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Palaeoenvironmental Evolution during the Upper Carboniferous and the Permian in the Schulter-Trogkofel Area (Carnic Alps, Northern Italy)

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With 11 figures and 3 tables

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Oberkarbon
Perm
Paläogeographie
Sedimentationsentwicklung

Zusammenfassung

Im Gebiet zwischen Trogkofel und Schulter (Karnische Alpen) wird die Sedimentationsentwicklung während des Jungpaläozoikums diskutiert.

Über den devonischen Flachwasserkalken, die die SW-Begrenzung des Untersuchungsgebietes bilden, folgen die vorwiegend klastisch ausgebildeten Auernig Schichten (Oberkarbon). Das terrigene Material stammt aus einem im SW liegenden Liefergebiet und wurde in einen flachen, subtidalen Sedimentationsraum transportiert, wo es mit kurzzeitig auftretenden, hohen Sedimentationsraten, die auf zeitweise starke Absenkung des Beckens zurückgeführt werden, zur Ablagerung kam. Während geringer oder fehlender klastischer Schüttung konnten sich Stillwasserbiotherme entwickeln, die in Form isolierter Kalklinsen vorliegen. Ein „Auernig Rhythmus" (sensu KAHLER, 1955) kann nicht bestätigt werden.

Diese Sedimentationsbedingungen dauern während der Ablagerung der größtenteils kalkigen Unteren Pseudoschwageringen Schichten und der vorwiegend klastischen Grenzland Bänke des untersten Perm an. Während der Ablagerung der Oberen Pseudoschwagerinen Schichten (oberes Assel) und des Trogkofelkalks (Sakmar) verschob sich der Sedimentationsraum in küstenfernere Bereiche des Schelfs, der klastische Einfluß ist gering. Der Trogkofelkalk wird als stratigraphisches Riff am Schelfrand interpretiert, die Mächtigkeit nimmt, wie auch bei den Unteren Pseudoschwagerinen Schichten nach NE hin zu.

Die Tarviser Breccie (oberstes Unterperm) überlagert im NE den Trogkofelkalk, während sie im SW über den Auernig Schichten folgt. Diese Schichtlücke wurde auf Erosion während der „Saalischen Phase" zurückgeführt. Bei Betrachtung der vorausgehenden Sedimentationsvorgänge muß die Schichtlücke jedoch zurückgeführt werden auf fehlende oder reduzierte Sedimentation aufgrund geringerer Absenkung des Ablagerungsraumes im SW. Die „Saalische Phase" bewirkte somit vermutlich nur eine kurze Regression, die mit mäßiger Erosion verbunden war.

Summary

The sedimentary evolution of the Late Palaeozoic of the Trogkofel and Schulter area (Carnic Alps) is discussed.

The stratigraphic succession begins with the predominantly quartzose Auernig Group (Upper Carboniferious), which follows to the Devonian shallow water limestones at the extreme west of the investigated area. The clastic material of the Auernig Group was derived from a source area situated in the SW and was transported into a shallow subtidal sedimentation area, where it was rapidly deposited with transient and high sedimentation rates during times of intense subsidence of the basin. During times lacking or of low clastic influx the construction of algal-mud mounds was possible, forming isolated carbonate lenses. An "Auernig Rhythm" (sensu KAHLER, 1955) cannot be confirmed.

These proceedings of sedimentation are to be persued during the Lowermost Permian, in the chiefly calcareous Lower Pseudoschwagerina Formation and the predominantly clastic Grenzland Formation. During the sedimentation of the Upper Pseudoschwagerina Formation (Uppermost Asselian) and the Trogkofel Formation (Sakmarian) clastic influx decreased and the sedimentation area moved seawards. The Trogkofel Formation is constructed by encrusting algae, forming a stratigraphic reef, which was situated on the shelf edge. An increase of thickness to the NE can be observed, which is also present in the Lower Pseudoschwagerina Formation.

The Tarvis Breccia (uppermost Lower Permian) overlies the Trogkofel Formation in the NE and the Auernig Group in the SW. This stratigraphic lacuna in the SW has been attributed to erosion during the "Saalian phase". However, considering the preceding sedimentary evolution, the missing sediments can be referred to a decrease of subsidence in SW' direction and lacking or reduced sedimentation during the latest Palaeozoic. The "Saalian phase" is believed only to cause a brief regression with moderate erosion.

1. Introduction

In the Carnic Alps a nonmetamorphic succession, beginning with the Middle Ordovician documents the Palaeozoic evolution of the Southern Alps. In the north the Palaeozoic series are limited by the Gailtal line, in the south they are covered by younger deposits.

The investigated area (Fig. 1) is located to the south of the Italian-Austrian border and extends from the Schulter (2091 m) in the west to the Trogkofel (Creta di Aip, 2279 m) in the east. It comprises the S' part of a NW-SE striking, about 2-4 km wide sector composed of Late Palaeozoic series (Tab. 1) which is wedged between Devonian and Lower Carboniferous sediments.

In the following, the sedimentary evolution during the Late Palaeozoic is discussed. A complete stratigraphic succession is developed in the NE of the investigated area. It extends from the Upper Carboniferious (Auernig Group) to the uppermost Lower Permian (Tarvis Breccia). In the SW the stratigraphic succession begins with the Upper Carboniferious, too and reaches to the Upper

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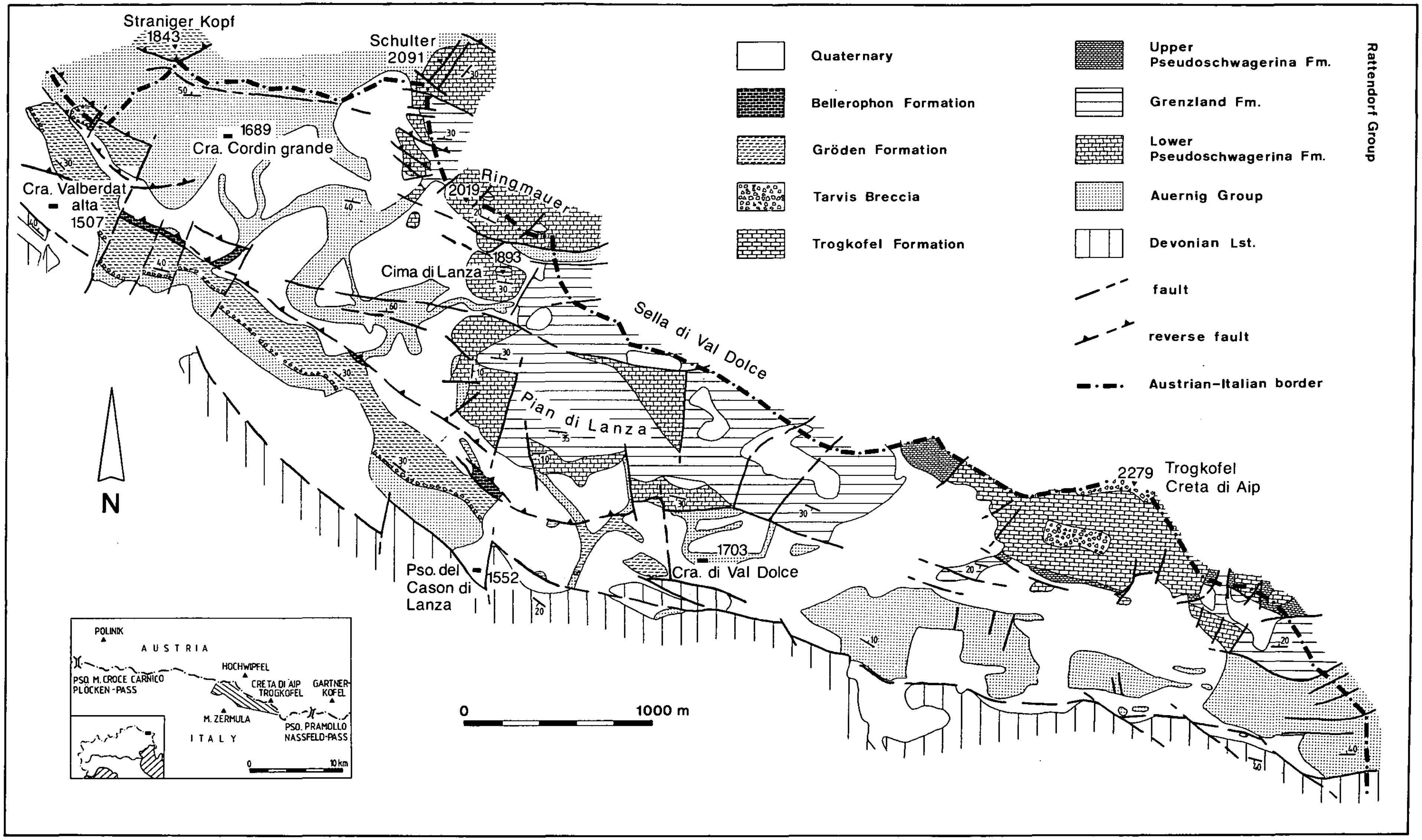

Fig. 1: Geologic map and index map of the investigated area.

Table 1: Correlation table; time units after FLÜGEL (1981) and VAI et al. (1980).

UPPER PERMIAN	Tatarian	Bellerophon Formation	
MIDDLE PERMIAN	Kasanian	Gröden Formation	
	Ufimskian		
	Kungurian		
LOWER PERMIAN	Cisjanskian	Trogkofel Group	Tarvis Breccia
	Artinskian		Lacuna
	Sakmarian		Trogkofel Formation
	Asselian	Rattendorf Group	Upper Pseudoschwagerina Formation
			Grenzland Formation
			Lower Pseudoschwagerina Formation
UPPER CARBONIFEROUS	Orenburghian	Auernig Group	
	Gzhelian s. l.		
	Kasimovian		

Permian (Bellerophon Formation), however, uppermost Carboniferious and Lower Permian deposits are missing. This lacuna was first recognized by HERITSCH (1936). He considered this region to be a topographic high during this period. A controversial interpretation was given by KAHLER (1980), who considered this lacuna to have been caused only by erosion attributed to the "Saalian phase" (uppermost Lower Permian).

2. Stratigraphy

2.1. Devonian shallow water limestones

In the extreme SW of the investigated area massive, light grey bioclastic detrital limestones, Givetian to Frasnian in age, are exposed. They are composed of floatstones and wackstones, rich in stromatoporids (*Amphipora* sp.), calcisphaeres, corals and stromatolitic algal crusts. The sedimentation area corresponds to a restricted back-reef environment.

2.2. Auernig Group (Gruppo dell'Auernig)

The Auernig Group, Stefanian A–C (REMY, 1969), respectively Upper Moscovian–Orenburghian (VAI et al., 1980) in age, is composed of argillites, siltstones, sandstones and conglomerates with intercalated calcareous lenses. According to HERITSCH et al. (1934) and SELLI (1963), the Auernig Group can be subdivided by the frequency of the occurrence of calcareous lenses (Tab. 2). In the investigated area the "untere kalkarme Schichtgruppe" is predominating. The total thickness of the Auernig Group is about 700 meters, although a complete succession doesn't exist anywhere.

The thin bedded dark argillites are locally several meters thick and often include floated plant detritus or bioclasts, e. g. crinoidal stems up to 10 cm in length, corals, brachiopods (productids, spiriferids) and occasionally trilobits, enriched in several horizons.

Table 2: Subdivision of the Auernig Group according to HERITSCH et al. (1934).

HERITSCH et al. (1934)	SELLI (1963)
Obere kalkarme Schichtgruppe	Formazione del M. Carnizza
Obere kalkreiche Schichtgruppe	Formazione dell' Auernig
Mittlere kalkarme Schichtgruppe	Formazione del Corona
Untere kalkreiche Schichtgruppe	Formazione del Pizzul
Untere kalkarme Schichtgruppe	Formazione di Meledis

The quartzose siltstones and sandstones are mostly thick bedded. Intercalations with through cross-bedding and erosive convex base partly occur. The quartz grains are angular to well rounded and mostly well sorted. Frequently quartz pebbles or pebbles of resedimented argillites or sandstones, up to 1 cm in diameter, are enclosed (Fig. 2). On the top surfaces *Zoophycos* is abundant.

The conglomerates form massive lenses with lateral extensions of several hundred meters and thicknesses of up to several meters. They are grain- or matrix-supported and commonly composed of angular to well

Fig. 2: Auernig Group; thin section photomicrograph of siltstone layers with well rounded quartz pebbles at the base; extreme E of the investigated area, 1900 m, scale bar 1 cm.

Table 3: Calcareous algae and microproblematica of the calcareous lenses of Auernig Group and Grenzland Formation (+ is indicating phylloid algae).

		Auernig Group	Grenzland Formation
Calcareous algae			
	Chlorophyta		
	Codiaceae		
	Anchicodium magnum ENDO 1951 [+]		×
	Eugonophyllum johnsoni KONISHI & WRAY 1961 [+]	×	×
	Ivanovia tenuissima KHVOROVA 1946 [+]	×	
	Neoanchicodium catenoides ENDO 1954		×
	Dasycladaceae		
	Anthracoporella spectabilis PIA 1920	×	
	Atractyliopsis carnica FLÜGEL 1966	× ?	×
	Macroporella maxima ENDO 1952	×	
	Mizzia cornuta KOCHANSKY & HERAK 1960	×	×
	Questionable Dasycladaceae		
	Pseudoepimastopora sp.	×	×
	Epimastopora alpina KOCHANSKY & HERAK 1960 [+]	×	×
	Epimastopora hunzaensis ZANIN-BURI 1965 [+]	×	×
	Epimastopora ketinii BILGÜTAY 1960 [+]	×	
	Epimastopora piae BILGÜTAY 1960 [+]	×	
	Globuliferoporella symmetrica (JOHNSON 1961)		×
	Pseudovermiporella nipponica (ENDO 1954)	×	
	Rhodophyta		
	Corallinaceae		
	Archaeolithophyllum missouriense JOHNSON 1956 [+]	×	
	Archaeolithophyllum lamellosum WRAY 1964		×
	Archaeolithophyllum sp. [+]	×	
	Ungdarella uralica MASLOV 1950	×	
	Rhodophyta incertae sedis		
	Efluegelia johnsoni (FLÜGEL 1966)	×	×
	Cyanophyta		
	Girvanella ducii WETHERED 1890	×	×
	Girvanella catenoides HOMANN 1972	×	×
	Girvanella permica PIA 1937	×	× ?
	Ortonella sp.		×
Microproblematica			
	Tubiphytes obscurus MASLOV 1956	×	×
	Ramovsia limes KOCHANSKY-DEVIDE 1973	× ?	×
	Aeolisaccus dunningtoni ELLIOTT 1958	×	×

Fig. 3: Auernig Group; thin section photomicrograph of the algal wackestones with longitudinal and transversal sections of *Anthracoporella spectabilis* PIA, fusulinids and bivalves; Trogkofel massif, 1750 m, scale bar 6 mm.

rounded, mostly unsorted, light quartz components with diameters up to 10 cm, embedded in a quartzose matrix. Furthermore, pebbles of black lydites occur.

The calcareous lenses are built up by massive algal-wackestones (Fig. 3) with predominantly phylloid algae (e. g. genera *Epimastopora, Anthracoporella, Eugonophyllum*) (Tab. 3), and rare brachiopods, fusulinids or echinoderm debris. The bioclasts are angular and unsorted. Furthermore coarse-bedded *Cyanophyceae*-bindstones and oncoid-grainstones with *Cyanophyceae* and *Dasyclydaceae* are common, comprising abundant microproblematica (*Tubiphytes obscurus* MASLOV), sessile and vagile smaller foraminifera, brachiopods, bryozoa and ostracods, together with much fineclastic biotic detritus. The bioclasts often are coated or bored, fusulinids and echinoderm debris sometimes are enriched in packstones. The thickness of the calcareous lenses exeeds up to 5 meters, the lateral extension amounts to several tens of meters.

2.3. Lower Pseudoschwagerina Formation (Formazione inferiore di Pseudoschwagerina)

At the Schulter, Ringmauer, Cima di Lanza and Pian di Lanza the Lower Pseudoschwagerina Formation (lowermost Asselian) is well exposed. The thickness, according to HOMANN (1969), is nearly constant, amounting 120–160 meters. In the realm of the Pian di Lanza, however, reduced thicknesses of 40–50 meters can be noted.

The Lower Pseudoschwagerina Formation is a predominantly calcareous succession with a 1–2 meters thick quartzose conglomerate at the base and intercalations of dark, quartzose sandstones (up to 1 meter thick) within the calcareous sequence.

The limestones can be subdivided into two units. The macroscopically massive, light grey limestones are composed of mudstones, containing fusulinids, shell detritus and occasionally pellets and intraclasts. Furthermore, calcareous algae (e. g. *Epimastopora alpina* KOCHANSKY & HERAK, *Eugonophyllum johnsoni* KONISHI & WRAY) and smaller foraminifera are abundant.

These massive limestones are overlain by well bedded dark grey limestones, built up by detrital packstones. The bioclasts are calcareous algae, fusulinids, gastropods and echinoderms. Furthermore, oncoids and intraclasts occur (Fig. 4).

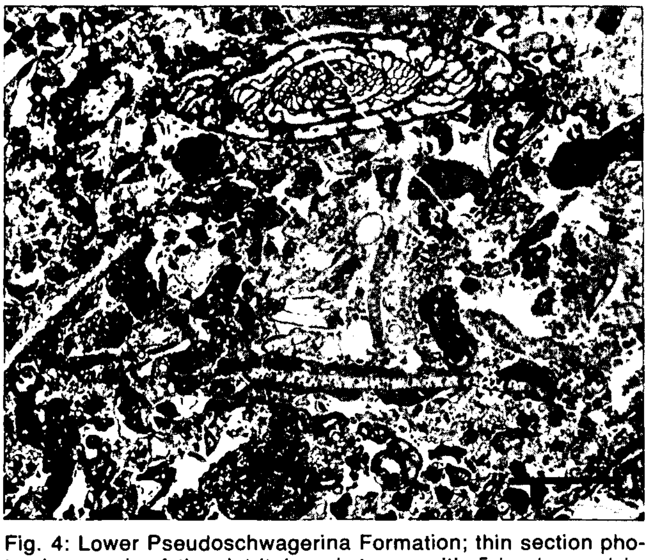

Fig. 4: Lower Pseudoschwagerina Formation; thin section photomicrograph of the detrital packstones with *Epimastopora alpina* KOCHANSKY & WRAY, fusulinids and abundant smaller foraminifera and Cyanophyta; west wall of the Schulter, 1900 m, scale bar 2 mm.

2.4. Grenzland Formation (Formazione di Val Dolce)

Similar to the Auernig Group, the bulk of this Middle Asselian succession is developed as argillites, siltstones, sandstones and conglomerates. Rarely calcareous lenses are intercalated, mostly developed as

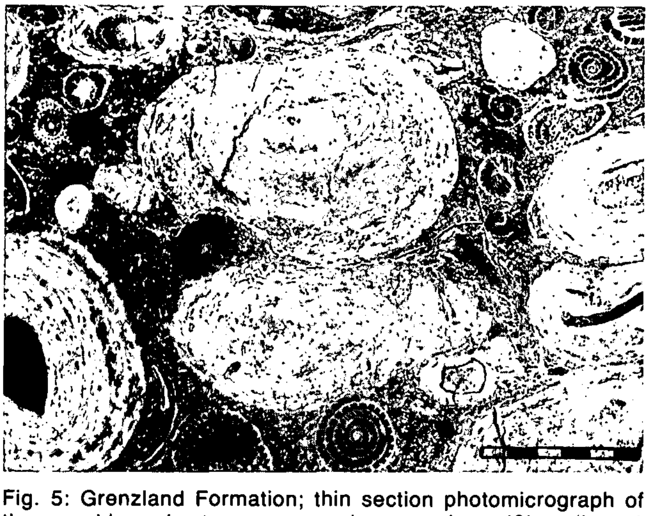

Fig. 5: Grenzland Formation; thin section photomicrograph of the oncoid wackestones; cyanophycean algae (*Girvanella* sp.) form irregular concentric crusts around foraminifera tests, calcareous algae or bivalves; western part of the Sella di Val Dolce, 1850 m, scale bar 10 mm.

- oncoid-wackestones or oncoid-grainstones with abundant phylloid algae and smaller foraminifera. The Phylloid algae, *Dasycladaceae*, fusulinids, echinoderm debris and shell debris are encrusted with blue-green algae. The components are redeposited (roundness, borings), winnowing is moderate to complete (Fig. 5).
- wackestones with high amount of insoluble residues. Calcareous algae are rare, floated fusulinids, bivalves, and brachiopods are present, that means, an enlarged terrigenous influx effects the reduction of bioclastic contents.
- bioclastic wackestones with abundant sessile foraminifera. The bioassociations are low diverse, e. g., *Ramovsia*-wackestones with rockforming occurrence of *Ramovsia limes* KOCHANSKY-DEVIDE, a problematic foraminifer or algae (Fig. 6).

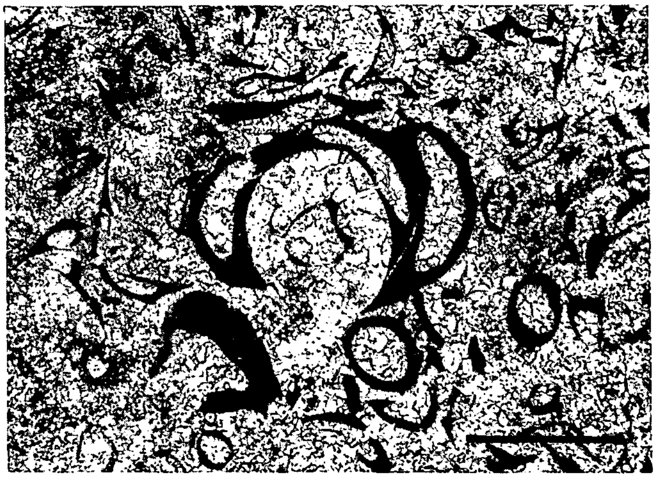

Fig. 6: Grenzland Formation; thin section photomicrograph of the *Ramovsia*-wackestone with transversal sections of *Ramovsia limes*; Sella di Val Dolce, scale bar 3 mm.

The composition of the calcareous algae and the microproblematica can be seen in Tab. 3.

The Grenzland Formation is well exposed in the south of the Schulter and at the Rattendorfer Sattel (Sella di Val Dolce), defined as type section. Here the thickness reaches about 125 meters. The sequences exposed on the Ringmauer and Cima di Lanza were considered as Grenzland Formation by FELSER & SEELMAIER (1936). HOMANN (1969), however, interpreted these sequences as clastic intercalations of the Lower Pseudoschwagerina Formation.

2.5. Upper Pseudoschwagerina Formation (Formazione superiore di Pseudoschwagerina)

In the realm of the Trogkofel massif a complete succession of these dark, well bedded limestones with rare clastic intercalations is not exposed. The oncosparites, biomicrites and the partly dolomitized biosparites or biopelsparites include a similar fauna described in the subjacent formations. Fusulinids and echinoderm debris sometimes are accumulated in packstones. According to FLÜGEL (1971) the thickness amounts to 175 meters.

2.6. Trogkofel Formation (Formazione del Trogkofel)

In the S' wall of the Trogkofel massif, the Upper Pseudoschwagerina Formation grades into light grey or red, firstly coarse bedded, then massive limestones of the Sakmarian Trogkofel Formation. Predominantly it is constituted by bindstones with *Tubiphytes obscurus* MASLOV, *Archaeolithoporella hidensis* ENDO and bryozoa. Partly accumulations of fusulinids or echinoderm debris occur. Furthermore, four horizons of internal calcareous breccias are intercalated, which wedge out in N' direction.

In the Trogkofel massif the thickness diminishes from 330 meters in the NE to approximately 170 meters in the SW. The Trogkofel Formation would wedge out within 1000 meters in the SW (BUGGISCH & FLÜGEL, 1980).

2.7. Tarvis Breccia) (Breccia di Tarvisio)

The Tarvis Breccia, uppermost Lower Permian in age, crops out on the Trogkofel massif, overlying the Trogkofel Formation with an erosional unconformity. Here the Tarvis Breccia is predominantly composed of angular to subangular grey dolomitic clasts, embedded in a red or yellow dolomitic matrix. Furthermore, the Tarvis Breccia is exposed SW' of the 130° striking reverse fault N' of the Cra. Valberdat alta and Pso. del Cason di Lanza. Here the Tarvis Breccia follows to the "Formazione di Meledis" (Auernig Group) (VAI et al., 1980; tab. 2). Besides the light, fine grained, calcareous or dolomitic pebbles, subangular monocrystalline quartz pebbles also are common. The thickness here amounts 0,5–2 meters, on the Trogkofel massif it reaches at least 20 meters.

2.8. Gröden Formation (Formazione della Val Gardena)

The Tarvis Breccia vertically passes into red coloured siltstones and argillites of the Gröden Formation (Middle Permian). The well bedded siltstones are predominantly quartzose with little feldspar contents. Partly resedimented argillitic components are abundant. The siltstones alternate or laterally interfinger with dark red argillites, up to several meters thick. In the investigated area the thickness amounts to at least 180 meters.

2.9. Bellerophon Formation (Formazione a Bellerophon)

The blocks wedged between Auernig Group and Gröden Formation in the SW of the investigated area are built up by the Upper Permian Bellerophon Formation. It is developed as thin bedded yellow or white micritic limestones or dolomites.

S' of the Cra. Cordin grande, at the top of the Bellerophon Formation a sequence of red or grey quartzose siltstones and conglomerates, about 5 meters thick, composed of micritic limestone pebbles with sparite filled cracks is exposed. It is not possible to decide, whether this sequence is part of the Bellerophon Formation or of the lowermost Triassic.

3. Palaeoenvironmental and palaeostructural investigations

The sedimentation of the Auernig Group is preceded by the deposition of the Lower Carboniferous Hochwipfel flysch and intense tectonic activities (Westfalian D, "Asturian phase"), attributed to the ceasing Variscan orogeny (FENNINGER et al., 1976). After the deposition of coarse conglomerates at the base of the Auernig Group, the clastic series with embedded calcareous lenses follow, characterized as molasse of the Variscan orogeny (FENNINGER & SCHÖNLAUB, 1972). The alternation of "terrestrial" (beds with plant detritus) and "marine" beds (calcareous lenses) is attributed to the "Auernig Rhythm", which expresses "repeated transgressions and regressions, differing intensity of aqueous transport, the clastic influx from the source area and redeposition along the coast" (KAHLER, 1955, p. 179).

According to field evidence and sedimentological investigations, however, the plant detritus and bioclasts embedded in the argillites and siltstones cannot be used as diagnostic feature for the sedimentary environment, because they are exclusively redeposited material. Furthermore, within the Auernig Group there is no evidence to be found supporting subaerial exposure. Therefore, referring to the trans- and regressions an "Auernig Rhythm" sensu KAHLER (1955) cannot be confirmed.

The sedimentary environment of the Auernig Group is to be deduced from the calcareous lenses inserted in the clastic sequences. The coarse bedding and the discontinous lateral appearance of the limestone lenses, together with the microfacies patterns and the included encrusting and sediment-fixing organisms support an interpretation of algal-mud mounds. They can be differenciated by the two predominating microfacies types, according to TOMMEY et al. (1977):

- the core of the algal-mud mound is constituted of massive, micritic, low diverse algal-wackestones with a subordinated marine fauna. The sedimentation area is situated in a low energetic, shallow-marine environment with temporary reduced water circulation.
- the bedded bioclastic *Cyanophyceae*-bindstones and oncoid-grainstones correspond to the flanking and capping beds. A higher algal diversity and a rich marine fauna is common. The occurrence of bioclasts indicate higher water energy of the intertidal zone.

The growth of the mud mounds is possible to a maximum water depth of several tens of meters. It started on subtidal shoals of a shallow-marine environment,

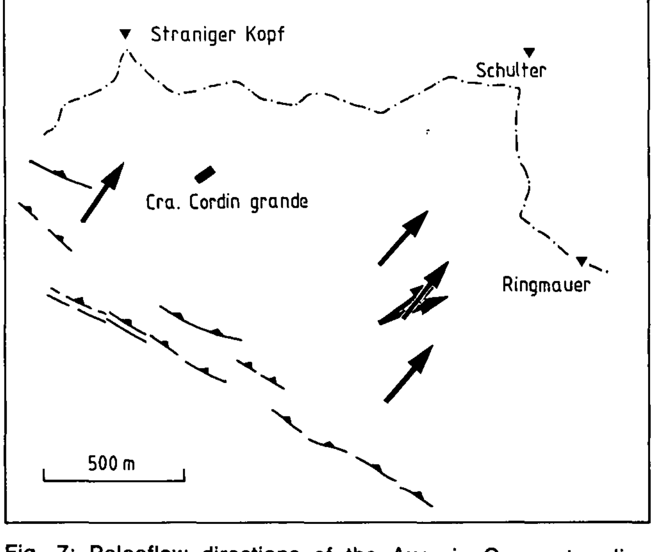

Fig. 7: Paleoflow directions of the Auernig Group, trending normal to the reverse fault. The beginning of the arrow indicates the situation of the outcrop.

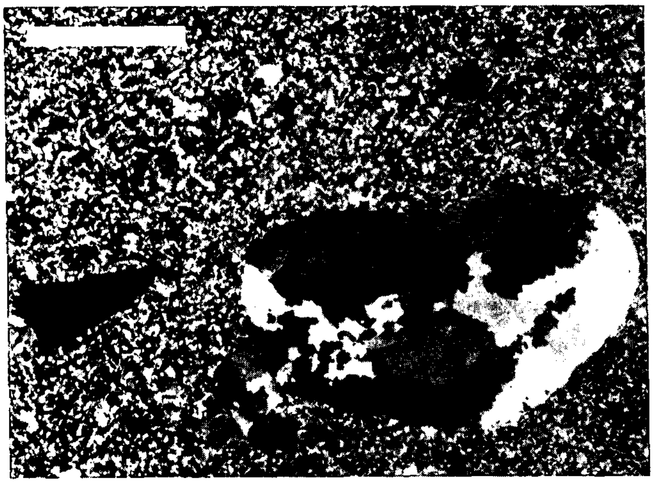

Fig. 8: Auernig Group; thin section photomicrograph of a polycrystalline quartz pebble, further explanation in the text; extreme E of the investigated area, 1900 m, scale bar 5 mm, crossed polars.

and it was stopped in the intertidal zone by the capping beds.

The clastic series of the Auernig Group were derived from a source area located to the SW. This is indicated by cross-bedding, exhibiting a principal palaeoflow direction to the NE (Fig. 7). Evidence of the composition of this source area is obtained by the examination of the recrystallization grains constructing the predominantly polycrystalline quartz pebbles of the conglomerates (Fig. 8). It is possible to show a two stage deformation history. The first stage with high metamorphic temperatures enabled the construction of large recrystallization grains. The undulose extinction and the sutured grain boundaries were caused by a second, weaker deformation. According to examinations of heavy minerals by FENNINGER & STATTEGGER (1977), however, evidence of plutonic supplying areas also exist.

In the basin following this source area to the NE, a low relief must be presumed, so that the further transport from the coast to shallow water areas of the basin was possible. This relief, also confirmed by slumping phenomena, is believed to have persisted due to subsidence and presumably synsedimentary tectonic activities, which were counteracting the filling up.

The clastic material was transported into the basin within submarine channels, documented by the intercalations with trough cross-bedding and erosive base, or it was deposited with high and transient sedimentation rates, testified in the large pebbles embedded at the base of siltstone layers, scours on top surfaces, thin lamination in fine clastic beds, occasionally graded beds or layers with small scale cross-bedding and the horizons enriched with bioclasts. These sediments can be interpreted as mass flow deposits.

The conglomerates with their massive and uniform aspect, with no grading or sorting, probably also represent a single event of deposition and can be considered as debris or grain flow deposits. Similar proceedings of sedimentation are described by NEMEC et al. (1980) in fan-delta slopes.

This kind of sedimentation prevents the growth of algal-mud mounds; a temporal separation of carbonate and clastic sedimentation is necessary. Therefore, the supply of clastic sediments is believed to be connected with increase of subsidence of the basin, and presumably with synsedimentary tectonic movements. Consequently a "kalkreiche Schichtgruppe" sensu HERITSCH et al. (1934) corresponds to low rate of subsidence and reduced clastic influx, while in the "kalkarme Schichtgruppe" as a consequence of strong subsidence the algal-mud mounds more often were suffocated by clastic material and only occur subordinated.

The Lower Pseudoschwagerina Formation was deposited in a sedimentation area similar to that of the Auernig Group, indicated by the massive mudstones, showing microfacies patterns, which correspond to those of the Auernig Group. Partly, these limestones are developed as algal-mud mounds, too (HOMANN, 1969), e. g. in the west wall of the Schulter. Here massive limestones laterally grade into well bedded packstones (Fig. 9).

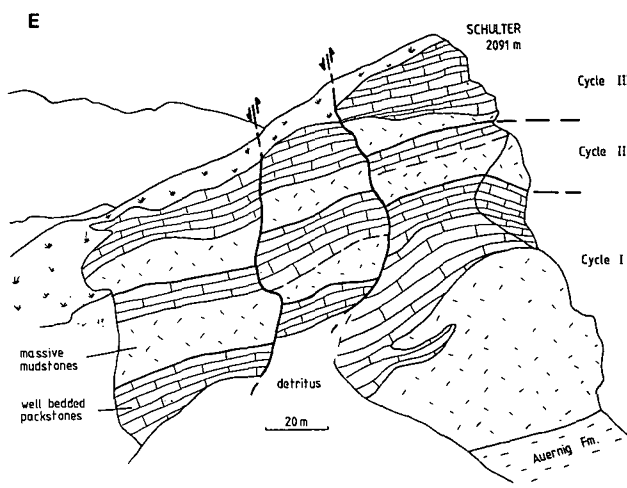

Fig. 9: West wall of the Schulter with three depositional cycles of the Lower Pseudoschwagerina Formation and the interfingering of the well bedded detrital packstones and the massive mudstones.

The alternation between clastic and calcareous sedimentation described in the Auernig Group occurs here as well, documented in four depositional cycles of the Lower Pseudoschwagerina Formation. According to HOMANN (1969) the cycles are caused by sea level alterations and are composed of a transgressive clastic horizon, followed by the massive limestones (culmination) and the well bedded regressive limestones. However, the terrigenous influx at the base of each cycle can also be explained, in analogy to the Auernig Group, with an increase of subsidence.

Evidence of further analogies to the Auernig Group is the increasing thickness of the Lower Pseudoschwagerina Formation to the NE, visible in the sections of Pso. del Cason di Lanza, Pian di Lanza and Ringmauer/ Trogkofel (Fig. 10). This augmentation results from the increase of subsidence in NE' direction, already testified by the Upper Carboniferous palaeoflow direction.

During the sedimentation of the Grenzland Formation the clastic influx predominates again. According to KAHLER (1955) the "Auernig Rhythm" occurs here, too. The calcareous lenses of the Grenzland Formation indicate a sedimentation area with intertidal to subtidal conditions. Oncoid bearing limestones document a milieu of high water energy. The bioclasts are encrusted by *Cyanophyceae* and sessile foraminifera during reduced clastic influx. The bioclastic wackestones point to a intertidal, moderate energy environment with sea gras meadows. Sessile foraminifera and *Ramovsia* presumably grew on not fossilized sea gras (sparitic cavity fillings within *Ra-*

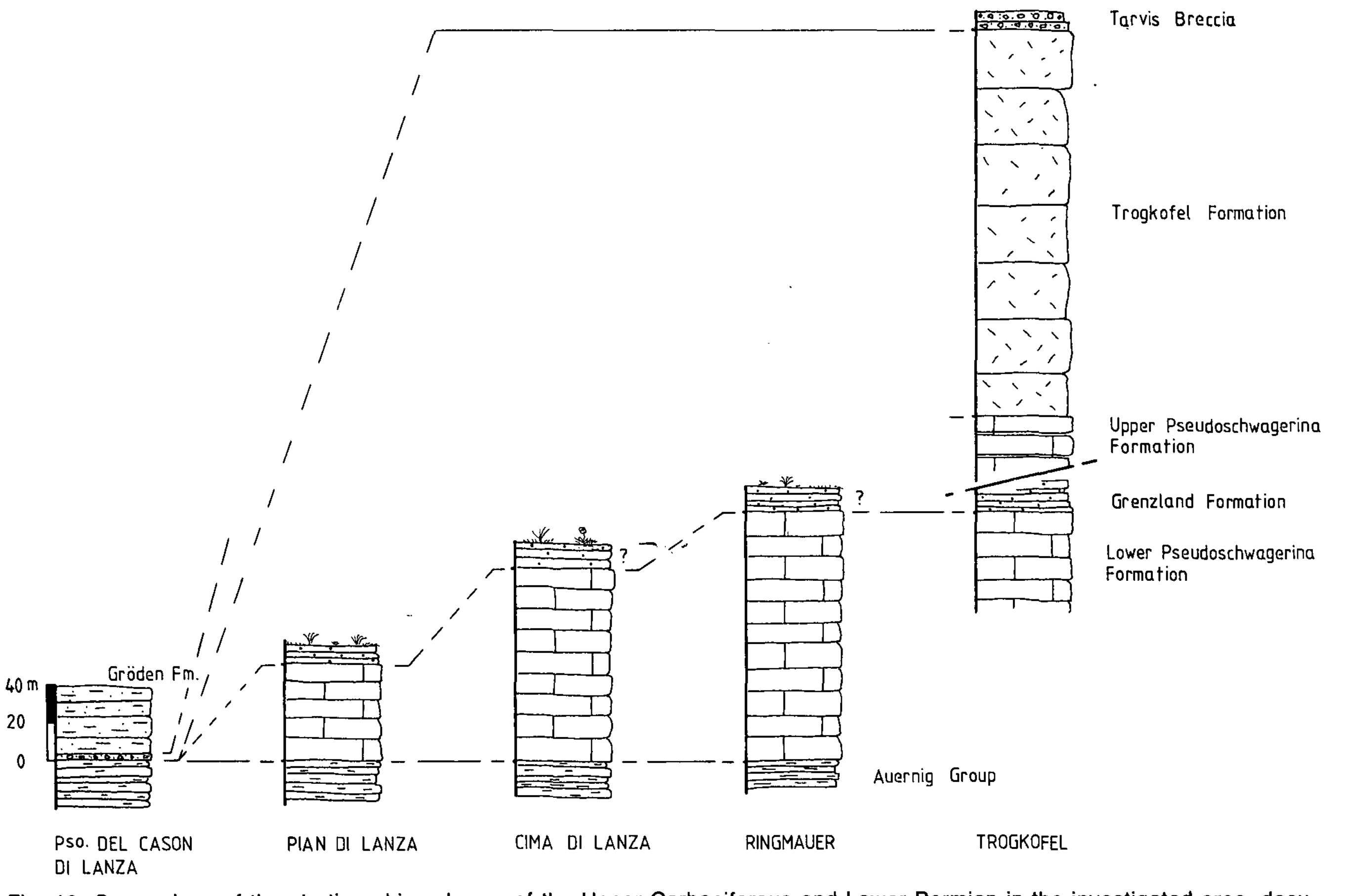

Fig. 10: Comparison of the stratigraphic columns of the Upper Carboniferous and Lower Permian in the investigated area, documenting the changing thickness of the Lower Pseudoschwagerina Formation.

movsia) and were floated to siltites after the decay of the substratum.

The Grenzland Formation corresponds, together with the E–W-striking coast line (BUGGISCH et al., 1976) to a facies pattern which is similar to that of the Auernig Group. However, in the shallow marine environment of algal mats and sea gras meadows, influenced by currents and waves, the depth was not sufficient for the construction of algal-mud mounds.

The clastic influence is diminuated again during the deposition of the Upper Pseudoschwagerina Formation. According to FLÜGEL (1971), it is deposited on a subtidal outer-shelf platform. The fauna documents the removal of the sedimentation area to regions, which were more and more withdrawn from the coast. The increasing distance could be the reason for decreasing clastic contents.

In the Trogkofel Formation this tendency continues. These deposits are characterized by FLÜGEL (1981) as a stratigraphic reef, situated near the shelf edge and constructed by encrusting organisms and crusts of submarine syndepositional cements. The decrease of thickness in NE' direction, according to BUGGISCH et al. (1976), is attributed to the synsedimentary destruction of the Sakmarian carbonate platform. This again corresponds to differences in subsidence, a tendency, which can be noted since the deposition of the Auernig Group.

In the uppermost Lower Permian the Tarvis Breccia follows in the NE of the investigated area to a complete stratigraphic succession (Trogkofel massif), while in SW' direction the sedimentation is reduced (Pian di Lanza) or presumably completly missing (Pso. del Cason di Lanza) (Fig. 10), as in the SW of the 130° striking reverse fault N' Cra. Valberdat alta and Pso. del Cason di Lanza (Fig. 11).

KAHLER (1980) attributes this stratigraphic lacuna at the base of the Tarvis Breccia and the origin of this breccia to tectonic movements and erosion in the uppermost Lower Permian, defined as "Saalian phase". This phase, however, would require an enormous amount of erosion within a very short time (the thickness of the missing series reaches up to 800 meters in the NE of the investigated area!).

However, subaerial erosion which preceded the deposition of the Tarvis Breccia cannot be denied completely, because of its erosive base and because of the freshwater limestones partly forming the matrix of the Tarvis Breccia (BUGGISCH & FLÜGEL, 1980, p. 46).

The stratigraphic lacuna here is attributed to an increasing subsidence in NE' direction, outlined during the Upper Carboniferous and Lower Permian by principal palaeoflow directions and differences in thicknesses. This interpretation is supported by BUGGISCH et al. (1976), assuming for the Asselian and Sakmarian an E–W-striking coast line with the shelf cut off in the north. A similar interpretation had already been given by HERITSCH (1936), who considered the region of the Pso. del Cason di Lanza as a topographic high, causing the lacuna.

The subsidence of the basin presumably was connected with synsedimentary faults, an assumption based on the evidence of the Upper Carboniferous palaeoflow directions, trending normal to the 130° striking reverse fault N' Cra. Valberdat alta and Pso. del Cason di Lanza (Fig. 1, 7). Moreover, this fault is limiting the area

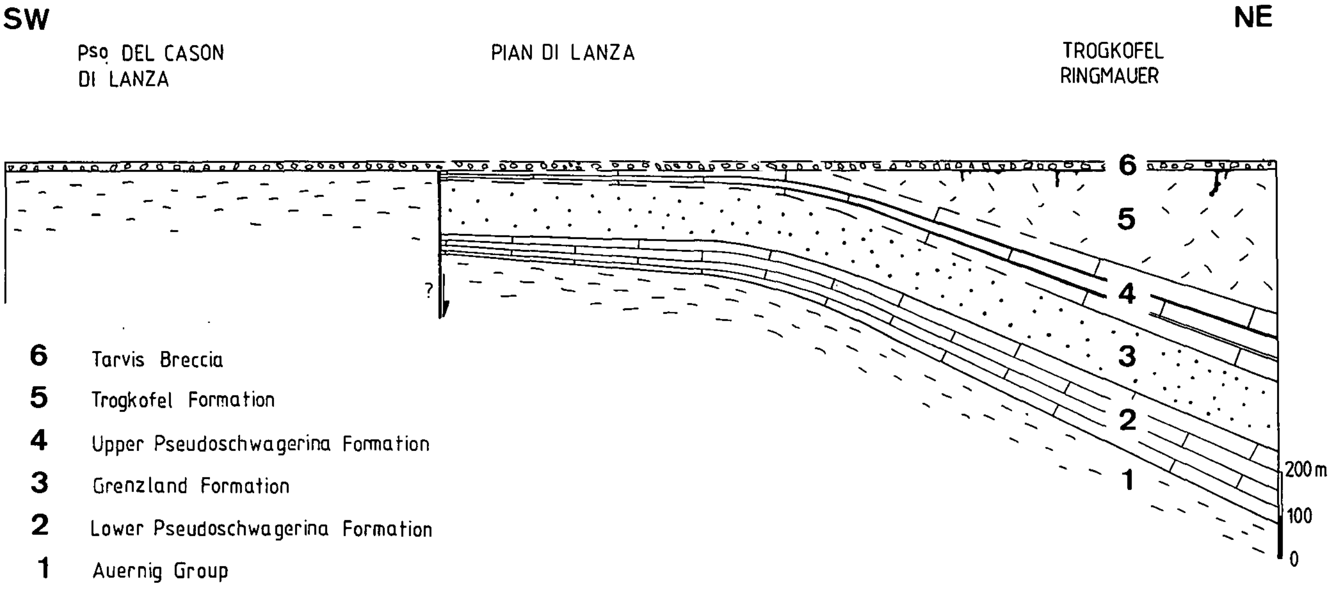

Fig. 11: Schematic cross-section showing the presumed sedimentary evolution during the Upper Carboniferous and Lower Permian.

without lacuna from that with discontinous sedimentation. Alpidic movements, however, reactivated this fault and complicated the recognition of synsedimentary tectonics.

The regression of the Tarvis Breccia is terminated by the marine Gröden Formation and Bellerophon Formation. According to BUGGISCH et al. (1976) these deposits introduce the alpine cycle.

4. Tectonics

In the investigated area three alpidic systems of faults with different directions and ages are to be differenciated (Fig. 1). Mostly the determination of dislocation is not possible.

To the oldest faults belong the N dipping, approximately 130° striking fault, limiting the Devonian shallow water limestones to the N, and the parallel running reverse fault N' Cra. Valberdat alta and Pso. del Cason di Lanza. Presumably these faults had already been active during the "Asturian phase" (Westfalian D) (SELLI, 1963) and during the Lower Permian, favouring differences in subsidence, which caused the lacuna between Auernig Group and Tarvis Breccia.

These two faults are cut by a second system with mostly N–S-striking, subvertical faults with moderate dislocations (about 10 meters), which often occur in the realm of the Cra. Valberdat alta and Pian di Lanza.

The youngest faults are E–W-running, N or S dipping faults, dislocating the Lower Pseudoschwagerina Formation in the north of the investigated area and S' of the Cima di Lanza. They can also be observed in the region S' and SE' of the Trogkofel massif. These faults presumably resulted in connection with the origin of the Gailtal line.

5. Conclusions

1. The sedimentation area of the Auernig Group is characterized by a subtidal, low energy marine environment. An "Auernig Rhythm" sensu KAHLER (1955) cannot be confirmed.
2. The clastic material of the Auernig Group is derived from a source area located to the SW.
3. During the Upper Carboniferous, deposition of clastic material respectively the growth of algal-mud mounds is due to the subsidence of the basin.
4. During the Lower Permian differences in thickness and the origin of the lacuna in the SW is to attribute to increasing subsidence in NE' direction.

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