The Permian-Triassic Boundary in the Carnic Alps of Austria (Gartnerkofel Region)				Editors: W.T. Holser & H.P. Schönlaub
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The Permian-Triassic of the Gartnerkofel-1 Core and the Reppwand Outcrop Section (Carnic Alps, Austria)

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With 8 Figures, 5 Tables and 2 Plates

Carinthia
Carnic Alps
Upper Permian
Lower Triassic
Sedimentology
Microfacies

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Contents

Zusammenfassung

In der 330 m tiefen Forschungsbohrung Gartnerkofel-1 am Naßfeld in den Karnischen Alpen wurden hauptsächlich Dolomitgesteine durchteuft, die der Bellerophon-Formation des Oberperms und der Werfen-Formation der Untertrias angehören. Der oberste Abschnitt umfaßt bis in eine Teufe von 57 m das Muschelkalk-Konglomerat der Anis-Stufe der Trias. Die mikrofazielle Auswertung von über 400 Dünnschliffen zeigte für die Bellerophon-Formation Bildungsbedingungen in einem flach marinen Milieu des Innenschelfs an. Die darüber folgende fossilreiche Wechselfolge von Kalken, Dolomiten und Mergeln wird durch erhöhte Wellen- und Strömungsaktivität gekennzeichnet. Als Bildungsraum wird ein karbonatischer Flachwasserschelf mit subtidalen bis supratidalen Bedingungen angenommen. Exakt an der Perm/Trias-Grenze tritt zwischen 231,04 und 224,50 m ein 6,50 m mächtiger Oolithhorizont auf, der dem Tesero-Horizont in den Dolomiten Südtirols entspricht. Die Faziesverteilung im Oberperm und in der Untertrias spricht für eine flach nach Südosten geneigte Karbonatrampe, die in den Südalpen zwischen den Dolomiten im Westen und den Dinariden im südöstlichen Europa vermittelt.

Abstract

The Gartnerkofel-1 core (depth 330 m) comprises mainly dolomitic carbonates of the Upper Permian Bellerophon Formation and the Lower Triassic Werfen Formation. Sediments of the Bellerophon Formation were deposited on a shallow marine inner-shelf area. They are conformably overlain by limestone-dolomite-marl alternations of the Werfen Formation. The environment in the Skythian is dominated by current and wave activity. The fossiliferous carbonates represent subtidal to supratidal conditions of an epicontinental, shallow marine shelf area. Oolitic horizons at the P/Tr boundary are comparable with oolites within the Tesero Horizon of the western part of the Southern Alps. The facies distribution in the Upper Permian and Lower Triassic is typical for the situation of a carbonate ramp, situated in the area of the Southern Alps and the Dinarids, and gently inclined towards the east.

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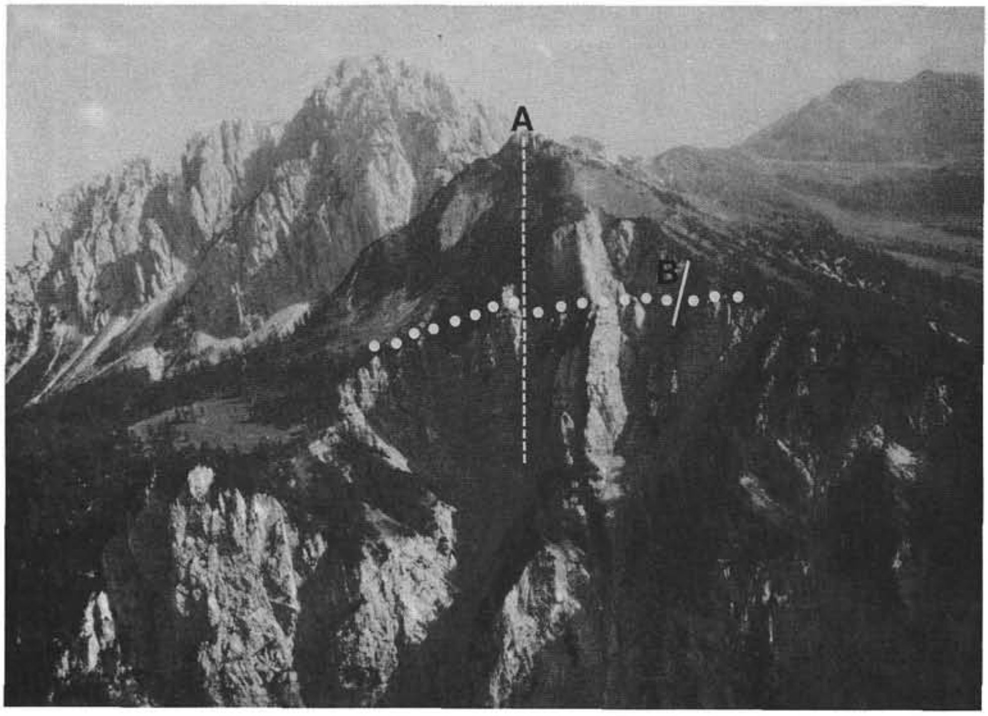
1. Introduction: Basin Development in the Carnic Alps and Karawanken Mountains

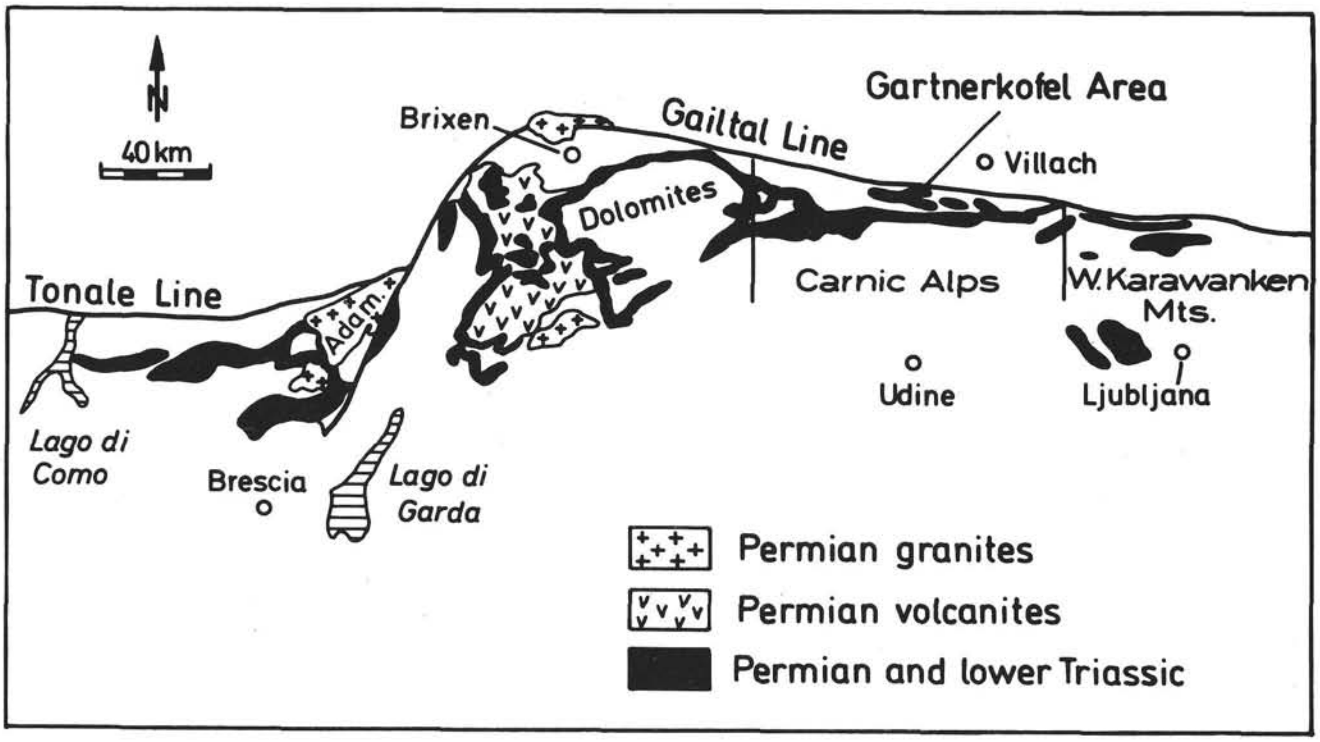
The sedimentary section intersected by Gartnerkofel-1, and also exposed in the nearby outcrop section of the Reppwand (Text-Fig. 1) comprises the Permian Bellerophon Formation and the overlying Triassic Werfen Formation. The following paragraphs put this section in the context of late Paleozoic–early Mesozoic sedimentation (K. BOECKELMANN, 1988); subsequent parts will describe details of sedimentation in the relevant sections.

In the eastern part of the Southern Alps (Text-Fig. 2) the Hercynian substratum (Ordovician to Lower Carboniferous) is unconformably overlain by sediments of three sedimentary cycles, each of them bounded by unconformities and showing a transgressive-regressive trend (Text-Fig. 3).

The first cycle comprises the Auernig Group, Rattendorf Group and Trogkofel Group (Upper Carboniferous to Lower Permian). Molasse-like shelf sediments (alternating sequences of fine- to coarse-grained clastic material with fossiliferous platform carbonates [rich in algae and foraminifers] or algal-cement-reefs) are indi-



Text-Fig. 1.
Aerial photograph from the north of the Reppwand with the Gartnerkofel (2195 m) in the background.
A: Drill site on Kammleiten (1998 m); B: Top of the outcrop section. Dotted line indicates the Permian–Triassic boundary between the Bellerophon Formation (below) and the Werfen Formation above. Photo: G. FLAJS, Aachen.



Text-Fig. 2.
Distribution of Permian and Lower Triassic rocks in the Southern Alps.

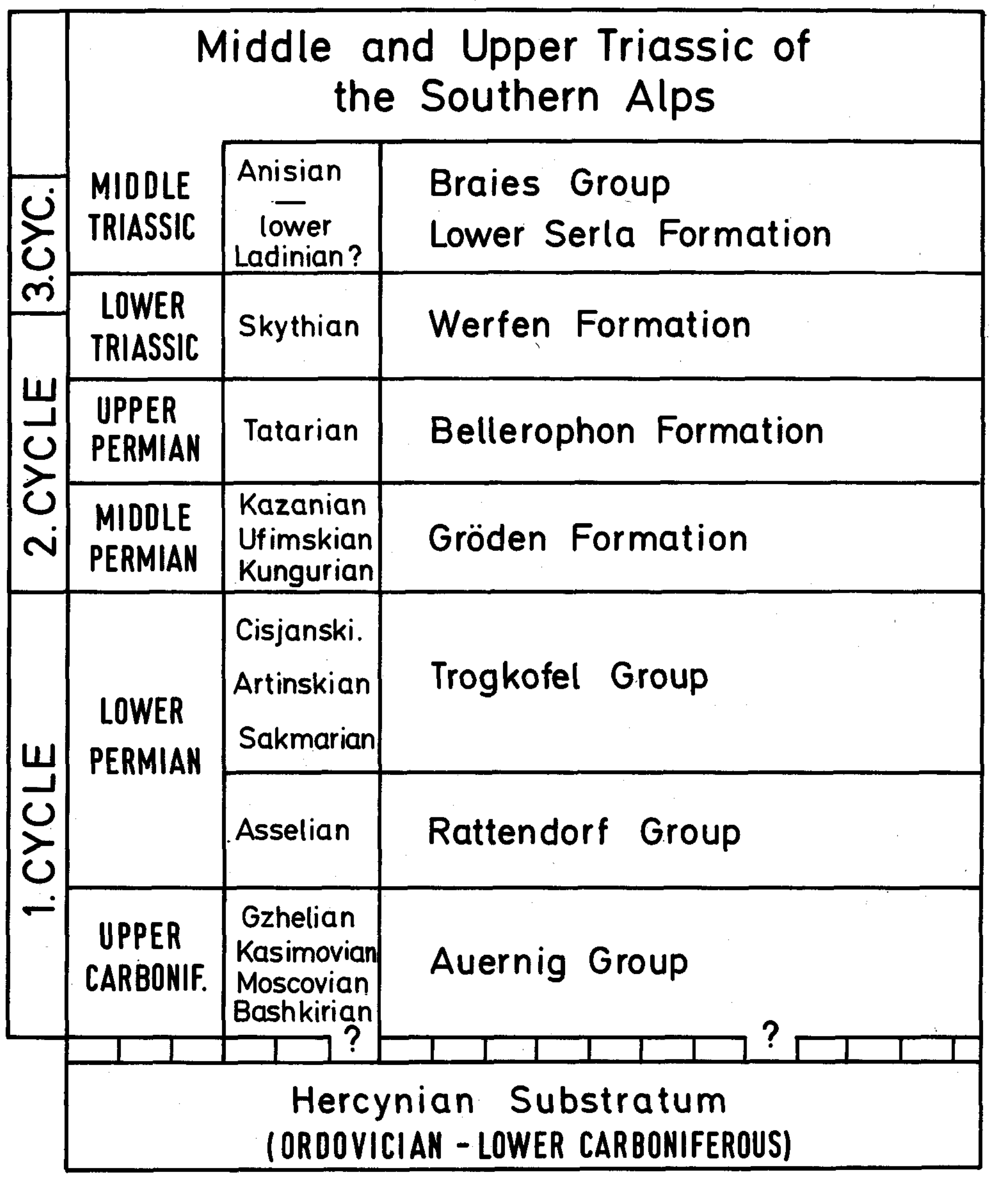


Fig. 3.
Stratigraphic column of the eastern part of the Southern Alps.

cative of deltaic, paralic and marine environments. The Auernig Group at the base of this cycle is dominated by terrigenous clastics and lagoonal carbonates, whereas the stratigraphic reefs of the Trogkofel Limestone are situated at platform margins (E. FLÜGEL, 1981). According to C. VENTURINI (1982) the sedimentation in the Upper Carboniferous and Lower Permian was under strong influence of synsedimentary tectonic activity. At the end of this period a climax of tectonic movements and uplift resulted in deposition of the Tarvis Breccia, with reworking of the Trogkofel Limestone.

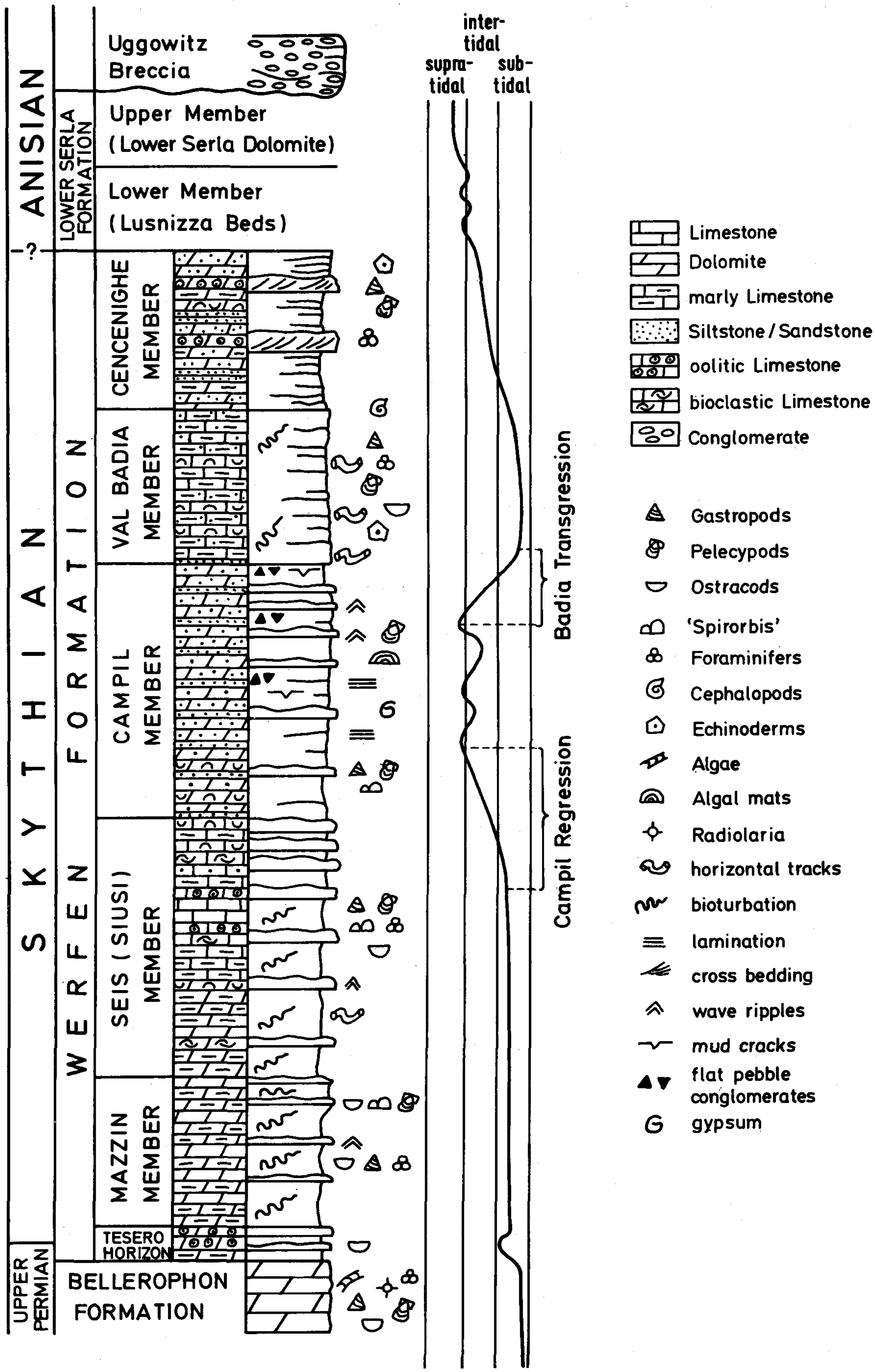
The second cycle comprises the Gröden Formation, Bellerophon Formation, and the lower and middle part of Werfen Formation (Middle Permian to Lower Triassic). The red beds of the Gröden Formation consist of fine-grained terrigenous material of a fluviatile environment, with marine ingressions in the eastern part of the Southern Alps. The continental material filled up the remaining depressions. The result was a final peneplanation of the Hercynian substratum.

The boundary between the Gröden and Bellerophon Formations is transitional. A decrease of continental red beds and an increase of lagoonal dolomite-gypsum cycles merge into the evaporitic lower part of the Bellerophon Formation (Table 1).

The middle and upper portion of the Upper Permian succession correspond to the Badiota Facies (B. ACCORDI, 1958) of the western part of the Southern Alps. The dark-coloured carbonates and shales were deposited on a shallow marine inner-shelf area, described by S. NOÉ (1987) as an eastward-dipping homoclinal ramp. Sedimentation of carbonate mud predominated. A subtidal environment and free water circulation facilitated the growth of a normal marine, small-sized fauna and flora. There was no coastal influence. Most of the

Table 1.
Lower part of the Bellerophon Formation at the Reppwand cliff from top to base.
After W. BUGGISCH (1974).

31 m	Light grey dolomite. Intraclast dolomite grainstone, ostracod mudstone, coated grain dolomite grain- and packstone. The final depth of Gartnerkofel-1 reached the upper part of this unit.
15 m	Rauhwacke, dolomitic marl.
15 m	Marly dolomite.
5 m	Bituminous dolomitic marl.
0,8 m	Bituminous dolomite.
3,5 m	Rauhwacke.
1 m	Dolomitic marl, dolomicrite.
	Gröden Formation



Text-Fig. 4.
Standard profile of the Werfen Formation in the Carnic Alps and Karawanken Mountains.
The total thickness is about 300–400 m. The degree of dolomitization is very different from section to section.

sediments are indicative of a low-energy environment of a sheltered marginal basin of the Tethys, not far from the coastal sabkha cycles (Fiammazza Facies) of South Tyrol. The thickness of this formation reaches about 400 m in the western Carnic Alps and the Cadore area, and about 200 m in the eastern Carnic Alps and western Karawanken Mountains.

The Upper Permian sediments are conformably overlain by limestone-dolomite-marl alternations of the Werfen Formation (Skythian), containing varying amounts of terrigenous material (quartz and mica). The fossiliferous carbonates represent subtidal to supratidal environments, and reach a thickness of 300 to 400 m. A subdivision into 9 lithostratigraphic units in the western part of the Southern Alps is based on the recognition of transgressive and regressive events (C. BROGLIO LORIGA et al., 1983, 1986). In the area investigated only 6 of these units can be identified, because of its more basinward position. Sedimentary cycles are better developed towards the coast.

The units of the Werfen Formation (Text-Figs. 4 and 5; Tables 2 and 3) are:

Tesero Horizon

The unit is only locally developed.

Alternation of fine-grained background sediments (nodular bioturbated mudstones), and oolitic grainstones and bioclastic grainstones with *Earlandia* (foraminifer), ostracods, echinoderm debris and intraclasts.

Environment

Shallow subtidal inner-shelf area with low clastic influx. Low water energy, occasionally agitated water. In the Italian Dolomites the P/Tr boundary lies within the Tesero Horizon (C. NERI & M. PASINI, 1985; M. PASINI, 1985). Mixed faunas (brachiopods, foraminifers) at the base of this horizon indicate a Permian age for the lower part of the Tesero oolites. S. NOÉ (1987) describes mixed faunas with characteristic uppermost Permian foraminiferal associations from Paularo (Italy), 16 km west of the Gartnerkofel area. At other localities the Bellerophon dolomites are directly followed by ostracod-rich mudstones of the Mazzin Member. The unit reaches a maximum thickness of 25 m in the Trento area and wedges out towards the east. In the Carnic Alps and Karawanken Mountains it is only locally developed, oolitic horizons were found by K. KRAINER (in preparation) and S. NOÉ (1987).

Mazzin Member

Alternation of fine-grained, ostracod-bearing, nodular background sediments and distal storm layers, with increasingly proximal tempestites (T. AIGNER, 1985) towards the top of the member. Fauna: Ostracods, *Earlandia, Spirorbis* (worm tube), gastropods, pelecypods (lower part of the *Claraia* Zone), rare foraminifers and echinoderms. Environment: Shallow subtidal inner-shelf area with low clastic influx. Alternating low and high water energy.

Andraz Horizon

The unit is developed only in the western part of the Carnic Alps. It wedges out towards the east and is not developed in the Gartnerkofel area. The sediment is composed of red- and yellow-coloured, fine-grained, unfossiliferous silty dolomite and vuggy dolomite.

Environment

Supratidal mud flat.

Seis Member

Background sediments are fine-grained, often nodular and bioturbated mud- and wackestones; proximal storm layers (coquina tempestites) with increasing proximality become more frequent towards the top of the member. Other sediments of higher water energy are bioclastic and oolitic grainstones. A "Gastropod Oolite Member", which has been identified in the western Dolomites (C. BROGLIO LORIGA et al., 1983) is not developed here. But a "gastropod oolite" facies, which means Fe-impregnated gastropod pack- and grainstones (real oolites are very rare) occurs from the Seis Member up to the Val Badia Member, with a maximum incidence at the upper Seis Member.

Fauna

Ostracods, *Earlandia, Spirorbis*, gastropods, pelecypods (middle and upper part of the *Claraia* Zone sensu C. BROGLIO LORIGA et al. [1983], lower part of the *Eumorphotis* Zone), rare foraminifers and echinoderms.

Environment

Shallow subtidal inner-shelf area, dominated by wave activity; increasing influence of terrigenous material (quartz silt and mica). In the uppermost part (transition to the Campil Member): temporary intertidal conditions.

Campil Member

Red-, green- and grey-coloured fine-grained dolomite, silty and sandy dolomite, siltstones, sandstones. Sedimentary structures include mud cracks, tepees, flat-pebble conglomerates, occurrence of gypsum, and intercalations of storm layers (coquina tempestites at the base, sandy tempestites in the upper part of the unit). Poor in fossils (molluscs and echinoderm debris), but in the uppermost part new foraminifers and much echinoderm debris appear, especially in dolomitic siltstones.

Environment

Intertidal to supratidal conditions of a tidal flat, under strong influence of terrigenous clastics. In the upper part (transition to the subtidal Val Badia Member), a clear transgressive trend. This so-called Badia Transgression marks the beginning of the third cycle.

Val Badia Member and Cencenighe Member

Outcrops of the Cencenighe Member are very rare.

Background sediments are fossiliferous silty or sandy wacke- and packstones, rich in bioturbation and ichnofossils. Sediments of higher water energy are coquina tempestites, bioclastic and oolitic grainstones. Intercalations of red, green and violet silt- and sandstones show increasing frequency and thickness towards the top of the two units.

The Cencenighe Member is characterized by a decrease of oolitic and bioclastic grainstones; typical sediments are thin layers of foraminiferal sands with *Meandrospira*, plus echinoderm packstones.

Fauna

Molluscs (upper part of the *Eumorphotis* Zone sensu C. BROGLIO LORIGA et al., 1983), foraminifers, echinoderms, *Spirorbis*, ostracods; at the boundary between the two units *Tirolites* gr. *cassianus* (QUENSTEDT) and *Dinarites dalmatinus* (HAUER) occur nearly in the same horizon.

Table 2.
The fauna of the Werfen Formation in the Carnic Alps and western Karawanken Mountains (K. BOECKELMANN, 1988).

	MEMBERS					
	Mazzin	An.	Seis	Campil	Val-Bad.	Cencenighe.
Cyclogyra-Rectocornuspira- Ass.	– – –		——			
Meandrospira pusilla HO					– – –	——
Glomospirella sp. *Glomospira sp.* *Ammodiscus sp.*				–	——	——
Spirorbis sp.	——		——	– –	——	——
Coelostylina werfensis WITTENBURG	– –		——	– – –	——	– –
Poligyrina gracilior (SCHAUROTH)	– –		——	– – –	——	– –
Turbo rectecostatus HAUER					——	– –
Natiria costata (MÜNSTER)					——	– –
Claraia clarai (EMMERICH)			–			
Claraia aurita (HAUER)			–			
Bakevillia sp.			– –	——	——	– –
Eumorphotis venetiana (HAUER)					– – –	
Eumorphotis cf. kittli (BITTNER)					——	
Eumorphotis hinnitidea (BITTNER)			– –			
Avichlamys sp.					– – –	– –
Neoschizodus sp.			– –	– – –	– – –	– –
Unionites canalensis (CATULLO)	——		——	——	——	– –
Unionites fassaensis (WISSMANN)	——		——	——	——	– –
Tirolites gr. cassianus (QUENSTEDT)					–	–
Dinarites dalmatinus (HAUER)					–	–
Echinoderms	– – –		– –	–	——	—— –
Ostracods	——		——	– –	——	—— –

Table 3.
Foraminifers of the Werfen Formation in the Carnic Alps and Karawanken Mountains.

MILIOLINA	FISCHERINIDAE	*Rectocornuspira kalhori* BRÖNNIMANN, ZANINETTI & BOZORGNIA*) *Cyclogyra* ? *mahajeri* BRÖNNIMANN, ZANINETTI & BOZORGNIA*) *Cyclogyra* nov. spec. ? sensu RESCH 1979*) *Meandrospira pusilla* HO**)
TEXTULARIINA	AMMODISCIDAE	*Glomospira* sp. RZEHAK**) *Glomospirella* sp. PLUMMER**) *Glomospirella facilis* HO**) *Glomospirella shengi* HO**) *Ammodiscus* aff. *A. paraprisous* HO**)
ROTALIINA	NODOSARIIDAE	*Nodosaria* sp. LAMARCK
FUSULININA	EARLANDIIDAE	*Earlandia* sp. PLUMMER***)

*) *Cyclogyra* – *Rectocornuspira* – ass. (with *Nodosaria*): Mazzin Mb. – Campil Mb.
**) *Glomospirella* – *Meandrospira* – ass. (with *Glomospira* and *Ammodiscus*): uppermost Campil Mb. – Cencenighe Mb.
***) *Earlandia* sp.: Tesero Hz. – Mazzin Mb.

Environment

Val Badia Member: Shallow subtidal inner-shelf area; in contrast to the lower part of Werfen Formation restricted conditions do not occur (cephalopods, numerous echinoderms, higher diversity of foraminifers with *Meandrospira, Glomospira*, and *Glomospirella*).

Cencenighe Member: Slight shallowing of the environment.

*

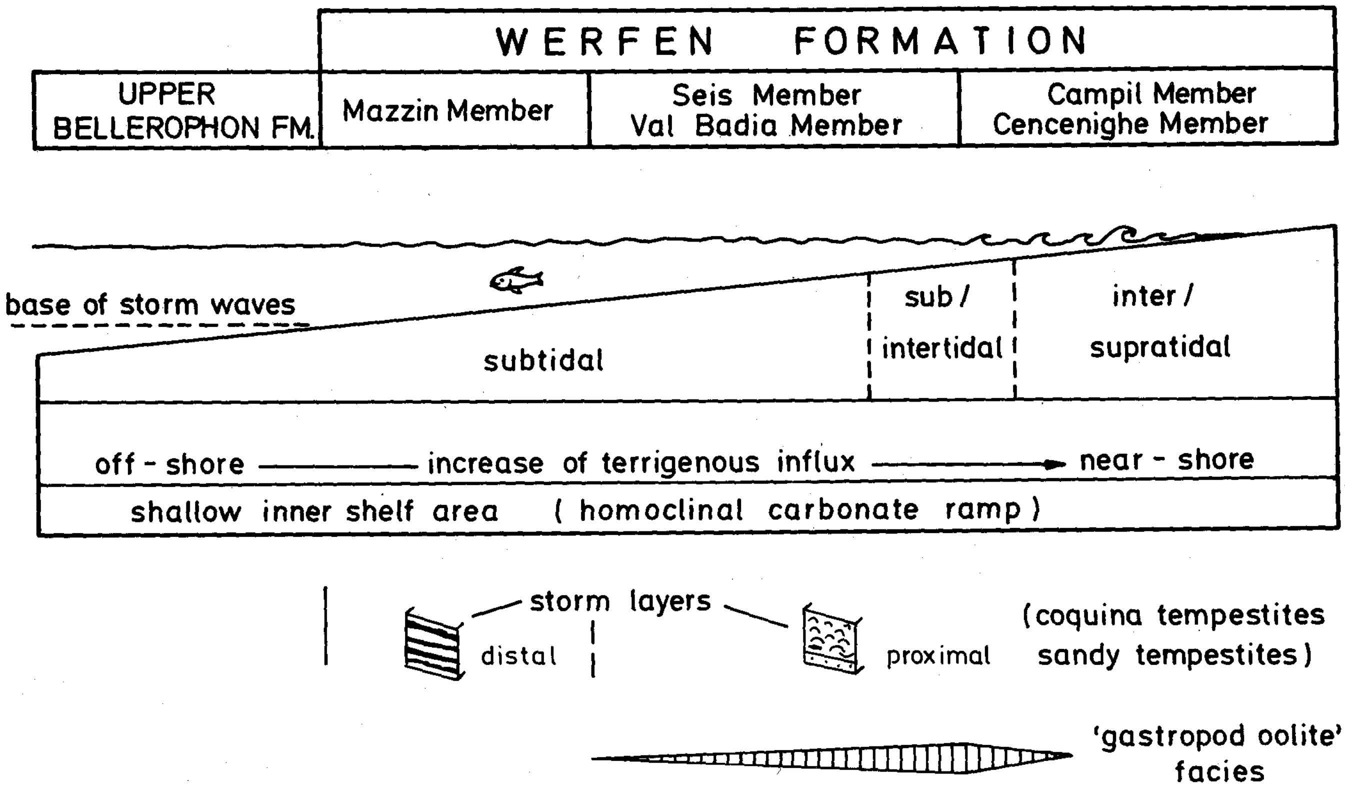
One can generalize the facies development in the Skythian as a regressive trend from the uppermost Permian to the Campil Member (subtidal to intertidal and supratidal conditions, Text-Figs. 4 and 5). A smaller regressive-transgressive event occurs at the P/Tr boundary (Tesero oolites). At the top of the Campil Member a transgression results in subtidal conditions of the Val Badia Member. The uppermost Skythian is characterized by a slightly regressive trend, which continues upward to lower Anisian times (gypsum-containing carbonates in the Lusnizza Beds).

The model that best describes the situation in the Skythian, is a carbonate ramp, gently inclined towards the east. The history of this ramp began in mid-Permian time with first marine ingressions over Gröden red beds, and can be followed through the Upper Permian and the Lower Triassic. It came to an end when rifting activity, starting in the Upper Anisian, resulted in a situation, which is comparable with a rimmed shelf model.

2. Description of the Gartnerkofel Core Section

(Text-Figs. 6 and 7)

Lithofacies types of individual samples are listed in Table 5.



Text-Fig. 5.
Facies scheme of the uppermost Bellerophon Formation and the Werfen Formation in the Carnic Alps and Karawanken Mountains (K. BOECKELMANN, 1988).

2.1. Unit 1: Middle and Upper Part of the Bellerophon Formation
(Pl. 1)

Depth: 330–231.04 m **Samples 301–206**

Precursors of most samples consist of homogeneous biomicrite (Pl. 1, Figs. 1–7). They are dolomitic mud- and wackestones, fossiliferous or poor in fossils. The different lithologies are mainly the result of micrite conversion to microspar or fine-grained sparite (H. R. Wanless, 1979) and of dolomitization (fine-, medium and coarse-grained dolomite). Samples with micritic matrix are also completely dolomitized, but show well preserved fossils and sedimentary structures. Generally all lithologies are only slightly or not at all influenced by terrigenous clastics.

The sediments are homogenized by strong bioturbation (Pl. 1, Figs. 1 and 2). Burrows of various shapes and orientations are filled with homogeneous, unfossiliferous microsparite or micrite (Pl. 1, Fig. 4). In some cases an open space at the top of such structures is diagenetically cemented by coarse-grained sparite. Intensive bioturbation can result in an irregular distribution of micrite and microsparite.

The fauna is highly diverse and contains foraminifers (*Hemigordius-Globivalvulina*-Association), ostracods, radiolaria, pelecypods, gastropods and rare echinoderms. Small-sized foraminifers (C. Jenny-Deshusses, this volume), ostracods and radiolaria predominate, their shells are normally completely replaced, shell structures are seldom preserved. The flora consists of Dasycladacea, Gymnocodiacea and rare Cyanophycea.

Stromatactis-like fenestral fabrics are a characteristic feature of the Bellerophon Formation: voids are filled with mechanically deposited internal sediment at the bottom (micrite, microsparite) and chemically deposited drusy cement at the top (Pl. 1, Fig. 5). These structures are arranged parallel to the bedding planes; they are up to 6 mm in length and 1 mm in height. Stromatactis appears together with definite burrows, and there are all transitions in terms of shape, dimension and filling between burrows and Stromatactis. The differentiation is therefore often difficult. This means also that bioturbation is probably an important process in the formation of the fenestral fabrics. R.G.C. Bathurst (1980) gives the following interpretation of Stromatactis: Filling (internal sediment and cement) of a system of cavities (here possibly originating from bioturbation), which developed between submarine crusts in a carbonate mud.

Only a very few samples, in the lower part of the core, are composed of high-energy carbonates: intrasparite and intrabiosparite (dolomitic grain- and packstones, Pl. 1, Figs. 8 and 9).

By comparison with results of W. Buggisch (1974) on the nearby Reppwand, the final depth of Gartnerkofel-1 is about 60 to 70 m above the boundary between the Gröden Formation and the Bellerophon Formation, and about 20 to 30 m above the evaporitic unit (Rauhwacke) at the base of the Bellerophon Formation.

Pressure Solution

Following the terminology of H.R. Wanless (1979) we find "sutured seam solution" which means common stylolites and grain contact sutures. Stylolites occur in the upper Permian rocks mainly between massive beds. This style of pressure solution is a typical feature of structurally resistant carbonates, that contain only a small content of impurities (clay, quartz silt).

Dolomitization

The unit is completely dolomitized. Fine-grained dolomite preserves sedimentary structures well, and in some cases also the form and internal structure of fossils (mimic replacement sensu D.F. Sibley & J.M. Gregg, 1987). Medium- and coarse-grained dolomite may preserve the form but not the structure of allochems (non-mimic replacement).

2.2. Werfen Formation
(Pl. 2)

Depth: 231.04 m–57 m **Samples 205–1**

The core is nearly completely dolomitized (in contrast to the outcrop section). In spite of this it is possible to subdivide the core into some units corresponding to the members of the Werfen Formation. Only the lower part of the Skythian sediments is preserved (Tesero Horizon, Mazzin Member, Seis Member, base of Campil Member). The upper part (Campil Member, Val Badia Member, Cencenighe Member) has been eroded in late Anisian time, and can be found as pebbles in the Muschelkalk Conglomerate (= Uggowitz Breccia).

The Lower Triassic sediments consist of dolostone-marl alternations, deposited in a shallow epicontinental sea. The strong influence of currents and wave activity results in the deposition of calcarenites or calcirudites, normally bioclastic or oolitic. These sediments of higher water energy are separated by fine-grained, low-energy, bioturbated background sediments.

Storm layers are quite common. These change from more distal tempestites in the Mazzin Member to more proximal coquina tempestites in the Seis Member, and to proximal sandy tempestites in the Campil Member. The content of terrigenous material in the carbonates (quartz silt and sand) is very low in the Tesero Horizon (most values of the insoluble residue range between 0.5 % and 8 %, carbonates affected by strong pressure solution reach values between 16 % and 42 %). The quartz content increases during the sedimentation of Mazzin Member and Seis Member. In the Campil Member nearly all samples show values of more than 20 % insoluble residue (percentages after P. Klein, this volume).

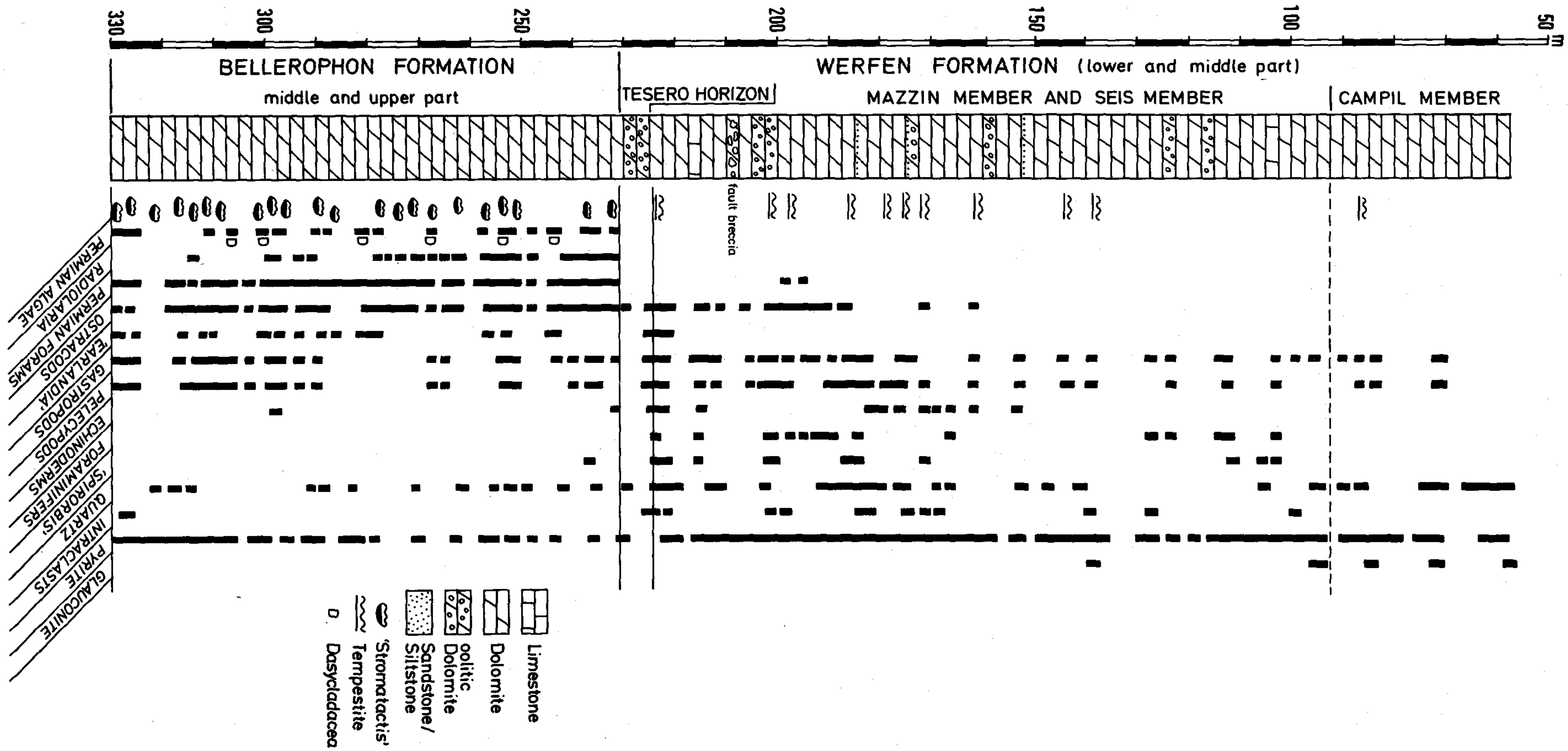
2.2.1. Unit 2: Tesero Horizon

Depth 231.04 m to about 224.50 m **Samples 205–196A**

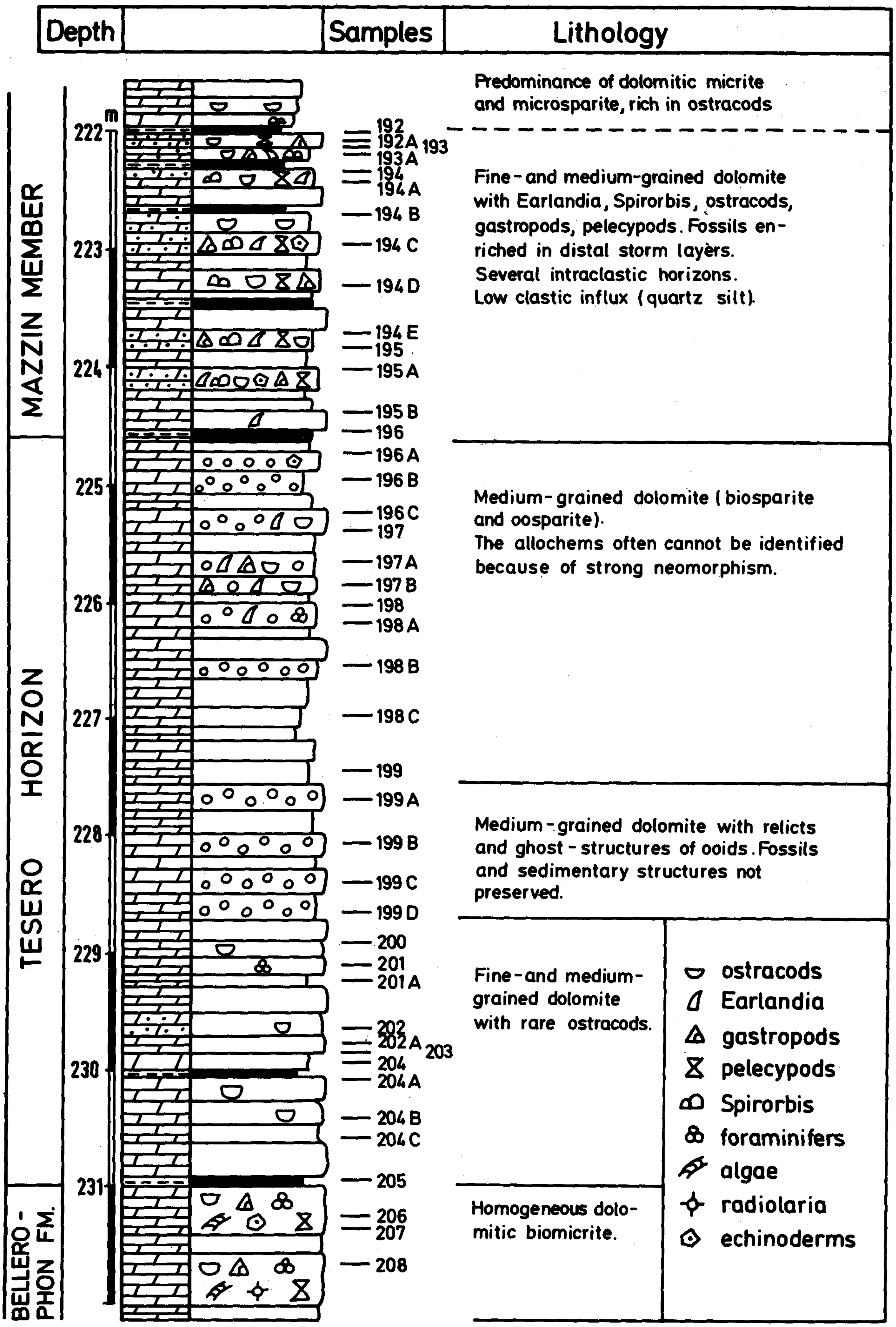
Lithology

Fine- to medium-grained dolomite (Text-Fig. 7; Pl. 2, Fig. 1).

The unit starts with a 2.2 m thick succession of thinly bedded dolomite with relics of ostracods. Sedimentary structures and other biota are destroyed by dolomitization. In contrast to the underlying Bellerophon Formation, an increase of thin marly and clayey interlayers is conspicuous. Furthermore, the carbonates contain more insoluble residue than in the uppermost Permian.



Text-Fig. 6.
Distribution of allochems in the Gartnerkofel-1 core.



Text-Fig. 7.
Detailed lithology and sampling of the Tesero Horizon.

The middle part (1.2 m) comprises oolitic grainstones. Fossils and sedimentary structures cannot be identified. The oolites pass over to a 3.1 m thick succession containing bioclastic or intraclastic grainstones and oolitic grainstones with *Earlandia*, ostracods, pelecypods, gastropods and echinoderm debris.

In comparison with other sections in the Southern Alps the P/Tr boundary should be situated within this unit. Permian foraminifers (especially fusulinids) are not preserved, so the exact position of the boundary remains uncertain.

2.2.2. Unit 3: Mazzin Member and Seis Member

(Pl. 2, Figs. 2–9)

Depth — **Samples**
224.50 m to the interval between 95 m and 82 m — **195b–20/26**

Lithology

Fine- to coarse-grained dolomite, a few samples have relict calcite.

All samples except nos. 184, 183 and 35 and completely dolomitized. Pressure solution and late dolomitization make it sometimes difficult to recognize sedimentary structures and fossil remains. For this reason a boundary between the two members could not be determined. Nevertheless, in the lower part strongly bioturbated, ostracod-rich, normally fine-grained wackestones with gastropods, pelecypods and *Spirorbis* predominate. Their nodular texture ist the result of pressure solution (swarms of microstylolites: "horsetail"-stylolites) and bioturbation. Other sediments, typical of the Mazzin Member, are thin layers of distal tempestites (bioclastic or intraclastic pack- and grainstones) with enriched *Earlandia*, *Spirorbis*, ostracods, pelecypods and gastropods. They grade upward into more proximal storm layers.

The Seis Member is characterized by coquina tempestites of increasing thickness and frequency from base to top, oolitic horizons, and gastropod-rich grain- or packstones with very well preserved shells. The background sediments are similar to those of the Mazzin Member.

The fauna contains gastropods, pelecypods, ostracods, foraminifers (*Cyclogyra-Rectocornuspira*-Association), *Spirorbis* sp.

Sample 184 is an unfossiliferous, microstylolitic, homogeneous calcitic microsparite; dolomite is enriched at stylolites. Sample 183 is a fine-grained dolomite with small relics of calcite (Pl. 2, Fig. 8). Sample 35 shows a well-cemented gastropod grainstone (Pl. 2, Fig. 7). The cement is preserved as calcite; the shells are partly replaced by dolomite.

Between 182 m and 152 m (samples 103–75) some lithologies are very similar to carbonates of the Val Badia Member. They are of reddish, greenish or grey color and contain a lot of echinoderm debris. They are rich in sub- or well-rounded quartz grains (sand to silt) and associated with bioclastic, intraclastic or oolitic grainstones and cross-bedded siltstones. Apart from this interval, the contents of clastic material is low. Angular quartz grains occur as silt and are dispersed in the sediment or enriched in mm-thick layers.

The boundary between Seis Member and Campil Member is transitional. In the interval between 95 m and 82 m we see an increase of red color in carbonates, and an increase of terrigenous material (quartz silt and mica flakes). Fossil layers become rare. Foraminifers disappear; pelecypods and *Spirorbis* predominate.

2.2.3. Unit 4: Campil Member

Depth — **Samples**
95/82 m–57 m — **20/26–1**

Lithology

This unit is composed of mixed dolomitic-siliciclastic material. It is unfossiliferous or poor in fossils (pelecypods and a few gastropods): shell layers are rare in the lower part and missing in the upper part. The color is red, green or grey, but the distribution of colors seems to be controlled by diagenesis and weathering, e. g. decolorization of red dolomite to greenish dolomite along faults and fissures. Most of the samples are altered to medium- and coarse-grained dolomite or silty dolomite. Typical sedimentary structures of the Campil Member are not preserved. The unit shows a stronger tectonic influence than do the underlying units.

2.2.4. Diagenesis

Carbonates of the Werfen Formation have been changed by neomorphism (micrite conversion to microspar and fine-grained sparite), dolomitization and pressure solution (with solution-dolomitization, H. R. Wanless, 1979). They contain significant amounts of clay or silt, and according to H. R. Wanless this will influence the character of change during diagenesis. We find "non-sutured seam solution", occuring as microstylolites, microstylolitic swarms ("horsetail" stylolites) and clay seams. Obviously there is a connection between pressure solution and dolomitization because dolomite rhombs grow preferentially along stylolitic surfaces. The typical result of "non-sutured seam solution" is a nodular limestone. The nodular texture of the background sediments is caused by bioturbation and later intensified or modified by this style of pressure solution.

A further stage of dolomitization took place later than pressure solution and solution-dolomitization, producing medium- and coarse-grained crystals overprinting all sedimentary and diagenetic structures. Such dolomite sometimes contains ghost structures of fossils, ooids, microstylolites or precursor calcitic veins.

3. Description of the Outcrop (Reppwand) Section

(Text-Fig. 1)

The profile begins in the uppermost part of Bellerophon Formation at an elevation of 1810 m, on the cliffs 500 m northwest of GK-1. It proceeds upward through the P/Tr boundary, the Mazzin Member and the basal part of the Seis Member. The thickness of the measured section is about 64.1 m.

3.1. Unit 1: Uppermost Part of Bellerophon Formation

Thickness 4.4 m — **Samples** 1–11 (base to top)

Lithology

Dolomitic mud- or wackestones, poor in fossils, or fossiliferous with Permian foraminifers (*Hemigordius-Globivalvulina*-Association), *Earlandia* (foraminifer), ostracods, radiolaria, shells of pelecypods and gastropods (in some cases large well-preserved gastropods), algae (Dasycladacea), and rare small echinoderms. No primary shell structures. Void fillings (burrows and Stromatactis-like textures) contain fine-grained internal sediment and coarser drusy cement. The sediment is homogenized by bioturbation, the micritic matrix is partly coarsened to microspar.

Sample no. 11 differs from the low-energy carbonates of nos. 1–10: it is a dolomitic foraminiferal-algal pack- or grainstone.

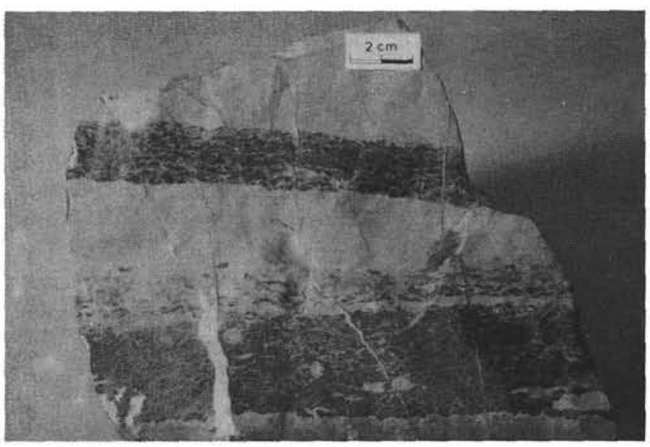
3.2. Unit 2: Basal Part of Werfen Formation

Thickness 4.0 m — **Samples** 12–27

Lithology

Unfossiliferous, inhomogeneous, fine- and medium-grained, often marly dolomite. Strong pressure solution (microstylolites, microstylolitic swarms). In some cases the rock is brown as a result of pyrite-limonite enrichment in zones of solution. Complete dolomitization destroys biogenic and sedimentary structures. Samples 22 to 27 are medium-grained dolomite with indeterminate allochems, probably originally a biosparite with ooids and shells of molluscs. Sample no. 24 contains large pelecypod shells (preserved as molds) oriented parallel to the bedding plane.

The unit shows more insoluble residue in the carbonates, and more thin clayey or marly interlayers, than the underlying unit. Lithology characteristic of the Tesero Horizon, e.g. oolites, were not clearly identified in the outcrop section.



Text-Fig. 8.
Storm layers in Unit 3 of the Werfen Formation.

3.3. Unit 3 Mazzin Member, Base of Seis Member

Thickness 55.7 m — **Samples** 28–90

Lithology

An alternating sequence of low- and high-energy carbonates. Background sedimentation: dolomitc mud- and wackestones (micrite, microspar, fine-grained sparite), unfossiliferous or poor in fossils, bioturbated, microstylolitic, often with nodular texture. Fossils: *Earlandia* (foraminifer), ostracods, shell remains of molluscs, rare small echinoderms.

Quartz silt and mica are dispersed in the sediment or enriched in 1 to 5 mm beds. Generally small amounts of clastic material are slightly increasing from base to top of this unit.

Storm layers are pack- and grainstones with accumulations of *Earlandia*, ostracods, *Spirorbis*, and shell remains (Text-Fig. 8). The matrix is fine-grained sparite with quartz silt.

Samples 40 to 43 are composed of calcitic micrite and microspar (mud- and wackestones with pelecypods, gastropods, *Spirorbis*, echinoderms), strongly bioturbated and pressure dissolved. Some medium- and coarse-grained dolomite results from late dolomitization. In these rocks sedimentary structures and biogenic content are destroyed; gastropods and ooids (?) occur as ghosts. Towards the top of the section gastropod-rich packstones become more frequent. Possibly the profile reaches the base of the Seis Member.

4. Comparison between Core and Outcrop Section

Unit 1 of the outcrop correlates with the uppermost part of unit 1 in the core. The Tesero Horizon is identified in the core (unit 2), but as a result of strong

Table 4.
Correlation of samples.

Unit	Outcrop Samples	Thickness	Core Samples	Thickness	Stratigraphy
Unit 1	1–11	4.4 m	211 –206	4.0 m	Bellerophon Formation
Unit 2	12–27	4.0 m	205 –196A	6.5 m	Tesero Horizon
Unit 3	28–61	24.2 m	195B–162	25.5 m	Mazzin and Seis Members
	62–67	9.0 m	161 –151	5.0 m	
	68–90	22.5 m	150 – 89	23.0 m	

Table 5.
Lithofacies Types of the Gartnerkofel-1 Core.

Unit 1: Bellerophon Formation **(Pl. 1)**

L 1 : Dolomitic micrite; well preserved, small sized fauna and flora; Stromatactis-like fenestral fabrics.
L 1a: Poor in fossils (mud- and wackestone).
L 1b: Rich in fossils (wacke- and packstone).

L 2 : Dolomitic microspar and fine-grained sparite, formed by micrite conversion; fossil content and sedimentary structures partly destroyed.
L 2a: Micrite conversion incomplete: relict micrite.
L 2b: Micrite conversion complete.

L 3 : Carbonates of higher water energy (fine- and medium-grained dolomitic grain- and packstones); intrasparite and intrabiosparite (reworked L 1 or L 2 micrite).

L 4 : Medium- and coarse-grained dolomite with relics of microspar and relics (molds, ghost-structures) of fossils.

Unit 2: Tesero Horizon **(Pl. 2, Fig. 1)**

L 5 : Dolomitic microspar and fine-grained sparite with badly preserved ostracods; some quartz silt; microstylolitic texture; rich in insoluble residue (marly dolomite).

L 6 : Fine- and medium-grained dolomite,
L 6a: Relics or ghost-structures of ooids, ostracods, *Earlandia* (foraminifer), rare echinoderms and intraclasts; allochems often not identifiable.
L 6b: Without any primary structures; iron-rich sediment with pyrite and iron oxide.

Unit 3: Werfen Formation (Mazzin Member and Seis Member) **(Pl. 2, Figs. 2–10)**

L 7 : Dolomitic microspar and fine-grained sparite; slightly silty (quartz silt dispersed in the sediment or enriched in thin layers or lenses); microstylolitic texture.
L 7a: Unfossiliferous or poor in fossils; rich in insoluble residue.
L 7b: Rich in fossils (wacke- and packstones); with ostracods, foraminifers, gastropods, pelecypods, worm tubes; in the lower part of unit 3: distal tempestites (thin layers with erosional base containing *Earlandia* [foraminifer], ostracods, *Spirorbis* [worm tube] and pelecypods).

L 8 : Dolomitic oobiosparite (oolitic grainstone).

L 9 : Fine- and medium-grained dolomite; more or less microstylolitic texture, pressure-solution phenomena partly overprinted by dolomitization.
L 9a: Unfossiliferous or poor in fossils.
L 9b: Rich in fossils; dolomitized coquina-tempestites.

L 10 : Medium- and coarse-grained dolomite; without primary structures.
L 10a: Poor in insoluble residue; anhedral crystals; ghost-structures of fossils or ooids.
L 10b: Euhedral or anhedral crystals; intercrystalline pores filled with reddish, clayey "groundmass"; no fossils or sedimentary structures preserved.

L 11 : Dolomitic microspar and fine-grained sparite, rich in terrigeneous clastics; oolitic-intraclastic-bioclastic dolomite with well rounded to subrounded quartz grains (sand and silt); rare dolomitic quartz silt, rich in mica flakes.

Unit 4: Werfen Formation (Campil Member)

L 12 : Dolomitic micrite, microspar, fine-grained sparite; red, green, grey; unfossiliferous or only a few relics of pelecypods.
L 12a: Rich in quartz silt.
L 12b: Poor in quartz silt.

L 13 : Medium grained dolomite: red, green, grey; stylolitic or microstylolitic texture; slightly silty (quartz and mica); unfossiliferous or poor in fossils (relics of pelecypods and gastropods).

L 14 : Medium and coarse grained dolomite; rich in pyrite and glauconite.
L 14a: Dolomitized gastropod-pelecypod wacke- and packstone.
L 14b: Without any primary structures.

Sample	Depth	Lithofacies Type															
3o1	330.00	2b	287	315.76	2a	271	299.60	1b	254	285.05	2a	240	269.75	2a	223	251.00	1a
300	329.04	2a	285	315.16	4	270	298.05	1b	253	282.71	2a	239	267.46	1b	222	247.95	1b
299	328.06	2b/3	283	314.36	2a	269	297.77	1b	252	281.45	2a	237	265.13	2b	221	244.28	2a
298	327.31	3	282	313.58	2a	268	296.40	2b	251	281.40	2a	235	263.25	2a	220	243.60	2a
297	326.55	3	281	312.10	2a	266	295.29	2b	250	280.44	2a	234	261.83	2a	219	243.17	2a
296	324.80	2b	280	311.34	2b	264	293.46	1b	249	279.67	2a	233	261.05	2a	218	241.89	2a
295	323.70	4	279	310.02	2b	263	292.60	2a	248	278.75	2a	231	259.17	2a	217	204.90	2b
294	322.90	4	278	308.10	2a	261	291.26	1b	247	277.98	1b	230	257.35	1a	216	240.26	2a
293	322.60	4	277	307.55	2a	260	291.15	2b	246	276.30	2a	229	256.97	2b	215	237.84	1b
292	321.43	2a	276	306.80	2b	259	290.37	2a	245	273.85	2a	228	256.54	2a	214	236.76	2a
291	318.87	4	275	305.80	2a	258	289.62	2b	244	272.95	2a	227	255.65	2a	213	236.65	2a
290	318.50	2a	274	303.15	2a	257	289.07	2a	243	271.20	2a	226	254.28	2a	212	235.77	2a
289	317.53	2a	273	301.10	2a	256	287.83	2a	242	270.80	2a	225	252.36	2a	211	235.25	2a
288	317,05	4	272	299.92	2a	255	286.33	2a	241	270.15	2a	224	251.85	2a	210	233.60	1a

Table 5 (continued).

Sample	Depth	Lithofacies Type										Additional Samples						
209	233.08	2a	160	198.36	7a/8	109	184.17	7a	54	127.46	7 a							
208	231.72	2a	159	197.73	7b	108	183.97	7a	53	127.40	7a	204C	230.60	6b	190A	220.51	7a	
207	231.37	1b	158	197.05	9a	107	183.61	7a	52	127.04	7a	204B	230.46	6b	284	314.85	2a	
206	231.25	1b	157	196.60	9a	105	183.40	7b	50	123.50	10a	204A	230.04	6b		314.80	2a	
204	229.92	6b	156	196.23	9a	104	182.70	7b	49	119.27	9a/10a	202A	229.74	5		314.70	2a	
202	229.65	5	155	195.90	9a	103	182.20	7b	48	118.64	9a/10a	201A	229.22	5		314.64	2a	
201	229.12	6b	154	195.38	9a	99	181.37	7a	47	117.70	9a/10a	199D	228.64	6a		314.50	2a	
200	228.94	6b	153	195.15	9b	98	180.33	7a	46	115.95	9a/10a	199C	228.53	6a		314.40	2a	
199	227.46	6b	152	194.75	9b	97	179.64	7a/9a	45	114.10	7a	199B	228.04	6a	283	314.30	2a	
198	226.00	6a	151	194.33	9b	96	177.72	9b	43	112.43	7a	199A	227.77	6a		314.20	2a	
197	225.40	6a	150	193.80	9b	95	177.43	9a/b	42	111.42	9a/7b	198C	227.02	6b		314.05	2a	
195	223.94	7a/b	149	193.55	9b	94	176.37	9b	40	107.75	10b	198B	226.52	6b		313.95	2a	
194	222.35	7b	148	193.00	9b	93	175.10	11	39	105.90	7a	198A	226.12	6b		313.85	2a	
192	222.08	7a/b	147	192.90	9b	92	174.90	11	38	105.32	7a	197B	225.84	6a		313.75	2a	
191	221.01	7a/b	146	192.23	9b	90	173.53	7a	36	103.45	9a	197A	225.64	6a		313.65	2a	
189	220.20	7a/b	145	191.53	7a	88	169.10	9a	35	102.93	7b	196C	225.22	6a	282	313.50	2a	
188	220.10	7a/b	144	191.06	7a	87	168.78	7a	33	100.42	10a/b	196B	225.01	6a				
187	219.70	7a/b	142	190.66	7a	85	166.35	7a	32	99.46	9b	196A	224.73	6a	226	254.28	2a	
186	216.62	11b	141	190.50	7a	84	164.60	9a	31	97.40	7a	195B	224.36	7a		254.15	1b/2a	
184	215.70	8b	139	190.00	9b	83	164.32	9a	30	96.05	9b	195A	224.04	7a		253.95	2a	
183	215.35	7b/10a	137	189.65	7b	81	162.36	7a/9b	28	95.30	7a	194E	223.71	9b		253.75	2b	223
182	215.07	7a	135	189.23	7a	80	161.04	7a	27	95.17	7a	194D	223.33	7a		253.55	2a	
181	214.25	7a	134	188.98	7a	79	158.33	*	26	90.56	7a	194C	223.01	7a/b		253.20	2a	
180	214.05	7a	132	188.44	7a	78	154.11	7a/9a	24	88.85	14b	194B	222.64	7a		253.00	2b	
179	213.65	10b	130	187.83	9a	77	153.50	7a	23	86.92	13	194A	222.46	7b		252.95	2b	
178	213.50	7a	128	187.45	9a	76	152.80	7a/b	22	86.26	13	193A	222.26	7b		252.70	1b	
177	212.30	7a	127	187.20	9a	75	152.69	7a/11	21	84.37	14a	192A	222.15	7a		252.30	1b/2a	
176	212.20	7a	126	187.05	9a	73	149.61	10b	20	82.85	14a	191F	222.05	7a	225	252.40	2a	
174	211.46	10b	125	186.93	7a	72	149.34	9a	18	81.52	13	191E	221.80	7a/10a		252.10	1a	
173	211.33	7a	123	186.80	7a	71	147.60	10b	17	79.67	13	191D	221.54	7a		251.95	2a	
172	210.03	*	122	186.77	7a	70	146.66	9a	13	75.32	12b	191C	221.37	7a	224	251.85	2a	
171	207.14	*	121	186.47	7a	68	144.33	9a	11	73.75	14b	191B	221.33	7a		251.75	1b	
170	206.89	7a	120	186.15	7a	67	143.26	9a/b	10	72.10	12b	191A	221.18	7a/10a		251.60	1b	
169	205.63	9a	119	185.96	7a/b	65	141.54	7a	9	71.70	12b	190C	220.90	7a		251.40	1b	
168	203.73	8	118	185.65	7a	64	140.60	10b	8	70.62	12b	190B	220.74	7a	223	251.00	1a	
167	202.50	8	116	185.51	7a	63	138.96	10b/9b	7	65.70	12b							
166	202.15	7 a/8	115	185.30	7a/b	61	137.23	10b	6	64.95	12a							
165	201.99	7a/8	114	185.26	7a/b	60	136.50	7a	5	63.00	12a							
164	201.31	8	113	184.96	7a/b	58	130.55	10a	4	61.65	12a							
163	199.45	7a	112	184.80	7a/b	57	130.40	10a	3	60.88	12a							
162	199.15	9 a	111	184.72	9b/11	56	130.10	7a	2	58.81	12a							
161	198.70	7a/8	110	184.43	9b/11	55	127.55	7a	1	57.53	12a							

* = Tectonic breccia.

neomorphism it is not clearly recognizable (lack of oolites) in the outcrop. Unit 3 of the outcrop section correlates with the lower part of unit 3 in the core. This comparison is based on lithology and faunal associations.

Acknowledgement

The author thanks the members of the Gartnerkofel Consortium for continuing discussion and exchange of respective results. In particular I am much indebted to Professor WILLIAM T. HOLSER for several scientific suggestions and critical review of the English Version of the manuscript.

Plate 1

Dolomite of Bellerophon Formation

Fig. 1: **Radiolarian wackestone (biomicrite).**
Radiolaria are calcified (medium-grained sparite) and some of them are replaced by microsparite.
GK-1, sample 239, lithofacies type 1b, scale: 0.25 mm.

Fig. 2: **Radiolarian-foraminiferal wackestone (biomicrite).**
Some burrows and fenestral fabrics. Center left: *Frondina permica*.
GK-1, sample 271, lithofacies type 1b, scale: 1 mm.

Fig. 3: **Radiolarian-ostracod wackestone (biomicrite)**
with a fenestral fabric oriented parallel to the bedding plane and filled with micrite, microsparite, sparite (base to top).
Center: ostracod.
GK-1, sample 271, lithofacies type 1b, scale: 1 mm.

Fig. 4: **Ostracod wackestone (biomicrite)**
with a horizontal burrow filled with homogeneous, unfossiliferous microsparite.
GK-1, sample 246, lithofacies type 1b, scale: 3.5 mm.

Fig. 5: **Mud- and wackestone ("dismicrite").**
Numerous Stromatactis-like voids with geopetal fabrics. GK-1, sample 275, lithofacies type 1b, scale: 3.5 mm.

Fig. 6: **Homogeneous radiolarian wackestone (biomicrite)**
in the lower part; nearly unfossiliferous microsparite with dark relics of micrite in the upper part. At the contact irregular stylolites.
GK-1, sample 218, lithofacies type 1b and 2a, scale: 4 mm.

Fig. 7: **Relic of ostracod mudstone (biomicrite)**
surrounded by homogeneous, unfossiliferous microsparite, rich in pyrite (opaque crystals).
GK-1, sample 227, lithofacies type 2a, scale: 1.5 mm.

Fig. 8: **Grainstone (biosparite) with a gastropod.**
The shell is replaced by even-grained sparite. Other allochems are indeterminate.
GK-1, sample 299, lithofacies type 3, scale: 2 mm.

Fig. 9: **Foraminiferal grainstone (biosparite)**
with *Glomospira* sp. Except for the foraminifers, all allochems are destroyed by neomorphism.
GK-1, sample 299, lithofacies type 3, scale: 1 mm.

Fig. 10: **Foraminiferal packstone (biomicrite and biosparite)**
with *Globivalvulina bulloides, Nodosaria* sp. The matrix consists of micrite and fine-grained sparite.
GK-1, sample 287, lithofacies type 1b, scale: 0.6 mm.

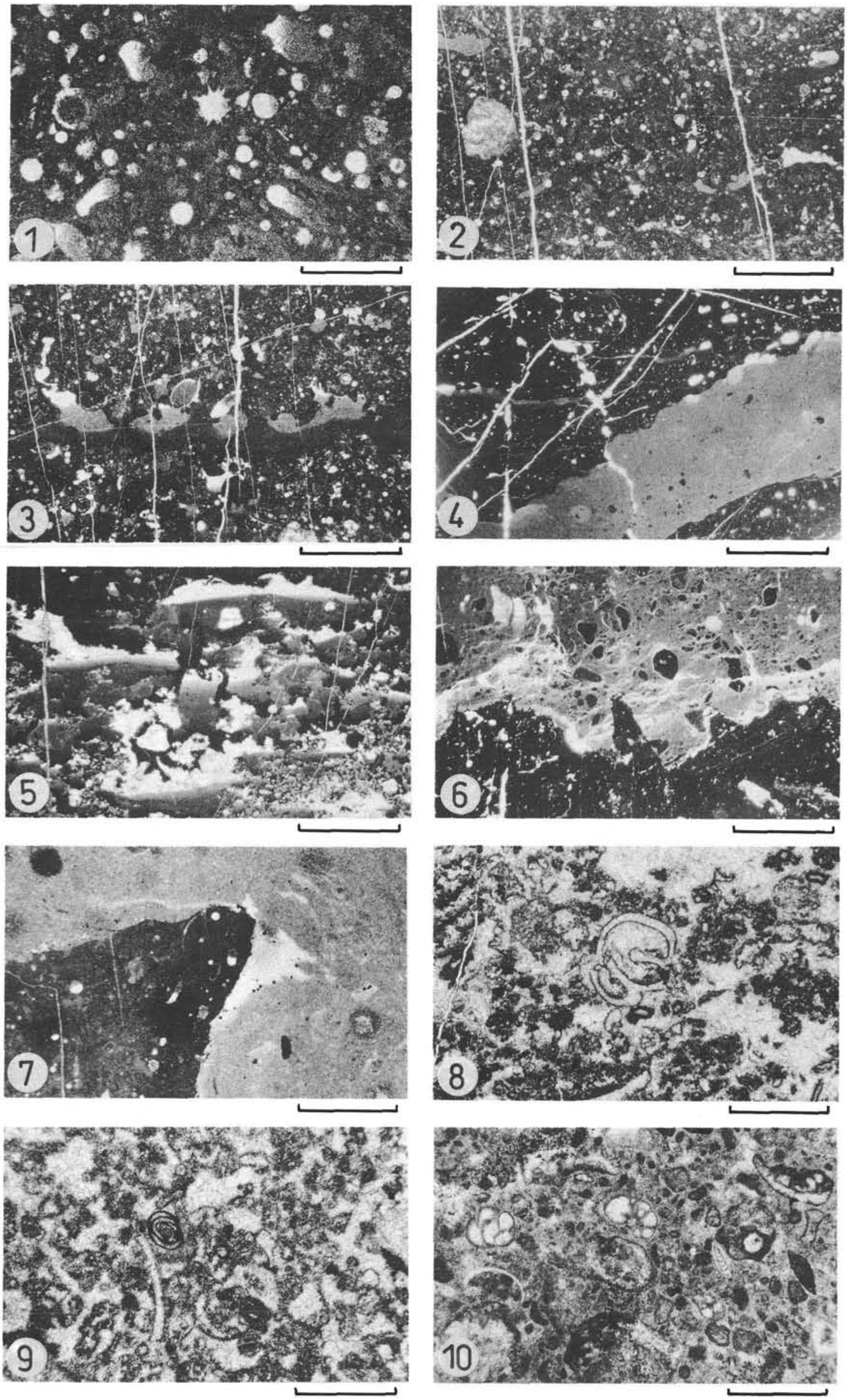

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Plate 2

Dolomite and partly dolomitized limestones of Werfen Formation

Fig. 1: **Dolomitic oolite grainstone (oosparite) of Tesero Horizon.**
Ooids are completely replaced by homogeneous microsparite. A fauna is not preserved.
GK-1, sample 199D, lithofacies type 6a, scale: 1.5 mm.

Fig. 2: **Dolomitic foraminiferal mud- and wackestone**
with small tubes of *Earlandia* sp. enriched in a thin horizon.
Lowermost part of the Mazzin member, GK-1, sample 194C, lithofacies type 7b, scale: 1 mm.

Fig. 3: **Microstylolitic ostracod mudstones**
are very typical for the Mazzin Member, but occur as well in the Seis Member. The sample consists of calcite; aggregates and crystals of dolomite (white patches) are dispersed in the sediment.
GK-1, sample 184, lithofacies type 7b, scale: 1.5 mm.

Fig. 4: **Dolomitic intraclast pack- and grainstone,**
rich in polycrystalline, angular or subrounded quartz grains. Some horizons in the Seis Member are rich in quartz (grainsizes between silt and medium sand). Such carbonates contain more echinoderm debris than other sediments. Generally the quartz content increases from the Tesero Horizon to the Campil Member more or less continuously.
GK-1, sample 93, lithofacies type 11, scale: 1.2 mm.

Fig. 5: **Vertical burrow in a homogeneous (in the upper part cross-bedded) dolomitic mudstone.**
Seis Member, outcrop section Garnitzengraben (BOECKELMANN, 1988), sample G55, scale: 4 mm.

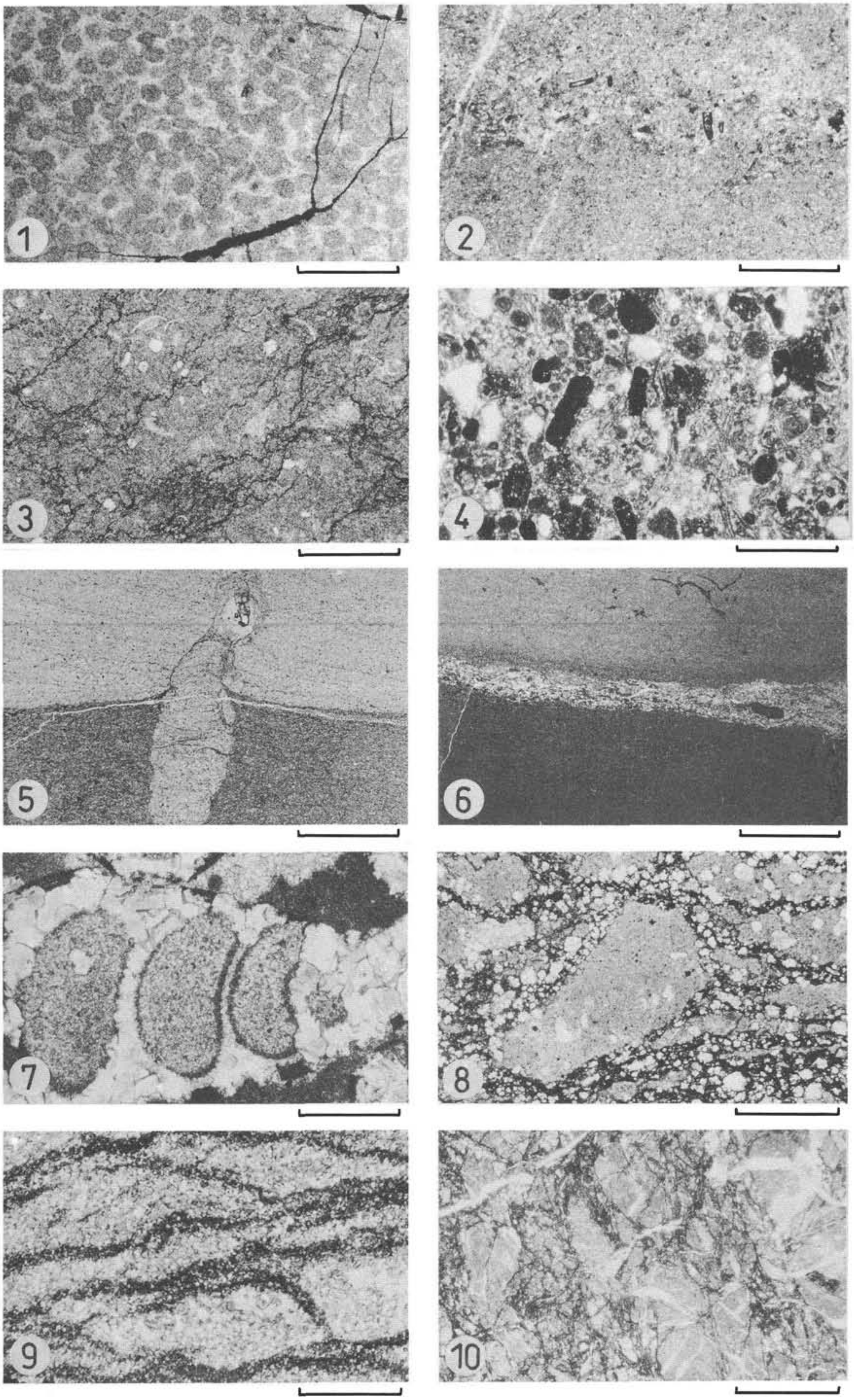
Fig. 6: **Small bioclasts**
of ostracods, *Spirorbis* sp. (worm tubes) and pelecypods are enriched in a thin distal storm layer. Other allochems are intraclasts and some quartz silt. The background sediment is a homogeneous mudstone.
Mazzin Member, outcrop section Monte Pallone (western Carnic Alps/Italy) (BOECKELMANN, 1988), sample P21, lithofacies type 7b, scale: 5 mm.

Fig. 7: **Partly dolomitized gastropod wacke- and packstone.**
The gastropod shell is replaced by coarse-grained dolomite. The intragranular pore space is filled with fine-grained calcitic sparite. The matrix is a homogeneous micrite.
GK-1, sample 35, lithofacies type 9b, scale: 0.75 mm.

Fig. 8: **Partly dolomitized microstylolitic mudstone (stylobreccia).**
The precursor sediment is a homogeneous calcitic mudstone, visible as large intraclast-like relics or nodules of light-grey material. Microstylolitic swarms appear black. White dolomite crystals grew preferentially in the zones of solution.
GK-1, sample 183, scale: 1.3 mm.

Fig. 9: **Coarse-grained dolomite (even-grained, subhedral and anhedral crystals).**
Dark lines are ghost-structures of solution seams.
GK-1, sample 73, lithofacies type 10a, scale: 2 mm.

Fig. 10: **Tectonized dolomite (tectonic breccia) rich in fractures and veins.**
GK-1, sample 171, scale : 1 mm.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