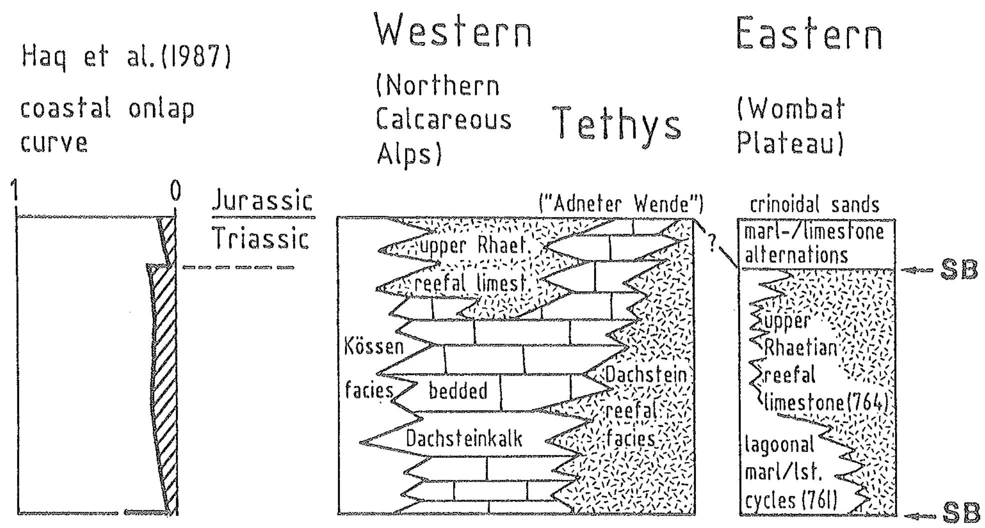


Fig. 18. Correlation of Eastern Tethys (Wombat Plateau) with Western Tethys (Northern Calcareous Alps) and parallelization with the Haq et al. (1987) cycle chart.

hantkeni permits to identify at least a Rhaetian interval in both localities. The characteristic species, *Galeanella*? *laticarinata*, considered of Norian-Rhaetian age in the type locality of Seram, also occurs in the upper interval of Site 764 containing *Triasina hantkeni*. This suggests a Rhaetian age for *Galeanella*? *laticarinata* in the Wombat Plateau, as well as probably in the Upper Triassic locality of Seram.

There is also a certain resemblance between the microfaunas from Sites 761 and 764 with those of Upper Triassic age of the Caucasus (EFIMOVA, 1974, 1975), at least as far as *Aulotortus* spp., *Auloconus*, '*Tetrataxis*', *Ophthalmidium*, 'Trochaminidae'.

Duostominidae, and Nodosariidae are concerned. In this area however *Triasina hantkeni* seems to be absent. Also the Rhaetian of New Guinea (KRISTAN-TOLLMANN, 1986) contains microfaunas that, in part, can be compared with those from Northwest Australia. Also in this locality the Aulotortidae and the Glomospirellae predominate.

The microfaunas of the Wombat Plateau are also related with those from the Upper Triassic of China (HE YAN & HU LAN YING, 1977; HE YAN, 1982), as shown by the occurrence in the Chinese localities of 'Trochamminidae', '*Tetrataxis*', *Glomospirella*, *Aulotortus* spp., Duostominidae, and Nodosariidae. As far as the distribution of *Triasina hantkeni* in the eastern Tethys is concerned, the species has also been described in China (HE YAN, 1980) and in the Philippines Islands (FONTAINE et al., 1979; see also AL-SHAIBANI et al., 1982).

In contrast to the above listed localities, the microfaunas described by HEATH & APTHORPE (1986) from the Lower? and Middle Triassic of the Australian Northwest Shelf, dominated by the Nodosariidae, differ strongly from those of the Wombat Plateau. In our opinion, they show in their overhauled morphology more of a Jurassic (Cretaceous?) than a Triassic aspect.

There are significant differences between the Upper Triassic foraminifers from the shallow carbonate platform drilled in ODP Sites 761 and 764 and the Upper Triassic (probably Rhaetian) foraminifers dredged from the northern escarpments of Wombat Plateau and northern Exmouth Plateau, (KRISTAN-TOLLMANN & GRAMANN, in press). The dredge samples contain rare Aulotortidae ('*Glomospirella*' *friedli* (= *Aulotortus friedli*)) and abundant Involutinidae (*Involutina liassica*, *Involutina turgida*, *Trochalina turris*, *Trocholina crassa*, *Coronipora austriaca*). This suggests a deeper sedimentary environment for these dredge samples ranging, according to the paleoecology of the Involutinidae in the Alps, from outer shelf or below (see also PILLER, 1978), whereas the foraminiferal assemblages of ODP Sites 761 and 764 a comparatively shallow environment.

5.5 Paleoecological and stratigraphical conclusions

5.5.1 Paleoecology

The stratigraphical alternation between Aulotortidae (*Aulotortus*, *Auloconus*, *Triasina*) and smaller foraminifers (*Duotaxis*, '*Tetrataxis*', 'Trochamminidae', *Ophthalmidium*) is characteristic for a reefal platform. This environment can, however, be differentiated into an inner zone (lagoon to patch reef) with abundant Aulotortidae, and a more external zone (patch reef to outer shelf) with small micrugranular or porcelaneous foraminifers (Fig. 17 C). The occurrence of *Galeanella? laticarinata*, in several cores of Site 764, places this site in a more reefal (external) environment whereas abundant Aulotortidae in Site 761 indicate a lagoonal facies.

5.5.2 Stratigraphy

On the basis of *Triasina oberhauseri* and *Triasina hantkeni*, the samples examined from Site 761 are of upper Norian/(or lower Rhaetian) to Rhaetian age. *Triasina oberhauseri* has been reported from various Norian localities of the western Tethys (KOEN-ZANINETTI & BRÖNNIMANN, 1968; BRÖNNIMANN et al., 1970; ABATE et al., 1984). But this species could extend into the lower Rhaetian, according to the palynological, nannoplankton and ostracode results (BRENNER et al., in press). Throughout the Tethyan realm, *Triasina hantkeni* defines the Rhaetian *Triasina hantkeni* Biozone (GAZDZICKI et al., 1979; GAZDZICKI, 1983; GAZDZICKI & REID 1983; ABATE, CIARAPICA & ZANINETTI, 1984; VACHARD & FONTAINE, 1988).

6 COMPARISON WITH THE TRIASSIC OF THE WESTERN TETHYS (WESTERN EUROPE)

The Triassic and early Jurassic series of the Wombat and Exmouth Plateaus show many similarities with the series of western Europe, despite their different geodynamic setting. Considering the distance between these two localities during late Triassic times, some of the similarities between these two types of series can be explained by the influence of global events.

6.1 Microfacies evolution

The microfacies types of the Rhaetian in Sites 761 and 764 can be combined in characteristic facies associations (Figs. 5 and 8). Biolithite facies, oncoid-grapestone facies, calcareous algae-foraminifers facies, and detritus mud facies could be combined to a facies model where they follow each other from reef to back reef to restricted lagoon (Fig. 8). This evolution is compatible with facies models for the Rhaetian of the Northern Calcareous Alps (e.g. PILLER, 1976; SCHÄFER, 1979; SCHOTT, 1983; SENOWBARI-DARYAN, 1980; STANTON & FLÜGEL, 1989).

The distribution of microfacies types at Site 764 (Section 4.3; Fig. 16) can be compared with those of the 'Oberrhätriffkalk' (upper Rhaetian reefal limestone; FABRICIUS, 1974; STANTON & FLÜGEL, 1989) or the 'Dachsteinriffkalk' (Dachstein reef limestone; ZANKL, 1971) of the Northern Calcareous Alps (Fig. 18). Site 761 reflects the lagoonal facies of the 'gebankter Dachsteinkalk' (bedded Dachstein limestone; PILLER 1976), whose cycles are similar to the well known regressive cycles of BRANDNER (1984).

6.2 Facies similarities

The Carnian-Norian facies of the Wombat Plateau (deltaics with coal seams and minor carbonates) are different from those of western Europe (piedmont siliciclastics, playa and sebkha type deposits with thick carbonate or evaporitic sequences), because of the higher (southern) paleolatitude of the Wombat Plateau and its more humid climates during the late Triassic. But towards the end of the late Triassic, the carbonate productivity and the development of reefs increased, possibly in connection with the northward drift of eastern Gondwana (GRADSTEIN & VON RAD, in press, OGG et al., in press). Therefore the Rhaetian facies of the Wombat Plateau is more similar to that of western Europe, especially in the Northern Calcareous Alps (Eastern Alps; Fig. 18). The marl/limestone alternations of the lower part of the Rhaetian sequence S4 at Sites 761 and 764 can be compared to the 'Kössen facies' (limestones and marly shales), which are also found in the lower part of the Rhaetian of the Alps. They are the same lithologies (marl-/limestone alternations) with comparable microfacies types (mudstones, wackestones, floatstones with echinoderm fragments and fine-grained bioclastic debris), which indicate similar environments in a broad shallow sea on a platform (cf. STANTON & FLÜGEL, 1989: Pls. 2, 3). The carbonate facies of Site 761 and the reefal carbonates of Site 764 (S4) show similarities to the 'Gebankter Dachsteinkalk' (bedded Dachstein limestone), and to the 'Oberrhätkalk' (upper Rhaetian limestone) facies of the Northern Calcareous Alps, respectively (Fig. 18). In addition to general trends, e.g., the regressive cycles from the bioturbated wackestones to algal bindstones described by BRANDNER (1984), we found similar to identical microfacies types (coral and calcisponge floatstone and boundstone, foraminiferal wackestone to packstone) and fauna (foraminifers, corals, sponges; cf. SCHÄFER & SENOWBARI-DARYAN, 1981: Table 1, Figs. 2, 3 and 6). The overlying foraminiferal and crinoidal limestones of sequence S5 correspond to the 'Zlambach beds'. This transgressive facies of (late ?) Rhaetian age represent the 'Adneter Wende' of the Western Tethys. In the Western Alps and in the Southern Alps, where the Rhaetian series are more restricted and more distant from the late Triassic shelf edge and the open marine areas, one can still observe a terrigenous-rich, more marine lower part, and a carbonate-dominated upper part in which patch-reefs and tidal-flats are developed (LUALDI, 1983; DUMONT, 1988; ACCORDI, 1976; THERY ET AL., 1989). These are more similar to those of Site 761. The thickness of the Alpine Rhaetian sequences is also comparable to that of the Australian sequences (one or two hundred meters), except in the Lombardy graben (one kilometer; MASETTI et al., 1989).

6.3 Sequence evolution

An outline of the Triassic series of the Western Alps (after MEGARD-GALLI & FAURE, 1988) is given in Fig. 11A.

During the middle Triassic (Anisian-Ladinian) the Alpine series are characterized by major transgressions resulting in the most marine environments. At the Australian margin, these beds were not drilled during the Leg 122, but a similar conclusion is given by KIRK (1985), based upon seismic and well data : the middle Triassic marine Locker Shale formation overlies a prominent lower Triassic angular unconformity, and consists of prodelta shales with interbedded delta front turbidites. The overlying Mungaroo Formation is non-marine to marginal-marine (regressive).

A marked regression occurred in the uppermost Ladinian-lower Carnian of the Alpine series, which led to the widespread development of evaporites (e.g., Raibl beds). This regression is consistent with the latest Ladinian major sea-level fall of the HAQ et al. (1987) cycle chart (Fig. 11B). It is overlain in the western Alps by three sedimentary cycles (cycles IV, V and VI, Fig. 11A; after MEGARD-GALLI & BAUD, 1977) which are roughly of Carnian, Norian and Rhaetian age. Cycle IV (Carnian in part) shows thickness and facies variations and is characterized by synsedimentary tectonics (MEGARD-GALLI & FAURE, 1988). It is likely that, as in the Wombat Plateau area, the eustatic signal has been strongly altered by extensional tectonics. This precludes a detailed comparison.

Cycle V (Norian, the 'Hauptdolomit') is made of a thick and widespread pile of intertidal to supratidal sequences ('Lofer cyclothems') with very little facies change. Its top is regressive. It seals the paleotopography and the structures produced by the Carnian tectonic pulses, and it accomodates the regular tectonic subsidence of the European platform. The Norian deltaic sequence of the Wombat Plateau (sequences S2, in part, and S3) is also much less disturbed by extensional tectonics than the Carnian one (Fig. 9). It shows more homogeneous, regressive facies. These facies are different from those of the Alpine Cycle V, but they have roughly the same significance regarding relative sea-level changes: they may both reflect the 224 MA/215 MA global, third-order sequence of the HAQ et al. (1987) cycle chart (Fig. 11). However, the S2/S3 sequence boundary observed in the Wombat Plateau area the ('220 Ma' SB of VON RAD et al., in press) is not identified in the western European series, and may have been produced by local tectonics.

The Norian Rhaetian sequence boundary is well identified both in the Wombat Plateau area, in Western Europe, and in other areas such as Canadian Arctic (EMBRY, 1988). Thus it is likely to represent a global event, which is consistent with the 215 MA sequence boundary of the HAQ et al. (1987) chart. In Western Europe, this SB is generally not a distinct unconformity, but a gradual transition of the regressive top (late HST) of the 'Hauptdolomit' formation and the transgressive base (TST) of the Rhaetian formation (Fig. 12A). No lowstand wedge or shelf margin wedge have been evidenced in the Western Alps. There is no lowstand systems tract (LST) between the SB and the TST in the Western Alps and at the Wombat Plateau, since the tops of carbonate platforms typically lack lowstand wedges (they can only be found off-banks).

Fig. 12A shows an example of the Rhaetian series in the Western Alpine internal nappes (after DUMONT, 1984, and unpublished data), which shows this gradual transgressive evolution (TST; 0 m to 60 m on Fig. 12A). This terrigenous-rich interval is overlain by a regressive carbonate wedge (60 m to 140 m) which contains *Triasina hantkeni* MAJZON (DUMONT & ZANINETTI, 1985; ZANINETTI et al., 1986). Inside this carbonate wedge we found a thin transgressive interval (97 m to 107 m on Fig. 12A) which contains small synsedimentary faults (DUMONT, 1984). Two possible sequence

interpretations are proposed in Fig. 12 :
(1) the 97 m/107 m transgression is due to a local tectonic event, and the next SB is placed at the top of the carbonate wedge (140 m.). This SB is between Rhaetian and Hettangian beds.
(2) the 97 m/107 m. transgression is the base of a TST, and the SB should be placed inside the carbonate wedge (97 m). This SB is overlain by Rhaetian beds with *Triasina hantkeni*.

Interpretation (2) is consistent with the HAQ et al. (1987) cycle chart, after which the 211 Ma sequence boundary is intra-Rhaetian (Fig. 11; Fig. 12). It is also consistent with the results of the Leg 122 which found a SB inside the uppermost Rhaetian beds (S4/S5; Fig. 12). Thus this latter SB is a good candidate for representing a global eustatic event (the '211 Ma' sequence boundary of the chart), but this has to be confirmed by more accurate paleontological data at several other localities in the Tethyan realm.

6.4 Syn-rift and post-rift tectonics (late Triassic-middle Jurassic)

The tectonic behaviour of the Northwestern Australian margin shows some unexpected similarities and some differences with western Europe.

(1) Carnian tectonics
An overview of the Alpine Triassic sequences is given in Fig. 19: the most important synsedimentary faults and slumps are found in the Carnian sequence (cycle IV, after MEGARD-GALLI & FAURE, 1988). Moreover, the Carnian coincides with a major change in the distribution of tectonic subsidence, as shown in Fig. 19B: in the Ligurian Alps, in the central Western Alps and in the Prealps, the pre-Carnian sequences (cycles I, II and III) are generally present (except if an décollement has truncated the series above them), whereas the thickness of the post-Carnian sequences (cycle V) varies from 0 to 800 m. This is probably a consequence of the late Ladinian-Carnian 'tectonic crisis' (MEGARD-GALLI & BAUD, 1977) which is also well expressed in the southern Alps (BOSELLINI et al., 1982). A similar tectonic crisis affected the Wombat Plateau area during Carnian times, as shown by the interpreted seismic profile (Fig. 19C).

(2) Rift volcanics at the Triassic/Jurassic boundary
A short-lived volcanic event occurred in western Europe around the Triassic/Jurassic boundary (DUMONT, in press). Lava flows or ashes are interbedded in some Rhaetian-Hettangian series of the western Alps, Pyrenees, northern and southern Spain. They are contemporaneous with the well-known rift volcanism of Morocco and of the eastern coast of Northern America (MANSPREIZER, 1988). Rift volcanics of the same age were dredged on the Wombat Plateau (213 Ma and 190-206 Ma: VON RAD & EXON, 1983) and some were drilled at the Scott Plateau, located to the NE of the Wombat Plateau (Hettangian; BINT, 1988 and pers. com.).

(3) Birth of marginal plateaus
A rim of non-subsiding or uplifted marginal plateaus developed along the European Tethyan margin soon after the Triassic (the so-called 'Briançonnais' domain). During Liassic times, deep and strongly subsiding basins formed between the marginal plateaus and the European continent (LEMOINE et al., 1986). At the Australian margin (BARBER, 1988; EXON et al., 1982), major tectonic events occurred in the earliest Jurassic, when the margin was split into a rim of marginal plateaus with a thick Triassic and a thin Jurassic cover on one hand (Exmouth, Wombat, Scott), and several broad nearshore grabens with thick Triassic and Jurassic series on the other hand (Barrow-Dampier basins).

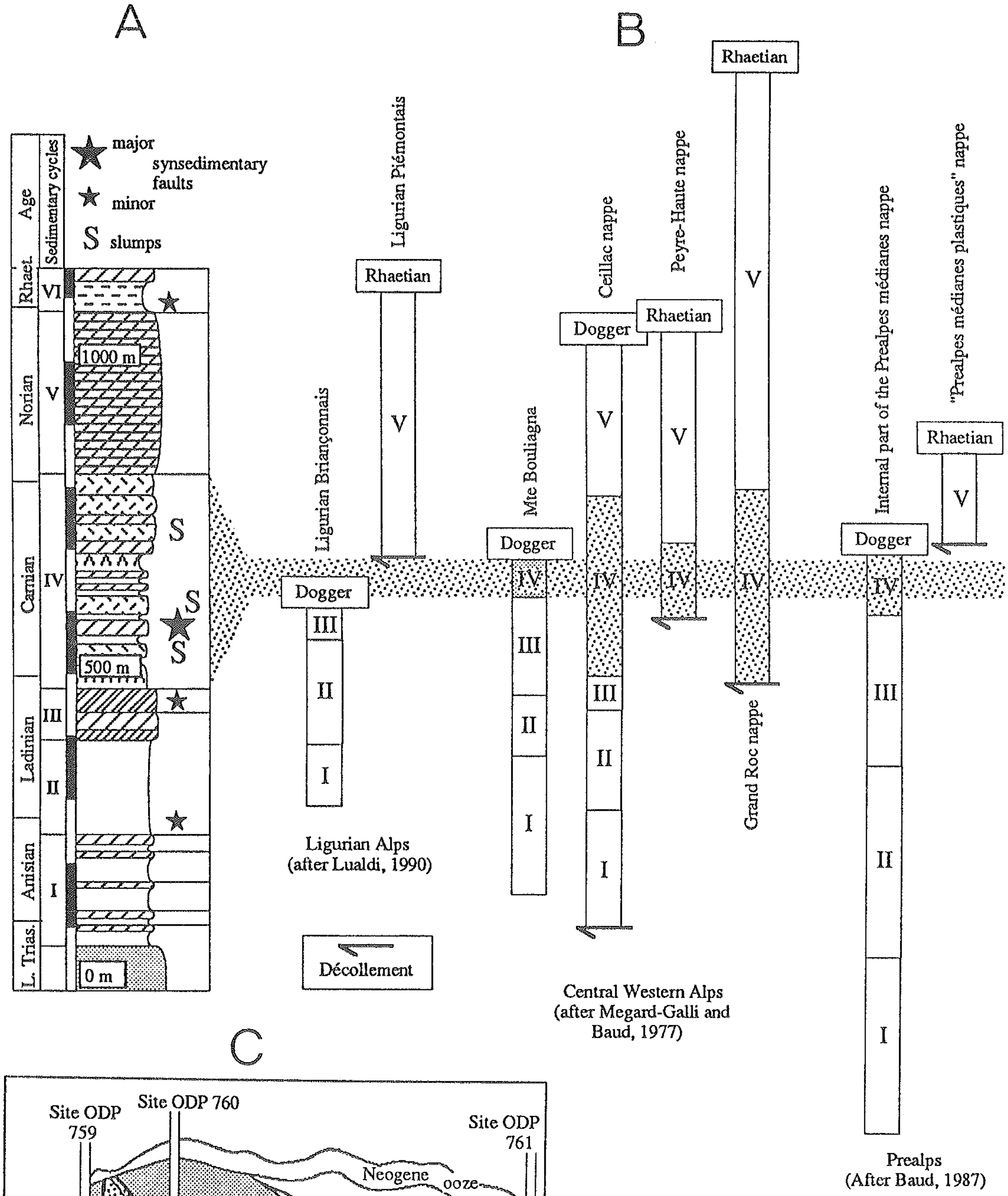
It is surprising to find such a similar tectonic and geodynamic behaviour at two continental margins which were so far apart. This suggests that not only eustasy, but also tectonic events may have been globally synchronous (and perhaps linked with eustasy). Global unconformities and third-order depositional sequences may have been influenced by global tectonic events. These features might be explained by the intraplate stress model of CLOETINGH (1986) and CLOETINGH et al. (in press).

(4) Callovian/Oxfordian extensional block-tectonics
A major block-faulting event occurred at Exmouth Plateau during mid-Jurassic (probably Callovian) times. At Wombat Plateau this 'late-rift' tectonic event caused the downwarping of the Wombat Halfgraben (south of the plateau; Fig. 2) and the uplift and subaerial erosion of the Wombat Plateau horst. This resulted in the formation of the conspicuous 'post-rift unconformity' (VON RAD et al., in press). There is clear evidence of substantial erosional truncation of the uppermost Rhaetian strata between Sites 761 and 764 in high-resolution seismic profiles (WILLIAMSON in press). This seismic and regional geological evidence for post-Rhaetian uplift and subaerial erosion is supplemented by the evidence of post-depositional, late-diagenetic fresh-water overprinting of the Rhaetian carbonates (RÖHL et al., in press), and by the composition of the lower Neocomian transgressive sand overlying the PRU in Site 761 (VON RAD & THUROW, in press). An alternative interpretation by SARTI (in press) suggests that Wombat Plateau did not experience any tectonic uplift or subaerial erosion in Jurassic times, but underwent slow subsidence, condensation or non-deposition on a sediment-starved, drowned carbonate platform. Because of the evidence discussed above, we cannot follow this interpretation. The postulated major mid-Jurassic block-tectonic event was probably of regional importance for NW Australia only. Elsewhere, e.g. in the Tethys Himalaya (Nepal) or at several circum-North Atlantic margins, a mid-Callovian to early Oxfordian hiatus is a marine hiatus, which was caused by a global (third-order) sea level rise (GRADSTEIN et al., 1989)

7 CONCLUSIONS

7.1 Microfacies and facies model

The Carnian and Norian paleoenvironment is characterized by fluviodeltaic to shallow-marine deposits. The siliciclastic sediments were derived from Gondwana in the southeast and distributed by laterally migrating delta lobes. Several limestone beds are intercalated within the siliciclastic



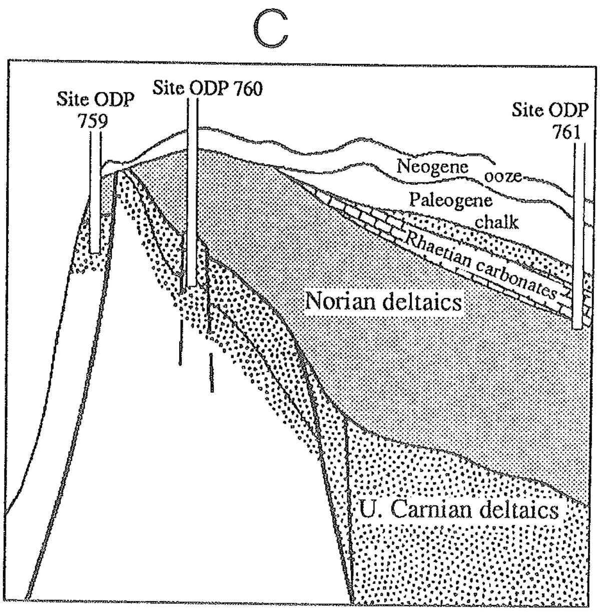


Fig.19. The Carnian extensional tectonics in the western Alps and at the NW Australian margin. A: The most important evidence of synsedimentary tectonics in the western Alps is found in the upper Ladinian to Carnian series (after MEGARD-GALLI & FAURE, 1988). B: In connection with this Carnian tectonics, the Carnian and post-Carnian series (cycles IV and V) show strong thickness variations in the Ligurian Alps, the central Western Alps and the Prèalps (after MEGARD-GALLI & BAUD, 1977, BAUD, 1987, and LUALDI, 1990). C: The NW Australian margin was also effected by a major extensional tectonic event during the Carnian, which was more or less sealed by the Norian to Rhaetian deposits. Interpretation of seismic line BMR 56-13, after SHIPBOARD SCIENTIFIC PARTY, 1990.

sequences. They interrupt the clayey to silty and fine-sandy background sedimentation. These carbonates are interpreted as bioclastic sands (grainstones), algal mats, patch reefs and storm deposits with reworked bioclasts. The carbonate beds become more abundant up-section, parallel to the shallowing-upward trend. We interpret the limestones as allochthonous accumulations (e.g., storm deposits and bioclastic sand-shoals) or local autochthonous carbonate buildups in

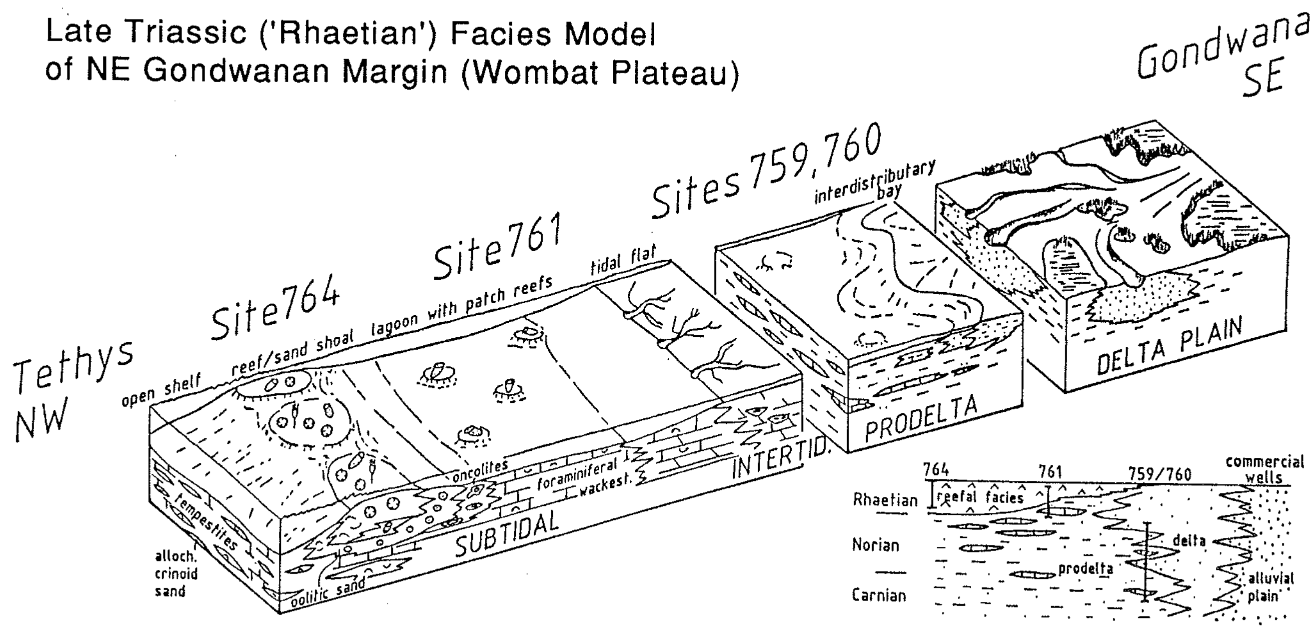


Fig. 20. Generalized facies model for the Wombat Plateau. Sites 759 and 760 represent the fluviodeltaic-dominated series of the Carnian and Norian, Sites 761 and 764 the Rhaetian carbonate platform. The time-equivalent Rhaetian series in the area of Sites 759 and 760 that have been eroded by the Jurassic post-rift unconformity, are assumed to be fluviodeltaic or mixed fluviodeltaic/shallow-water carbonate. Alternatively, there was no deposition at this location during Jurassic times, due to the northward tilting of the Wombat block and emersion of its southern flank. Site 761 reflects the intertidal to shallow-subtidal lagoonal areas. Site 764 reflects the better ventilated subtidal oolite shoals, reef, and reefal debris areas (modified after Röhl et al., in press).

restricted areas without siliciclastic dilution.

The first recovery of Rhaetian reefal limestones offshore NW Australia demonstrated an important link between eastern and western Tethys. It is also of interest as a potential hydrocarbon reservoir in areas off NW Australia, where the Rhaetian reefal limestone which are underlain by hydrocarbon source rocks of the Mungaroo Formation to accumulate and preserve gas or oil (Williamson et al., 1989). The development of the Rhaetian carbonate platform documents a major southward transgression of the southern Tethys Sea that took place during early Rhaetian times. The gradual development of a carbonate ramp resulted in local algal bindstones and coral/sponge reefs alternating with lagoonal facies including typical molluscs like *Megalodon* and foraminifers like *Triasina hantkeni.*

The distinguished twenty-five microfacies types within the Carnian to Rhaetian limestones point to carbonate sand shoal facies, lagoonal facies, and patch reef facies. All transitions to open marine environments occur in the lowermost and uppermost parts of the Rhaetian sites

Our interpretation of the different sedimentation areas of the Upper Triassic (Carnian, Norian, and Rhaetian) on Wombat Plateau is summarized in Fig. 20. The three-dimensional facies model shows the fluviodeltaic setting, the siliciclastic-dominated marine environments, and the carbonate platform as separate blocks. The Carnian and Norian sediments of Sites 759 and 760 are deposited in a deltaic and prodeltaic environment (Fig. 20). 'Coal measure sequences', delta plain sandstones, siltstones and fine-grained sandstone turbidites, and finally calcareous tempestites intercalated with silty claystones. Autochthonous carbonates were deposited in intra-distributary bays and on tidal flats. Calcisponge patch reefs flourished in relatively deeper areas in front of the intra-distributary bays. Coarse-grained carbonate sands are more common in the front of delta lobes. The lagoonal facies of the Rhaetian in Site 761 is dominated by peloid- and foraminifer-rich wackestones (Fig.20). Algal laminites occur in the shallower, calcisponge patch-reefs in

Plate 56 — Upper Triassic microfacies types of the Wombat Plateau (NW Australia).

Fig. 1. Quartz-sandstone with ooids and bioclastic layers (stained by Alizarin-S); Carnian-Norian, sample 122-759B-11R-1, 12-16 cm; scale = 5 mm.

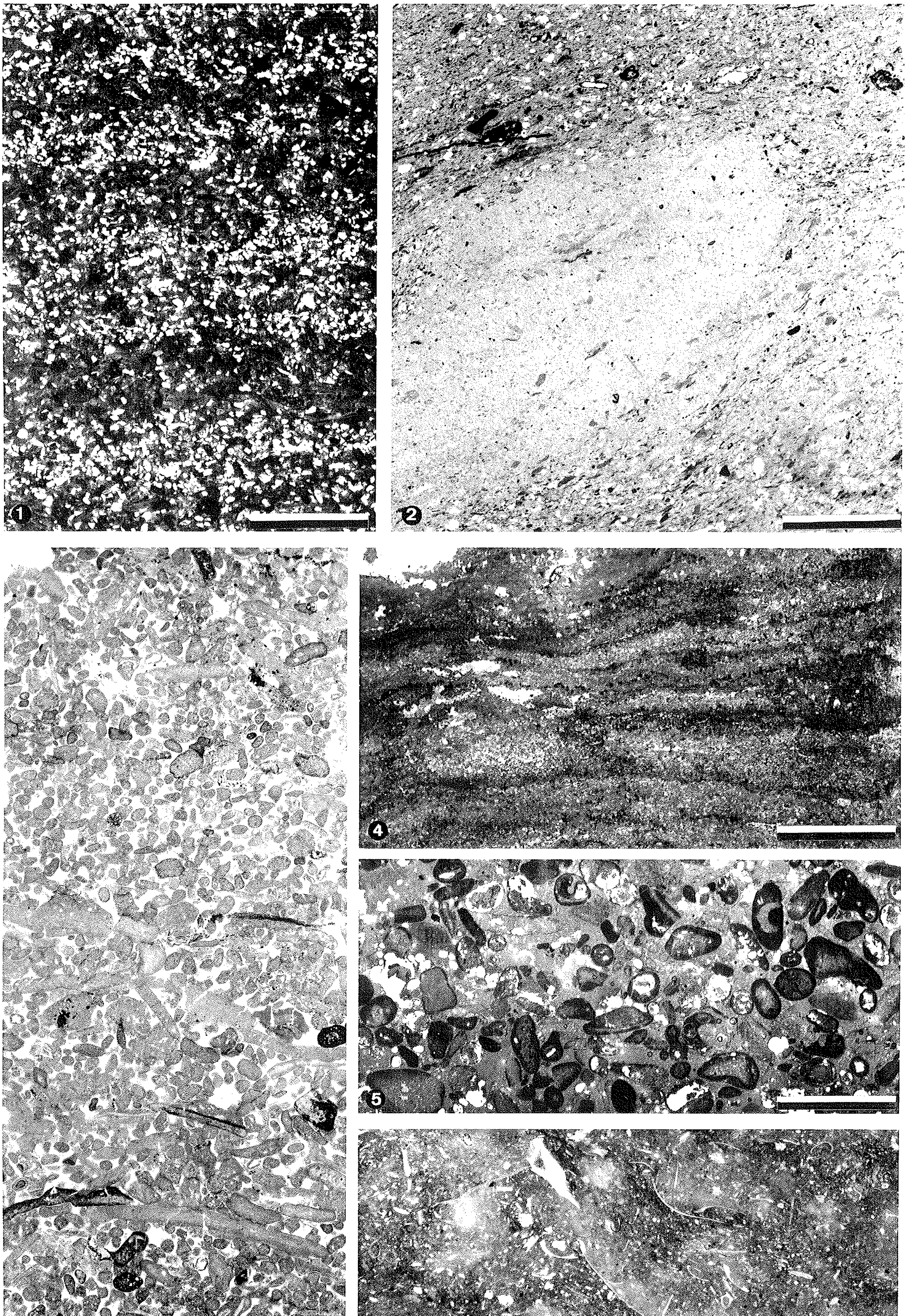
Fig. 2. Bioturbated wackestone with quartz (MFT 2); Norian, sample 122-760B-8R-3, 82-86 cm; scale = 5 mm.

Fig. 3. Codiacean grainstone (MFT 20) with peloids, ooids, surficial ooids, and oomolds; Norian, sample 122-759B-19R-CC, 11-13 cm; scale = 5 mm.

Fig. 4. Algal bindstone (MFT 21); Rhaetian, sample 761B-33X-1, 41-43 cm; scale = 5 mm

Fig. 5. Grainstone (MFT 17/22) with surficial ooids, oomolds, echinoderms (crinoids), and gastropods; Carnian-Norian, sample 122-760B-15R-1, 59-60 cm; scale 5 mm.

Fig. 6. Wackestone to floatstone (MFT 7/13) with pelecypods, ostracodes, and rare echinoderm fragments; Rhaetian, sample 122-761C-22R-1, 53-56 cm; scale = 5 mm.



the deeper areas of the ramp. The Rhaetian of Site 764 is dominated by subtidal limestone types, characterized by reefal facies and associated sediments, whereas several grainstone types were deposited on nearby shoals.

7.2 Foraminiferal biostratigraphy

The occurrence of Aulotortidae (*Aulotortus, Auloconus, Triasina*) and smaller foraminifers (*Duotaxis, 'Tetrataxis'*, 'Trochamminidae', '*Ophthalmidium*') characterize a reefal platform, which can be differentiated into (1) a lagoon to patch reef environment with abundant Aulotortidae, and (2) a patch reef to shelf zone with small foraminifers. On the basis of *Triasina oberhauseri* and *Triasina hantkeni* the samples of Site 761 are of upper Norian to Rhaetian age, those of Site 764 are of Rhaetian age.

7.3 Sequence stratigraphy and Tethyan connections

The potential of sequence-stratigraphic interpretations was tested at this very old passsive continental margin in a mixed clastic-carbonate (Carnian-Norian) and in a pure carbonate system (Rhaetian). The identification of unconformities (interpreted as sequence boundaries) and the comparison of the sequences with those of the HAQ et al. (1987) cycle chart led to the estimation of the major causes for the development of depositional sequences at the Wombat Plateau.

The Carnian - Norian series were affected by significant extensional tectonics, as proven by erosional unconformities and the deposition of conglomeratic layers. The structural deformation is also shown by seismic evidence. Our investigations suggest that the eustatic signal within the Carnian and Norian can still be discerned, although it is mixed with the tectonic signal. Because of the higher latitude and its more humid climate, the Carnian - Norian facies of the Wombat Plateau is different from that of western Europe. In connection with the northward drift of eastern Gondwana to lower latitudes (about 25-30°S, according to OGG et al., in press) the carbonate productivity increased during Rhaetian/ Liassic times. The Rhaetian series show only weak evidence of tectonic influence. A good argument in favor of global sea level fluctuations is the correlation of two SB's (S3/4, and to a lesser degree S4/S5) and of the resulting conspicuous facies changes between the eastern Tethys (NW Australia) and the western Tethyan outcrops in the western, northern and eastern Alps. The Norian/Rhaetian boundary correlates well with a global sequence boundary ('215 Ma' after HAQ et al., 1987) which caused the 'early Rhaetian transgression', well known form all over the world. The marl/limestone alternations of the lower part of the Rhaetian sequence S4 can be compared with the marly 'Kössen' facies. The upper parts of sequence S4 in Sites 761 and 764 are similar to the 'Gebankter Dachsteinkalk' (bedded Dachstein limestone) and to the 'Oberrhätkalk' (upper Rhaetian limestone) facies of the Northern Calcareous Alps. The 'latest Rhaetian drowning event' coincides with the worldwide latest Rhaetian sequence boundary ('211 Ma' after HAQ et al., 1987) that led to the Hettangian (early Jurassic) transgression or to the 'Adneter Wende' in the Alps.

Our detailed investigations of the upper Triassic series of the Wombat Plateau show that regional tectonics are less important for the distribution of sediments and definition of depositional sequences than eustatism. Correlations of the Rhaetian series over long distances between the eastern and western Tethyan realm suggest that sedimentation is mainly controlled by global sea level changes.

ACKNOWLEDGEMENTS

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Plate 57 Upper Triassic microfacies types of the Wombat Plateau (NW Australia).

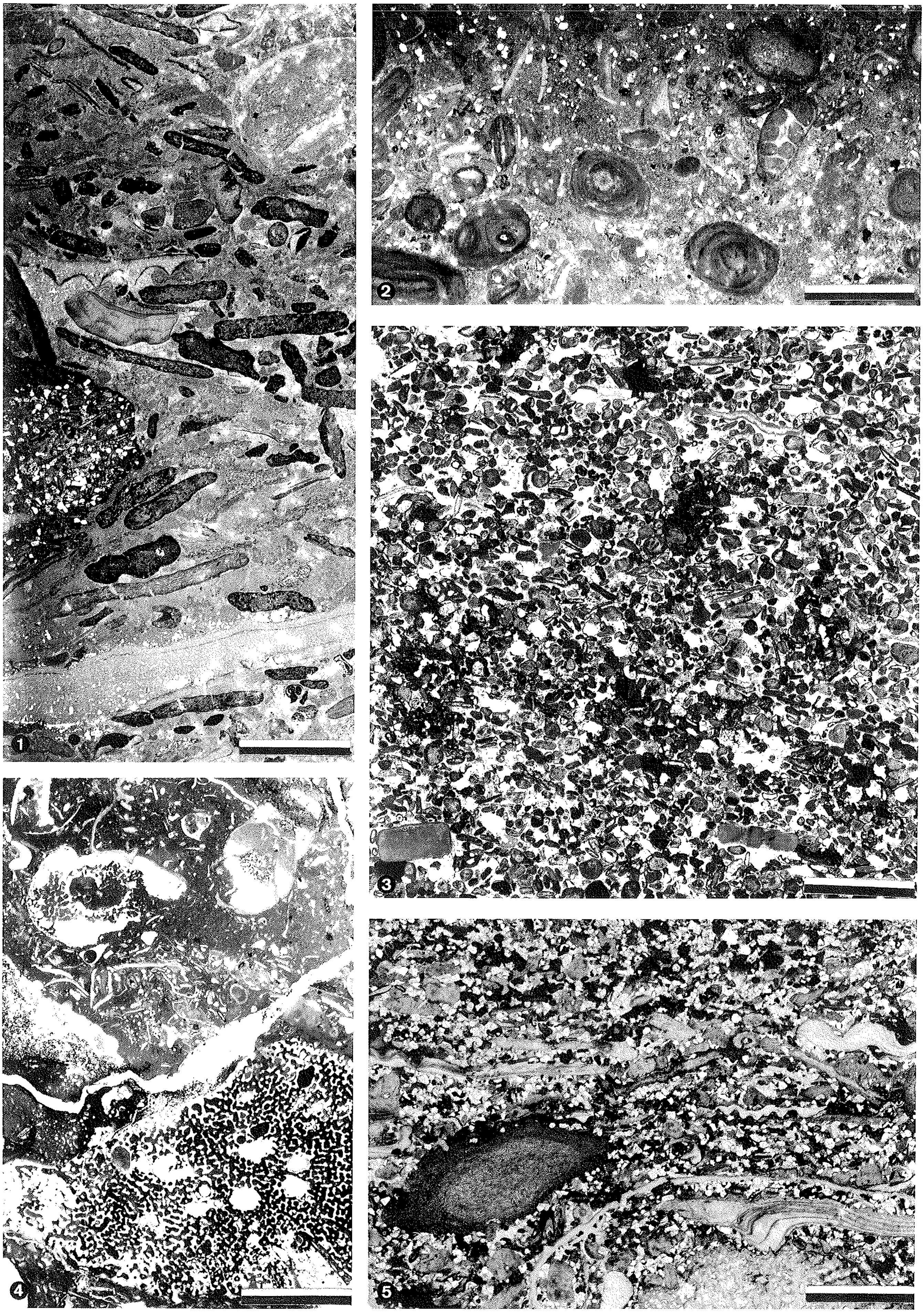
Fig. 1. Codiacean packstone to floatstone (MFT 12), note different preservation of codiacean fragments; large thick-shelled mollusc fragments, peloids, echinoderm fragments and extraclast consisting of quartz (not stained by Alizarin-S) - bearing oolitic grainstone (ooids are dolomitized); Carnian-Norian, sample 122-760B-21R-1, 120-123 cm; scale = 5 mm.

Fig. 2. Oncolitic grainstone (MFT 18) with quartz, brachiopod fragments and gastropods; Carnian-Norian, sample 122-760B-17R-2, 15-17 cm; scale = 5 mm.

Fig. 3. Skeletal grainstone (MFT 22) with crinoids, coated grains with Involutinidae-nuclei, pelecypods, and surficial ooids; Norian, sample 122-760B-9R-2, 38-42 cm; scale = 5 mm.

Fig. 4. Sponge/hydrozoan floatstone (MFT 14) sponges and hydrozoans (*Disjectopora*?) are recrystallized, pelecypods, crinoids and gastropods; Rhaetian, sample 122-761C-30R-1, 28-31 cm; scale = 5 mm.

Fig. 5. Quartz-sandstone with large skeletal fragments; base of Rhaetian, sample 122-761C-32R-CC, 1-5 cm; scale = 5 mm.



REFERENCES

ABATE, B., CIARAPICA, G & ZANINETTI, L. (1984): *Triasina oberhauseri* KOEHN-ZANINETTI et BRÖNNIMANN, 1968, dans le Trias supérieur récifal (Facies 'Back-Reef') de la plateforme Panormide, Sicile. – Rev. Paléobiologie, **3**/1, 19-25; Genève

ACCORDI G. (1976): Il Retico dei Monti Martani (Perugia). – Bull. Soc. Geol. Italiana, **95**, 3-26; Roma

AL-SHAIBANI, S., ALTNER, D., BRÖNNIMANN, P., CARTER, D.J. & ZANINETTI, L., (1982): *Triasina hantkeni* MAJZON, 1954 (Foraminifère), dans le Trias supérieur de la Téthys (Europe et Asie). – Arch. Sci., **35**/2, 137-142, Genève

AL-SHAIBANI, S., CARTER, D.J. & ZANINETTI, L. (1983): Geological and micropaleontological investigations in the Upper Triassic (Asinepe Limestone) of Seram, Outer Banda Arc, Indonesia. – Arch, Sci., **36**/2, 297-313. Genève

AL-SHAIBANI, S., CARTER, D.J. & ZANINETTI, L. (1984): Microfaunes associées aux Involutinidae et aux Milioliporidae dans le Trias supérieur (Rhétien) de Seram, Indonésie; précisions stratigraphiques et paléoécologie. – Arch. Sci., **37**/3, 301-316, Genève

BARBER, P.M. (1988): The Exmouth Plateau deep water frontier: A case history. – In: PURCELL, P.G., & PURCELL, R.R. (eds.): The North West Shelf Australia, Proceedings of the North West Shelf Symposium, 173-187, Perth

BINT, A.N. (1988): Gas fields of the Browse Basin. – In: PURCELL, P.G., & PURCELL, R.R. (eds.): The North West Shelf Australia, Proceedings of the North West Shelf Symposium, 413-418, Perth

BOSELLINI, A., CASTELLARIN, A., DOGLIONI C., GUY, F., LUCCHINI F., PERRI, M.C., ROSS, 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. – Soc. Geol. Ital., 189-209, Roma

BRALOWER, T.J., BOWN, P.R. & SIESSER, W.G. (in press): Taxonomy and evolutionary lineages of upper Triassic calcareous nannoplankton from ODP Sites 759, 760, 761, 764, Wombat Plateau. – In: VON RAD, U. HAQ, B.U. et al.: Proc. ODP, Sci. Results, **122**, College Station

BRANDNER, R. (1984): Meeresspiegelschwankungen und Tektonik in der Trias der NW-Tethys. - Jb.Geol. Bundesanstalt, **126**/4, 435-475, Wien.

BRENNER, W. (in press): Late Triassic palynology of the Wombat Plateau, NW Australia. – In: VON RAD, U. HAQ, B.U. et al.: Proc. ODP, Sci. Results, **122**, College Station

BRENNER, W., BOWN, P.R., BRALOWER, T.J., CRASQUIN-SOLEAU, S., DÉPÊCHE, F., DUMONT, T., MARTINI, R., SIESSER, W.G. & ZANINETTI, L. (in press): Correlation of Carnian to Rhaetian foraminiferal, calcareous nannofossil, ostracode, and palynological biostratigraphy. – In: VON RAD, U. HAQ, B.U et al.: Proc. ODP, Sci. Results, **122**, College Station

BRÖNNIMANN, P., POISSON, A. & ZANINETTI, L. (1970): L'Unité de Domuz Dag (Taurus Lycien - Turquie); microfaciés et Foraminifères du Trias et du Lias. – Riv. Italiana Paleont., **76**/1, 1-36, Milano

BRÖNNIMANN, P., WHITTAKER J.E. & ZANINETTI, L. (1975): Triassic foraminiferal biostratigraphy of the Kyaukme-Longtawkno area, Northern Shan States, Burma. – Riv. Ital. Paleont., **81/1**, 1-30, Milano

CIARAPICA, G. & ZANINETTI, L. (1984): Foraminifères et biostratigraphie dans le Trias supérieur de la serie de La Spezia (Dolomies de Coregna et Formation de La Spezia, nouvelles formations), Appenin septentrional. – Rev. Paléobiologie, **3/1**, 117-134, Genève

CLOETINGH, S. (1986): Intraplate stresses: A new tectonic mechanism for fluctuations of relative sea level. – Geology, **14**, 617-620, Boulder

CLOETINGH, S., STEIN, C., REEMST, P., GRADSTEIN, F.M., WILLIAMSON, P.E., EXON, N.F. & RAD, U.VON (in press): The relationship between continental margin stratigraphy, deformation, and intraplate stresses for the Indo-Australian region. – In: GRADSTEIN, F.M., LUDDEN, J.N. et al., Proc. ODP, Sci. Results, **123**, College Station

COCOZZA, T. & GANDIN, A. (1990): Carbonate deposition during early rifting: the Cambrian of Sardinia and the Triassic-Jurassic of Tuscany, Italy. – In: TUCKER, M.E. WILSON, J.L., CREVELLO, P.D., SARG, J.R. & READ, J.F.: Carbonate Platforms. Facies, sequences and evolution. – Int. Assoc. Sediment. Spec. Publ., **9**, 9-37, London

DÉPÊCHE, N, & CRASQUIN-SOLEAU, N. (in press): Triassic marine ostracodes of the Australian margin (Ocean Drilling Program Leg 122, Holes 759B, 760B, 761C, 764A-B). – In: VON RAD, U., HAQ, B.U. et al.: Proc. ODP Sci. Results, **122**, College Station

DI STEFANO, P., GULLO, M. & SENOWBARI-DARYAN, B. (1990): The Upper Triassic reef of Monte Genuarolo (Southwestern Sicily). – Boll. Soc. Geol. It., **109**, 103-114, Rome

DOGLIONI, C., BOSELLINI, A. & VAIL, P.R. (1990): Stratal patterns: a proposal of classification and examples from the Dolomites. – Basin Research, **2**, 83-95, Oxford

DUMONT, T. (1984): Le Rhétien et le Lias inférieur prépiémontais:

Plate 58 — Upper Triassic Microfacies types of the Wombat Plateau (NW Australia): ooids, peloids, oncoids and coated grains.

Fig. 1. Oolitic grainstone with inter- and intraparticle porosity; MFT 17; Rhaetian, sample 122-761C-12R-1, 12-14 cm; scale = 300 µm.

Fig. 2. Oolitic grainstone, ooids contain dolomitized nuclei, calcitic coatings, and even-rim cement (stained by Alizarin-S), dolomitized blocky cement; MFT 17, Norian, sample 122-760A-38X-1, 6-9 cm; scale = 100 µm.

Fig. 3. Spalling of ooid cortices within oolitic grainstone (MFT 17) signs early compaction; Carnian, sample 122-760B-20R-CC, 16-18 cm; scale = 100 µm.

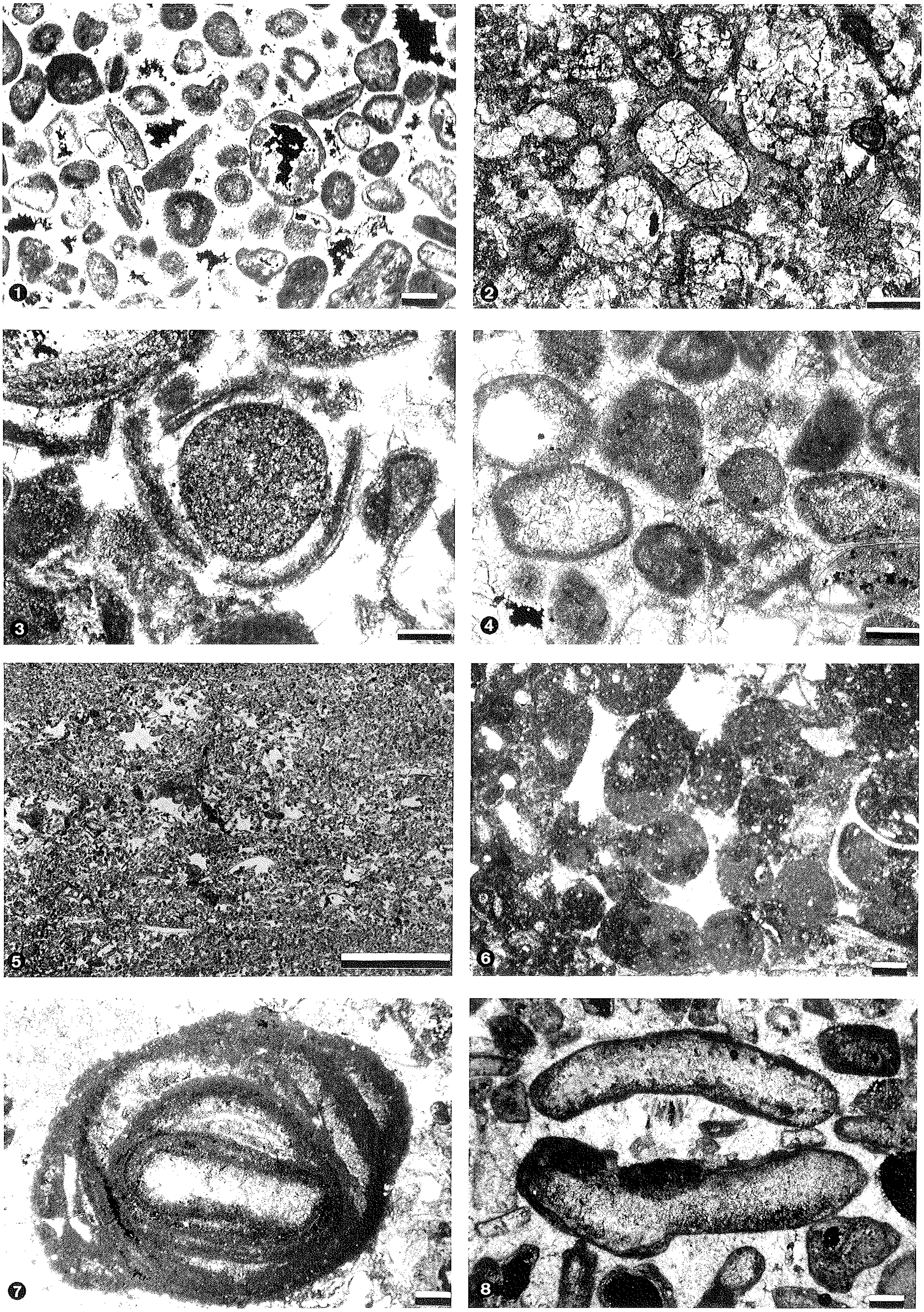
Fig. 4. Oolitic grainstone, MFT 17, sparitized ooids, oomolds, granular calcite cement; Carnian-Norian, sample 122-760B-15R-1, 23-25 cm; scale = 100 µm.

Fig. 5. Peloidal grainstone with keystone vugs, MFT 21; Rhaetian, sample 122-761C-12R-1, 52-55 cm; scale = 5 mm.

Fig. 6. Fecal pellets within peloidal packstone, MFT 9; Rhaetian, sample 122-761C-12R-1, 8-10 cm; scale = 300 µm.

Fig. 7. Oncoid of an oncolitic grainstone (MFT 18), irregular concentric micrite layers and spar-filled interstices; Carnian-Norian, sample 122-760B-17R-2, 15-17 cm; scale = 300 µm.

Fig. 8. Micrite coatings surround pelecypod fragments, coated-grain grainstone, MFT 16; Rhaetian, sample 122-31-CC, 8-12 cm; scale = 300 µm.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enregistrement sédimentaire du passage des carbonates de plateforme triassiques au Jurassique hémipélagique lors du début du rifting téthysien. – Géologie Alpine, **60**, 13-25, Grenoble

— (1988): Late Triassic-early Jurassic evolution of the western Alps and of their European foreland; initiation of the Tethyan rifting. – Bull. Soc. Geol. France, **4/4**, 601-612, Paris

— (in press): The Late Triassic (Rhaetian) sequences of Wombat Plateau (NW Australia, ODP Leg 122): Sea-level changes, Tethyan rifting, and overprint of Indo-Australian breakup. – In: von Rad, U. Haq, B.U et al.: Proc. ODP, Sci. Results, **122**, College Station

Dumont, T. & Zaninetti, L. (1985): Découverte de *Triasina hantkeni* Majzon (foraminifère) dans un faisceau calcaire de la formation rhético-hettangienne prépiémontaise (nappe de Rochebrune, SE de Briancon, Alpes occidentales). – Arch. Sciences de Genève, 38/1, 63-70, Genève

Efimova, N.A. (1974). Triassic Foraminifers of the NW Caucasus and Cis-Caucasus. – Voprozy Mikropal., 17, 54-83, Moscow (Akad. Nauk)

— (1975). Foraminifères des dépôts de la série de Khodzin. – In Nouvelles données stratigraphiques des dépôts mésozoiques contenant du gaz et du pétrole: régions du Sud de l'URSS. – Buznacov, N.V. Ed. Travaux Ministère Géologie, **171**, 47-61, Moscow

Embry, A.F. (1988): Triassic Sea-Level Changes: Evidences from the Canadian Arctic Archipelago. – In: Wilgus, C.K., Hastings, B.S., Kendall, C.G., Posamentier, H.W., Ross, C.A. & Van Wagoner, J.C. (eds.): Sea-level changes: an integrated approach. – Soc. Econ. Pal. Min., Spec. Publ., **42**, 299-260, Tulsa

Embry, A.F. & Klovan, J.E. (1971): A late Devonian reef tract on northeastern Banks Island, Northwest Territories. – Bull. Can. Petrol. Geol., **19**, 730-781, Toronto

Exon, N.F., von Rad, U. & Stackelberg, U.von (1982): The geological development of the passive margins of the Exmouth Plateau off northwest Australia. – Marine Geology, **47**, 131-152, Amsterdam.

Fabricius, F.H. (1974): Die stratigraphische Stellung der Rhät-Fazies. – Schriftenr. Erdwiss. Kommiss. österr. Akad. Wiss., **2**, 87-92, Wien

Flügel, E. (1982): Microfacies analysis of limestones. – 633 pp, Berlin (Springer)

Fontaine, H., Beauvais, L., Poumint, C. & Vachard, D. (1979): Données nouvelles sur le Mésozoique de l'Ouest des Philippines. Découverte de Rhétien marin. – C.R. somm. Soc. Géol. France, 3, 117-121, Paris

Fontaine, H., Rodziah, D. & Singh, U. (1990): Discovery of an Upper Triassic limestone basement in the Malay Basin, offshore Peninsula Malaysia: regional implications. – J. Southeast Asian Earth Sciences, **4**, 219-232, Oxford

Gazdzicki, A. (1983): Foraminifers and biostratigraphy of Upper Triassic and Lower Jurassic of the slovakian and polish Carpathians. – Paleont. Polonica, **44**, 109-169, Warsaw

Gazdzicki, A., Kozur, H. & Mock, R. (1979): The Norian-Rhaetian boundary in the light of micropaleontological data. – Geologija, **22/1**, 71-112, Ljubljana

Gazdzicki, A. & Reid, P. (1983): Upper Triassic Involutinidae (Foraminifers) of Lime Peak in Yukon, Canada. – Acta Geol. Pol., **33/1-4**, 99-106, Warsaw

Gradstein, F.M., Gibling, M.R., Jansa, L.F., Kaminski, M.A., Ogg, J.G., Sarti M., Thurow, J.W., Rad, U.von & Westermann, G.E.G. (1989): Mesozoic stratigraphy of Thakkhola, Central Nepal. – Lost Ocean Expedition, Spec. Rep., **1**, 115 pp., Halifax (Seabord)

Gradstein, F.M. & Rad, U.von (in press): Stratigraphic evolution of Mesozoic continental margin and oceanic sequences, NW Australia and N. Himalayas. – In: Davies, T.A., Meyer, A. & Wise, S.W. Jr. (eds.): The evolution of Mesozoic and cenozoic continental margins – Soc. Econ. Paleont. Min., Spec. Publ. Tulsa

Haq, B.U., Hardenbol, J. & Vail, P. (1987): Chronology of fluctuating sea levels since the Triassic (250 million years ago to present). – Science, **235**, 1156-1166, Washington

Haq, B.U., Rad U.von, O'Connell, S. et al. (1990): Proc. ODP, Init. Repts., **122**, 826 pp.; Ocean Drilling Program, College Station

Heath, R.S. & Apthorpe, M.C. (1986): Middle and Early (?) Triassic Foraminifers from the Northwest Shelf, Western Australia. – J. Foram. Res., **16/4**, 313-333, Washington

Henrich. R. & Zankl, H. (1986): Diagenesis of Upper Triassic Wetterstein reefs of the Bavarian Alps. – In: Schroeder, J.H. & Purser, B.H. (eds.): Reef Diagenesis. 245-268, Berlin (Springer)

He Yan (1980): Sketch of the Triassic foraminiferal biostratigraphy of NW Sichuan (Szechuan), China. – Riv. Italiana Paleont., **85/3-4**, 1167-1174, Milano

— (1982): Upper Triassic Foraminifers of Eastern Xizang. – In: Stratigraphy and Paleontology in W Sichuan and E Xizang,

Plate 59 Upper Triassic microfacies types of the Wombat Plateau (NW Australia): Calcareous algae, bryozoa, borings and microproblematica.

Fig. 1. Dasycladacean (*Diplopora* sp.) fragment within skeletal wackestone to packstone, echinoderm fragment, moldic porosity, MFT 7-9; Rhaetian, sample 122-761C-22R-1, 5-8 cm; scale = 300 μm.

Fig. 2. Different preservation of green algae (Codiacea), floating in recrystallized matrix, MFT 12-13; Carnian, sample 122-760B-21R-1, 120-123 cm; scale = 300 μm.

Fig. 3. Codiacean plate within oolitic grainstone. Note oomoldic porosity and dolomite rhombs in micrite, MFT 15; Rhaetian, sample 122-761C-12R-1, 12-16 cm; scale = 300 μm.

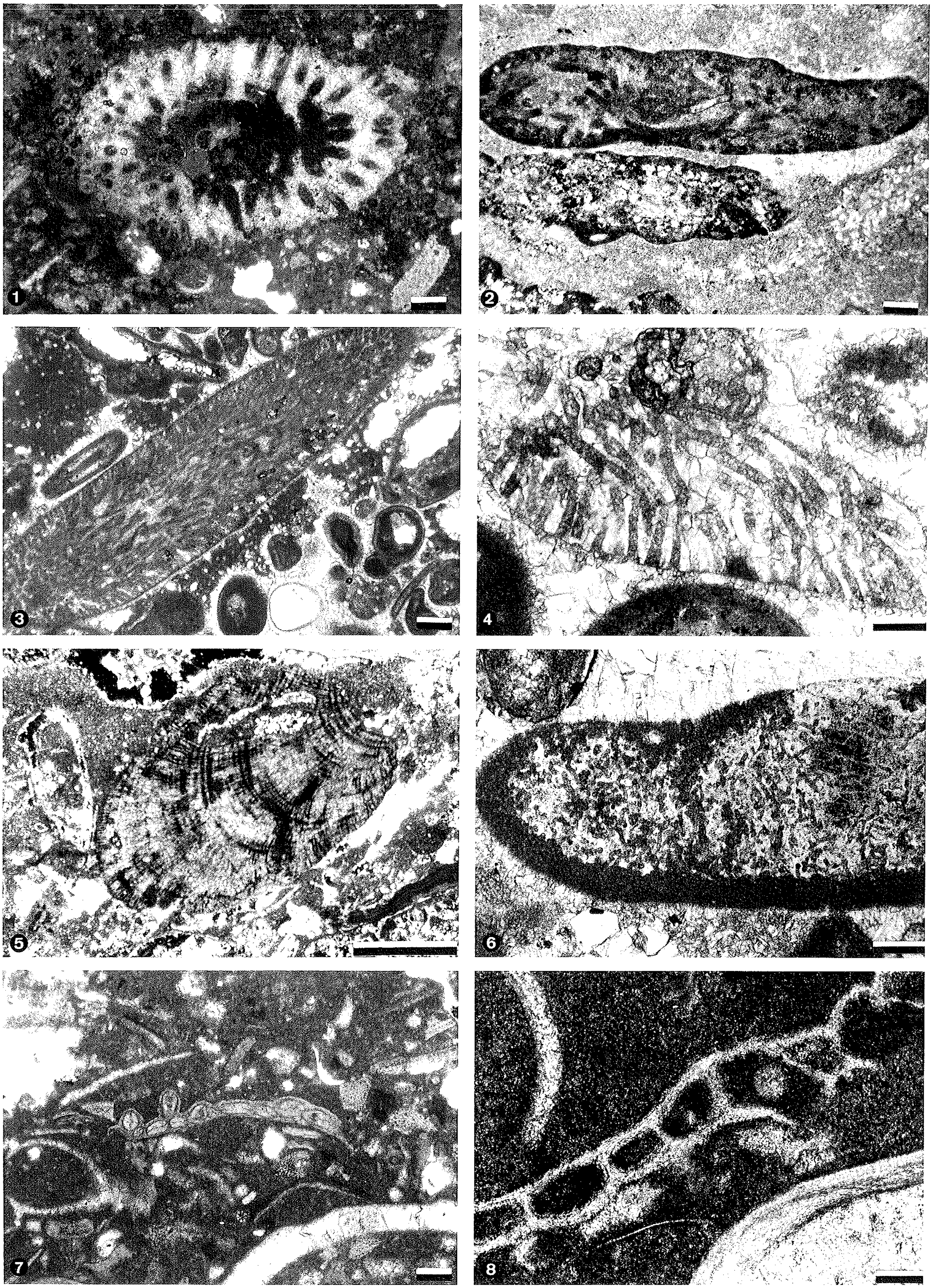
Fig. 4. Blue-green algae with typical branching of filaments, even-rim and blocky calcite cement, coated-grain grainstone (MFT 16); Carnian-Norian, sample 122-760B-15R-1, 59-60 cm; scale = 100 μm.

Fig. 5. Red algae fragment within skeletal packestone to floatstone (MFT 10); Rhaetian, sample 122-764B-30R-1, 6-9 cm; scale = 2000 μm.

Fig. 6. Intensive boring in an echinoderm fragment, skeletal grainstone (MFT 22); Rhaetian, sample 122-760B-9R-2, 35-38 cm; scale = 100 μm.

Fig. 7. Bryozoan fragment in skeletal wackestone (MFT), echinoderm and pelecypod fragments, biomoldic porosity; Rhaetian, sample 122-764B-26R-1, 19-21 cm; scale = 300 μm.

Fig. 8. Problematicum 2 (Senowbari-Daryan, 1980) in calcisponge floatstone (MFT 14); Rhaetian, sample 122-764B-27R-1, 95-99 cm; scale = 100 μm.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Part 2. (The People's Publishing House of Sichuan)
HE YAN & HU LANG-YING (1977): Triassic Foraminifers from the area in the east flank of the Lancangjing River, Yunnan. – In: Mesozoic fossils from Yunnan, China, Part 2. Centre de Recherches Géologiques sur les fossiles de l'Académie des Sciences de Chineà Nankin. Traduction de l'Institut Français du Pétrole, Réf. **26193**, (1978)
ITO, M., O'CONELL, S., STEFANI, A. & BORELLA, P. (in press): Fluvial dominated deltaic successions in Wombat Plateau: The Upper Triassic depositional sequences and siliciclastic/carbonate cycles. – In: RAD, U. VON, HAQ, B.U. et al.: Proc. ODP Sci. Results, **122**, College Station
KENDALL, C.G.St.C. & SCHLAGER, W. (1981): Carbonates and relative changes in sea level. - Marine Geology, 44, 181-212, Amsterdam
KIRK, R.B. (1985): A seismic stratigraphic case history in the Eastern Barrow Subbasin, North West Shelf, Australia. – In: BERG, O.R. & WOOLVERTON, D. G. (eds.): Seismic stratigraphy II, an integrated approach. – Amer. Ass. Petrol. Sed. Memoir **39**, 183-208, Tulsa
KOEHN-ZANINETTI, L. & BRÖNNIMANN, P. (1968): *Triasina oberhauseri*, n. sp., une Foraminifère de la Dolomie Principale des Alpes Calcaires septentrionales (Autriche). – Publ. Inst. Paléont. Univ. Genève, 1-8, Genève (Impimerie Fontana)
KRISTAN-TOLLMANN, E. (1986 a). Beobachtungen zur Trias am Südostende der Tethys-Papua/Neuguinea, Australien, Neuseeland. – N. Jb. Geol. Paläont., Mh., **1986**, 201-222; Stuttgart
— (1986 b). Foraminiferen aus dem rhätischen Kuta-Tal von Papua/Neuguinea. – Mitt. österr. geol. Ges., **78**, 291-317, Wien
KRISTAN-TOLLMANN, E. & GRAMANN, F. (in press): Paleontological evidence for Triassic age of rocks dredged from the northern Exmouth Plateau (Tethyan foraminifers, echinoderms and ostracods).- In: VON RAD, U. HAQ, B.U et al.: Proc. ODP Sci. Results, **122**, College Station
LAKEW, T. (1990): Microfacies and cyclic sedimentation of the Upper Triassic (Rhaetian) Calcare di Zu (Southern Alps). – Facies, **22**, 187-232, Erlangen
LEMOINE, M., BAS, T., ARNOULD-VANNEAU, A., ARNAULD, H., DUMONT, T., GIDON, M. BOURBON, M., GRACIANSKY, P.C.DE, RUDCKIEWIZ, J. L., MEGARD-GALLI, J., & TRICART, P. (1986): The continental margin of the Mesozoic Tethys in the western Alps. – Marine and Petroleum Geol., **3**, 179-200, London
LUALDI, A. (1983) Ricerche stratigraphico-sedimentologiche nel Prepiemontese Ligure: III-II Trias dell'unita di Arnasco-Castelbianco. – Atti Ist. Geol. Univ. Pavia, **30**, 197-214, Pavia
MANSPREIZER, W. (1988): Triassic-Jurassic rifting and opening of the Atlantic: an overview. – In: MANSPREIZER, W. (ed.): Triassic-Jurassic rifting: Continental breakup and the origin of the Atlantic Ocean and passive margins. – 41-79, New York (Elsevier)
MASETTI, D., STEFANI, M. & BURCHELL, M. (1989): Asymmetric cycles in the Rhaetic facies of Southern Alps: Platform-basin interactions governed by eustatic and climatic oscillations. – Riv. Ital. Paleont. Strat., **94**/3, 401-424, Milano
MEGARD-GALLI, J. & BAUD, A. (1977): Le Trias moyen et supérieur des Alpes nord-occidentales: données nouvelles et corrélations stratigraphiques. – Bull. Bur. Rech. Géol. Min., **4**/3, 233-250, Orléans
MEGARD-GALLI J. & FAURE, J.L. (1988): Tectonique distensive et sédimentation au Ladinien supérieur-Carnien dans la zone Briançonnaise. – Bull. Soc. Géol. France, **4**/5, 705-716, Paris.
MOORE, C.H. (1989): Carbonate diagenesis and porosity. – Dev. Sed., **46**, 338 pp; Tulsa
MUSSMANN, W.J., MONTANEZ, I.P. & READ, F.J. (1988): Ordovician Knox paleokarst unconformity, Appalachians. – In: JAMES, N.P. & CHOQUETTE, P.W. (eds.): Paleokarst – 211-228, Berlin (Springer)
NEUMANN, A.C. & LAND, L.S. (1975): Lime mud deposition and calcareous algae in the Bight of Abaco, Bahamas: a budget. – J. Sed. Petrol., **45**, 763-786, Tulsa
OGG, J.G., KODAMA, K. & WALLICK, B. (in press): Lower Cretaceous magnetostratigraphy and paleolatitudes off NW Australia (ODP Site 765 and DSDP Site 261, Argo Abyssal Plain, and ODP Site 766, Gascoyne Abyssal Plain). – In: GRADSTEIN, F.M., LUDDEN, J.N. et al.: Proc. ODP Sci. Results, **123**, College Station
PILLER, W. (1976): Fazies und Lithostratigraphie des gebankten Dachsteinkalkes (Obertrias) am Nordrand des Toten Gebirges (S'Grünau/Almtal, Oberösterreich). – Mitt. Ges. Geol., Bergbaustud. Österr., **23**, 113-152, Wien
— (1978): Involutinacea (Foraminifera) der Trias und des Lias. – Beitr. Paläont. Österreich, **5**, 1-164, Wien
POSAMENTIER, H.W. & VAIL, P.R. (1988): Eustatic control on clastic deposition. - II - Sequence and systems tracts models. – In: WILGUS, C.K., HASTINGS, B.S., KENDALL, C.G., POSAMENTIER,

Plate 60 Upper Triassic microfacies types of the Wombat Plateau (NW Australia): dolomitization, porosity development, bioturbation.

Fig. 1. Echinodermal packstone (MFT 11), angular crinoid fragments, biomolds, recrystallized pelecypod fragments; Rhaetian, sample 122-764B-23R-1, 98-102 cm; scale = 300 µm.

Fig. 2. Skeletal floatstone (MFT 13) with crinoid fragments, pelecypod fragments, ? algal lumps (center), biomolds and interparticle porosity; Rhaetian, sample 122-764B-12R-1, 2-5 cm; scale = 300 µm.

Fig. 3. Skeletal packstone to floatstone (MFT 10/13) with siliciclastic allochems (quartz and dolomitized ooids). Note residual geopetal infilling and two cement generations within bivalves; Carnian-Norian, sample 122-759B-13R-2, 22-25 cm; scale = 300 µm.

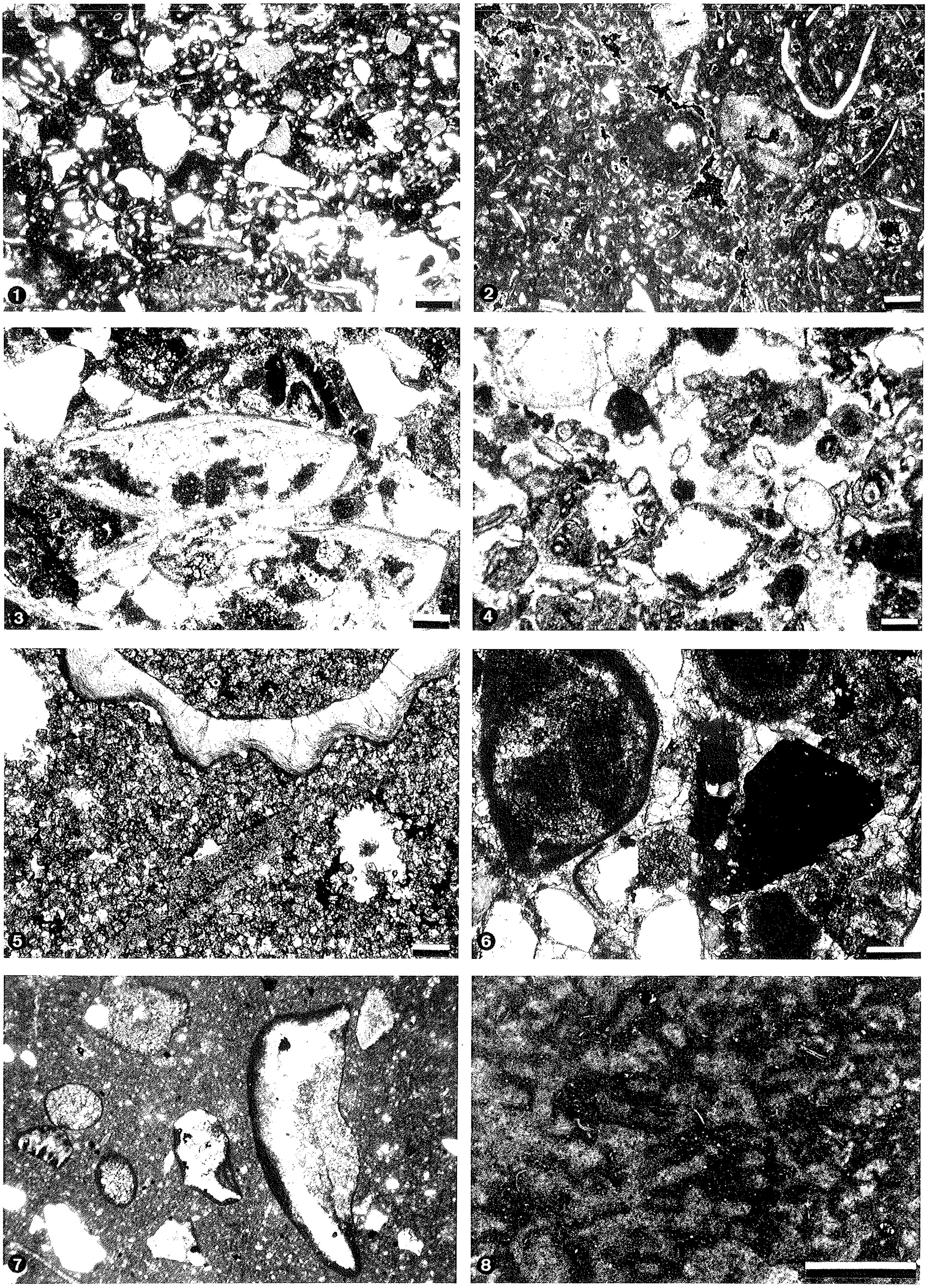
Fig. 4. Coated grain grainstone (MFT 16) with oomolds, biomolds (*Aulotortus*) and interparticle porosity; Rhaetian, sample 122-761B-32X-CC, 24-27 cm; scale = 300 µm.

Fig. 5. Strongly dolomitized ?floatstone with biomolds and residual echinoderm and pelecypod fragments; Rhaetian, sample 764B-11R-CC, 3-6 cm; scale = 300 µm.

Fig. 6. Oolitic grainstone (MFT 17) with quartz. Note that even-rim cement is precipitated at calcareous allochems and not at siliciclastics, crossed nicols; Carnian-Norian, sample 122-759B-11R-1, 12-16 cm; scale = 100 µm.

Fig. 7. Coated grain wackestone (MFT 4b), allochems show coatings and recrystallized, dedolomitized nuclei; Carnian, sample 759B-23R-2, 105-109 cm; scale = 300 µm.

Fig. 8. Bioturbated peloidal wackestone (MFT 2); Rhaetian, sample 122-764A-8R-CC, 4-8cm; scale = 5 mm.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H.W., Ross, C.A. & Van Wagoner, J.C. (eds.): Sea-level changes: an integrated approach. – Soc. Econ. Pal. Min., Spec. Publ., **42**, 125-154, Tulsa

Purser, B.H. (1973): The Persian Gulf: Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. – 471 pp., Berlin (Springer)

Purser, B.H. & Schroeder, J.H. (1986): The diagenesis of reefs: a brief review of our present understanding. - In: Schroeder, J.H. & Purser, B.H. (eds.): Reef Diagenesis. – 424-446, Berlin (Springer)

Quilty, P.G. (1990). Triassic and Jurassic foraminiferid faunas, northern Exmouth Plateau, eastern Indian Ocean. – J. Foram. Res. 20, 349-367, Washington

Röhl, U., Rad, U.von & Wirsing, G. (in press): Microfacies, paleoenvironment and facies-dependent carbonate diagenesis in Upper Triassic platform carbonates off NW Australia. – In: Rad, U.von, Haq, B.U. et al.: Proc. ODP, Scient. Results, **122**, College Station

Salaj, J., Borza, K. & Samuel, O. (1983): Triassic foraminifers of the West Carpathians. – Geologicky Ustar Dionyza Stura, Bratislava

Sarg, J.F. (1988): Carbonate sequence stratigraphy. – In: Wilgus, C.K. Hastings, B.S., Kendall, C.G., Posamentier, H.W., Ross, C.A. & Van Wagoner, J.C. (eds.): Sea-level changes: an integrated approach. – Soc. Econ. Petrol. Min., Spec. Publ., **42**, 155-182, Tulsa

Sarti, M. (in press): Sequence stratigraphy, Wombat Plateau: rift tectonics, sea-level changes and the opening of the Tethys. – In: Rad, U.von, Haq, B.U. et al., Proc. ODP Sci. Results, **122**, College Station

Sarti, M., Russo, A. & Bosellini, F. (in press): Rhaetian strata, Wombat Plateau: analysis of fossil communities as a key to paleoenvironmental changes. – In: Rad, U.von, Haq, B.U. et al.: Proc. ODP. Scient. Results, .**122**, College Station

Scaturo, D.M., Strobel, J.S., Kendall, C.G.St.C., Wendte, J.C., Biswas, G., Bezdek, J. & Cannon, R. (1989): Judy Creek: a case study for a two-dimensional sediment deposition simulation. – Soc. Econ. Paleont. Mineral., Spec. Publ., **44**, 63-7, Tulsa

Schäfer, P. (1979): Fazielle Entwicklung und palökologische Zonierung zweier obertriasischer Riffstrukturen in den nördlichen Kalkalpen ('Oberrhät'-Riff-Kalke, Salzburg). – Facies, **1**, 3-245, Erlangen.

Schäfer, P. & Senowbari-Daryan, B. (1981): Facies development and paleoecologic zonation of four Upper Triassic patch-reefs, northern Calcareous Alps near Salzburg, Austria. – Soc. Econ. Paleont. Mineral., Spec.Publ., **30**, 241-259, Tulsa

Scholle, P.A., Bebout, D.G. & Moore, C.H. (eds.) (1983): Carbonate depositional environments. – Amer. Ass. Petrol. Geol. Memoir, **33**, 708 pp, Tulsa

Schott, M. (1983): Sedimentation und Diagenese einer absinkenden Karbonatplattform: Rhät und Lias des Brunnstein-Auerbach-Gebietes, Bayerische Kalkalpen. – Facies, **9**, 1-6, Erlangen

Senowbari-Daryan, B. (1980): Fazielle und paläontologische Untersuchungen in oberrhätischen Riffen (Feichtenstein- und Gruberriff bei Hintersee, Salzburg, Nördliche Kalkalpen). – Facies, **3**, 1-237, Erlangen

Shipboard Scientific Party (1990): Sites 761 and 764.- In: Haq, B.U., von Rad, U., O'Connell, S., et al., Proc. ODP. Init. Repts., Vol. **122**, 161-211, 353-384; College Station

Stanley, G.D.Jr. (1988): The history of early Mesozoic reef communities: a three-step process. – Palaios, **3**, 170-183, Tulsa

Stanton, R.J.Jr. & Flügel, E. (1989): Problems with reef models: the Late Triassic Steinplatte 'reef' (Northern Alps, Salzburg/ Tyrol, Austria). – Facies, **20**, 1-138, Erlangen

Thery, J.M., Cros, P., & Bouroullec, J. (1989): Relationship betwen organic matter and sedimentological conditions in the Triassic of northern Italy. – Bull. Centres Rech. Explor. Prod. Elf Aquitaine, **13**, 23-33, Pau

Tucker, M.E. & Wright, V.P. (1990): Carbonate sedimentology, 182 pp., Oxford (Blackwell)

Vachard, D. & Fontaine H. (1988): Biostratigraphic importance of Triassic foraminifers and algae from South-East Asia. – Rev. Palèobiologie, 7/1, 87-98, Genève

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. & Hardenboll, J. (1988): An overview of the fundamentals of sequence stratigraphy and key definitions. – Soc. Econ. Paleont. Mineral., Spec. Publ., **42**, 39-45, Tulsa

Veevers, J.J. (1988): Morphotectonics of Australia's northwestern margin. – In: Purcell, P.G. & Purcell, R.R. (eds.): The North West Shelf Australia. – Proc. of North West Shelf Symp., 19-27, Perth

von Rad, U. & Exon, N.F. (1983): Mesozoic-Cenozoic sedimentary and volcanic evolution of the starved passive margin off northwest Australia. – Amer. Assoc. Petrol. Geol. Mem., **34**, 253-281, Tulsa

von Rad, U., Exon, N.F. & Haq, B.U. (in press): Rift to drift history of Wombat Plateau, NW Australia: Triassic to Tertiary ODP Leg 122 results. – In: Rad, U. von, Haq, B.U. et al.: Proc. ODP, Scient. Results, **122**, College Station

Plate 61 — Upper Triassic microfacies types of the Wombat Plateau (NW Australia): calcisponges, corals, typical foraminifers.

Fig. 1. Coral/calcisponge boundstone (MFT 25) with recrystallized corals (*Retiophyllia paraclathrata* Roniewicz) and calcisponges; Rhaetian, sample 122-764B-24R-1, 127-129 cm; scale = 5 mm.

Fig. 2. *Astraeomopha* sp., recrystallized; Rhaetian sample 122-764B-14R-CC, 2-5 cm; scale 2000 µm.

Fig. 3. *Solenolmia* sp.?, recrystallized and ostracode; Rhaetian, sample 122-764B-27R-1, 95-99 cm; scale = 2000 µm.

Fig. 4. Calcisponge, dolomitization increases to the right; Rhaetian, sample 122-764B-28R-3, 47-51 cm; scale = 2000 µm.

Fig. 5. Foraminiferal grainstone (MFT 15) with several Involutinidae (*Aulotortus* sp.); sample 122-761C-16R-1, 52-55 cm; scale = 5 mm.

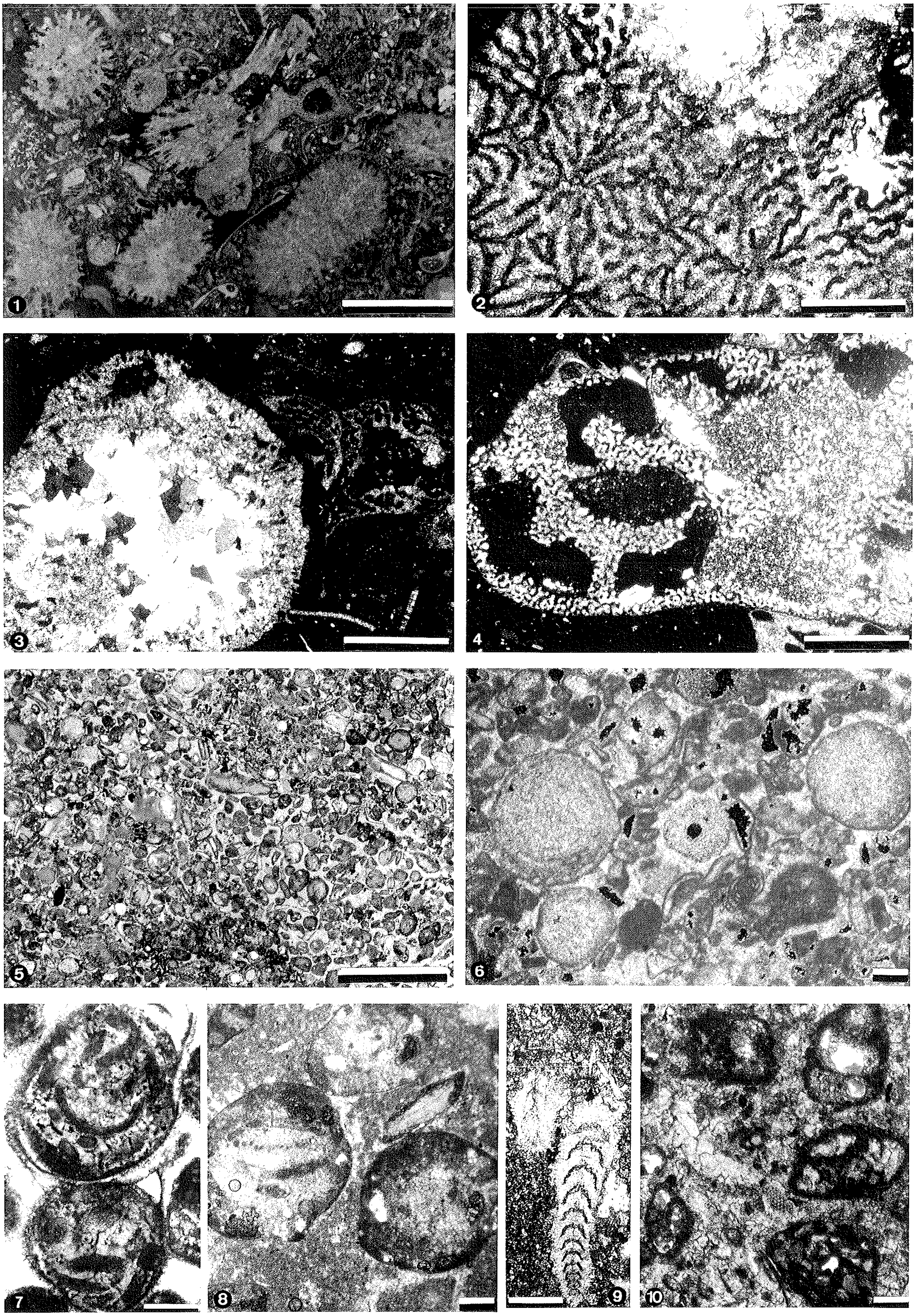
Fig. 6. Foraminiferal grainstone (MFT 15) with *Triasina hantkeni* Majzon and *Glomospirella* sp.; Rhaetian, sample 122-761C-16R-1, 23-26 cm; scale = 300 µm.

Fig. 7. *Aulotortus friedli*; Carnian, sample 122-759B-19R-CC, 11-13 cm; scale = 100 µm.

Fig. 8. *Aulotortus* sp. within intraclast; Norian, sample 122-760B-8R-3, 18-21 cm; scale = 300 µm.

Fig. 9. *Frondicularia* sp.; Carnian-Norian, sample 122-759B-8R-1, 14-17 cm; scale = 100 µm.

Fig. 10. Duostominid foraminifers; Rhaetian, sample 122-764B-4R-1, 38-41 cm; scale = 300 µm.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VON RAD, U., HAQ, B.U. et al. (in press): Proc. ODP, Sci. Results, **122**, College Station

VON RAD, U., SCHOTT. M, EXON, N.F., MUTTERLOSE, J., QUILTY, P.G. & THUROW, J. (1990): Mesozoic sedimentary and volcanic rocks dredged from the northern Exmouth Plateau: petrography and microfacies. – Bur. Min. Res. J. Australian Geol. Geophys., **11**/4, 449-472, Canberra

VON RAD, U. & THUROW, J. (in press): Bentonitic clays as indicators of early Neocomian post-breakup volcanism off NW Australia (ODP Leg 122). – In: RAD, U.VON, HAQ, B.U. et al.: Proc. ODP, Scient. Results, **122**, College Station

VON RAD, U., THUROW, J., HAQ, B.U., GRADSTEIN, F, LUDDEN, J. et al. (1989): Triassic to Cenozoic evolution of the NW Australian continental margin and the birth of the Indian Ocean (preliminary results of ODP Legs 122 and 123). – Geol. Rundschau, **78**/3, 1189-1210, Stuttgart

WALKER, K.R. & ALBERSTADT, L.P. (1975): Ecological succession as an aspect of structure in fossil communities. – Paleobiology, **1**, 238-25,; Chicago

WIEDMANN, J., FABRICIUS, F., KRYSTYN, L. REITNER, J. & ULRICHS, M. (1979): Über Umfang und Stellung des Rhaet. – Newsl. Stratigr., **8**/2, 133-152, Berlin

WILLIAMSON, P.E. (in press): Seismic sequence analysis of a Late Triassic carbonate reefal platform on the Wombat Plateau, Australia. – In: RAD, U.VON, HAQ, B.U. et al.: Proc. ODP, Scient. Results, **122**, College Station

WILLIAMSON, P.E., EXON, N.F., HAQ, B.U., VON RAD, U., O'CONNELL, S. & Leg 122 Shipboard Scientific Party (1989): A Northwest Shelf Triassic reef play: results from ODP Leg 122. – Austral. Petrol. Explor.Ass. J., **29**/1, 328-344, Sidney

WILSON, J.L., (1975): Carbonate facies in geologic history. – 471pp., New York (Wiley)

ZANINETTI, L., MARTINI, R. & DUMONT, Th. (in press): The Triassic foraminifera from ODP Leg 122, Sites 761, 764, Wombat Plateau, NW Australia. – In: RAD, U.VON, HAQ, B.U. et al.: Proc. ODP, Sci. Results, **122**, College Station

ZANINETTI, L., MARTINI, R., SALVINI-BONNARD, G., CIARAPICA, G. & DUMONT, T. (1986): Sur quelques foraminifères du Trias supérieur du domaine subbriançonnais (Alpes occidentales et Préalpes médianes); comparison avec des microfaunes de l'Apennin septentrional et des Carpates occidentales; découverte de *Triasina hantkeni* dans le domaine subbriançonnais. – Revue de Paléobiologie, **5**/2, 261-268, Genève

ZANKL, H. (1971): Upper Triassic facies in the Northern Limestone Alps. – In: MÜLLER, G. (ed.): Sedimentology of parts of Central Europe, guide book, 147-185; Frankfurt

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Plate 62 Upper Triassic of Wombat Plateau (NW Australia): foraminifera

Scale for all Figs. is 200 µm

Fig. 1, 2. *Triasina hantkeni* MAJZON
Fig. 1 sample 122-761C-16-1, 23-26 cm.
Fig. 2 sample 122-761C-15-1, 18-21 cm.

Fig. 3. *Triasina oberhauseri* KOEHN-ZANINETTI & BRÖNNIMANN, sample 122-761C-32-3, 2-4 cm.

Fig. 4. *Gandinella* sp. aff. *G. falsofriedli* (SALAJ, BORZA & SAMUEL), sample 122-761C-13-1, 6-9 cm.

Fig. 5, 6. *Gandinella falsofriedli* (SALAJ, BORZA & SAMUEL), sample 122-764B-5-1, 19-13 cm.

Fig. 7. *Aulotortus sinuosus pragsoides* (OBERHAUSER), sample 122-761C-12-1, 16-19 cm.

Fig. 8. *Aulotortus friedli* (KRISTAN-TOLLMANN), sample 122-761C-13-1, 1-3 cm.

Fig. 9. *Auloconus permodiscoides* (OBERHAUSER), sample 122-764B-5-1, 9-13 cm.

Fig. 10. *Aulotortus tumidus* (KRISTAN-TOLLMANN), sample 122-761C-13-1, 6-9 cm.

Fig. 11. *Trocholina* sp., sample 122-764B-27-1, 60-64 cm.

Fig. 12. *Ophthalmidium* sp., sample 122-764B-20-1, 72-76 cm.

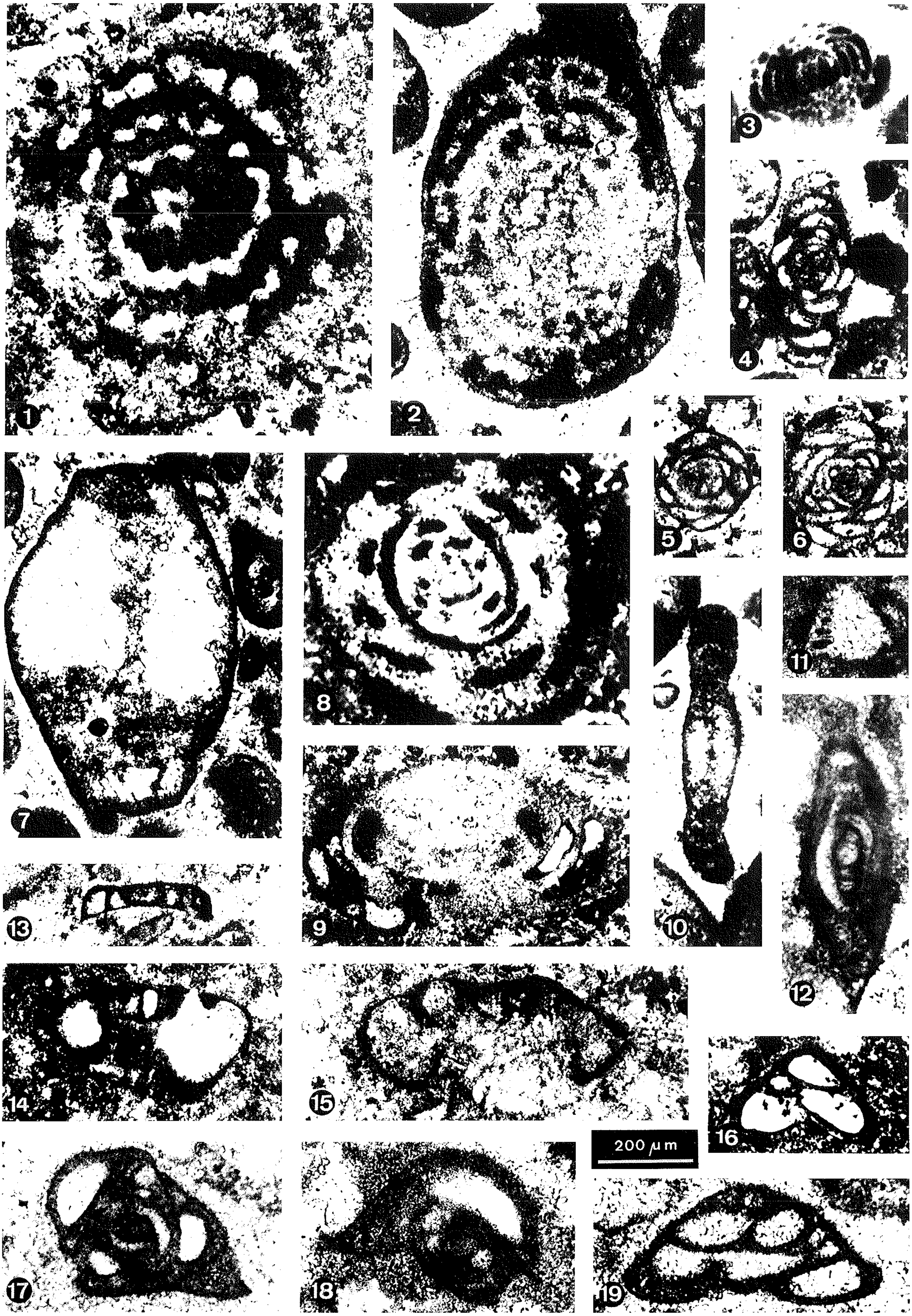
Fig. 13. *Planiinvoluta carinata* LEISCHNER, sample 122-764A-7-1, 12-14 cm.

Fig. 14, 15. Duostominidae
Fig. 14. sample 122-764A-9-CC, 4-8 cm.
Fig. 15. sample 122-764A-8-CC, 25-29 cm.

Fig. 16. Duotax*is birmanica* ZANINETTI & BRÖNNIMANN in BRÖNNIMANN, WHITTAKER & ZANINETTI, sample 122-761C-24-1, 69-73 cm.

Fig. 17, 18. Galea*nella? laticarinata* AL-SHAIBANI, CARTER & ZANINETTI
Fig. 17. sample 122-764B-23-1, 72-76 cm.
Fig. 18. sample 122-764B-23-1, 98-102 cm.

Fig. 19. 'T*etrataxis*' *inflata* KRISTAN, sample 122-764B-14-CC, 5-8 cm.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