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The type-section of the Gutenstein Formation at Gutenstein revisited (Anisian, Northern Calcareous Alps, Lower Austria): Lithostratigraphy, biostratigraphy and regional overview

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Abstract

New biostratigraphic data derived from the stratotype of the Gutenstein Formation at the village Gutenstein (Lower Austria) help to solve some long-standing problems about the stratigraphy of the Anisian stage within the eastern part of the Northern Calcareous Alps. At Gutenstein, the lower lithostratigraphic boundary of the Anisian Gutenstein Formation to the underlying lower Anisian Reichenhall Formation is defined, assuming a normal stratigraphic contact of the Reichenhall Formation to the underlying Werfen Formation and to the overlying Gutenstein Formation. Microfacial data confirm the sedimentary origin of the rauwackes of the Reichenhall Formation. A detailed lithostratigraphic and facies-oriented definition of the Gutenstein Formation includes prevailing thin and planar-bedded, black colored, sometimes fine-bedded limestone (rarely dolostone) and radiolarian (calcispheres) bearing, black colored mud- to wackestone, mostly containing some fine crinoid debris. Upsection, a quick change to an upper (Pelsonian) member of the Gutenstein Formation with nodular bedding planes and brachiopod-, crinoid-, conodont- and ammonite accumulations is presented. The general depositional environment of the Gutenstein Formation is interpreted as a dysoxic outer carbonate ramp deposit, with a shallowing upward trend to rather thick-bedded mid- and inner carbonate ramp settings of the Annaberg- and Steinalm formations. The approximate interval of the Anisian/Ladinian boundary within the type-section of Gutenstein is determined with help of new fossil findings such as dasycladalean green-algae. Based on distinct lithological differences on a regional scale, which occur in thick basinal stratigraphic successions within the Gutenstein Formation like at Großreifling (Styria, Bajuvaric Nappe System), at Innerfahrafeld (elevation Fuchsriegel, Lower Austria) and on mount Kasberg at Grünau (Upper Austria, Tirolic Nappe System), a subdivision of the Gutenstein Formation into a lower *Gutenstein Member*, and an upper *Kasberg Member* (= *Upper Gutenstein Formation*), is proposed herein. The lower member corresponds to the black, thin- and planar-bedded interval, whereas the Kasberg Member is characterized by nodular bedding planes, greater bed thicknesses and higher fossil content.

1. Introduction

The Northern Calcareous Alps (NCA), a prominent part of the East Alpine fold-and-thrust belt in Austria, comprise a wealth of classical Mesozoic stratigraphic locations such as the original type-sections for the Anisian, termed after the Latin name of the Enns river in Styria and Upper Austria by Mojsisovics et al. (1895). Despite the existence of some classical fossil assemblages, of numerous well-known outcrops and a wealth of publications (see overview by Tollmann, 1976a; Krystyn and Lein, 1996), the Anisian and Ladinian lithostratigraphic units of the NCA and their relation and correlation to different sections in-side and outside of the Eastern Alps are still in discussion and clear-cut lithostratigraphic definitions are pending. Especially the ages, geometries and facies relationships of Middle Triassic carbonate platforms and ramps to the adjacent slope and basinal units such as the Gutenstein Formation, Annaberg Formation, Steinalm Formation, Reifling- and Raming formations (defined in part for the first time by Tollmann, 1966) are strongly debated due to their isolation and destruction by strong, polyphase alpine deformation.

The classical reports on the definition of the Gutenstein Formation (first described by Hauer, 1853) at its type-locality in the surroundings of the village Gutenstein (Lower Austria), published by Flügel and Kirchmayer (1963) and Summesberger and Wagner (1971), have left several open questions, which need to be resolved: (1) The exact localization of the fossil assemblage termed "*Reichenhaller Fauna*", discovered and first described already by Bittner (1897) from strata underlying the Gutenstein Formation, and its stratigraphic relationship to the so-called "*Reichenhall Rauwacke*" in between. (2) The differently reported thicknesses of the Gutenstein Formation of only 30 m at its type-locality (Summesberger and Wagner, 1971, profile sheet) or of 100–150 m within the same profile section (Summesberger, 1966). (3) The apparently insufficient differentiation between the predominantly thin-bedded limestone beds of the Gutenstein Formation and the thick-bedded or massive strata above and below it, which had resulted in an incorrectly defined lithostratigraphy. (4) The flora of dasycladalean green algae, described by Pia (1912, 1927) and Flügel and Kirchmayer (1963) from the type-area, which may or may not be assigned to individual horizons within the stratigraphic succession of Gutenstein. Closely related to questions (3) and (4) is the recently proposed concept of the existence of an exclusively shallow-marine depositional environment, extending continuously from the middle Anisian (Pelsonian) up to the earliest Carnian (Moser, 2019a), without any intercalation of intervening basinal deposits like that of the pelagic Reifling Formation or allodapic Raming Formation within the section at Gutenstein. In this study, based on old and new paleontological and sedimentological data, the evidences for the depositional environment of the Gutenstein Formation are discussed in detail. Finally, a proposal is made for a lithostratigraphically and facially founded subdivision of the Gutenstein Formation into a lower and an upper portion, corresponding to two different lithostratigraphic members.

2. Geological Setting

The thrust nappe stack of the NCA (Tollmann, 1976b; Mandl, 2000) forms part of the Eastern Alps and was originally situated at the northwestern edge of the Neo-Tethys ocean (Fig. 1). In Triassic times, the NCA were part of a wide low-latitude continental shelf, ranging from the epicontinental marginal sea ("*Germanic Triassic*", "*Muschelkalkmeer*") in the north-west to a carbonate dominated shallow-water shelf area including large reefal and lagoonal systems to the south-east (Ott, 1972; Wolff, 1973; Tollmann, 1976a; Brandner and Resch, 1981; Lein, 1987; Rüffer, 1995; Mandl, 2000; Strauss et al., 2023). During the Early Mesozoic, this shelf area bordered the extensive Tethyan equatorial gulf to the east of the supercontinent Pangaea. Afterwards, during the Early Jurassic, it transformed into a part of the Adriatic plate, which had been separated from the Laurasian subcontinent by the Penninic-Liguric oceanic realm ("Alpine Tethys") since Middle to Late Jurassic times (Faupl and Wagreich, 2000). This separation started about the same time, as the northern part of the Atlantic began to open (Frisch et al., 2011). Starting from the Early Cretaceous onwards, the NCA were sheared off their Austroalpine polymetamorphic crystalline basement and thrusted as nappe stack northwest- to northward, mainly without suffering any increased metamorphosis (Mandl, 2000). The main tectonic units (nappes) within the studied area (Fig. 2) were firstly formed during the late Early Cretaceous, including in the eastern Northern Calcareous Alps the mega-tectonic unit of the Tirolic Ötscher Nappe System (Kober, 1912; Tollmann, 1967), which is subdivided from north to south into the Reisalpen Nappe, Unterberg Nappe and Göller Nappe (Spitz, 1919; Spengler, 1928; Tollmann, 1967), and had been tectonically reactivated after the deposition of the Cretaceous-Paleogene Gosau Group during the Paleogene and Miocene (Wagreich, 1995).

Within the NCA, the Triassic stratigraphic succession (see Fig. 3) started during the Lower Triassic epoch with green and violet shales, silt- and quarzitic sandstones of the Werfen Formation (Mostler and Rossner, 1984). From the Anisian (early Middle Triassic) onwards, deposition of carbonates began with the mostly evaporitic, shallow marine, dolomitic-calcareous brecciated Reichenhall Formation (Schenk, 1967). This formation, including rauwackes, forms the stratigraphic base of the lower- to middle Anisian Gutenstein Formation (Flügel and Kirchmayer, 1963), the latter being widespread within the eastern and central part of the NCA (Bechstädt and Mostler, 1974). During the Anisian, the oxygen-poor and bituminous facies had been widely distributed along the shallow marginal sea of Europe and extended from the epicontinental sea of Germany, Poland and Spain to the South- and Austroalpine domain as well as to the Inner West Carpathians and the Mid-Hungarian tectonic units. On top of the Gutenstein Formation, transitional beds are present either into the shallow marine carbonates of the middle Anisian (Pelsonian) Annaberg- and Steinalm formations (Tollmann, 1966; Pia, 1924; Moser and Piros, 2021) or into the deeper marine pelagic limestones of the Reifling- and Raming formations, the latter comprising the upper Anisian (Illyrian) and different parts of the Ladinian (Arthaber, 1896; Gessner, 1963; Lein, 1989; Velledits et al, 2007). The onset of the Reifling Formation on top of the Steinalm- and Gutenstein formations has been designated by Schlager and Schöllnberger (1974) as "*Rei-*

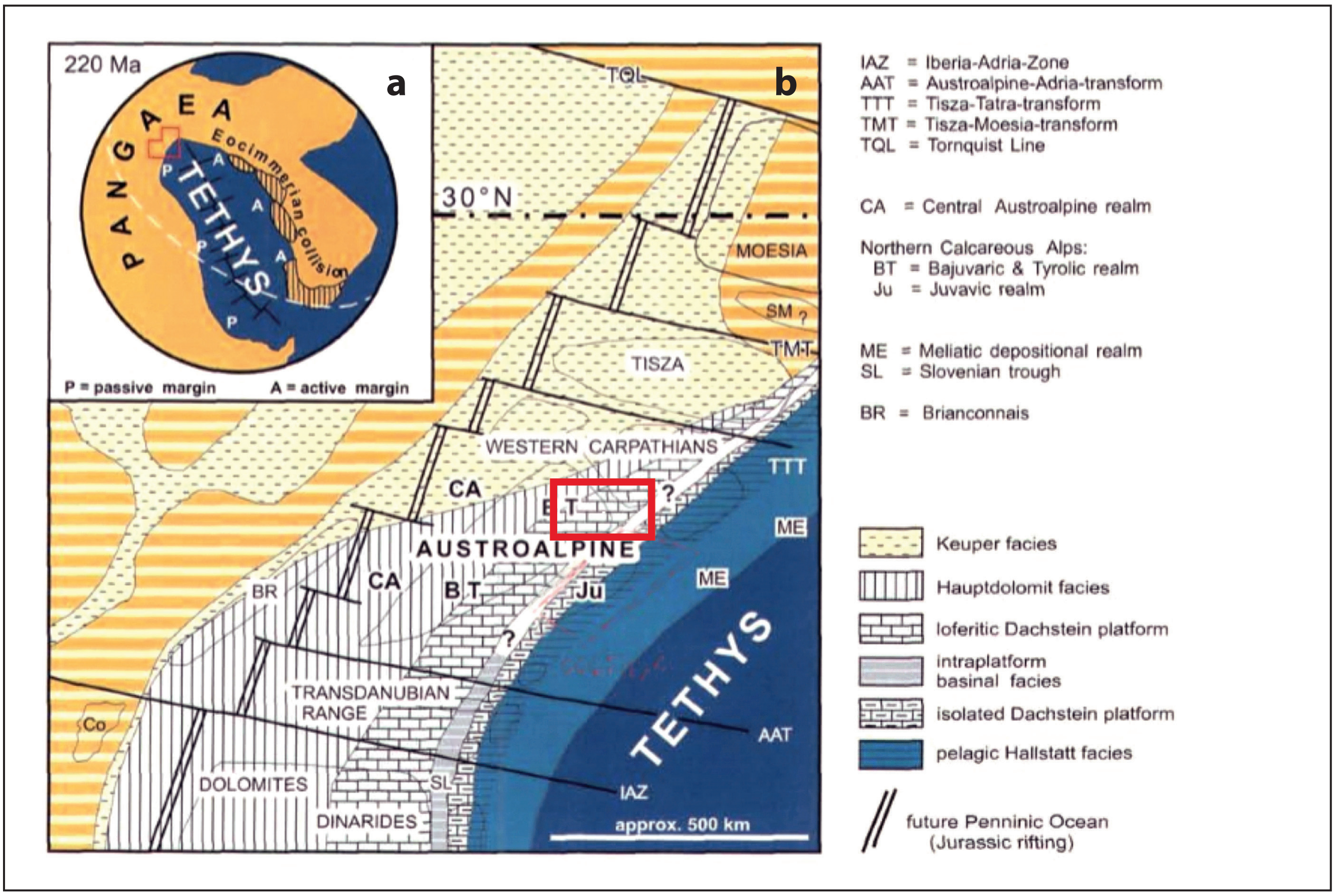

Figure 1: The paleogeographic position of the Austroalpine Triassic units in the northwestern Tethyan gulf (from: Mandl, 2000: Fig. 2, with permission from the publisher).

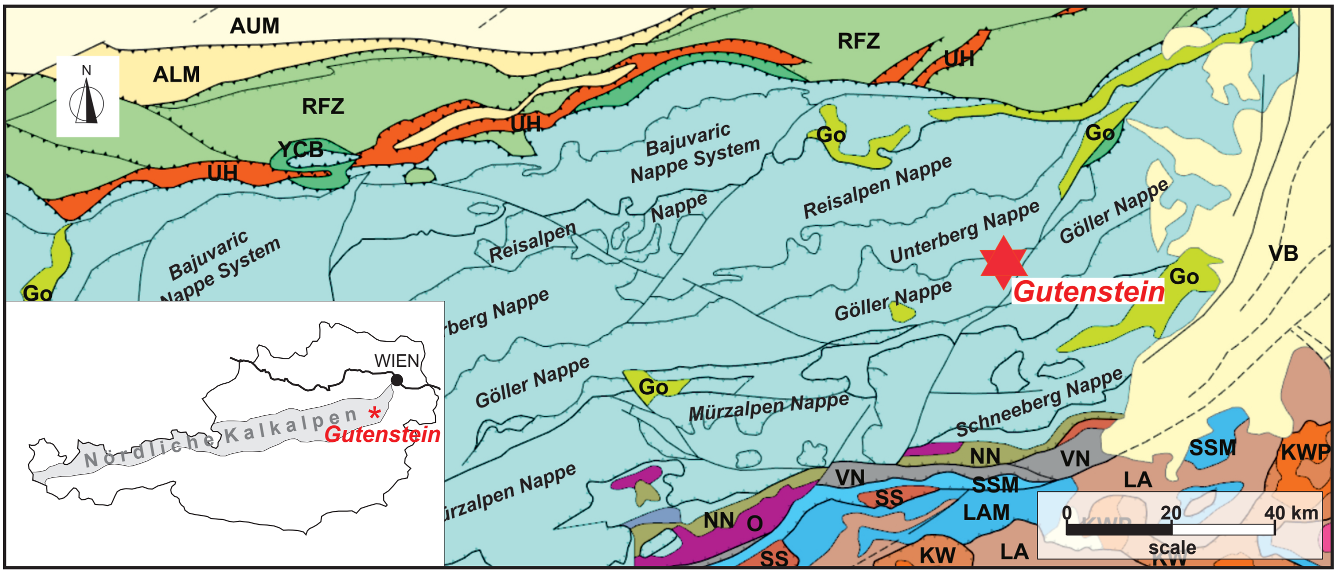

Figure 2: Tectonic overview of the eastern part of NCA (light blue) and adjacent units, showing the Bajuvaric Nappe System in the north, the Tirolic or Ötscher Nappe System (=Reisalpen Nappe, Unterberg Nappe, Göller Nappe) in the middle part of the NCA, and the Juvavic Nappe System (= Mürzalpen- and Schneeberg nappes) in the south. Go = Gosau Group, NN = Noric Nappe, O = Ordovician Blasseneck Porphyr, VN = Veitsch Nappe, KW = Koralpe-Wölz Nappe System, KWP = Koralpe-Wölz Nappe System – Pretul Orthogneis, SS = Silvretta-Seckau Nappe System, SSM = Silvretta-Seckau Nappe System – Mesozoic cover, LA = Lower Austroalpine, LAM = Lower Austroalpine – Mesozoic cover, YCB = Ybbsitz Klippen Belt, RFZ = Rhenodanubic Flysch Zone, UH = Ultrahelvetic, ALM = Allochthon Molasse; AUM = Autochthon Molasse, VB = Vienna Basin (modified after the base map: Multithematische Geologische Karte von Österreich 1:1 000 000, Geological Survey of Austria).

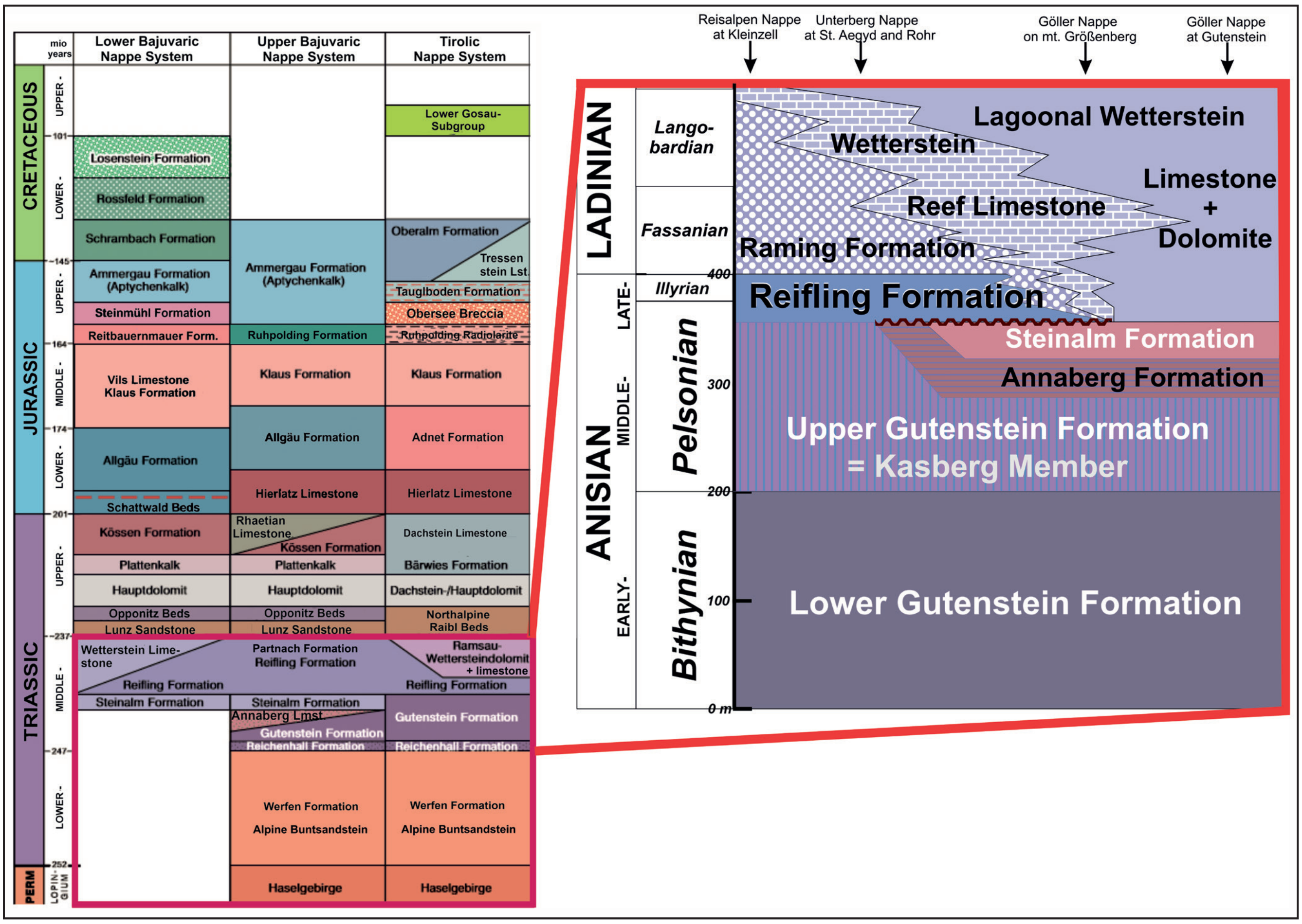

Figure 3: The position of the Middle Triassic succession at the type-locality in Gutenstein (Lower Austria) within the stratigraphic chart of the NCA (Left table from: Moser and Schnabel, 2019, Tab. 6) and the paleogeographic/stratigraphic position of the profile sections of Gutenstein, Größenberg, St. Aegyd/Neuwald, Rohr i. Geb. and Kleinzell within the Tirolic Nappe System of Lower Austria.

fling event" and is uniformly developed within many Austroalpine, Inner Carpathian and Mid-Hungarian tectonic units. Within the higher tectonic units to the south (Tirolic Göller Nappe, Juvavic Mürzalpen Nappe, see Fig. 2), the Reifling Formation is (partly or completely) substituted by thick carbonate platform deposits of the Wetterstein limestone and Wetterstein dolomite (Tollmann, 1976a) or by the allodapic Grafensteig limestone (Hohenegger and Lein, 1977).

The depositional area of the Gutenstein Formation within the eastern and central part of the NCA is mainly located within the broad tectonic unit of the Tirolic-Noric Nappe System and often occupies the basal sequence at the front of each nappe. In most cases the Gutenstein Formation occurs here as the lowest part of nearly complete Middle Triassic stratigraphic successions, which have mostly been preserved despite tectonic truncation. The basal Werfen Formation and the Late Permian Haselgebirge were lateron sheared off during the initial tectonic movements and squeezed into thrust- and strike-slip faults by salt-tectonics (Strauss et al., 2018). At its type locality in Gutenstein, the Gutenstein Formation is part of the Tirolic Göller Nappe and forms on top of the Reichenhall- and Werfen Formation a NE-SW trending, parallel to the nappe boundary striking belt of outcrops.

According to Moser and Moshammer (2018), the Gutenstein Formation itself can be defined as mainly thin and planar-bedded, black-colored and fine-grained limestone, deposited in moderate water-depth and poor in fossils like radiolarians (calcispheres), crinoids, ammonites, brachiopods and conodonts. In some regions, the 300–400 m thick Gutenstein Formation can be subdivided into two distinct intervals of lower and middle Anisian age.

Chronostratigraphically, the Anisian Stage is subdivided into the lower Anisian (Aegaen and Bithynian), middle Anisian (Pelsonian) and upper Anisian (Illyrian) Substage. Whilst the number of early Anisian index fossils is very low, the middle Anisian Substage (Pelsonian) can be subdivided into the *Balatonicus*-, *Zoldianus*- and *Binodosus* ammonite-zone with the help of ammonites, brachiopods and conodonts (Vörös and Pálfy, 2002). These biozones are represented within the Upper Gutenstein Formation and can approximately be dated with the help

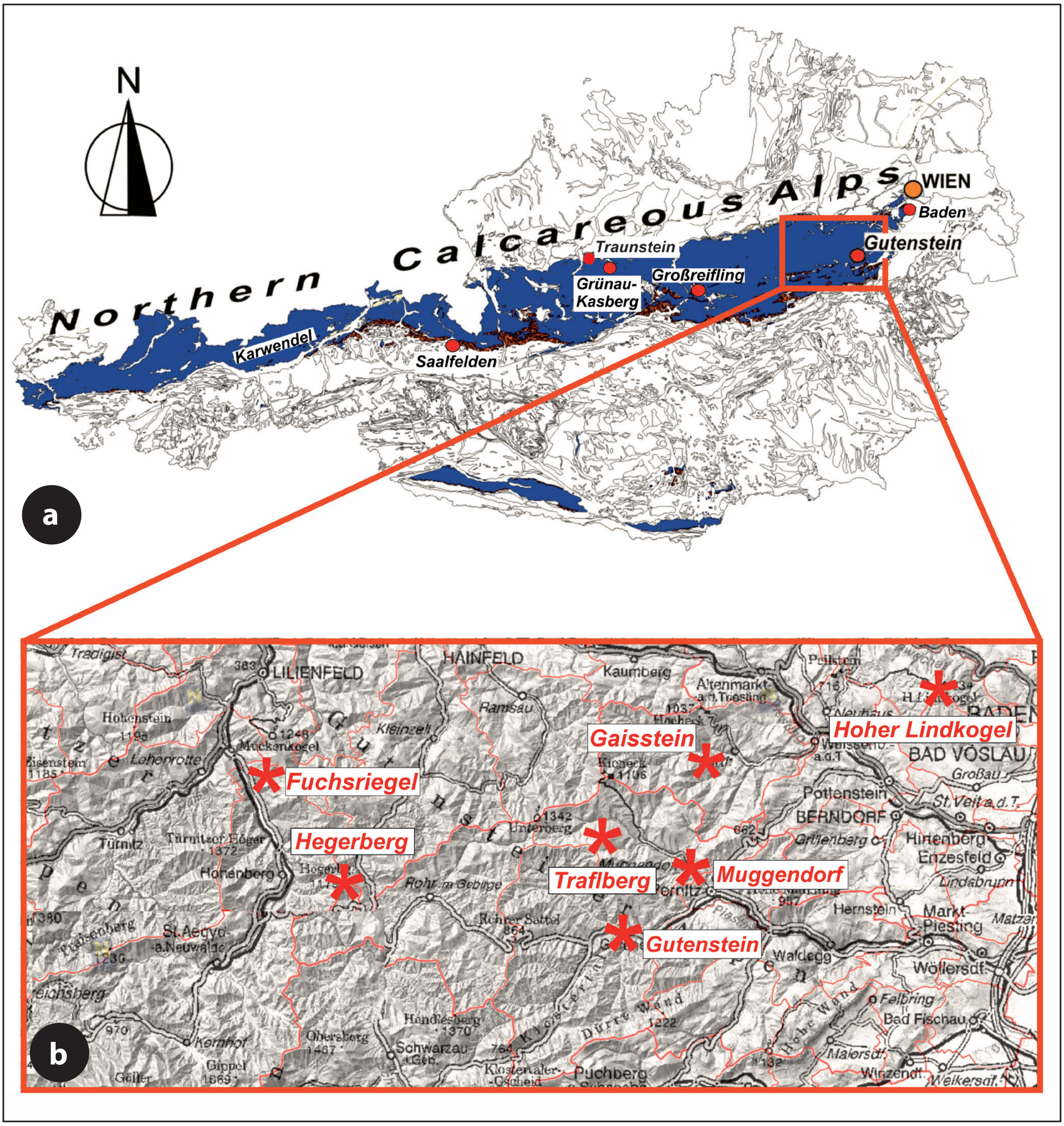

Figure 4: (a) Location of the type-locality of the Gutenstein Formation at Gutenstein and main localities mentioned in the text (modified from the base map: Multithematic Geological Map of Austria 1: 3,000,000, Geological Survey of Austria); **(b)** Further locations important for the litho- and biostratigraphy of the Gutenstein Formation (with permission from the Federal Office for Surveying "© BEV – 2020, Bundesamt für Eich- und Vermessungswesen in Wien, N77333").

of conodonts. The upper Anisian (Illyrian) is subdivided into three ammonite-zones: the *Trinodosus*-, *Reitzi*- and *Secendsis* Biozone, whereby the *Trinodosus*- and *Reitzi* ammonite-zones are exactly characterized by a rich fossil assemblage, mainly represented by ammonites, conodonts and brachiopods which characterize the lower Reifling Formation (Bittner, 1890; Arthaber, 1896).

2.1. Overview of the research history of the type locality Gutenstein

The "*black, platy limestones*" of the Gutenstein Formation, described firstly by Stur (1871) at its type-locality near the village Gutenstein (Figs 4a, b), are situated along the northern nappe boundary of the Göller Nappe, which represents a southern tectonic unit of the Tirolic Ötscher

Authors:		FLÜGEL & KIRCHMAYER 1963	SUMMESBERGER & WAGNER 1971	KRYSTYN & LEIN 1996	MOSER, WAGREICH & PIROS (this paper)
LADINIAN	CORDEVOLIAN	Wettersteindolomit	Wettersteindolomit (> 200 m)	Wettersteindolomit	Wetterstein dolomite (> 300 m)
	LONGOBARDIAN				
	FASSANIAN	Mikrofazies 4			
ANISIAN	ILLYRIAN	Mikrofazies 3; Gutensteiner Kalk (1200 m)	Wettersteinkalk (40 m)	Steinalmkalk (40 m)	Steinalm Formation (40 - 80 m) Annaberg Formation
	PELSONIAN	Mikrofazies 2			
	BITHYNIAN	Mikrofazies 1	Gutensteiner Kalk (30 m)	Gutensteiner Kalk (30 m)	Gutenstein Formation (30 m)
	AEGEAN	„Reichenhaller Fauna" (BITTNER, 1897)	„Reichenhaller Fauna" (BITTNER, 1897)	„Reichenhaller Fauna" (BITTNER, 1897)	Reichenhall Formation (50 m)

Figure 5: Schematic representation and comparison of the lithostratigraphic interpretations at the type area of the Gutenstein Formation at Gutenstein, Lower Austria, from different authors and this paper.

Nappe System (Fig. 2). In this studied area, the Gutenstein Formation is underlain by the Lower Triassic fine-grained siliciclastics of the Werfen Formation and the cavernous rauwackes and gastropod-rich dolomitic limestones of the Reichenhall Formation („*Reichenhaller Rauwacke*", Fig. 5). The latter was first described by Bittner (1897), who derived an early Anisian mollusk fauna with *Natica stanensis* Pichler, *Myophoria* sp., *Modiola* sp. and *Gervillea* sp. from the elevations Teinberg (596 m) and Kroisberg (595 m) in the east of Gutenstein (Fig. 6). To the south, carbonates of the Wetterstein limestone and Wetterstein dolomite (Summesberger, 1991) overlay the Gutenstein Formation in an upright succession (Fig. 6). Following this general geological situation, the type-section at Gutenstein was lithologically and facially first reported in detail by Flügel and Kirchmayer (1963). The 2700 m long composite type-section, as described by Flügel and Kirchmayer (1963), consists of five sub-profiles, from east to west (Fig. 6): (1) the surroundings of creek Panzengraben (mount Kroisberg, 595 m, mount Teinberg, 596 m), (2) the small quarry Paßbrücke, (3) the rock wall above the houses between Taborweg and Kaisersteig, (4) the vicinity of the lower Längapiesting valley and (5) the elevation Mariahilfberg. At the elevation Mariahilfberg, Flügel and Kirchmayer (1963) described two clearly distinguishable carbonate units: (A) a stratigraphically lower, well-stratified, thin and platy bedded, black limestone (calcilutite with silicifications of chert, showing fine bedding or, rarely, graded bedding) and (B) in stratigraphic higher position, a rather thick-bedded, slightly brighter colored and also bituminous, (dolomitic) limestone. Both of these lithostratigraphic units were originally subsumed under the original definition of the Gutenstein Formation by Flügel and Kirchmayer (1963). Up dip, the whole section is completed by the dasycladalean-bearing dolostones from Mariahilfberg (Fig. 6).

Summesberger and Wagner (1971) published another study on the type-section of Gutenstein and additionally compared this profile section with the stratotype-section of the Anisian stage at Großreifling (Styria, Fig. 4a). Here, Summesberger and Wagner (1971) had already noticed, that the definitions of the two different lithotypes of the Gutenstein Formation at its type-locality at Gutenstein, as given by Flügel and Kirchmayer (1963), confirm only to a small extent with the lithostratigraphic characteristics of the presumably same stratigraphic units at Großreifling and surroundings ("Großreifling Imbricate Zone", "Großreiflinger Scholle", Sulzbach Nappe, Bajuvaric Nappe System, both in Styria). Summesberger (1966) and Summesberger and Wagner (1971) noticed that the reduced thickness of between 30 and 150 m for the Gutenstein Formation within its type-section at Gutenstein, is inconsistent with the huge thickness of 1200 m reconstructed by Flügel and Kirchmayer (1963). Consequently, they concluded, that Flügel and Kirchmayer (1963) did not take in account the structural conditions such as changes in the strike-direction or small offsets along faults, respectively. Thus, the undisturbed and continuous profile section of the Gutenstein Formation (Fig. 6) comprises, as defined by Hauer (1853), Stur (1871) and Pia (1930) at Gutenstein, only the outcrops on the southern flank of mount Teinberg (596 m), the outcrops along the roads at the southern outlet of the creek Panzengraben and the outcrops within the small quarry north of the site Paßbrücke, and corresponds exclusively only to profile section I of Flügel and Kirchmayer (1963). All other outcrops, described by Flügel and Kirchmayer (1963) (= section III and IV with outcrops 13–16 and 4–6), are positioned within the strike-direction of profile section I and do not represent a continuous stratigraphic succession but only lateral equivalents. Hence, Summesberger and Wagner (1971) explained the reduced thicknesses of the Gutenstein Formation at its type-locality either by a tectonically formed contact with the Werfen Formation at the base, or by tectonic reduction within the Anisian part of the type-section. Additionally, Summesberger and Wagner (1971) emphasized that the first occurrence of the algae-bearing Wetterstein limestone or dolomite should be situated chronostratigraphically in the lowermost part of the type-section at Gutenstein, in fact even at the level of the *Binodosus* Zone (= Pelsonian, middle Anisian), only slightly above the uppermost beds of the Gutenstein Formation (Fig. 5). Lateron, this horizon was revised to the Steinalm Formation by Krystyn and Lein (1996).

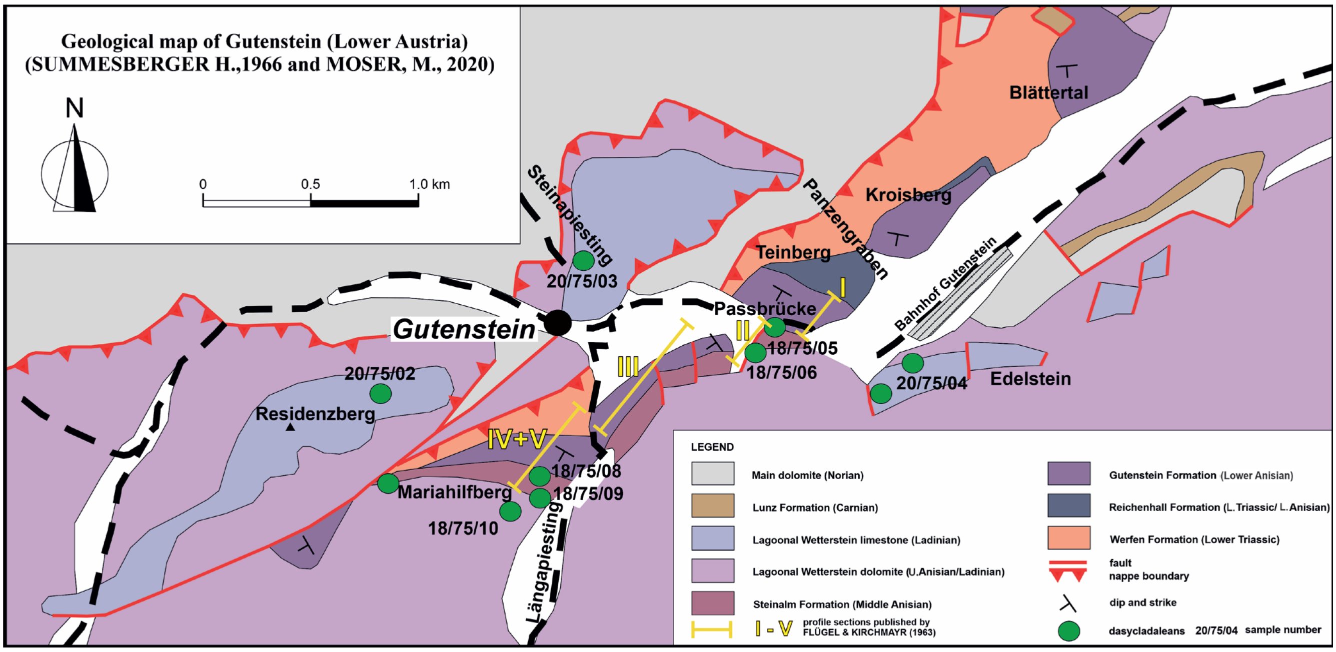

Figure 6: Geological map of Gutenstein with location of the sample points 18/75/05 – 18/75/10, 20/75/02 – 20/75/04; Template: Geological Map-sheet 1:50 000 BMN 75 Puchberg / Schneeberg (Summesberger, 1991).

Nevertheless, Summesberger and Wagner (1971) were the first to recognize that the chert – spheres, which occur within the Gutenstein Formation, are precipitated by early-diagenetic processes and are not the product of ooid silicifications. Besides, Summesberger and Wagner (1971) proposed that within the lower, only 30 m thick section of the Gutenstein Formation, the entire Bithynian Substage (lower Anisian) may be included, biostratigraphically indicated by the occurrence of the crinoid *Dadocrinus gracilis* Buch (Bittner 1897), which appeared during the early- to middle Anisian within the Alpine realm (Pia, 1930; Gasche, 1938).

A more recent and detailed summary of the whole type-section of the Gutenstein Formation at Gutenstein (Lower Austria) was published by Krystyn and Lein (1996). These authors also indicated that the chronostratigraphic range of the Gutenstein Formation extends from the Bithynian upwards to the lowermost Pelsonian Substage. Additionally, they recognized that the subsequent part of the stratigraphic succession at Gutenstein is represented by the Anisian Steinalm Formation (referring to Bechstädt and Mostler, 1974; see Fig. 5). The presence of Wetterstein dolomite at Gutenstein-Mariahilferberg is interpreted by Krystyn and Lein (1996) as in hangingwall-position offset along a fault cutting through the Steinalm Formation.

2.2. Discussion of the litho- and biostratigraphic issues of the type-section at Gutenstein

Herein, we discuss several stratigraphic problems that result from a literature study on the type section at Gutenstein. (1) The dasycladalean-flora, collected within the uppermost portion of the type-section at Gutenstein by Pia (1912, 1920, 1927) and Flügel and Kirchmayer (1963), was derived from different stratigraphic horizons, as Krystyn and Lein (1996) already have mentioned. Consequently, the range of the individual species of dasycladalean algae listed therein indicates contradictory biostratigraphic ages of these samples. (2) The lack of differentiation between any individual formations or members within the type-section presented in Gutenstein has led Flügel and Kirchmayer (1963) to an uncritical confrontation of genetically different and contradictory microfacies-types, such as "*thin-bedded calcilutites and micrites with radiolarians*" on the one hand, and "*sparitic-intraclastic limestones with detritus, dasycladaleans, corals and crinoids* "or "*dasycladalean-dolosparite*" on the other. All these lithotypes were subsumed by these authors under the same collective lithostratigraphic term "*Gutenstein limestone*" (Fig. 5). In this manner, the work of Flügel and Kirchmayer (1963) caused some confusion on the (litho) facial characterization and definition of the Gutenstein Formation itself. (3) The misinterpretation of the chert – spheres, which occur mostly along the bedding planes of some thin-bedded limestone-beds of the Gutenstein Formation, as „*well-weathered ooids*", which – in their view – should be derived from a "*shallow-marine environment*" (Flügel and Kirchmayer, 1963), has resulted in some further confusion. (4) No consideration was given by these authors to the initial definition of the Steinalm Formation by Pia (1924), who was the first to describe the Steinalm Formation near Saalfelden (Salzburg, Fig. 4a) as "*bright, thick-bedded dasycladalean limestone*" of *Anisian age*. Within the same publication, Pia (1924) formally separated the Steinalm Formation from the Gutenstein Formation – the latter also defined by himself (Pia, 1930).

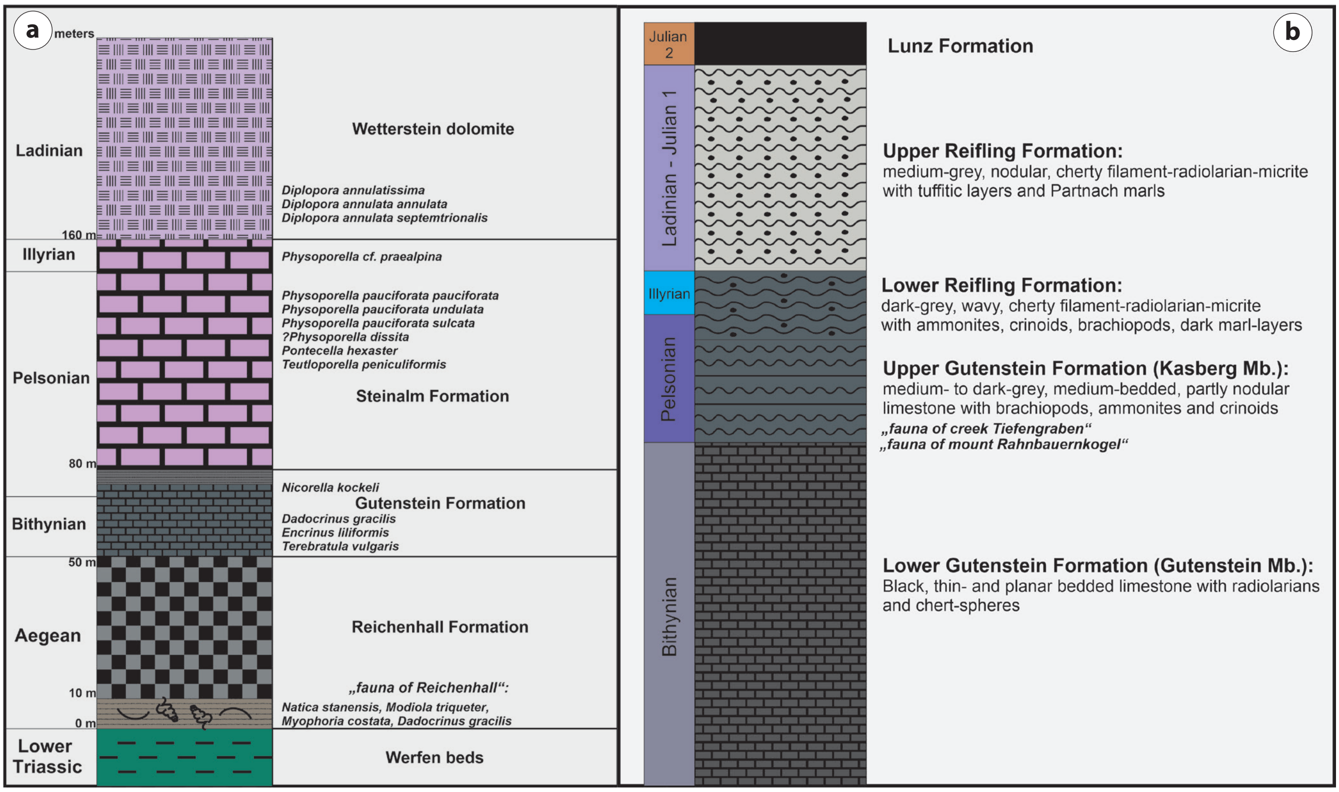

Figure 7: (a) Vertical section through the Middle Triassic succession at Gutenstein (Lower Austria), including the locations of Panzengraben, Passbrücke, Längapiesting and Mariahilfberg; **(b)** The lithostratigraphic subdivision of the Gutenstein and Reifling formations at Großreifling and within the *„Großreifling Imbricate-Zone"* (Großreiflinger Scholle, both in Styria).

Unfortunately, we must admit that Pia (1924) used the generalizing terms "*Diplopores*" and "*Diploporenkalke*" in the same manner as the systematic term for the family of *Diploporidae* for his biostratigraphic definition of the Steinalm Formation, which, based on the co-occurrence of *Diplopora*- algae, would pretend misleadingly a Ladinian (and also Illyrian) age for the Steinalm Formation. In fact, the typical Anisian dasycladalean-genera *Physoporella* sp. and *Oligoporella* sp. belong systematically to the family of the "*Diploporidae*", but dominate by far over the few and rare Anisian dasycladalean-genera of *Diplopora* sp. itself (as reported by Moser and Moshammer, 2018). At all, these genera can be assigned only to the family of *Diploporidae*, which are known since the Late Paleozoic, so that the term "*Diploporenkalke*" seems to be inaccurate to characterize an exclusively Anisian lithostratigraphic unit, what likely resulted in additional disagreements in the past.

Nevertheless, based on the first descriptions and definitions by Pia (1924, 1930), the Steinalm Formation represents a well-mappable stratigraphic unit and is easily separable from similar lithologic units like the Wetterstein limestone, especially within the Bajuvaric Nappe System of the NCA, with the help of the fossil content (dasycladalean algae, foraminifers). Based on the presence of calcareous green algae (see also Bechstädt and Mostler, 1974), the "*massive grey limestone*" of the outcrops 17–19 in section II of Flügel and Kirchmayer (1963) can be attributed to the lithotype of the Steinalm Formation. In this context, Flügel and Kirchmayer (1963) clearly differed between a biogene rich microfacies 2a and 2b ("*biopelsparite*, *intrabiopelsparite*"), which can likely be associated with the dasycladalean-bearing Steinalm Formation (Fig. 7a), and a micritic microfacies type 1, poor in fossils, which may be associated with the thin-bedded Gutenstein Formation (mudstone, wackestone, Figs 7a, b and 8) sensu stricto. Unfortunately, both types of microfacies were not considered as independent formations by Flügel and Kirchmayer, although both can clearly delimited from each other. As a result, Summesberger and Wagner (1971) came to the misleading statement that "*the Gutenstein Limestone represents a shallow-marine deposit, consisting mainly of crinoids, algae and sponges*".

However, because these authors did not pay any attention to the existing lithostratigraphic definition of the Steinalm Formation by Pia (1924), they were not able to recognize that parts of the "Wetterstein limestone" would correspond better to the stratigraphically older level of the algae-bearing Steinalm Formation on top of the Gutenstein Formation (Fig. 7a). Additionally, Summesberger and Wagner (1971) did not define any internal lithostratigraphic subdivision of formations at Gutenstein and subsumed all the different lithologies repeatedly under the general term "*Gutenstein limestone*".

Figure 8: The Gutenstein Formation at its type-locality (quarry "Passbrücke") in Gutenstein (Lower Austria). Well visible are thin-bedded beds with planar bedding planes and black color. Note the arising bed-thicknesses top left, which represent the stratigraphic base of the Steinalm Formation.

3. Methods

To get new biostratigraphical and microfacial data of the Middle Triassic rock succession at Gutenstein, 18 rock samples were collected (Tab. 1).

For comparison 15 samples were taken from the Gutenstein Formation outside of Gutenstein (Figs. 4a, b): from mount Hegerberg (1179 m), mount Fuchsriegel (984 m), mount Gaisstein (974 m) in the Gutenstein- and Türnitz Alps (Lower Austria, Fig. 4b), from mount Traunstein (1691 m) in the outer Salzkammergut-region (Upper Austria, Fig. 4a) and from mount Hoher Lindkogel (834 m) in the Wienerwald-region near Vienna (Lower Austria, Fig. 4b). From most of these in total 33 rock samples thin-sections were produced. For the preparation of thin-sections, at first a representative rock sample with the highest potential fossil content or with the most characteristic microfacies was selected in the field. Thereby it turned out to be useful to sample by humic acid slightly weathered rock-pieces, which directly can be derived from host rock portions and let recognize clearly all sedimentary fabrics or delicate fossil structures on the weathered surfaces. Next, the rock samples were cut into slices and the polished sections were cut into individual plugs exactly at the place of fossils. The edge length of the plugs was 50 × 50 millimetres. Then, the fossil-bearing side was polished smoothly and standard thin sections were produced with a thickness of 0.05–0.06 mm by the thin section lab of the Department of Geology (University of Vienna).

In order to get more information about the micro-fauna, samples were dissolved with the help of acetic acid. In the field, 1–2 kg crushed rock material was collected. The rock fragments were dissolved with half a litre of 80 % acetic acid diluted with two to three litres of warm water for the period of one week. After this time, the insoluble residue of the sediment was sieved with flowing water into two grain-size classes, whereby conodonts were enriched within the grain-size class between 0.125 and

sample	location	coordinates UTM 33 N	stratigraphic unit
18/75/01	240 m E pt. 596, 530 m alt.	567534/5303221	Reichenhall Formation
18/75/02	320 m SE pt. 596, 530 m alt.	567533/5303017	Reichenhall Formation
18/75/03	320 m SE pt. 596, 530 m alt.	567519/5302994	Gutenstein Formation
18/75/04	370 m SE pt. 596, 480 m alt.	567475/5302903	Gutenstein Formation
18/75/05	290 m S pt. 596, 480 m alt.	567337/5302937	Steinalm Formation
18/75/06	340 m S pt. 596, 480 m alt.	567304/5302883	Steinalm Formation
18/75/07	400 m SSW pt. 596, 485 m alt.	567206/5302833	Wetterstein dolomite
18/75/08	170 m SW Lohmühle, 530 m alt.	566310/5302224	Steinalm Formation
18/75/09	310 m SW Lohmühle, 500 m alt.	566268/5302077	Steinalm Formation
18/75/10	370 m SW Lohmühle, 510 m alt.	566209/5302063	Wetterstein dolomite
18/75/11	220 m S Paßbrücke, 550 m alt.	567320/5302700	Wetterstein dolomite
20/75/02	280 m NE pt. 818, 730 m alt.	565263/5302583	Wetterstein limestone
20/75/03	360 m NNE Gutenstein, 550 m alt.	566366/5303204	Wetterstein limestone
20/75/04	1.750 m E Gutenstein, 500 m alt.	568009/5302756	Wetterstein limestone
21/75/04	190 m S pt. 596, 535 m alt.	567229/5303005	Gutenstein Formation
21/75/05	190 m S pt. 596, 535 m alt.	567229/5303005	Gutenstein Formation
21/75/06	192 m S pt. 596, 535 m alt.	567229/5303003	Gutenstein Formation
21/75/07	180 m SSW pt. 596, 534 m alt.	567221/5303024	Reichenhall Formation

Table 1: Locations and coordinates (UTM 33 N) of the samples coming from the type-locality at Gutenstein (Lower Austria).

0.3 mm. Afterwards, the wet sediment residue with the scattered conodonts was dried at 80° C for about an hour within a drying oven. Under the microscope, the dried residue part has been searched three times for fossil remains. Besides the widely scattered, but stratigraphically important pectiniform conodonts and holothurian sclerites, some juvenile brachiopods and ammonites have been collected in this way.

4. Results and Discussion

Based on the published data, our observations in the field and our laboratory analyses we report and discuss the resulting 4 litho- and biostratigraphic issues about the Gutenstein Formation at the type locality: (1) the facies, microfacies and sedimentary environment, (2) the lithostratigraphic subdivision of the Gutenstein Formation based on comparison and correlation with other profile sections within the NCA, including the definition of a new lithostratigraphic member, the Kasberg Member (in German: "Kasberg-Subformation"; Fig. 7b), (3) refinement of biostratigraphy with help of conodonts and dasycladalean green algae, (4) the lower and upper lithostratigraphic boundaries of the Gutenstein Formation (Fig. 7a), (5) evidences for the sedimentary nature of the underlying Reichenhall rauwackes at Gutenstein (Figs 9a, b).

4.1. Gutenstein Formation

4.1.1. Microfacies and Environment

The thin-bedded Gutenstein Formation at Gutenstein is rich in organic material and often finely laminated. Flügel and Kirchmayer (1963) described already fine-grained micrite as characteristic microfacies, containing numerous radiolarians, some ostracods, sometimes small and thin shells of pelecypods and, rarely, intraclasts. In accordance with their findings, the ratio between matrix and components is around 95:5, which corresponds to mud- and wackestones (Dunham, 1962), fine bedded micrites and biogene-bearing micrites respectively (Folk, 1962).

Spherical fossil relics, filled by blocky calcite, are observed in many thin-sections of the Gutenstein Formation, and the question arises if those represent radiolarians or some other (planktonic ?) organisms like dinoflagellates or oligosteginids (Schlager and Schöllnberger, 1974) or even spores of calcite-secreting algae (Pokorný, 1963). The following arguments support the occurrence of radiolarians and thus infer a deeper marine environment for most of the Gutenstein Formation: **(a)** The skeletons of at least parts of these spheric organisms originally consisted of silica, as it can be seen in specimens, where the spheres are positioned as the nucleus of siliceous concretions like chert spheres (Flügel and Kirchmayer, 1963: "*Hornsteinkügelchen*", see Figs 9c, d). **(b)** The average diameter of the spheres of Gutenstein- (and other Reifling- and Raming formations) do show an average size of 0.1–0.3 mm, corresponding very well to the size-distribution of skeletons of Middle Triassic radiolarians with values between 0.1–0.2 mm (Dumitricà et al., 1980), what is up the twice as big as the diameter of the theca coming from cysts of dinoflagellates (Georgescu, 2018) or of oligosteginid calcispheres (Hussain, 2017), which are smaller than 0.1 mm. **(c)** Some specimen of spheres let recognize the contour of a latticed test with spines as is typical of radiolarians (Fig. 9d, above left). **(d)** The first appearance of dinoflagellates is reported from the late Ladinian Substage and the Late Triassic (Janofske, 1992; Dal Corso et al., 2022). **(e)** Bechstädt and Mostler (1976) described a fauna rich in individuals of radiolarians, coming from the Gutenstein- und Reifling Formation within the central and western NCA. **(f)** The solution residue of samples coming from the Gutenstein Formation additionally contained foraminifers of the family *Nodosariidae*, which are typical of deeper-water carbonates like that of he Reifling and Raming formations. **(g)** In the area of the Gutenstein Alps near Innerfahrafeld (Rosental, Lower Austria), trace fossils were found (Moser, 2021a), which indicate a deep-water environment within the lower part of the Gutenstein Formation. The trace fossils were named and determined by Alfred Uchman (Krakau) as *Rotundusichnium zumayense* (= *Scolicia zumayensis*). **(h)** The trace fossil *Thalassinoides*, which also had been observed at the location of (g), does occur even in pelagic deep-water environments (Bromley and Ekdale, 1986) and, additionally, is not abundant within the Gutenstein Formation. **(i)** The habitat of the very long and slender stemmed and -armed crinoid *Dadocrinus gracilis* Buch was described by Gasche (1938) from a fine-grained calcareous depositional system with calm sea-water at greater depths and longer distances to the mainland. As a qualification it can be said, that thin-sections, taken from Gutenstein Formation, let recognize calcispheres in the size range of radiolarians (0.1–0.3 mm), but also very small calcispheres (≤0.1 mm), which could also be derived from redeposited spores of algae or simple spherical shaped foraminifers (like *Psammosphaera*).

Within all thin-sections, taken from the Gutenstein Formation at mount Teinberg (596 m) near Gutenstein (Fig. 6), a finely bedded wackestone, consisting of numerous layers of very fine-grained silty carbonate-detritus of different grain-size, is visible. Between the thin layers of finest detritus some clay coatings are visible, which may be the product of pressure solution. Along the surface of the single sedimentary layers, tiny chert-spheres are present. The silica, which builds up the concentric structured spheres, may be derived from dissolved skeletal elements like radiolarians, which consist of skeletal opal, or spiculae of siliceous sponges. Together with some carbonate, the silica precipitated early-diagenetically under decreasing pH-values in a concentric manner around tiny bio- and lithoclasts like crinoids, radiolarians or peloids. During diagenesis, the radiolarians were largely calcified and form small white globules. The interpretation of the chert-spheres as silicified "ooids" (Flügel and Kirchmayer, 1963) is outdated and should better be interpreted as

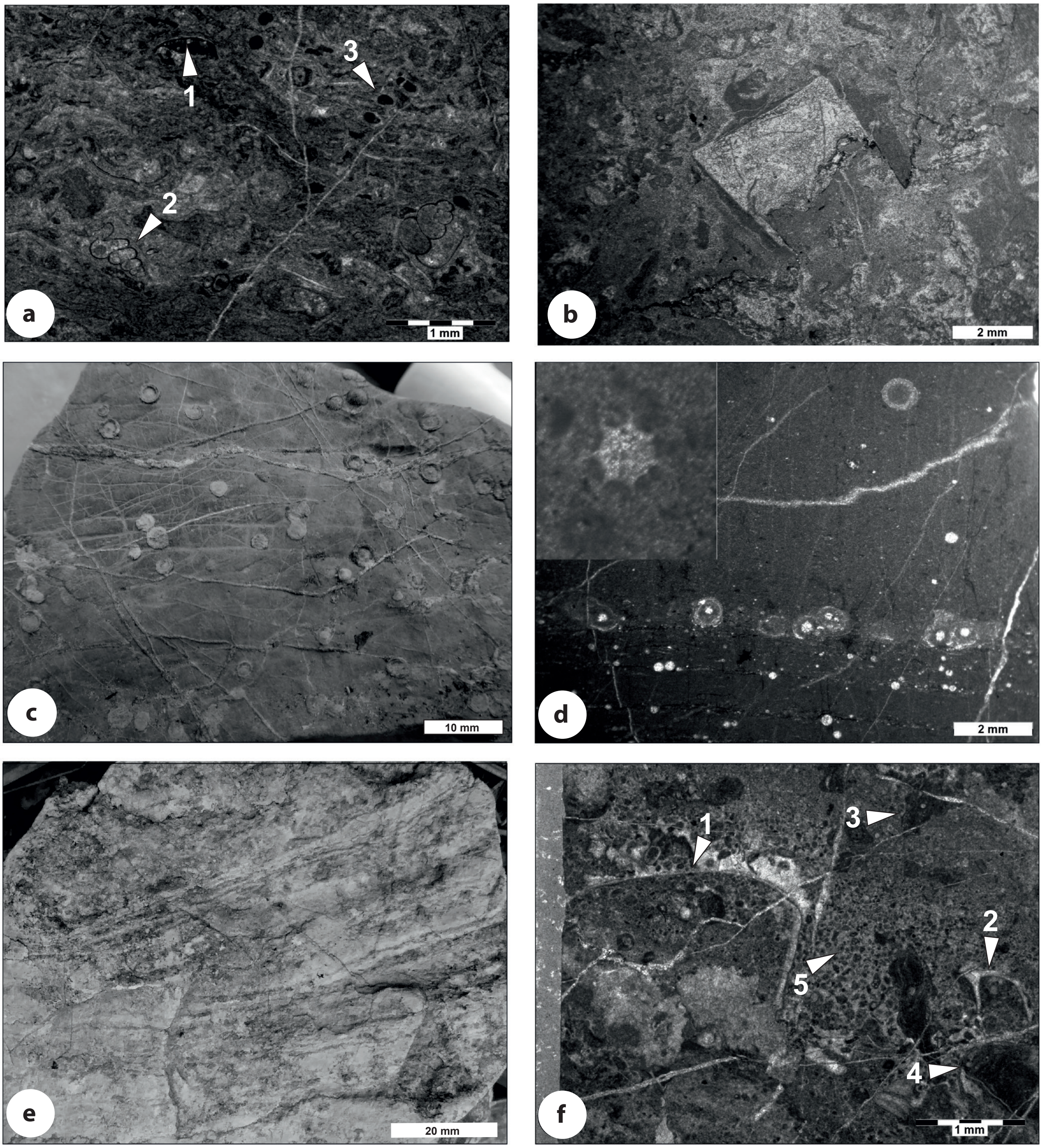

Figure 9: (a), (b) Microfacies of the Reichenhall Formation at Gutenstein (Lower Austria). **(a)** Brownish grey intrabiosparite, containing numerous large (1) pelecypods and (2) gastropods as well as rounded (3) plasticlasts (NE flank of Mount Teinberg, 530m alt.). **(b)** Thin-section coming from the Reichenhall Rauwacke on Mount Teinberg, showing a nice cubic, in part microbially encrusted hopper crystal within the matrix of the breccia (2 km ENE of Gutenstein, Lower Austria); **(c), (d)** Lithology and microfacies of the Gutenstein Formation: **(c)** Chert-spheres, which weather out on the planar bedding-planes of Gutenstein limestone, coming from mount Teinberg (1.5 km NE of Gutenstein). **(d)** Radiolarian (calcispheres) bearing, dark-grey, fine-bedded, calcilutite (Hoher Lindkogel, 25 km ENE of Gutenstein); **(e)** Light-grey colored, thick-bedded, loferitic limestone coming from the Steinalm Formation (Längapiesting-valley south of Gutenstein): thin layers of cyanophycean algae (stromatolites or cyanobacteria), which represent open-marine, lagoon-like facies conditions, indicating a shallow-marine environment with rather turbulent seawater. **(f)** Medium-grey biopelsparite with isolated and resedimented skeletal grains of (1) pelecypods, (2) gastropods, (3) tubiphytes and foraminifers, as well as (4) oncoids and (5) pellets at the base of the Steinalm Formation (Location: outcrop next to former inn „Zur Paßbrücke“, east of Gutenstein).

concretions originated during early diagenetic processes.

The development of pseudomorphs after evaporite minerals were sometimes described from the Gutenstein Formation (e.g. Sikabonyi, 1997) and were found in a sample from the top of the Gutenstein Formation on mount Traunstein (1691 m) in the outer Salzkammergut region (Upper Austria), where twinned gypsum-crystal rosettes were replaced lateron by barite. Additionally, the finely bedded limestone is rich in radiolarians (calcispheres) and small pelecypods and bears thin and graded bedded carbonate-silt layers. Altogether, the appearance of evaporitic minerals, like halite and gypsum, may indicate a slightly elevated salinity within the organic-rich carbonate ramp deposits of the Gutenstein Formation, separated by swells from the open sea. Nevertheless, the depth of deposition of the main parts of the Gutenstein Formation does not necessarily have to be above the storm wave base (estimated to be around 80 m) because the precipitation of gypsum cumulates can take place from dense bottom brines within a basin, which shows a strongly stratified water column of any water depth (Reading, 1996; Roveri et al., 2014). Besides, the observation of evaporitic minerals in the Gutenstein Formation is scarce and may indicate an intermittent restricted environment therein.

An important issue represents the apparently abrupt change in facies from the hypersaline environment of the Reichenhall Formation into the restricted open marine environment of the Gutenstein Formation. To clarify this question, thin-sections have been made from the lowermost beds of the Gutenstein Formation. In general, we infer that the Gutenstein Formation was deposited at greater subtidal depths during its depositional history. Nevertheless, both, sedimentary structures, which in part can be derived from the dissolution of evaporite minerals, and the intercalation of rauwacke-layers at the base of the Gutenstein Formation let expect a transitional environment at the beginning of deposition. On mount Teinberg (596 m) at Gutenstein, the lithologically sharp contact between the Reichenhall- and Gutenstein Formation is well exposed. Thin-sections coming from these basal layers of the Gutenstein Formation, taken only half a meter above the topmost beds of the Reichenhall Formation, show a fine-bedded black mudstone (laminated biopelmicrite) with fine crinoid litter (radialia, columnalia), ostracods, radiolarians (calcispheres), nodosariid foraminifers, thin-shelled pelecypods and small chert-spheres. Nevertheless, fine-bedded mud- and siltstones, which are devoid of fossils, as well as finely cemented dispersions within the sediment, which can traced back to dissolved evaporites within the basal beds of the Gutenstein Formation, infer intermittent elevated salinities within this part of the formation. The solution residue of these limestones is rich in detrital quartz and siliceous sponge-spiculae. Rarely some phyllitic extraclasts and holothurian sclerites have been observed. Similar facies are present in the basal layers of the Gutenstein Formation on mount Hoher Lindkogel (834 m) near Baden (Fig. 4b) in Lower Austria (location: Kaiserwald), where black colored, fine-bedded mud- and wackestones rich in radiolarians (calcispheres), that are arranged in thin layers, appear together with chert-spheres.

The biogenes, like radiolarians (calcispheres), nodosariid foraminifers, siliceous sponge-spicules and thin-shelled pelecypods, support a deep and outer carbonate-ramp position of the main part of the Gutenstein Formation, as far as indicators of a shallow-marine, restricted lagoonal environment can be seen mainly at the base of the formation. Subsidence, which caused the facies-change from the shallow-marine and hypersaline environment of the Reichenhall Formation to the slightly deeper marine, restricted environment of the Gutenstein Formation, took place quickly, was tectonically controlled and superimposed by the "*Muschelkalk – Transgression*" during the Bithynian (Riech, 1978; Götz, 2002). Some observations seem to corroborate a rather shallow-marine environment of the Gutenstein Formation: (a) Sikabonyi (1997) described calcitic pseudomorphs after gypsum coming from a micritic mudstone of the Gutenstein Formation, but unfortunately did not give any reference of the origin or location of the sample "*P 113*". (b) Thrombolites can be found within the lowermost part of the Gutenstein Formation on mount Hoher Lindkogel (834 m) near Baden (Fig. 4b) in Lower Austria (Moser, 2023), where some black-colored and oxygen-poor, fine bedded pelmicrites are visible, which show in some layers a linear arranged clotted fabric with characteristic arborescent and bushy textures. Hips (2007) was one of the first who described calcimicrobial beds from mud-dominated, oxygen- depleted Anisian sediments of the Aggtelek Karst in northern Hungary, corresponding largely to the Gutenstein Formation in the Eastern Alps. The calcimicrobial beds, as described herein, correspond to thrombolites sensu Aitken (1967). Within our sample coming from mount Hoher Lindkogel (Fig. 4b), the micritic sediment surrounding the thrombolites is slightly bioturbated and the surface of the microbial knobs is irregularly developed, as can similarly seen within the occurrences in Hungary.

The microfacies of the Gutenstein Formation remains constant up section and consists regularely of fine bedded and fine-grained wackestones or mudstones (biomicrites, micrites) which contain some fine crinoid litter, small and thin-shelled pelecypods, ostracods, nodosariid and glomospirid foraminifers, spicules of siliceous sponges, radiolarians (calcispheres) and, commonly, pellets and peloids (biopelmicrites). Some beds within the Gutenstein Formation let recognize the deposition of distal tempestite layers, which are composed of graded bedded carbonatic silt-detritus, mixed and chaotic deposited shells of pelecypods or ostracods, redeposited small shells of juvenile ammonites and gastropods, redeposited angular and subangular shaped intraclasts and remains of *Tubiphytes* – knots. The latter may be swept out via tidal outlets from an inner carbonate-ramp area.

The uppermost part of the Gutenstein Formation (herein defined as "Kasberg Member", see chapter 4.3.), shows a general change in fossil-content, lithology and microfacies. The dark-grey, granular grain- and packstones (biopelmicrites/sparites) are relatively rich in fossils and often bear some large crinoids (encrinites), brachiopods, pelecypods, gastropods, ammonites, ostracods, conodonts, remains of fishes (teethes, otoliths, vertebra, scales), siliceous sponges, spines of sea urchins, sclerites of holothurians, glomospirid and rotaliid foraminifers as well as tempestitic beds with a coarse-clastic and erosive basal layer. Based on the fossil content the facies seems to be restricted, but some habitats are more open marine than in the lower part of the formation, but still oxygen-deficient. The somewhat more open marine facies is connected with a transgressive system tract, which is reported from the marginal marine "*Muschelkalk Sea*" during the middle Pelsonian (Götz, 2002) of the northlying Germanic-Polish trough. Although many of the fossils of the Kasberg Member, like conodonts and ammonites, indicate a deeper marine environment, the dominance of bentonic organisms like crinoids, gastropods, sea urchins and brachiopods would also attest a mid-ramp configuration somewhat nearer to the coast. Sikabonyi (1997) and Moser and Moshammer (2018) recognized the faunal proximity of the Upper Gutenstein Formation to that of the Annaberg Formation and indicated a change in facies within the upper part of the Gutenstein Formation. The occurrence of the shallow-marine, mid-Pelsonian Steinalm Formation on top of the Gutenstein Formation on mount Kasberg (1747 m, Upper Austria) seems to validate the gradual shallowing upward trend of the depositional environment within the Gutenstein Formation during the early and middle Pelsonian. The slope of the Anisian carbonate ramp was steep enough to trigger slumping and sliding, as is visible by some intercalated chaotic folded layers in the Gutenstein Formation, clearly not related to tectonism (Heinrich and Wessely, 2015).

Rarely, thin and graded bedded tempestitic layers are present, which can be recognized by an erosive basal surface and distinct fossil accumulations. These are interpreted as distal accumulations triggered by storm-generated currents (e.g. distal tempestites). In such tempestitic layers, which show at the base an erosive contact and, not rarely, graded bedding, a lot of ammonites, mixed and whirled pelecypods, gastropods, crinoids, *Tubiphytes*-knots, ostracods and micrite-intraclasts are represented. Additionally, the lateral appearance of fossil-rich layers within the Upper Gutenstein Formation at Großreifling (Gessner, 1963) points to brief events of fossil accumulations within the *Binodosus* ammonite-zone. Sometimes, cross-sections through small ammonites are visible within the limestones coming from the Gutenstein Formation. Bioturbation in the Gutenstein Formation is not as common as in the Annaberg Formation ("Wurstelkalk", vermicular limestone, consisting of branched traces of *Thalassinoides* and elongated traces of *Planolites*). The biogenes (like radiolarians) are present in thin layers and were later weakly deformed and enriched diagenetically by pressure-solution and in thin clay- and organic-rich layers (Fig. 9d).

The fossil-content of the Gutenstein Formation does increase upsection so that epi- and endobenthonic fossils like crinoids, brachiopods, gastropods, foraminifers, conodonts and ostracods are more frequent within the Upper Gutenstein Formation (Moser and Moshammer, 2018), indicating a gradual opening of the shallow marine depositional system, starting from a more restricted sedimentary environment within the Gutenstein Member (Lower Gutenstein Formation). Conodonts can be found in the Upper Gutenstein Formation, corroborating its middle Anisian (Pelsonian) age (Krystyn and Lein, 1996; Moser and Moshammer, 2018; Moser, 2021a). Similarly, in other areas, like the Tirolic Göller Nappe or some (central) parts of the Reisalpen Nappe, the Gutenstein Formation can gradually pass upwards into the middle Anisian Annaberg Formation by an increasing abundance of shallow water allochems like oncoids and cortoids, indicating a shallowing upward trend. Often the crinoids are redeposited and can rarely be found unbroken with stalk and theca. Also, with increasing wave-energy, the grainsize rises within the Upper Gutenstein Formation, so that pack- and grainstones may appear, which contain some large remnants of crinoids, brachiopods, pelecypods and gastropods, which are distributed in a microsparitic matrix.

Based on our data, the litho- and microfacies of the Gutenstein Formation does mainly correspond to black, oxygen- and fossil-poor deposits of an outer carbonate ramp setting sensu Ahr (1973), situated along the southeastern passive continental margin of Pangaea (Fig. 1). For the lower Anisian part of the Gutenstein Formation within the Juvavic domain Bechtel et al. (2005) assumed a marine environment with limited water exchange and a stratified water column. The depth of the depositional area of the Gutenstein Formation did extend from the euphotic zone over the normal storm wave base down to the floor of a restricted pelagic basin in a low-energetic setting with calm seawater (see also Rüffer, 1995). Based on the fine-grained sediment, the pelagic and benthic fauna (radiolarians, conodonts, ammonites, thin-shelled pelecypods, nodosariid foraminifers) and the sedimentary structures, the depositional depth may have ranged around 80 and 100 m. The fine-grained and black sediment indicates suboxic or anoxic bottom water conditions with restricted circulation and low bioturbation. In contrast, planktonic life could develop in the upper water layers. The sedimentary environment seems to be characteristic of the initial stage of the continental break-up during the Middle Triassic Tethyan rifting (Frisch et al., 2011), because the oxygen-poor facies appears widespread also in other parts of the Alpine orogenic chain.

In summary, facies and depositional environment of the Gutenstein Formation are still in discussion, varying from a restricted, oxygen-poor lagoonal environment (Lein et al., 2012: 472) to a deeper marine, hemipelagic outer carbonate ramp deposit, as suggested herein. Almost no fossils can be found to be characteristic of a lagoonal environment, but, in contrast, several typical pelagic fossils, such as radiolarians, ammonites and conodonts represent a deeper-marine environment with a minimal depositional depth of 80 m for the greater part of the Gutenstein Formation.

4.1.2. New biostratigraphic data derived from the Gutenstein Formation at the type-locality at Gutenstein

The lower Anisian age of the Gutenstein Formation at Gutenstein can be supported with the help of the holothurian-sclerite *Theelia multiradiata* Kozur 1969, coming from the lowermost beds of the Gutenstein Formation on mount Teinberg at Gutenstein (sample 21/75/06 C; location see Tab. 1). Additional samples were taken from the lower and upper portion of the Steinalm Formation, excavated along a small limestone-cliff on the western flank of the Längapiesting-valley between 530–540 m a.s.l. (sample 18/75/08; location see Table 1), and, next, well-exposed in rocks nearby a residential house in Gutenstein, No. 28 (250 m SSW of Lohmühle, 500 m a.s.l.), also situated in the Längapiesting valley (sample 18/75/09; location see Tab. 1). The dasycladalean flora, which was derived from these samples (Table 2), clearly indicates a (middle) Anisian age, and, thus, an assignment of the limestone-cliffs between Paßbrücke, Lohmühle and Mariahilfberg to the middle Anisian Steinalm Formation (Fig. 6). Another rock-sample, taken from the uppermost portion of the somewhat dolomitic Steinalm Formation, situated slightly beneath the stratiform contact to the light-grey Wetterstein dolomite (sample 18/75/10; location see Tab. 1 and Fig. 6), yielded a quite similar, still Anisian dasycladalean flora (Tab. 2). Besides, a rock sample, derived from the rocks on the southern side of the location Paßbrücke, next to the memorial cross (sample 18/75/06, location see Tab. 1 and Fig. 6), yielded the Anisian dasycladaleae ?*Physoporella dissita* Pia. All these data together are in accordance with the statements of Pia (1927) and Flügel and Kirchmayer (1963), who mentioned the occurrence of Anisian *Physoporella* – algae within the area of Mariahilfberg near Gutenstein. On the other hand, the co-occurence of Anisian *Physoporella* – algae (Pelsonian, Illyrian) together with the Ladinian species *Diplopora annulata annulata* Schafhäutl, as described by Flügel and Kirchmayer (1963) seems to be erroneous, as already stated by Krystyn and Lein (1996). But, additionally, since the Anisian/Ladinian boundary has shifted to the base of the *Eoprotrachyceras curionii* Zone (Brack et al., 2005), the onset of *Diplopora annulata annulata* Schafhäutl must be shifted into the latest Anisian (Illyrian), but not earlier then the *Aplococeras avisianum* Subzone (Piros and Preto, 2008, Fig. 3). The biostratigraphic data suggest that the Pelsonian Steinalm Formation extends upwards into the Illyrian (upper Anisian) Substage at the locality Paßbrücke. Flügel and Kirchmayer (1963) also described *Physoporella* cf. *praealpina* Pia from the lowest level of Wetterstein dolomite at the beginning of the mountain-track Taborweg. This calcareous alga is said to represent a late Anisian (Illyrian) position in co-occurrence with *Diplopora annulatissima* Pia in the region of the Western Alps (Ellenberger, 1958) and the Western Carpathians (Bystrický and Veizer, 1965; Piros and Preto, 2008). Based on our samples, the fossil calcareous green algae *Physoporella* cf. *leptotheca* Kochansky-Devidé occurs within the Steinalm Formation at the location Paßbrücke (sample 18/75/05, Fig. 6 and 11a), described also from the Lower Prosanto Formation of the Silvretta Nappe (Eichenberger, 1986) and the upper Anisian of the Dolomites (Bassi and Fugagnoli, 2005). All these combined biostratigraphic data may indicate a middle- to upper Anisian age of the Steinalm Formation at Gutenstein. In addition, these data explain the absence of the open-marine and neritic basinal facies of the upper Anisian (Illyrian) Reifling Formation at Gutenstein as predominantly stratigraphic feature – and, hence, is not tectonically caused (as inferred by Krystyn and Lein, 1996), because the Reifling Formation within the NCA already starts its sedimentation during the latest Pelsonian (Tollmann, 1976a; Lein et al., 2012). This situation is corroborated by the Middle Triassic stratigraphic succession of mount Grössenberg (near Kalte Kuchl, Lower Austria), which is part of the same tectonic unit and which consists in the same way of a continuous succession of shallow-water limestones/dolomites beginning with the middle Anisian Annaberg Formation and extending upward into the late Ladinian Wetterstein Formation (Moser, 2019a). A similar result is reported by Rüffer (1995) from the western part of the NCA, where no any deep marine basinal development was found within the inner platform area between Steinalm Formation and lagoonal Wetterstein limestone in some parts of the Karwendel- and Wetterstein mountains in Tyrol (Rüffer, 1995).

Summarizing, the chronostratigraphic range of the Gutenstein Formation at its type-locality comprises the main part of the lower Anisian (Bithynian) Substage and only minor parts of the Pelsonian Substage, which mainly is represented by the overlying Steinalm Formation. The assumption of Flügel and Kirchmayer (1963), that the Gutenstein Formation, as it is defined here, would comprise only a middle Anisian age, cannot be confirmed, because the main part of this time-period is represented by the Steinalm Formation between the locations Paßbrücke, Lohmühle and Mariahilfberg. Naturally, this in contrast to the profile section at Großreifling (Styria), where the Gutenstein Formation is part of a thick Middle Triassic basinal sequence of the Bajuvaric Reifling Basin and, hence, comprises additionally the Pelsonian *Balatonites balatonicus*-Biozone there. *Balatonites balatonicus* Mojsisovics indicates the middle Anisian Substage (Summesberger and Wagner, 1972) and, consequently, no shallow marine Steinalm Formation is developed in this basin-near and deeper marine profile section (Fig. 7b).

The problem of the different thicknesses of the Gutenstein Formation at Gutenstein of only 30 m (Summesberger and Wagner, 1971) or 100–150 m (Summesberger,

1966) can be considered as to be the result of tectonic reduction on the one hand or as result of its shorter stratigraphic extent of only 1–2 m.y. (lower Anisian) on the other (Fig. 7a).

An important marker horizon, which is represented within all profile sections of Gutenstein, is designated as dark-grey dasycladalean dolomite, which continuously occupies the basal part of the Wetterstein dolomite area. It occurs, for example, directly at the beginning of the mountain trail Taborweg or, in the same way, at the outer end of a creek, coming down from Mariahilfberg on the western flank of the Längapiesting valley, and also, at the elevation Mariahilfberg itself (parking place, Fig. 6). Numerous calcareous algae (dasycladaleans) and small gastropods were cited by Flügel and Kirchmayer (1963, sample 9) from these *"dark dolomitic beds"*, from where only the Ladinian genus *Diplopora* sp. was determined, likely cause of poor preservation and strong recrystallization within the dolomitic bedrock. Following Piros (2002), the *Diplopora annulata – Diplopora annulatissima* – Assemblage-Zone represents the early Ladinian and corresponds to the lowermost portion of the Wetterstein dolomite and limestone at Gutenstein (Tab. 2).

The region around mount Residenzberg (818 m), Steinapiesting – Theresiensteig (0.5 km NE' Gutenstein) and mount Edelstein (2 km east of Gutenstein), situated between Gutenstein and Pernitz in the Piesting valley (Fig. 6), is built up by Ladinian Wetterstein limestone in a typical shallow-marine and lagoonal facies. The Wetterstein limestone shows large *Diplopora*-type dasycladalean green algae, oncoids, stromatoliths with LF-fabrics, pelecypods and crinoids. In some regions (Edelstein), the lagoonal Wetterstein limestone is strongly dolomitized and thus forms no steep cliffs anymore.

A typical early Ladinian flora of dasycladalean green algae was derived from the samples 20/75/02 (Location see Tab. 1 and Fig. 6) and 20/75/03 (Location see Tab. 1 and Fig. 6), coming from the the Wetterstein limestone intercalations within the lowest portion of the Wetterstein dolomite in the surroundings of Gutenstein at mount Residenzberg (818m, northern side) and along the mountain trail Theresiensteig (outlet of Steinapiesting-river. "Lange Brücke", 550 m a. s. l.). See Table 2.

The lagoonal Wetterstein limestone of Theresiensteig is in direct continuation of mount Residenzberg, indicating that both occurrences of Wetterstein limestone represent the uppermost Anisian to lower Ladinian (Fassanian) interval. Indeed, in the area east of Gutenstein, within the Wetterstein dolomite some intercalations of Wetterstein limestone occur at mount Edelstein and Hornungkogel (1.8. km ESE' Gutenstein), from where a typical Ladinian dasycladalean flora could be derived (sample 20/75/04; location see Tabs. 1, 2 and Fig. 6). The co-occurrence of *Diplopora annulata annulata* Schafhäutl with *Teutloporella peniculiformis* Ott and *Diplopora annulatissima* Pia indicates a latest Anisian (former: Fassanian 1) age (Piros and Preto, 2008), which corresponds to the latest Anisian *Secedensis* Zone and the Fassanian *Curionii* Zone (Budai et al., 2004), dating the onset of the Wetterstein carbonate-platform into the latest Illyrian *Secedensis* Zone.

4.2. Stratigraphic relationships of the Gutenstein Formation at Gutenstein

4.2.1. The boundary of the Gutenstein Formation to the underlying Reichenhall Formation

Results:

On mount Teinberg (596 m, 1 km east of Gutenstein) the up to 50 m thick Reichenhall Rauwacke is exposed, not indicated on the Geological Map BMN / ÖK 75 Puchberg/Schneeberg, edited by Summesberger (1991). Near the base of this brecciated rauwacke-layer, a dark-grey, fine-grained, dolomitic limestone with large shells of gas-

	Gutenstein - Steinalm Formation					Dolomite	Wetterstein Limestone			
Sample	18/75/08	18/75/09	18/75/10	18/75/06	18/75/05	Probe 9*	20/75/02	20/75/03	20/75/04	
Physoporella sp.	+	+	+							M. Anisian
Physoporella pauciforata pauciforata BYSTRICKÝ	+	+	+							M. Anisian
Physoporella pauciforata undulata BYSTRICKÝ	+	+	+							M. Anisian
Physoporella pauciforata sulcata BYSTRICKÝ	+	+	+							M. Anisian
Pontecella hexaster (PIA) GÜVENÇ	+	+	+							M. Anisian
Teutloporella peniculiformis OTT	+	+	+							M. Anisian
?*Physoporella dissita* PIA				+						L.? Anisian
Physoporella cf. *leptotheca* KOCHANSKY DEVIDÉ					+					L.? Anisian
Diplopora annulatissima PIA						+		+		E. Ladinian
Diplopora annulata annulata SCHAFHÄUTL						+	+		+	E. Ladinian
Diplopora annulata septemtrionalis PIA						+				E. Ladinian
Griphoporella gümbeli (SALOMON) PIA							+			E. Ladinian
Teutloporella peniculiformis OTT									+	E. Ladinian
Gyroporella ladinica BYSTRICKÝ									+	E. Ladinian
? *Diplopora annulata dolomitica* PIA									+	E. Ladinian
? *Favoporella annulata* SOKAĆ									+	E. Ladinian
* Sample 9 from Flügel and Kirchmayer, 1963										

Table 2: Dasycladalean green-algae, collected from the samples at Gutenstein (type locality).

tropods, pelecypods, crinoids and glomospiral foraminifers forms a rocky ridge on the eastern flank of mount Teinberg (sample 18/75/01 in Fig. 6, Tab. 1). It overlies sharply the fine-grained siliciclastics of the uppermost Werfen Formation, which occupy the meadows between mount Teinberg and mount Kroisberg, and corresponds to the "*gastropod horizon*", reported by Rothpletz (1888). The brecciated rauwacke-layer, together with the gastropod-rich limestone, represents a major part of the Reichenhall Formation. The general chronostratigraphic range of the Reichenhall Formation comprises the upper Olenekian (uppermost Lower Triassic) and the Aegean (lowermost Anisian), as Spötl (1988) already has specified. A thin-section, derived from sample 18/75/01 (location see Table 1), which was taken from a gastropod-rich limestone on mount Teinberg, shows subrounded micrite-intraclasts (plasticlasts) within an intrabiosparitic matrix. This indicates that the deposits on the seafloor were subject of a high-energetic storm- environment and, generally, part of a shallow-marine depositional system. Schenk (1967) described a strikingly similar, fossil-rich tempestite facies from the Reichenhall Formation in the Karwendel-mountains (Tyrol), which was deposited within a nearshore and shallow-marine storm-influenced environment (Fig. 6a). Bittner (1897) described the gastropod-rich "*Fauna of Reichenhall*" from three sites east of Gutenstein (Teinberg, Panzengraben, Kroisberg), but also some similar gastropod-fauna from the uppermost Werfen Formation.

Two thin-sections, prepared from the overlying rauwacke-layer on mount Teinberg (sample 18/75/02 and 21/75/07, Tab. 1), show **(A)** a monomictic, dark-grey breccia, in which angular shaped, dark-grey, medium-grey or beige colored, sometimes finely layered biodetritic micrite-intraclasts with fine crinoid-litter prevail, and from which cubic- or rhombic-shaped spaces, filled with finest granular calcite spar can be interpreted as relics of former evaporite minerals or of disintegrated angular dolomite-lithoclasts (vadose zone), and **(B)** cubic or prismatic, in part microbially encrusted hopper crystals (Fig. 9B) and pseudomorphs after anhydrite, which appear within the matrix and components of the breccia. Also, clotted fabrics of microbial origin are visible. Hence, both thin-sections give, cause of its typical shallow-marine facies, evidence for a sedimentary origin of the rauwackes, and of the originally hypersaline environment. Therefore, we assume an assignment of the thick rauwacke-layer to a normal stratigraphic succession within the Reichenhall Formation at Gutenstein.

Discussion:

Anisian rauwackes (Reichenhall or Saalfelden Rauwacke) have been described based on their brecciated nature with beige (sub)angular dolomite clasts, floating in a dark-grey calcareous matrix (Schenk, 1967). Schenk (1967) termed this kind of bedrock "*Reichenhall Breccia*". Within the western and central part of the NCA, the components of this polymictic sedimentary breccia comprise supplementary allochthonous clasts, coming from the Lower Triassic Werfen Formation and 'Alpiner Buntsandstein' (Pirkl 1961; Schenk 1967; Moser 2018). With reference to Schenk (1967) and Spötl (1988), we infer that the sedimentary base of the Reichenhall Formation, formed by bituminous sediments, has been reworked within the monomictic Reichenhall breccia (Rauwacke) by submarine sliding, possibly caused by salt-tectonics or by leaching of evaporites ("collapse-breccias") or by volume change due to dolomitization within this evaporitic environment (Krauter, 1968). Following Frisch (1975), the oxygen-poor and hypersaline sedimentary conditions within the Reichenhall Formation resulted in the formation of a hostile, fossil-poor shallow marine environment with sporadic stromatolites. Additionally, the development of desiccation cracks and the widespread synsedimentary dolomitization of the limestones, triggered by hypersaline Mg-rich fluids, are typical of this horizon. Frisch (1975) and Miller (1965) described benthic marine fossils, like crinoids, pelecypods and gastropods, within a restricted marine environment, indicating slightly deeper-neritic depositional conditions during sea-level highstand, excluding sabkha or terrestrial saline environments like that of gypsum pans.

On the other hand Summesberger and Wagner (1971) described a tectonically formed rauwacke or, rather, a tectonically formed breccia, composed of lithoclasts of both Gutenstein limestone and Wetterstein dolomite, in the footwall of the Gutenstein Formation at Gutenstein. But a tectonic origin of these rauwacke-layers with Wetterstein clasts, assumed by Summesberger and Wagner (1971), seems to be unlikely because the rauwackes show no direct contact with an overlying or underlying Wetterstein dolomite, so that the presumed tectonic rework of dolomite-components within the rauwacke-layers could also be the result of a misinterpretation of the components itself within the breccia. Something interesting on the side seems to be, that Krulla (1909) mentioned former iron minings "*at the contact of the Gutenstein limestone with the Werfen Formation*" in the vicinity of the farmhouse "Scheitalerhof" (NW of Blättertal near Gutenstein). These iron mineralisations resemble the brown iron ore-deposits of the "Werfen Imbricate Zone" (Werfener Schuppenzone) in Salzburg (Heissel, 1955), which occurre exactly in the same stratigraphic level of the mineral-bearing Anisian Reichenhall Formation in Salzburg. Nevertheless, following Leine (1968: 66), the development of limonite-crusts is widespread within the different alpine rauwackes and could also be traced back to the release of iron, caused by the calcitification (dedolomitization) of the dolomite-components within the breccia.

The contact of the Reichenhall Formation to the overlying Gutenstein Formation on mount Teinberg (596 m, east of Gutenstein) is sharp, so that a rapid increase of the accommodation space from a predominantly marginal- to shallow-marine hypersaline environment of the

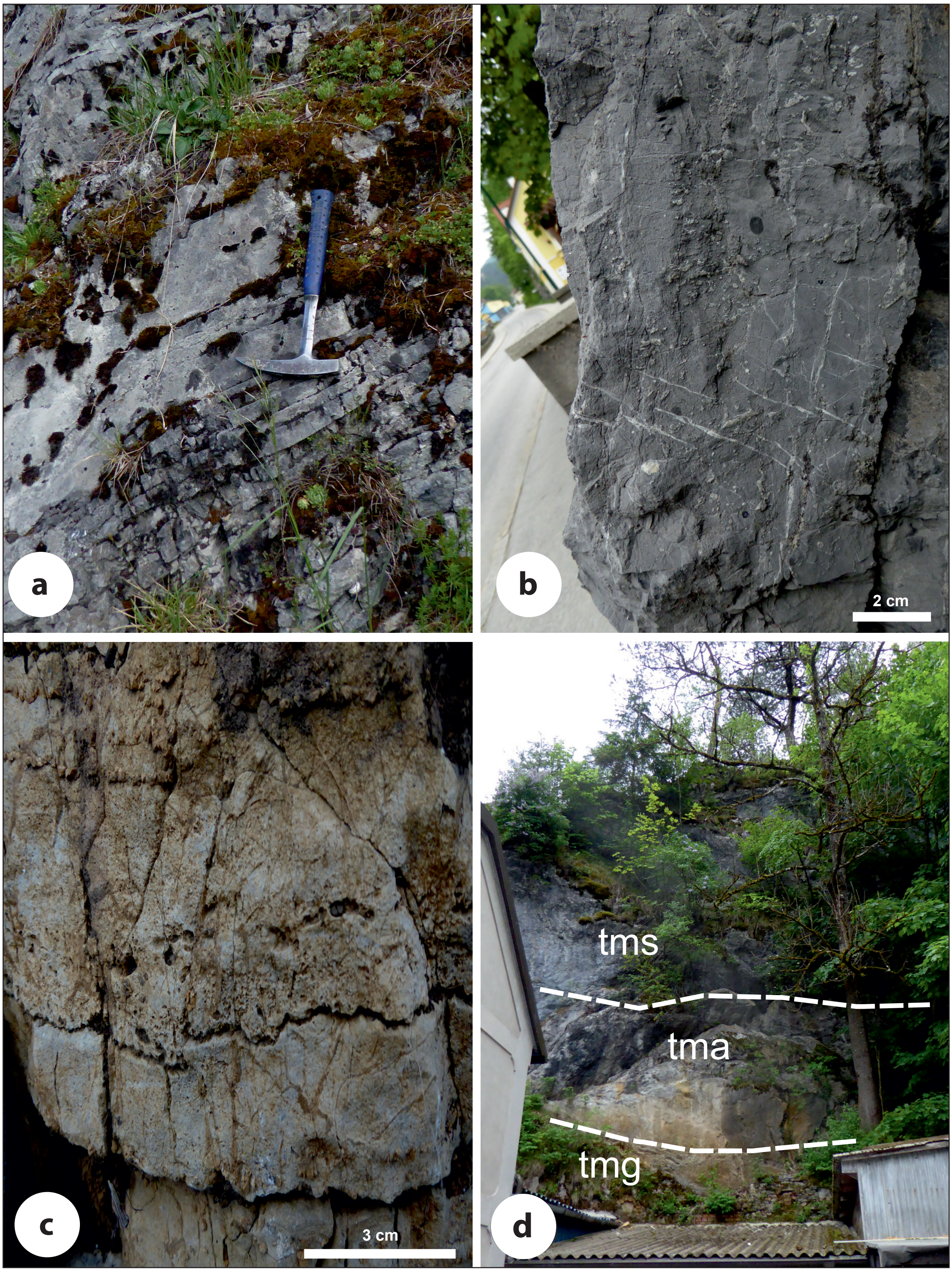

Figure 10: (a) 20 cm thick bed of a planar-bedded, coarse grained biodetritic layer (at pike of hammer), intercalated into the upper portion of the Gutenstein Formation at Gutenstein (Location: outlet of Längapiesting valley, south of Gutenstein); **(b)** Fine-grained detritus of crinoids within a dark-grey and micritic limestone bed (wackestone, biomicrite) of the uppermost part of the Gutenstein Formation, indicating a transition into the microfacies of the Annaberg Formation (Location nearby former inn „Zur Paßbrücke"); **(c)** Graded bedded layer with erosive contact at the base (superimposed by stylolithization) within the Gutenstein Formation at mount Gaisstein (974 m, Gutenstein Alps, Lower Austria); **(d)** At the bottom of the rockface (below the dashed line) steeply inclined strata of the well bedded and dark-grey colored Gutenstein Formation (tmg), which are overlain (above the dashed line) by thick bedded, browngrey colored, biodetritic limestones of the Annaberg Formation (tma) and the massive, light colored limestone with dasycladacelan green-algae of the Steinalm Formation (tms), corresponding to section III of Flügel and Kirchmayer, 1963 (exposed along the southern margin of the market area in Gutenstein).

Reichenhall Formation to the rather open-marine, radiolarian-bearing depositional environment of the Gutenstein Formation above is assumed. The rapid increase in water-depth ("drowning") during the earliest Anisian corresponds well to the "*Muschelkalktransgression*" (transgressive system tract, TST) in Central and Northern Europe (Riech, 1978; Szulc, 1999) on the one hand and to a significantly increased subsidence of the continental margin during the early Anisian on the other. Accordingly, Sarnthein (1966) has described the rework of Reichenhall stromatolites at the base of the deeper marine crinoidal calcarenites of the Middle Triassic "Muschelkalk"- succession within the western NCA. Also, Lein et al. (2012) proposed a TST for the beginning of the Bithynian (A-1-sequence). Thin-sections, coming from the region of the Tirolic "Muggendorf Outlier" (Lower Austria, 7 km NE of Gutenstein, see Figs 4a, b), a back-thrusted part of the Unterberg Nappe, show dark, finely bedded and sterile pelmicrites which bear some remnants of crinoids at the base of the Mid-Triassic stratigraphic succession. In addition, ostracods, thin-shelled pelecypods and nodosariid foraminifers indicate a deeper, fullymarine environment. Geopetal fabrics within the intercalated breccious rauwackes testify to mass transport processes. Based on these facts, we infer the possibility, that the lowermost part of the Gutenstein Formation may comprise deeper-water evaporites, as is indicated by the occurrence of laminated carbonates, rich in organic material and a sporadic occurrence of evaporitic cumulates within the black and fine bedded limestones. Also, in other parts of the NCA, the thin-bedded limestones of the basal Gutenstein Formation are interbedded with thick rauwacke-layers (e.g. Moser, 2021b). This could possibly be explained by at times increased subsidence within the shallow-marine environment, where hypersaline, Mg-rich fluids had dolomitized some of the limestone-beds of the Gutenstein Formation.

4.2.2. The boundary of the Gutenstein Formation to the overlying litho-units (Annaberg Formation, Steinalm Formation)

Results:

In the type-area of Gutenstein, the Gutenstein Formation comprises an upper interval of increasing bed thicknesses and some bright greyish rock colors. Particularly, this is observed within the rocky ravine of the Piesting-river at the location Paßbrücke (bridge over the Piesting-river), and also along the upper part of the rocks exposed above the houses between Taborweg and Kaisersteig and at the entrance into the Längapiesting valley (Fig. 10a). These rocks are part of the overall gradual transition from the thin-bedded, mainly fine-grained, pelitic limestones of the underlying Gutenstein Formation into the upsection thick-bedded or massive limestones, which „*complete the development of Gutenstein Limestone upwards*" (Summesberger and Wagner, 1971). Thin-sections, prepared from rock-samples taken in the surroundings of the location "Passbrücke" (sample 18/75/04), reveal a microfacies of finely layered wackestones (biomicrites), which resembles that of the Annaberg Formation (as defined by Moser and Piros, 2021), including fine crinoidal detritus (Figs. 10b, c) and small bivalve shells (Fig. 10f) floating within the micritic matrix (Moser, 2019b). Middle- to thick-bedded, slightly brighter-colored limestones are also exposed next to the former inn "Zur Paßbrücke" (sample 18/75/05, Figs. 6 and 10d) and at the memorial cross on the opposite side of the Piesting ravine east of Gutenstein (sample 18/75/06, Fig. 6). These rocks show medium-grey to light-grey colored, sometimes finely bedded biopelsparites, rich in crinoids, foraminifers, ostracods, molluscs (pelecypods, gastropods), dasycladalean green algae and oncoids (Fig. 10f). Additionally, Summesberger and Wagner (1971) noted alga, crinoids and brachiopods as some common biogenic fragments at this location. These biogenes indicate a deposition in slightly agitated fully marine seawater with a maximum depositional depth of 10–30 m. Thus, the thick-bedded limestones are part of a significant shallowing-upwards trend, since the activity of dasycladalean green algae, as well as the activity of the oncoid-forming cyanobacteria and cyanophyceans depends on the photic zone in the topmost 10–30 m of the shallow-marine water column. In the outermost Längapiesting valley, exactly at the boundary between the underlying black-colored limestones of the Gutenstein Formation and the overlying dark- to light-grey colored Wetterstein dolomite, a distinct, light-grey colored cliff of thick-bedded to massive limestone of the Steinalm Formation occurs. This limestone occasionally shows fine-layered microbial laminites (stromatolites, Fig. 10E), which are typical of a shallow-marine, lagoonal and intertidal environment (Bechstädt and Mostler, 1974). Thin-sections show light-grey colored grain- to packstones (after Dunham, 1962) or biopelsparites and biosparites (after Folk, 1962), poor in micrite, but rich in small dasycladalean green algae (Figs. 11a–h, 12a–h), crinoids, pelecypods, foraminifers, ostracods, peloids, intraclasts and some oncoids. Oncoids and dasycladalean green algae can be considered to be representative allochems or skeletal grains of the subtidal zone within an inner carbonate-ramp setting. The pelmicritic matrix between the components was largely removed by the agitated sea water.

Following Summesberger and Wagner (1971, plate 1), the average thickness of the Steinalm Formation within the profile section of Gutenstein amounts up to 40 m. Nevertheless, if we assume a medium steep inclination of the entire succession of rocks between Paßbrücke and Lohmühle towards the south (Figs. 6, 7a), a thickness of up to 80 m seems to be more realistic. At Gutenstein, the continuous development of an Anisian distal carbonate ramp environment, passing upsection through an inner carbonate ramp stage into a Ladinian rimmed carbonate platform stage can be assumed, altogether ranging

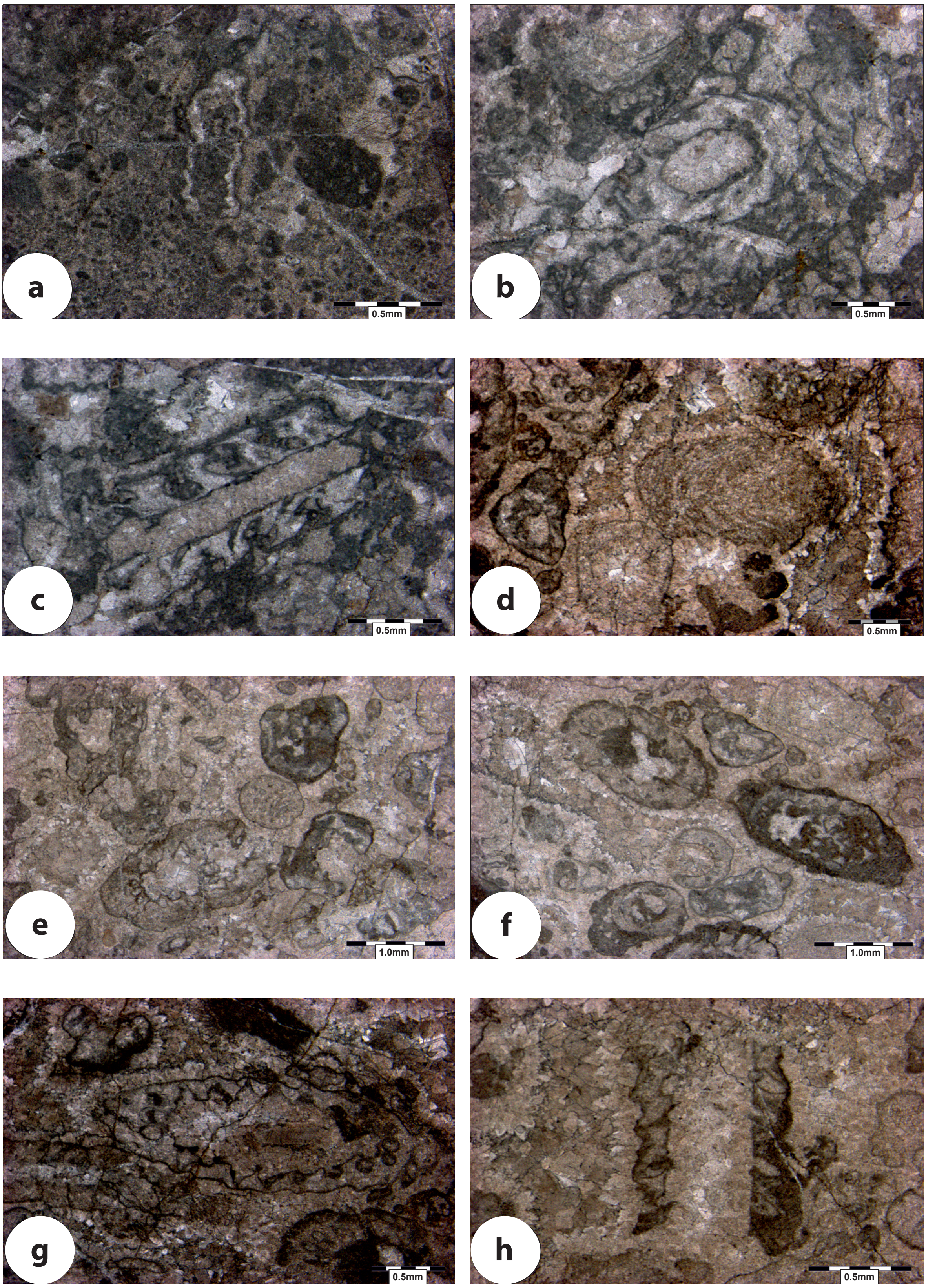

Figure 11: Dasycladalean green algae of the Steinalm Formation at Gutenstein (Lower Austria): **(a)** ? *Physoporella leptotheca* Kochansky-Devidé (Location: excavation at former inn „Zur Paßbrücke"), sample 18/75/05; **(b)** *Physoporella pauciforata sulcata* Bystrický), sample 18/75/08; **(c)** *Physoporella pauciforata sulcata* Bystrický (Location of picture B, C: western side of „Längapiesting"- valley, 1 km south of Gutenstein), sample 18/75/08; **(d)** *Teutloporella peniculiformis* Ott, sample: 18/75/09; **(e)** *Physoporella pauciforata pauciforata* Bystrický, *Physoporella pauciforata undulata* Bystrický, sample: 18/75/09; **(f)** *Physoporella pauciforata pauciforata* Bystrický, *Physoporella pauciforata sulcata* Bystrický, sample: 18/75/09; **(g)** *Physoporella pauciforata pauciforata* Bystrický, sample: 18/75/09; **(h)** *Physoporella pauciforata sulcata* Bystrický; (Location D – H: „Längapiesting" – valley, rocky outcrop next to house Längapiesting nr. 28), sample:18/75/09.

from the early Anisian (Bithynian) upwards to the earliest Carnian (Julian 1). Hence, the development of inner carbonate ramp deposits on top of the Gutenstein and Annaberg formations is represented by 80 m of shallow marine and peritidal-lagoonal deposits of the Steinalm Formation (Pelsonian-Illyrian; Fig. 7a), and, subsequently, continued into a rimmed carbonate platform environment, built up by a 300–400 m thick succession of lagoonal Wetterstein limestone and dolomite (Fig. 7a). Unfortunately, the determinations of some of the species of Illyrian dasycladalean green algae are still uncertain for the time being. Hence, the stratigraphic range of the Steinalm Formation up to the late Anisian can only be inferred from the lithostratigraphic succession. However, the complete absence of any reef-facies at the base of the Wetterstein dolomite of Gutenstein can also be regarded as an indirect evidence for the primary absence of the basinal facies of Reifling- and/or Raming formations. Mass occurrences of dasycladalean green algae, like in between the basal Wetterstein limestone and dolomite in the surroundings of Gutenstein, indicate marine water depths of only a few meters and slightly elevated salinities (*chloralgal association*, Tucker and Wright, 1990; Piros and Preto, 2008). This prolongs the inner carbonate ramp facies conditions of the Anisian Steinalm Formation upsection into the lagoonal shallow water facies conditions of the Ladinian Wetterstein dolomite and limestone. In any case, the beginning of the Ladinian stage can be situated around the base of the Wetterstein dolomite (Fig. 7A). Between the calcareous Steinalm Formation in the footwall and the overlying Wetterstein dolomite, no larger stratigraphic gap must be assumed (as interpreted formerly by Krystyn and Lein, 1996). Hence, the microfacies of the Steinalm Formation are similar to that of the overlying lagoonal Wetterstein limestone/dolomite and consist of biopelsparitic grain- and rudstones, which bear some dasycladalean green algae, pelecypods, gastropods, crinoids, foraminifers, ostracods and small oncoids. Consequently, the boundary between the Steinalm- and Wetterstein Formation can only be defined with the help of the different flora of dasycladalean green-algae and the different fauna of foraminifers. In addition, the Wetterstein Formation is generally characterized by rather white rock colores.

Discussion:

The biodetritic crinoid- and brachiopod-bearing upper part of the Gutenstein Formation at Gutenstein contains *Nicoraella kockeli* Tatge, which indicates an early Pelsonian age for this horizon (Krystyn and Lein, 1996). A change in microfacies is observable in profile sections, where the Annaberg Formation appears in the hanging wall of the Bithynian part of the Gutenstein Formation (Moser and Piros, 2021), as far as the limestones of the Annaberg Formation represent the transition from the outer carbonate-ramp deposits of the Gutenstein Formation into the inner carbonate-ramp deposits of the Steinalm Formation. Based on the fact that the occurrence of the transitional beds of the Annaberg Formation within the NCA is strictly linked upwards to the presence of the Steinalm Formation (Moser, 2019b), the occurrence of the three Anisian lithostratigraphic units, the Gutenstein Formation, Annaberg Formation and Steinalm Formation, represents a sequence of related facies. Following models by Ahr (1973), we interpret the depositional area of the Gutenstein Formation to the distal part of a carbonate ramp, the Annaberg Formation to an intermediate or inner part of the carbonate ramp and the Steinalm Formation to the innermost part of this very flat inclined ramp-like structure. The shallowing upwards trend of this facies succession can either be addressed to a stagnant sea level during the Pelsonian or to tectonic movements, which have eventually been driven by salt-tectonics in the subsurface (Strauss et al., 2018), as is possibly evidenced by the origin of intraformational breccias within the Annaberg Formation. Hence, the topography of the Pelsonian part of the carbonate ramp could have been a lot more complex, causing the juxtaposition of different vertical and lateral facies zones, as is, for example, visible in the different parts of the Tirolic Reisalpen Nappe (Moser, 2021a).

The rocky limestone-cliffs of Gutenstein, which Summesberger and Wagner (1971) and Summesberger (1991) have assigned to the Wetterstein limestone, are in part reinterpreted as Anisian Steinalm Formation (Fig. 6). However, at the locations Residenzberg (818 m), Theresiensteig (Steinapiesting), Edelstein and Raimundviertel, all of them located within the surroundings of Gutenstein, the lower part of the lower Ladinian lagoonal Wetterstein limestone does appear (Figs. 6, 13a-f). Also, according to our interpretations, the Steinalm Formation in the foot wall and the lagoonal Wetterstein limestone/dolomite in the hanging-wall form a continuous facies succession without any stratigraphic gap in between, as we have argued above.

From the sequence-stratigraphic point of view (Rüffer, 1995), the facies of the upper Bithynian/lower Pelsonian part of the Gutenstein Formation seems to pass through a Falling Stage System Tract (FSST) and transfers into a Lowstand System Tract (LST), which was characterized by the sedimentation of the middle Pelsonian peritidal Steinalm Formation. Rüffer (1995) has linked this LST with the regressive part of a sequence of third order A3, which does correlate with similar situated sequence-boundaries outside of the Alps. Also, Goggin and Jacquin (1993) interpreted for the Middle Triassic of the Paris Basin a regressive trend during the middle Pelsonian, corresponding to the upper part of the Gutenstein Formation, and a transgressive trend starting during the late Pelsonian, corresponding to the "*Reiflinger Wende*" (Schlager and Schöllnberger, 1974) in the hangingwall of the Gutenstein Formation within the NCA. However, the same result could be achieved through a stagnating base level and the filling of the remaining accommodation space with fine-grained calcareous sediments. Indicating an inter- to

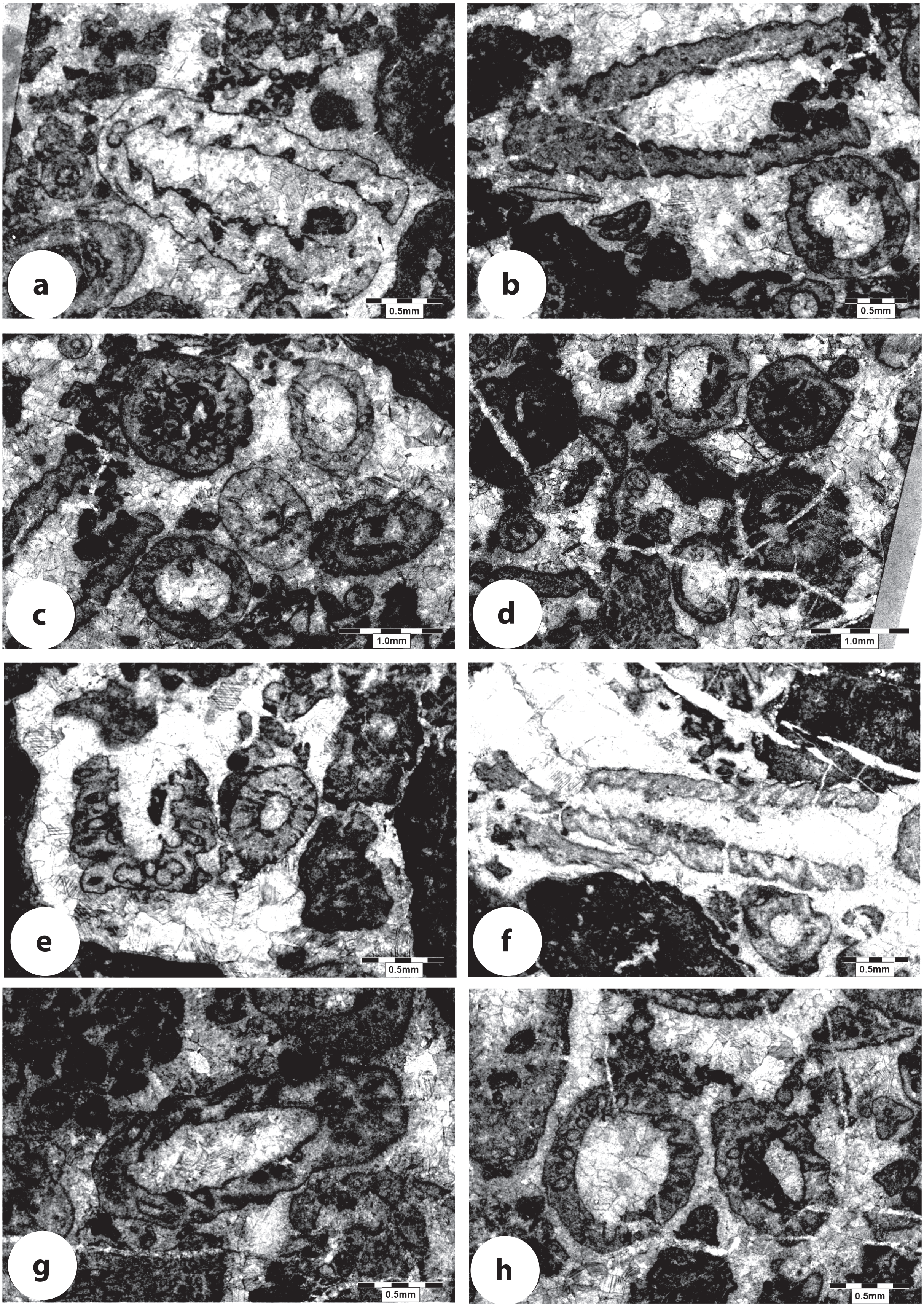

Figure 12: Dasycladalean green algae of the Steinalm Formation at Gutenstein (Lower Austria); **(a), (b), (f), (g)** *Physoporella pauciforata sulcata* Bystrický; **(c)** *Physoporella pauciforata sulcata* Bystrický, *Physoporella pauciforata pauciforata* Bystrický; **(d)** *Physoporella pauciforata pauciforata* Bystrický, *Physoporella pauciforata undulata* Bystrický; **(e)** *Physoporella pauciforata pauciforata* Bystrický, *Poncetella hexaster* (Pia) Güvenc; **(f)** *Physoporella pauciforata undulata* Bystrický; Sample: 18/75/10, creek on the western side of the valley „Längapiesting", 520 m alt. (1.2 km south of Gutenstein).

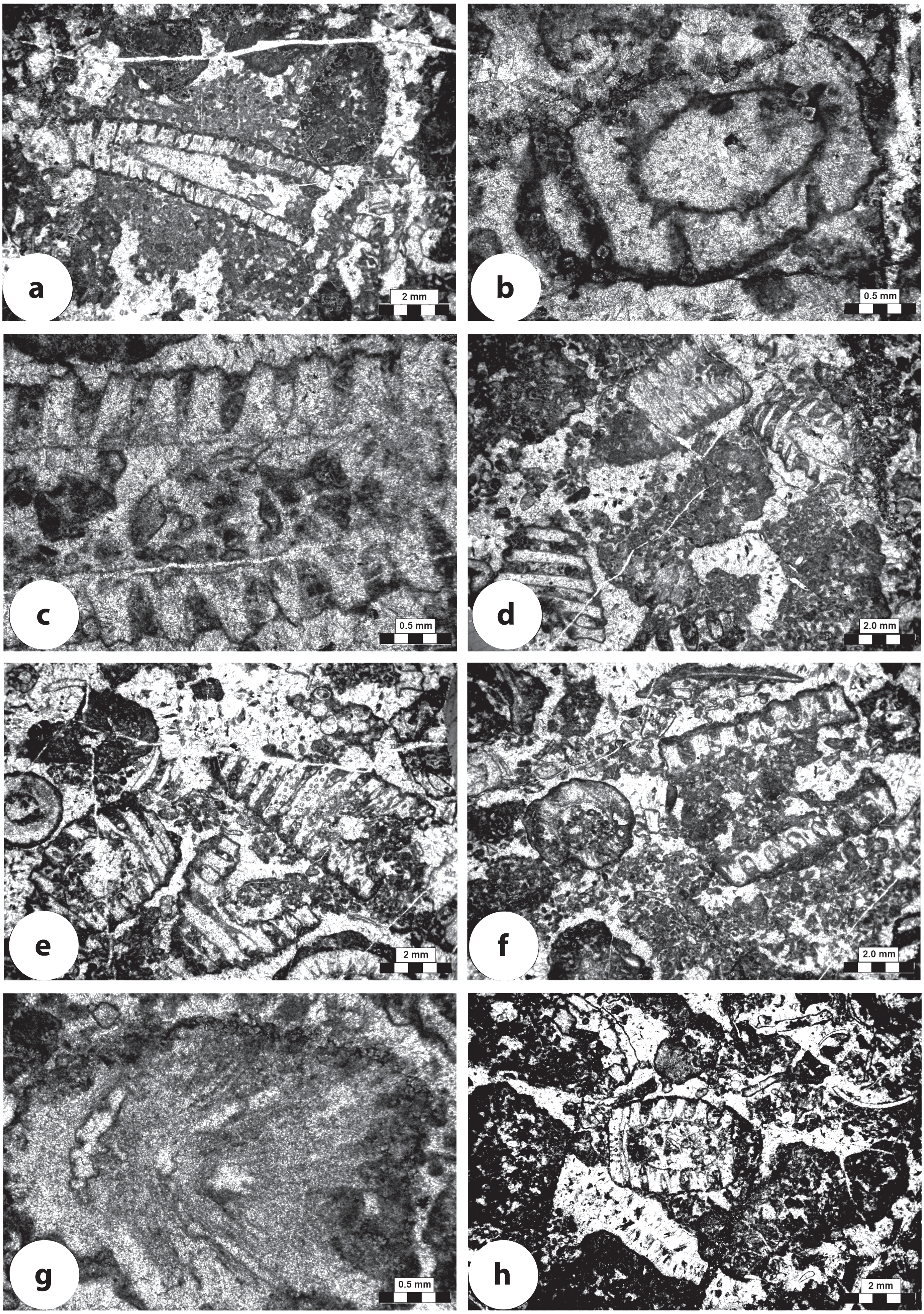

Figure 13: Dasycladalean green algae of the Wetterstein Formation at Gutenstein (Lower Austria); **(a), (c)** *Diplopora annulata annulata* Schafhäutl (Location **a:** Edelstein, sample 20/75/04; Location **c:** elevation Residenzberg, sample 20/75/02). **(d)** *Griphoporella gümbeli* (Salomon) Pia (elevation Residenzberg, sample 20/75/02); **(e), (f), (g), (h)** *Diplopora annulatissima* Pia (trail Theresiensteig, Steinapiesting, sample 20/75/03); **(b)** *Teutloporella peniculiformis* Ott (Edelstein, sample 20/75/04).

subtidal environment, Rüffer (1995) also cites stromatolites and dasycladalean green algae as constituents of a homoclinal ramp deposit during lowstand conditions like that of the Steinalm Formation. In other regions, such as the Tirolic Totengebirge Nappe (Upper Austria) or the Tirolic Reisalpen Nappe (Lower Austria), the facies-transition from the thin-bedded black-colored Lower Gutenstein Formation to the thicker-bedded, grey-colored Upper Gutenstein Formation (Kasberg Member, Moser and Moshammer, 2018) can equally interpreted as a gradual shallowing upward sequence (highstand system tract: De Zanche et al., 1993; highstand system tract: Lein et al., 2012; maximum flooding surface: Hagdorn, 1991; Götz et al., 2005).

In some parts of the Bajuvaric Nappe System, like the Lunz- and Reichraming Nappe, the Gutenstein Formation is replaced by the Annaberg Formation and, within the Sulzbach Nappe, is superimposed by the Steinalm Formation. Similar might be true for the Juvavic domain of the Mürzalpen-, Dachstein- and Schneeberg nappes. In the western part of the NCA, some authors (e.g. Pia, 1924; Hirsch, 1966; Kobel, 1969; Wagner, 1970) cite the occurrence of black, well bedded limestones of the "*Gutenstein Formation*" in the area of the Rhätikon- (Vorarlberg) and Steinerne Meer mountains (Salzburg), although, in later publications, the occurrence of the Gutenstein Formation, in its herein defined facies, is questioned there (Bechstädt and Mostler, 1974). Based on its higher bed-thicknesses, intense bioturbation (vermicular limestones), terrigenous influence (clay and silt) and increased growth of shallow-water organisms like dascladalean green algae, gastropods or crinoids, the majority of the lower and middle Anisian limestones and dolomites of the western NCA must be assigned to the shallow-marine Virgloria Formation (Richthofen, 1859) or Annaberg Formation (Tollmann, 1966), but not to the slightly deeper and dysoxic facies of the Gutenstein Formation (Kobel, 1969). Similar arguments can be cited from different occurrences of the so-called "*Gutenstein Formation*" within the Inner West-Carpathians, Malé Carpathians and Dinarides (Andrusov, 1959; Dimitrijević and Dimitrijević, 1991; Michalík et al., 1992; Hips, 1998), which may better assigned to the likewise tempestitic-oolithic and shallow-marine facies of the Annaberg Formation (like in Lower Austria), but not to the Gutenstein Formation (Moser and Moshammer, 2018). In the area of the Silica Nappe, which is located in the Slovakian-Hungarian part of the Inner Western Carpathians, Hips (2007) has differed between a Jósvafő Limestone Member, which does correlate lithostratigraphically with the Gutenstein Formation of the NCA, and an "*Annaberg Limestone Member*" upsection. Subsequently, based on the descriptions by Flügel and Kirchmayer (1963), she assigned both members to "*lagoonal deposits*" as part of a monotonous and restricted shelf environment slightly below the storm wave base (Hips, 2007). However, the lithological and facial descriptions of thick-bedded or massive, dark-grey colored, laminated, cross-bedded and also, burrowed mudstones, which bear some pelecypod-coquina layers (as tempestites), gastropods, crinoids, bioclastic packstones and evaporite crystal moulds (Hips, 2007) clearly exclude the assignment of these lithotypes to the Gutenstein Formation. These mudstones may be interpreted alternatively as shallow-marine depositional facies similar to that of the Annaberg Formation. Consequently, no radiolarians, ammonites or tempestitic layers are cited from these limestones.

4.3. The bio- and lithostratigraphic subdivision of the Gutenstein Formation at Großreifling (Styria), Grünau (Kasberg, Upper Austria) and Innerfahrafeld (Fuchsriegel, Lower Austria)

In contrast to Gutenstein, the surroundings of Großreifling (Styria), Grünau (Upper Austria) and Innerfahrafeld (Lower Austria) have provided particularly significant fossil data from the upper part of the Gutenstein Formation. Due to the development of a thick and continuous Anisian and Ladinian open and deep marine basinal succession in Großreifling (Styria), which excludes the occurrence of the shallow water facies like that of Steinalm- or Annaberg formations, the boundary between the upper part of the middle Anisian Gutenstein Formation and the lower part of the upper Anisian lower Reifling Formation is biostratigraphically well constrained. Concerning ammonites, the well-known "Upper Binodosus Fauna" fauna, cited by Summesberger and Wagner (1972) from the topmost layers of the Gutenstein Formation within the Rahnbauerkogel- and Tiefengraben – sections near Großreifling (Fig. 14), correlates well with occurrences of *Balatonites egregius* Arthaber 1896 (Fig. 14) and *Balatonites balatonicus* Mojsisovics 1873 at Großreifling (Tatzreiter, 2001). All these fossil findings indicate an age between the latest Bithynian and the late Pelsonian. We will notice that this important horizon is not included in the chronostratigraphic range of the Gutenstein Formation at its type-locality at Gutenstein (Fig. 7a). Nevertheless, the 60–70 m thickness of the Gutenstein Formation at Großreifling comprises a similar value as is exposed at Gutenstein. Based on this study and on Summesberger and Wagner (1972), it can be confirmed, that in some regions, especially where the Gutenstein Formation passes upwards directly into the deep-marine Lower Reifling Formation, as is visible at Großreifling (Styria) or Innerfahrafeld (Lower Austria), the Gutenstein Formation does comprise both, a lower Anisian (Bithynian) Substage and a middle Anisian (Pelsonian) portion. This fact is biostratigraphically constrained by the cited ammonites (see above and Arthaber, 1896, and Tatzreiter, 2001), which were taken from the uppermost beds of the Gutenstein Formation in Großreifling (mount Rahnbauernkogel and creek Tiefengraben, Figs. 4a, 7b, 14) and by conodonts (Moser, 1993) from the Anisian bedrock "*Mittelanisischer Knollenkalk*" („*middle Anisian nodular limestone*") in the Kasberg-region near Grünau. Additional data come from Sikabonyi (1997), who cites a small Pelsonian ammo-

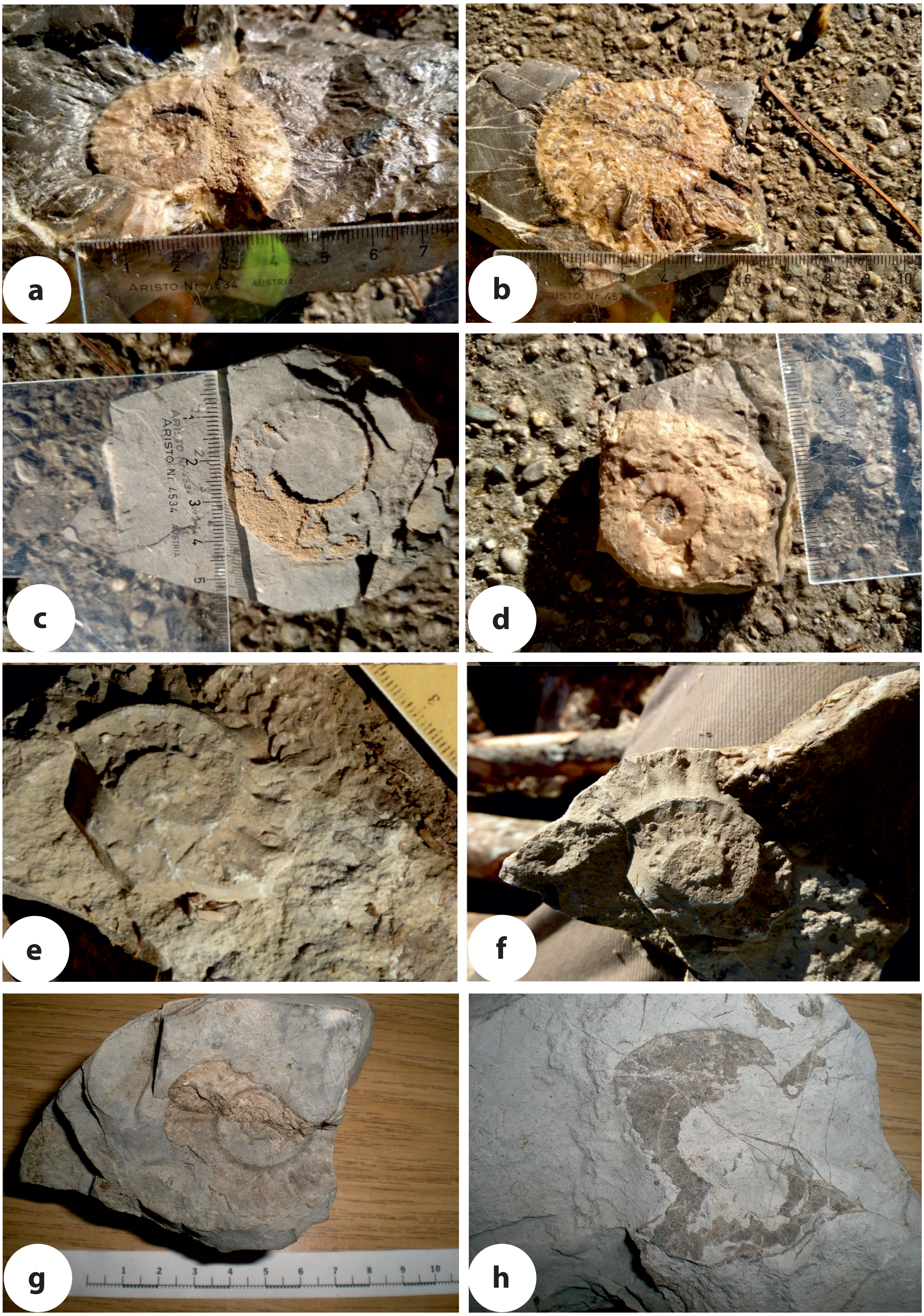

Figure 14: *Balatonites* sp., from the Gutenstein Formation at Großreifling (Styria): Determinations: Attila Vörös (Budapest); **(a) – (d)** *Balatonites egregius* Arthaber, 1896 (mount "Rahnbauernkogel", 500 m NE of Großreifling, 580m alt., Styria); **(e), (f)** *Balatonites* sp. (Forest road to creek "Tiefengraben", 1.75 km NE of Großreifling, 540m alt., Styria); **(g), (h)** ? *Balatonites* sp. (Gutenstein Formation at Großreifling, Styria).

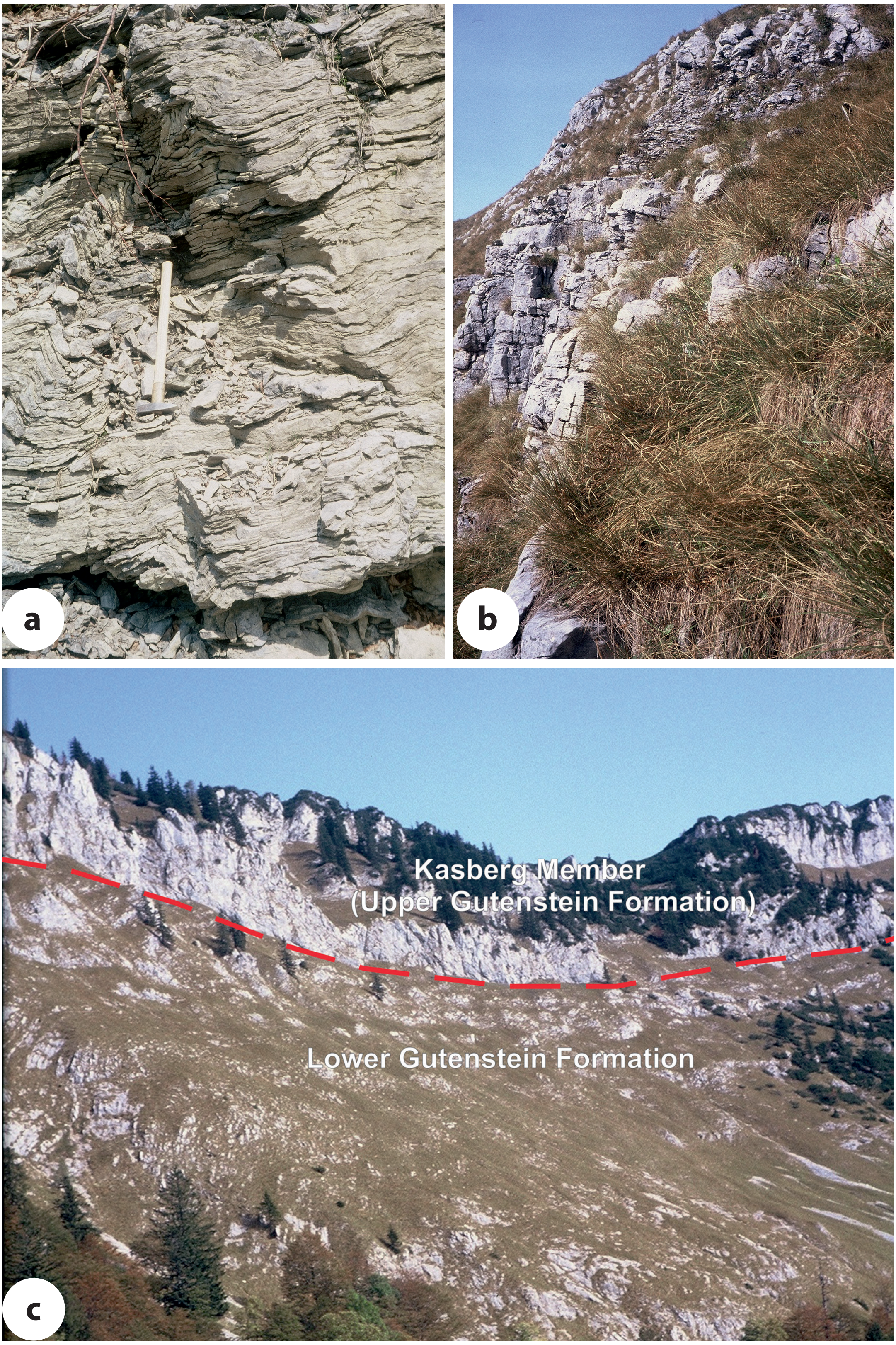

Figure 15: Representative outcrop photographs, showing the lithostratigraphic subdivision of the Gutenstein Formation at Mount Kasberg (Upper Austria); **(a)** Very thin and planar-bedded, dark-grey and slightly folded limestone of the Gutenstein Member within the Kasberg- area between the Alm- and Steyr-valley in Upper Austria; **(b)** Alternating thin- and medium-bedded as well as coarse- and fine-grained bituminous limestones with planar or wavy bedding planes, typical of the Kasberg Member (Upper Gutenstein Formation) between Mount Spitzplaneck (1617 m) and Mount Kasberg – summit (1747 m), cliff about 1430 m a.s.l.; **(c)** The lithostratigraphic subdivision of the Gutenstein Formation into a completely thin-bedded lower section ("Gutenstein Member") and a thin- to medium-bedded, planar and/or wavy-bedded, fossiliferous upper section (Kasberg Member) is developed on mount Kasberg in Upper Austria (Moser and Moshammer, 2018). The red, dashed line indicates the morphologically distinct boundary between the two members of the Gutenstein Formation; Location: mountain ridge between Mount Spitzplaneck (1617 m) and Mount Kasberg (1747 m).

nite-fauna from the Gutenstein Formation at Türnitz (SW of farm Hölzel), with the genera *Norites* sp. and *Balatonites* sp., and some brachiopods like *Decurtella decurtata* Girard 1843, all of which are typical of the Upper Gutenstein Formation of Pelsonian age. Also, we found Pelsonian ammonites (*Balatonites* sp.) and brachiopods within the Upper Gutenstein Formation at Mount Gaisstein (974 m, near Furth/Triesting) and on the elevation Fuchsriegel (984m, near Innerfahrafeld, Lower Austria, Fig. 4b), within the lowermost beds of the Upper Gutenstein Formation. Finally, a sample taken from the Upper Gutenstein Formation at Mount Gaisstein (Fig. 4b) yielded several specimens of the early- to middle Anisian conodont-species *Nicoraella microdus* (pers.comm. L. Krystyn, Vienna).

In all these sections a distinct development of the Gutenstein Formation exists, deviating in its upper portion from the characteristic lithologic parameters of the stratotype at Gutenstein itself, making possible a further subdivision (Fig. 15) into a lower and an upper member (Krystyn and Lein, 1996; Moser and Moshammer, 2018; Moser and Krystyn, 2020a; Moser 2021a). All former descriptions (Summesberger and Wagner, 1972; Moser, 1993; Moser and Piros, 1994; Krystyn and Lein, 1996; Moser and Moshammer, 2018; Moser and Krystyn, 2020a) agree with the fact, that the bedding planes of the Upper Gutenstein Formation develop a nodular or wavy-layered appearance and show an on average larger bed thickness than the lower part (Figs. 8, 15b, c). Additionally, the Upper Gutenstein Formation is characterized by the frequent occurrence of brachiopods and crinoids (encrinites and crinoid-brachiopod limestone) and is often rich in conodonts and occasionally ammonites. New conodont data, coming from the Upper Gutenstein Formation, were derived from the area around Mount Fuchsriegel (984 m, Fig. 4b) in the vicinity of Innerfahrafeld (Lower Austria, see Tab. 3). The presence of *Paragondolella bifurcata* (det. Krystyn, Vienna) indicates, together with the brachiopods *Punctospirella fragilis* Schlotheim 1813 and *Piarorhynchella trinodosi* Bittner 1890 (det. M. Siblik, Prague), a late Pelsonian age (Moser, 2021a). Additionally, holothurian sclerites such es *Priscopedatus staurocumithoides* Mostler 1968, *Priscopedatus* cf. *tyrolensis* Mostler 1968, and *Tetravirga* sp. confirm the Pelsonian age of the Upper Gutenstein Formation at Innerfahrafeld. Given the fact that these different lithofacies within the upper part of the Gutenstein Formation can be mapped at least on a scale of 1:10 000 (Moser and Moshammer, 2018) and since these differences, if available, can be identified in the field easily (Fig. 15c), a definition of two regional members is possible. Accordingly, the "*Mittelanisischer Knollenkalk*" (Moser, 1993), which also includes bankwise intercalations of biodetritic crinoid-rich limestones (e.g. encrinites) and crinoid-brachiopod bioarenitic limestones (Moshammer, 2000), comprises the upper portion of the Gutenstein Formation in the Mount Kasberg-area (Fig. 15c) and occurs, *inter alia*, also in the summit region of Mount Kasberg (1747 m) itself. Consequently, herein we emphasize to designate an upper member of the Gutenstein Formation as "*Kasberg Member*" nov. nom., as is defined in Upper Austria by Moser & Moshammer (2018). The small conodont fauna (Tab. 3), which Moser (1992) reports from the "*Mittelanisischer Knollenkalk*" (= Kasberg Member of this study) at Mount Kasberg (Figs 4a, b) and from the Upper Gutenstein Formation at Mount Fuchsriegel (Moser, 2021a) and Gaisstein (Moser and Krystyn, 2023), correlates well with the conodont fauna, which Tatzreiter (2001) has derived from the creek Tiefengraben (Großreifling), including the appearance of *Balatonites balatonicus* Mojsissovics (Arthaber, 1896).

We propose to define the lithostratigraphic base of the Kasberg Member (a synonym of "Upper Gutenstein Formation" or "Mittelanisischer Knollenkalk") with the occurrence of the first thick, wavy or nodular beds, which commonly contain some crinoids, brachiopods and ammonites as characteristical bioclastic elements. In contrast, the Gutenstein Formation, as is developed in the area of Großreifling (and the adjacent „*Großreiflinger Scholle*"), but also in other regions, shows not in any case a clear-cut lithostratigraphic subdivision into two members. There, the upper part of the Gutenstein Formation reveals a alternation of nodular and planar-shaped bedding planes and a clear demarcation of the Kasberg Member in the field is impossible in this case. The nodular beds within the Gutenstein Formation at Großreifling already start within the late lower Anisian (upper Bithynian) and become more and more common up-dip (Summesberger and Wagner, 1972, profile sheet). Nevertheless, within the Scheiblinggraben- and Tiefengraben sections, situated in the surroundings of Großreifling, the planar- and thin-bedded bedrocks also prevail in the upper part of the Gutenstein Formation. Thus, a distinct middle Anisian upper member of the Gutenstein Formation is lithologically not universal distinguishable in such regions. Therefore, a separation of a lower Anisian and middle Anisian part within the Gutenstein Formation seems to become possible only with the help of (micro)fossils and, for the field-geologist, with the help of morphological criteria like steep cliffs, which characterize the in average thicker-bedded upper part of the Gutenstein Formation. For the deeper, lower Anisian (Bithynian) part (Figs. 8, 15a) of the classical developed Gutenstein Formation, as it was described by Hauer (1853), Stur (1871) and Pia (1930), only the stratigraphic terms "Lower Gutenstein Formation", "Gutenstein Member" or even Gutenstein Formation are applicable.

Solution residues, extracted from crinoid-brachiopod-limestones coming from the Kasberg Member (Kasberg, Fuchsriegel, Figs. 4a, b) are rich in microfossils (described in chapter 4.1.1.) and contain, besides disarticulated brachialia and columnalia of crinoids, echinoid-spines and numerous broken brachiopod-fragments.The occurrence of broken and overturned shells may indicate redeposition during short high-energetic storm- events, whereby the bioclasts were transported from sublittoral to external parts of the carbonate ramp setting. Besides this, we regard the appearance of

	Upper Gutenstein Formation (Kasberg Member)						stratigraphic range
	Gutenstein [1]	Kasberg, Rabenstein [2]	Großreifling [3]	Innerfahrafeld [4]	Fuchsriegel [4]	Gaisstein [5]	
Paragondolella bifurcata		x	x	x	x		Late Pelsonian
Nicorella kockeli	x	x	x				Pelsonian
Paragondolella bulgarica	x		x				Pelsonian
Nicorella germanica		x					Pelsonian
Nicorella microdus						x	Early Pelsonian
	[1] Krystyn and Lein 1996	[2] Moser and Moshammer 2018	[3] Tatzreiter 2001	[4] Moser 2021a		[5] Moser and Krystyn 2023	

Table 3: Conodonts, derived from the Upper Gutenstein Formation (Kasberg Mamber) at different locations in Lower Austria and Upper Austria.

dark-grey colored, cm-thick layers of marls, which can be intercalated between the limestones-beds, as a characteristical feature of the middle Anisian Kasberg Member (Tatzreiter, 2001), as is visible similarly in other regions of the NCA within the upper, Pelsonian part of the Gutenstein Formation.

5. Conclusions

After the reassessment of the type locality at Gutenstein (Lower Austria), we conclude that only the basal 70–90 m (section I, outcrop 20–24 of Flügel and Kirchmayer, 1963) correspond to the (tectonically slightly reduced) real thickness of the Gutenstein Formation in its characteristic form of thin- and planar bedded, black limestones. For these, we emphasize a deeper marine, hemipelagic outer carbonate ramp deposit. The up to 80 m thick massive shallow-water limestones on top of the Gutenstein Formation at Gutenstein correspond to the Steinalm Formation (as is defined by Pia, 1924). The stratigraphic range of the Steinalm Formation at Gutenstein seems to comprise the middle and upper Anisian. Only the onset of Wetterstein dolomite appears during the lowest Ladinian or uppermost Anisian *Secedensis* Zone. Hence, we assume a continuous development of a carbonate platform on top of the carbonate ramp deposits of the Gutenstein Formation at Gutenstein (platform succession), extending from the middle Anisian (Pelsonian) Steinalm Formation up to the Ladinian and lowest Carnian Wetterstein dolomite formation, without intercalation of basinal deposits such as the Reifling- and Raming formations in between (Fig. 16). This sequence of related facies is regarded as to be typical of the Tirolic Göller Nappe, paleogeographically situated more to the south of the NCA in respect to other thrust sheets of the Tirolic and Bajuvaric Nappe System (Fig. 2). Paleogeographically towards the north, the upper Anisian and Ladinian basinal Reifling- and Raming formations substitute different parts of the Wetterstein dolomite and limestone of the Göller Nappe in the south, as is reported from different sections within the Unterberg- and Reisalpen Nappe (Moser and Krystyn, 2020a, b), which were paleogeographically situated further to the north. The supply of shallow-marine detritus into the allodapic Raming Formation during the uppermost Anisian of the Reisalpen- and Unterberg Nappe (Moser and Krystyn, 2020b) in the north very likely corresponds to the onset of the shallow-marine platform facies within the upper Anisian and lower Ladinian Wetterstein Formation of the Göller Nappe in the south (Moser, 2019a). In certain regions of the Tirolic Nappe System (Totengebirge Nappe, Reisalpen Nappe), the 300–400 m thick Gutenstein Formation can be subdivided into a newly defined, middle Anisian upper member, the Kasberg Member (= Upper Gutenstein Formation) and a lower Anisian lower member, which corresponds to the classical (Lower) Gutenstein Formation as Gutenstein Member or Formation. The Kasberg Member comprises wavy-nodular and planar-bedded grey limestones with elevated bed- thicknesses and is typified by a diverse fossil content, such as ammonites, conodonts, brachiopods and crinoids. The so far determined stratigraphic age of this Kasberg Member is Pelsonian (middle Anisian), attested by conodonts, brachiopods and ammonites.

Appendix

A1. Formal lithostratigraphic definition of the Gutenstein Formation

Designation:

The lithostratigraphic term ‚Gutensteiner Kalk' has been introduced 1853 by Franz Hauer as *„Guttensteiner Kalk"* and 1858 by Dionys Stur as *"Gutensteiner Kalk"*, named after the village Gutenstein in Lower Austria (district Wiener Neustadt-Land).

Synonyms:

In literature, there exist several synonyms of the term 'Gutensteiner Kalk' like: *Gutensteiner Schichten* (Götzinger et al, 1954), *Gutensteiner Dolomit* (Stur, 1871), *Gutensteiner Kalk* (Hauer, 1853), *„Kugelkalk"* (Wessely, 1984), *„Knitterschichte"* (Rosenberg, 1953), *„Balatonitenschichten"* (Rosenberg, 1952). Also some terms of stone cutters exist like: *„Marble of Privatonberg"* (at Heiligenkreuz), *„Marble of Türnitz"*, *„Marble of Lilienfeld"*, *„Marble of Bludenz"*, *„Black marble of Spital/Pyhrn* (Kieslinger, 1966).

Type-area:

The type-area of the Gutenstein Formation is situated within the Gutenstein Alps between the Traisen-, Triesting- and Piesting valley in Lower Austria, including the

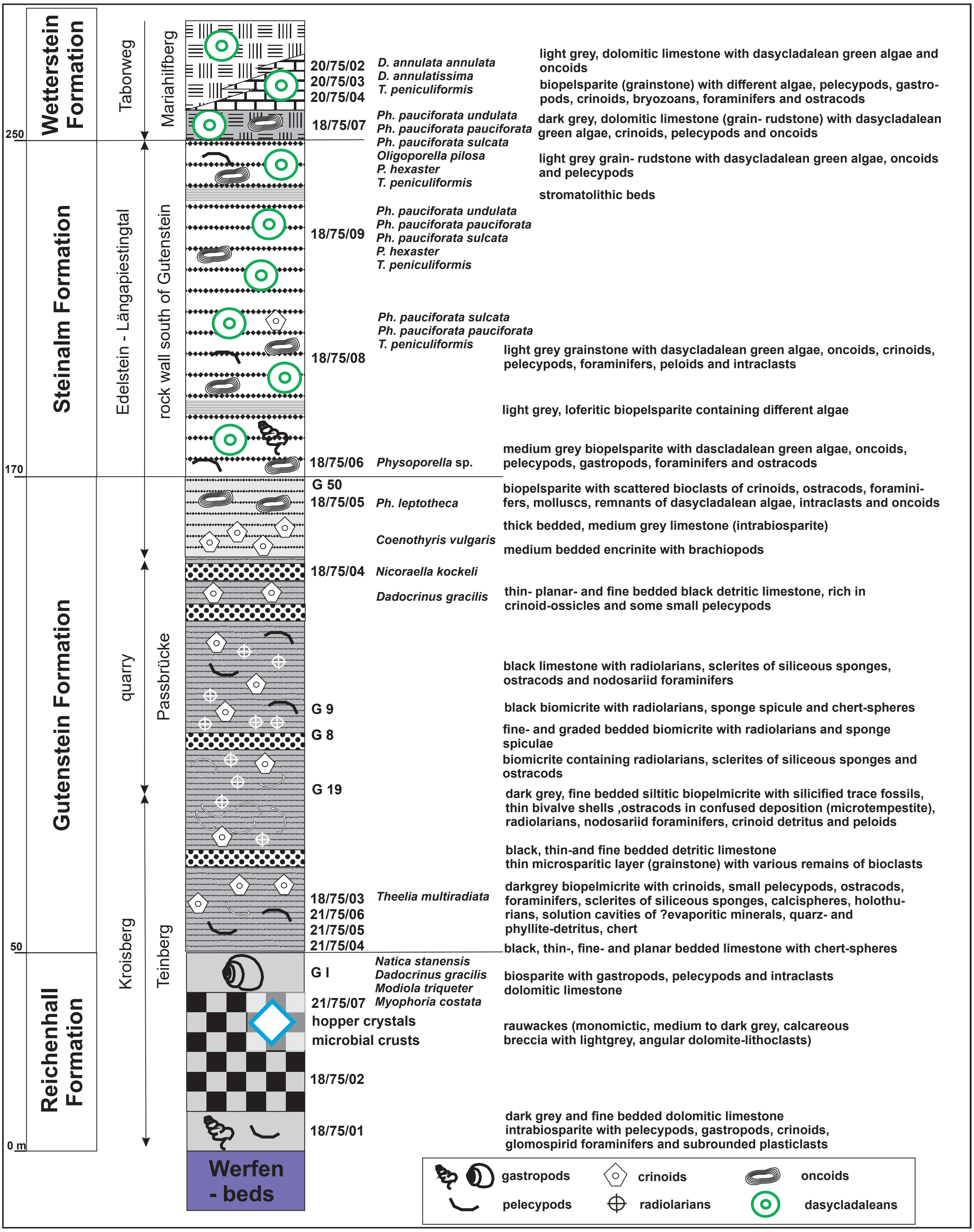

Figure 16: The type section, lithostratigraphy and biostratigraphy of the Gutenstein Formation at the type locality at Gutenstein.

surroundings of Gutenstein (Mount Kroisberg, 597 m, Mount Teinberg, 596 m, Paßbrücke – Lohmühle and the elevation Mariahilfberg).

Type-locality:

The type-locality Gutenstein is situated on ÖK 50-sheet 75 Puchberg/Schneeberg and UTM 4206 Pernitz in the federal state of Lower Austria.

Type-section:

The type-section for the Gutenstein Formation comprises the old quarry Paßbrücke near the former inn „Zur Paßbrücke" (situated at Vorderbruck, 1 km east of Gutenstein) and the outer sector of creek Panzengraben and Längapiesting valley (Fig. 16). **(1)** quarry „Zur Paßbrücke": UTM 33N: 5 67 375 / 5 302 931 resp. WGS84: 15°45′03′′/ 47° 52′34′′ **(2)** Mount Traflberg: UTM 33N: 5 64 321 / 5 309 175 resp. WGS84: 15°51′40′′/ 47°55′57′′

Reference sections:

As reference sections we suggest: **(1)** Mount "Rahnbauerkogel" near Großreifling (Styria) (UTM 33N: 4 78 825 / 5 279 636 resp. WGS84: 14°43′04′′/47°40′11′′): Bed 3–8 in: Arthaber (1896), Bed 1–8 in: Rosenberg (1953), Sequence II, Bed 1–6 in: Gessner (1963), Summesberger and Wagner (1972); **(2)** Kasberg-road (Kasberg, 1747 m, western flank, Kasberg road, Upper Austria, UTM 33N: 3 47 834 / 5 291 413 resp. WGS84: 13°58′19′′ / 47°48′20′′): Moser & Moshammer (2018); **(3)** Forest road on the western hillside of mount Fuchsriegel (984 m) at Innerfahrafeld (Türnitz – Gutenstein Alps, Lower Austria, UTM 33N: 5 44 806 / 5 312 342 resp. WGS84: 15°36′00′′ / 47°57′46′′): Moser (2021a).

Lithology:

The main lithology of the Gutenstein Formation is represented by thin-bedded (2–10 cm-bedded), black-colored, fine-grained limestone or dolomite with planar bedding- planes and occasionally with small chert-spheres. Most of the Gutenstein Formation is poor in fossils, but radiolarians (mostly preserved as calcispheres), crinoids, pelecypods and foraminifers occur. Some limestone beds show a fine lamination of very fine-grained biodetritus and, rarely, graded bedding, too. Elevated contents of organic carbon and some fine-grained pyrite are present in most of the blackish limestones. The main lithology described herein is consistent with the whole eastern NCA. In some regions, where the Gutenstein Formation shows great thicknesses, an upper part can be separated (see Kasberg Member), showing an alternation of planar- and wavy/nodular bedding planes, in average greater bed-thicknesses and a greater fossil content which mainly consists of crinoids, brachiopods, conodonts and ammonites. Occasionally, evidence of evaporites may occur at the base of the Gutenstein Formation.

Lithostratigraphic superunit and subdivision:

The „Alpine Muschelkalk Group" was emphasized by Rüffer (1995) as a lithostratigraphic superunit including the Gutenstein Formation. As a lithostratigraphic subdivision of the Gutenstein Formation the following terms have been proposed: **"**Gutensteinerkalk-Basisschichten" (Cornelius and Plöchinger, 1952), „Gutensteiner Basisschichten" (Tollmann, 1966), „Mittelanisischer Knollenkalk" (Moser, 1992), Kasberg Member (Moser and Moshammer, 2018), Unterer Gutensteiner Kalk, Oberer Gutensteiner Kalk (Krystyn and Lein, 1996), Obere Gutenstein Formation (Moser, 2021a). The **"**Gutensteiner Basisschichten", which represent a lithostratigraphic significant unit within the Juvavic "*Lammertal-Zone*", replace the Reichenhall Formation lithostratigraphically and chronostratigraphically (Tollmann, 1976a) and are partly allocated to the Lower Triassic (Mostler and Rossner, 1977). Recent investigations (Gawlick, 1996; Moser, 2024) suggest the liquidation of the lithostratigraphic term "Gutensteiner Basisschichten", because no Gutenstein Formation exists in this part of the Juvavic unit and confusions with other stratigraphic horizons are evident.

Chronostratigraphic range:

The chronostratigraphic age comprises the early and middle Anisian (Bithynian–Pelsonian), based on the following fossil content: crinoids – *Dadocrinus gracilis* Buch, *Encrinus liliformis* Lamarck, brachiopods – *Coenothyris vulgaris* Schlotheim, *Decurtella decurtata* Girard, foraminifers – *Meandrospira deformata* Salaj, *Pilammina densa* Pantić, *Pilaminella grandis* Salaj, conodonts – *Nicoraella microdus*, *Nicoraella kockeli* Tatge, *Nicoraella germanica* Kozur, *Gondolella bifurcata* (Budurov and Stefanov), *Gondolella bulgarica* (Budurov and Stefanov), ammonites – *Balatonites balatonicus* Mojsissovics, *Balatonites egregius* Arthaber.

The Gutenstein Formation comprises the following conodont zones (biozones):

- *Neogondolella regalis* Assemblage Zone (latest Aegean – early Bithynian)
- *Gondolella bulgarica* – *Nicoraella germanica* Assemblage Zone (late Bithynian)
- *Nicoraella kockeli* Zone (Pelsonian)

Facies:

The facies is representative for an outer carbonate-ramp setting and/or shallow neritic, moderately deep **(**basinal) setting, indicating reduced circulation of seawater under oxygen-poor dysoxic to anoxic depositional conditions. The depositional depth may have been situated between 30 m and 100 m according to the habitat of the fossil content. At the base, intermittent evaporitic intervals may indicate sea-level fluctuations in the transitional zone to the underlying evaporitic Reichenhall Formation.

Thickness:

The average thickness of the Gutenstein Formation is between 100 and 300 m.

Lower boundary:

The underlying units are represented by the Reichenhall Formation. The lower boundary of the Gutenstein Formation is defined with the first bed of black, thin and planar-bedded limestone (or dolomite), usually without or with minor rauwacke-beds and with reduced biodetritic input from the hinterland.

Upper boundary:

The overlying units are represented by the Annaberg-, Steinalm- and/or Reifling formations, defining the upper boundary of the Gutenstein Formation as a gradual transition into thin- to thick-bedded and rather bright-colored limestones or dolomites (Annaberg Formation) or, otherwise, with the first bed of nodular, marly and cherty developed filament- and radiolarian- rich limestones of the Reifling- or Raming formations. Lateral units are represented by the Annaberg Formation ("*Annaberg limestone and dolomite*"), Steinalm Formation and Virgloria Formation.

Distribution area:

The Gutenstein Formation is widely distributed within the Tirolic Nappe System in Lower Austria (Reisalpen-, Unterberg- and Göller Nappe) and Upper Austria (Totengebirge Nappe, Staufen-Höllengebirge Nappe), but occurs also in some minor parts of the Bajuvaric Sulzbach Nappe of Lower Austria, Upper Austria and Styria.

A2. Formal lithostratigraphic definition of the Gutenstein Member

Designation:

The herein emphasized lithostratigraphic term Gutenstein Member is derived from the superior stratigraphic unit Gutenstein Formation. The Gutenstein Member replaces the term "Lower Gutenstein Formation" (e.g. Krystyn and Lein, 1996; Moser and Moshammer, 2018).

Type-area:

The type-area of the Gutenstein Member corresponds to the type-area of the Gutenstein Formation, the Gutenstein Alps of Lower Austria.

Type-locality:

The type-locality Gutenstein is situated on ÖK 50-sheet 75 Puchberg/Schneeberg and UTM 4206 Pernitz in the federal state of Lower Austria.

Type-section:

The type-section for the Gutenstein Member is exposed in the old quarry Passbrücke near the former inn „Zur Passbrücke" (situated at Vorderbruck, 1 km east of Gutenstein); quarry „Zur Passbrücke": UTM 33N: 5 67 375 / 5 302 931 resp. WGS84: 15°45'03''/ 47° 52'34''.

Reference sections:

As reference sections we suggest: Kasberg-road (Kasberg, 1747 m, western flank, Upper Austria, UTM 33N: 4 22 808 / 5 295 536 resp. WGS84: 47°48'30''/13°58'8''): Moser and Moshammer (2018).

Lithology:

In regions, where the Gutenstein Formation shows great thicknesses of 300 to 400 m, a lower part can be separated, showing thin-bedded (2–10 cm-bedded), black-colored, fine-grained limestones or dolomites with planar bedding-planes and occasionally some small chert-spheres. Most of the Gutenstein Member is poor in fossils, but radiolarians (mostly preserved as calcispheres), crinoids, thin pelecypods and foraminifers occur. Some limestone beds show a fine lamination of very fine-grained biodetritus and, rarely, some gradation. High contents of organic carbon and some fine-grained pyrite are present in most of these blackish limestones.

Lithostratigraphic superunit and subdivision:

The lithostratigraphic superunit is the Gutenstein Formation.

Chronostratigraphic range:

The chronostratigraphic age of the Gutenstein Member comprises approximately the early Anisian (Bithynian), based on the following fossil content: crinoids – *Dadocrinus gracilis* Buch, *Coenothyris vulgaris* Schlotheim, *Pilammina densa* Pantić, *Nicoraella microdus*, *Nicoraella germanica* Kozur.

The Gutenstein Member comprises the *Neogondolella regalis* Assemblage Zone (latest Aegean – early Bithynian) and *Paragondolella bulgarica* – *Nicoraella germanica* Assemblage Zone (late Bithynian).

Facies:

The environment is represented by an outer carbonate-ramp setting or neritic and moderately deep basin-near facies, indicating reduced circulation of seawater under oxygen-poor dysoxic to anoxic depositional conditions. The depositional depth was situated between 30 m and 100 m water depth according to the habitat of the fossil content. At the base, intermittent evaporitic intervals may indicate sea-level fluctuations in the transition zone to the underlying evaporitic Reichenhall Formation.

Thickness:

The average thickness of the Gutenstein Member is between 100 and 300 m.

Lower boundary:

The underlying units are represented by the Reichenhall Formation. The lower boundary of the Gutenstein Member is defined with the first bed of black, thin- and planar-bedded limestone (or dolomite), usually without or with minor rauwacke-beds and with reduced biodetritic input from the hinterland.

Upper boundary:

The overlying unit is represented by the Kasberg-Member, defined with the first dm-thick and nodular limestone-beds (more abundant in fossils).

Distribution area:

The Gutenstein Member (and the Kasberg Member, see below) are distributed in regions with elevated thicknesses of the Gutenstein Formation, like the Tirolic Totengebirge Nappe, Reisalpen Nappe and the Bajuvaric Sulzbach Nappe of the NCA.

A3. Formal definition of the Kasberg Member

Type-area and designation:

The type-area of the Kasberg Member is situated within the Kasberg-region between the Alm- and Steyr valleys in Upper Austria and can be located on ÖK 50 sheet 67 Grünau/Almtal, on UTM-sheet 3206 Gmunden and UTM-sheet 4201 Kirchdorf/Krems (Upper Austria). The name, first used by Moser and Moshammer (2018), is derived from Mount Kasberg, 1747 m near the village Grünau (Upper Austria). Some synonyms can be specified like *Oberer Gutensteiner Kalk* (Krystyn and Lein, 1996), *Mittelanisischer Knollenkalk* (Moser, 1992) and *Obere Gutenstein Formation* (Moser, 2021a).

Type-section:

As a composite type-section we propose the surroundings of Kasberg summit (1747 m, 6.5 km SSE of Grünau) and the region of the elevation Rabenstein (8.4 km SSE of Grünau, Upper Austria). Coordinates Kasberg summit: UTM 33N: 4 24 960 / 5 294 740 resp. WGS84: 13°59′52′′/47°48′05′′, coordinates Rabenstein: UTM 33N: 4 25 375 / 5 292 765 resp. WGS84: 14°0′12′′/47°47′03′′

Reference sections:

Reference sections can be found on Mount Rahnbauerkogel, 690m NNE of Großreifling (Styria, UTM 33N: 4 78 780 / 5 279 595 resp. WGS84: 14°43′03′′/47°40′10′′) and in creek Tiefengraben, 1.8 km NE of Großreifling (Styria, UTM 33N: 4 79 900 / 5 280 255 resp. WGS84: 14°43′55′′/47°40′30′′).

Lithology:

The dominant lithology of the Kasberg Member is represented by thin-, medium- and thick-bedded, dark- to brown-grey colored, wavy or nodular limestones with thick-bedded, bioclastic layers which may contain some scattered crinoids and brachiopods. Subordinately, thin marl- layers can be intercalated between the limestone-beds. As lithostratigraphic superunit we denote the Gutenstein Formation and a potential "Alpine Muschelkalk Group". No further lithostratigraphic subdivision can be quoted.

Chronostratigraphic age:

The chronostratigraphic age of the Kasberg Member is middle Anisian (Pelsonian, *Nicoraella kockeli* Biozone), based on the following fossil content: *Balatonites balatonicus* Mojsissovics, *Balatonites egregius* Arthaber, *Nicoraella kockeli* Tatge, *Nicoraella germanica* Kozur, *Paragondolella bifurcata* (Budurov and Stefanov), *Paragondolella bulgarica* (Budurov and Stefanov), *Meandrospira deformata* Salaj, *Pilammina densa* Pantić, *Pilaminella grandis* Salaj.

Facies:

Facies and accommodation space of the Kasberg Member are represented by an outer to mid-carbonate-ramp facies within a moderately deep setting, indicating reduced circulation of seawater under oxygen-poor dys-/anaerob depositional conditions, but with an elevated content of benthic organisms like redeposited crinoids, brachiopods, pelecypods and foraminifers. The depositional depth can be assumed to be between 30 and 100 m.

Thickness:

The average thickness of the Kasberg Member comprises 100 m to 150 m. The upper part of the Gutenstein Formation within the Gutenstein Alps (Lower Austria) shows thicknesses between 80 and 100 m.

Lower boundary / Upper boundary:

The underlying unit is represented by the lower part of the Gutenstein Formation (Gutenstein Member, see above). The transition into the upward following Kasberg Member is defined by the first appearance of wavy bedded, more than 30 cm thick, dark-grey or brownish-grey limestone beds. The overlying unit, above the Kasberg Member, is represented **(a)** by the Steinalm Formation, defining the upper boundary with exclusively thick-bedded, dark- to light-grey colored limestones which are rich in oncoids and dasycladalean green algae, or is represented **(b)** by the Lower Reifling Formation. Within the main part of the Gutenstein Alps of Lower Austria the Upper Gutenstein Formation merges into the dark-grey colored, wavy-bedded, cherty, marly and micritic limestones of the Lower Reifling Formation, which are characterized microfacially by filaments and radiolarians.

Distribution area:

The regional distribution area of the Kasberg Member is not restricted to the main area of Mount Kasberg (Totengebirge Nappe), but partially includes the imbricate zone of Großreifling ("Großreiflinger Scholle", Sulzbach Nappe) and some of the Tirolic tectonic units of Lower Austria (Reisalpen- and Unterberg Nappe of the Gutenstein Alps and Mount Hoher Lindkogel near Baden, Figs. 4A, B).

Lateral units:

The lateral interfingering units of the Kasberg Member are represented by the Annaberg- and Steinalm formations, as is visible on Mount Kasberg (Upper Austria) or at the type locality in Gutenstein (Lower Austria).

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