Arbeitsbericht NAB 19-14

Lithostratigraphy of Consolidated Rocks expected in the Jura Ost, Nördlich Lägern and Zürich Nordost Regions

December 2019

Peter Jordan & Gaudenz Deplazes

National Cooperative for the Disposal of Radioactive Waste

Hardstrasse 73
P.O. Box 280
5430 Wettingen
Switzerland
Tel. +41 56 437 11 11

www.nagra.ch

Arbeitsbericht NAB 19-14

Lithostratigraphy of Consolidated Rocks expected in the Jura Ost, Nördlich Lägern and Zürich Nordost Regions

December 2019

Peter Jordan[1] & Gaudenz Deplazes[2]

[1] Gruner Böhringer AG, Oberwil
[2] Nagra

KEYWORDS
Lithostratigraphy, Manual, TBO, Northern Switzerland, Consolidated Rocks, Jura Ost, Nördlich Lägern, Zürich Nordost

National Cooperative for the Disposal of Radioactive Waste

Hardstrasse 73
P.O. Box 280
5430 Wettingen
Switzerland
Tel. +41 56 437 11 11

www.nagra.ch

Nagra Arbeitsberichte ("Working Reports") present the results of work in progress that have not necessarily been subject to a comprehensive review. They are intended to provide rapid dissemination of current information.

Summary

As a work aid for recording the drill cores of the current campaign, the names and definitions of stratigraphic units to be used were compiled. The compilation is based on the valid definition and nomenclature of the Swiss Committee for Stratigraphy (SKS) and comprises the expected solid rock formations from the Permian to the Miocene. Additions and deviations from the Swiss Lithographic Scheme are introduced where, according to current knowledge, the units recognised by the SKS (including informal units accepted as "in use") are not valid or do not reflect the expected succession. This applies in particular to the insufficiently known formations of the Middle Jurassic in north-eastern Switzerland, i.e. the Nördlich Lägern and Zürich Nordost siting regions. There, the proposed lithostratigraphy largely follows the concepts formulated in previous Nagra work reports (Nagra Arbeitsberichte).

The manual is based on the state of knowledge before the start of the current drilling campaign. The insights from the campaign are expected to improve the knowledge especially on the local lithostratigraphy of the Middle Jurassic and to potentially be integrated into the formal Swiss Lithographic Scheme.

Zusammenfassung

Als Arbeitshilfe für die Aufnahme der Bohrkerne der aktuellen Kampagne wurden die zu verwendenden Schichtnamen und -definitionen der erwarteten Festgesteinsformationen vom Perm bis ins Miozän zusammengestellt. Die Zusammenstellung orientiert sich wo immer möglich an der gültigen Definition und Nomenklatur des Schweizer Komitees für Stratigraphie (SKS). Zusätze und Abweichungen werden nur dort eingeführt, wo nach aktuellen Kenntnissen die vom SKS als formell anerkannten oder als "in Gebrauch" akzeptierten Einheiten nicht gültig sind oder die erwartete Schichtfolge nicht abbilden. Das betrifft insbesondere die Formationen des Mittleren Jura in der aufschlussarmen Nordostschweiz, namentlich den Standortgebieten Nördlich Lägern und Zürich Nordost. Dort folgt die Nomenklatur weitgehend den in den vorhergehenden Nagra Arbeitsberichten formulierten Konzepten.

Das Manual beruht auf dem Kenntnisstand vor Beginn der aktuellen Bohrkampagne. Die Ergebnisse der Tiefbohrungen werden helfen, insbesondere die Schichtfolge des Mittleren Juras besser zu verstehen und in die formelle Gliederung des SKS einzubinden.

.

Table of Contents

List of Tables

List of Figures

List of Appendices

(Note: In the digital version of this report (PDF), the appendices can be found in the "ANLAGEN" register (paper-clip symbol).)

1. Introduction

The present manual provides a comprehensive list and description of the hard rock formations and members to be used to describe the lithostratigraphy of the planned deep boreholes.

The listing and description of the formations and members focus on the situation (facies, thickness) as they have been expected within the three siting regions of interest, namely Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO), before the start of the deep borehole campaign in 2019. Please note that deviating and supplementary findings from the first boreholes were not considered here. The description also includes formations and members whose occurrence is hypothetical because their lateral distribution is not yet exactly known, or their outcrop is probably higher than the kelly bushing (drill floor) of the planned deep boreholes.

The stratigraphy of the NL and ZNO regions, which have few natural and artificial outcrops, is not yet fully formalised. Some of the set formations and members are informal, but necessary for the first reporting of the planned deep boreholes. This concerns especially the middle and late Dogger Group sediments. It is planned to formalise at least some of these formations and members - or to correlate and integrate them to existing formal units - afterwards, based on the results from the deep boreholes. In the JO region, where more natural and artificial outcrops exist, the stratigraphy is better formalised. However also in JO exist some stratigraphic units that have not been formalised yet, mainly on a member level (e.g. members of Hauptrogenstein). In this case the deep boreholes might give additional evidence for a potential formalization.

The informal units of the upper Malm Group are intended to simplify the classification based on facts that can be recognized in borehole cores.

Informal and unofficial units are consistently written in chevron quotation marks (e.g., «Wellendolomit»). Informal are all units that are accepted as to be in use by the Swiss Committee on Stratigraphy but are not formally defined or do not follow the official nomenclature rules. Units that have been formalized in Germany alone and whose definition is adopted here are considered to be formal. Unofficial are traditional or new defined Nagra internal terms.

The Appendices A to D give a schematic overview relative to time and thickness of the Paleo-Mesozoic and of the Cenozoic sediments. The Appendices E and F present schematic correlations of Mid and Upper Dogger Group sediments. For comparison purposes, the formal units of adjacent Germany are listed in the Paleo-Mesozoic schemes (Appendices A and B). The Appendices should be consequently used parallel with the reading of the text. Accordingly, there is no cross-references to the Appendices within the text.

2. Crystalline basement

2.1. General and main characteristics

The crystalline basement of the three regions under investigation can be understood as a continuation of the crystalline rocks outcropping in the Black Forest Mountain range. The few deep boreholes reaching the crystalline basement of Northern Switzerland document its petrographic heterogeneity.

2.2. Definition

Occurrence: Black Forest-type crystalline basement is expected in all three regions JO, NL and ZNO, however at very different depths depending on the occurrence of Permocarboniferous troughs.

Lithology and subdivision: The crystalline rocks may be grouped petrographically into igneous rocks, gneisses and dykes.

Igneous rocks encountered in earlier deep boreholes comprise biotite-granite and granophyre with xenoliths and, within the contact metamorphic zone, syenite, monzonite, hornblende granite, aplite and aplitic granite associated with hornfels.

The gneisses comprise leucocratic biotite-plagioclase gneiss, garnet-biotite-plagioclase-alkali feldspar gneiss, cordierite-biotite-plagioclase-alkali feldspar gneiss, hornblende-biotite-plagioclase gneiss, banded hornblende-alkali feldspar gneiss, metapelitic gneiss, calc-silicate rocks and migmatite.

The most abundant dykes are granitic porphyres, quartz porphyres. and granophyres. Besides, aplites, pegmatites and lamprohyres are quite common.

Upper boundary: At the interface between Meso- or Palaeozoic sediments and crystalline basement, palaeosoils, autochthonous conglomerates and weathered crystalline rocks may be found. In the latter case, the delimitation to overlying sedimentary rocks may be challenging and arbitrary. One argument may be the homogeneity and petrographic similarity or derivability to the underlying crystalline rock. However, if there are any signs of fluvial or debris flow, it should be addressed as sedimentary rock.

3. Seismic stratigraphy of pre-Mesozoic sediments

In the regional cross-sections of Nagra (2014) and Jordan et al. (2015), a seismic stratigraphy of the pre-Mesozoic sediments is shown which has also been adopted in the prognostic sections of the planned deep boreholes. This seismic stratigraphy includes (from top, first expression from Jordan et al. (2015), second and third from JO and NL prognostic sections):

- Obere Abteilung (Perm); Perm / Obere Serie; Obere Trogfüllung
- Untere Abteilung (Perm und Karbon undifferenziert), Perm, Mittlere Serie, Mittlere Trogfüllung
- Permokarbon vermutet, Untere Trogfüllung

The various names of the different intervals reflect changing concepts on the age of the pre-Mesozoic units. The seismic units are characterised by a distinct pattern and important reflectors in between. There is no explicit correlation between this seismic stratigraphy and the lithostratigraphic scheme presented here. A correlation with the findings of the Weiach borehole suggests that the uppermost unit (Obere Abteilung, Obere Serie or Obere Trogfüllung) corresponds roughly to the Weitenau Formation (see below). In the NL region, the boundary between the middle and lower units may correspond to the top of the coal seams. In the JO region, however, typical coal seam reflections are recorded at even deeper levels within the lowermost unit.

The seismic units listed above should not be used when describing the cores.

4. «Pre-Weitenau Formation deposits»

4.1. General and main characteristics

In the boreholes of Riniken (Matter et al. 1987) and Weiach (Matter et al. 1988) sediments have been encountered that lie below the strata known from the High Rhine area, classically described as «Rotliegend» or «Rotliegendes» and recently reviewed and described as Weitenau Formation by Nitsch & Zedler (2009).

While Riniken shows a fanglomerate dominated succession, Weiach shows a subtler structure starting (from the top) with lacustrine sediments. Such lacustrine sediments have also been encountered in Wintersingen borehole (Schmassmann & Bayramgil, 1946) where they overlay crystalline basement and are overlain by the «Unterer Schuttfächer» of Weitenau Formation. Based on pollen findings (zone VCI following Hochuli 1985), Blüm (1989) postulates an Autunian, i.e. Permian age of the lacustrine sediment. Also, he states, following Falke (1974), that «Rotliegendes» is rather some facies than a lithostratigraphic unit, he includes the lacustrine sediments in the «Rotliegendes» as he postulates that «Rotliegendes» facies sets on already in late Carboniferous time.

In Weiach, Matter et al. (1988) localize the Carboniferous (Stephanian) / Permian (Autunian) boundary within the «Grosszyklische Grobsandstein-Ton-Serie» underlaying the lacustrine Sediments (Figure 1). As following fluvial sediments and a coal-bearing sequence were again underlain by fluvial and alluvial sediments, Matter et al. (1988) summarize the whole some 1000 m thick pre-Mesozoic sediment succession as «Rotliegendes und Karbon». Figure 1 gives a more detailed overview. In Riniken, the whole, evenly some 1000 m thick fanglomerate dominated succession was denoted as "Rotliegendes" (Matter et al. 1987).

Later, Nitsch & Zedler (2009) have suggested, to denote the upper part of the sequence, corresponding to the sediments outcropping in the High Rhine area as Weitenau Formation (the uppermost 173 m in Riniken and 262 m in Weiach) and the remining sediments, as Weiach Formation, denoting the sequence of Weiach borehole as a reference. From a genetic-paleogeographic point of view, Nitsch & Zedler (2009) interpret the Weiach Formation as fill of the Permocarboniferous grabens and the Weitenau Formation as a post-extensional sediment reaching over the limits of the grabens.

The proposal by Nitsch & Zedler (2009) was questioned by experts involved in the Weiach and Riniken borehole survey who argue that the sequence below Weitenau Formation is too varied to be put in two formations only. Considering that so far only two, admittedly quite differing borehole sequence give insight in this sequence, the takeover of the German stratigraphic term or the introduction of new stratigraphic units was postponed. And it was decided to use the informal term «Pre-Weitenau Formation deposits» instead.

4.2. Definition

Occurrence: «Pre-Weitenau Formation deposits» have so far only be detected in the Riniken and Weiach borehole (Matter et al. 1987, 1988) and, to a much lesser extent, in Wintersingen borehole (Schmassmann & Bayramgil, 1946, Blüm 1989). «Pre-Weitenau Formation deposits» similar or different from the habitus of Weiach or Riniken are expected in the domain of the Permocarboniferous troughs.

Lithology and subdivision: So far, two differing stratigraphic successions are known. At Riniken about 760 m of predominantly fanglomeratic sediments consisting mainly of cyclic crystalline breccia and sandstone deposits have been found.

The sole, some 75 m thick sedimentary unit of Wintersingen «Pre-Weitenau Formation deposits» corresponds to the topmost sequence of Weiach bore hole.

In the Weiach borehole, the «Pre-Weitenau Formation deposits» comprise grey to black clastic, fluvial, alluvial and lacustrine sediments. They include coarse- to fine-grained sandstone (mostly organised in fining-upward sequences), clay to siltstone (occasionally showing rhythmic alternation), coal seams, algal stromatolites, etc. The succession (Figure 1) may be divided as follows (from top) (Matter et al. 1988):

- lacustrine sediments («Lakustrische Serie», informal, ca. 135 m)
- fluviatile sediments («Grosszyklische Grobsandstein-Ton-Serie», informal, ca. 90 m)
- alluvial sediments («Obere Kleinzyklische Sandstein-Ton-Serie», informal, ca. 80 m)
- coal-bearing swamp, fluvial and alluvial sediments («Kohle Serie», informal, ca. 200 m)
- alluvial sediments («Mittlere Kleinzyklische Sandstein-Ton-Serie», informal, ca. 90 m)
- fluvial sediments («Feinkonglomeratische Grobsandstein-Serie», informal, ca. 110 m)
- alluvial sediments («Untere Kleinzyklische Sandstein-Serie», informal, ca. 70 m)

Thickness: At Weiach borehole, the «Pre-Weitenau Formation deposits» are some 760 m thick. In Riniken borehole an about 825 m thick fanglomerate dominated succession has been drilled without reaching its base. At Wintersingen about 75 m of lacustrine sediments have been encountered before reaching the crystalline basement. At all other boreholes of Northern Switzerland reaching the depth in question, no «Pre-Weitenau Formation deposits» have been detected. Thus, thickness of 0 m to significantly more than 800 m can be expected.

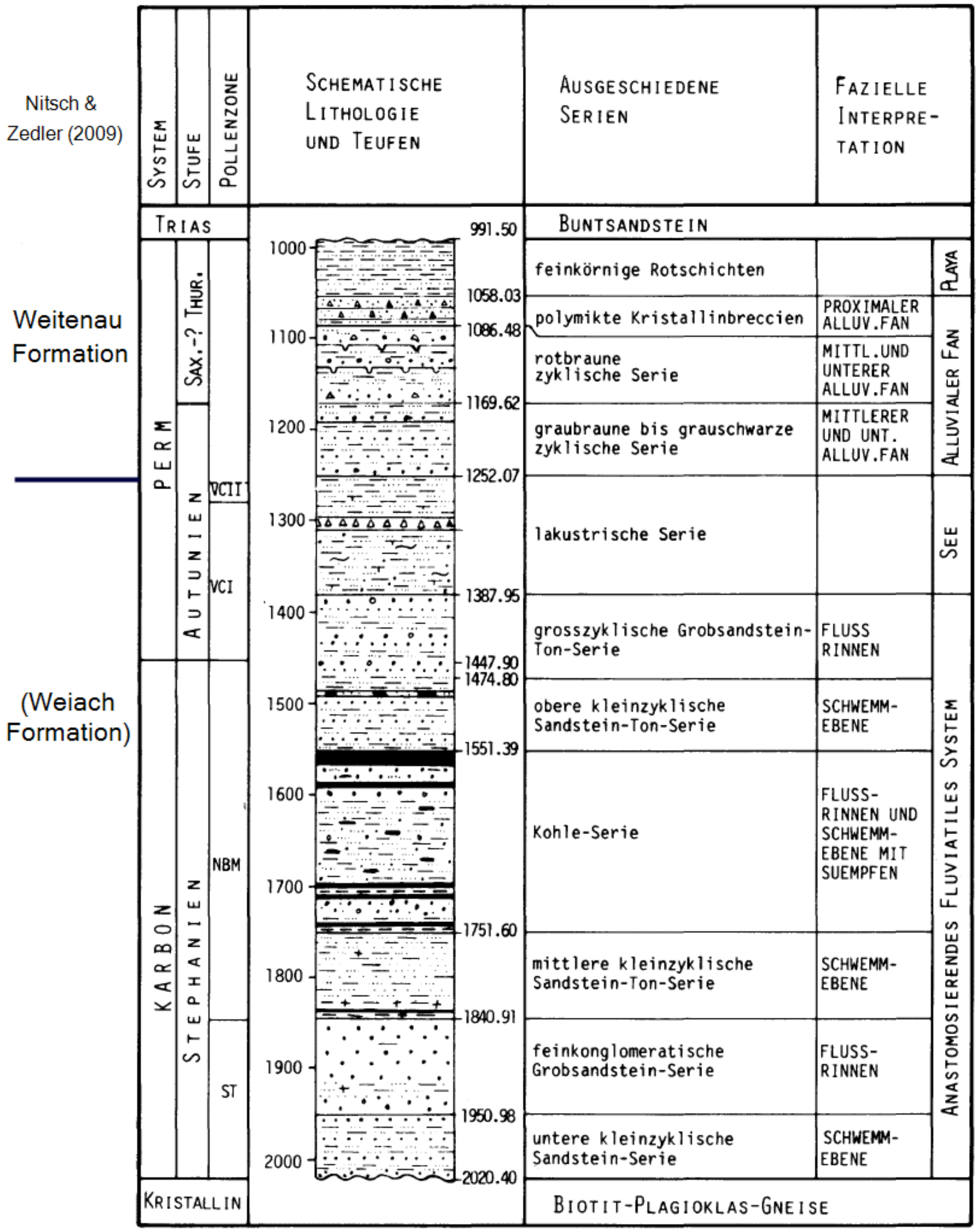


Figure 1: The «Rotliegendes und Karbon» of Weiach borehole (Matter et al. 1988, modified).

At left, the proposition by Nitsch & Zedler (2009). While the Weitenau Formation is adapted here (section 5) the concept of a Weiach Formation is recjected and represented here by the term «Pre-Weitenau Formation deposits».

Upper boundary: The upper boundary is erosional and defined by the base of the lower alluvial fan of the Weitenau Formation

Lower boundary: The «Pre-Weitenau Formation deposits» overlie crystalline basement. In Wintersingen, there is a sharp contact between the basal bed of the «Lakustrische Serie» (a kind of transgressive sediment with breccias, sandstone and claystone) and the underlaying biotite granite. In Weiach, details are not known due to core loss (Matter et al. 1988). In Riniken, the lower boundary was not reached.

Lateral equivalents: The term «Pre-Weitenau Formation deposits» encompasses all lithostratigraphic units known or yet to be discovered within the Permocarboniferous troughs, so that there are no lateral equivalents on principle.

Names previously in use: At Weiach, the «Pre-Weitenau Formation deposits» correspond to the mayor (lower) part of «Rotliegendes und Karbon» of Matter et al. (1988), at Riniken, to the mayor (lower) part of «Rotliegendes» of Matter et al. (1987), and, at Wintersingen, to the «Lakustrische Serie» of Blüm (1989).

4.3. Additional information

Origin of name: Placeholder for a still to establish litho-stratigraphy (see section 4.1).

Type locality and type region: As there are no formal units defined, there is neither a type locality nor a type region.

Reference section: Weiach borehole gives the most diverse sequence and is therefore to be used as reference section.

Chronostratigraphic age: Evidence from Weiach and Wintersingen points to a «Stephanian» (Kasimovian / Gzhelian) to «Autunian» (Asselian / Saksmarian) age (Hochuli 1985, Blüm 1989, Matter et al. 1988).

Genetic and paleogeographic interpretation: Sedimentological evidence such as channel and tabular cross-bedding, fluvial and climbing-ripple cross-lamination point to formation in an anastomosing fluvial environment with channels and alluvial plains, including swamps and temporary lakes where the coal seams originate from.

5. Weitenau Formation

5.1. General and main characteristics

The Weitenau Formation has recently been defined by Nitsch & Zedler (2009) as uniting the trinity «Unterer Schuttfächer» (lower alluvial fan) - «Playa Serie» (playa sediment succession) – «Oberer Schuttfächer» (upper alluvial fan) named and monographically treated by Blüm (1989) based on older descriptions (e.g., Lutz 1964) and new own findings.

5.2. Definition

Occurrence: The Weitenau Formation is found, at various thickness, throughout Northern Switzerland. However, at some places, such as the Böttstein or Benken boreholes (Peters et al. 1986, Nagra 2001), the Weitenau Formation is completely missing. At other places, the «Oberer Schuttfächer» only is absent.

Lithology and subdivision: The Weitenau Formation is subdivided into 3 informal members: «Unterer Schuttfächer», «Playa Serie» and «Oberer Schuttfächer» (Blüm 1989, Nitsch & Zedler 2009, Geyer et al. 2011).

The «Unterer Schuttfächer» encompasses mostly grey or reddish brown to red arkose and fanglomerate. The polymict crystalline breccia is composed of plutonic, volcanic and metamorphic rocks (including cobbles up to 10 cm in diameter) in an argillaceous silty matrix.

The «Playa Serie» is characterised by brownish red siltstone and sandstone showing irregularly shaped greenish reduction spots and adhesion ripple marks. In Riniken borehole, a playa sediment succession proper is distinguished from the underlying succession of clayey sandstones interrupted by breccia (Matter et al. 1987).

The «Oberer Schuttfächer», mainly composed of reddish brown to red arkose, is documented from the Fricktal area and adjacent Germany but is missing at Riniken and Weiach (Blüm 1989).

Thickness: Probably up to 300 m: Weiach borehole ca. 261 m, Riniken borehole ca. 173 m (Matter et al. 1987, 1988).

Upper boundary: The Weitenau Formation is overlain by Wiesental Formation or Dinkelberg Formation.

In the case where the Wiesental Formation is present, the upper boundary is characterized by a change of dominant rock colour from reddish brown to grey at the level of a palaeosoil («Karneol-Anhydrit-Horizont»).

In the case where the Weitenau Formation is directly overlain by the Dinkelberg Formation, the boundary is marked by a transgressive discontinuity, often followed by a basal conglomerate with walnut-sized tetrahedral quartz pebbles (Disler 1914). The delimitation is easier when the Weitenau Formation is terminated by the fine-grained «Playa Serie» and more sophisticated when the transgressional Triassic sediments overlie the «Oberer Schuttfächer» of the Weitenau Formation. Generally, the overlying Dinkelberg Formation is finer-grained (fine- to medium-grained arenite), has less pebbles (if any; except for the basal conglomerate), and more mica and less feldspar components than the underlying Permian sediments

Lower boundary: The lower boundary is erosional and is defined as the base of the lower alluvial fan. Little is known yet about the diversity of this lower boundary. In some places, such as the Weiherfeld borehole, the formation directly overlies crystalline basement. At Wintersingen and Weiach, it is underlain by lacustrine sediments (Blüm 1989, Matter et al. 1988) of «Pre-Weitenau Formation deposits» (Section 4). In Riniken (Matter et al. 1987), no lacustrine sediments have been encountered and the lower limit of the Weitenau Formation is less evident. In analogy to Weiach, it was drawn arbitrarily at the base of the cyclic sandstone succession (cf. Blüm 1989).

Lateral equivalents: Within the area under investigation, no lateral equivalents occur.

Names previously in use: The Weitenau Formation corresponds to what was traditionally named «Rotliegend» or «Rotliegendes» by the geologists working in the High Rhine area (e.g., Disler 1914, Lutz 1964, see also Nitsch & Zeidler 2009).

It is only partly identical to the «Rotliegendes» or «Perm» of Matter et al. (1987) and Matter et al. (1988) (see Figure 1).

5.3. Additional information

Origin of name: The formation is named after the Weitenau monastery and Weitenauer Berge north of the Wiesental (NE of Basel).

Type locality and type region: There is no type locality defined yet, as there are no continuous surface outcrops showing the whole Weitenau Formation. Rather good partial outcrops are found in the Weitenauer Berge which have been defined as type region by Nitsch & Zedler (2009).

Reference section: The boreholes of Wintersingen and Weiherfeld/Rheinfelden, revised by Blüm (1989), may serve as reference sections.

Chronostratigraphic age: Due to the lack of biostratigraphically relevant remains, dating of the Weitenau Formation is highly hypothetical. Geyer et al. (2011) suggest a Cisuralian (Early Permian) age for the whole succession and, consequently, a large time gap between the Weitenau Formation and the Lopingian (Late Permian) Wiesental Formation. In contrast, Blüm (1989) postulates a Saxonian to possibly Thuringian age. Considering that these terms are very vague and used inconsistently, according to a correlation scheme of Geyer et al. (2011) this would give a late Early to Middle or even Late Permian age.

Genetic and paleogeographic interpretation: The Weitenau Formation probably documents the latest, post-extensive and transpressive phase of the Variscan orogeny, i.e. mainly uplift and erosion. Under arid climate conditions, the erosional debris from the Black Forest High was transported southwards, mainly by debris flow. Following the post-orogenic concept, the Weitenau Formation is believed to seal the faults and overtop the Variscan graben. It is not known yet if the absence of the Weitenau Formation at some places is due to non-deposition or later (pre-Triassic) erosion.

6. Wiesental Formation

6.1. General and main characteristics

The Wiesental Formation has recently been defined by Nitsch & Zedler (2009) as addressing rocks in the High Rhine - Lake Constance area that are believed to belong to the Late Permian (Lopingian) Zechstein Group.

6.2. Definition

Occurrence: Southernmost Baden-Württemberg. Occurrences in Switzerland have not yet been confirmed.

Lithology and subdivision: The mostly grey and rarely reddish-brown arkose has minor pebble content, some of eolian origin (Windkanter), and anhydrite, dolomite or siliceous cement. At the base, a palaeosoil, known as the «Karneol-Anhydrit-Horizont» can be found.

Informally, the some 1 to 6 m metres thick «Karneol-Anhydrit-Horizont» at the base of the formation can be considered as a bed.

Thickness: The formation occurs only occasionally. Then, thickness is generally moderate, but, locally, can reach up to 50 m.

Upper boundary: The distinctive feature of the Wiesental Formation is its grey colour, which is different from the red to reddish brown of the overlying Dinkelberg Formation separated by an erosional contact.

Lower boundary: The erosive contact to the lying Weitenau Formation, also recognizable by a change of colour to red, is additionally marked by a palaeosoil («Karneol-Anhydrit-Horizont») which is taken as part of the Wiesental Formation.

Lateral equivalents: There are no lateral equivalents in the area under investigation.

Names previously in use: None, if recorded separately, the corresponding succession has been erroneously assigned to the «Buntsandstein» (now Dinkelberg Formation) or to the «Rotliegend» (now Weitenau Formation).

6.3. Additional information

Origin of name: Wiesental (valley of the creek Wiese) northeast of Basel.

Type locality and type region: No formal type locality is defined. Type region are the Weitenauer Berge north of the Wiesental.

Reference section: Nitsch & Zedler (2009) propose the southern slope (Swiss coord. 2620.575/1279.750) of the Luchskopf north-west of Hägelberg/Steinen in the Wiesental as a reference section.

Chronostratigraphic age: No direct evidence, probably Lopingian (Late Permian) proposed by lithological correlation with dated rocks elsewhere (Nitsch & Zedler 2009).

Genetic and paleogeographic interpretation: It is postulated that sand and pebbles have been transported southwards from the Late Permian Black Forest High (Nitsch & Zedler 2009, Geyer et al. 2011).

7. Dinkelberg Formation

7.1. General and main characteristics

The Dinkelberg Formation corresponds to the Buntsandstein as outlined by Disler (1914). It corresponds to the Middle and Upper Buntsandstein of the German Stratigraphic Scheme (Figure 2), including the Vogesensandstein, Plattensandstein and Rötton Formations (Geyer et al. 2011; LithoLex, consulted 16.05.2018). The Lower Buntsandstein, the Eck Formation, wedges out further north and does not occur in Switzerland (e.g., Geyer et al. 2011). Some confusion is introduced by certain stratigraphers who tried to identify the «Lower Buntsandstein» in Switzerland (see discussion in Bitterli et al. 2000, and Section 6.2).

7.2. Definition

Occurrence: The Dinkelberg Formation is found in North-Western and central Northern Switzerland including all three siting regions JO, NL and ZNO. Further to the East, it is wedging out along a line Zürich – Stein am Rhein.

Lithology and subdivision: A formal subdivision is not yet established in Switzerland. In adjacent Germany, the formal subdivision includes (from bottom): Vogesensandstein Formation, Plattensandstein Formation and Rötton Formation. This subdivision can also be used in Switzerland in ranks of informal members (Figure 2):

The «Vogesensandstein» (also known as «Diagonalgeschichteter Sandstein») is an up to 50 m thick reddish brown, coarse-grained, often normally graded arenite with or without pebbles. Its extent towards the south is the least of the three informal members. It may be missed in some of the planned boreholes. The boundary between «Vogesensandstein» and «Plattensandstein» is often marked by the up to 1.5 m thick, crimson, purple or whitish, often anhydritic carnelian bed («Karneolhorizont VH2»), a non-continuous palaeosoil.

The «Plattensandstein» is an up to 15 m thick, mostly well-bedded (2 to 10 cm) reddish brown, in some places light grey to white, fine to medium-grained sandstone with significant mica content. Sandstone beds vary between a few centimetres up to about 10 cm in thickness. They are separated by mostly thin greenish claystone.

The up to 3 m thick «Rötton» is a reddish brown silty and, in some places also sandy, claystone.

Thickness: In most cases, thickness varies between some 10 to 25 m. In North-western Switzerland, up to 100 m were achieved. Towards North-eastern Switzerland, the Dinkelberg Formation wedges out completely.

Upper boundary: In most cases, the reddish to variegated claystone of the uppermost Dinkelberg Formation («Rötton») is overlain, along a transgressive discontinuity, by often fossiliferous, sometimes silty to sandy greyish to yellow or olive marl followed by an alternation of grey dolostone and dark marl of «Wellendolomit» (Disler 1914; Hofmann et al. 2000).

Lower boundary: In most cases, the Dinkelberg Formation overlays the Weitenau Formation, but locally, also Wiesental Formation or, directly, crystalline basement.

The lower boundary is always a transgressive discontinuity, that is often followed by a basal conglomerate with walnut-sized tetrahedral quartz pebbles (Disler 1914). Where underlain by Wiesental Formation, the lower boundary is also marked by a colour change from grey to red.

Lateral equivalents: The Dinkelberg Formation corresponds to the succession Vogesensandstein Formation, Plattensandstein Formation and Rötton Formation of the German Stratigraphic Scheme.

Towards the east, outside the area under investigation, there is, in the upper part, a transition to some more proximal, coarse-grained facies.

Names previously in use: The succession was generally described as «Buntsandstein» or under its (informal) member names: «Vogesen / Diagonalgeschichteter Sandstein», «Plattensandstein», and «Rötton».

7.3. Additional information

Origin of name: In the Dinkelberg area, the reddish freestone (plate-shaped rock) of the «Plattensandstein» was quarried in many locations.

Type locality and type region: The left and right banks of the River Rhine between Augarten (Rheinfelden, Switzerland) and Warmbach (Rheinfelden, Germany), Profile I to VI of Disler (1914) now partly flooded (coord. ca. 2623.000/1265.800 and 2624.000/1266.250, left bank, and 2623.000/1266.000 and 2624.950 /1266.875, right bank) have been assigned as type locality by Jordan (2016).

Reference section: Kaisten borehole, drilling metre 94.00 – 124.95 (Peters et al. 1989) are proposed as reference section by (Jordan 2016). The corresponding core section is preserved in the Nagra core store facility.

Chronostratigraphic age: There are no data from Northern Switzerland. Lepper et al. (2005) propose Late Olenekian to Early Anisian for occurrences of Buntsandstein Gruppe in Germany.

Genetic and paleogeographic interpretation: The sequence documents two fluvial/alluvial transgression episodes coming from the north and corresponds to the second and third cycle of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

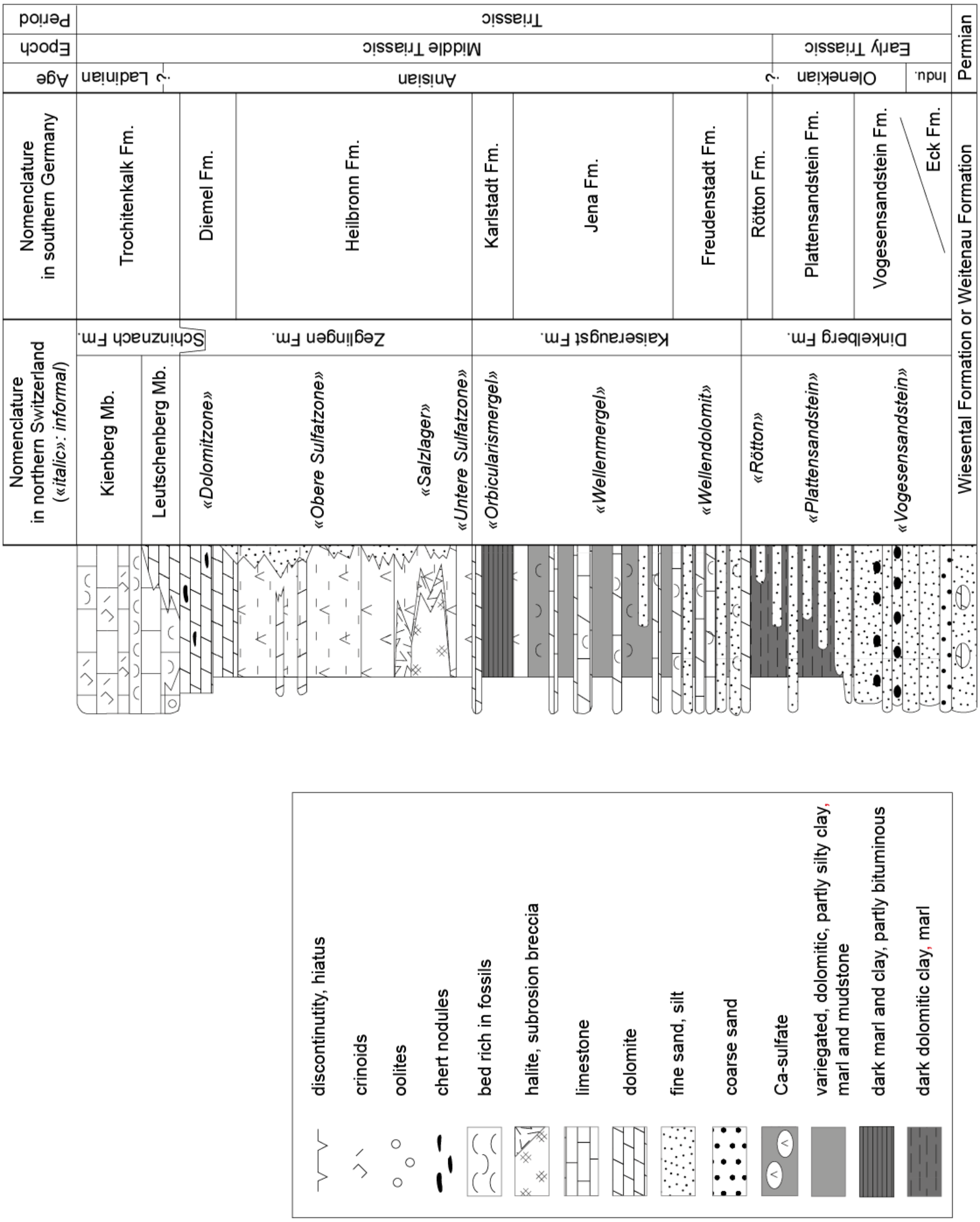


Figure 2: Stratigraphic scheme of the Dinkelberg, Kaiseraugst and Zeglingen Formations.
Indu.: Induan; Fm.: Formation; Mb.: Member. Modified after Jordan (2016)

8. Kaiseraugst Formation

8.1. General and main characteristics

The Kaiseraugst Formation corresponds to the «Wellengebirge» as traditionally interpreted in Switzerland (e.g., Müller et al. 1984). It includes the basal «Wellendolomit», the «Wellenmergel» (or «Wellenkalk»), and the «Orbicularismergel» on top (Figure 2). In Germany, all three sections are dealt with as proper formations, whereby the uppermost Karlstadt Formation (corresponding to the former «Orbicularismergel») is part of the Middle Muschelkalk subgroup, while the other two, the Freudenstadt Formation and Jena Formation, form the Lower Muschelkalk subgroup (Hagdorn and Simon 2005). For the Swiss realm, it is suggested to maintain, for the moment, the old names as informal members until an integrated revision is done. The only divergence to the former Swiss scheme is the bituminous «Unterer Dolomit», hitherto considered as the base of the «Anhydritgruppe», now added to the Kaiseraugst Formation.

The Kaiseraugst Formation is represented by sublittoral to fully marine sediments including dolostone, (crinoidal) limestone, marl and shale. The marine character documented by the abundance of marine macrofossils (at some levels in the form of coquina) in all three informal members distinguishes the formation from the underlying and overlying formations, where macrofossils are rare or virtually absent.

8.2. Definition

Occurrence: The Kaiseraugst formation is documented from entire Northern Switzerland with a trend of thickness decrease from north-west to south-east.

Lithology and subdivision: Until an integral review, the traditional informal subdivision «Wellendolomit», «Wellenmergel» and «Orbicularismergel» shall be maintained (Figure 2). The following thickness data refer to the area under investigation.

The 5 to 10 m thick «Wellendolomit» consists of dark grey claystone and marl with sandstone, dolostone and limestone interlayers. The dolostone at the base is often light grey to white and occasionally fine-layered. It represents marginal marine facies that dominates around the Sissach rise, a swell connecting the Black Forest high zone with the Aar Massif high zone (Sissach Barre, Frank 1930; "Black Forest−Aar massif" rise, Trümpy 1980; Sissach rise Jordan 1983; see also Geier et al. 2011). Evidence from other parts of the sedimentary basin shows that dolomitization must be, at least partly, secondary, as typical marine beds can be followed from the non-dolomitised to the dolomitised domain. One of them, also found in the area under investigation, is the fossiliferous «Buchi Marl».

The 20 to 27 m thick «Wellenmergel» (or «Wellenkalk» where limestone dominates) consists of dark grey, well bedded, silty and calcareous claystone with mostly thin (1 to 20 cm) but occasionally up to 1 m thick interbeds of fossiliferous sandy limestone to calcareous silt- to sandstone. It represents the non-dolomitised, stratigraphically higher part of the transgressive sequence and the high stand. The transgressive sequence is characterised by partly sandy carbonates in alternation with marl. The high stand is documented by an alternation of marl and subordinate limestone.

The 6 to 10 m thick «Orbicularismergel» comprises (partly thin) dolomite beds and brownish grey, bituminous argillaceous to calcareous marl with some coquina levels and few sulphate interlayers.

Horizons with sulphcretes, desiccation cracks and roots document periods of emergence. Such horizons occur, especially, in the «Orbicularismergel».

Some levels of the Kaiseraugst Formation contain galenite, sphalerite, chalcopyrite, etc. (Hofmann 1985; Hofmann et al. 2000).

The fossil record includes cephalopods (*Beneckeia buchi* and nautilids are abundant), bivalves, gastropods, brachiopods and echinoderms. A typical fossil in the bituminous upper part is the clam *Myophoria*, now *Neoschizodus orbicularis* which is usually found, however, only as debris in coquina.

Thickness: Thickness decreases from North-western Switzerland, where it reaches 60 m, towards south and east (Jordan 2016). In the area under investigation, a thickness from about 30 to 45 m is expected.

Upper boundary: The upper boundary is given by the onset of the evaporite facies. In most cases, the Zeglingen Formation starts with a massive anhydrite bed. Regarding clay mineralogy, the boundary corresponds to the onset of corrensite. On the other hand, bituminous shales and dolostone, abundant in the upper Kaiseraugst Formation, disappear. The often bituminous «Unterer Dolomit», hitherto considered as the base of the «Anhydritgruppe», is now added to the Kaiseraugst Formation. N.B. Pedogenetic sulphate horizons (dolocretes) and secondary sulphate deposits in shales and dolostone also occur in the Kaiseraugst Formation. The diagnostic criterion for the Zeglingen Formation is massive marine sulphate.

Lower boundary: The lower boundary is characterised by a transgressive discontinuity. In most cases reddish to purple claystone of the Dinkelberg Formation are overlain by often fossiliferous (including brachiopods, bivalves, gastropods, bones of vertebrae), at some places silty to sandy greyish to yellow or olive marl is overlain by an alternation of grey to white, occasionally fine-layered dolostones and dark marl of the Kaiseraugst Formation (Disler 1914; Hofmann et al. 2000).

Lateral equivalents: The Kaiseraugst Formation corresponds to the Freudenstadt Formation, Jena Formation, and Karlstadt Formation of the German Stratigraphic Scheme (DSK 2005; Etzold and Schweizer 2005; Geyer et al. 2011).

Names previously in use: The Kaiseraugst Formation corresponds to the former «Wellengebirge» including «Wellendolomit», «Wellenkalk» or «Wellenmergel», and «Orbicularismergel».

8.3. Additional information

Origin of name: Name of the municipality where the left bank type sections are localised.

Type locality and type region: Before the construction of the different barrages, good and, at low water, easily accessible outcrops of the Kaiseraugst Formation were found along both banks of the River Rhine upstream of Kaiseraugst AG. Disler (1914) recorded some of the most relevant sections before they were partially flooded. Parts of them are still accessible. His sections VI, VII and VIII have been chosen as the type locality by Jordan (2016). Their localization is: Profiles VI (ca. coord. 2623.639/ 1265.975 to 2623.960/1265.950), VII (ca. coord. 2622.750/1266.000 to 2622.075/ 1265.915) and VIII (ca. coord. 2622.800/1265.775 to 2622.140/1265.725).

The type region of the Kaiseraugst Formation is the Lower High Rhine area.

Reference section: The Kaisten borehole (coord. 2664.642/1265.624), drilling metre 46.40 to 94.00 (Peters et al. 1989) was assigned as Reference section (Jordan 2016). It is not fully cored and shows some core losses, but base and top – in a close to bedrock surface situation - are preserved.

At Riniken borehole (coord. 2656.605/1261.780), the transition from the overlying Schinznach Formation to the Kaiseraugst Formation (extending from drilling metre 749.44 to 793.90) is fully cored, but the rest of the formation is not cored.

The Kaisten and Riniken core sections are preserved in the Nagra core store facility.

Chronostratigraphic age: The corresponding layers in Germany are well dated and document an Anisian age (e.g., Hagdorn and Simon, 2005, Geyer et al. 2011).

Genetic and paleogeographic interpretation: The sequence documents the build-up of a connection between the northern Central European Basin (Germanic Basin) and the Tethys Ocean. This marine strait follows a proto-Rhenish depression (Hagdorn & Nitsch 2009). The overall transgressive-regressive cycle is overlain by different subcycles (e.g., Pöppelreiter 2002).

9. Zeglingen Formation

9.1. General and main characteristics

The Zeglingen Formation (Jordan 2016) includes the Anisian (Middle Muschelkalk) evaporite sequence and corresponds to the former «Anhydritgruppe» (e.g., Müller et al. 1984). The only discrepancy with the traditional concept is that the «Unterer Dolomit», formerly considered as part of the «Anhydritgruppe» by some authors (e.g., Matter et al. 1986) is now part of the underlying Kaiseraugst Formation.

The Zeglingen Formation has acted as a main décollement horizon of the thin-skinned Jura fold and thrust belt. Rock salt and sulphate horizons may therefore have been subjected to tectonic perturbations such as shearing, folding and thrusting. This goes for the JO area but, possibly, in a lesser amount, also for the NL and ZNO areas.

9.2. Definition

Occurrence: The Zeglingen Formation is found all over Northern Switzerland. The rock salt deposits («Salzlager», informal) are restricted to an area north and west of a line Bern – Zürich – Schaffhausen. Thus, it may be missed in the south-eastern part of ZNO region.

Lithology and subdivision: The Zeglingen Formation encompasses an evaporitic megacycle with eight subcycles (Dronkert et al. 1990). The megacycle starts with sulphate followed by rock salt, again sulphate, and finally carbonate. The term sulphate includes gypsum and anhydrite (for more explanations, see below). The informal subdivision of the Zeglingen Formation (Figure 2) includes (from bottom; thickness data refer to the area under investigation):

The 10 to 20 m thick «Untere Sulfatzone» (lower sulphate succession), including massive sulphate beds and alternations of dolostone, marl and anhydrite.

The up to 40 m thick «Salzlager» (rock salt deposit) which may be (partially) replaced by sulphate breccia or may be primarily absent. The initial rock salt facies is restricted to a south-west to north-east trending basin. Its south-eastern boundary may be localized within or south-east of the ZNO area. Subrosion of rock salt (resulting in sulphate breccia) is documented from Triassic as well as from Pleistocene to Holocene time.

The 20 to 45 m thick «Obere Sulfatzone» (upper sulphate succession), including massive and nodular sulphate (chicken wire) as well as alternations of dolostone, marl and anhydrite

The around 10 m thick «Dolomitzone» (dolostone succession) which is characterised by thin-bedded (stromatolitic) dolostone with siliceous nodules separated by thin marl horizons.

In a sedimentary environment, gypsum prevails. During diagenesis gypsum was completely replaced by anhydrite. During the Oligocene to Miocene or even Pliocene extensional and compressional tectonic processes anhydrite veins have formed. In the context of the Pleistocene to Holocene exhumation processes, at depth less than 300 m, gypsum veins have formed in (predominantly horizontal) decompaction gaps. In the domain close to Pleistocene or actual surface, anhydrite may be replaced partly or fully by gypsum.

Thickness: In the area under investigation, the total thickness of the Zeglingen Formation may vary between 50 and 95 m.

Upper boundary: The boundary to the Schinznach Formation is defined by the onset of marine sedimentation and thus termination of evaporite sabkha facies of the Zeglingen Formation. This means the change from finely bedded (stromatolitic) dolostone to marine carbonates. These have been initially all limestones, but are now, in some regions, partially dolomitised. In the absence of shell or coquina layer, the much more massy habitus of the Schinznach beds, and the absence of siliceous nodules, allows the distinction from the fine bedded dolostone of Zeglingen Formation.

Lower boundary: The lower boundary is characterized by the onset of the evaporite facies. In most cases, the Zeglingen Formation starts with a massive anhydrite bed. Regarding clay mineralogy, the boundary corresponds to the onset of corrensite (e.g., Peters 1964, Peters et al. 1986). On the other hand, bituminous sediments (shale and dolostone), abundant in the upper Kaiseraugst Formation, disappear.

The often bituminous «Unterer Dolomit», hitherto considered as the base of the «Anhydritgruppe», is now added to the Kaiseraugst Formation. It must be stressed that pedogenetic sulphate horizons (dolocretes) and secondary sulphate deposits in shales and dolostone also occur in the Kaiseraugst Formation. The diagnostic criterion for the Zeglingen Formation is massive marine sulphate.

Lateral equivalents: The Zeglingen Formation corresponds to the Heilbronn Formation (sulphate - rock salt - sulphate succession) and Diemel Formation (dolostone succession) of the German Stratigraphic Scheme (DSK 2005; Etzold and Schweizer 2005; Geyer et al. 2011).

Names previously in use: «Anhydritgruppe».

9.3. Additional information

Origin of name: Name of the municipality where the type locality is located

Type locality and type region: The gypsum quarry Wissbrunn or Weissbrunn (coord. 2636.250/1251.300) at Zeglingen BL is the formal type locality. However, the section originally reported by Merki (1961) is incomplete, tectonically disturbed and, since the quarry has been abandoned, increasingly inaccessible.

Type Region is the eastern Folded Jura including the former Kienberg gypsum quarry (coord. 2640.200, 1254.000) which, despite also progressive decay, now offers a better insight in the evenly heavy deformed formation.

Reference section: There are two borehole sections designed as reference sections by Jordan (2016):

Böttstein borehole (coord. 2659.342/1268.556), drilling metre 197.20 to 261.00 (Peters et al. 1986): except for a very short sequence, fully cored and preserved in the Nagra core store facility.

Borehole 106 (coord. 2619.825/1260.6502) of Schweizer (Rhein-) Salinen AG, drilling metre 430.9 to 567.6 (Widmer 1991): fully cored. Selected sections of the core are conserved in the collection of the Natural History Museum Basel.

Chronostratigraphic age: The corresponding sections in adjacent Southern Germany are dated to be of Anisian (Illyrian) age (e.g., Hagdorn and Simon 2005; Geyer et al. 2011; Bernasconi et al. 2017).

Genetic and paleogeographic interpretation: The Swiss salina basin with rock salt deposits in the centre is part of a greater marine system extending from the northern Germanic Basin to the south along proto-Rhenish structures and further to the Burgundy Basin in the Lyon area of France (Hagdorn & Nitsch 2009). Dronkert et al. (1990) recognise a transgressive-regressive megacycle with eight meso-sequences and many sub-sequences. The marine salt deposits document a high stand, which is followed by a regression ending in a sabkha-type coastal environment.

10. Schinznach Formation

10.1. General and main characteristics

The Schinznach Formation (Pietsch et al. 2016) encompasses a 65 to 80 m thick succession of predominantly marine carbonates sandwiched between two evaporitic sequences. It documents a marine transgression and regression during the Late Anisian and Early Ladinian. The maximum flooding is represented by the base of the Liedertswil Member (Section 10.4.2). Significant portions of the formation are partly of fully dolomitised by syn- and post-sedimentary processes.

10.2. Definition

Occurrence: The Schinznach Formation is found all over Northern Switzerland, and, thus, in all three regions JO, NL and ZNO.

Lithology and subdivision: The Schinznach Formation consists of often dolomitic greyish limestone and, especially within the upper part, beige dolostone, comprising (from base to top) macrofossil-poor limestone, bioclastic limestone, limestone with interbedded marl and locally macrofossil-rich dolostone. Oolites are intercalated in the lower and the upper third. At the top, above the dolostone, there are marl or claystone and finally dolostone. The upper third of the Schinznach Formation may locally contain anhydrite.

The Schinznach Formation is subdivided in Leutschenberg Member, Kienberg Member Liedertswil Member, Stamberg Member, and Asp Member (Pietsch 2016). For practical reasons it was decided here, not to distinguish between Leutschenberg Member and Kienberg Member (Figure 3).

Thickness: The thickness of the Schinznach Formation is constant over long distances. In the region under investigation it may vary between 65 and 75 m, with 60 m and 80 m, respectively, as extremes (Pietsch et al. 2016).

Upper boundary: The upper boundary is fixed atop the last occurrence of decimetre to metre-thick continuous dolostone or rauhwacke bed of the Asp Member overlain by marl or massive sulphate of Bänkerjoch Formation.

Lower boundary: The lower boundary is defined by the onset of marine sedimentation and thus termination of evaporite sabkha facies of the Zeglingen Formation. This means the change from finely bedded (stromatolitic) dolostone to marine carbonates. These have been initially all limestones, but are now, in some regions, partially dolomitised. In the absence of shell or coquina layer, the medium- to thick-bedded ("massy") habitus of the basal Schinznach Formation, and the absence of siliceous nodules, allows the distinction from the fine bedded dolostone of Zeglingen Formation.

Lateral equivalents: The Schinznach Formation corresponds to the Trochitenkalk Formation, Meissner Formation, Rottweil Formation, and Erfurt Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

Names previously in use: The Schinznach Formation corresponds to the «Oberer Muschelkalk» (including «Hauptmuschelkalk» and «Trigonodusdolomit») and «Unterer Keuper» or «Lettenkohle» of the classical Swiss Stratigraphic Scheme (e.g., Müller et al. 1984). In the concept of Merki (1961), it corresponds to the «Oberer Muschelkalk». For more details, see Pietsch et al. (2016).

10.3. Additional information

Origin of name: Name of spa and municipality close to type locality.

Type locality and type region: The type locality is a railway cut (coord. 2655.000/1256.725) close to the thermal spa site of Bad Schinznach in the municipality of Schinznach Bad AG. Due to intense train traffic, it is hardly accessible. The section was originally reported by Merki (1961) and re-examined by Pietsch et al. (2016).

The type region is the eastern Folded Jura.

Reference section: The core, from core meter 814.08 to 887.90, of the Weiach borehole, well documented by Matter et al. (1988) and preserved in the Nagra core store, is determined as the reference and boundary stratotype section (Pietsch et al. 2016).

Chronostratigraphic age: Chronostratigraphic age evidence originates mainly from the Liedertswil and Asp Members which indicate Late Anisian to Early Ladinian (Pietsch et al. 2016, Hagdorn et al. 2015; Bernasconi et al. 2017).

Genetic and paleogeographic interpretation: The Schinznach Formation documents the temporary establishment of an open marine seaway connecting the northern European (Germanic) basin with the Tethys Ocean and terminating the restricted marine evaporite environment documented by the Zeglingen Formation. The axis of this seaway approximately followed the ridge of the actual Vosges Mountains, leaving the area in question in a marginal position. The transgressional phase is marked by cyclic shallow water deposits rich in encrinites and coquina and some oolites. Maximum flooding is documented by limestone and marl alternation with sporadic occurrence of ceratite cephalopods. Locally, oolitic carbonates prevail in the regressive phase which finishes with dolostone. Secondary partial or complete dolomitization also affected earlier deposits. The uppermost part of the formation originates from a littoral, deltaic to brackish environment with alternating marine and terrestrial intercalations.

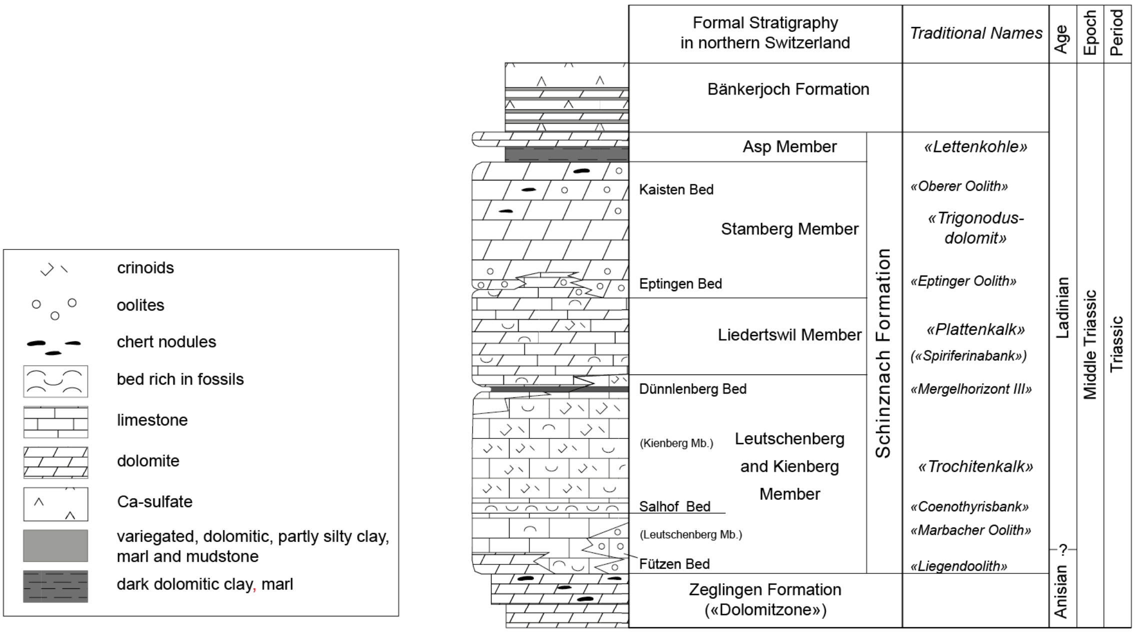


Figure 3: Stratigraphic scheme of the Schinznach Formation.

Mb.: Member. Based on Pietsch et al. (2016) and Jordan (2016)

10.4. Members of the Schinznach Formation

10.4.1. Leutschenberg Member and Kienberg Member

10.4.1.1. General and main characteristics

The Leutschenberg and Kienberg Members represent what were the «Unterer Trochitenkalk» and «Oberer Trochitenkalk» of Merki (1961). There are good arguments to distinguish the two, but for present purposes they can be taken as one unit which corresponds to the traditional «Trochitenkalk» (e.g., Müller et al. 1984; c.f. Figure 3).

The two members consist of many coarsening-upward sequences of grey micritic to sparitic limestone rich in burrows and with encrinites, coquinas and, in the lower part, also calcareous oolites, separated by mostly thin marl layers. In the lower part, burrows and, locally, the whole succession may be secondarily dolomitised.

10.4.1.2. Definition

Occurrence: The Leutschenberg Member and Kienberg Member are found in all three regions JO, NL and ZNO.

Lithology: The two members consist of grey, often bioturbated (with distinct burrows) mud- and wackestones grading into float- to rudestone. In the eastern Folded Jura coquinas with *Trochites*, (but not coquinas in general) are rare to absent in the lower part and very abundant in the upper part. This led to the distinction of the Leutschenberg Member and Kienberg Member.

In the Wutach area, and possibly in the NL and ZNO area, the lower part (Leutschenberg Member) may be partly or nearly fully oolitic (Fützen bed of Pietsch et al. 2016, «Liegendoolith» and «Marbacher Oolith» in the German stratigraphic scheme, Paul 1971, Geyer et al. 2011; see also Hofmann et al. 2000).

The fossil record includes crinoids, especially Trochites (stem elements of *Encrinus liliiformis* Lamarck), and brachiopods, among them *Coenothyris vulgaris* Schlotheim. The latter is very abundant in a bed locally found at the base of Kienberg member and formerly called "Coenothyrisbank" now Saalhof Bed (Pietsch et al. 2016). Caution: The species *Coenothyris vulgaris* is not distinctive for (the lower) Schinznach Formation. It may be also found in the Kaiseraugst Formation.

Bedding planes and burrows are often secondarily dolomitised, as well as, locally, the entire lowest part of the Leutschenberg Member. In the basal part of Weiach borehole, small anhydrite nodules and cavities resulting from sulphate solution have been found (Matter et al. 1988).

Thickness: Thickness may vary between 8 and 32 m.

Upper boundary: Pietsch et al. (2016) defined the upper boundary by the last occurrence of float- to rudestone rich in crinoid detritus (> 10 % of stratum) with a minimum thickness of 10 cm. They thus reject the concept of Merki (1961) who drew the boundary with a clay interlayer with glauconite. Pietsch et al. (2016) point out that, at some places, there is not one but a succession of glauconite-bearing clay horizons, and, at other places there are none. Additionally, the limit between Kienberg and Liedertswil Member is believed to a heterochronous facies boundary. The clay horizons, the lowest and most prominent now called Dünnlenberg Bed (Pietsch 2016), are believed to be synchronous time marker crossing the member boundary.

Lower boundary: The lower boundary is identical to that of the corresponding formation (see Section 10.2).

Lateral equivalents: The Kienberg Member and Liedertswil Member are about the same as the Trochitenkalk Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011). However, the latter ends with the «Spiriferinabank» that is not found in the eastern Folded Jura (Merki 1961). In the Wutach area, the top of the new defined Kienberg Member is localized by Pietsch et al. (2016) some 10 m below the «Spiriferinabank». The brachiopod *Punctospirella fragilis* (Schlotheim), formerly posed to the genus *Spiriferina*, may but must not occur in the «Spiriferinabank» and can also be found in layers above and below this marker bed (Geyer et al. 2011).

Names previously in use: «Trochitenkalk» or «Unterer Trochitenkalk» and «Oberer Trochitenkalk». The «Obere Trochitenschichten» of the German Stratigraphic Scheme are not fully identical with the «Oberer Trochitenkalk» of Merki (1961) (see above).

10.4.1.3. Additional information

Origin of name: The Members are named after the hill and the municipality, respectively, where the type localities are found.

Type locality and type region: The section at the western side of Leutschenberg Hill (coord. 2636.950/1251.250) near Zeglingen BL was named type locality of the Leutschenberg Member and the section close to Saalhof (coord. 2640.710/1253.860) near Kienberg SO, for the Kienberg Member (Pietsch et al. 2016). Both sections show nearly the full range of both members.

Type region is the eastern Folded Jura.

Reference section: There are no reference sections for both members.

Chronostratigraphic age: The two members are believed to be of Late Anisian age (see Section 10.4.2.3).

Genetic and paleogeographic interpretation: The Leutschenberg and Kienberg Members represent the marine transgression phase (see Section 10.3).

10.4.2. Liedertswil Member

10.4.2.1. General and main characteristics

The Liedertswil Member (Figure 3) is distinguished from the underlying members by slightly thicker but nonetheless thin (i.e. some several centimetres) shale interlayers (which results in the «Plattenkalk», meaning the flagstone nature of limestone layers) and the significantly reduced abundance of crinoidal, and, in the upper part, shell detritus.

10.4.2.2. Definition

Occurrence: The Liedertswil Member is found at very variable thickness in all three regions JO, NL and ZNO.

Lithology: The Liedertswil Member consists of grey limestone rich in shell detritus (but almost free of encrinites i.e. crinoidal limestones) in the lower part and macrofossil-poor mud- and wackestones in the upper part. The limestone beds are separated by prominent but still thin marl layers. In these marl layers and in the immediately adjacent limestone, glauconite often occurs. For details concerning the «Mergel-horizont III» (now Dünnleberg Bed) considered by Merki (1961) as the limit between the preceding two members, see Section 10.2).

Locally, the Liedertswil Member contains oolite beds, traditionally named «Eptinger Oolith» or «Dögginger Oolith». Pietsch et al. (2011) merge them as Eptingen Bed and point out that this bed may locally be also a part of the Stamberg Member when in a fully dolomitized environment.

The originally fully marine Liedertswil Member may be partly, but never fully, dolomitised. The completion of secondary dolomitization is diagnostic for the overlying Stamberg Member. Thus, the boundary between the Liedertswil and Stamberg Members is petrographic and diagenetic rather than sedimentary or allostratigraphic.

Thickness: As the upper boundary of the Liedertswil Member is petrographically defined, thickness varies locally and at high amplitude. Values from 1.5 to about 27 m are reported.

Upper boundary: The upper boundary towards the Stamberg Member is purely petrographic. It is given by the onset of sustainable complete (secondary) dolomitization. The depth of post-sedimentary dolomitization of initially marine limestone varies locally. The carbonates of the Liedertswil Member are generally dolomitised to different degrees, but dolomitization is never complete except for some subordinate beds.

Lower boundary: The lower boundary is atop the last occurrence of float- to rudestone rich in crinoid detritus (> 10 % of stratum) with a minimum thickness of 10 cm (see also Section 10.4.1.2). Trochite bearing horizons, typical for underlaying Kienberg Member, may also occur in the Liedertswil Member; however, they are thinner than 10 cm or have a crinoid content of less than 10 %.

Lateral equivalents: The Liedertswil Member corresponds roughly to the Meissner Formation of the German stratigraphic scheme (e.g., Geyer et al. 2011). While its upper boundary is identically, i.e. petrographically defined, there are significant differences at its lower boundary. The Liedertswil Member starts with the offset of prominent crinoidal layers which is, in most cases quite some metres deeper in the stratigraphic column than the «Spiriferinabank», the basal bed of the Meissner Formation.

Names previously in use: The «Plattenkalk» of Merki (1961) corresponds to what is now Liedertswil Member.

However, the term «Plattenkalk» used by other authors, or the «Nodosuskalk», a term widespread in older Swiss geological literature may diverge from the actual definition of the Liedertswil Member. The «Tonplattenregion» used by Paul (1971) for the Wutach region rather corresponds in its lower boundary with the German Meissner Formation but ends with the «Obere Oolithbank» above the Eptingen Bed of Pietsch et al. (2016) (for further discussion see above and Section 10.4.3.2).

10.4.2.3. Additional information

Origin of name: Name of municipality where the type section is found.

Type locality and type region: The type locality, the section (coord. 2620.930/1248.530) at Dünnleberg south of Liedertswil BL has been recorded by Merki (1961) and Herold (1992) and was revised by Pietsch et al. (2016).

Type region is the eastern Folded Jura.

Reference section: There is no reference section.

Chronostratigraphic age: Rare findings of ceratites prove the Middle European Compressus and Evolutus Zones (Pietsch et al. 2016), which are correlated with the turn from Anisian to Ladinian (Urlichs 1987).

Genetic and paleogeographic interpretation: The Liedertswil Member documents the high stand and the first phase of regression. In Northern Switzerland and adjacent southern Germany, ceratite ammonite findings are restricted to the Dünnleberg Bed proper and some overlying horizons (Pietsch et al. 2016) at the base of the member.

10.4.3. Stamberg Member

10.4.3.1. General and main characteristics

Indicative for the Stamberg Member (Figure 3) is that it consists of dolostone and (very subordinately) of dolomite marls. It encompasses the regressive sequence from marine limestone (but later fully dolomitised) to coastal early diagenetic dolomite.

10.4.3.2. Definition

Occurrence: The Stamberg Member is found in all three regions JO, NL and ZNO.

Lithology: In the lower part occur layered, macrofossil-poor mud- and wackestones quite like the Liedertswil Member but fully dolomitised. In the upper part occur structureless, partly porous dolostone often with chert nodules, locally sandy or anhydritic. Chert nodules, at least in some cases related to stromatolites, may also occur in the lower part and, sporadically, in the highly dolomitised parts of the Liedertswil Member. Macro-porosity (up to 3 cm) may originate from dissolved shells. Often, millimetre-thick pores are linearly arranged.

Locally, the sequence includes one or two thicker oolitic beds: the Eptingen Bed in the lower part (included in the Liedertswil Member when not fully dolomitised, see Section 10.4.2.2) and the Kaisten Bed in the upper part (Pietsch et al. 2016). Additionally, thinner oolite horizons may occur.

Thickness: As the lower boundary of the Stamberg Member is petrographically defined, thickness varies locally and at high amplitude. Values from 15 to about 37 m are reported.

Upper boundary: The upper boundary is at the base of the first decimetre-thick argillaceous marl layer of the Asp Member. This is often fossiliferous, yielding predominantly fragments such as fish teeth and scales, conchostraca, or plant remains (bone beds).

Lower boundary: The lower boundary towards the Liedertswil Member is purely petrographic. It is given by the onset of sustainable complete (secondary) dolomitization. The depth of post-sedimentary dolomitization of initially marine limestone varies locally. The carbonates of the Stamberg Member are generally fully dolomitized if not sedimentary dolomite by origin.

Lateral equivalents: The Stamberg Member corresponds to the Rottweil Formation of the German Stratigraphic Scheme with some minor deviations in the definition of its upper boundary. The dolomitic «Basisschichten», in Germany part of the hanging Erfurt Formation (which correspond to the Asp Member) are taken here as part of the Stamberg Member as they can hardly be distinguished from the underlaying dolomite beds.

Names previously in use: The Stamberg Member corresponds to the purely petrographic defined «Trigonodusdolomit» of Merki (1961). Other traditional applications of the term «Trigonodusdolomit» may differ in the definition of the upper or lower limit.

10.4.3.3. Additional information

Origin of name: Hill at the foot of which the type section lies.

Type locality and type region: The section (2628.625/1248.025) at the foot of the Stamberg south of Eptingen BL was named type locality by Pietsch et al. (2016).

Reference section: There is no reference section.

Chronostratigraphic age: Fossil evidence from Liedertswil and Asp Member (Sections 10.4.2.3 and 10.4.4.2) gives an Early Ladinian age for the Stamberg Member.

Genetic and paleogeographic interpretation: The Stamberg Member represents the end of the mid-Triassic marine episode. The regressive cycle starts with sediments of Liedertswil type which have later been dolomitised. They are interrupted and followed by coastal sediments including oolites. Finally, synsedimentary dolomite dominates, which probably formed in an inter- or subtidal coastal environment under arid conditions.

10.4.4. Asp Member

10.4.4.1. General and main characteristics

The thin Asp Member (Figure 3) includes often fossiliferous dark shales and partly anhydritic dolostone. The Asp Member corresponds to what was «Lettenkohle» or «Unterer Keuper». The succession was only recently integrated into the Schinznach Formation and thus the Muschelkalk Group (Pietsch et al. 2016).

10.4.4.2. Definition

Occurrence: The Asp Member is found in all three regions JO, NL and ZNO.

Lithology: Dark, often fossiliferous (bone beds), partly dolomitic shales, prevailing at the base, and often anhydritic dolostone. Coal seams, as the old name «Lettenkohle» suggests, have never been found in the area in question

Thickness: Reported thickness varies between about 3 and 5 m.

Upper boundary: The top of the Asp Member is represented in most cases by a (cavernous) dolostone. Commonly, the Bänkerjoch Formation starts with massive anhydrite beds of various thicknesses or a conglomerate of anhydrite and dolostone in a clay matrix. A further criterion is the offset of bituminous shale and dolostone which are abundant in the Asp Member of the Schinznach Formation.

Lower boundary: The lower limit is given by the base of the first decimetre-thick argillaceous, black, locally bituminous marl. This is often fossiliferous, yielding predominantly fragments such as fish teeth and scales, conchostraca, or plant remains (bone beds).

Lateral equivalents: Erfurt Formation of the German Stratigraphic Scheme, which also includes some beds corresponding to the uppermost Stamberg Member and lowermost Bänkerjoch Formation

Names previously in use: The Asp member corresponds exactly or approximatively to what was called «Lettenkohle», «Lettenkeuper» or «Unterer Keuper».

10.4.4.3. Additional information

Origin of name: Hamlet close to type locality.

Type locality and type region: The section (coord. 2646.375/1255.125) close to the hamlet of Asp near Densbüren AG, reported by Furrer (1977) and shown in Pietsch et al. (2016), is now nearly completely weathered and overgrown.

Reference section: Pietsch et al. (2016) designated the Nagra borehole of Weiach, drilling depth from 814.08 to 819.13, well documented by Matter et al. (1988) and preserved in the Nagra core store, as reference section.

Chronostratigraphic age: The rich fossil record of corresponding strata in Southern Germany, recently monographically treated by Hagdorn et al. (2015), gives an Early Ladinian age.

Genetic and paleogeographic interpretation: The Asp Member represents the interplay between deltaic to brackish environments, dominating at the base, and inter- to subtidal coastal evaporite environments.

11. Bänkerjoch Formation

11.1. General and main characteristics

The Bänkerjoch Formation corresponds to what used to be «Gipskeuper» in traditional (informal) Swiss stratigraphy (e.g., Müller et al. 1984). It is a succession of gypsum and anhydrite, massive or in alternation with shale and dolostone, starting with the first occurrence of sulphate sediments and ending approximately with the offset of sulphate facies (Figure 4). It differs slightly from the Grabfeld Formation (e.g., Etzold & Schweizer 2005, Geyer et al. 2011), which replaced the former «Gipskeuper» in Germany.

11.2. Definition

Occurrence: The Bänkerjoch Formation is found in all three siting regions JO, NL and ZNO.

Lithology and subdivision: Evaporitic sequence deposited in a marine to terrestrial salina or sabkha environment. The sequence can be subdivided into regressive meso- and microcycles and consists of sulphates, sulphate-shale alternations, shale with nodular sulphate and shale. Fossiliferous dolostone and sandstone beds document marine ingressions and siliciclastic pulses from the Vindelician High.

There is no formal subdivision of the Bänkerjoch Formation. The traditional subdivision in north-eastern Switzerland includes the German allostratigraphic marker bed (Leitbänke) concept introduced, for instance, by Schalch (1916), a petrographic concept by Schindler (1962) and a genetic concept by Dronkert et al. (1990). The concept of Dronkert et al. (1990) derives from an initially purely lithological scheme introduced by Matter et al. (1988) and later applied to all Nagra deep borehole records. For recording the Benken borehole (Nagra, 2001), the scheme was expanded with the adjunction of the marker beds of Schalch (1916) and Hofmann et al. (2000). The marker beds were also later identified in existing deep boreholes of central Northern Switzerland (Jordan et al. 2015). The extended (informal) scheme includes from top to base (Figure 4):

I: «Claystone with anhydrite nodules », including in its lower part (but not at the bottom) the marker bed 1, which corresponds to the «Quarzitische Bank» of Schalch (1916)

II: «Cyclic sequence»

III: «Thin-layered anhydrite claystone sequence» including in its middle part the marker bed 2, which corresponds to the «Muschelbank mit Mytilus» of Schalch (1916), which is identified by Hofmann et al. (2000) as «Pseudocorbula-Bank» or «Bleiglanzbank»

IV: «Banded massive anhydrite»

V: «Dolomite and anhydrite»

Thickness: In the area under investigation, thickness of 30 to 130 m is expected.

Upper boundary: The Limit to the Klettgau Formation is set at the top of a horizon consisting of one or more dolomite layers above the offset of sulphate facies. This dolomite horizon corresponds to the uppermost bed of the «Graue Estherienschichten» of southern Germany. At places where the dolostone horizon is missing, the offset of sulphate facies is taken as the upper boundary. In a few cases, the siliciclastic sandy channel («Schilfsandstein») facies of the Ergolz Member erodes down to the dolomite horizon or the sulphate facies. But in most cases, the dolomite horizon is overlain by (sulphate-free) variegated claystone, marl and dolostone

Lower boundary: The onset of the evaporitic facies defines the boundary to the Schinznach Formation. In most cases, the Bänkerjoch Formation starts with massive anhydrite beds of various thicknesses or a conglomerate of anhydrite and dolostone in a clay matrix. The top of the Asp Member is represented in most cases by a (cavernous) dolostone. With respect to clay mineralogy, the boundary is said to correspond to the onset of corrensite (e.g., Peters 1964, Peters et al. 1986, Matter et al. 1988). A further criterion is the offset of bituminous shale and dolostone which are abundant in the Asp Member of the Schinznach Formation.

The delimitation follows the traditional Swiss scheme: The equivalents of the southern German «Fränkischer Grenzdolomit» and the underlying evaporite («Böhringen Sulfat») are part of the Bänkerjoch Formation.

Lateral equivalents: The Bänkerjoch Formation mostly corresponds to the Grabfeld Formation of southern Germany (excluding the sulphate-free upper part of the «Estherienschichten») and the uppermost part of the Erfurt Formation (e.g., Etzold & Schweizer 2005, Geyer et al. 2011).

Towards the east, it correlates to the massive siliciclastic Benk Formation which may reach as far as the Lake Constance area according to the paleogeographic reconstruction by Beutler & Nitsch (2005). Towards the south, the Bänkerjoch Formation wedges out

Names previously in use: The Bänkerjoch Formation corresponds to the «Gipskeuper» as it was traditionally defined in Switzerland.

11.3. Additional information

Origin of name: Bänkerjoch, a road pass close to the type locality.

Type locality and type region: Riepel quarry (coord. 2645.300 /1253.850) was chosen as type locality as the present-day outcrop conditions and accessibility are quite good and the stratigraphic succession has been repeatedly recorded (Schindler 1962, Rick 1990, Kleiner 2009, Meier 2011, Bernasconi et al. 2017) under differing outcrop conditions and from various scientific points of view. It is the only outcrop where the top and base of the formation are or have been exposed (see section compilation by Jordan et al. 2016a and b). Further, it can easily be correlated with the borehole reference section at the Weiach borehole. The Riepel section includes the upper four stratigraphic I to IV units of the current informal stratigraphic scheme developed for the Nagra boreholes (Matter et al. 1988), including the marker bed 2 (see below). The lowermost unit V is apparently missing, as well as the marker bed 1, which were expected in the uppermost unit I.

Type region is the eastern Folded Jura.

Reference section: The Weiach borehole (coord. 2676.745/1268.618), drilling depth 739.35 – 814.08 m, well documented by Matter et al. (1988) and preserved in the Nagra core store, was chosen as reference section by Jordan et al. (2016b).

Chronostratigraphic age: The corresponding succession in Germany was suggested to be of Late Ladinian to Early Carnian age. (DSK 2005; Kozur & Bachmann 2008). Dating bases on fossile record, mainly moluscs, in the marine intercalations (Geyer et al. 2011). A chemostratigraphic correlation confirmed that age (Bernasconi et al. 2017).

Genetic and paleogeographic interpretation: The Bänkerjoch Formation was deposited under (semi)arid conditions in the southern extension of the Middle European or Germanic Basin. The basin was influenced by periodic marine ingressions from the southwest and rare signs of erosional events in the Bohemian (Vindelician) Massif (Beutler & Nitsch 2005). Fully marine conditions are documented by the bivalve fauna of dolostone and sandy interlayers including the marker horizons «Pseudocorbula-Bank» and «Quarzitische Bank» (see above). The dominant sedimentary environments, however, were peri-marine (salina) to terrestrial evaporite (sabkha), organised in regressive cycles. According to Dronkert et al. (1990), the present-day Bänkerjoch Formation can be subdivided into two mesocycles, with the upper one consisting of 27 microcycles.

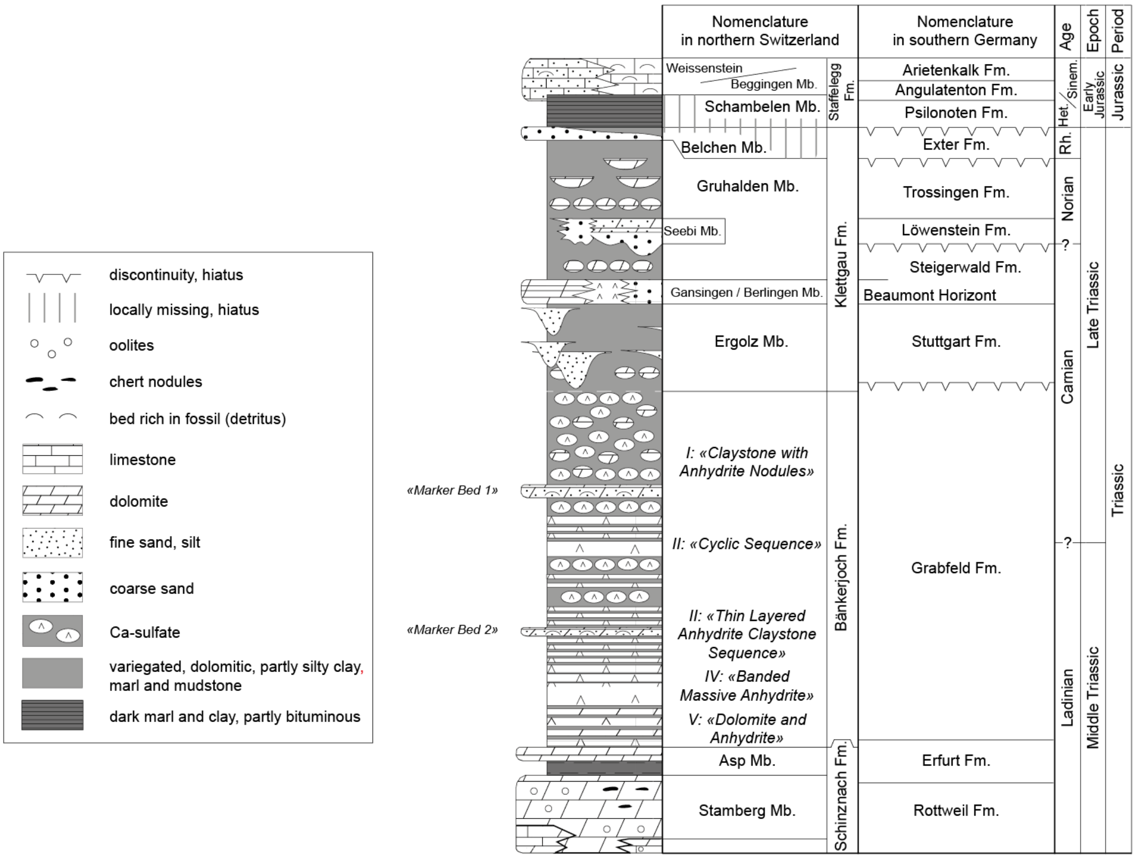


Figure 4: Synthetic section of the Bänkerjoch Formation and Klettgau Formation.

Informal units in italic. Rh.: Rhetian; Het.: Hettangian; Sinem.: Sinemurian, Fm.: Formation; Mb.: Member. Modified from Jordan (2016) and Jordan et al. (2016b)

12. Klettgau Formation

12.1. General and main characteristics

The Klettgau Formation was recently defined by Jordan et al. (2016b). It encompasses around 30 to 75 m of playa sediments with fluvial and marine intercalations of Late Triassic age (Figure 4). It includes what was formerly known as «Sandsteinkeuper» (e.g., Hofmann et al. 2000), «Mergelkeuper», (e.g., Jordan et al. 2008), or, more neutrally, «Oberer Mittelkeuper». It also comprises the «Oberer Keuper» or «Rhät», thin or absent in the areas in question. In other words, the Klettgau Formation encompasses the whole interval between the Bänkerjoch Formation (Jordan et al. 2016) and the Staffelegg Formation of Early Jurassic age (Reisdorf et al. 2011).

The Klettgau Formation is characterised by terrestrial to restricted marine fluvial and alluvial sediments originating from a semi-arid environment.

12.2. Definition

Occurrence: The Klettgau Formation is found in all three regions JO, NL and ZNO. However, some of its members are restricted to one or another region (see Section 12.4).

Lithology and subdivision: The Klettgau Formation (Figure 4) is a quite heterogeneous succession dominated by variegated playa sediments with mostly silty shales and dolocretes (Jordan et al. 2016). Fine-grained to coarse-grained carbonatic or quartzitic fluvial sandstones are found in channels and overspill layers. Another important lithology is carbonate, locally fossiliferous, and now mostly present as dolostone, and sulphate partially replaced by calcite. Bone beds are found at several levels. Estuarine to shallow-marine fossiliferous sandstone and marine shale are restricted to the uppermost part that was fully eroded in the Late Triassic or Early Jurassic in most of the areas in question here.

The Klettgau Formation is subdivided, from bottom to top, into Ergolz, Gansingen, Berlingen, Gruhalde, Seebi and Belchen Members (Jordan et al. 2016b). The members (cf. Figure 4) will be described individually in the following sections.

Thickness: The thickness varies between 30 to 60 m, and locally can reach up to 75 m.

Upper boundary: The upper boundary of the Klettgau Formation is defined by a heterochronous (late Early Hettangian to Early Sinemurian) transgression of the Staffelegg Formation over an erosional surface of variable extent in depth. In most areas in Northern Switzerland, including the JO, NL and most of the ZNO regions, the upper boundary of the Klettgau Formation is clearly defined by the transgression of dark, often fossiliferous, marine marl and limestone over terrestrial playa-type greyish to variegated dolomitic marl. In some parts of the ZNO (and possibly also NL) region, the boundary may be marked by the top of the Belchen Member (Section 12.4.6.2).

Lower boundary: The Klettgau Formation always overlies the Bänkerjoch Formation. The problem of delimiting the two formations was addressed above, when discussing the Bänkerjoch Formation (Section 11.2). In the areas in question, in most cases, it can be set atop of a horizon consisting of one or more dolomite layers above the offset (or, in the drilling direction, onset) of sulphate facies of the Bänkerjoch Formation.

Lateral equivalents: To the north, the Klettgau Formation corresponds (from bottom) to the uppermost parts of the Grabfeld Formation, the Stuttgart Formation, the Steigerwald Formation, the Hassberge Formation (disputed, see below), the Löwenstein Formation, the Trossingen Formation, and the Exter Formation of the German Stratigraphic Scheme (e.g., Etzold & Schweizer 2005, DSK 2005, Geyer et al. 2011).

Names previously in use: The succession expected in most of the areas in question here was formerly addressed as «Sandsteinkeuper» or «Mergelkeuper», although sandstone dominates nowhere and there are other important lithologies besides marl. A more neutral term was «Oberer Mittelkeuper». The Belchen Member, possibly encountered in the eastern ZNO region, was addressed as «Rhät» or «Oberkeuper».

12.3. Additional information

Origin of name: The Klettgau area, where the type locality is located.

Type locality and type region: The abandoned Seebi quarry (coord. 2680.575/1291.800) in Schleitheim SH (Hofmann et al. 2000; Schalch 1916) is classified as a geotope of national significance. Public access is guaranteed and facilitated by technical means. However, now, the quarry shows only a part of the full formation.

Reference section: The best outcrop today, however, is the Gruhalde clay pit in Frick (coord. 2642.925/1261.890 to 2643.075/1261.950), although the youngest part of the formation, the Belchen Member, is missing here due to erosion during the Early Jurassic. Furthermore, the section does not include the thick beds of coarse Vindelician sand inputs, which are restricted to north-eastern Switzerland (now Berlingen and Seebi Members). To include all variations of the formation and their boundaries, the Siblingen (Nagra 1992) and Berlingen-1 boreholes (Büchi et al. 1965, Bläsi 1995) and the Belchen/Chilchzimmersattel outcrop in Eptingen BL have been chosen as additional reference sections (Jordan 2016).

Chronostratigraphic age: Carnian to Rhetian (DSK 2005; Kozur & Bachmann 2008).

Genetic and paleogeographic interpretation: The Klettgau Formation incorporates sediments deposited over a very long time, around 26 to 30 million years according to DSK (2002). This time is characterised by several changes in the environment, including long periods of omission and erosion. The common pattern in this time is a broad depression connecting the Central European (Germanic) Basin with the Tethys Ocean, which reaches from Hesse to Northern Switzerland and, via the so-called Burgundy gateway, further to southern France (Beutler & Nitsch 2005). Within this depression, several marine ingressions, generally from the south-west, are documented. Riverine input originated initially from Scandinavia. Later, the direction of sediment transport changed to ENE-WSW. Northern Switzerland was then episodically covered by clastic delivery from the Vindelician High, which limited the depression in the south-east (Beutler & Nitsch 2005; Etzold & Schweizer 2005).

12.4. Members of the Klettgau Formation

12.4.1. Ergolz Member

12.4.1.1. General and main characteristics

The Ergolz Member replaces the former «Schilfsandstein» and «Untere Bunte Mergel» or «Schilfsandstein-Gruppe» of traditional Swiss Stratigraphic Scheme. As such, it corresponds to the Stuttgart Formation and the (locally eroded) Obere Bunte Estherienschichten Subformation of the Grabfeld Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

12.4.1.2. Definition

Occurrence: The Ergolz Member is found in all three siting regions JO, NL, and ZNO.

Lithology: In most cases, the Ergolz Member starts with often silty (but not sandy) and, in most cases, sulphate-free variegated claystone to dolomitic marl and thin layers of dolostone and fine-grained sandstone (Figure 4). Locally, this equivalent to the German Obere Bunte Estherienschichten Subformation may be cut or fully eroded by channels filled by fine- to medium-grained sandstone («Rinnenfazies», channel fills, Etzold & Schweizer 2005). Otherwise they are overlain by silty to sandy variegated marl with dolocretes, etc. («Überflutungsfazies» (overbank deposits) or, in the older literature, «Normalfazies», Etzold & Schweizer 2005). At some localities, «Rinnenfazies» dominates and only the uppermost part of the section is built up by «Überflutungsfazies». At other locations, different levels of «Rinnenfazies» separated by «Überflutungsfazies» can be distinguished. Finally, at some further locations «Rinnenfazies» can be fully absent or only represented by thin horizons of fine sandstone.

Thickness: The thickness varies between 6 and 23 m. There are regional trends, but thickness may also change locally due to changes from alluvial «Überflutungsfazies» to fluvial «Rinnenfazies».

Upper boundary: In most cases, the Ergolz Member is overlain by massive, in some places porous, marine limestone, which is now dolomitised (dolomite facies of Gansingen Member). It can easily be distinguished from dolocretes in the underlying Ergolz Member. Only where the overlying Gansingen Member has been almost fully eroded, can its basal layer be nodular (see discussion below).

Towards the north-east, the upper boundary is successively defined by the onset of sulphate rocks, today partly altered into dolostone or limestone, i.e. the eastern, evaporite facies of the Gansingen Member, or the onset of the coarse-grained sandstone of the Berlingen Member (see respective discussions below).

Lower boundary: The lower boundary of the Ergolz Member is always identical with the lower boundary of the Klettgau Formation (Sections 11.2 and 12.2). In most cases, it is at the top of a horizon consisting of one or more dolomite layers above the offset of sulphate facies of the Bänkerjoch Formation. In some cases, the «Rinnenfazies» channels have eroded at a level below the dolomite horizon. In this case, the lower boundary is defined by the onset of fluvial sand facies.

Lateral equivalents: To the north-east, the Stuttgart Formation and the uppermost parts of the Grabfeld Formation of the German Stratigraphic Scheme (Etzold & Schweizer 2005; Geyer et al. 2011) are the equivalents of the Ergolz Member. To the east, but probably only outside the areas under investigation here, there may be a transition to the coarse-grained clastic marginal facies adjacent to the Vindelician High (Beutler & Nitsch 2005).

Names previously in use: «Schilfsandstein» and «Untere Bunte Mergel», «Schilfsandstein-Gruppe», «Schilfsandstein im weiteren Sinn».

12.4.1.3. Additional information

Origin of name: Name of the creek along the type section.

Type locality and type region: The natural outcrop along the Ergolz creek near Riedacher/Füllinsdorf BL was studied by Strübin (1901) and Disler (1914). Their records were reviewed on-site in spring 2015 by Jordan et al. (2016a). The actual outcrop covers most of the overlying Gansingen Member, all the Ergolz Member and the uppermost beds of the Bänkerjoch Formation.

The Ergolz section represents the common appearance of the Ergolz Member dominated by «Überflutungsfazies» (overbank deposits, see above) with distal echoes of «Rinnenfazies». The reddish fine-sand «Rinnenfazies» (channel fills) proper are suitable for masonry and can be found in many abandoned or active quarries such as Seebi (Schalch, 1916) or Röt near Gansingen (Wildi 1976), respectively.

The type region is the Basel Tabular Jura.

Reference section: The Weiach borehole (coord. 2676.745/1268.618), drilling metre 704.32 to 724.32 («Schilfsandstein sensu lato» in Matter et al. 1988 without basal «Dolomitbank») was denoted by Jordan et al. (2016b) as the reference section. The section has been fully cored and is conserved in the Nagra core store facility.

Chronostratigraphic age: Carnian (DSK 2005; Kozur & Bachmann 2008).

Genetic and paleogeographic interpretation: The lowest part (Estherienschichten Subformation in the German Stratigraphic Scheme) corresponds to the end of a regressive cycle, where a marine evaporitic environment was replaced by a playa to fluvial environment.

The overlying «Schilfsandstein» facies documents a large system of meandering or even anastomosed rivers coming from Scandinavia that reached the Tethys shoreline near Lyon (Beutler & Nitsch 2005). An analysis of borehole and outcrop data confirms the concept of Wurster (1968) that channel facies is concentrated along NNE – SSE trending lineaments.

In southern Germany, two sedimentary cycles each beginning with abundant sandy channels and ending with nearly pure overbank facies are well documented (Etzold & Schweizer 2005). There is evidence that these two cycles can also be distinguished in Northern Switzerland.

12.4.2. Gansingen Member

12.4.2.1. General and main characteristics

The Gansingen Member corresponds to the Beaumont Horizon of the Steigerwald Formation in southern Germany (Figure 4). Originally, the fossiliferous «Dolomit von Gansingen» was described as a local curiosity by von Alberti (1864). In the mid-20th century, the term «Gansingen Dolomit» became more and more popular among Swiss geologists, first as an equivalent to the basal «Hauptsteinmergel» then to the whole Beaumont Horizon. In the traditional Swiss Scheme, the «Gansingen Dolomit» was a succession rich in dolostone forming small cliffs and ridges within the surrounding marl (e.g., Müller et al. 1984). This concept was consequently applied to the core recordings of the Nagra deep drilling programme (e.g., Matter et al. 1988, Nagra 1992a, Nagra 1992b, Nagra 2001) and was consequently adopted for the definition of the Gansingen Member (Jordan et al. 2016b).

Towards the north-east, the marine late diagenetic dolomite facies (initially limestone) is successively replaced by some evaporitic facies. The primary calcium sulphate is partly replaced by dolomite or even calcite as, for instance, in the Seebi section. According to the Nagra borehole records (e.g., Matter et al. 1988, Nagra 1992a, Nagra 1992b, Nagra 2001), this facies is also integrated into the Gansingen Member (Figure 4). This agrees with Schalch (1916) who correlated the heterogeneous dolostone and limestone outcropping in the Klettgau and adjacent Wutach area as equivalents of the «Hauptsteinmergel». He also included the local «Duröhrlestein» variety, characterised by thin dark bituminous calcite (anthraconite or stinkstone) interlayers.

12.4.2.2. Definition

Occurrence: The dolomite facies of the Gansingen Member is expected in the JO siting region and the evaporite facies in the ZNO region. The Weiach borehole showed dolomite facies. However, there may be a transition to evaporite facies in the eastern parts of the NL region.

Lithology: The dolomite facies comprises locally fossiliferous or oolitic, partly cavernous massive yellowish grey dolomite continuing upwards to laminated (stromatolitic) dolostone with marly intercalations and a typical banding with fine red horizons.

Towards north-eastern Switzerland there is a lateral transition to sulphate rocks that are, in most cases, altered to dolostone or limestone (evaporite facies).

Thickness: The maximum thickness is some 6 m. In some places, the Gansingen Member may be reduced or even missing due to intra-Triassic erosion.

Upper boundary: The upper boundary towards the Gruhalde Member is gradual in most cases. At the reference section, in the Gruhalde clay pit in Frick, where the outcrop conditions are excellent and a bed by bed analysis of carbonate and clay mineral contents is available (Peters 1964), the upper boundary was defined where dolomite contents drop from 85 % to less than 50 % and desiccation features document the change from a marine to playa environment.

At some locations, the upper boundary is erosional. At the type locality, the Gansingen Member is overlain by probably younger parts of the Gruhalde Member (see above). In the Klettgau area, the Gansingen Member is locally directly overlain by coarse sandstone of the Seebi Member (Nagel 1990).

Lower boundary: In most cases, the lower boundary of the Gansingen Member is sharp, independent of whether it is dolomitised limestone or calcified/dolomitised sulphate rock resting on top of variegated dolomite marl. Only where Late Triassic erosion cut down to the basal layers, the latter may be disintegrated to nodules by subrosion processes. Generally, due to the compact texture (even when porous) and the local presence of ooids or bivalves, the basal bed of the Gansingen Member can easily be distinguished from dolocrete nodules or layers of the underlying Ergolz Member.

Lateral equivalents: The equivalent in the north to north-east is the Beaumont Horizon of the Steigerwald Formation (Etzold & Schweizer 2005; Geyer et al. 2011). To the east, there is a transition to the Berlingen Member.

Names previously in use: «Gansinger Dolomit (sensu lato) », «Hauptsteinmergel», «Beaumont Horizont».

12.4.2.3. Additional information

Origin of name: Name of the municipality where the type locality is situated.

Type locality and type region: To maintain the name Gansingen, the Röt quarry near the village of Gansingen was chosen as the type locality (Jordan et al. 2016b). At this location, the Gansingen Member is very fossiliferous, in some layers even forming a coquina, as already mentioned by von Alberti (1864) and later described by Wildi (1976). However, only 0.4 to 1.0 m of the very basal layers of the Gansingen Member resisted Late Triassic erosion here.

The type region is the Fricktal Tabular Jura.

Reference section: The 6 m thick succession of the Gruhalde clay pit in Frick AG (Gsell 1968; Peters 1964) is complete and unaffected by erosion and was determined as the reference section of the Gansingen Member (Jordan et al. 2016b).

Chronostratigraphic age: Carnian (DSK 2005; Kozur & Bachmann 2008).

Genetic and paleogeographic interpretation: The corresponding Beaumont Horizon in the adjacent Upper Rhine Graben area is interpreted by Beutler and Nitsch (2005) to document a marine transgression connecting the Tethys and the Central European Basin. In the area discussed here, the low diverse and dwarfed fauna found in the Frick and Gansingen outcrops (Wildi 1976), with several species of gastropods and bivalves, is dominated by euryhaline genera such as *Bakevellia*, *Costatoria* and *Pseudocorbula*, also characteristic of brachyhaline or hyposaline environments of the Erfurt Formation (Hagdorn 2015). The occurrence of *Unionites* sp. in Gansingen suggests a brackish environment. Stenohaline organisms such as cephalopods or echinoderms are missing. The restricted marine facies was bordered to the east by salina or littoral sabkha-type evaporitic environments (also part of Gansingen Member). The sabkha is again replaced eastwards by siliciclastic marginal facies adjacent to the Vindelician High (Berlingen Member). In a regressive cycle, the marine to lagoonal environment was successively replaced by a playa environment.

12.4.3. Berlingen Member

12.4.3.1. General and main characteristics

In the Berlingen and Herdern boreholes east of the ZNO region, a coarse-grained sandstone with calcitic matrix is found at the level where the Gansingen Member is expected (sandy layers of «Bunte Mergel (mit Sandlagen) » by Büchi et al. 1965). This sandstone can clearly be distinguished from the fine-grained sandstone of the Ergolz Member. These layers are significantly older than the Seebi Member, to which they show some similarities. A correlation with the «Kieselsandstein» of southern Germany (now Hassberge Formation, e.g., Etzold & Schweizer 2005) has been postulated by Bläsi (1995), but not yet proven (see below).

12.4.3.2. Definition

Occurrence: The Berlingen Member may occurs in the eastern part of the ZNO region but is definitively absent in all other areas.

Lithology: Medium-grained to coarse-grained, poorly sorted sandstone with quartz, feldspar and rocky fragments of the surrounding members. The matrix contains quartz cement, sulphate or clay in alternation with layers of clayey sandstone and claystone with dolomite nodules.

Thickness: Up to 5 m.

Upper boundary: The limit to the overlying Gruhalde Member is given with the onset of variegated marl over medium- to coarse-grained sandstone.

Lower boundary: The limit to the underlying Ergolz Member is set at the base of the first medium- to coarse-grained sandstone bed over variegated marl.

Lateral equivalents: To the west, there is a not yet well documented transition to the evaporite facies of the Gansingen Member.

Names previously in use: «Sandlagen» of «Bunte Mergel (mit Sandlagen) » by Büchi et al. (1965), «Kieselsandstein» *sensu* Bläsi (1995).

12.4.3.3. Additional information

Origin of name: Name of type locality.

Type locality and type region: The Berlingen-1 borehole (coord. 2719.686 / 1280.194), drilling metre 2120.8 – 2125.0 (Büchi et al. 1965) was denoted by Jordan et al. (2016b) as the type locality. The member comprises the interval denoted as «Kieselsandstein» by Bläsi (1995) and, additionally, the overlaying sandstone interval. The cores are conserved in the swisstopo core repository and/or in the SEAG core repository at Wermatswil.

As the Berlingen Member has been yet only found in the deep boreholes of the Thurgau Seerücken region, this must be regarded as type region.

Reference section: There is no formal reference section. The Berlingen Member was also encountered in the Herdern borehole.

Chronostratigraphic age: Carnian (DSK 2005; Kozur & Bachmann 2008).

Genetic and paleogeographic interpretation: The Berlingen Member is interpreted as sandy marginal facies of the Vindelician High. From the genetic point of view, it shows affinities to the Hassberge Formation of southern Germany (e.g., Etzold & Schweizer 2005), even though it is probably significantly older.

12.4.4. Gruhalde Member

12.4.4.1. General and main characteristics

The Gruhalde Member encompasses all sediments between the Gansingen or Berlingen Member (below) and the Belchen Member or Staffelegg Formation (above). In north-eastern Switzerland it is interrupted by the massive sandy interval of the Seebi Member.

The Gruhalde Member represents a very long span, some 20 million years according to the Stratigraphic Scheme for southern Germany (DSK 2005). This period includes several important paleogeographic revolutions, such as the Old Cimmerian discontinuity. In fact, it is a 3 to 20 m thick succession of predominantly variegated playa-type dolomitic marl. In traditional Swiss stratigraphy it was summarised as «Obere Bunte Mergel». And some authors have denoted the upper part as «Knollenmergel» or «Zanklodonmergel» (c.f. Diebold et al. 2006).

12.4.4.2. Definition

Occurrence: The Gruhalde Member is found in all three siting regions JO, NL, and ZNO.

Lithology: The Gruhalde Member is a heterogeneous succession of variegated to greyish dolomitic marl with dolomite interlayers, mostly dolocrete, but also oolitic shallow marine dolostone, and intercalations of coarse sand, in most cases sandy dolostone to dolomitic sandstone. Widespread, often channel-type erosion affected the succession.

For more details, see the description of the succession at the type locality (Section 12.4.4.3).

Thickness: The total thickness varies between 3 and 20 m, including the interlaying Seebi Member where present.

Upper boundary: The upper boundary of the Gruhalde Member is defined by the transgression of the estuarine to marine Belchen Member or the fully marine Staffelegg Formation, generally above a sharp erosional contact. The upper boundary is often erosional and there is evidence that, in some places, erosion had eliminated important portions of the Gruhalde Member before the sedimentation of the overlying units started (Jordan et al. 2016a and b).

Inner boundaries: The top of the Seebi Member is marked by the offset of the coarse-grained sand facies or sandy dolomite facies.

The base of the Seebi Member is defined by the onset of coarse-grained sandstone or, in some places, sandy dolostone over variegated marl.

If the thickness of the sand layers does not exceed 1 m, they are taken as a bed of the Gruhalde Member (see Section 12.4.5.2).

Lower boundary: In many places, the lower boundary towards the Gansingen Member is defined by an erosional surface. In complete sections, the lower boundary is gradual, given by the decrease in dolomite content (see Section 12.4.2.2).

In the area where the Berlingen Member occurs, the lower boundary of the Gruhalde Member is defined by the offset of the coarse-grained sandstone.

Lateral equivalents: To the north and north-east, the Gruhalde Member corresponds to the Trossingen, Löwenstein, and Steigerwald Formations of the German Stratigraphic Scheme (e.g., Etzold & Schweizer 2005, Geyer et al. 2011). A. Etzold (pers. comm. 2015, see Jordan et al. 2016a and b) suggests correlating the lower two parts of the Gruhalde Member at the Gruhalde pit (Section 12.4.4.3) with the Rote Wand Subformation, the upper part of the Stuttgart Formation. The middle (third) part can be correlated, due to the presence of coarse-grained sandstone, with the German Löwenstein Formation (previously «Stubensandstein»). The presence of *Plateosaurus* remains points to a Late Norian age (C.A. Meyer, pers. comm. 2015) and thus to the upper part of the Löwenstein Formation or the Trossingen Formation (Etzold & Schweizer 2005; Geyer et al. 2011). The uppermost part of the section may correlate with the German Trossingen Formation (although a marine ingression is not reported from there, Geyer et al. 2011).

Equivalents of the intercalating Seebi Member, thin beds of coarse-grained sandstone, can be followed further to the west (see Section 12.4.5).

Names previously in use: «Obere Bunte Mergel», «Knollenmergel», «Zanclodonmergel».

12.4.4.3. Additional information

Origin of name: Name of the type locality.

Type locality and type region: The Gruhalde clay pit in Frick AG gives the best insight today in the whole of Northern Switzerland into the succession of the Gruhalde Member. The section was originally described by Peters (1964), Gsell (1968), Gygi & Rieber (1989), Meyer & Furrer (1995), and A. Etzold (pers. comm. 2015). Reisdorf et al. (2011) revised the Jurassic part of the section. From April to October 2015, the Triassic part was recorded anew by Jordan et al. (2016a) using the findings of the authors cited above. According to Jordan et al. (2016a and b), four parts can be distinguished:

The first part starts above a desiccation horizon. It comprises a 2.8 m thick succession of variegated, predominantly greenish-grey dolomitic marl and dolostone, which show some affinities to the underlying Gansingen Member, including the persistence of the strata in outcrop scale.

The second part is 1.8 m thick. It is dominated by bright to dark (brownish) red dolomitic marl. At various levels, para-conformities can be suspected (see below).

The third part is about 5 m thick and is first variegated, then changes to light grey colour with purple striation further up. It is characterised by non-persistent layers and abundant channel structures. The channel fills consist of silty marl to coarse-grained sandstone, with mainly quartz and, subordinately, dolomite intraclasts and extraclasts, feldspar and mica. The matrix is dolomitic. Quartz grains show pressure solution and syntaxial growth. The channels are carved into dolomitic marl, which represents overbank deposits affected by pedogenesis. The finding of many bones, including articulated skeletons of the prosauropod dinosaur *Plateosaurus engelhardti* (e.g., Sander 1992, Foelix et al. 2011, Hofmann & Sander 2014), points to a terrestrial playa environment traversed by some channels. This is supported by sedimentological evidence.

The upper, fourth part of the Gruhalde Member starts with a 20 cm thick persistent marker horizon consisting of well sorted, fine-grained sandstone (predominantly quartz, feldspar, intraclasts, ooids and mica). It alternates laterally and vertically with oolitic lenses. The presence of miliolid foraminifers in the sandstone and oolite documents marine to brackish conditions. This basal bed is followed by 10 m of mainly greyish to light purple marl where some channels, filled with dolostone and dolomitic marl, are carved in. In the basal levels of this upper part, *Plateosaurus* remains were also found, while in the uppermost part fragmented but articulated skeletons of prosauropod and theropod dinosaurs have been detected (e.g., Meyer & Thüring 2003, Foelix et al. 2011).

The type region is the Fricktal area.

Reference section: No reference section has been defined.

Chronostratigraphic age: The Gruhalde Member is not only the member representing the longest timespan within the Klettgau Member but also in the whole Mesozoic succession of Northern Switzerland. Sedimentation started in the Late Carnian and continued, probably with many interruptions, to the Late Norian and possibly even to the Early Rhetian. In Northern Switzerland, fossil evidence that can be used for the determination of age is rare. See Section 12.4.3.2 for a possible correlation with the better dated sediments of southern Germany.

Genetic and paleogeographic interpretation: With a view to the more complete succession in adjacent southern Germany, the history of the Gruhalde Member can be summarized synoptically as follows:

The marine episode documented in the Gansingen Member is followed by a coastal playa. Coarse-grained detrital input is restricted to north-eastern Switzerland. Evidence at the Seebi quarry suggests that it is linked with erosion affecting parts of the Gansingen Member. Possibly, sedimentation continued in what are termed the Hassberge and Mainhart Formations in southern Germany (e.g., Etzold & Schweizer 2005).

Following the Old Cimmerian orogenic movements, erosion cut at least down to the «Rote Wand», but in some places even the basal layers of the Gansingen Member were affected. The fluvial coarse-grained siliciclastics of the Seebi Member are well documented in north-eastern Switzerland and probably extended into central Northern Switzerland but were later mostly eroded. In north-eastern Switzerland, the sandy facies developed to a possibly coastal sabkha-type environment, where sandstone and marl were dolomitized. At the same time, a playa developed in north-western Switzerland, slowly prograding towards the east, where rivers carved channels into the muddy plains. The playa was later drowned, resulting in a short episode of marine or brackish sediments, but, at least in the Frick area, playa sedimentation continued, accentuated by ephemeral channel incisions.

In some places, erosion eliminated most of the previously deposited sediments before the deposition of the Belchen Member. Only a few metres of the oldest well-layered variegated strata were left, for instance at the type locality of the Belchen Member (Jordan et al. 2016b).

12.4.5. Seebi Member

12.4.5.1. General and main characteristics

The Seebi Member corresponds to the former Stubensandstein. It consists of medium-grained to coarse-grained sandstones or conglomerates and the overlying sandy dolostone as found in the Schaffhausen area (Figure 4).

12.4.5.2. Definition

Occurrence: As the minimum thickness for a member on its own was defined as 1 m (Jordan et al. 2016b), the occurrence of the Seebi Member is restricted to the ZNO region. In the other areas, thinner lateral equivalents may be encountered.

Lithology: The Seebi Member comprises poorly sorted sandstones and conglomerates with predominantly polycrystalline quartz grains of volcanic, metamorphic or mylonitic origin, dolostone and clay pebbles, feldspar and, in most cases, calcitic matrix, dolomitic sandstones and crumbly sandy dolomitised sulphcretes. For more details see next section.

Thickness: In north-eastern Switzerland, the thickness reaches up to 10 m. The minimum thickness is, by definition, 1 m. Correlated coarse sandstone or sandy dolostone occurrences with a thickness less than 1 m are taken as part of the Gruhalde Member.

Upper boundary: The upper boundary is given with the return of variegated marl of the upper part of Gruhalde Member over sandstone or sandy dolostone.

Lower boundary: The lower boundary is given with the onset of coarse-grained sandstone or conglomerate, in some cases sandy dolostone over variegated marl of the lower part of Gruhalde Member, in most cases above an erosional discontinuity.

Lateral equivalents: To the west, the Seebi Member is continued by thin beds of coarse-grained sandstone, taken as part of the Gruhalde Member.

To the north and north-east, it corresponds to the Löwenstein Formation of the German Stratigraphic Scheme (e.g., Etzold & Schweizer 2005, Geyer et al. 2011).

Names previously in use: «Stubensandstein»

12.4.5.3. Additional information

Origin of name: Name of the type locality.

Type locality and type region: The abandoned Seebi quarry (coord. 2680.575/1291.800) near Schleitheim SH, which is also the type locality for the Klettgau Formation, shows in its higher level a representative but incomplete section of the Seebi Member. This section was described already by Schalch (1916) and Hofmann et al. (2000) and was newly recorded in May 2015 by Jordan et al. (2016a).

The 5.2 m thick section comprises all three characteristic lithotypes of the Seebi Member: coarse-grained sandstone to conglomerate, sometimes cross-bedded, forming 5 to 15 cm thick partly channelized beds; silty to sandy dolomitic mudstone; and dolomitic marl. The section ends with a conglomerate bed with no visible overlying strata.

The type region is the eastern Klettgau area.

Reference sections: The reference section (drilling metre 709.12 – 720.60) of the Benken borehole (coord. 2690.990/1277.843) shows the Seebi Member in a more distal marly facies («Stubensandstein» in Nagra 2001). It starts with a 4 m thick alternation of coarse-grained sandstones and conglomerates, sandy marl and sandy dolostones. The matrix of the sandstones is calcitic in the lower part and dolomitic in the upper part. It is followed by an approximately 1.9 m thick sandy dolostone succession and a succession of 5.4 m crumbly and cavernous brownish caliche-type dolomite nodules in a dolomitic to clayey matrix. At some levels, oncoids and chert in the form of nodules and joint fill are found.

Sandy dolostones in the upper part of the Seebi Member are also reported in the Schlattingen borehole (Albert et al. 2012) and in outcrops in the Klettgau area (Hofmann et al. 2000). In the Siblingen borehole (Nagra 1992b), the Seebi Member is represented by sandy dolostone only. In the Herdern and Berlingen boreholes (Büchi et al. 1965), the Seebi Member is developed in purely sandy facies.

Chronostratigraphic age: Norian (DSK 2005; Kozur & Bachmann 2008).

Genetic and paleogeographic interpretation: Following the Old Cimmerian orogenic movements, the Seebi Member represents a widespread progradation of fluvial facies from the east, i.e. from the Vindelician High. It was successively replaced by a playa to sabkha environment where sulphcretes formed. These original gypsum deposits were later altered to dolomite or calcite.

12.4.6. Belchen Member

12.4.6.1. General and main characteristics

There was much confusion with the term Rhät or Oberer Keuper when it was used as a lithostratigraphic unit. Traditionally it included «Rhätsandstein» and «Rhätmergel» (Jordan et al. 2016b). The purely lithostratigraphic definition of the Belchen Member aims to bring such discussions to an end.

12.4.6.2. Definition

Occurrence: The Belchen Member may be encountered in some parts of the ZNO and possibly also of the NL regions. In most cases, including the whole JO region, it is missing due to early or pre-Jurassic erosion.

Lithology: The Belchen Member comprises predominantly medium-grained, well-sorted, mostly carbonate-free quartzitic sandstone with thin shale interlayers overlain by dark marl and claystone with sandy interlayers and burrows and bone beds.

Thickness: Up to a few metres. Outside the areas in question up to 15 m is reached.

Upper boundary: The upper boundary is defined by the transgression of the marine Staffelegg Formation (Reisdorf et al. 2011). The delimitation of the Belchen Member is clear where sandstone is overlain by marl or limestone of the Schambelen Member or the Beggingen Member (Reisdorf et al. 2011), respectively.

In the far north-east of Switzerland (Lake Constance area), delimitation becomes more complicated as definitely Early Hettangian calcitic sandstone overlies slightly calcitic sandstone of the Belchen Member (Kiefer et al. 2015). It is not very probable that this configuration reaches as far west as the ZNO region. However, to be on the safe side, this Early Hettangian coarse sandstone is defined here as informal «Herdern Member» of the Staffelegg Formation (see Section 13.4.3). Kiefer et al. (2015) suggested as criteria for delimitation a significant increase in calcite matrix and the presence of crinoids, which are not known from the Belchen Member.

Lower boundary: The lower boundary towards the underlying Gruhalde Member is erosional and starts in almost all cases with the typical light grey to light green quartzitic sandstone. In some places, the basal layer is developed as a bone bed, very rarely as a thin dark claystone layer.

Lateral equivalents: In the German Stratigraphic Scheme (e.g., Etzold & Schweizer 2005), Geyer et al. 2011), the Belchen Member corresponds to the Exter Formation.

Names previously in use: «Rhät», «Rhätsandstein», «Rhätmergel», «Oberer Keuper»

12.4.6.3. Additional information

Origin of name: Belchen area where the type locality is situated.

Type locality and type region: Road cut section (coord. 2627.690/1246.165) below the Chilchzimmersattel road pass 2.5 km SW of Eptingen BL (Jordan et al. 2016a and b) close to the original section of Erni (1910).

Reference section: For the situation in question here, the Herdern borehole may serve as the reference section.

Chronostratigraphic age: Rhetian (Schneebeli-Hermann et al. 2018, Looser et al. 2018), a local onset of the Belchen Member in the Late Norian is possible (c.f. Achilles & Schlatter 1986).

Genetic and paleogeographic interpretation: The lower part of the Belchen Member documents a brackish estuarine to marginal shallow marine environment, where open sea was located to the west, and is interpreted as a seaway connecting the Tethys with the marine Central European Basin (Beutler & Nitsch 2005). With time, the estuarine facies became progressively restricted towards the east. It was replaced increasingly by shallow marine sandstones and finally by siltstone and marl. This succession was later incised by regional erosion of Late Triassic or Early Jurassic age, which incises deepest in central Northern Switzerland (Aare Massif – Black Forest High, e.g., Trümpy 1980).

13. Staffelegg Formation

13.1. General and main characteristics

The Staffelegg Formation corresponds to what was «Lias» in traditional (informal) Swiss stratigraphy. It is a succession of moderate to strongly condensed fully marine sediments. Claystone and marl predominate. Phosphorite and, locally, iron ooids are typical for condensed and reworked sediments. Bituminous sediments are found in the Schambelen and Rietheim Members. In adjacent areas, sand inputs («Herdern Member», informal, and Weissenstein Member) are documented, which may reach the area under investigation. Fossils such as ammonites, belemnites, clams, among them the typical *Gryphaea* oysters, snails, brachiopods, crinoids, marine foraminifera, etc. are abundant in most limestone and some of the marl and claystone layers.

13.2. Definition

Occurrence: The Staffelegg formation is found, with some variation in its composition, throughout all three siting regions JO, NL, and ZNO.

Lithology and subdivision: The fully marine Staffelegg Formation is characterized mainly by dark coloured, partly bituminous, claystone and marl. In addition, in distinct levels, often fossiliferous, biodetritic and, partly, sparitic limestone and marl with marly limestone nodules are found. Strongly condensed in some parts, then phosphoritic and, occasionally, containing iron ooids, the quite thin formation represents a very long period.

Though only some 25 to 50 m thick, the Staffelegg Formation shows a high lateral and vertical diversity. The scheme of Reisdorf et al. (2011) covers Northern Switzerland between the Cantons of Jura and Schaffhausen and includes 11 members and several beds. Recently, Kiefer et al. (2015) have described some peculiarities from north-easternmost Switzerland where the Staffelegg Formation is only reached by deep boreholes. They concern mainly the lower part of the formation where the typically marly sediments are replaced by coarse sand. This succession is informally denominated here as the «Herdern Member».

The succession expected in the regions under investigation (JO, NL and ZNO siting regions, see Figure 5) thus starts (from the bottom) with the Schambelen Member (with possible transition to the «Herdern Member») followed by the Beggingen Member (with possible transitions to Weissenstein or «Herdern Member»), and the Frick Member. The subsequent Grünschholz, Breitenmatt and Rickenbach Members are expected to be strongly condensed in the area under investigation and therefore summarised here as one stratigraphic unit. The Staffelegg Formation is then completed by the Rietheim and Gross Wolf Members.

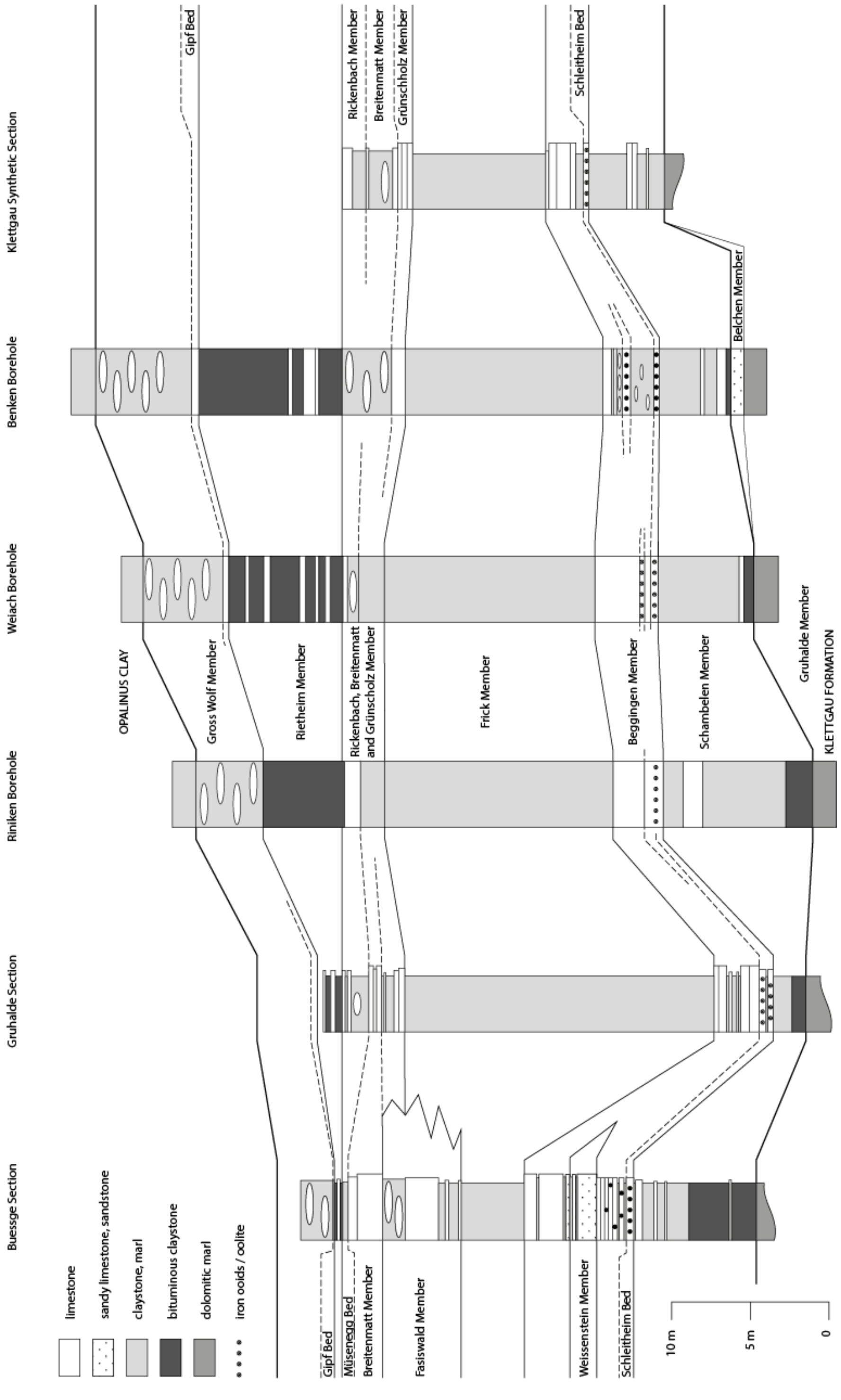


Figure 5: Variability and thickness of the Staffelegg Formation in the area under investigation.

The Riniken borehole (Matter 1987, modified) and the Buessge and Gruhalde sections (interpretation after Reisdorf et al. 2011) represents the possible variability of Staffelegg Formation in the JO siting region. The Weiach boreholoe section (interpretation after Kiefer et al. 2015) is the only evidence yet for the NL siting region. The Benken boreholoe section (interpretation after Kiefer et al. 2015) and the synthetic section of the Klattgau area (Hofmann et al. 2000, modified) gives hints for the development of the Staffelegg Formation in the ZNO area.

Thickness: In the area under investigation thickness of the Staffelegg Formation may vary between 25 and 50 m.

Upper boundary: In the eastern Folded Jura, the boundary is drawn above the Eriwis Bed (Reisdorf et al. 2011), a thin, phosphoritic, condensed layer abundant in ammonites and belemnites of the Aalensis Subzone (detailed description in Section 13.4.8). The occurrence of the Eriwis Bed has not yet been proven for the three siting regions. In the case of its absence, the upper boundary of the Staffelegg Formation is drawn with the significant drop in calcium carbonate content. This is manifested in a, in most cases sharp, change of colour from light to dark grey and the offset of marly limestone nodules, characteristic for Gross Wolf Member.

The formation boundary does not coincide with the biostratigraphic limit between the Early and Middle Jurassic (Toarcian to Aalenian) but is rather diachronous (Reisdorf et al. 2011). In some cases, as for instance at Mont Terri, far west of the area under investigation, the biostratigraphic limit was found within the basal Opalinus Clay, meaning that its first some 35 m are of Toarcian (Aalensis Zone) age (Hostettler et al. 2017).

Matter et al. (1988) posit an Aalenian (Opalinus Zone) age of the uppermost 25 cm of «Lias» (now Staffelegg Formation) based on a finding of a *Leioceras opalinum* (Reinecke). This is contradicted by Tröster (1987) who identifies the ammonite, based on an expertise by Dr W. Riegraf, as a *Pleydellia subcompacta* (Branco) of Toarcian (Aalensis Subzone) age. The late Toarcian assessment of the uppermost Staffelegg Formation at Weiach is confirmed by micropaleontological evidence (Tröster 1987).

Lower boundary: The limit to the Late Triassic Klettgau Formation is throughout all three siting region marked by an erosional surface documenting a longer period of no-deposition and erosion. It is given by the onset of the (fully) marine facies above terrigenous or brackish sediments. In most cases, the boundary is marked by a colour change from beige, greenish or reddish colours to dark grey or black.

The onset of Staffelegg Formation is undisputed heterochronous (e.g., Jordan 1983, Reisdorf et al. 2011). In the northeast, in Schaffhausen area, it starts at in very early Hettangian (Schlatter 1983). In the Hauenstein area, west of the area under investigation, it starts in the Sinemurian Semicostatum Zone (Jordan 1983). This heterochronity goes along with changes in facies and nature of the lower most stratigraphic unit. However, in the area under investigations, persistently the Schambelen Member is expected at the base of the Staffelegg Formation (for more details see Section 13.4.1.2).

Lateral equivalents: In adjacent southern Germany, a quite similar, likewise thin (some 50 m) section is subdivided into eight formations (from top): Jurensismergel, Posidonienschiefer, Amaltheenton, Numismalismergel, Obtususton, Arietenkalk, Angulatenton, and Psilonotenton Formations (e.g., Geyer et al. 2011)

Names previously in use: The Staffelegg Formation corresponds to the «Lias» as described by Jordan (1983).

13.3. Additional information

Origin of name: The name is derived from the Staffelegg, a road pass not far from the type locality and the site of the Staffelegg clay pit section representing the upper part of the formation and the boundary to the Opalinus Clay (Reisdorf et al. 2011).

Type locality and type region: Type locality are the two complementary sections of Buessge south of Thalheim AG (coord.: 2649.925/1253.050 and 2649.840/1253.000; Jordan 1983; Reisdorf et al. 2011, Kiefer et al. 2015).

Type region is the eastern Folded Jura.

Reference section: Due to the nearly perfect outcrop conditions at the time of recording (Jordan 1983), no reference section was formally defined by Reisdorf et al. 2011. Another excellent outcrop of the lower part of the formation is found today at the Gruhalde clay pit in Frick AG (coord. 2642.850/1261.890).

Chronostratigraphic age: The chronostratigraphic age is well defined by fossil record. Both, the lower and the upper boundary, are heterochronous.

In the area under investigation, the Staffelegg Formation starts in the Hettangian. In the east, the Schaffhausen area (and probably the ZNO siting region), the Staffelegg Formation starts in the Planorbis Zone. In areas adjacent to the JO siting region, the oldest sediments are of early Liasicus Zone age (Reisdorf et al. 2011). More to the west, the oldest sediments of the Staffelegg Formation are of Angulata Zone or even Sinemurian age (Figure 6).

In the west, far outside of the area under investigation, the topmost layers of the Staffelegg Formation are documented to be of earliest Aalensis Zone (Hostettler et al. 2017). In the area under investigation, the upper boundary of Staffelegg Formation coincides with the Toarcian / Aalenian limit (Tröster 1987). For more details see Section 13.4.8.3 and Figure 6).

Genetic and paleogeographic interpretation: The Staffelegg Formation documents the flooding of the Sissach rise separating the Swabian Basin in the north-east and Rhodanian Basin in the south-west and interconnecting the Black Forest High in the north and the Alemannic land in the south (which corresponds to the actual Alpine Central Massifs). Both were also submerged during the Lower to Middle Jurassic. The Staffelegg Formation is thus characterised by fairly to extremely condensed and reworked sediments. Nevertheless, in the area in question, there are still some distinct affinities to the Swabian succession which will be outlined when describing the members.

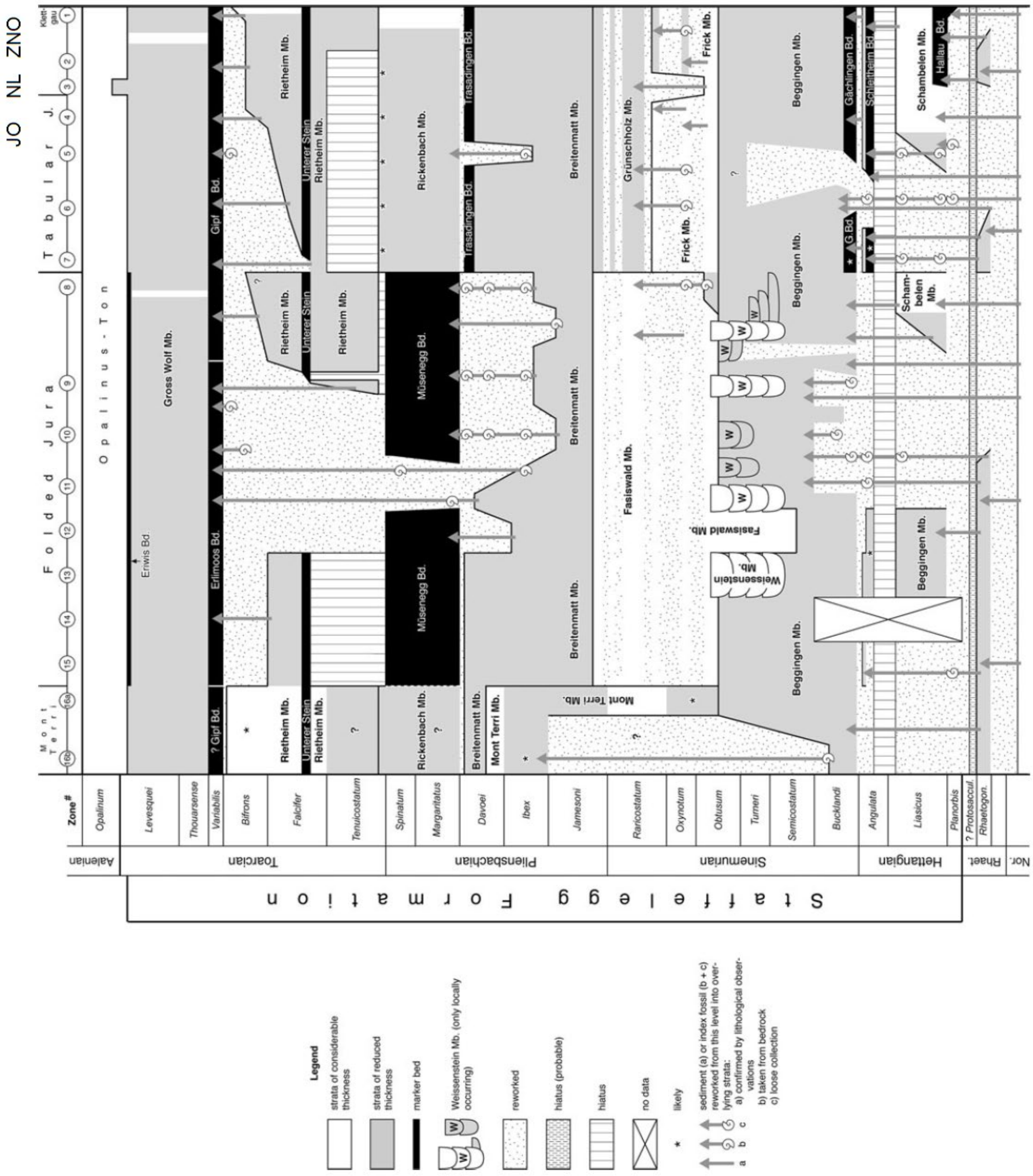


Figure 6: Chronostratigraphy of Staffelegg Formation after Reisdorf et al. (2011).

The scheme mostly focus to areas west of the area of investigation. The column below the encirceld number 5 represents the Gruhalde section at Frick, below 3 the Weiach borehole section (see discussion in Section 13.2), and below 1, at the right edge, the Wutach - Schaffhausen area (cf. Figure 5). The numbers 4 and 8 refer to the rather vague description of the succession in the Zurzach area and Lägern range by Heim (1919). The added letters top right give the approximative position of JO, NL ans ZNO siting regions.

13.4. Members of the Staffelegg Formation

13.4.1. Schambelen Member

13.4.1.1. General and main characteristics

The Schambelen Member is mainly composed of dark, in the lower part bituminous, terrigenous mudstone with thin intercalations of silt- and sandstone.

13.4.1.2. Definition

Occurrence: The Schambelen Member is found in all three siting regions JO, NL and ZNO.

Lithology: The lower part is composed of dark fine-layered bituminous terrigenous mudstone, subordinately with small interlayers of thin, bituminous limestone, silt- and sandstone layers. Subordinately, small interlayers of thin, sometimes bituminous, limestone, silt- and sandstone occur. The carbonate content varies between 5 and 8 %. Fossils, mainly (often dwarf sized) ammonites, are often pyritised.

In the north-east of the area under investigation, bituminous shales and limestone are restricted to the very base of the member and distinguished as the Hallau Bed (Reisdorf et al. 2011).

In the upper part of the member, the colour changes from dark to greenish grey. The carbonate content increases, the layering vanishes, and fine-grained sands is ubiquitous rather than concentrated in layers.

Thickness: In the area under investigation, the thickness of Schambelen Member may vary between about 5 to 9 m, including up to 2 m Hallau Bed. The maximum was found at Riniken borehole in the west, the minimum at Benken borehole, in the east (Figure 5). Remarkably, thickness seems to increase again eastward as "debatable" 16.5 m have been found at Schlattingen borehole (Kiefer et al. 2015).

Upper boundary: The boundary to the Schleitheim Bed of the Beggingen Member is marked by a transgressive onset of iron oolite or bioclastic limestone rich in iron ooids with bivalves mainly of the genera *Cardinia* and *Plagiostoma***.** At some localities components of the Schambelen Member may be found in a basal conglomerate of the overlaying Beggingen Member.

Lower boundary: The lower boundary of the Schambelen Member is erosional and transgressive. At some places, evidence for reworking, e.g., basal conglomerate or single extraclasts of Triassic sediments, is found in the overlying basal Jurassic layers. In most cases, the succession starts with a dark thin sand layer already containing ammonites and is followed by bituminous, thin layered shales. For more details on the sediments below the boundary, see Sections 12.4.4.2 and 12.4.6.2).

In the ZNO region where the Gruhalde Member may be locally followed by the younger, still Triassic, brackish estuarine to marginal shallow marine Belchen Member (Figure 5), the delimitation is more sophisticated, especially where Schambelen Member shows a transition to «Herdern Member» (Section 13.4.3 and

Kiefer et al. 2015). The dark to light greenish marl and sandstone of brackish origin are followed by few decimetres of dark grey marl. Its content of echinoderm remains documents a fully marine environment and, thus, a Jurassic age. These marls are followed by two distinct limestones separated by bituminous shales completing the Hallau Bed.

Lateral equivalents: To the north and north-east, the Schambelen Member corresponds to the Psilonotenton Formation (Hallau Bed, bituminous lower part) and the predominantly marly lower part of the Angulatenton Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011). Towards the east, there may be a transition to the more siliciclastic «Herdern Member» (Section 13.4.3 and Kiefer et al. 2015).

Names previously in use: Names in use have been «Insektenmergel» for Schambelen Member, «Psilonotenbank» for Hallau Bed, and «Schwaichel», mainly in the Schaffhausen are, for the (not-bituminous) part above the «Psilonotenbank» (see Reisdorf et al., 2011, for details). Beetle-type insect remains (mostly hardened wing parts of Hemiptera) are, despite the old name «Insektenmergel», extremely rare (Etter pers. comm. 2017).

13.4.1.3. Additional information

Origin of name: Name of type locality for Schambelen Member and of municipality of type locality for Hallau Bed.

Type locality and type region: Schambelen section (coord. 2659.310/1257.000; outcrops in nearby Reuss River visible at low water) and Brateln (temporary exposure, coord. 2676.400/1284.500) on Hallauerberg near the village of Hallau SH, respectively (Reisdorf et al. 2011).

The type regions are the easternmost Folded Jura and the Schaffhausen Region, respectively.

Reference section: There is no reference section defined. While the formal type locality is not accessible now, the nearby section in Reuss river (accessible at low water stand) and the Gruhalde clay pit in Frick AG (coord. 2642.850/1261.890) give good insights.

Chronostratigraphic age: In the east, the Hallau bed documents Planorbis Zone. At the type locality, more to the west, Liasicus to Angulata Zone is documented (Reisdorf et al. 2011) (cf. Figure 6). An early Hettanginian age is also confirmed by palynomorphes (Schneebeli-Hermann et al. 2018, Looser et al. 2018).

Genetic and paleogeographic interpretation: The base of the Schambelen Member seems to be diachronous with the earliest onset in the north-east and latest in the Hauenstein area south-west of the JO region (Figure 6). However, basal conglomerates, typical for transgressive sediments, are rare except from local clasts of Triassic sediments. In fact, thin-shelled ammonites are found in the most basal layers and anoxic conditions are documented a few centimetres above. Evidence for bioturbation and wave base interactions is found only in the upper part of the member. Thus, submergence must have been very rapid and pronounced - which contradicts the documented diachronicity. An aspect not fully understood yet.

13.4.2. Beggingen Member

13.4.2.1. General and main characteristics

The Beggingen Member encompasses a limestone-dominated interval between the marly Schambelen and Frick Members. In the area under investigation (JO, NL and ZNO regions), the iron oolitic Schleitheim and bioclastic Gächlingen Beds can be distinguished in the lower part.

13.4.2.2. Definition

Occurrence: Throughout the area under investigation, the Beggingen Member sensu stricto with the Schleitheim Bed at the base may be expected. Concerning Gächlingen Bed see comments below.

Lithology: The Schleitheim Bed (Reisdorf et al. 2011) at the base is characterised by its abundance of bivalves, especially of the genera *Cardinia* and *Plagiostoma*. Oysters of the genus *Gryphaea* are missing. In the ZNO region, the Schleitheim Bed is expected to be an iron oolite. Towards the west (NL, JO regions), the content of iron ooids decreases, and the Schleitheim Bed becomes successively a bioclastic packstone with iron ooids.

The younger Gächlingen Bed was introduced by Reisdorf et al. (2011) to replace the former «Kupferfelsbank». According to Bloos et al. (2005) this latter term was applied to different beds of varying age it should be omitted or restricted to the type region east to southeast of Donaueschingen (Bloos 1976) where it marks the base of the German Arietenkalk-Formation (Litholex, consulted 15.03.2019). The common feature of these beds are abundant iron ooids within a biosparitic limestone and fossils of Sinemurian age including Bucklandi or Semicostatum Zone ammonites and *Gryphaea arcuata* (Lamarck). Such layers may be found at different levels of what is now Beggingen Member (Jordan 1983).

At the boreholes of Weiach (Matter et al. 1988) and Siblingen (Nagra 1992), an iron oolitic bed some few centimetres above the Schleitheim Bed was identified as «Kupferfelsbank». At Benken borehole (Nagra 2001), the term was attributed to an iron oolitic bed some 2 m above the Schleitheim Bed.

It is recommended to avoid the terms Gächlingen Bed and «Kupferfelsbank» when recording the new cores. They should be reviewed when new material is available.

The Beggingen Member proper consists of bedded, partly slightly silty to sandy, bioclastic, sparitic, pyrite-bearing limestone separated by mostly very thin marly interlayers. However, the Beggingen Member of Gruhalde section at Frick AG shows in its upper part an about 1 m thick dominantly marly intercalation with two some 10 cm thick (each) limestone interlayers. At Benken borehole (Nagra 2001) and at the type section of Schambelen (Jordan 1983), the lower part of the Beggingen Member above the Schleitheim Bed consists of silty marl with limestone nodules and iron oolitic marly limestone, respectively. Phosphatized, reworked fossils predominate in the hardgrounds on the top but are also found within the beds at all localities. Among the abundant fossils, oysters of the species *Gryphaea arcuata* (Lamarck) and ammonites, in the upper part, mostly of the genus *Arnioceras*, are the most prominent.

Thickness: Within the area of investigation, the thickness of the Beggingen Member may vary between 1 and 5 m including Schleitheim Bed (Figure 5).

Upper boundary Beggingen Member and of Schleitheim Bed: The member's delimitation towards the overlying Frick Member is given with the onset of marl or claystone facies over the topmost phosphoritic hardground of the Beggingen Member.

The upper boundary of Schleitheim Bed, i.e. the lower boundary of the Beggingen Member proper (i.e. the former «Arietenkalk» proper) is given by the onset of the characteristic oysters of the genus *Gryphaea* with its first appearing species *Gryphaea arcuata* (Lamarck). This limit between Schleitheim Bed and the "rest" of the Beggingen Member is in most cases a transgressive horizon which may also contain reworked materials of the underlying strata or quartz pebbles, etc.

Lower boundary of Beggingen Member: The base of the Beggingen Member is defined by the onset of iron oolitic limestone to iron oolite rich in large bivalves of the genera *Cardinia* and/or *Plagiostoma*. At some places it is marked by a basal conglomerate containing components of the underlaying Schambelen Member.

Lateral equivalents: To the north and north-east, the Schleitheim Bed corresponds to the upper part of Angulatenton Formation and the remaining part of the Beggingen Member to the Arietenkalk Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

Towards the east, there may be a transition to the more siliciclastic «Herdern Member». To the south-west, there may be interfingering with the sandy Weissenstein Member.

Names previously in use: The Schleitheim Bed corresponds to the former «Cardinienschichten» or «Angulatenschichten», the rest of the member to the «Arietenkalk» sensu stricto or «Gryphitenkalk». The «Eisenooidreiche Folge» of Jordan (1983) comprise all basal, iron-oolitic beds including Schleitheim Bed and «Kupferfelsbank» (see above).

13.4.2.3. Additional information

Origin of name: Name of municipalities of type localities

Type locality and type region: Hölderli (temporary exposure, coord. 2682.120/1290.980) at the village of Beggingen SH and Buckforen (coord. 2679.700/1287.470) near Schleitheim SH, respectively.

Type region is the Klettgau hill range on the left side of Wutach creek.

Reference section: There are no reference sections.

Chronostratigraphic age: Hettangian to Sinemurian, Angulata to Obtusum Zone (Reisdorf et al. 2011).

Genetic and paleogeographic interpretation: The Beggingen Member represents a period of permanent reworking, indicating a setting above the (storm) wave base, and low siliciclastic input. As contemporary siliciclastic sediments are known from the west, south and east of the area in question, a genesis on an isolated high zone (swell) may be suggested.

13.4.3. «Herdern Member»

13.4.3.1. General and main characteristics

In the Lake Constance area, the lowermost Staffelegg Formation consists of coarse calcitic marine sandstone with crinoid detritus replacing the Beggingen and Schambelen Members (Kiefer et al. 2015). To be prepared if this unit reaches as far as the ZNO region, it is informally defined here as the «Herdern Member».

13.4.3.2. Definition

Occurrence: Easternmost Switzerland, possibly in parts of ZNO siting region.

Lithology: The «Herdern Member» consist of coarse calcitic sandstone of marine origin with crinoid detritus, partly sandy marls and, subordinately, some thin, occasionally nodulous, phosphoritic or iron oolitic beds.

Thickness: 0 – 21 m (latter the thickness at reference section Berlingen)

Upper boundary: At the borehole Herdern reference section, the upper boundary can be drawn at the erosional base of the first massive (sandy) limestone of the Beggingen Member facies at 1865.50 m depth. At the borehole Berlingen reference section, the upper boundary is drawn at the base of a massive limestone at 2043 m depth. However, at Berlingen, there is a multiple recurrence of coarse sandy layers pointing to an interfingering of the two members.

Lower boundary: The lower boundary to the Triassic Belchen Member, evenly coarse-grained sandstone, is given by an increase in calcite matrix and the onset of crinoid detritus, which indicate fully marine conditions (see also Section 13.4.1.2).

Lateral equivalents: The lateral equivalents to the west are the Beggingen and Schambelen Members.

Names previously in use: «Lias alpha» sensu Kiefer et al. (2015).

13.4.3.3. Additional information

Origin of name: Name of SEAG borehole where one of the reference sections is located.

Type locality and type region: There is no formal type locality yet.

Reference section: SEAG Herdern borehole, depth 1864.61 to 1879.50 m and SEAG Berlingen borehole, depth 2038.7 to 2064 m.

Chronostratigraphic age: Hettangian and possibly Early Sinemurian.

Genetic and paleogeographic interpretation: The «Herdern Member» is interpreted as terrigenous coastal facies of the Vindelician High.

13.4.4. Weissenstein Member

13.4.4.1. General and main characteristics

The Weissenstein Member represents an interval of increased terrigenous input within the Beggingen Member, or, outside the area in question, replacing the Beggingen Member completely (Figure 5 and Figure 6). It is represented by bioclastic sandy limestone which has, in the distal areas, high affinities to the limestone of the Beggingen Member.

13.4.4.2. Definition

Occurrence: The known maximum thickness is found around Weissenstein south of Solothurn. Thickness decreases generally towards east. The Weissenstein Member possibly reaches the south-western part of the JO siting region. It will definitively be missing in the NL and ZNO siting regions.

Lithology: Bioclastic, fine-grained sandy limestone, partly concentrated in channels.

Thickness: In JO siting region may reach locally some few decimetres to metres. It is missing in the other areas.

Upper and Lower boundary: In the JO area, the Weissenstein Member occurs, if ever, as an interbed of the Beggingen Member from which it is distinguished by a fine-grained quartz sand content higher than 5 %.

Lateral equivalents: The Weissenstein Member is laterally interfingering with the Beggingen Member.

Names previously in use: «Feinsandkalk-Lage des Arientakalks», «sandiger Arietenkalk», «sandiger Gryphitenkalk» (see Reisdorf et al. 2011 for additional information)

13.4.4.3. Additional information

Origin of name: Hill range close to the type locality.

Type locality and type region: Käspisbergli section (coord. 2610.560/1235.140), north of Günsberg SO.

The type region is the eastern Folded Jura including the Weissenstein inlayer.

Reference section: There is no reference section.

Chronostratigraphic age: Sinemurian, Semicostatum to Obtusum Zone (Reisdorf et al. 2011).

Genetic and paleogeographic interpretation: The Weissenstein Member is interpreted as the distal part of an alluvial fan originating from the Alemannic Land in the south.

13.4.5. Frick Member

13.4.5.1. General and main characteristics

This monotonous succession of dominantly dark grey claystone is one of the dominant members of the Staffelegg Formation in the area under investigation.

13.4.5.2. Definition

Occurrence: Tabular Jura and adjacent area including all three siting regions JO, NL and ZNO.

Lithology: Monotonous succession consists mainly of dark grey, bioturbated, terrigenous, claystone and siltstone with mica. Reworked sediments and calcareous or phosphoritic concretions are found in the uppermost part of the member (Reisdorf et al. 2011)

Thickness: Thickness is expected to vary between 10 and 20 m within the area of investigation (Figure 5). East of it, towards Lake Constance, a rapid reduction to some 2 m is documented (Kiefer et al. 2015).

Upper boundary: Towards the overlying Grünschholz Member, the transition may be somewhat gradual over a few decimetres. Reisdorf et al. (2011) suspect an erosional surface to be a persistent regional feature, which can be taken as the member's boundary. Above this surface, nodular phosphoritic and glauconitic limestone is the typical facies of the Grünschholz Member.

Lower boundary: The delimitation towards the underlying Beggingen Member is given with the onset of the marl to (silty) claystone facies over the topmost phosphoritic hard-ground.

Lateral equivalents: In the German Stratigraphic Scheme (e.g., Geyer et al. 2011) the Frick member corresponds to the Obtususton Formation in similar facies. Towards the west, outside the area of investigation, mostly nodular limestone interlayer become abundant (Fasiswald Member, Reisdorf et al. 2011).

Names previously in use: The Frick Member corresponds to the «Obtususton», «Obtusum-Ton» and «Obtusus-Turneri-Ton» in the narrower sense while the «Obtusum-Schichten» of Jordan (1983) includes also what is now Fasiswald Member (see Reisdorf et al. 2011 for details).

13.4.5.3. Additional information

Origin of name: Name of municipality of type locality.

Type locality and type region: The Gruhalde clay pit in Frick AG (coord. 2642.850/1261.890), in which the member is excellently exposed, was defined as type locality by Reisdorf et al. (2011).

The Type region is the Fricktal Tabular Jura.

Reference section: There is no reference locality.

Chronostratigraphic age: Sinemurian, Obtusum to Raricostatum Zone (Reisdorf et al. 2011).

Genetic and paleogeographic interpretation: The Frick Member represents a timespan of high fine-grained terrestrial input repelling the carbonate facies (Fasiswald Member) to the swell region in the west of the area in question.

13.4.6. Grünschholz, Breitenmatt and Rickenbach Members

13.4.6.1. General and main characteristics

In the area under investigation, the three members established by Reisdorf et al. (2011) encompass some few metres of condensed and reworked sediments (Figure 5 and Figure 6). Without good and sophisticatedly analysed fossil evidence it will be hard to difference them (Kiefer et al. 2015).

13.4.6.2. Definition

Occurrence: The three members are found, in varying composition and facies, throughout all three siting regions.

Lithology: The 1.0 to 1.5 m thick Grünschholz Member, the former «Obliqua-Schichten» sensu stricto, consists of an intercalation of calcareous marl and predominantly concretionary limestone beds, glauconite and calcareous phosphoritic concretions. Locally, the member may be very fossiliferous with ammonites, belemnites, bivalves and some brachiopods. The oyster *Gryphaea obliqua* Sowerby may be abundant. But in a borehole core it can be only hardly be differentiated from other gryphaeid oysters. In addition, it is not restricted to this member.

The 0.5 to 3.5 m thick Breitenmatt Member, the former «Numismalis-Schichten», consists of an intercalation of ash grey marl and strongly bioturbated, glauconitic and phosphoritic, occasionally sandy, predominantly concretionary limestone beds rich in belemnites, gryphaeid oysters, mostly *Gryphaea cymbium* Lamarck and often partly silificated, and other fossils including ammonites and echinoderms.

The up to 0.7 m thick Trasadingen Bed, the former «Davoei-Bank», denominates a splintery marly limestone at the top of the Breitenmatt Member which can be observed at several localities.

The Rickenbach Member, the former «Margaritatus- und Spinatus-Schichten», is up to 5 m thick in the northern Klettgau area. It consists here of interlayering of glauconitic and phosphoritic marl and concretionary marly limestone rich in fossils, especially belemnites. Towards the south-west, the thickness decreases rapidly due to condensation and increased reworking.

In the south-west of the area under investigation, in the JO siting region, the Rickenbach Member is represented by the up to 0.7 m thick, highly condensed and reworked phosphoritic, locally highly fossiliferous, marly Müsenegg Bed. The fossil record comprises belemnites, gastropods, bivalves, crinoids and, mainly in the upper part, ammonites.

Thickness: In the area under investigation, the total thickness of the three members and two beds is estimated to vary between some 3m (or less) and 10 m (Figure 5).

Upper boundary: The delimitation towards the overlying Rietheim Member is characterised by the onset of fine-layered bituminous shale.

Lower boundary: The delimitation towards the underlying Frick Member is marked by an erosional surface and the onset of glauconitic and phosphoritic, bioturbated nodular limestone.

Lateral equivalents: In adjacent Baden-Württemberg, the Grünschholz Member and the Breitenmatt Member proper correspond to the Numismalismergel Formation, and the Rickenbach Member and the Müsenegg Bed to the Amaltheenton Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

Names previously in use: The list comprises a wide range of synonyms which reflects the proposed or proven correlation with prominent layers in adjacent area on one hand and the unique local habitus on the other hand: «Obliqua-Schichten», etc. for Grünschholz Member, «Numismalis-Schichten», «Uptonien-Schichten», «Jamesoni-Schichten» and «Davoei-Schichten» for Breitenmatt Member, «Davoei-Bank» for Trasadingen Bed, «Amaltheen-Schichten», «aschgraue Mergel», or «Kondensiertes Pliensbachien» for Müsenegg Bed, and «Amaltheen-Schichten» or «Margaritatus- und Spinatusschichten» for Rickenbach Member (see Reisdorf et al. 2011 for details).

13.4.6.3. Additional information

Origin of name: Name of type localities or municipality where type localities are localized.

Type locality and type region: Grünschholz Member: Grünschholz (coord. 2651.000/1265.700), NW of Galten AG, recorded by Buser (1952).

Breitenmatt Member: Breitenmatt (coord. 2654.040/1265.280), ESE of Gansingen AG, recorded by Buser (1952).

Trasadingen Bed: A former pit (coord. 2674.100/1280.050) near Kilchstieg SW of Trasadingen SH, recorded by Schalch (1880).

Müsenegg Bed: Müsenegg (coord. 2652.570/1253.350) S of Schinznach AG, recorded by Jordan (1983).

Rickenbach Member: Hintere Egg or Waldegg (coord. 2631.180/260.320) NNE of Rickenbach BL, recorded by Buxtorf (1901).

Type region for Müsenegg Bed and Grünschholz, Breitenmatt and Rickenbach Members is the Baselland-Fricktal Tabular Jura and adjacent Folded Jura. The type region for the Trasadingen Bed is the Klettgau hill range on the left side of Wutach creek.

Reference section: Though all type localities have been temporary outcrops or are later filled material excavation sites, no reference sections have been defined by Reisdorf et al. 2011. Fair outcrops of the interval can be found at the upper end of Gruhalde clay pit in Frick AG (coord. 2642.850/1261.890).

Chronostratigraphic age: Sinemurian to Pliensbachian, Raricostatum to Spinatum Zone (Reisdorf et al. 2011).

Genetic and paleogeographic interpretation: The succession represents a time of very low terrestrial input and a repeated reworking, probably on a swell above a storm wave base.

13.4.7. Rietheim Member

13.4.7.1. General and main characteristics

The Rietheim Member represents what was «Posidonienschiefer», a fine-layered bituminous shale and, subordinately, fine-layered, evenly bituminous limestone.

13.4.7.2. Definition

Occurrence: The Rietheim Member is found in all three siting regions. While very thin in the south-west, the member becomes more prominent towards the NL and ZNO region (Figure 5).

Lithology: The Rietheim Member is built by dark, bituminous, fine-layered marl to claystone and, subordinately, centi- to decimetre-thick bituminous limestone beds («Stinkkalk»), of which the «Unterer Stein» is the most prominent, showing a fine layering by colour change between light and dark grey (Figure 6). The fossil record comprises flat pressed, mostly pyritized ammonites, and possidonia-type Clams («*Possidonia*» *bronni* (Volz)). Rare findings are *Ichthyosaurus* sp. and other mega fossils in calcareous concretions.

Thickness: Thickness varies from few decimetres in the south-west of JO region to up to 10 m in ZNO region (Figure 5).

Upper boundary: The offset of fine-layered bituminous shale or limestone gives the upper boundary towards Gipf Bed or Gross Wolf Member proper. At most localities, the Rietheim Member is overlain by the Gipf Bed consisting of reworked or condensed sediments, locally, including iron ooids (see Section 13.4.8.1).

Lower boundary: Towards the underlaying Rickenbach Member or Müsenegg Bed the Rietheim Member is delimited by the onset of fine-layered bituminous shale.

Lateral equivalents: In adjacent Baden-Württemberg, the Rietheim Member corresponds to the Posidonienschiefer Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

Names previously in use: «Posidonienschiefer», etc. (see Reisdorf et al. 2011 for details)

13.4.7.3. Additional information

Origin of name: Name of municipality of type locality

Type locality and type region: Natural outcrop (coord. 2662.910/1271.865) near Rietheim AG recorded by Kuhn & Etter (1994).

Reference section: No reference section has been set.

Chronostratigraphic age: Toarcian, Tenuicostatum to Bifrons Zone (Kuhn & Etter 1994, Reisdorf et al. 2011, Montero-Serrano et al. 2015)

Genetic and paleogeographic interpretation: The facies and genesis of the Rietheim Member are like the famous Posidonienschiefer Formation of southern Germany; thus, the thickness is reduced due to its marginal position with respect to the euxinic basin.

13.4.8. Gross Wolf Member

13.4.8.1. General and main characteristics

The Gross Wolf Member, a predominantly grey, occasionally phosphoritic marl with nodular fine-grained limestone beds, is accompanied by the regionally quite variable Gipf Bed and the thin but very fossiliferous Eriwis Bed at its bottom and top, respectively.

13.4.8.2. Definition

Occurrence: The Gross Wolf Member is found throughout all three siting regions. This goes also for the Gipf bed at its base but with significant variations in its local facies. The Eriwis Bed has yet only been found in eastern Folded Jura and adjacent areas.

Lithology: Forming the base of the Gross Wolf Member, the facies of the usually thin, but in some places up to 1.75 m thick, Gipf Bed varies widely. Essentially, the observed facies is condensed, yellowish to grey, glauconite-bearing, sometimes pyritic and sometimes bituminous marl, rich in fossils, especially belemnites. Concretionary limestone layers of up to about 20 cm thickness can be intercalated at the thickest occurrences. The Gipf Bed may include intraclasts and clasts from the underlying Rietheim Member. In the south-west of the JO region it is developed as iron oolite.

The Gross Wolf Member proper consists of grey, occasionally phosphoritic marl and nodular, concretionary, fine-grained limestone with glauconite and pyrite. Macrofossils, especially belemnites and ammonites are abundant, but gryphaeic oysters are missing.

In the eastern Folded Jura, the Gross Wolf Member is usually terminated by the Eriwis Bed, a thin (up to 0.3 m), in most cases dark grey, sometimes also brownish or reddish phosphoritic, condensed layer abundant in belemnites and ammonites of the Aalensis Subzone, mainly of the genera *Cotteswoldia* and *Pleydellia*.

Thickness: Thickness may vary between some 2 m in the northwest an up to 6 m in the east (Figure 5).

Upper boundary: The occurrence of the fossiliferous Eriwis Bed has not yet been proven for the three siting regions. In the case of its absence, the upper boundary of the Staffelegg Formation is drawn with the significant drop in calcium carbonate content. This is manifested in a, in most cases sharp, change of colour from light to dark grey and the offset of marly limestone nodules, characteristic for Gross Wolf Member.

Lower boundary: The lower boundary, generally between Gipf Bed and Rietheim Member is marked by the offset of fine-layered bituminous shale and the onset reworked or condensed sediments, locally, including iron ooids.

Lateral equivalents: Jurensismergel Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

Names previously in use: The Gross Wolf Member corresponds to the former «Jurensismergel». The Gipf Bed includes the «Variabilis-Horizont» of Jordan (1983) and the Eriwis Bed is the «Pleydellienbank» of Jordan (1983).

13.4.8.3. Additional information

Origin of name: The Gross Wolf Member and the Eriwis Bed derivates their names from two clay pits designated as their respective type localities. The term Gipf bed refers to the municipality of the type locality.

Type locality and type region: The Gross Wolf clay pit (coord. 2645.724/1253.350) is the type locality of the member.

The type locality of the two members are a clay pit (coord. 2642.125/1261.775) near Gipf AG and the Eriwis clay pit (coord. 2652.000/1256.250) near Schinznach Dorf AG.

The type regions are the Fricktal Tabular Jura for the member, and the eastern Folded Jura for the two beds.

Reference section: There are no reference sections defined.

Chronostratigraphic age: In the area under investigation, the Gross Wolf member is of Late Toarcian age (Tröster 1987).

Genetic and paleogeographic interpretation: The Gipf Bed marks a transition between euxinic and normal conditions, possibly resulting from the storm wave base coming within the reach of the sea ground. This would explain the variety of facies types extending from reworking to iron ooid formation.

The Gross Wolf Member sensu stricto represents a period of low sedimentation rate in unrestricted marine conditions, with the Eriwis Bed forming a hardground on the top.

14. Opalinus Clay

14.1. General and main characteristics

In Switzerland, the Opalinus Clay is a formally accepted stratigraphic unit in the rank of a formation. However, there is no specific reference publication. Usually authors refer to Wetzel & Allia (2003), but they give no formal definition. The suffix «formation» is traditionally omitted (Remane et al. 2005), contrary to the approximately equivalent Opalinuston Formation in Germany (see below).

The Opalinus Clay is a monotonous succession of dark grey claystone with carbonatic and sandy lenses that generally become more abundant in the upper part.

14.2. Definition

Occurrence: The Opalinus Clay is found in all three siting regions JO, NL and ZNO.

Lithology and subdivision: The dominant lithology is dark grey silty to marly, partly strongly sandy claystone. In some levels, small bivalves, siderite or limestone nodules, (carbonatic) sand lenses or sandy marl occur.

There is no formal subdivision for Switzerland, but variations in the abundance of non-claystone components usually give a kind of stratification. Commonly, pure claystone dominates in the lower part and marl, limestone nodules and sand lenses are found mainly in the upper part (Figure 7). However, locally, sandstone layers may also occur in the lower part (e.g., EWS Lausen borehole, Vogt et al. 2016). A new subdivision based on available records of boreholes has been proposed by Mazurek & Aschwanden (in prep.), that should be used as a basis for the subdivision of the Opalinus Clay (Figure 8).

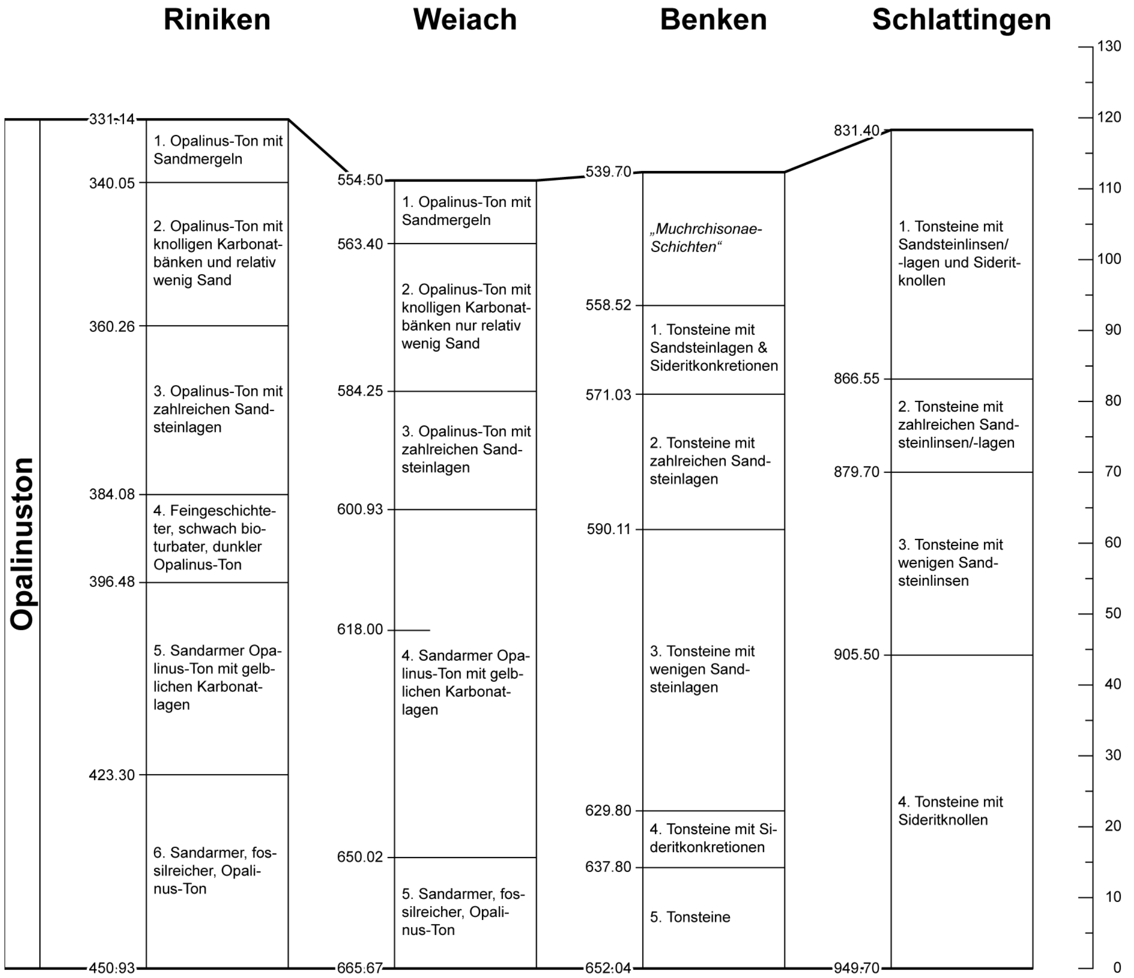


Figure 7: Comparison of the Opalinus Clay succession as originally published in different deep boreholes of Northern Switzerland.

Compilation by Stephan Wohlwend (pers. comm.). The units 1 to 4, 5 or 6 in the different boreholes, respectively, correspond to the original description and cannot be correlated directly. Scale to the right in metres.

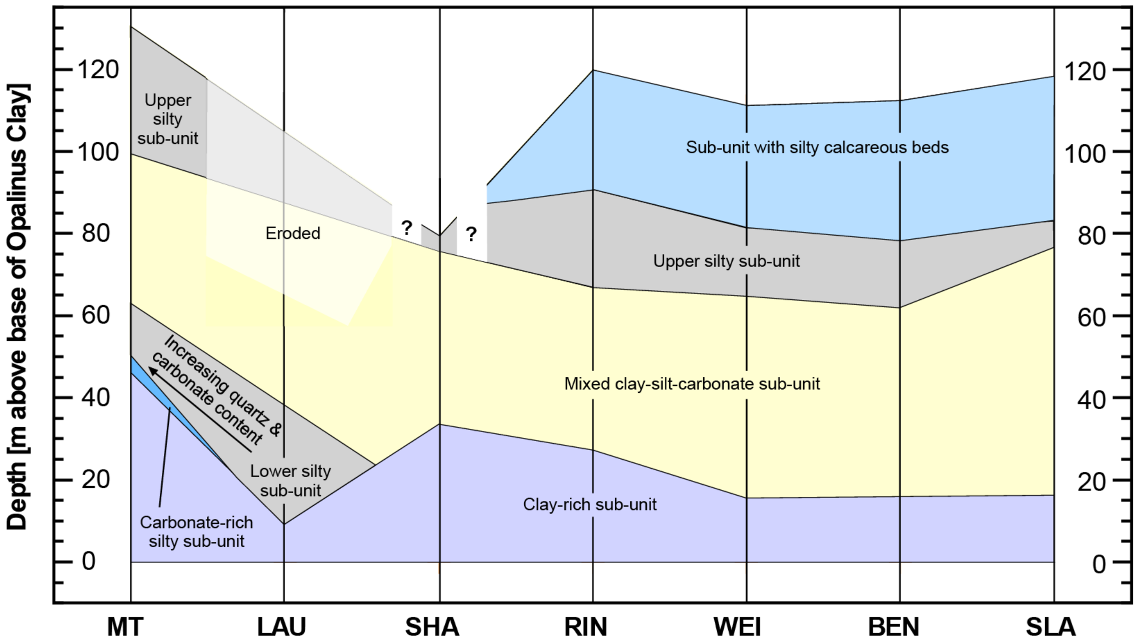


Figure 8: Lateral correlation of lithological sub-units in the Opalinus Clay in cored boreholes with the new nomenclature proposed by Mazurek & Aschwanden (in prep.).

MT: Mont Terri (BDB-1), LAU: Kernbohrung Lausen, SHA: Schafisheim, RIN: Riniken, WIE: Weiach, BEN: Benken, SLA: Schlattingen.

Thickness: The regional thickness variation between 80 to 130 m is traced back to a multiple basin and swells paleogeography by Wetzel & Allia (1996)

Upper boundary: Formally, the upper boundary is defined by the limit between Opalinum Subzone and Comptum Subzone which correlates to a regression discontinuity (Burkhalter 1996). Recently, this delimitation was the subject of several discussions, as it often does not coincide with a lithological boundary.

In the most eastern part of the area under investigation here, Bläsi et al. (2013) suggest to also include Murchisonae Zone age sediments with similar facies to the Opalinus Clay. In adjacent Germany, this succession is known as the Achdorf Formation. The name Achdorf Formation was chosen in 2009 only (Franz & Nitsch 2009, c.f. Geyer et al. 2011) to replace the preoccupied name Eichberg Formation (Bloos, Dietl & Schweigert 2005 and others).

In the eastern Folded Jura and the adjacent Tabular Jura, which includes the JO region, Wohlwend et al. (2019) propose to draw the upper limit at the base of the first persistent more than 1 m thick calcareous, sandy beds, irrespective of whether it is of Opalinum or Comptum Subzone age. This concept should be applied when recording the JO region cores. In this context it must be noted that, in the upper part of the Opalinus Clay, sandy marl intercalations can be found that have great affinity with similar uncondensed lithologies within the Passwang Formation. At places where no 1 m thick calcareous, sandy beds are present, the base of the Passwang Formation has to be drawn at the base of the iron-oolitic hardground with reworked intraclasts.

The few and dispersed insights into the stratigraphy of the eastern regions NL and ZNO suggest that the overlying strata, informal «Murchisonae-Oolith Formation» sensu Bläsi et al. (2013), are first reduced to thin iron oolitic beds and then wedge out completely (Bläsi et al. 2013). At Weiach borehole (Figure 9), the boundary was drawn between a bored nodular bed of siderite limestone and a compact bed of sandy and iron oolitic, biosparitic limestone. It will show if this also applies to other borehole sites in the NL region.

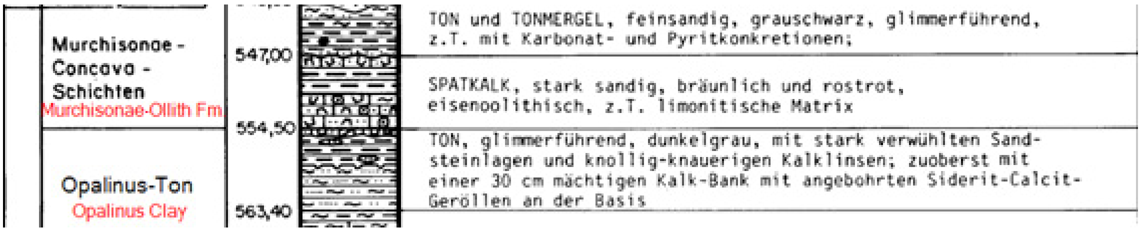


Figure 9: Top of the Opalinus Clay in the Weiach borehole.

After Matter et al. (1988). Actually used formal and informal formation names are are added).

In the Schlattingen borehole, the Opalinus Clay is directly overlain by the Wedelsandstein Formation starting with the «Sowerbyi-Oolith», an iron oolite (Bläsi et al. 2013). In the initial report of the Benken borehole (Nagra 2001), «Murchisonae-Schichten in Opalinuston-Fazies» has been distinguished from Opalinus Clay proper (Figure 10). This concept was thought to correspond to the Achdorf Formation of the German Stratigraphic Scheme, which resembles the Opalinus Clay from a facies point of view but is of Comptum Subzone to Concavum Zone age. However, the age of the section in the Benken borehole, initially denoted as «Murchisonae-Schichten in Opalinuston-Fazies», was later found to be of Opalinus Subzone age and therefore to be Opalinus Clay proper (Bläsi et al. 2013). Thus, the concept of limiting the Opalinus Clay at the base of the first iron oolitic limestone bed will probably also apply for the western part of the ZNO region. In the eastern part, a direct overlay by the Wedelsandstein Formation cannot be excluded. In this case, the top of the Opalinus Clay is defined at the base of the first sandy limestone layer or iron oolite (Sowerbyi-Oolith).

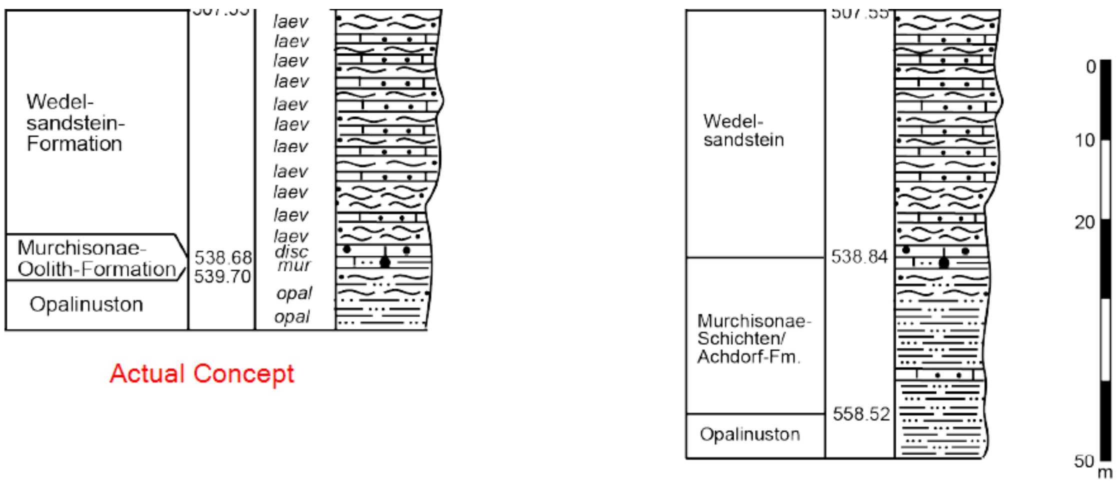


Figure 10: Recent (left) and former definition of the top of the Opalinus Clay in Benken borehole.

Modified after Bläsi et al. (2013).

Lower boundary: The lower boundary is defined by the onset of dark grey claystone above the fossiliferous lighter grey marl with nodular limestone of the Gross Wolf Member of the Staffelegg Formation. The drop of calcium carbonate content is manifested in most cases by a sharp change of colour from light to dark grey and the offset of marly limestone nodules, characteristic for Gross Wolf Member. The occurrence of the fossiliferous Eriwis Bed, marking the top of Gross Wolf Member of Staffelegg Formation (see Section 13.4.8.2) has not yet been proven for the three siting regions.

Lateral equivalents: In adjacent Baden-Württemberg, the corresponding succession is assigned to the Opalinuston Formation of the German Stratigraphic Scheme (Franz & Nitsch 2009). Considering that Murchisonae Zone-aged facies equivalents are also included (cf. Section 16.2 and Figure 11), in far north-eastern Switzerland the Opalinus Clay also corresponds to the German Achdorf Formation.

Names previously in use: Over time there have been different forms of spelling such as «Opalinus-Ton», «Opalinuston», or «Opalinuston Formation».

14.3. Additional information

Origin of name: The formation name originates from the ammonite *Leioceras opalinum* (Reinecke), formerly *Ammonites opalinus*.

Type locality and type region: There is no formal type locality. The work of Wetzel & Allia (1996) is focused on the eastern Folded and Tabular Jura area.

Reference section: The borehole records of Riniken, Weiach and Benken (Matter et al. 1987, Matter et al. 1988, Nagra 2001) may be used as a reference section for the JO, NL and ZNO regions, respectively.

Chronostratigraphic age: In most of the JO, NL and ZNO siting regions: Early Aalenian, Opalinum Zone, Opalinum Subzone. From Schlattingen borehole, there is evidence that Opalinus Clay facies may continue in to middle Aalenian Bradfordensis Zone (Albert et al. 2012). This may possibly apply also to parts of the ZNO siting region. Towards west, the onset of Opalinus Clay starts increasingly earlier in Late Toarcian (Hostettler et al. 2017).

Genetic and paleogeographic interpretation: The Opalinus Clay represents a timespan of high terrigenous clastic input. Wetzel & Allia (2003) suggest a deposition in different tectonically induced basins resulting in the documented regional variations in thickness.

15. Passwang Formation

15.1. General and main characteristics

The Passwang Formation corresponds to what was «Unterer Dogger» in older publications concerning the Tabular and Folded Jura (e.g., Lusser 1980). It is a succession of brownish to reddish grey sandy marl and partially nodular limestone. In some horizons, iron-ooids are abundant. In the sandy intervals, the ichnofossil *Zoophycos* is common. Outlining the cyclic genesis of the sequence, Burkhalter (1996) established the «Passwang Alloformation». It was later extended and redefined lithostratigraphically (see below).

15.2. Definition

Occurrence: The delimitation of the Passwang Formation was and is subject to many discussions (e.g., Wohlwend et al. 2019). Focussing on the area under investigation, the Passwang Formation is present in the JO siting region while its lateral equivalents (Sections 16 to 18 and 20, see Figure 11) are found in the other two regions (see also Appendix E). Only in the upper part, there is, within JO siting region, a more formal than lithologically justified transition from Rothenfluh Member of Passwang Formation to informal «Blagdeni-Schichten» of Klingnau Formation.

Lithology and subdivision: In the area under investigation, the Passwang Formation encompasses dark to light grey, often sandy and limonitic limestone, iron-oolites and mostly sandy micaceous marls and sandy limestone nodules. Characteristic for sandy intervals is the ichnofossil *Zoophycos.*

Based on recent field investigations and the review of borehole findings in the area in question (Wohlwend et al. 2019), a tentative informal stratigraphy was established for the recording of the planned deep boreholes. It bases on the formal scheme established by the Swiss Committee on Stratigraphy in 2004 basing on Burkhalter (1996) and Gonzalez & Wetzel (1996). But it considers particularities in the context of the condensed sedimentation in the Sissach rise realm and the transition to the conditions further east (Figure 11, Appendix E). There is the intention for a comprehensive revision of the stratigraphy of the middle part of the Dogger Group based on the expected new findings from the planned boreholes.

The stratigraphic units to be used are, from bottom to top (Figure 11):

- Sissach Member sensu Burkhalter (1996) in not or only slightly condensed facies including internal and basal condensed and / or iron-oolitic horizons.
- «Condensed equivalents of the Sissach Member localized at its top (or replacing the uncondensed facies completely) and the Hauenstein Member and Hirnichopf Members» of Burkhalter (1996), that are, in the area under investigation, expected to be found as thinned or condensed equivalents only.
- Waldenburg and Brüggli Member of Burkhalter (1996) combined but without «Humphriesi-Schichten» sensu Burkhalter (1996)
- informal «Humphriesi-Schichten» sensu Burkhalter 1996)
- Rothenfluh Member sensu Gonzalez & Wetzel (1996).

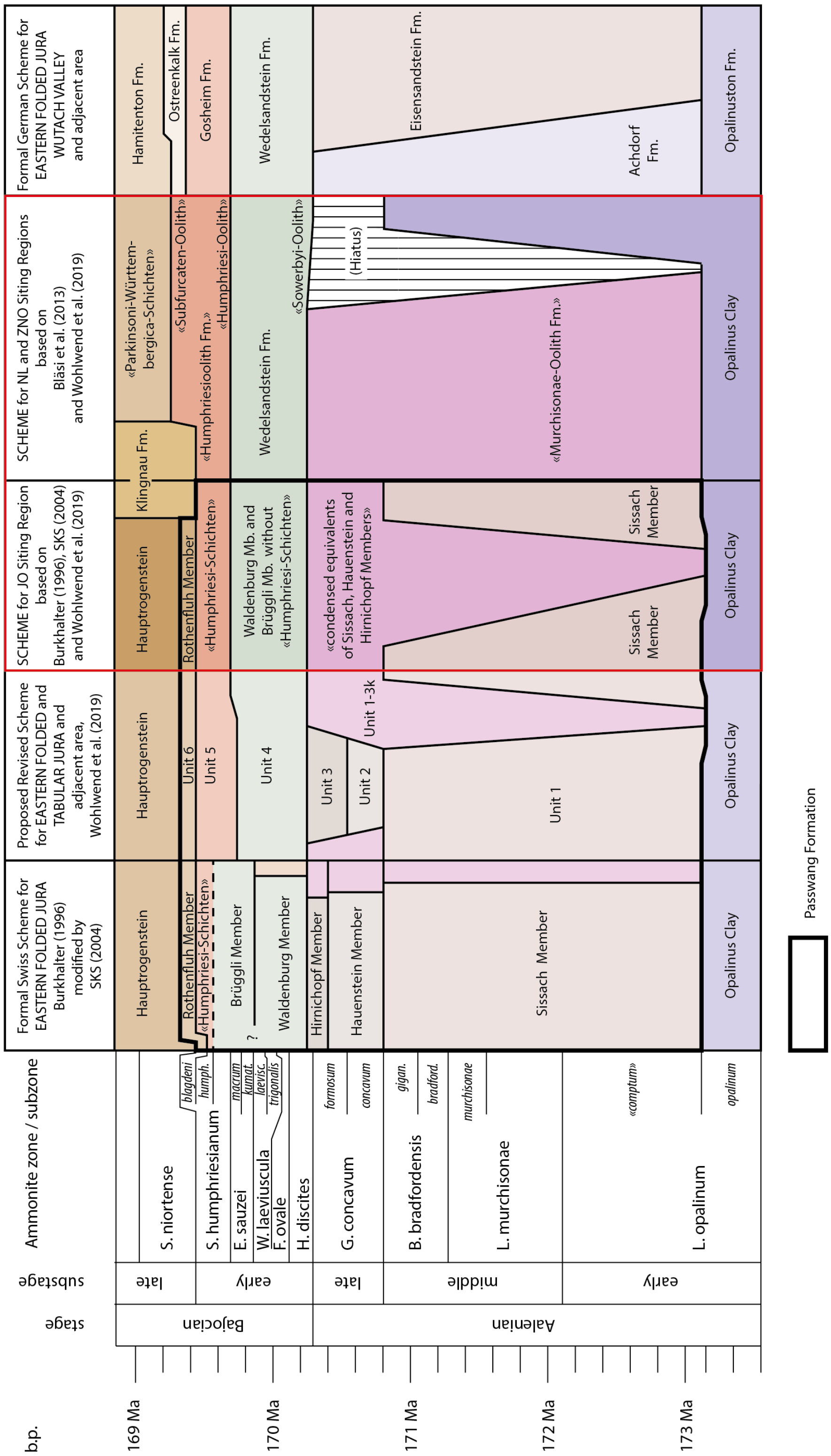


Figure 11: Stratigraphic scheme for the lower middle Dogger Group in the three siting regions.

The schemes to be used for JO and NL and ZNO regions are shown in the middle, within a red frame. To the left, the actual formal scheme and a new scheme proposed by Wohlwend et al. (2019), and to the right the actual formal scheme for adjacent southern Germany are shown (Geyer et al. 2011; Litholex consulted 04.05.2018). The black frame shows the extent of the Passwang Formation. Fm.: Formation; Mb. Member; b.p.: bevor present (time scale).

Thickness: Across JO siting region, thickness is expected to decrease from some 65 m to 40 m, from northwest to south east, resulting from increasing condensation and transition of Rothenfluh Member to the basal part of Klingnau Formation.

Upper boundary: In the domain where the Passwang Formation is overlain by the Hauptrogenstein (Section 21), the upper boundary is marked by the onset of calcareous oolites. In the domain where the Passwang Formation is overlain by the Klingnau Formation, the upper boundary is marked by the offset of iron-oolites of the «Humphriesi-Schichten».

Lower boundary: As the boundary between Opalinus Clay and Passwang Formation is rather gradual, different bio- and lithostratigraphic arguments have been proposed (e.g., Burkhalter 1996; Wohlwend et al. 2019). In the upper part of the Opalinus Clay, sandy marl intercalations can be found that have great affinity with similar uncondensed lithologies within the Passwang Formation. Without knowing all possible local variations yet, it is proposed to draw the lower boundary at a striking erosive regressional discontinuity, with local reworking, at the base of the lowermost iron-oolite or dark red, limonitic, probably sandy biomicritic limestone (Wohlwend et al. 2019).

Lateral equivalents: Within the JO siting region, a transition from the Rothenfluh Member to the lowest part of the Klingnau Formation (section 20) is expected (Appendix E). This transition is not defined by direct lithological evidence but by the fact that the overlaying Hauptrogenstein is wedging out.

In the NL and ZNO siting regions, the Murchisonae-Oolith Formation, the Wedelsandstein Formation and the Humphriesioolith Formation (all based on definition of the German Stratigraphic Scheme, see Sections 16 to 18) are the lateral equivalents of the Passwang Formation (Appendix E). Correlation and delimitation are subject to on-going disputations. Based on the current knowledge the transition area is outside the siting regions proper (i.e. in between JO und NL region).

Names previously in use: Originally an allostratigraphic unit («Passwang-Alloformation», Burkhalter 1996), the Passwang Formation was redefined and extended (addition of Rothenfluh-Member) by the Swiss Committee on Stratigraphy to match and replaced what was called «Unterer Dogger» by many authors (e.g., Lusser 1980, Müller et al. 1984).

15.3. Additional information

Origin of name: The formation is named after the Passwang, a historic mountain pass and a present-day road tunnel in the middle of several outcrops of the formation

Type locality and type region: There is no formal type locality of the Passwang Formation. Nor is there a subaerial outcrop showing the whole formation. The formation is defined by its members to which type profiles are attributed (see below).

The type region is the Passwang area.

Reference section: For the area under investigation, the Nagra Riniken borehole (Matter et al. 1987; Wohlwend et al. 2019) can give some indications. However, they are limited as most of the formation was not cored.

Chronostratigraphic age: Extensive fossil evidence gives an Aalenian to Bajocian, late Opalinum Zone to terminal Humphrieasianum Zone (Blagdeni Subzone) age.

Genetic and paleogeographic interpretation: The Passwang Formation documents a timespan of predominantly starving sedimentation documented by many hardgrounds and iron-oolites. Locally, possibly tectonically induced, relatively thick bodies of fine- to medium-grained terrestrial clastic input have been formed (Burkhalter 1996).

15.4. Members of the Passwang Formation

15.4.1. Sissach Member (predominantly uncondensed part)

15.4.1.1. General and main characteristics

Towards the west, the Sissach Member consists of often sandy, partly limonitic limestone with some iron-oolite beds. In the domain of the Sissach rise which, for the stratigraphic interval in question, coincides with the JO region, the overall thickness is reduced and iron-oolite layers become more important. The overlying «condensed equivalents of the Hauenstein and Hirnichopf Members» are only represented by thin iron-oolite, which is amalgamated with the topmost iron-oolite of the Sissach Member (Figure 12). This topmost part is here considered as an own stratigraphic unit (Section 15.4.2).

Thus, the term Sissach Member as it is used here, encompasses predominantly sandy, partly limonitic or sparitic limestone with intercalated sandy marls. At the base and at internal levels hardgrounds and iron-oolites are found.

15.4.1.2. Definition

Occurrence: In the area under investigation, it is restricted to the JO siting region. But even here, it may be locally missing, or more precisely, completely replaced by condensed sediments which are grouped here to another stratigraphic unit (see Section15.4.2).

Lithology: The predominant lithology of the uncondensed Sissach Member is reddish grey, subordinately argillaceous, mostly sandy, partly sparitic or limonitic biodetritic limestone and sandy to silty marl. Medium quartz grain size goes up to 150 µm and is, thus, greater than in many other members of the Passwang Formation. In the JO region, limestone dominates in the lower part, and marl in the upper. At the top of the limestone sequences iron-oolite or iron-oolitic to limonitic limestone is found. The Sissach Member and specifically the iron-oolites are fossiliferous, including ammonites and bivalves.

Thickness: The thickness varies between 1 m and up to 15 m.

Upper boundary: Formally, the upper boundary of the Sissach Member is defined by the omission discontinuity at the top of the iron-oolite of the Bradfordensis Zone. At places where this iron-oolite is amalgamated with younger iron-oolites (and this is expected for JO siting region), the boundary is drawn at the base of the iron-oolite (Figure 12).

Lower boundary: The lower boundary is identical with the lower boundary of the formation (Sections 14.2 and 15.2). It is a striking erosive regressional discontinuity, with local reworking, at the base of the lowermost iron-oolite or dark red, limonitic, probably sandy biomicritic limestone. Generally, it is of early «Comptum» Subzone age but may also include final Opalinum Subzone.

Lateral equivalents: Toward the east of the JO siting region, the uncondensed Sissach Member may be replaced by its condensed equivalents which are, here, considered as an own stratigraphic unit (see Section 15.4.2). Wohlwend et al. (2019) report a reappraising of uncondensed Sissach Member east of River Aare, i.e. east of JO siting region, in the Surb - Dangstetten area. Consequently, also a transition of uncondensed Sissach Member to Murchisonae-Oolith-Formation (Section 16) is possible (Appendix E).

Names previously in use: The uncondensed Sissach Member is identical to Unit 1 of Wohlwend et al. (2019) and corresponds to the former «Murchisonaeschichten» or «Murchisonae-Concava-Schichten» evenly in their uncondensed facies.

15.4.1.3. Additional information

Origin of name: Regional village north of the municipality Thürnen BL where the type locality is found.

Type locality and type region: Type locality is the Grütsch section (coord. 2629.120/1255.390) west of Thürnen BL (south-east of Sissach BL), and type region is the Basel Tabular Jura.

Reference section: The Frickberg section (coord. 2646.092/1262.999) give a good insight into the condensed succession, including the top of the Sissach and the «condensed equivalent of the Hauenstein and Hirnichopf Members» (Figure 12).

Chronostratigraphic age: Generally, Aalenian, Opalinum Subzone of Opalinus Zone to Bradfordensis Zone. Locally the member may also include the terminal Opalinus Subzone.

Genetic and paleogeographic interpretation: The Sissach Member is built up by two-and-a-half parasequences. The high stand of the first sequence is represented by the Opalinus Clay. The boundary between Opalinus Clay and Sissach Member is formally defined by the regression discontinuity followed by «Comptum» Subzone low stand sediments (locally condensed and iron-oolitic) (for boundary definition used here, see above). The second parasequence includes the Haugi and Murchisonae Subzones («Sinon- und Discoideum-Zone» in Burkhalter 1996); and the upper parasequence the Bradfordensis Subzone («Staufensis- und Bradfordensis-Subzone in Burkhalter 1996).

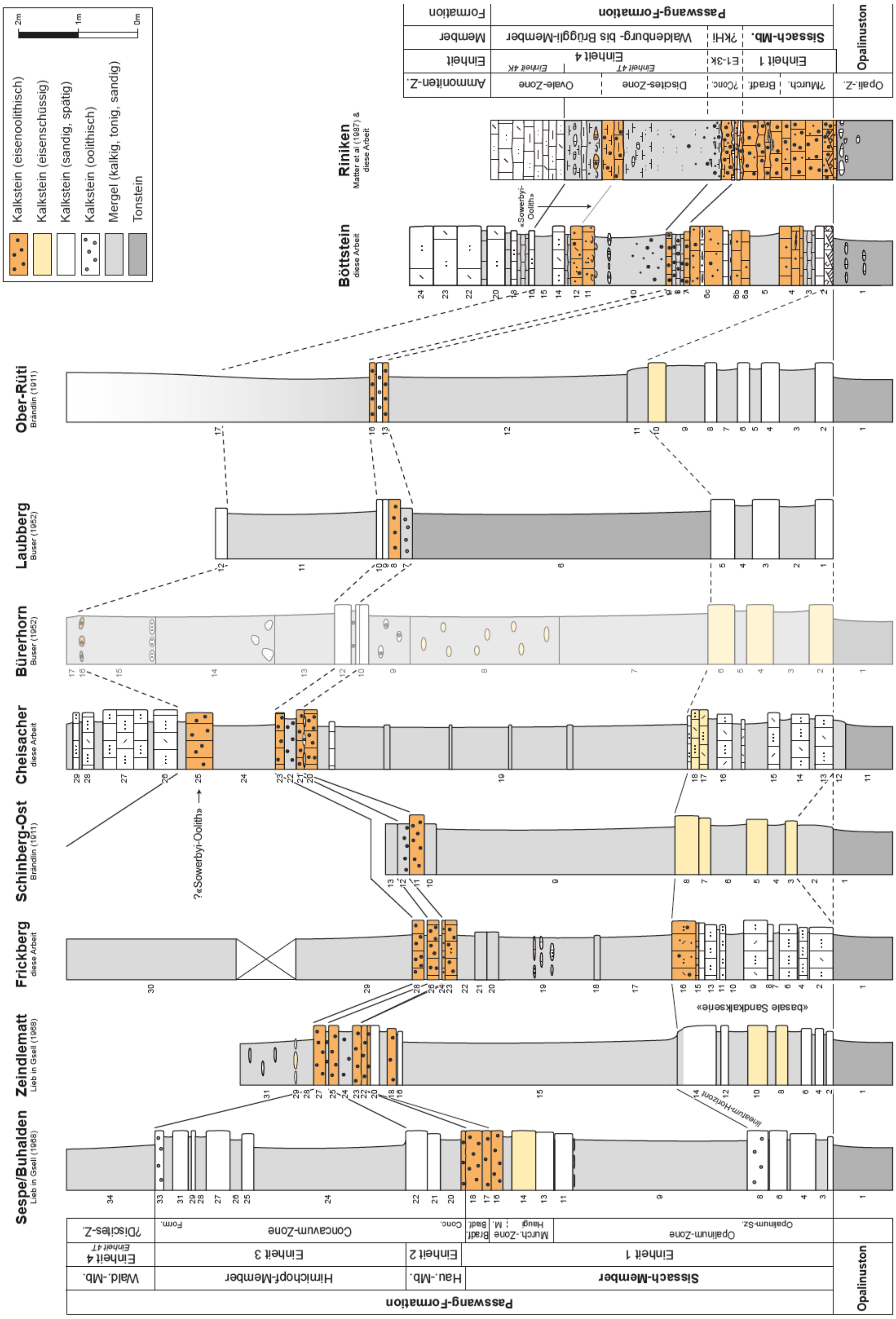


Figure 12: Lower part of Passwang Formation.

West (left) to east transition from the mostly uncondensed facies (Sespe/Buhalden, outside siting region) to the highly condensed facies as expected in JO siting region (from Wohlwend et al. 2019).

15.4.2. «Condensed equivalents of the Sissach, Hauenstein and Hirnichopf Members»

15.4.2.1. General and main characteristics

In the JO siting regions, the Hauenstein and Hirnichopf Members are only represented by heavily condensed, mostly iron-oolitic sediments which can, when amalgamated, hardly be differentiated from the underlying iron-oolite at the top of the formal Sissach Member (Burkhalter 1996, Wohlwend et al. 2019). Thus, they are here summarized to one combined unofficial unit «condensed equivalents of the Sissach, Hauenstein and Hirnichopf Members» corresponding to the unit 1-3k of Wohlwend et al. (2019).

15.4.2.2. Definition

Occurrence: As the Sissach Member is formally restricted to the area west of River Aare plus Achenberg and lower Surb valley region east of River Aare, the condensed equivalents of its lowest three members are only be found in the JO siting region. Here, the condensed equivalents overlay the uncondensed parts of the Sissach Member (Section 15.4.1) or directly the Opalinus Clay (Figure 11, Figure 12).

Lithology: The «condensed equivalents of the Sissach, Hauenstein and Hirnichopf Members» consist predominantly or exclusively of iron-oolites, separated by hardgrounds and, occasionally, thin limestone and shale layers.

Thickness: The thickness is in general < 1 m.

Upper boundary: Top of the amalgamated iron-oolite towards sandy marl of Waldenburg and Brüggli Member.

Lower boundary: Base of the amalgamated iron-oolite towards sandy marl or (marly) limestone of the Sissach Member or (silty) marl to claystone of Opalinus Clay.

Lateral equivalents: The «condensed equivalents of the Sissach, Hauenstein and Hirnichopf Members» correspond to the Murchisonae-Oolith Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011) which also applies to the NL and ZNO siting areas (Section 16).

Names previously in use: The «condensed equivalents of the Sissach, Hauenstein and Hirnichopf Member» is identical to unit 1-3k of Wohlwend (2019) and correspond to the upper, condensed part of the «Murchisonae-Concavus-Schichten» or «Sowerbyi-Concavus-Murchisonae-Schichten» of Brändlin (1911) and of the «Murchisonae-Concava-Schichten» of Bläsi (1987).

15.4.2.3. Additional information

Origin of name: The name refers to the three formal members involved.

Type locality and type region: There is no type locality for the partial or full amalgamation of the condensed members.

Reference section: The Frickberg Osthalde section (coord. 2646.092/1262.999) gives a good insight into the amalgamation of the condensed top of the Sissach Member with the «condensed equivalents of the Hauenstein and Hirnichopf Members».

Chronostratigraphic age: Dependant of the locality, the amalgamation includes the basal «Concava» Subzone, or even the topmost Opalinum Subzone up to the basal Discites Zone.

Genetic and paleogeographic interpretation: The highly condensed interval documents a long period of starved sedimentation, submarine erosion and re-sedimentation.

15.4.3. Waldenburg Member and Brüggli Member (without «Humphriesi-Schichten»)

15.4.3.1. General and main characteristics

At many places, the interval once called «Sowerbyi-Sauzei-Schichten» can be divided in a lower part, where sandy marl, and an upper part, where sandy limestone predominates. At some places, the lower part corresponds to the Waldenburg Member, and the upper to the Brüggli Member of Burkhalter (1996) except the oolitic sequence at the top of the latter («Humphriesi-Schichten» sensu Burkhalter 1996). However, at some places, especially in the JO siting region, the two are difficult to differentiate. That is why it is recommended here to take them as one stratigraphic unit in a first attempt.

15.4.3.2. Definition

Occurrence: According to the higher-ranking formation, the Waldenburg and Brüggli Member are restricted to the JO siting region. But there, without being distinguished, they are expected everywhere.

Lithology: Within the JO siting region, the unified members are represented by sandy marl, thin or medium bedded alternations of sandy marl and sandy limestone, partly nodular, and thicker beds of sandy limestone. In the lower part, one to some few metres above the «condensed equivalent of the Sissach, Hauenstein and Hirnichopf Members», a thin iron-oolite bed is found in some sections. Locally, thin iron-oolitic limestone beds may also occur at higher levels. Typical for the sandy marl and limestone part is the locally very abundant ichnofossil *Zoophycos*. The typical grain size of detritic quartz is about 40 und 50 µm in the lower, marly part. It goes up to 60-70 µm in the basal and 75 und 95 µm in the upper predominantly calcareous part (Burkhalter 1996; Wohlwend et al. 2019).

Thickness: The typical thickness in the area under investigation is 15 to 20 m, but, locally, it may deviate in both directions.

Upper boundary: The upper boundary is marked by the base of the iron-oolite of the informal «Humphriesi Bed» (Section 15.4.4).

Lower boundary: The lower boundary is marked by the top of the amalgamated iron-oolite of the «condensed equivalents of Hauenstein and Hirnichopf Members».

Lateral equivalents: The unified Waldenburg and Brüggli Members (without «Humphriesi-Schichten») corresponds to the Wedelsandstein Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011) which also applies to the NL and ZNO siting areas (Section 17, see also Appendix E).

Names previously in use: The unified Waldenburg and Brüggli Members are identical to unit 4 of Wohlwend et al. (2019) and have been commonly referred as «Sauzei- und Sowerbyi-Schichten».

15.4.3.3. Additional information

Origin of name: The names refer to the type localities of both formal Formations.

Type locality and type region: The type localities of the formal units (Burkhalter 1996) are the section (2623.480/1248.050) north of Waldenburg BL medieval town and Tiergarten section (coord. 2599.100/1231.670) north-east of Brüggli/Selzach SO.

Reference section: For the informal union of Waldenburg and Brüggli Member, the Cheisacher sections (coord. 2651.151/1264.504 and 2651.140/1264.472) gives a good reference. The reference section Rüschgraben (coord. 2601.410/1233.200) shows the base of the member.

Chronostratigraphic age: The unified members originate from the early Discites Zone to the late to latest Sauzei Zone.

Genetic and paleogeographic interpretation: The base of the unified members, i.e. the base of the formal Waldenburg Member is defined at the omission discontinuity dating from the Discites Zone. It is followed by two parasequences which cannot be distinguished in all sequence. Possibly, in the area under investigation, the first is present only in a condensed form or fully missing. The marly high stand deposits of the second parasequence are followed, above a regression discontinuity, often locally marked by an iron-oolite and addressed as formal base of the Brüggli Member, by dominantly sandy and calcareous sediments. The top of the second parasequence is regarded here as an own informal stratigraphic unit, the «Humphriesi Bed» (see below).

15.4.4. «Humphriesi-Schichten»

15.4.4.1. General and main characteristics

The traditional «Humphriesi-Schichten», regarded by Burkhalter (1996) as an informal subunit of his «Brüggli-Schichten» (now Brüggli Member) are set here, based on Wohlwend et al. (2019), as an own lithostratigraphic unit 5. The main reason is that this succession of iron-oolites is an excellent, easy to identify marker bed.

15.4.4.2. Definition

Occurrence: According to the higher-ranking formation, the informal «Humphriesi Bed» is restricted to the JO siting region where it is expected everywhere.

Lithology: The «Humphriesi-Schichten» are a succession of dark-red, fossiliferous iron-oolites and, subordinately, iron-oolitic limestone separated by thin marl horizons. There is some detritic quartz, but the typical grain size (25-45 µm) is significantly smaller than in the underlaying sediments. The fossils found include abundant belemnites, ammonites, bivalves etc.

Thickness: In the JO siting region, thickness may vary between some 2 and 5 m.

Upper boundary: The upper boundary is marked by the top of iron-oolite hardground and the onset of grey marl of Rothenfluh Member.

Lower boundary: The upper boundary is marked by the base of iron-oolite with a typical red color above sandy marl or limestone of Waldenburg and Brüggli Members.

Lateral equivalents: The «Humphriesi-Schichten» are identical to unit 5 of Wohlwend et al. (2019) and correspond to the lower part of the informal «Humphriesioolith Formation» sensu Bläsi et al (2013) of NL and ZNO siting regions (Section 18) and to the Humphriesioolith Member of the Gosheim Formation of the German Strati-graphic Scheme (Figure 13, Appendix E).

Names previously in use: «Humphriesioolith»

15.4.4.3. Additional information

Origin of name: The name derives from *Stephanoceras humphresianum* which was *Ammonites humphriesi* Sowerby.

Type locality and type region: There are no formal type locality or type region for the «Humphriesi-Schichten» of Burkhalter (1996).

Reference section: The upper Cheisacher sections (coord. 2651.140, 1264.472) southeast of Gansingen AG may serve as a reference locality.

Chronostratigraphic age: According to Wohlwend et al. (2019) the informal «Humphriesi-Schichten» represent the Humphriesianum Zone, and, locally, even the latest Sauzei Zone.

Genetic and paleogeographic interpretation: The informal «Humphriesi-Schichten» documents a time of starved sedimentation between two phases of increased terrigenous clastic import.

15.4.5. Rothenfluh Member

15.4.5.1. General and main characteristics

The Rothenfluh Member corresponds to the former «Blagdeni-Schichten»: marly bioclastic mud- and wackestone interbedded with fine-grained, often sandy, nodular limestone. The member was originally named by Gonzalez & Wetzel (1996) as part of the Hauptrogenstein. By decision of the Swiss Committee on Stratigraphy in 2004 it was designed a member of the Passwang Formation.

15.4.5.2. Definition

Occurrence: The occurrence is formally restricted to the domain where the Passwang Formation is overlain by the Hauptrogenstein (Section 21).

Lithology: The Rothenfluh Member consists of marl to marly bioclastic limestone interbedded with fine-grained, often sandy, nodular limestone. Possibly, locally, coral reef detritus or even coral reefs may be encountered.

Thickness: In the area under investigation, thickness varies between 10 to 30 m.

Upper boundary: The upper boundary is defined by the onset of calcareous ooids of Hauptrogenstein, if the onset is gradual, the boundary is set at the base of first oolite bed with at least 10 cm thickness.

Lower boundary: The lower boundary is marked by the hardground at the top of dark-red iron-oolite of the informal «Humphriesi-Schichten» and the onset of grey marl.

Lateral equivalents: Towards the east, the Rothenfluh Member corresponds to the informal lowest part of the Klingnau Formation (below the «Subfurcaten Beds» of Gonzalez & Wetzel 1996) (see also Appendix E).

Names previously in use: «Blagdenischichten»

15.4.5.3. Additional information

Origin of name: Name of municipality where type locality is found

Type locality and type region: Rothenfluher Fluh section (coord. 2635.800/1257.500) north-north-west of Rothenfluh BL.

Reference section: There is no reference section.

Chronostratigraphic age: Bajocian, Blagdeni Subzone of Humphriesianum Zone (possibly until Niortense Zone).

Genetic and paleogeographic interpretation: The Rothenfluh Member documents a phase of increased terrestrial clastic input and a sedimentation probably below storm wave base.

16. «Murchisonae-Oolith Formation»

16.1. General and main characteristics

The Murchisonae-Oolith Formation, formally established in the German Stratigraphic Scheme (Franz & Nitsch 2009), was adapted by Bläsi et al. (2013) to describe the succession above the Opalinus Clay found in the boreholes between the River Aare and the Schaffhausen area and showing great petrographic affinities to the German formation. In the original reports, the interval was named, e.g., «Murchisonae-Concava-Schichten» (Weiach, Matter et al. 1988) or «Murchisonae-Schichten Dogger β» (Benken, Nagra 2001).

It was decided to maintain the term «Murchisonae-Oolith Formation» sensu Bläsi et al. (2013) as an unofficial stratigraphic unit for the current campaign and to establish, if necessary, a new formal unit based on the findings in the new boreholes. One of the essential differences is the «Comptum-Bank» which marks the base of the formal German Murchisonae-Oolith-Formation. In the Swiss scheme the top of Opalinus Clay is not defined at the base of the «Comptum-Bank» but as described in Section 14 by a facies change. Also not yet clarified are the relation to the contemporary Passwang Formation (Section 15) of eastern Folded Jura and Achdorf Formation of adjacent southern-German Wutach region and the spatial context and range of the Murchisonae-Oolith Formation (Appendix E).

16.2. Definition

Occurrence: The «Murchisonae-Oolith Formation» sensu Bläsi et al. (2013) is expected in the NL and ZNO siting regions. In the latter it may locally be missing (Figure 10 and Figure 11).

Lithology and subdivision: The «Murchisonae-Oolith Formation» sensu Bläsi et al. (2013) encompasses brownish to reddish, often fossiliferous, sandy marl and claystone, layered or nodular sandy, sparitic and marly limestone and iron oolite of Late Aalenian age.

There is no subdivision established for the «Murchisonae-Oolith Formation» sensu Bläsi et al. (2013).

Thickness: The thickness varies in the three drillings Weiach, Benken and Schlattingen between 0 and 15 m.

Upper boundary: The upper boundary is defined at the base of the «Sowerbyi-Oolith», an iron-oolite marker bed.

Lower boundary: The lower boundary is marked by the first sandy limestone or iron oolite above the claystone of Opalinus Clay.

Lateral equivalents: To the west, the «Murchisonae-Oolith Formation» corresponds to the (uncondensed) Sissach Member and the «condensed equivalents of Sissach, Hauenstein and Hirnichopf Members» (Figure 10, Figure 11, Appendix E). To the east, the «Murchisonae-Oolith Formation» wedges out. In Schlattingen-1 borehole, for instance, it is missing (Albert et al. 2012).

Names previously in use: «Murchisonae-Concava-Schichten» (Weiach, Matter et al. 1988) or «Murchisonae-Schichten Dogger β» (Benken, Nagra 2001).

16.3. Additional information

Origin of name: *Ludwigia murchisonae*, an ammonite

Type locality and type region: There is no type locality or type region defined.

Reference section: The Weiach section, bore depth 539.17 to 554.5 m, as interpreted by Bläsi et al. (2013) may serve as a reference section.

Chronostratigraphic age: Aalenian, Late Opalinum to Bradfordensis Zone (Bläsi et al. 2013) or even Concavum Zone (Wohlwend et al. 2019).

Genetic and paleogeographic interpretation: The «Murchisonae-Oolith Formation» sensu Bläsi et al. (2013) represents a timespan of starving sedimentation with sporadic terrestrial clastic input in a transitory area between the Sissach rise and the Swabian Basin.

17. Wedelsandstein Formation

17.1. General and main characteristics

The Wedelsandstein Formation, formally established in the German Stratigraphic Scheme (Bloos et al. 2005), was adapted by Albert et al. (2012) and Bläsi et al. (2013) based on new biostratigraphic findings in the drill cores of Weiach (Matter et al. 1988) and Benken (Nagra 2001). However, Wohlwend et al. (2019) conclude, that there is a high affinity in facies and age to unified Waldenburg and Brüggli Members of Passwang Formation (Section 15.4.3, Appendix E), it was decided to maintain the formal German unit to describe the findings in NL and ZNO siting regions.

17.2. Definition

Occurrence: The Wedelsandstein Formation is found in the NL and ZNO siting regions.

Lithology and subdivision: In the area under investigation, the Wedelsandstein Formation starts with an iron-oolite («Sowerbyi-Oolith») which is followed by grey, reddish or brownish silty to fine-grained sandy argillaceous marl with many up to some decimetre-thick sandy limestone interlayers. In the lowest part, also additional iron-oolite beds may be found. The ichnofossil *Zoophycos* is often very abundant.

The «Sowerbyi-Oolith» may be considered as informal bed.

Thickness: Thickness reported from the few boreholes having reached this horizon in the NL and ZNO siting regions varies between 15 and 32 m.

Upper boundary: The upper boundary is defined by the base of the «Humphriesi-Oolith» sensu stricto of informal «Humphriesioolith Formation» (see Section 18).

Lower boundary: The lower boundary is defined by the base of the «Sowerbyi-Oolith».

Lateral equivalents: Lateral equivalents to the west are the unified Waldenburg and Brüggli Members (Section 15.4.3: see also Appendix E).

Names previously in use: in an immediate way «Sowerbyi-Schichten» in traditional stratigraphy, «Parkinsoni-Schichten» of Weiach (Matter et al. 1988) and «Wedelsandstein» of Benken (Nagra 2001), due to stratigraphic reinterpretation (Bläsi et al. 2013) the term covers also a section originally denoted as «Humphriesi-Schichten» and «Blagdeni-?Subfurcaten-Schichten» in Weiach (Matter et al. 1988) (compare Fig. 3 in Bläsi et al. 2013).

17.3. Additional information

Origin of name: German name of ichnofossil *Zoophycos*, common but not ubiquitous and not restricted to this formation.

Type locality and type region: The type locality of the German Wedelsandstein Formation is close to Reutlingen south of Stuttgart D (LithoLex, consulted 21.03.2019).

Reference section: The Benken section from bore depth 507.55 to 538.68 m interpreted by Bläsi et al. (2013) may act as reference section.

Chronostratigraphic age: Bajocian, Discites to Sauzei Zone.

Genetic and paleogeographic interpretation: The Wedelsandstein Formation represents a timespan with increased terrigenous clastic input.

18. «Humphriesioolith Formation»

18.1. General and main characteristics

Already used in the description of different cores, the «Humphriesioolith Formation» was informally used by Bläsi et al. (2013). The application of this formation was inspired by a then valid German formation (e.g. Geyer et al. 2011) which later was significantly reorganised and integrated as subformation into the now formal Gosheim Formation (Franz 2015, Bloos et al. 2005, LithoLex consulted 15.11.2019).

Following Bäsi et al. (2013), the informal «Humphriesioolith Formation» includes a lower oolite, the «Humphriesi-Oolith» sensu stricto, a marl dominated interval («Blagdeni-Schichten») and an upper iron-oolite, the «Subfurcaten-Oolith». The «Subfurcaten-Oolith» was in the textual description of Geyer et al. (2011) not included in the Humphriesioolith Formation for the area south of Spaichingen. As there are only few accessible records yet, it was decided to maintain the informal units («Humphriesi-Oolith», «Blagdeni-Schichten» and «Subfurcaten-Oolith») for the current campaign and to establish, if necessary, a new formal unit based on the findings in the new boreholes.

18.2. Definition

Occurrence: The «Humphriesioolith Formation» is found in the NL and ZNO siting regions.

Lithology and subdivision: The «Humphriesi-Oolith» is a thin, mostly some decimetres, rarely up to 2.5 m thick iron-oolite, at some places missing or replaced by iron-oolitic limestone.

The «Blagdeni-Schichten» consist of sandy marl and limestone, bedded or nodular, of variable thickness. At some places, they are missing.

The «Subfurcaten-Oolith» is a partly fossiliferous iron-oolite of variable thickness (up to 4 m at Benken section).

Thickness: The thickness of the «Humphriesioolith Formation» varies between some few and about 13 m.

Upper boundary: The upper boundary is set at the top of the «Subfurcaten-Oolith» with the onset of the dark grey micaceous claystone of informal «Parkinsoni-Württembergica-Schichten».

Lower boundary: The lower boundary is set at the base of the «Humphriesi-Oolith» expected to overlay the fine-grained sandy argillaceous marl of Wedelsandstein Formation.

Lateral equivalents: The lower two informal units, «Humphriesi-Oolith» and «Blagdeni-Schichten» correspond to the German Gosheim Formation with its subformations Humphriesioolith and Blagdeni-Schichten (Figure 13, Appendix E), and to the «Humphriesi-Schichten» and Rothenfluh Member of the Passwang Formation in the west. The informal «Subfurcaten-Oolith» corresponds to the Subfurcaten-Oolith of the Ostreenkalk Formation of the German Stratigraphic Scheme (LithoLex consulted 21.03.2019).

Names previously in use: The informal members have been known as «Humphriesioolith», «Blagdeni-Schichten» and «Subfurcaten-Oolith»

18.3. Additional information

Origin of name: The name derives from *Stephanoceras humphresianum* which was Ammonites humphriesi Sowerby.

Type locality and type region: There are no formal type locality or type region.

Reference section: The Benken section from bore depth 495.05 to 507.55 m interpreted by Bläsi et al. (2013) may serve as reference section.

Chronostratigraphic age: Bajocian, Sauzei to Niortense Zone

Genetic and paleogeographic interpretation: The «Humphriesioolith Formation» represents a time of distinctive starving sedimentation on the Sissach rise.

19. «Parkinsoni-Württembergica-Schichten»

19.1. General and main characteristics

The denominations «Parkinsoni-Württembergica-Schichten», «Parkinsoni-Schichten» or «Württembergica-Schichten» can be found in various older publications. As Bläsi et al. (2013) give a concise definition, it was decided to maintain the term «Parkinsoni-Württembergica-Schichten» as an informal formation for the current campaign and to establish, if necessary, a new formal unit based on the findings in the new boreholes.

19.2. Definition

Occurrence: The «Parkinsoni-Württembergica-Schichten» are found throughout the NL and ZNO siting regions.

Lithology and subdivision: The «Parkinsoni-Württembergica-Schichten» are characterised by monotonous dark grey micaceous claystone with sporadic, sometimes sandy, limestone beds and nodules.

Thickness: In the NL and ZNO siting regions, thickness of 25 to 35 m is expected.

Upper boundary: Onset of narrow bedded alternation of characteristic, often fossiliferous sandy marl and limestone of Variansmergel Formation.

Lower boundary: The lower boundary is defined at the top of the «Subfurcaten-Oolith» from the «Humphriesioolith Formation» with the onset of dark grey micaceous claystone.

Lateral equivalents: To the west, the «Parkinsoni-Württembergica-Schichten» correspond to the Klingnau Formation without the basal part below the «Subfurcaten Beds» of Gonzalez & Wetzel (1996) (Section 20). The equivalents in northeast are the Hamitenton Formation and the Dentalienton Formation of the German Stratigraphic Scheme (Figure 13) which are separated by the «Oberer Parkinsoni-Oolith» (Appendix E).

Names previously in use: Traditionally, the «Parkinsoni-Schichten» and «Württembergica-Schichten» have been addressed as two independent stratigraphic units.

19.3. Additional information

Origin of name: The informal unit is named after the ammonites *Parkinsonia parkinsoni* (Sowerby) and *Parkinsonia württembergica* (Oppel).

Type locality and type region: There are no type locality or type region defined.

Reference section: The Benken section from bore depth 466.90 to 495.05 m interpreted by Bläsi et al. (2013) may serve as reference section.

Chronostratigraphic age: Late Bajocian to Middle Bathonian, (Latest Niortense -) Garantiana to Zigzag and, eventually, Aurigerus-Zone.

Genetic and paleogeographic interpretation: The «Parkinsoni-Württembergica-Schichten» represents a time of increased terrigenous clastic input.

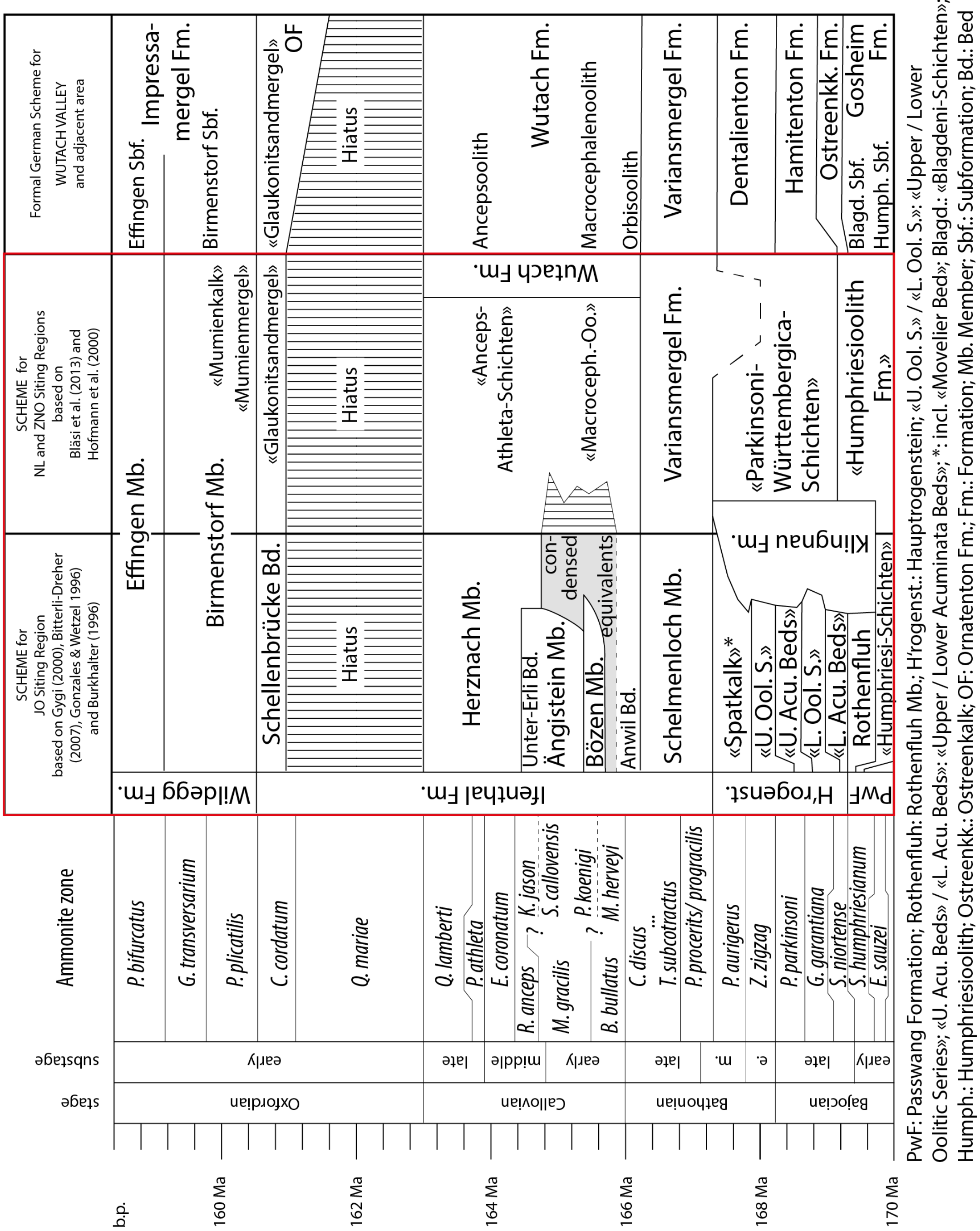


Figure 13: Stratigraphic scheme for the upper middle to upper Dogger and lowest Malm Group in the three siting regions.

The schemes to be used for JO and NL and ZNO regions are shown within a red frame. b.p.: bevor present (time scale).

20. Klingnau Formation

20.1. General and main characteristics

The Klingnau Formation was established by Gonzalez & Wetzel (1996) to characterise the transition from the Hauptrogenstein platform (Celtic facies) to the Swabian Basin facies. The Klingnau Formation is characterised by an interfingering of basin (dark, sometimes sandy claystone) and platform sediments (mainly oolitic limestone). At the base, oolites are rare or missing.

20.2. Definition

Occurrence: Formally, the Klingnau Formation is defined for the valley of the River Aare between Brugg and Koblenz and adjacent areas. Thus, it applies for the eastern part of JO siting region and the western of NL siting region (Figure 13, Figure 14).

Lithology and subdivision: Gonzalez & Wetzel (1996) suggest a subdivision of the Klingnau Formation by informal beds (Figure 14, from bottom to top, spelling according to Gonzalez & Wetzel 1996):

- «Subfurcaten Beds»
- «Lower Parkinsonien Bank»
- «Upper Parkinsonien Bank»
- «Württembergica Beds»
- «Knorri Clays»

The domain below the «Subfurcaten Beds», corresponding to the Rothenfluh Member of Passwang Formation (Section 15.4.5), consists of marly bioclastic mud- and wackestone interbedded with fine-grained, often sandy, nodular limestone. Calcareous ooids are absent. Their traditional name «Blagdeni-Schichten» should be used here (Encl. A).

The «Subfurcaten Beds», corresponds laterally to the «Subfurcaten-Oolith» of informal «Humphriesioolith Formation». However, they are formed, in the domain of the Klingnau Formation, of bioturbated bioclastic beds often containing ammonites. The «Lower Parkinsonien Bank» and the «Upper Parkinsonien Bank» have a similar composition as the «Subfurcaten-Oolith». All three beds are rather persistent, but thickness may vary between a few decimetres and a few centimetres. The above-described interval can be studied in Tegerfelden at the Surb (Wohlwend et al. 2019).

The main body of the Klingnau Formation between the «Subfurcaten Beds» and the «Württembergica Beds» consists of alternations of cm to dm thick marls and bioturbated, bioclastic limestone including oolitic intercalations from the Hauptrogenstein platform. Towards east and south the lithology is increasingly dominated by marls and mudstones. The main depositional trend is coarsening and thickening upward (Gonzalez & Wetzel 1996). In the western part, thin oolite layers may be found. Concerning demarcation to Hauptrogenstein, see below).

The «Württembergica Beds» forming a lenticular layer at the top of the Klingnau Formation are found only east of River Aare. They can be up to a few metres thick and consist of an alteration of marl and fine-grained, strongly bioturbated wake- to packstone, characteristically very rich in molluscs (Gonzalez & Wetzel 1996).

The «Knorri Clays» are found above the «Württembergica Beds» and replace the «Spatkalk» of the Hauptrogenstein Formation (Section 21.4.4) east of the Lägern Chain. They are a few metres thick and consist of dark claystone with occasional layers of fine-grained, nodular limestone, locally with accumulations of the oyster *Ostrea knorri* Voltz (Gonzalez & Wetzel 1996).

Thickness: Thickness has a maximum, about 50 m, in the lower Aare Valley and decreases towards east to a few metres.

Upper boundary: The upper boundary is marked by the base of the sparitic limestone of «Spatkalk» of Hauptrogenstein (Section 21.4.4) or, in places the «Knorri Clays» occurs, the persistent onset of sparitic limestone of «Spatkalk» or the onset of the narrow interlayering of sandy biodetritic marl and limestone of the «Variansmergel Formation» (Section 22.4.1).

Lower boundary: The lower boundary is marked by the top of the iron-oolite «Humphriesi-Schichten» of Passwang Formation or «Humphriesioolith Formation».

Lateral equivalents: To the west, in its lowest part, below the «Subfurcaten Beds», the Klingnau Formation corresponds to the Rothenfluh Member of Passwang Formation. Above the «Subfurcaten Beds», there is an interfingering of Klingnau Formation type sediments with oolite beds of Hauptrogenstein (Appendix E). It is recommended to address sediments with oolitic intercalations of less than 10 cm thick and separated by more than 30 cm of non oolitic sediments as part of the Klingnau Formation. If appropriate, also the term «Intercalation of Hauptrogenstein and Klingnau Formation» may be used.

To the east, the Klingnau Formation corresponds to the upper part of the «Humphriesioolith Formation» and the «Parkinsoni-Württembergica-Schichten» (Sections 18 and 19).

Names previously in use: According to Gonzalez & Wetzel (1996), the Klingnau Formation corresponds to the «Parkinsoni-Schichten» of Mühlberg (1900), Schmassmann (1945) and Voss (1969).

20.3. Additional information

Origin of name: The Formation is named after the municipality where the type locality is found.

The informal beds are named after ammonites («*Ammonites subfurcatus*» Zieten, *Parkinsonia parkinsoni* (Sowerby) and *Parkinsonia württembergica* (Oppel)) and an oyster (*Ostrea knorri* Volz).

Type locality and type region: Type locality is the Blitzberg section (coord. 2662.000/1270.200) near Klingnau AG, recorded by Gonzalez & Wetzel (1996). The type region is the lower Aare Valley around Klingnau.

Reference section: There is no reference section.

Chronostratigraphic age: Bajocian to Bathonian, Humphriesianum to Zigzag or Aurigerus Zone (Gonzalez & Wetzel 1996).

Genetic and paleogeographic interpretation: The Klingnau Formation represents the transition between the carbonatic Celtic Platform and the marly Swabian Basin realm.

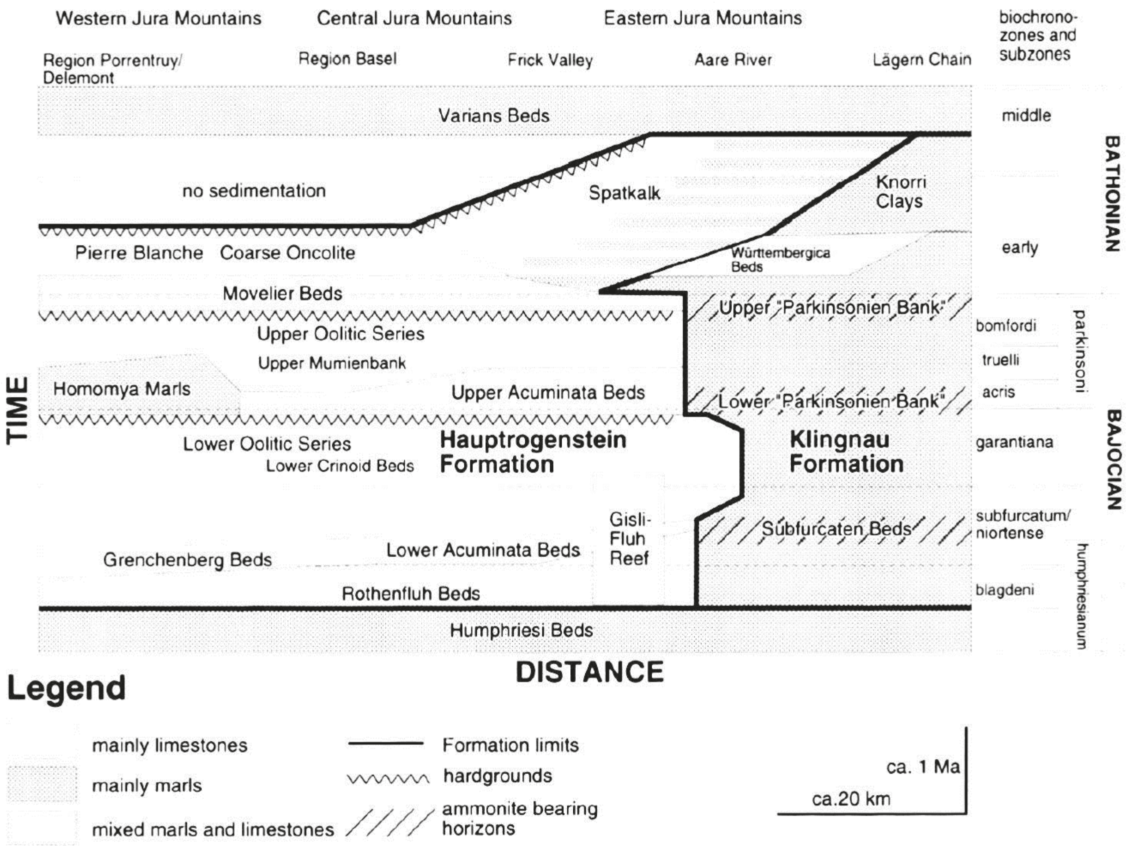


Figure 14: Stratigraphic scheme of the Hauptrogenstein Formation and Klingnau Formation from Gonzalez & Wetzel (1996).

21. Hauptrogenstein

21.1. General and main characteristics

In their sedimentological analysis of the transition from the Celtic platform realm to the Swabian Basin, Gonzalez & Wetzel (1996) defined, besides the Klingnau Formation (see Section 20), the «Hauptrogenstein-Formation». The Swiss Stratigraphic Committee decided later to keep the traditional name Hauptrogenstein (without appendix "Formation") as one of the few exceptions to the formal stratigraphic nomenclature (Remane et al. 2005). However, from the subdivision proposed by Gonzalez & Wetzel (1996), only the «Rothenfluh Beds» at the base of the Hauptrogenstein have been accepted as a formal member. Later, in 2004, the Swiss Stratigraphic Committee decided to move the Rothenfluh Member from the Hauptrogenstein to the newly established Passwang Formation (see Section 15.4.5).

21.2. Definition

Occurrence: The Hauptrogenstein is mainly restricted to the area east of the River Aare, thus the JO siting region. The informal «Spatkalk», only, persists into the NL region.

Lithology and subdivision: According to the modified definition by the Swiss Stratigraphic Committee, the Hauptrogenstein is restricted to predominantly oolitic and subordinately sparitic and oncolitic platform sediments (mainly organised in submarine dune forsets resulting in characteristic cross-bedding) with some marly interlayers with few or no ooids.

Gonzalez & Wetzel (1996) suggest a subdivision of the Hauptrogenstein by informal units that corresponds to members or beds, which roughly coincide with the traditional subdivision (in angular brackets below). For the area under investigation these are (Figure 14, from bottom to top, spelling according to Gonzalez & Wetzel 1996):

- «Lower Acuminata Beds»
- «Lower Oolitic Series»
- «Upper Acuminata Beds»
- «Upper Oolitic Series»
- «Movelier Beds»
- «Spatkalk» (of Hauptrogenstein)

Thickness: In the northwest of JO siting region, the Hauptrogenstein may reach a maximum thickness of some 110 m. Towards east it is wedging out. The «Spatkalk», only, may be found, some metres thick, in the NL siting region.

Upper boundary: The upper boundary is given by a hardground and the offset of the mostly sand-free, (often coarsely) sparitic «Spatkalk» and the persistent onset of the narrow interlayering of sandy biodetritic marl and limestone of the «Variansmergel Formation» or of the Schelmenloch Member of the Ifenthal Formation.

Lower boundary: The boundary to the underlaying Passwang Formation is given by the onset of calcite oolite sedimentation (Celtic platform facies), and, if gradual, by the first calcite oolite bed of at least 10 cm thickness.

Lateral equivalents: To the east, the Hauptrogenstein interfingers, on relatively short distance, with Klingnau Formation type sediments (Appendix E). The formal lateral boundary is given, when oolite beds are thinner than 10 cm and marl interlayers are at least 30 cm thick (Section 20.2). If appropriate, also the term «Intercalation of Hauptrogenstein and Klingnau Formation» may be used.

Names previously in use: «Hauptrogenstein-Formation» (Gonzalez & Wetzel 1996)

21.3. Additional information

Origin of name: Rogen means fish eggs in northern German local language, and Rogenstein becomes oolite when translated into scientific Greek. «Haupt» refers to the important role of the formation in landscape modelling.

Type locality and type region: The Schleifenberg section (coord. 2622.750/1259.900) near Liestal BL (Gonzalez 1993) has been designed as type locality by Gonzalez & Wetzel (1996). Type region is the Basel Tabular Jura.

Reference section: There are no reference sections.

Chronostratigraphic age: Bajocian to Bathonian, late Humphriesianum to Zigzag or Aurigerus Zone.

Genetic and paleogeographic interpretation: The Hauptrogenstein represents the outer boundary of the Celtic platform including a tidal-dominated lagoon, with the fringe locally represented by coral bioherms and the bioclastic forereef.

21.4. Members of the Hauptrogenstein

21.4.1. «Lower Acuminata Beds»

21.4.1.1. General and main characteristics

The «Lower Acuminata Beds» (Gonzalez & Wetzel 1996) are considered as part of the sealing formations fringing the Opalinus Clay host formation.

21.4.1.2. Definition

Occurrence: The «Lower Acuminata Beds» are found throughout the domain where the Hauptrogenstein occurs.

Lithology: The «Lower Acuminata Beds» is an alternation of calcite oolite beds and marl. Possibly, locally, coral reef detritus or even coral reef bodies (bioherms) may be encountered.

Thickness: According to Gonzalez & Wetzel (1996), maximum thickness is about 5 m (Gonzalez & Wetzel 1996). Other authors, some of which using diverging older definitions, mention up to 20 m for «Untere Acuminata-Schichten» (see compilation in Beilage 3.1 of Nagra 2014).

Upper boundary: The upper boundary is set at the top of the last marl bed of at least 5 cm thickness

Lower boundary: The lower boundary is identical to the Hauptrogenstein. It is defined by the base of the first persistent calcite oolite layer of at least 10 cm thickness.

Lateral equivalents: The lateral equivalent is the part of the Klingnau Formation below the «Subfurcaten Beds».

Names previously in use: «Untere Acuminata-Schichten», «Untere Acuminatenschichten».

21.4.1.3. Additional information

Origin of name: *Praeexogyra acuminata* (Sowerby), formerly *Ostrea acuminata*, an oyster. N.B.: *Praeexogyra acuminata* is neither restricted to, nor distinctive for, the «Lower Acuminata Beds».

Type locality and type region: Same as for Hauptrogenstein.

Reference section: There is no reference section.

Chronostratigraphic age: Bajocian, Niortense Zone.

Genetic and paleogeographic interpretation: The «Lower Acuminata Beds» represents a transition from basin to platform sediments and is characterised by an alternation of marl and oolite limestone. In some places, coral reefs have formed and the «Untere Acuminaten-Schichten» may comprise reef detritus.

21.4.2. «Lower Oolitic Series»

21.4.2.1. General and main characteristics

The informal «Lower Oolitic Series» of Gonzalez & Wetzel (1996) encompass the lower massy oolite sequence of Hauptrogenstein. It corresponds to the «Unterer» and «Mittlerer Hauptrogenstein» including «Meandrina-Schichten» of Schmassmann (1945) and Müller (1984) (latter corresponds to the informal «Meandrina-Beds» of Gonzalez & Wetzel 1996).

21.4.2.2. Definition

Occurrence: The «Lower Oolitic Series» extends little bit more to the east than the other members of the Hauptrogenstein, except the «Spatkalk».

Lithology: The well bedded to massive succession is build up by generally fine-grained ooids. Cross-bedding is often clearly visible. Some horizons are rich in shell detritus, crinoid remains, oysters, etc. Hardgrounds end the succession but are also found within the successions. Possibly, locally, coral reef detritus or even coral reef bodies (bioherms) may be encountered. The informal «Meandrina-Beds» denotes an interval that, though also oolitic in nearly all cases, contain, at some localities, a higher content of clay minerals so the rock may be classified as argillaceous limestone or even a calcareous marl (Schmassmann 1945).

Thickness: Maximum thickness may reach to 50 or even 60 m in the northwest of JO siting region.

Upper boundary: The upper boundary, generally a hardground, is given by the offset of ooids as dominant components and the onset of marl with few or no ooids.

Lower boundary: The lower boundary is set at the top of the last marl bed of «Lower Acuminata Beds» of at least 5 cm thickness.

Lateral equivalents: The «Lower Oolitic Series» correspond to the part of the Klingnau Formation between «Subfurcaten Beds» and «Lower Parkinsonien Bank» (Gonzalez & Wetzel 1996) (see also Appendix E).

Names previously in use: «Unterer Hauptrogenstein», «Meandrina-Schichten», «Mittlerer Hauptrogenstein».

21.4.2.3. Additional information

Origin of name: See Section 21.3.

Type locality and type region: Same as for the formation (Section 21.2).

Reference section: There is no reference section.

Chronostratigraphic age: Bajocian, Garantiana Zone.

Genetic and paleogeographic interpretation: The «Lower Oolitic Series» is the uppermost, oolitic part of the first coarsening-upwards succession (Gonzalez & Wetzel 1996) starting with the Rothenfluh Member and continuing with the «Lower Acuminata Beds».

21.4.3. «Upper Acuminata Beds» and «Upper Oolitic Series»

21.4.3.1. General and main characteristics

The «Upper Acuminata Beds» and the «Upper Oolitic Series» of Gonzalez & Wetzel (1996) represent the second coarsening-upwards succession of Hauptrogenstein. The clear distinction between a lower marly interval with less (and, rarely, no) ooids and a massy oolite Succession which can be determined west of the JO siting region, is becoming more and more blurred towards the east. There are indications that the «Upper Acuminata Beds» may be fully missing in the northern part of JO siting region (Schmassmann 1945). That is why they are described together here. In the eastern part of JO siting region an interfingering with or a full replacement by the adjacent Klingnau Formation may be observed (Section 20.2).

21.4.3.2. Definition

Occurrence: The «Upper Acuminata Beds» and the «Upper Oolitic Series» extents somewhat less to the east than the «Lower Oolitic Series». They may be missing and replaced by Klingnau Formation at some places in the JO siting region.

Lithology: The «Upper Acuminata Beds» are a locally fossiliferous, in most cases oolitic, predominantly marly succession (argillaceous limestone to calcareous marl) with some oolitic and non-oolitic limestone intercalation.

The «Upper Oolitic Series» consists of bedded to massive, often cross-bedded oolites. Some horizons are rich in shell detritus, crinoid remains, oysters, etc. Hardgrounds end the succession but are also found within the successions.

Thickness: Possibly up to 20 m (predominantly «Upper Oolitic Series») at some places, possibly completely missing at others. In the area under investigation; the thickness of «Upper Acuminata Beds» may vary between 0 and 3 m.

Upper boundary: The upper boundary is defined by a hardground followed by some marly sediments with lenticular bioclastic (sparitic) to oolitic, locally fossiliferous limestone interlayers.

Lower boundary: The lower boundary, generally a hard ground, is given by the offset of ooids as dominant components and the onset of marly «Upper Acuminata Beds» significantly less oolitic.

Lateral equivalents: The «Upper Acuminata Beds» and «Upper Oolitic Series» corresponds to the part of the Klingnau Formation between «Lower Parkinsonien Bank» and «Upper Parkinsonien Bank» (Gonzalez & Wetzel 1996) (see also Appendix E).

Names previously in use: «Obere Acumina-Schichten», «Homomyen-Mergel», «Obere Acuminenschichten»; «Obere Hauptrogenstein».

21.4.3.3. Additional information

Origin of name: See Section 21.3.

Type locality and type region: Same as for the formation (Section 21.2).

Reference section: There is no reference section.

Chronostratigraphic age: Bajocian to Bathonian, Parkinsoni to Zigzag Zone.

Genetic and paleogeographic interpretation: The «Upper Acuminata Beds» and «Upper Oolitic Series» represents the second coarsening-upwards sequence of Gonzalez & Wetzel (1996).

21.4.4. «Movelier Beds» and «Spatkalk»

21.4.4.1. General and main characteristics

According to Gonzalez & Wetzel (1996), the «Movelier Beds» and the «Spatkalk» (both informal, the latter in the rank of a member) represent the third and last coarsening-upwards succession of Hauptrogenstein.

The term «Movelier Beds» originating from the internal platform (the type locality is sited in the canton of Jura) was exported to eastern domains by different authors with various meanings. For Schmassmann (1945), for instance, it encompasses all what is summarized here as «Movelier Beds» and «Spatkalk». Diebold et al. (2006) denotes the whole succession as «Spatkalk», only mentioning, that there is a fossiliferous and, locally, iron-oolitic horizon at its base. Here, the definition of Gonzalez & Wetzel (1996) is used (see below).

The onset of «Spatkalk» sedimentation marks a dramatic reduction of sedimentation rate in the domain of the platform and the transportation of biogenic detritus, mainly crinoids, from the platform far in to the adjacent basin in the east. Thus, in the transitory domain, which may coincide with JO siting region, the «Spatkalk» may also comprise iron-oolitic lenses and layers.

21.4.4.2. Definition

Occurrence: The «Movelier Beds» sensu Gonzalez & Wetzel (1996) may be only found in the JO siting region. It is expected to wedge out towards east within the siting region.

The «Spatkalk» probably extents to some parts of the NL siting region.

Lithology: Following Gonzalez & Wetzel (1996), the «Movelier Beds» are a thin marl alternating with lenticular limestone, both rich in complete as well as broken biogenous components, such as corals, brachiopods and molluscs.

The «Spatkalk» is quite heterogeneous. Sparitic (mainly crinoidal) limestone (literal for "Spatkalk") is the dominant facies. As originating from tempestites, it often shows pronounced crossbedding The «Spatkalk» may, mainly in its western part (JO siting region), also comprise partly coarse-grained, partly limonitic calcareous oolitic limestone («Coarse Oolith», «Coarse Oncolite», «Ferrugineus-Oolith», informal, terms not to be used here) and iron-oolitic limestone (or even iron-oolite).

Thickness: Maximum Thickness is 22 m at the eastern limit of JO siting area (Diebold et al. 2006). The «Movelier Beds» never reache more than some few decimetres.

Upper and internal boundaries: Locally, the fossiliferous «Movelier Beds» may be followed by Klingnau Formation sediments (including «Württembergica Bed») which are again followed by «Spatkalk».

The Top of the «Spatkalk» is generally a hardground representing a shorter or longer time of non-sedimentation or erosion (Gonzalez & Wetzel 1996, Diebold et al. 2006). It is overlain by sandy biodetritic, often fossiliferous marl and limestone of the «Variansmergel Formation» or of the Schelmenloch Member of the Ifenthal Formation.

Lower boundary: The lower boundary is defined by a hardground followed by the «Movelier Beds».

Lateral equivalents: The «Movelier Beds» and «Spatkalk» correspond to the uppermost part of the Klingnau Formation including «Knorri Clays».

Names previously in use: «Movelier-Schichten»; for cross denominations see above.

21.4.4.3. Additional information

Origin of name: Sparitic nature of the rock and municipality of type locality.

Type locality and type region: The Cheisacher section (coord. 2650.600/1264.000) near Sulz AG has been proposed as the type locality of «Spatkalk» by Gonzalez (1993). Older informal descriptions of «Movelier Beds» refer to the road to Movelier (coord. 2590.500/1250.300) at Soyhières JU.

Reference section: A reference locality for «Spatkalk» is the Flüeli quarry (coord. 2646.425/1252.910) at Schellenbrücke/Asperchlus near Küttigen AG. Gonzalez (1993) proposes LA Haute Joux JU (coord. 2593.250/1250.400) near Movelier as a reference section for the «Movelier Beds»

Chronostratigraphic age: Bathonian, Zigzag and, possibly, Aurigerus Zone.

Genetic and paleogeographic interpretation: In Early Bathonian time, the former Hauptrogenstein platform had obviously fallen dry (sedimentation gap). At its border, sparitic limestone, mainly consisting of echinoderm remains, was deposited, marking the shallow water domain. As it is interfingered with the «Knorri Clays» of the Klingnau Formation, a continuation of sedimentation until the early Middle Bathonian is suggested (Gonzalez & Wetzel 1996).

22. Variansmergel Formation, Wutach Formation and Ifenthal Formation

22.1. General and main characteristics

The Ifenthal Formation was recently established by Bitterli-Dreher (2012) to describe the situation in the Folded and Tabular Jura west of the zone of maximum condensation ("Sissach rise") including JO siting region (Appendix F). In the area under investigation, the three formations represent a thin, partly highly condensed interval of mainly Late Bathonian, and, true for Ifenthal-Formation only, Early Oxfordian age.

The Variansmergel Formation (Genser 1966) and the Wutach Formation (Bloos et al. 2006) are formal units of the German Stratigraphic Scheme based on the situation found in the Wutach area and northeast of it. Bläsi et al. (2013) have adopted these German formations to describe the sediments found in deep boreholes east of the Sissach rise. The arguments have been some differences in facies and the fact that the formal definition of the Ifenthal-Formation by Bitterli-Dreher (2012) does not explicitly include the area in question. In fact, Bitterli-Dreher (2012) lines out the similarity of the sedimentary succession on both sides of the rise but refers to the old and newly created names to describe the situation in the deep boreholes and in the canton of Schaffhausen and proposes to discuss the relations later. A good opportunity to do that will be when the data of the current campaign will be available. Until then, the formal German formations will be used to describe the situation in NL and ZNO region.

However, as there are many similarities between the corresponding Swiss and German formations, members and beds and, at the same time, subtle differences, it is useful to describe them together. This is done simply, as the Ifenthal Formation is defined by its members (Bitterli-Dreher 2012). The description starts with the definition of the Ifenthal Formation as it encompasses the timespan of deposition of the German Variansmergel, Wutach and Ornatenton Formations (Appendix F).

22.2. Definition of Ifenthal Formation

Occurrence: Condensed to highly condensed sediments representing mainly the Late Bathonian to Early Oxfordian are expected to be found at any place with the three siting regions.

Lithology, subdivision and thickness: Within the area under investigation, the three formations (Ifenthal, Variansmergel and Wutach) are represented, in their distal facies (i.e. west or east of maximum condensation), by an alternation of often fossiliferous and limonitic marl and bedded or lenticular, often argillaceous limestone followed by predominantly, often fossiliferous, iron-oolitic limestone and iron-oolites with, regionally, some glauconitic sandy marl interlayers.

For the Tabular and eastern Folded Jura, Bitterli-Dreher (2012) has established a detailed stratigraphy of the Ifenthal Formation including 5 members and 3 beds (Table 1). One of them, the Saulcy member wedges out before reaching the area under investigation.

Table 1 Subdivision and thickness of Swiss Ifenthal Formation, and German Variansmergel and Wutach Formation in outcrops and boreholes.

Schlatt. = Schlattingen-1. Values from of Bitterli-Dreher (2012), Diebold et al. (2006), Matter et al. (1987), Mater et al. (1988), Nagra (2001), Albert et al. (2012) and Bläsi et al. (2013).

<table>
<tr><th colspan="2">Formal Swiss Stratigraphic Scheme</th><th>JO *)
cm</th><th>Riniken
cm</th><th>Weiach
cm</th><th>Benken
cm</th><th>Schlatt.
cm</th><th>Formal German Strat. Scheme</th></tr>
<tr><td rowspan="8">Ifenthal Formation</td><td>Schellenbrücke Bed</td><td>f - 25</td><td>450</td><td>20 °)</td><td>75 °)</td><td>40 °)</td><td>(part of Ornatenton Fm.)</td></tr>
<tr><td>Herznach Mb.</td><td>f – 340</td><td rowspan="6"></td><td>164</td><td>50</td><td>315</td><td>Wutach Fm.</td></tr>
<tr><td>Unter-Erli Bed</td><td>0 - f</td><td rowspan="5">326</td><td rowspan="5">268</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>Ängistein Mb.</td><td>f - 150</td></tr>
<tr><td>Bözen Mb.</td><td>f - 300</td></tr>
<tr><td>Saulcy Mb</td><td>n.e.</td></tr>
<tr><td>Anwil Bed</td><td>f - 30</td></tr>
<tr><td>Schelmenloch Mb.</td><td>f - 500</td><td>500</td><td>454</td><td>1257</td><td>710</td><td>Varians-mergel Fm.</td></tr>
</table>

*): known minima and maxima from outcrops and boreholes in JO siting region and adjacent area; °): «Glaukonitsandmergel» including «Mumienmergel» and «Mumienkalk» (see Section 22.4.7 and 23.4.1); f = few; n.e. = not existent.

In the (at this level) destructively performed boreholes of Riniken (Matter et al. 1987) and Schlattingen (Albert et al. 2012) it was only possible to roughly distinguish a lower unit (then «Varians-Schichten») from the rest («Anceps-Athleta - and Macrocephalus-Schichten»). At Weiach and Benken, in the original records (Mater et al. 1988 and Nagra 2001), four units have been distinguished (from bottom): «Varians-Schichten», « (Aspidoides-) Macrocephalus-Oolith», «Anceps-Athleta-Schichten» or «Anceps-Oolith/Grenzkalk» and, finally, «Glaukonit-Sandmergel».

Later, Bläsi et al. (2013) proposed to identify the «Varians-Schichten» of Weiach, Benken and Schlattingen borehole and of the Schaffhausen region with the German Variansmergel Formation (Genser 1966) of adjacent southern Germany (Franz & Rohn 2004). Bläsi et al. (2013) states, that there is no significant difference between «Varians-Schichten» in the eastern Folded and Tabular Jura and in Schaffhausen and adjacent areas (Appendix F). The only argument, to extend the German stratigraphic unit to northeastern Switzerland is that the Ifenthal Formation is not defined in the area in question ("Die Fazies der Variansmergel ist im gesamten Jura verbreitet, westlich der Linie Lägern-Acheberg ist sie nun Teil der Ifenthal-Formation.", Bläsi et al. 2013).

Furthermore, Bläsi et al. (2013) suggest the extension of the German Wutach Formation (Bloos et al. 2006, Dietel 2010) to the same region in northeastern Switzerland. This formation summarizes the mostly highly condensed, iron-oolitic sediments between Variansmergel Formation and Ornatenton Formation which corresponds to the highly condensed Swiss Schellenbrücke Bed of Ifenthal Formation (Section 22.4.6).

For the reasons already outlined above, the formal German Variansmergel and Wutach Formation will be provisionally maintained for describing the new boreholes in NL and ZNO siting regions.

Upper boundary: Top of highly condensed and reworked Schellenbrücke Bed in the west or of glauconitic and sandy «Glaukonitsandmergel» in the middle and eastern parts.

Lower boundary: In the JO and parts of NL regions, the lower boundary is marked by the onset of characteristic often fossiliferous and limonitic shale limestone alternation or iron-oolite above a hardground atop the mostly sparitic «Spatkalk» or marly «Parkinsoni-Württembergica-Schichten». In the ZNO region, the transition from the «Parkinsoni-Württembergica-Schichten» is more gradual. The limit is a significant increase in fossil abundance (Bläsi et al. 2013).

Lateral equivalents: The Ifenthal Formation corresponds to the formal German Variansmergel Formation (Genser 1966), Wutach Formation (Bloos et al. 2006, Dietel 2010) and Ornatenton Formation (Quenstedt 1846), see Appendix F.

Names previously in use: «Oberer Dogger», «Callovien», «Cordatum- bis Varians-Schichten»

22.3. Additional information

Origin of name: Village close to type sections of the members of the Ifenthal Formation.

Type locality and type region: Type locality for the Ifenthal Formation is the region S and SE of Ifenthal SO, type sections are assigned to the members. Type region is the eastern Folded Jura.

Reference section: There are no reference sections.

Chronostratigraphic age: Middle Bathonian to Oxfordian (Cordatum Zone).

Genetic and paleogeographic interpretation: The Ifenthal, Variansmergel and Wutach Formations document a time of reduced terrigenous input which decreases during the two megacycles. In the areas under investigation, starving sedimentation, represented by hardgrounds and iron oolites, is particularly characteristic of its position on the Sissach rise.

22.4. Details on Variansmergel Formation, Wutach Formation, «Glaukonitsandmergel» and Members of the Ifenthal Formation

22.4.1. Schelmenloch Member and Variansmergel Formation

22.4.1.1. General and main characteristics

The Schelmenloch Member of the Ifenthal Formation (Bitterli-Dreher 2012) and the Variansmergel Formation represent what was previously called «Varians-Schichten». There is no significant difference in facies between the two (Bläsi et al. 2013), thus they can be described together.

22.4.1.2. Definition

Occurrence: The former «Varians-Schichten» are found in all three siting regions. The term Schelmenloch Member is valid in JO region, the term Variansmergel Formation temporarily in NL and ZNO region (Appendix F).

Lithology: In western JO region and in the ZNO region, the succession is characterized by an alternation of silty to sandy, often fossiliferous and limonitic marl and limestone. Among the fossils, the brachiopod *Rhynchonelloidella alemannica* may be locally abundant, which is with its former name *Rhynchionella varians*, eponymous for the (former) name of the succession.

In the culmination of the Sissach rise, i.e. in the eastern parts of JO region and in the NL region, the typical sediments may be (partly) replaced by iron-oolite. In the Weiach borehole (Matter, the thickness of the some 4.5 m thick «Varians-Schichten» shows facies affinities to the underlying «Parkinsoni-Württembergica-Schichten» (Section 19) and the «Spatkalk» (Section 21.4.4) (Matter et al. 1988).

Thickness: The thickness in the uncondensed domain in the west may go up to some 5 m, in the east up to some 12.5 m. In the condensed domain it may be locally reduced to dome decimetres.

Upper boundary: In the domain of typical «Varians-Schichten» facies, the upper boundary is given by the base of the fossiliferous iron-oolite of Anwil Bed in the west and of the Orbisoolith of Wutach Formation in the east (for details, see Section 22.4.2). In the domain of maximum condensation, drawing the boundary is more sophisticated, as the Schelmenloch Member or Variansmergel Formation, too, are replaced by iron oolites. «Ifenthal Formation, undifferentiated» will here be the best solution.

Lower boundary: The lower boundary is, identically to the Ifenthal Formation (see Section 22.4.1.2).

Lateral equivalents: There is no lateral equivalent at reasonable distance.

Names previously in use: «Varians-Schichten»

22.4.1.3. Additional information

Origin of name: The formal member is named after the Schelmenloch ravine south of Reigoldswil BL.

The Variansmergel Formation and the former «Varians-Schichten» named after the brachiopod *Rhynchonelloidella alemannica* which used to be called *Rhynchionella varians*.

Type locality and type region: The Schelmenloch section south of Reigoldswil BL represents the basin facies. Of more importance are here type locality representing the swell facies. It is found south and south-east of Ifenthal SO and consists of two partial sections: Graben north of Oberwald (coord. 2631.650/1246.800) and east of Ängistein (coord. 2630.950, 1246.390). The Type locality of the German Variansmergel Formation is found at the western end of Buchberg near Blumberg (Litholex consulted 10.12.2019).

Reference section: Bitterli-Dreher (2012) denotes the Asperchlus (coord. 2646.440/1252.890) as a reference section.

Chronostratigraphic age: Bathonian to Callovian, Zigzag or Subcontractus to Herveyi or Koenigi Zone.

Genetic and paleogeographic interpretation: The Schelmenloch Member and the «Variansmergel Formation» in typical «Varians-Schichten» facies in the west and the east result from reworking and starved sedimentation on a swell above the storm wave base. The increasing condensation which goes along with increase of iron-oolite is the result of starved sedimentation in the domain of Sissach rise.

22.4.2. Wutach Formation

22.4.2.1. General and main characteristics

Bläsi et al. (2013) have proposed to introduce the formal German Wutach Formation (Dietl 2010) to summarize the sediments between Variansmergel Formation (Section 22.4.1) and Wildegg Formation (Section 1) replacing the terms «Anceps-Athleta - and Macrocephalus-Schichten» and «Glaukonit-Sandmergel» (Schlattingen-1), «Macrocephalus-Oolith», «Anceps-Oolith/Grenzkalk» and «Glaukonit-Sandmergel» (Benken) or «Aspidoides-Macrocephalus-Oolith», «Anceps-Athleta-Schichten» and «Glaukonit-Sandmergel» (Weiach) (Albert et al. 2012, Nagra 2001, Matter 1988). However, in the new revised stratigraphy of Schlattingen, Benken and Weiach by Bläsi et al. (2013) the «Glaukonit-Sandmergel» was not included into the Wutach Formation.

The «Glaukonitsandmergel», characterized by Zeiss (1955), is also not part of the formal Wutach Formation (Dietl 2010) but of the Ornatenton Formation (Quenstedt 1846; Litholex consulted 19.11.2019). It was decided to maintain the term Wutach Formation for the NL and ZNO siting regions but to reduce it to the extent of the formal German definition. The Wutach Formation corresponds in its stratigraphic range and in its facies the (condensed) swell facies (Bitterli-Dreher 2012) of the Ifenthal Formation without Schelmenloch Member and without Schellenbrücke Bed (Figure 13, Table 1 and Appendix F).

22.4.2.2. Definition

Occurrence: The formal German Wutach Formation is used for describing the findings in the ZNO and NL regions (see above).

Lithology and subdivision: The Wutach Formation comprises a succession of highly condensed sediments, predominately iron-oolite layers, often fossiliferous, and some slightly iron-oolitic or even iron-oolite free limestone and marl interlayers (Dietl 2010). It is divided by three beds (from bottom, see Figure 13):

- Orbisoolith (which corresponds to what is called (erroneously) «Aspidoides-Oolith» by Hahn 1971, cited in Hofmann et al. 2000, c.f. «Aspidoides-Macrocephalus-Oolith» of Matter et al. 1986)
- Macrocephalenoolith («Macrocephalus-Oolith»)
- Ancepsoolith («Anceps-Athleta-Schichten»)

It is recommended to use the traditional Swiss terms (in brackets) where a subdivision of Wutach Formation is possible to facilitate correlation with previous recordings.

Deviating subdivisions of the thin interval are proposed, for example, by Dietl (2010) again from bottom to top:

- Orbisoolith
- «Rotes Erzlager»
- «Graublaues Erzlager»
- «Violettes Erzlager»
- «Grenzkalk»

This concept is contradicted by Hofmann et al. (2000) who report from a digging performed by Schalch in 1915 a succession of ore colour, from bottom to top, from brownish-red (to be identified as Orbisoolith) to dark grey, to brown, to intense red, and, finally to dark grey. The ore section is followed by dark «Übergangsschichten» (which correspond to the «Grenzkalk»), a dark grey limestone bed with small yellowish-brown iron ooids.

Thickness: Thickness in the existing deep boreholes varies between 3.5 and 5.1 m.

Upper boundary: The upper boundary is at the base of the mostly thin «Glaukonitsandmergel» or equivalents of Birmenstorf Member of Wildegg Formation (see Section 23.4.1).

Lower boundary: In the domain of typical «Varians-Schichten» facies of underlaying Variansmergel Formation, the lower boundary is given by the base of the first fossiliferous iron-oolite (see Section 22.4.1.2). In the domain of maximum condensation, i.e. in parts of NL and ZNO region, drawing the boundary is more sophisticated, as the Variansmergel Formation may be replaced partly or fully by iron-oolite. If the total interval between «Spatkalk» or «Parkinsoni-Württemberica-Schichten» and Wildegg Formation is an iron-oolite, it is recommended to use the term «Ifenthal Formation, undifferentiated» (what corresponds to "«Variansmergel Formation» and «Wutach Formation», undifferentiated").

Lateral equivalents: The lateral equivalents are, to the west, the Ifenthal Formation without Schelmenloch Member, and, to the east, the formal Wutach Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011; Appendix F).

Names previously in use: For the description of the corresponding interval in the existing deep boreholes the terms «Anceps-Athleta- and Macrocephalus-Schichten», «Aspidoides-Macrocephalus-Oolith», «Macrocephalus-Oolith», «Anceps-Athleta-Schichten», «Anceps-Oolith/Grenzkalk» and «Glaukonit-Sandmergel» have been used. In adjacent Germany «Dogger-Erz» and «rotes, graublaues and violettes Erzlager» corresponds to actual Wutach-Formation.

22.4.2.3. Additional information

Origin of name: For the formal German Wutach Formation, the creek at the foot of Eichberg where the type locality is found.

Type locality and type region: Type locality of the Wutach Formation is the Eichberg north of Blumberg D.

Type region is the Wutach Valley.

Reference section: There is no formal reference section. The cored sections of Weiach and Benken boreholes may serve as informal reference.

Chronostratigraphic age: Late Bathonian to Early Oxfordian, Hodsoni to Cordatum Zone.

Genetic and paleogeographic interpretation: The Wutach Formation a long time of starved sedimentation, submarine erosion and re-sedimentation in the domain of the Sissach rise.

22.4.3. Anwil Bed and condensed equivalents of Bözen and Ängistein Members

22.4.3.1. General and main characteristics

The Anwil Bed has been defined by Bitterli-Dreher (2012) to describe a highly condensed, fossiliferous iron-oolite sequence at the top of the Schelmenloch Member. It corresponds to the «Macrocephalus-Oolith» of some authors (historically, terms with «Macrocephalus» or «Macrocephalen» have been applied to very different levels and actual members of the today Ifenthal Formation, Bitterli-Dreher 2012).

Towards east, the highly condensed sediments replacing successively the hanging Bözen Member (Section 22.4.4) and Ängistein Member (Section 22.4.5) are amalgamated with the Anwil Bed to form an iron-oolite succession that can be only unravelled by sophisticated analysis of fossil record (Appendix F). It is the «Aspidoides-Macrocephalus-Oolith» in the original core description of Weiach (Matter et. al. 1988) and corresponds, thus, to the lower part of the Wutach Formation (Section 22.4.2).

22.4.3.2. Definition

Occurrence: In the western part of JO siting region, the Anwil Bed probably will be encountered as an isolated bed. To the east of the siting region, amalgamation with hanging condensed layers becomes common.

Lithology: In the area of investigation, the Anwil Bed and the condensed equivalents of the Bözen and Ängistein Members consists mainly of, often fossiliferous, iron-oolite beds, separated by thin marl beds, and, subordinately, partly sparitic limestone with less iron-ooids.

Thickness: Few decimetres to about 3.5 m.

Upper boundary: In the case the Anwil Bed proper is followed by the Bözen Member, the upper boundary is given by the offset of iron-oolite. At places, where the equivalents of Bözen and Ängistein Members are overlain by Herznach Member (Section 22.4.6), drawing the boundary is more sophisticated. Finding the true limit requires careful study of the fossil record.

Lower boundary: The lower boundary is given by the onset of iron-oolite above Schelmenloch Member.

Lateral equivalents: The lateral equivalent of the Anwil Bed is the «Orbisoolith» (Section 22.4.2.1). The amalgamated succession including the equivalents of Bözen and Ängistein Member correspond to what was named, for instance, «Aspidoides-Macrocephalus-Oolith» when recording the existing deep boreholes (Matter et al. 1988).

Names previously in use: « Macrocephalus-Oolith», «Aspidoides-Macrocephalus-Oolith» etc.

22.4.3.3. Additional information

Origin of name: Municipality of type section.

Type locality and type region: Type locality of Anwil Bed is the no more accessible scientific excavation SSW of Anwil BL. Type region is the adjacent Tabular and Folded Jura.

Reference section: Bitterli-Dreher (2012) denotes a section along the access road to Wartenfels castle (coord. 637.400/1248.940) north of Lostorf SO as reference section for Anwil Bed.

A good reference for the amalgamated sequence is the Weiach section from bore depth 479.85 to 483.11 m (Matter et al. 1988), even it is not in the actual range of validity of Ifenthal Formation.

Chronostratigraphic age: Bathonian to Callovian, Discus to Herveyi, and including the amalgamated equivalents of Bözen and Ängistein Member, up to Gracilis or Callovensis Zone.

Genetic and paleogeographic interpretation: The succession documents a time of starved sedimentation, submarine erosion and re-sedimentation in the domain of the Sissach rise.

22.4.4. Bözen Member

22.4.4.1. General and main characteristics

The Saulcy Member (Bitterli-Dreher 2012) and the Bözen Member represents what were «Callovienton» or the marly part of the «Macrocephalenschichten». From the west, still outside the area under investigation, the underlying claystone of Saulcy Member wedges out, then, within the JO sting area, the Bözen Member. Both are replaced by iron-oolite layer (Appendix F).

22.4.4.2. Definition

Occurrence: While the uncondensed Saulcy Member will be missing in the entire JO siting region, it is expected that the uncondensed Bözen Member will be encountered in most of the JO boreholes.

Lithology: In the area under investigation, the Bözen Member is a marly interval with nodular limestone.

Thickness: Thickness varies between some 12.5 m at the western limit of JO siting region and some few decimetres. At the eastern limit, it is expected to be replaced by iron-oolite.

Upper boundary: The boundary towards the Ängistein Member is marked by the onset of sparitic limestone. Where Ängistein Member is missing or replaced by condensed sediments, the upper boundary of uncondensed Bözen Member is marked by an iron-oolite.

Lower boundary: The lower boundary is given by the onset of marly sediments atop the iron-oolitic Anwil Bed.

Lateral equivalents: Towards east, the marly Bözen Member is wedging out and is replaced by thin condensed, iron-oolite beds which here are considered as a part of the Anwil Bed and condensed equivalents of Bözen and Ängistein Members (Section 22.4.3, Appendix F).

Names previously in use: Upper, marly, part of «Macrocephalenschichten» or «Callovienton».

22.4.4.3. Additional information

Origin of name: Locality of a municipality close to the type section.

Type locality and type region: Type locality is the Wolftalhof or Wolftel (coord. 2648.150/1262.290) near Hornussen AG. Type region is the Eastern Tabular Jura.

Reference section: The Hübstel borehole is designed as reference section. Its core is stored in the Herznach Museum (Bitterli-Dreher 2012).

Chronostratigraphic age: Callovian, Calloviense and/or Koenigi Zone.

Genetic and paleogeographic interpretation: The Bözen Member represents a timespan of increased terrigenous input.

22.4.5. Ängistein Member and Unter-Erli Bed

22.4.5.1. General and main characteristics

The Ängistein Member proper represents what were «Kornbergsandstein» or «Äquivalente der Dalle Nacrée» (Bitterli-Dreher 2012).

22.4.5.2. Definition

Occurrence: The Ängistein Member proper wedges out towards the Sissach rise and is replaced by an iron oolite. Thus, last relicts of typical (uncondensed) Ängistein Member may only be expected in the western part of JO siting region.

Lithology: The Ängistein Member is a sparitic limestone formed from fine-grained echinoderm detritus. The Unter Erli Bed is a marker bed at the top of the member characterised by shell relicts giving red cavities when weathered at the surface.

Thickness: At the western limit of JO siting region, a thickness of about 2 m is expected. Towards east, the Ängistein member wedges out and is replaced by thin iron-oolite bed which here are considered as a part of the Anwil Bed and condensed equivalents of Bözen and Ängistein Members (Section 22.4.3).

Upper boundary: Most probably, the Ängistein Member is overlain by the Herznach Member. Then the upper boundary is given by the onset of iron-oolite. In some few cases, a nearly direct overlaying by Wildegg Formation is reported, i.e. the Herznach Member is reduced to some few centimetres if at all (Diebold et al. 2006). Then, the offset of sparitic limestone alone gives the argument.

Lower boundary: The lower boundary towards the Bözen Member is given by the onset of sparitic limestone.

Lateral equivalents: Within the JO siting region, the Ängistein Member shows a transition to condensed (iron-oolite) equivalents (Appendix F) which are grouped here, together with the Anwil bed, to an own stratigraphic unit (Section 22.4.3).

Names previously in use: «Kornbergsandstein» and «Äquivalente der Dalle Nacrée» for Ängistein Member proper, «Lumachellenbank» or «Spatkalkbank» for Unter Erli Bed. Bitterli-Dreher (2012) stresses that both latter names are unfounded as the Unter Erli Bed is neither a real coquina nor more sparitic than the underlying strata.

22.4.5.3. Additional information

Origin of name: Localities of type sections.

Type locality and type region: Four sections south and south-west of Ifenthal (coord. 2631.600 - 2631.750/1246.750 - 1246.800, 2630.850/1246.270, 2631.930/1246.800, 2630.990/246.220) give the type locality (Bitterli-Dreher 2012).

Reference section: Several localities are proposed as reference sections (see Bitterli-Dreher 2012)

Chronostratigraphic age: Callovian, Callovensis to Jason Zone.

Genetic and paleogeographic interpretation: The Ängistein Member represents the distal tongue of a widespread submarine dune setting in the west (Bollement Member, Hostettler 2012).

22.4.6. Herznach Member and Schellenbrücke Bed

22.4.6.1. General and main characteristics

The Herznach Member (Bitterli-Dreher 2012) corresponds to the Herznach Formation of Gygi (2000b). It includes what was «Cordatum-Mariae-Schichten», «Lamberti-Cordatum-Schichten», «Anceps-Athleta-Schichten», etc. It encompasses the main body of middle to late Callovian age, and the thin Schellenbrücke Bed (Gygi 1977) which was deposited atop in Oxfordian Cordatum zone proving an important hiatus (Figure 13).

22.4.6.2. Definition

Occurrence: The Herznach Member is probably found throughout the JO siting region. But it is not completely out of the question that it is lacking at some places.

Lithology: The Herznach Member consists predominantly of, often very fossiliferous, iron-oolite or limestone rich in iron-ooids, and, subordinately, marl layers from Middle and Late Callovian and Early Oxfordian age which are, in some places, very fossiliferous (especially ammonites). The Schellenbrücke Bed forms the thin top of the sequence. It is characterized by a complex hardground geometry between different iron-oolitic limestone and iron-oolite beds (Gygi 1981).

Thickness: Thickness may vary from some few centimetres up to 3.5 m, possibly even more (5 m at type locality, outside JO region). For Schellenbrücke Bed, thickness up to 20 cm is known.

Upper boundary: The upper boundary to Birmenstorf Member (Section 23.4.1) is given by the offset of iron ooids and distinctive change in rock colour from (reddish) brown to light grey.

Lower boundary: In the west of JO siting region, the lower boundary is defined with the offset of sparitic limestone of Ängistein Member and the onset of iron-oolite. At places, where the Herznach Member overlays the condensed equivalents of Bözen and Ängistein Members (Section 22.4.3), drawing the boundary is more sophisticated. Finding the true limit requires careful study of the fossil record.

Lateral equivalents: To the east, the main body corresponds to the upper part of the Wutach Formation (Section 22.4.2), and the Schellenbrücke Bed to the «Glaukonitsandmergel» of German Ornatenton Formation (Gygi 2000a) (Section 22.4.7 and Appendix F).

Names previously in use: «Cordatum-Mariae-Schichten», «Lamberti-Cordatum-Schichten», «Anceps-Athleta-Schichten», etc.

22.4.6.3. Additional information

Origin of name: The Member takes its name from the abandoned iron mine of Herznach. The Schellenbrücke Bed is named after a former bridge located at today's Asperchlus locality (Gygi 1977).

Type locality and type region: According to Gygi (2000b), the type locality of the Herznach Member is the abandoned iron mine of Herznach (coord. 2645.325/1258.350), now open to visitors. The mine's museum exhibits the Hübstel borehole (coord. 2645.289/12509.031) core displaying the base of the member.

Reference section: The Asperchlus section (coord. 2646.450/1252.880) along the actual main road is a reference for both, the whole Herznach Member and the Schellenbrücke Bed. Since recent road work, its accessibility is restricted.

Chronostratigraphic age: Callovian, Anceps to Lamberti Zone and Oxfordian, Cordatum Zone; the Mariae Zone is probably missing (hiatus). Gygi (2000a) indicates latest Early Callovian for oldest elements of Herznach Formation. Thus, they are, possible due to reworking, older than the Unter Erli Bed, where Bitterli-Dreher (2012) indicates Middle Callovian.

Genetic and paleogeographic interpretation: The Herznach Member documents the maximum of starving sedimentation in the Late Callovian. Missing fossil records point to a long time without sedimentation (Mariae Zone) before the onset of reworking in the Cordatum Zone. The lateral transition from the Schellenbrücke Bed to the «Glaukonitsandmergel» of informal and formal Wutach Formation documents an increase in water depth on the eastern boundary of the Sissach rise.

22.4.7. «Glaukonitsandmergel»

22.4.7.1. General and main characteristics

In NL and ZNO siting area a thin interval of characteristic sediments is expected to overlay the Wutach Formation. It was addressed «Glaukonit-Sandmergel» when recording the Benken and Weiach borehole sections (Nagra 2001, Matter et al. 1988).

The term «Glaukonitsandmergel» was established by Zeiss (1955) in the Wutach area and is now an informal subformation of the formal Ornatenton Formation (Quenstedt 1843) within the German Stratigraphic Scheme. It corresponds to the «Glaukonitischer Tonmergel or (Grenzglaukonit)» of Hofmann et al. (2000) and consists of grey claystone to marl with mica and quartz sand and, in the lower part some, in the upper part, much glauconite. Following this definition, it does not fully cover what was named «Glaukonit-Sandmergel» in the Benken and Weiach borehole sections. There also overlaying thin oncolitic sediments where included which corresponds to the «Mumienmergel Bed» and «Mumienkalk Bed» of Gygi (1977) and the «Glaukonitischer Mergelkalk (or Birmenstorf Schichten)» of Hofmann et al. (2000).

To avoid further confusions, it was decided to adopt the name «Glaukonitsandmergel» with its actual definition in in the German Stratigraphic Scheme (LithoLex consulted 20.11.2019) for the actual campaign. The mostly very thin overlaying glauconitic and oncolitic marl and limestone will be integrated into the Wildegg Formation as proposed by Gygi (2000a). For more details, see Section 23.4.1.

22.4.7.2. Definition

Occurrence: The «Glaukonitsandmergel» is found in the Wutach area and adjacent Swiss territory including the NL and ZNO siting regions

Lithology: The «Glaukonitsandmergel» comprise dark grey green shimmering, claystone with mica and quartz silt to fine sand and glauconite, dominant in the upper part (up to 15% in Benken borehole, Nagra 2001). In some levels it may contain iron ooids (Matter et al. 1988).

Thickness: The integral thickness rarely exceeds some few decimetres. A maximum of about 70 cm is reported from Benken bore hole (Nagra 2001) for the total of «Glaukonitsandmergel», «Mumienmergel» and «Mumienkalk».

Upper boundary: Where the «Mumienmergel» and/or «Mumienkalk» are present, the boundary can be drawn at an omission horizon below the first occurrence of oncoids, or below the first limestone, where Birmenstorf Member is present. In cases by direct overlay by Effingen Member, drawing a boundary may be more sophisticated, but it is supposed that a kind of omission surface must be detectable in any cases.

Lower boundary: The lower boundary is characterized by decrease the iron ooid content and the increase of detritic sand and glauconite. In some places, the boundary is clearly erosive. Where the «Glaukonitsandmergel» is missing, encrusted clasts of the underlaying strata may found in the «Mumienmergel» above an erosive horizon.

Lateral equivalents: According to Gygi (2000a), the «Glaukonitsandmergel» corresponds in age to the Schellenbrücke Bed. Details on transition and limiting are still pending.

Names previously in use: «Glaukonit-Sandmergel», «Glaukonitischer Tonmergel», «Grenzglaukonit».

22.4.7.3. Additional information

Origin of name: The names are derived from its mineral composition.

Type locality and type region: Gygi (2000a) identified the section RG 87 (Gygi 1977, Swiss coord. 2680.230/1300.430 to 2680.300/1300.460) at the eastern end of Eichberg as the type locality of Zeiss (1955.

Type locality is the Wutach area.

Reference section: there is no reference section.

Chronostratigraphic age: Cordatum Zone (to the east, outside the area of investigation, Mariae to Cordatum Zone). (In the text and in Table 4, Hofmann et al. (2000) give, correctly, an Early Oxfordian age for the «Glaukonitischer Tonmergel», and, in Figure 9, erroneously, a Late Callovian age.)

Genetic and paleogeographic interpretation: Starving sedimentation but less submarine erosion than Schellenbrücke Bed (and less biogenic production) points to relatively deeper water.

23. Wildegg Formation

23.1. General and main characteristics

The Wildegg Formation has been formally defined by Gygi (1969) unifying the «Birmenstorfer-schichten», «Effingerschichten» and «Geissbergschichten» of Moesch (1863, 1857, and 1867, respectively), now Birmenstorf, Effingen and Geissberg Members. The Geissberg Member was later transferred to the Villigen Formation (Gygi 2000a).

The integration of «Mumienkalk Bed» and «Mumienmergel Bed» of Gygi (1977) which correspond to the «Glaukonitischer Mergelkalk (or Birmenstorf Schichten») of Hofmann et al. (2000) into the Wildegg Formation was proposed by Gygi (2000a). The recognition by the Swiss Committee on Stratigraphy is still pending for formal reasons, since the names do not comply with the nomenclature rules. In the German Stratigraphic Scheme, these oncolitic-stromatolitic beds are part of the formal Birmenstorf Subformation (Litholex, consulted 22.11.2019). As the two beds are probably found throughout ZNO and important parts of NL siting regions, they are integrated as informal units into the Birmenstorf Member.

In its type region, which includes the JO region, the Wildegg Formation is a thick succession of monotonous grey, somewhat sandy, calcareous marl with mostly marly limestone intercalations, with the most prominent being the basal Birmenstorf Member and the Gerstenhübel Bed in the middle or lower third of the formation. To the east, in the NL and ZNO regions, the thickness decreases dramatically without significant changes in facies of the main body. The base however, the Birmenstorf Member is represented by the oncolitic-stromatolitic «Mumienkalk» and «Mumienmergel».

23.2. Definition

Occurrence: The Wildegg Formation is found in all three regions JO, NL, and ZNO; however, in the latter two with strongly decreasing thicknesses towards the east (Figure 15).

Lithology and subdivision: The dominant lithology of the Wildegg Formation is grey calcareous marl, which is interlayered with mostly argillaceous, at the base glauconitic, micritic limestone beds. Individual limestone beds are mostly bundled in 3 – 12 m thick successions which are surrounded by calcareous marl successions (Deplazes et al. 2013). However, the thickest limestone succession, the Gerstenhübel Bed, can reach thicknesses of over 30 m. Fossil records include ammonites and siliceous sponges in various abundance.

The Wildegg Formation is subdivided into the thin, often very fossiliferous and partly condensed Birmenstorf Member at the base, and the thick to very thick Effingen Member.

Thickness: Thickness varies between up to 265 m in the JO region (Gygi 2000) and down to 14 m in the north-east beyond the ZNO region (Deplazes et al. 2013).

Upper boundary: The upper boundary to the Geissberg and Hornbuck Members of the Villigen Formation is gradual: a decrease in clay mineral content and an increase of carbonate content, increasing thickness of limestone beds, change in rock colour from middle to yellowish grey, increase in fossil content, re-occurrence of sponges (Hornbuck Member) which become very rare above the middle of the formation (Gygi 2000a). The proposal to set the limit at the boundary between sequence Ox6 and Ox7 (Wetzel & Strasser 2001) is academic rather than practical.

The upper boundary must be set occasionally regarding the overall transition.

Lower boundary: In the JO siting region, the lower limit corresponds to the top of the characteristic Schellenbrücke Bed hardground and is striking due to an obvious change in rock colour, the onset of abundant sponges, and the offset of iron ooids. However, the up to 10 cm thick, condensed basal horizon of the formation still may contain chamositic iron ooids.

In the NL and ZNO regions, delimitation becomes more sophisticated as there may be a transition between glauconitic marl of «Glaukonitsandmergel» and less but still glauconitic marl of basal Effingen Member. It is easier to fix where «Mumien-mergel» is present. Here it is drawn at the base, often an omission surface, below the lowermost oncolite.

Lateral equivalents: The Wildegg Formation corresponds to the Impressamergel Formation of the German Stratigraphic Scheme without its Hornbuck Member (in Germany: Hornbuck Subformation) (e.g., Geyer et al. 2011).

Names previously in use: Before Gygi (1969), the «Birmenstorfer Schichten» and the «Effinger Schichten» were treated as two independent stratigraphic units. In the Schaffhausen area, Hofmann et al. (2000) denotes the lowest beds as «Glaukonitischer Mergelkalk (or Birmenstorf Schichten)» (see Section 23.4.1).

23.3. Additional information

Origin of name: Municipality of type section.

Type locality and type region: The type locality is the Jakobsberg/Unteregg quarry (coord. 2653.810/1252.790) near Wildegg AG (Gygi 1969) and the type region is the easternmost Folded Jura.

Reference section: The borehole records of Riniken, Weiach and Benken (Matter et al. 1987, Matter et al. 1988, Nagra 2001) may be used as a reference section for the JO, NL, and ZNO regions, respectively.

Chronostratigraphic age: Oxfordian, possibly Plicatilis or Transversarium to early Hypselum Zone.

Genetic and paleogeographic interpretation: The Wildegg Formation documents a period of important terrigenous input. While the Birmenstorf Member marks the transgressive event, the Effingen Member was formed in the distal basin centre (Deplazes et al. 2013).

23.4. Members of the Wildegg Formation

23.4.1. Birmenstorf Member, «Mumienmergel» and «Mumienkalk»

23.4.1.1. General and main characteristics

The «Birmenstorferschichten» were first described by Moesch (1863). Later, they were integrated by Gygi (1969) as a member into the Wildegg Formation.

The informal «Mumienkalk Bed» and «Mumienmergel Bed» of Gygi (1977) replace the "classical" facies of Birmenstorf Member in the Wutach area and adjacent Swiss territory. Here the extension "bed" is omitted to point out the informal status of the terms. According to Gygi (1977 and 2000b) «Mumienkalk» and «Mumienmergel» are independent members of the Wildegg Formation. As there is a lateral (and possibly also a vertical) replacement, they are discussed here together with the Birmenstorf Member.

23.4.1.2. Definition

Occurrence: The Birmenstorf Member is found in its "classical" fossiliferous limestone facies in JO siting region. In large parts of ZNO and NL siting region, it is replaced by the oncolitic-stromatolitic «Mumienkalk» and «Mumienmergel». Albert et al. (2012) and Bläsi et al. (2013) postulate a recurrence of the "classical" facies in the Schlattingen-1 borehole area which may also apply for some parts of ZNO region. In the western part of NL region, a transition from "classical" limestone to oncolitic-stromatolitic may be observed.

Lithology: In its type area, which includes the JO region, the Birmenstorf Member starts with an up to 10 cm thick condensed bed that often contains chamositic iron ooids. The main body forms an up to 5 m thick, grey to greenish-grey, often very fossiliferous, glauconitic, micritic and somewhat marly limestone with marl interlayers. Fossil records comprise abundant ammonites and siliceous sponges. However, the occurrence of siliceous sponges is not distinctive for the Birmenstorf Member. They may also be found in the overlying Effingen Member (Gygi 2000a).

At the proposed type locality of Gygi (1977, c.f. 2000a), the «Mumienkalk» and «Mumienmergel» consist of encrusted fossils (oncoids), mainly ammonites but also sponges and others, and lithoclasts, forming often a compact glauconitic, slightly silty limestone bed in the upper part («Mumienkalk»), but are embedded in a glauconitic, silty "grey marl with a violet tinge" in the lower part «Mumienmergel». Oncoids my reach diameters up to 25 cm. Oncoids with diameters larger than 3-4 cm tend to be flattened. Locally, iron ooids may be found.

Thickness: The thickness decreases from up to 5 m in the JO region to some 0.25 cm in the ZNO region.

Upper boundary: The upper boundary is formally biostratigraphically defined, i.e. the limit between the Transversarium and Bifurcatus Zone (Gygi 2000a, following the initial definition of Oppel & Waagen 1866). More applicable is the traditional practical delimitation drawn at the base of the first massive marl layer of the Effingen Member. In the east, Gygi (2000a) set the top of the Birmenstorf Member at the top of the «Mumienkalk» few centimetre-thick oncolitic limestone.

Lower boundary: The lower boundary is identical to that of the Wildegg Formation (see Section 23.2).

Lateral equivalents: The Birmenstorf Member of the Swiss Stratigraphic Scheme corresponds to the Birmenstorf Subformation of the German Stratigraphic Scheme forming the base of the Impressamergel Formation.

Names previously in use: «Birmenstorfer Schichten», «Glaukonitischer Mergelkalk».

23.4.1.3. Additional information

Origin of name: Municipality of formal type section

Type locality and type region: Type locality for the Birmenstorf Member is the Nettel vineyard (coord. 2661.685/1257.710) north-east of Birmenstorf AG. The outcrop is no longer accessible. The type region is the easternmost Folded Jura.

Gygi (2000a) proposes the section RG 81 (Gygi 1977, Swiss coord. 2680.980/1287.240) at Räckolterenbuck / Gächlingen SH as type locality for «Mumienkalk» and «Mumienmergel». Type region is the Randen area.

Reference section: As the type locality is no longer accessible, Gygi (1969) has proposed the Eisengraben section (coord. 2651.560/1264.080) at the Cheisacher, close to Neumatt north-west of Mönthal AG, as a reference section for the Birmenstorf Member.

Chronostratigraphic age: Oxfordian, possibly Plicatilis and Transversarium Zone.

Genetic and paleogeographic interpretation: The Birmenstorf Member corresponds to the transgressive phase which resulted in the Effingen Member basin.

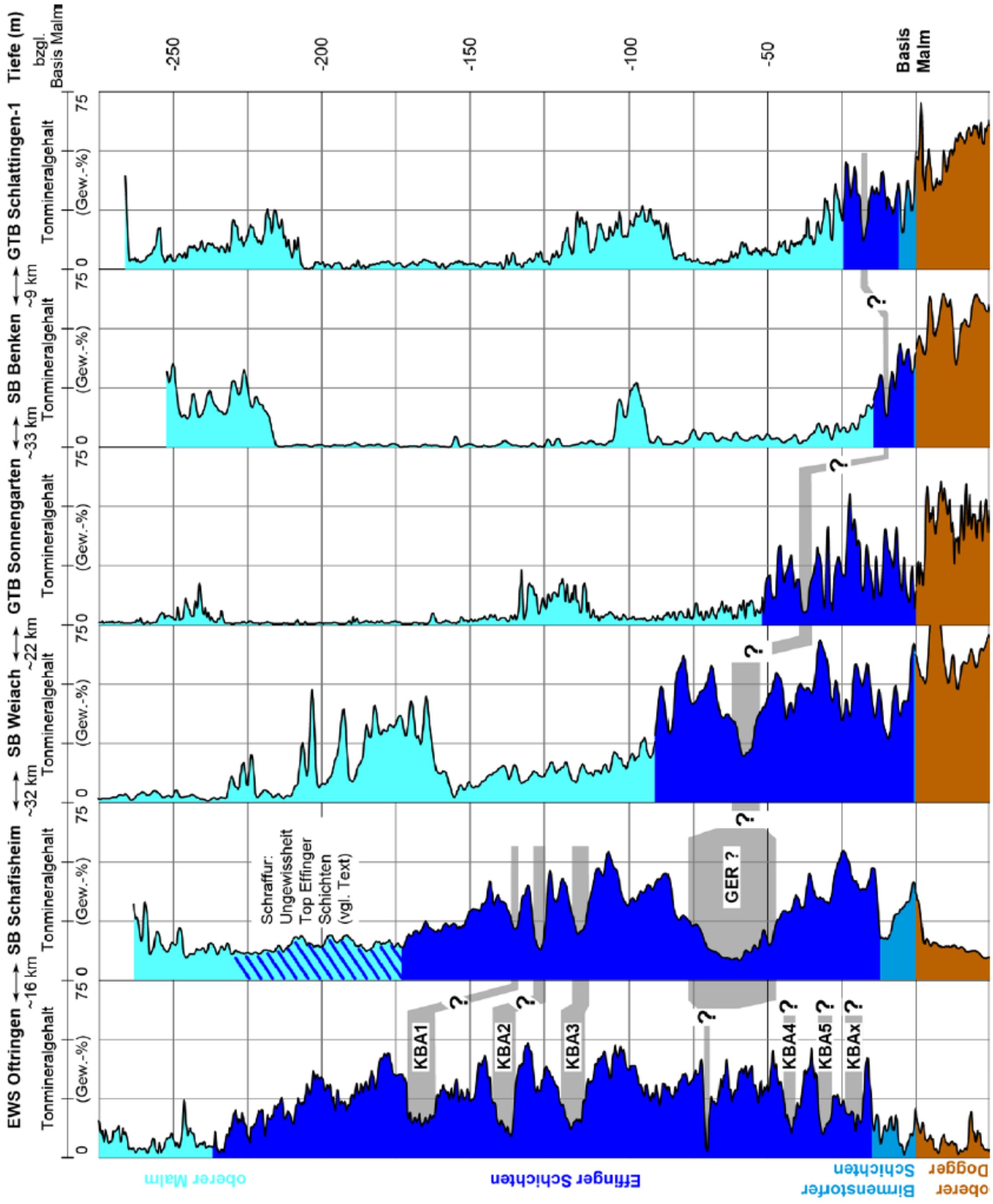


Figure 15: West to east Correlation between borehole sections at the level of Wildegg Formation.

The correlation (out from Deplazes et al. 2013) bases on clay mineral content. Brown: upper Dogger Group, turquois: Birmenstorf Member, dark blue: Effingen Member, light blue: younger Malm Group sediments. The grey bars show possible correlation of limstone bed succesions.

23.4.2. Effingen Member

23.4.2.1. General and main characteristics

The «Effingerschichten» were first described by Moesch (1857). Later, they were integrated as a member into the Wildegg Formation by Gygi (1969). The Effingen Member has recently been reviewed integrally by Deplazes et al. (2013).

23.4.2.2. Definition

Occurrence: The Effingen Member is found in all three regions JO, NL, and ZNO, however in the latter two with significantly smaller thickness (Figure 15).

Lithology: The dominant lithology is grey, occasionally silty to sandy, calcareous marl. Interbedded are often light grey, mostly marly, micritic limestone bed successions, of which the most prominent is the Gerstenhübel Bed approximately in the middle of the member. Fossils are much less abundant than in the Birmenstorf Member, but encompass mainly the same spectrum: ammonites, belemnites, siliceous sponges (virtually missing in the upper part), echinoderms, and bivalves. The fossils are often broken. Further components in some beds are pellets or larger quartz grains. Trace fossils are found at the base of some limestone beds.

Jordan (2013) and Deplazes et al. (2013) have shown that the several bundles of limestone to marly limestone beds are quite continuous for many kilometres at the southern slope of the easternmost Folded Jura. Some limestone bed successions, especially the Gerstenhübel Bed, might also extend even further (Figure 15).

Thickness: Thickness varies from some 13 m in the east of the ZNO region up to 265 m in the JO region (Gygi 2000, Deplazes et al. 2013; c.f. Figure 15).

Upper boundary: The upper boundary is gradual and identical to that of the Wildegg Formation (Section 23.2).

Lower boundary: For practical reasons, in the west (JO region), the lower boundary is set at the base of the first massive marl layer above massive marly limestone of the Birmenstorf Member. In the other regions, it is set atop the Glauconitic marl of Gygi (1977). i.e. the uppermost of the three thin beds representing the «Glaukonitischer Tonmergel Bed» and summing up to a maximum of 0.4 to 0.75 m in thickness. On the other hand, persistent occurrence of sponges down to the formations lower boundary is an argument to distinguish a Birmenstorf Member also in the eastern two siting regions (c.f. Albert et al 2012, Bläsi et al. 2013).

Lateral equivalents: The Impressamergel Formation of adjacent Germany corresponds mainly to the Effingen Member as the Birmenstorf Member wedges out towards the east following Gygi (2000a) and the German Stratigraphic Scheme concept (e.g., Geyer et al. 2011).

Names previously in use: The terms «Effinger Schichten» or, in some borehole reports of north-eastern Switzerland, «Impressamergel» were used to describe the succession.

23.4.2.3. Additional information

Origin of name: Municipality of formal type section.

Type locality and type region: Rugen or Ruge hill (coord. 2650.330/1260.723) north of Effingen AG has been identified by Gygi (2000a) as Moesch's (1857) eponymous rather than type locality. The section, if any, must have been incomplete and is no longer accessible. Following Moesch (1857), the western Fricktal must be denoted as type region

Reference section: Gygi (2000a) proposes the type locality of the Wildegg Formation, the Jakobsberg quarry (coord. 2653.810/1252.790) west of Wildegg AG, as the reference locality.

Chronostratigraphic age: Oxfordian, Bifurcatus to basal Hypselum Zone. Some authors, e.g., Gygi 2000a, consider the Hypselum Zone as the (basal) subzone of Bimmamatum Zone which results in Bifurcatus to basal Bimmamatum Zone as chronostratigraphic age indication (e.g., Deplazes et al. 2013).

Genetic and paleogeographic interpretation: The Effingen Member represents a shallowing-upwards megacycle documenting the filling of a deeper basin which developed in the Transversarium and, possibly, already in the Plicatilis Zone (Section 24.4.1.3).

24. Villigen Formation

24.1. General and main characteristics

The formation was established by Gygi (1969) by redefining and grouping older independent units. Later (Gygi 2000a), he added the Geissberg Member, formerly part of the Wildegg Formation. For more details see below and definition and discussion of its members (Section 24.4).

24.2. Definition

Occurrence: The Villigen Formation is found in all three siting regions, however with different members (see below).

Lithology and subdivision: Above the marly interval of the Wildegg Formation, the Villigen Formation represents a succession dominated by mostly pure, micritic, locally fossiliferous with ammonites, bivalves or sponges, in some layers glauconitic limestone; at the base, the transition from marly to pure limestone facies is included (Geissberg Member).

In the western part, the formation is subdivided into the Geissberg, Crenularis, Wangen und Letzi Members and, in the east, into the Hornbuck, Küssaburg and Wangental Members (Table 2). Gygi (1969) who established this scheme gives few arguments for distinguishing the coeval western and eastern members of the Villigen Formation and, if there are any, the transition zone is so broad that he gives a geographic argument, the River Rhine, as a delimitation (Gygi 2000a). This line follows the River Rhine from Koblenz to Eglisau, crossing the outcropping Malm Group sediments, and must be extended from there along the River Töss, approximatively.

The eastern units of Gygi (1969) base on the work of Würtenberger & Würtenberger (1866) who described the Upper Jurassic sediments of the German Klettgau and adjacent area. Vice versa, the member proposed by Gygi (1969) has been re-introduced in to the German Stratigraphic Scheme as subformations (from the stratigraphic rank identical to Swiss members) of the traditional Impressamergel and Wohlgeschichtete Kalke Formation (e.g., Geyer et al. 2011).

The Hornbuck, Küssaburg and Wangental Members have been applied to the Weiach borehole (Matter et al. 1988). For the recording of the Benken and Schlattingen boreholes, the terms "Hornbuck-Schichten" and "Wohlgeschichtete Kalke" was used (Nagra 2000, Albrecht et al. 2012), latter in reference to the formal German formation which includes Küssaburg and Wangental subformations.

Following Gygi (2000a), Geissberg, Crenularis, Wangen und Letzi apply for the JO regions, while Hornbuck, Küssaburg and Wangental Members apply for the ZNO region. The NL region is in a transitory domain.

Table 2 Gygi's (1969) stratigraphic concept for Middle Oxfordian to Kimmeridgian in northern Switzerland and adjacent area in comparison with the actual German Stratigraphic Scheme (Litholex, consulted 19.11.2019)

The Burghorn Fm. was later introduced (Bitterli-Dreher et al. 2007). The Wangental, Küssaburg and Hornbuck Members have been adobted by the German stratigraphers. Formations (Fm.) and equivalents in bold; Members (Mb.) and German Subformations (Sbf. / S.) in regular letters.

<table>
<tr><th colspan="4">Swiss Stratigraphic Scheme</th><th colspan="2">German Stratigraphic Scheme</th></tr>
<tr><td></td><td></td><td rowspan="10">Rhein-Töss Line</td><td rowspan="2">Felsenkalke / Massenkalk</td><td rowspan="2"></td><td>Unt. Felsenkalk Fm. /

Massenkalk Fm.</td></tr>
<tr><td rowspan="3">Burghorn Fm.</td><td rowspan="2">Wettingen Mb.</td><td></td></tr>
<tr><td rowspan="2">Schwarzbach Fm.</td><td rowspan="2"></td><td rowspan="2">Lacunosamergel Fm.</td></tr>
<tr><td>Baden Mb.</td></tr>
<tr><td rowspan="4">Villigen Fm.</td><td>Letzi Mb.</td><td>Wangental Mb.</td><td>Wangental Sbf.</td><td rowspan="2">Wohlgeschichtete Kalke Fm.</td></tr>
<tr><td>Wangen Mb.</td><td>Küssaburg Mb.</td><td>Küssaburg Sbf.</td></tr>
<tr><td>Crenularis Mb.</td><td rowspan="2">Hornbuck Mb.</td><td rowspan="2">Hornbuck Sbf.</td><td rowspan="4">Impressamergel Fm.</td></tr>
<tr><td>Geissberg Mb.</td></tr>
<tr><td rowspan="2">Wildegg Fm.</td><td>Effingen Mb.</td><td>Effingen Mb.</td><td>Effingen Sbf.</td></tr>
<tr><td>Birmenstorf Mb.</td><td>Birmenstorf Mb.</td><td>Birmenstorf S.</td></tr>
</table>

Thickness: Thickness may vary between 50 and 95 m.

Upper boundary: The upper boundary is well defined by the change from the pure limestone of the Villigen Formation to the marly limestone of the Burghorn and Schwarzbach Formations.

Lower boundary: The lower boundary towards the Wildegg Formation is gradual: increase in carbonate content, increasing thickness of limestone beds, re-occurrence of sponges (Hornbuck Member). The proposal to set the limit at the boundary between sequence Ox6 and Ox7 (Wetzel & Strasser 2001) is academic rather than practical.

Lateral equivalents: The Villigen Formation corresponds to the Hornbuck Member (or Subformation) of Impressamergel Formation and Wohlgeschichtete Kalke Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

Names previously in use: «Geissbergschichten» sensu Moesch (1857)

24.3. Additional information

Origin of name: Municipality of type section

Type locality and type region: The type locality at Schrannenkopf (coord. 2657.700/1264.080) east of Schranne near Villigen AG is composed of several partial sections on both sides of the forest road (Gygi 1969).

Type Region is the Aargau Tabular Jura.

Reference section: There is no reference section.

Chronostratigraphic age: Late Oxfordian to Early Kimmeridgian, Hypselum to Planula Zone.

Genetic and paleogeographic interpretation: Geographically (horizontally), the Villigen Formation relates the Celtic or Rauracian platform in the west with the Swabian Basin in the east. Chronologically (vertically), it documents a general decrease in terrigenous input and an increase in carbonate production also in the deeper water.

24.4. Members of the Villigen Formation

24.4.1. Geissberg Member

24.4.1.1. General and main characteristics

The Geissberg Member was defined, as a member of the Wildegg Formation by Gygi (1996) on the base of the «Geissbergschichten» by Moesch (1867) which are not to be confused by the «Geissbergschichten» of Moesch (1857) which are identical to the Villigen Formation. Later, Gygi (2000a) transferred the Geissberg member to the Villigen Formation.

24.4.1.2. Definition

Occurrence: The Geissberg Member is found southwest of the Rhine-Töss Line (Table 2), i.e. in the JO and NL siting areas.

Lithology: The Geissberg Member represents the transition from the marly Wildegg Formation to the pure limestone of the younger members of the Villigen Formation. It consists of thickly bedded limestone with marly interlayers.

Thickness: 15 to 20 m, locally eventually more.

Upper boundary: The upper boundary, towards the Crenularis Member, is marked by the onset of glauconite.

Lower boundary: The (gradual) lower boundary is identical to that of the Villigen Formation (see Section 24.2).

Lateral equivalents: The Geissberg Member is distinguished from its lateral equivalent, the lower part of the Hornbuck Member, by the absence of sponges, and, from the overlying Crenularis Member, by the absence of glauconite. Locally, bivalves may be abundant. The transition between the two members is gradual.

Names previously in use: «Geissbergschichten» (sensu Moesch 1867), not «Geissberg-schichten» sensu Moesch (1857)

24.4.1.3. Additional information

Origin of name: Hill including type and reference section.

Type locality and type region: Type locality is the Chamerenfels scarp (coord. approx. 2655.000/1264.400) at the western end of the Geissberg Mountain (Gygi 1969).

Type region is the Aargau Tabular Jura.

Reference section: The Gabenchopf quarry (coord. 2656.500/1265.000) within the Geissberg Mountain and west of Villigen is established as reference section by Gygi (2000a).

Chronostratigraphic age: Oxfordian, Hypselum Zone.

Genetic and paleogeographic interpretation: The Geissberg Member represents a transition from the terrigenous input-dominated Effingen Member to carbonatic members of the upper part of the Villigen Formation.

24.4.2. Crenularis Member

24.4.2.1. General and main characteristics

The Crenularis Member was formally introduced by Gygi (1969).

24.4.2.2. Definition

Occurrence: The Crenularis Member is found southwest of the Rhine-Töss Line (Section 24.4.1.2 and Table 2), i.e. in the JO and NL siting areas.

Lithology: The Crenularis Member is a glauconitic, often fossiliferous biomicritic limestone with uneven bedding planes. The fossil record includes bivalves and siliceous sponges. Ammonites and the eponymous echinite *Hemicidaris crenularis* (Lamarck) are rather rare. Gygi (2000a) includes isolated local sponge bioherms, as for instance near Mellikon AG (Gygi 1967), in the Crenularis Member, although sponge bioherms are a typical feature of the adjacent Hornbuck Member.

Thickness: About 3 m, locally thicker, for instance 17 m at Mellikon AG, because of the growth of an isolated sponge bioherm (see above).

Upper boundary: The upper boundary to the Wangen Member is marked by the offset of glauconite and the onset of white chalk-like limestone.

Lower boundary: The lower boundary to the Geissberg Member is characterised by the onset of glauconite.

Lateral equivalents: The lateral transition to the upper part of the Hornbuck Member is marked by the occurrence of sponge bioherms. However, isolated sponge bioherms can also occur in the Crenularis Member (Section 24.4.5).

Names previously in use: «Crenularisschichten»

24.4.2.3. Additional information

Origin of name: The echinite *Hemicidaris crenularis* (Lamarck), found occasionally in the formation

Type locality and type region: The type locality proposed by Gygi (1967) is a synthetic section based on five individual outcrops (coord. 2657.890/1264.040, 510 m asl) along the road from Villingen AG to the Geissberg Mountain.

Reference section: Later, Gygi (2000a) favoured the continuous section in the Gabenchopf quarry (coord. 2656.500/1265.000) which he appointed as the reference section.

Chronostratigraphic age: Oxfordian, Bimammatum Zone.

Genetic and paleogeographic interpretation: The Crenularis Member was formed in the euphotic realm with high biogenic production and little terrigenous input.

24.4.3. Wangen Member

24.4.3.1. General and main characteristics

The name «Wangenerschichten», or «Weisse Kalke», is traditionally associated with chalk-like white limestone. Gygi (2000a) proved that the «Weisse Kalke» of Moesch (1863), found in central Canton Aargau, are older than the «Wangenerschichten» of Moesch (1867) at the eponymous village of Wangen near Olten SO. As the term «Weisse Kalke» was replaced long ago by the term «Wangenerschichten» or Wangen Member (Gygi 1969) also in central Canton Aargau, Gygi (2000a) reclaimed priority for this older and earlier defined succession and proposed a new type locality at the northern entrance of the Bözberg railway tunnel for what he calls the revised Wangen Member sensu Gygi (1969), which also includes underlying, not chalk-like micritic limestone. This story is of no great relevance here as both the Wangen and the Bözberg «Wangenerschichten» or Wangen Member never occur in the same section and only the latter, the Wangen Member sensu Gygi (1969), is relevant for the area under investigation here. The former «Wangenerschichten» of Wangen are now included in the Balsthal Formation of Gygi (see Gygi 2000b).

24.4.3.2. Definition

Occurrence: The Wangen Member is found southwest of the Rhine-Töss Line (Table 2), i.e. in the JO and NL siting areas.

Lithology: The Wangen Member consists of predominantly well-bedded, micritic, non-porous limestone with a light beige colour, at the top, locally, white, chalk-like, porous limestone. Fossil record includes predominantly bivalves. Ammonites are virtually absent

Thickness: 10 to 12 m.

Upper boundary: The absence of glauconite and the chalk-like facies distinguish the Wangen Member from the Letzi Members, but it is the «Knollen Bed» (Section 24.4.4.2) that best marks the limit to the overlying Letzi Member.

Lower boundary: The absence of glauconite and the chalk-like facies distinguish the Wangen Member from the Crenularis Member.

Lateral equivalents: There is a broad transition to the adjacent Küssaburg Member in the north-east, which is quite like the Wangen Member sensu Gygi (1969). Gygi (2000a) proposes the River Rhine (now Rhine-Töss Line) as an arbitrary limit (see above and Table 2).

Names previously in use: «Weisse Kalke», not «Wangenerschichten» sensu Moesch (1867).

24.4.3.3. Additional information

Origin of name: Wangen SO to which the name «Wangenerschichten» sensu Moesch (1867) refers.

Type locality and type region: Gygi (2000a) defined the section recorded by Gygi (1969) in an old quarry (coord. 2650.220/1258.150) above the northern entrance of the Bözberg railway tunnel as type locality of the revised Wangen Member sensu Gygi (1969).

Reference section: The Gabenchopf quarry (coord. 2656.500/1265.000) within the Geissberg Hill west of Villigen AG.

Chronostratigraphic age: Oxfordian, Bimammatum Zone.

Genetic and paleogeographic interpretation: The Wangen Member results from high planktonic calcite production in a euphotic zone deposited at somewhat greater depth and the virtual absence of terrigenous input.

24.4.4. Letzi Member with «Knollen Bed»

24.4.4.1. General and main characteristics

The Letzi Member is introduced by Gygi (1969).

24.4.4.2. Definition

Occurrence: The Letzi Member is found southwest of the Rhine-Töss Line (Section 24.4.1), i.e. in the JO and NL siting areas.

Lithology: The Letzi Member is a well-bedded pure micritic limestone that was used for lithographic purposes. Macrofossils, mostly bivalves, are rare. It is underlain by a glauconitic «Knollen Bed» (i.e. bed with nodules) only a few decimetres thick, which is recognised by Gygi (1969) as an important regional marker horizon.

Thickness: About 20 to 25 m.

Upper boundary: The limit to the Baden Member of the Burghorn Formation, and locally the Schwarzbach Formation, can be localised by the renewed onset of glauconite above the glauconite-free main body of the Letzi Member.

Lower boundary: The Lower boundary is marked by the characteristic glauconitic «Knollen Bed». The Letzi Member proper is almost free of glauconite. (At places, where the «Knollen Bed» is missing or not clearly identifiable, drawing a boundary may be sophisticated.)

Lateral equivalents: The transition to its north-eastern equivalent, the Wangental Member, characterised by somewhat thicker marly interbeds, is gradual.

Names previously in use: «Letzischichten»

24.4.4.3. Additional information

Origin of name: Hump close to the type locality.

Type locality and type region: Old quarry (coord. 2652.040/1262.200) southwest of Mönthal AG.

Reference section: The Mellikon quarry (coord. 2668.300/1268.500) serves as reference locality.

Chronostratigraphic age: Early Kimmeridgian, Planula Zone.

Genetic and paleogeographic interpretation: Analogous to the Wangen Member, the Letzi Member documents high planktonic calcite production in a euphotic zone deposited at somewhat greater depth and the virtual absence of terrigenous input except at the base of the member («Knollen Bed»), which results in the delimitation of the Wangen and Letzi Members.

24.4.5. Hornbuck Member

24.4.5.1. General and main characteristics

Referring to Würtenberger & Würtenberger (1866), the Hornbuck Member was introduced by Gygi (1969) for the area northeast of the River Rhine (now Rhine-Töss Line, Section 24.4.1). Later, the Hornbuck Member sensu Gygi (1969) was re-imported in the German Stratigraphic Scheme where it is a subformation (with member rank) of the Impressamergel Formation (Table 2).

24.4.5.2. Definition

Occurrence: The Hornbuck Member is found northeast of the Rhine-Töss Line (Section 24.4.1), i.e. in the ZNO siting area.

Lithology: The Hornbuck Member is a succession of somewhat marly limestone beds with thin marl intercalations. Siliceous sponges and ammonites are the dominant macrofossils. Especially in the upper part, sponges form bioherms and the limestone beds are thicker and less marly.

Thickness: 10 to 20 m.

Upper boundary: The upper boundary to the Hornbuck Member is drawn where marly interbeds become very thin and sponges disappear.

Lower boundary: The lower boundary to the Effingen Member of the Wildegg Formation is defined by the offset of important sand input and the onset of siliceous sponges, which goes together with the first non-marly limestone beds. Generally, the transition is gradual and the boundary must be set regarding the overall situation (for more details see 24.2).

Lateral equivalents: The Hornbuck Member corresponds to the Geissberg and Crenularis Members in the west. The distinctive difference is the abundance of siliceous sponges: the lower part of the Hornbuck Member contains sponges, while sponges are virtually absent in the Geissberg Member. In the higher part, sponges bioherms are abundant, while, in the Crenularis Member, sponges are only found isolated or as isolated bioherms (see Section 24.4.2). However. the transition between the adjacent members is gradual. In this context, it is noteworthy that Gygi (1991, 2000a) recognises the Crenularis Member below the Küssaburg Member at its type locality in the Steingraben (see Section 24.4.6.2) which. is northeast of the Rhine-Töss Line.

In the German Stratigraphic Scheme, the Hornbuck Member is called Hornbuck Subformation (with member rank), which belongs to the Impressamergel Formation.

Names previously in use: «Hornbuck-Schichten»

24.4.5.3. Additional information

Origin of name: Hill close to the type locality

Type locality and type region: The type locality is a road cut (coord. 2675.850/1276.220) north of Hornbuck and east of Griessen in the German Klettgau.

The type region is the Klettgau - Randen area.

Reference section: There is no reference section.

Chronostratigraphic age: Oxfordian, Bimmamatum Zone.

Genetic and paleogeographic interpretation: Compared with its western equivalents, the Hornbuck Member is characterised by the presence of siliceous sponges documenting a somewhat greater water depth.

24.4.6. Küssaburg Member

24.4.6.1. General and main characteristics

Referring to Würtenberger & Würtenberger (1866), the Küssaburg Member was introduced by Gygi (1969) for the area northeast of the River Rhine (now Rhine-Töss Line, Section 24.4.1). Later, the Küssaburg Member sensu Gygi (1969) was re-imported in the German Stratigraphic Scheme (e.g., Geyer et al. 2011) where it is the lower subformation (with member rank) of the Wohlgeschichtete Kalke Formation (Table 2).

24.4.6.2. Definition

Occurrence: The Hornbuck Member is found northeast of the Rhine-Töss Line (Section 24.4.1), i.e. in the ZNO siting area.

Lithology: The Küssaburg Member is a succession of well-bedded, micritic limestone.

Thickness: About 30 to 35 m.

Upper boundary: The upper boundary is marked by the base of the glauconitic and nodular «Knollen Bed» (Section 24.4.4).

Lower boundary: The lower boundary is drawn where the marly interbeds become very thin and sponges, typical for the underlying Hornbuck Member, disappear.

Lateral equivalents: The only distinctive difference between the two adjacent members is that the Wangen Member may locally contain porous chalk-like limestone in its upper part, some facies not yet documented from the Küssaburg Member. However, the transition is gradual.

In the German Stratigraphic Scheme, the Küssaburg Member is called Küssaburg Subformation (with member rank), which belongs to the Wohlgeschichtete Kalke Formation.

Names previously in use: «Küssaburg-Schichten»

24.4.6.3. Additional information

Origin of name: The name originates from a ruined castle built on this member.

Type locality and type region: Steingraben section (coord. 2670.550/1273.020) south-west of Geisslingen in the German Klettgau.

Reference section: There is no reference section.

Chronostratigraphic age: Oxfordian, Bimmamatum Zone, Hauffianum Subzone.

Genetic and paleogeographic interpretation: The genesis and paleoenvironment of the Küssaburg Member is quite like that of Wangen Member (see Section 24.4.3). The absence of chalk possibly points to conditions less favourable for coccoliths in the euphotic domain.

24.4.7. Wangental Member with basal «Knollen Bed»

24.4.7.1. General and main characteristics

Referring to Würtenberger & Würtenberger (1866), the Wangental Member was introduced by Gygi (1969) for the area northeast of the River Rhine (now Rhine-Töss Line, Section 24.4.1). Later, the Wangental Member sensu Gygi (1969) was re-imported in the German Stratigraphic Scheme (e.g., Geyer et al. 2011) where it is the upper subformation (with member rank) of the Wohlgeschichtete Kalke Formation (Table 2).

24.4.7.2. Definition

Occurrence: The Wangental Member is found northeast of the Rhine-Töss Line (now Rhine-Töss Line, Section 24.4.1), i.e. in the ZNO siting area.

Lithology: The Wangental Member is a succession of well-bedded, micritic limestone with up to 45 cm thick marly interlayers. Like the adjacent Letzi Member, it is underlain by the thin glauconitic and nodular «Knollen Bed» (see Section 24.4.4). The prevailing macrofossils are ammonites (Gygi 2000a).

Thickness: About 25 to 40 m.

Upper boundary: The upper boundary is identical to the upper boundary of the Villigen Formation (Section 24.2). It is drawn where the succession becomes marly.

Lower boundary: The lower boundary is given by the base of the «Knollen Bed».

Lateral equivalents: The lateral equivalent to the southwest is the quite similar Letzi Member.

In the German Stratigraphic Scheme, the Wangental Member is called Wangental Subformation (with member rank), which belongs to the Wohlgeschichtete Kalke Formation.

Names previously in use: «Wangental-Schichten»

24.4.7.3. Additional information

Origin of name: The name originates from a valley formed in the member.

Type locality and type region: Type locality is a section in the eastern Mülitobel (coord. 2679.125/1277.450) south of Osterfingen SH.

Type region is the Klettgau - Randen area.

Reference section: There is no reference section.

Chronostratigraphic age: Early Kimmeridgian, Planula Zone.

Genetic and paleogeographic interpretation: Corresponding to the adjacent Letzi Member, the Wangental Member documents high planktonic calcite production in a euphotic zone deposited at somewhat greater depth and the virtual absence of terrigenous input except at the base of the member («Knollen Bed»).

25. Burghorn Formation

25.1. General and main characteristics

The Burghorn Formation encompasses the youngest Late Jurassic sediments of central Northern Switzerland that were not eliminated completely by the Cretaceous to Paleogene erosion. The Formation was created by Bitterli-Dreher et al. (2007) to unify the Baden Member and the Wettingen Member established by Gygi (1969).

According to today's knowledge, the Burghorn Formation is not encountered by any of the planned boreholes. Nevertheless, for the sake of completeness, it will be presented here.

25.2. Definition

Occurrence: Central northern Switzerland, JO siting region, Lägern Range south of, but, probably not within NL siting region.

Lithology and subdivision: Marl at the base (Baden Member) followed by layered then massy limestone.

Thickness: Up to 45 m.

Upper boundary: The upper boundary is erosional throughout, at some point karstic with cavities filled by Eocene residual sediments (Siderolithic Group), and locally followed by various Molasse sediments.

Lower boundary: Onset of marly facies above Letzi Member of Villigen Formation.

Lateral equivalents: Schwarzbach Formation, lower part of the «Felsenkalke».

Names previously in use: «Badener und Wettinger Schichten»

25.3. Additional information

Origin of name: One of the culminations of the Lägern Range situated above the type locality

Type locality and type region: Type locality is the footpath (coord. 2669.780/1259.200) on the southern slope of the Lägern Range below the Burghorn culmination.

Type region is the Lägern range and adjacent Folded and Tabular Jura.

Reference section: There is no reference section.

Chronostratigraphic age: Kimmeridgian, Platynota to Eudoxus Zone.

Genetic and paleogeographic interpretation: The Burghorn Formation represents a terrigenous clastic input and the recurrence of carbonate production domination. Relative to its equivalents in the northeast it was formed probably at a shallower depth.

25.4. Members of the Burghorn Formation

25.4.1. Baden Member

25.4.1.1. General and main characteristics

The Baden Member was formally established by Gygi (1969) referring to Mösch (1867).

25.4.1.2. Definition

Occurrence: Lägern range and adjacent Folded and Tabular Jura, JO siting region.

Lithology: The Baden Member is a sequence, few metre-thick, of grey, glauconitic and marly micritic limestone intercalating with glauconitic marl. The most abundant macrofossils are siliceous sponges and ammonites.

Thickness: About 2 to 4 m.

Upper boundary: The Baden Member is distinguished from both the underlying Letzi Member as well as the overlying Wettingen Member by its marl content. Consequently, the top of the highest marl layer marks the upper boundary.

Lower boundary: The base of the lowest marl layer marks the lower boundary.

Lateral equivalents: Toward northeast, the Baden Member continues gradually into the Schwarzbach Formation (Section 26).

Names previously in use: «Badenerschichten»

25.4.1.3. Additional information

Origin of name: Town of Baden AG, the formal type locality

Type locality and type region: The abandoned quarry (coord. 2664.930/1258.100) at the foot of the Hundsbuck west of Baden town centre is the formal type locality.

Reference section: The natural outcrop (coord. 2658.060/1263.950) along a small path west of the ruined castle of Besserstein near Villigen gives today better insights.

Chronostratigraphic age: Kimmeridgian, Platynota to early Divisium Zone.

Genetic and paleogeographic interpretation: The Baden Member, like its lateral equivalent, the lower part of the Schwarzbach Formation, documents the interruption of autochthonous carbonate production by terrigenous clastic input.

25.4.2. Wettingen Member

25.4.2.1. General and main characteristics

The Wettingen Member was formally established by Gygi (1969) referring to Mösch (1867).

25.4.2.2. Definition

Occurrence: Lägern range and adjacent Folded and Tabular Jura, JO siting region.

Lithology: The around 10 m thick base of the Wettingen Member consists of dark beige, well-layered micritic limestone. The upper part consists of light grey massy sparitic limestone with silicified fossils and nodules which occur particularly in horizons with sponges.

Thickness: Up to 45 m.

Upper boundary: The upper boundary is erosional (see Section 25.2).

Lower boundary: The lower boundary is defined by the offset of the thick marl interlayers of the Baden Member, i.e. at the top of the last of these interlayers

Lateral equivalents: The lower part of the Wettingen Member (see above) corresponds to the top of Schwarzbach Formation; the upper part is closely related to the «Felsenkalke», which may be laterally replaced by «Massenkalk» (Sections 27 and 28).

Names previously in use: «Wettingerschichten»

25.4.2.3. Additional information

Origin of name: Wettingen AG, the formal type locality

Type locality and type region: There is no suitable type locality for the Wettingen Member at the eponymous locality (Gygi 2000a). The «Wettingerschichten» have been described by Moesch (1867) based on blocks of the 1718 landslide at Berg (coord 2668.000/1258.250) north-east of Wettingen. Gygi (2000a) proposes the naturally outcropping Geissberg section (coord. 2658.080 /1264.035) and the Mellikon quarry (coord. 2668.300/1268.500) as reference localities for the lower boundary and basal part of the formation.

Reference section: The naturally outcropping Geissberg section (coord. 2658.080/1264.035) and the Mellikon quarry (coord. 2668.300/1268.500) are reference sections for the lower boundary and basal part of the member.

Chronostratigraphic age: Kimmeridgian, Divisium to Eudoxus or Beckeri Zone.

Genetic and paleogeographic interpretation: Laterally as well as vertically, the Wettingen Member represents the transition from planktonic to benthic carbonate production.

26. Schwarzbach Formation

26.1. General and main characteristics

Referring to Würtenberger & Würtenberger (1866), the Schwarzbach Formation was introduced by Gygi (1969). In the Swiss Stratigraphic Scheme, it is formally valid but not recognised as a lithostratigraphic unit for mapping purposes (oral communication, A. Morard, 31.10.2018). There, rocks corresponding in facies and stratigraphic position should be addressed as "Baden Member". As the formation was used, with its previous names (Weiach: «Schwarzbach-Schichten», Matter et al. 1986, Benken: «Mittlere Malmmergel», Nagra 2001) to describe the findings of the existing deep boreholes, it will be maintained here.

26.2. Definition

Occurrence: Formally, the Schwarzbach Formation is restricted to the area northeast of the Rhein (now Rhine-Töss Line, Section 24.4.1). But is recommended here, to use it in both NL and ZNO siting region.

Lithology and subdivision: The Schwarzbach Formation consists of grey, glauconitic and marly micritic limestone intercalating with glauconitic marl.

Thickness: 10 to 20 m

Upper boundary: The lower boundary to the Top of the Villigen Formation is set at the onset of marly facies.

Lower boundary: The upper boundary is marked by the onset of massive limestone of the «Felsenkalke» or «Massenkalk».

Lateral equivalents: To the southwest, the Schwarzbach Formation correlates stratigraphically to the Badener Member and the lower part of the Wettingen Member. Looking at facies only, the Schwarzbach Formation corresponds to the Baden Member. The transition of the marly upper part of the Schwarzbach Formation to the limestone-dominated lower part of the Wettingen Member is continuous. The delimitation between the lower part of the Schwarzbach Formation and the Baden Member is purely academic.

To the northeast, the Schwarzbach Formation corresponds to the formal Lacunosamergel Formation of the German Stratigraphic Scheme (e.g., Geyer et al. 2011).

Names previously in use: «Schwarzbach-Schichten», «Mittlere Malmmergel», «Badenerschichten»

26.3. Additional information

Origin of name: Schwarzbach creek east of Griessen in German Klettgau.

Type locality and type region: There is no type locality (Gygi 2000a). Type region is the Klettgau - Randen area.

Reference section: Gygi (2000a) designates an abandoned quarry (coord. 2688.070/1286.340) at Sommerhalde near Sommerwies/Schaffhausen SH as reference section.

Chronostratigraphic age: Kimmeridgian, Platynota to early Divisum Zone.

Genetic and paleogeographic interpretation: The Schwarzbach Formation documents a time of increased terrigenous clastic input.

27. «Felsenkalke»

27.1. General and main characteristics

The «Felsenkalke» were introduced by Gygi (2000a, 2000b) in his stratigraphic scheme without being defined. For the description of the corresponding sequences in the Weiach, Benken and Schlattingen boreholes (Matter 1988, Nagra 2001, Albert et al. 2012), the terms «Quaderkalk» and «Plattenkalk» were used. The German Stratigraphic Scheme distinguishes an Untere Felsenkalke and an Obere Felsenkalke Formation, followed by the Liegende Bankkalke Formation, the Zementmergel Formation, and, finally, the Hangende Bankkalke Formation (e.g., Geyer et al. 2011). In a section near Engen, some 20 km north-east of Schaffhausen SH, the latter is reached (Geyer et al. 2011, referring to Ziegler 1977). However, a correct differentiation of all these formations in a core will be difficult as petrographic diversity is small and most of the units (Obere Felsenkalke to Zementmergel Formations) originate from the same ammonite zone, the Beckeri Zone. Thus, the «Felsenkalke» is informally introduced here (in the rank of a formation) to integrally describe the whole, well-bedded, limestone succession atop the Schwarzbach Formation.

27.2. Definition

Occurrence: NL and ZNO siting regions.

Lithology and subdivision: In general, the informal «Felsenkalke» consists of predominantly light brown to yellowish white, well-bedded predominantly pure micritic to sparitic limestone separated by thinner and thicker marl or marly limestone layers. From top to bottom, some variations may be encountered:

- fine (5 cm) to coarse-bedded (1 m) limestone, occasionally with pyrite
- coarse-bedded (traditionally addressed as «Quaderkalk» meaning "ashlar") to massy limestone with up to chicken egg-sized silex nodules
- glauconitic, fine-bedded (6 to 10 cm) limestone

The partly greenish marl or marly limestone horizons separating the limestone beds are generally very thin. In the Weiach and Benken boreholes, a distinct, some 1.5 m thick glauconitic horizon was recognized about 20 m and 50 m above the base of the formation, respectively (Matter 1988, Nagra 2001). It could correlate to the «Glaukonithorizont» of the German Stratigraphic Scheme, which occurs at the base of informal Unit 4 which makes up the top of the Untere Felsenkalke. In this case, it would be a valuable marker horizon.

At various horizons, the «Felsenkalke» are fossiliferous, including ammonites, sponges, belemnites, crinoids and brachiopods.

Thickness: Up to 250 m.

Upper boundary: If not overlain by «Massenkalk», the top «Felsenkalke» is always erosional. In most cases, they are overlain by various Molasse units including Siderolothic Group.

Lower boundary: The lower boundary is marked by the onset of well-bedded limestone above the marly sequence of the Schwarzbach Formation.

Lateral equivalents: Laterally, «Felsenkalke» are interfingering with the «Massenkalk» (Figure 16).

In the German Stratigraphic Scheme, the interval corresponding to the informal «Felsenkalke» is subdivided (from bottom to top) in Untere Felsenkalke Formation, Obere Felsenkalke Formation, Liegende Bankkalke Formation, Zementmergel Formation, and Hangende Bankkalke Formation. All of them interfinger with the Massenkalke Formation which corresponds to informal «Massenkalk».

Names previously in use: «Quaderkalk», «Plattenkalk», «Bankkalk», «Flaserkalk», «Bretterkalk», «Felsenkalk».

27.3. Additional information

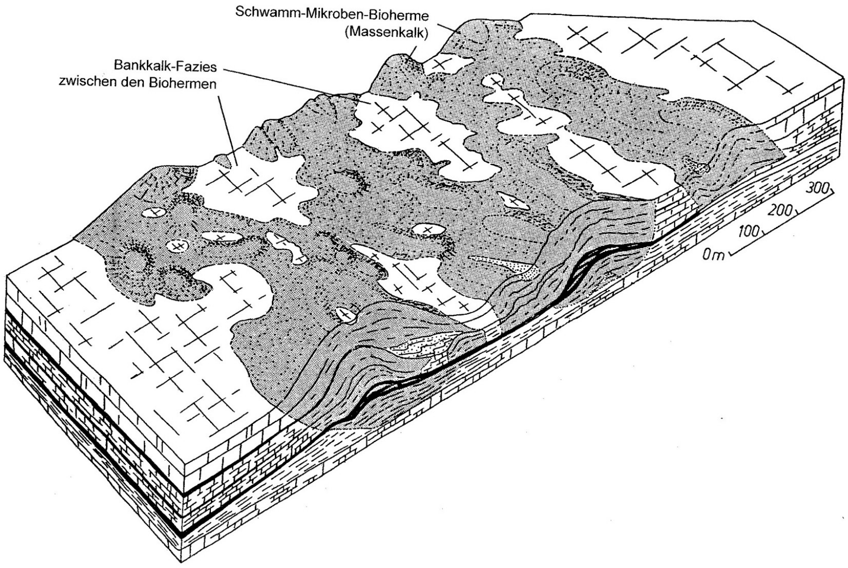
Origin of name: Reference to the German Untere and Obere Felsenkalke Formation. There the name derives from the cliff forming character of the two formations.

Type locality and type region: NL and ZNO siting regions.

Reference section: There is no type locality for the «Felsenkalke». The type localities of the German Untere and Obere Felsenkalke Formations are localised at the Grabenstettener Steige, some 25 km east of Tübingen in Germany, which is not very helpful for the lithostratigraphic task to be performed here. The borehole sections of Weiach and Benken may serve as reference sections

Chronostratigraphic age: Kimmeridgian, Divisum to Beckeri Zone.

Genetic and paleogeographic interpretation: The «Felsenkalke» represents the realm outside or between the sponge bioherms formed by autochthonous benthic carbonate production and reef detritus. It documents a time of maximum carbon sequestration.



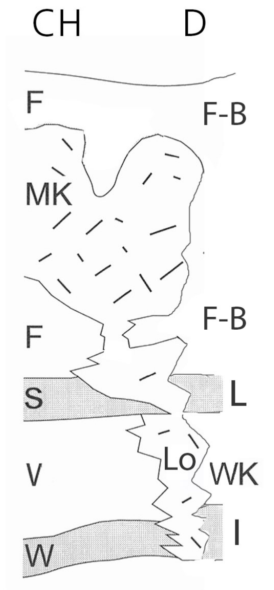


Figure 16: Diagramm showing the relation between «Felsenkalke» and «Massenkalk» (left) from Geyer et al. (2011). Right schematic section showing the succession in the Swiss (CH, left) / German (D, right) boundary area: F: «Felsenkalke», MK: «Massenkalk»; S: Schwarzbach Fm.; V: Villigen Fm.; W: Wildegg Fm.; F - B: Untere Felsenkalke to Obere Bankkalke Fm.; L: Lacunosamergel Fm.; WK: Wohlgeschichtete Kalke Fm.; I: Impressamergel Fm.; Lo: Lochen Fm. (older sponge reefs).

28. «Massenkalk»

28.1. General and main characteristics

In the German Stratigraphic Scheme, the Massenkalk Formation represents the siliceous sponge bioherm facies which interfingers with different Late Jurassic units, starting with the Lacunosamergel Formation (Geyer et al. 2011 referring to Meyer & Schmidt-Kaller 1989). In the area in question, sponge bioherms are encountered for the first time in the Hornbuck Member. In the scheme proposed here, the «Massenkalk» interfingers with (or superposes) the «Felsenkalke» only. This means that older bioherms are taken as part, and local curiosity, of the corresponding formations

28.2. Definition

Occurrence: NL and ZNO siting areas.

Lithology and subdivision: The «Massenkalk» is characterised by the (initial) dominance of siliceous sponges and the diagenetic silicification of other fossils and siliceous nodules. At some places, sponges are no more visible due to dolomitization and dedolomitization, which leads to a characteristic saccharoidal limestone. Layering is virtually absent.

Thickness: Up to 250 m.

Upper boundary: At the last occurrence, the top of is erosional, and the «Massenkalk» is overlain by different Molasse units of Siderolithic Group sediments.

Lower boundary: The lower boundary is set with the dominance of siliceous sponge bioherms. or the onset of saccharoidal limestone (see above).

Lateral equivalents: The «Massenkalk» is laterally interfingering with the «Felsenkalke» (Figure 16).

Names previously in use: None, beside the spelling «Massenkalke». For some local level the term «zuckerförmiger Kalk» (saccharoidal limestone, see above) was used, referring to the relatively large grain size of recrystallized calcite reminiscent of sugar grains.

28.3. Additional information

Origin of name: Massive habitus of the rock, absence of layering.

Type locality and type region: There is no type section. Type region are the NL and ZNO siting regions.

Reference section: The Weiach and Benken borehole sections may serve as reference sections.

Chronostratigraphic age: Kimmeridgian, Divisum to Beckeri Zone.

Genetic and paleogeographic interpretation: The «Massenkalk» represent bioherms (composed mostly of siliceous sponges) which are also rich in other benthic life forms.

29. Siderolithic Group (Eocene residual sediments)

29.1. General and main characteristics

The Siderolithic Group encompasses residual sediments of a long-lasting period of predominantly chemical weathering which is dating from the Eocene Epoch.

29.2. Definition

Occurrence: Eocene residual sediments may be found in different forms in all three siting regions.

Lithology and subdivision: The Siderolithic Group comprises different residual sediments like pisolithic iron («Bohnerz»), pure or kaolinitic quartz sand («Glassand»), bolus clay («Boluston»), refractory clay («Huppererde»), breccia, silex nodules or lacustrine sediments. For most of the various manifestations, a bright to brownish red, at some places also green, colour is typical.

There are no stratigraphic but only petrographic subdivisions (see above).

Thickness: The Eocene residual sediments occur as up to several metre-thick, stratiform deposits and as fills of karstic cavities. In the latter case, Siderolithic sediments may penetrate several metres up to many decametres into the underlying Mesozoic limestone.

Delimitation: Colour and petrography make it easy to distinguish the Siderolithic Group from adjacent formations. However, delimitation can be complicated if a borehole hits karst fill.

Lateral equivalents: There are no lateral equivalents outside the group.

Names previously in use: See names in brackets in the lithology and subdivision text above.

29.3. Additional information

Origin of name: The name refers to the iron-bearing rock.

Type locality and type region: There is no formal type locality or type region for the Siderolithic Group.

Reference section: In the areas in question, the limestone quarries of Regensburg (coord. 2676.060/1259.760) near Dielsdorf ZH or at Mellikon AG (coord. 2668.275/1268.500) give an insight into Eocene deposits atop and within Jurassic limestone.

Chronostratigraphic age: The Siderolithic Group is dated by mammal teeth (MP 14 to MP 19) to Late Lutetian up to Priabonian.

Genetic and paleogeographic interpretation: The Siderolithic Group documents a time of karstification and chemical erosion in a (sub-) tropical climate. It is observed over a very wide area, including not only the whole Folded and Tabular Jura but also the Helvetic realm and further areas throughout Europe.

30. «Ältere Krustenkalke» (Oligocene)

30.1. General and main characteristics

The informal «Ältere Krustenkalke» (Hofmann et al. 2000) encompasses sediments of a pre-Molasse period of erosion, probably of Rupelian Age. The name «Jüngerer Krustenkalk» refers to younger similar formations, also known as «Albstein» within the Molasse (see Section 32.2).

30.2. Definition

Occurrence: «Ältere Krustenkalke» are found in JO and, possibly also in NL and ZNO siting region.

Lithology and subdivision: The «Ältere Krustenkalke» are characteristic light coloured, occasionally nodular limestone related to algal activity in freshwater ponds and forming incrustations on older sediments. They may include shales and pisolithic limestone.

Thickness: The thickness may range up to some few metres.

Upper boundary: The upper boundary is given by the Molasse transgression.

Lower boundary: The delimitation to the Siderolithic Group may be gradual due to reworking. The delimitation of Oligocene freshwater to Jurassic marine limestone may be difficult at some places if there is no fossil evidence.

Lateral equivalents: There are no lateral equivalents.

Names previously in use: None.

30.3. Additional information

Origin of name: Crust-like nature of many deposits.

Type locality and type region: There is no type locality or type region.

Reference section: A reference section is found near Letzi (coord. 2651.900/1262.200).

Chronostratigraphic age: Hofmann et al. (2000) suggest a Rupelian age.

Genetic and paleogeographic interpretation: The «Ältere Krustenkalke» documents a second phase of widespread erosion.

31. Lower Freshwater Molasse Group (Untere Süsswassermolasse, USM)

31.1. General and main characteristics

The Lower Freshwater Molasse Group (USM) are the oldest Molasse sediments expected. The Lower Marine Molasse Group is missing.

31.2. Definition

Occurrence: The fluvio-terrestrial USM Group extends to a line between Brugg AG and Schaffhausen SH, which means it is expected to be virtually missing in most of the JO region except for Bözberg-1 site.

Lithology and subdivision: In the NL and ZNO regions, the USM Group consists of an alternation of sandstone with variegated clayey and sandy siltstone and marl. Cross-bedding may be found in channel fill sandstone. The main transport direction is north-west to south-east at the basin margin and south-west to north-east in the basin centre, which is possibly reached by the southernmost boreholes of the NL and ZNO regions. In the alluvial plains, palaeosoils may be found.

The sole borehole in the JO region that is expected to encounter the USM Group is Bözberg-1, which is located close to the famous Chalofen sections (e.g., Diebold et al. 2006, see Figure 17). Although only some 90 to 180 m apart, the two sections show differences in facies and thickness. Consequently, further variations must be expected for the borehole section. The USM consists here of some 5 to 15 m of yellowish, locally also reddish, partly sandy marl and siltstone with some nodular limestone and conglomerate horizons, the latter mainly formed by pebbles of Jurassic origin.

The subdivision established in the basin centre applies only to a limited degree in the distal area in question. Locally, particularly in the NL region, the more marly and clayey top («Obere Bunte (Granitische) Molasse», «Oberaquitane Mergelzone», USM II) may be distinguished from the underlying «Untere Bunte (Granitische) Molasse» (USM I), an alternation of variegated marl and sandstones with abundant quartz and red feldspar components, mica, and a minor content of carbonate components. In the JO region, the equivalent of the «Obere Bunte Molasse» is characterised by calcareous conglomerates («Ältere Juranagelfluh»).

Thickness: Up to 450 m.

Upper boundary: The upper boundary is defined by the onset of the Miocene marine OMM Group or Pleistocene to Holocene unconsolidated rock above an erosional surface.

Lower boundary: The lower boundary is erosional and transgressive above the Late Jurassic, Eocene (Siderolithic) or Early Oligocene sediments («Krustenkalke»). It is often marked by a basal conglomerate consisting of components of the underlaying rock.

Lateral equivalents: None

Names previously in use: None.

31.3. Additional information

Origin of name: Soft rock ("Molasse") of fluvial and lacustrine fresh water ("Süsswasser") origin.

Type locality and type region: There is no formal type locality or type region for the USM Group. The characterisation given here refers to the subjurassic area, i.e. northern boundary of the Molasse Basin.

Reference section: The Weiach and Benken boreholes may serve for comparisons concerning the NL and ZNO siting regions.

The Chalofen sections (e.g., Diebold et al. 2006) is a reference to Bözberg-1 site (Figure 17).

Chronostratigraphic age: (? terminal Rupelian,) Chattian and Aquitanian

Genetic and paleogeographic interpretation: The Lower Freshwater Molasse Group (USM) represents the second and completing part of the first Molasse cycle.

32. Upper Marine Molasse Group (Obere Meeresmolasse, OMM) and freshwater equivalents

32.1. General and main characteristics

The Upper Marine Molasse Group is defined by its marine facies. This paragraph deals also with contemporary freshwater sediments expected in JO and ZNO siting regions.

32.2. Definition

Occurrence: For geometric reasons, OMM Group sediments are only expected in the JO and ZNO regions (kelly bushing of all planned boreholes in the NL region is below the local base of the OMM Group). The following description therefore concentrates on the peculiarities of these areas representing the coastal domain of the younger Molasse Sea.

Lithology and subdivision: In the ZNO region, the marine sediments start with fossiliferous (gastropods, bivalves), somewhat marly limestone with coarse-grained sand and glauconite. This «Randen Grobkalk» is interpreted as beach rock (Hofmann et al. 2000, Kazmaier 2019). It is followed by sandstone, a conglomerate composed of oysters and quartz pebbles and, finally, siltstone which intercalates with the coarse-grained sandstone. This so-called «Graupensand» is a prominent feature of the basin centre, with indications of a north-east to south-west transport. The siltstone is overlain by reddish marl with gastropods («Helicidenmergel»), documenting already predominantly freshwater conditions, and volcanic tuff originating from the nearby Hegau volcanoes. The some 5 to 20 m thick sequence is terminated by concretionary limestone («Albstein»).

The sole borehole in the JO region that is expected to encounter the OMM Group is Bözberg-1, which is located close to the famous Chalofen sections (e.g., Diebold et al. 2006, see Figure 17). Though only some 90 to 180 m apart, the two sections show differences in facies and thickness. Consequently, further variations must be expected for the borehole section.

The lower part of the sequence (identified as OMM I or Luzern Formation) consists of some 5 to 10 m of micaceous and glauconitic, locally fossiliferous (oysters) fine-grained sandstone with some conglomerate beds with pebbles of predominantly Alpine or Jurassic origin (the latter are addressed as «Mittlere Juranagelfluh»). The around 12 m thick upper part (identified as OMM II or St. Gallen Formation) encompasses fossiliferous (bivalves), coarse-grained sandstone and limestone and subordinate variegated marl. The sequence is interrupted by several hardgrounds.

At other locations in the JO region, but consistently above the kelly bushing of the other planned boreholes, the OSM Group reaches a thickness of several decametres and includes freshwater equivalents including the «Helicidenmergel» and «Albstein» («Jüngerer Krustenkalk»).

The OMM Group is traditionally subdivided into OMM I (Luzern Formation, auct. «Burdigalien») and OMM II (St. Gallen Formation, auct. «Helvetien»).

In the JO region, near the Bözberg-1 site, the fine-grained, glauconitic sandstone is assigned to OMM I, while the overlying predominantly coarser sediments are believed to belong to OMM II. In the ZNO region, delimitation is less clear. At least the thin «Helicidenmergel» and the «Albstein» are freshwater equivalents to OMM II.

Thickness: 5 to 65 m in the are under investigation.

Upper boundary: The upper boundary is traditionally drawn above the generally thin «Albstein» («Jüngerer Krustenkalk»), thus including also freshwater equivalents of the Upper Marine Molasse like the «Helicidenmergel». In the ZNO region, this limit should be easy to locate as the thin «Helicidenmergel» also include volcanic ash (tuff).

In the JO region, near Bözberg-1 site, the «Helicidenmergel» are obviously missing and the upper boundary of the OMM is marked by the offset of marine bivalve fossils and of well-rounded coarse quartz grains.

Lower boundary: The lower boundary is defined by the onset of marine sediments.

Lateral equivalents: None.

Names previously in use: None.

32.3. Additional information

Origin of name: Soft rock ("Molasse") of marine origin.

Type locality and type region: There is no formal type locality or type region for the OMM Group.

Reference section: The Benken borehole may serve for comparison for the development in the ZNO region and the Chalofen sections (Figure 17, coord. 2653.750/1258.630, 2653.820/1258.710 and 2653.750/1258.630, and 2653.860/1258.760) for the JO region.

Chronostratigraphic age: Burdigalian, MN 3a to MN 4b, Eggenburgian and Ottnangian of the Paratethys stratigraphy.

Genetic and paleogeographic interpretation: The Upper Marine Molasse Group (OMM) represents the marine to brackish initial part of the second Molasse cycle.

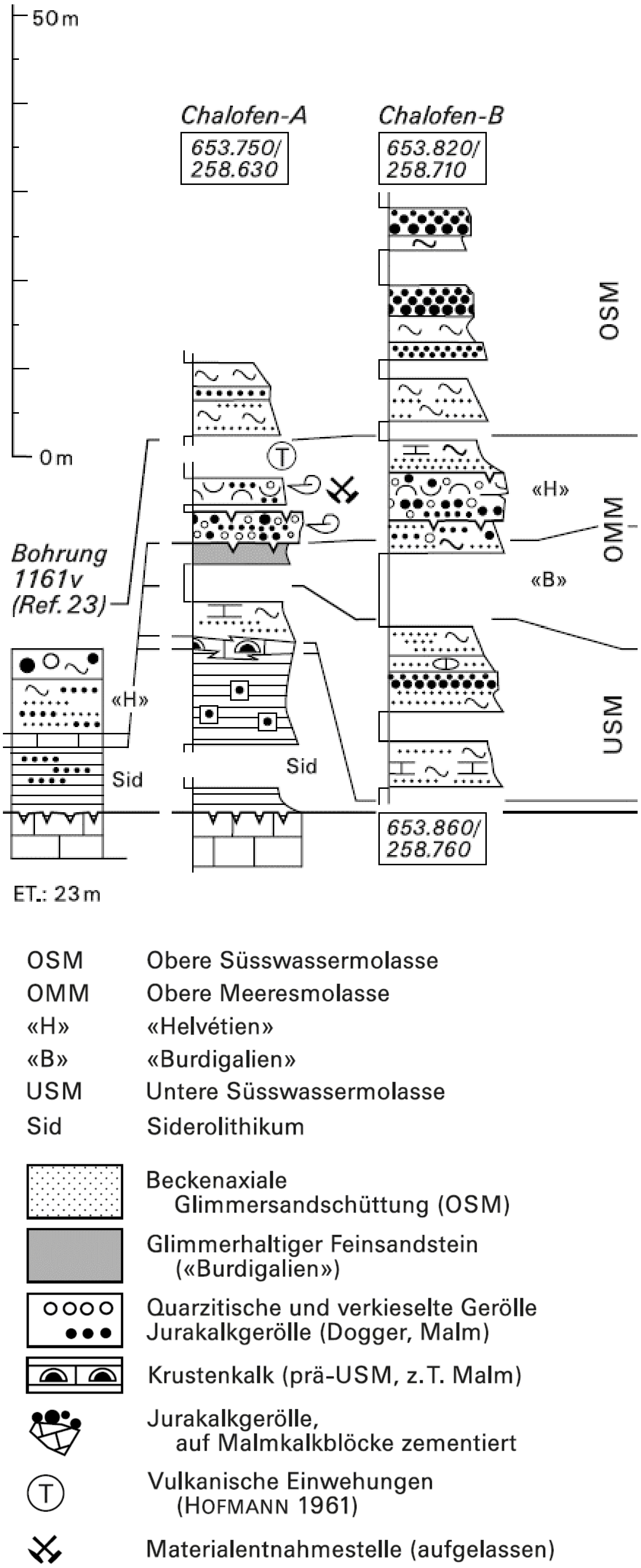


Figure 17: The Chalofen-A and B Siderolothic to OSM group sections.

The sections are situated close to Bözberg-1 potential drill site. Extracts from Fig. 10 of Diebold et al. (2006).

33. Upper Freshwater Molasse Group (Obere Süsswassermolasse, OSM)

33.1. General and main characteristics

The Obere Süsswassermolasse, though an important, very thick group of Swiss Molasse basin stratigraphy, is only encountered locally and in its very marginal facies by the present boring campaign.

33.2. Definition

Occurrence: Though present in all three regions, the Upper Freshwater Molasse Group will probably only be encountered at two sites in the JO siting region (Bözberg-1 and Zeihen) as kelly bushing of all other planned boreholes is too low to touch this group.

Lithology and subdivision: At Bözberg-1 and Zeihen site, predominantly «Jüngere Juranagelfluh» is expected (Figure 17).

Outside the occurrence of the OMM Group, the OSM overlays a distinct paleorelief showing gentle hills and valleys carved in. The OSM can start with thin sediments documenting swamps, freshwater lakes and alluvial plains, but the main body is dominated by variegated marl with conglomerate beds of pebbles of Jurassic origin. They come from the now eroded sedimentary cover of the Black Forest. Middle to Late Jurassic limestone prevails. These conglomerate beds proper or, more generally, including the surrounding variegated marl, are denoted as «Jüngere Juranagelfluh» or Aargauer Juranagelfluh.

There is no means or reason to subdivide the OSM sediments at the two drill sites.

Thickness: 25 to 75 m, outside planned drilling sites up to 150 m Aargauer Juranagelfluh in a broader sense can be found.

Upper boundary: In any case, the upper bound is erosional, and the OSM sediments are overlain by Pleistocene or Holocene unconsolidated rock.

Lower boundary: The lower limit may be erosional and discordant above Mesozoic strata or Eocene/Oligocene residual sediments. In the case where OSM Group sediments overlay OMM Group sediments, the lower boundary is drawn at the offset of marine sediments or atop the (Miocene) «Albstein» («Jüngerer Krustenkalk»).

Lateral equivalents: None.

Names previously in use: None.

33.3. Additional information

Origin of name: Soft rock ("Molasse") of fluvial and lacustrine fresh water ("Süsswasser") origin.

Type locality and type region: There is no type locality or type region for the OSM.

Reference section: For Aargauer Juranagelfluh: Sigerst/Deckerhübel (coord 2654.500/1258.625) and Letzi - Hoomel (coord. 2651.750/1262.700)

Chronostratigraphic age: Burdigalian to Serravallian, MN 5 to MN 7/8, Carpathian to Sarmatian of the Paratethys stratigraphy

Genetic and paleogeographic interpretation: The Upper Freshwater Molasse Group (OSM) represents the post-marine part of the second Molasse cycle.

34. Acknowledgements

Dr. H.R. Bläsi (Univ. Bern) and Dr. S. Wohlwend (ETH Zürich) are thanked for their contribution during the preparation and review process of this manual.

Dr. A. Morard (swisstopo and Swiss Committee on Stratigraphy) is acknowledged for reviewing the formal and substantive definition of the units listed here and giving essential comments on their improvement.

35. References

Achilles, H. & Schlatter, R. (1986): Palynostratigraphische Untersuchungen im 'Rhät-Bonebed' von Hallau (Kt. Schaffhausen) mit einem Beitrag zur Ammonitenfauna im basalen Lias. Eclogae geol. Helv. 79/1, 149-179.

Albert, W., Bläsi, H.R., Madritsch H., Vogt, T. & Weber, H.P. (2012): Geologie, Stratigraphie, Strukturgeologie, bohrlochgeophysikalisches Logging und Wasserproben der Geothermie-bohrung Schlattingen SLA-1 (Rohdaten). Nagra Project Report NPB (restricted).

Bernasconi, S. M., Meier, I., Wohlwend, S., Brack, P., Hochuli, P. A., Bläsi, H., Wortmann, U. G. & Ramseyer, K. (2017): An evaporite-based high-resolution sulfur isotope record of Late Permian and Triassic seawater sulfate. Geochimica et Cosmochimica Acta, 204, 331-349.

Beutler, G. & Nitsch, E. (2005): Paläogeographischer Überblick. Deutsche Stratigraphische Kommission, 2005: Stratigraphie von Deutschland IV: Keuper. – Cour. Forsch.-Inst. Senckenberg 253, 15-30.

Bitterli, T., Graf, H.R., Matousek, F. & Wanner, M. (2000): Blatt 1050 Zurzach. Geol. Atlas der Schweiz 1:25'000, Erläuterungen 102. Bundesamt für Wasser und Geologie, Bern.

Bitterli-Dreher, P. (2012): Die Ifenthal-Formation im nördlichen Jura.- Swiss Bull. F. angewandte Geol. 17/2, 93-117.

Bläsi, H.R. (1995): Fazies, Diagenese und wasserführende Systeme in den kalkigen und sandigen sedimentkörpern von Schilfsandstein bis Dogger beta in den Bohrungen Lindau-1, Herdern-1, Berlingen-1, Kreuzlingen-1 und Meersburg, Teil 1: Fazies und Stratigraphie. Unpubl. Nagra Interner Ber. Nagra, Wettingen.

Bläsi, H.R., Deplazes, G., Schnellmann, M. & Traber, D. (2013): Sedimentologie und Stratigraphie des 'Braunen Doggers' und seiner westlichen Äquivalente. Nagra Arbeitsbericht NAB 12-51.

Bloos G., Dietl G., Schweigert G. (2005): Der Jura Süddeutschlands in der Stratigraphischen Tabelle von Deutschland 2002.- Newsletters on Stratigraphy 41 / 1-3, 263-277.

Blüm, W. (1989): Faciesanalyse im Rotliegenden des Nordschweizer Permokarbon- Trogs (Hochrhein- Region zwischen Basel und Laufenburg).- Eclogae geol. Helv. 82/2, 455-489.

Büchi, U.P., Lemcke, K., Wiener, G. & Zimdars, J. (1965): Geologische Ergebnisse der Erdölexploration auf das Mesozoikum im Untergrund des schweizerischen Molasse-beckens. Bulletin der Schweizerischen Vereinigung von Petroleum-Geologen und -Ingenieuren 32/82, 7-38.

Burkhalter, R.M. (1996): Die Passwang-Alloformation (unteres Aalenien bis unteres Bajocien) im zentralen und nördlichen Schweizer Jura. Eclogae geol. Helv. 89/3, 875-934.

Buxtorf, A. (1901): Geologie der Umgebung von Gelterkinden im Basler Tafeljura. Beitr. geol. Karte Schweiz. [N.F.] 11.

Deplazes, G., Bläsi, H.R., Schnellmann, M. & Traber, D. (2013): Sedimentologie und Stratigraphie der Effinger Schichten. Nagra Arbeitsbericht NAB 13-16.

Diebold, P., Bitterli-Brunner, P. & Naef, H. (2006): Blatt 1069/1049 Frick-Laufenburg. Geol. Atlas der Schweiz 1:25'000, Erläuterungen. Bundesamt für Landestopografie swisstopo

Dietl, G. (2010): Die Wutach-Formation (clw) des südwestdeutschen Juras – Beschreibung und Gliederung. Jh. Ges. Naturkde. Württemberg, Stuttgart, 166, 5-21.

Disler, C. (1914): Stratigraphie und Tektonik des Rotliegenden und der Trias beiderseits des Rheins zwischen Rheinfelden und Augst. Verhandlungen der Naturforschenden Gesellschaft in Basel. Band XXV.

Dronkert, H., Bläsi, H.R. & Matter, A. (1990): Facies and origin of Triassic evaporites from the Nagra boreholes, Northern Switzerland. Nagra Technischer Bericht, NTB 87-02.

DSK (2005): Deutsche Stratigraphische Kommission (Hrsg.): Stratigraphie von Deutschland IV – Keuper. Courier Forschungsinstitut Senckenberg 253.

Erni, A. (1910): Das Rhät im schweizerischen Jura. Eclogae geol. Helv. 11/1, 5-54.

Etter, W. (2016): Insektenmergel. https://www.nmbs.ch/home/museum/forschung/forschung-geowissenschaften/insektenmergel.html. (last access: 13 November 2019)

Etzold, A. & Schweizer, V. (2005): Der Keuper in Baden-Württemberg. Deutsche Stratigraphische Kommission, 2005: Stratigraphie von Deutschland IV: Keuper. – Cour. Forsch.-Inst. Senckenberg 253, 214-258.

Frank, M. (1930): Beiträge zur vergleichenden Stratigraphie und Bildungsgeschichte der Trias-Lias-Sedimente im alpin-germanischen Grenzgebiet der Schweiz. - N. Jb. Mineral. Geol. Paläont. (B) 64, 325-426.

Franz, M. (2015): Beschluss der Subkommision Jura der Deutschen Stratigraphischen Kommission/DSK betreffend Gosheim Formation vom 30.09.2015.

Franz, M. & Rohn, J. (2004): Geologische Karte von Baden-Württemberg 1:25'000, Erläuterungen zu Blatt 8117 Blumberg. Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg, Freiburg i.Br.

Falke, H. (1974): Das Rotliegende des Saar-Nahe-Gebietes. Jber. Mitt. oberrhein. geol. Ver., N.F. 56,1-14.

Foelix, R., Pabst, B. & Kindlimann, R. (2011): Die Saurier in Frick. Mitteilungen der aargauischen Naturforschenden Gesellschaft, 37, 59-75.

Franz, M. & Nitsch, E. (2009): Zur lithostratigraphischen Gliederung des Aalenium in Baden-Württemberg. LGRB-Informationen 22, 123-146.

Furrer, H. (1977). Lettenkohle-Bonebeds Detailprofil 1:50 an neuem Anschnitt der Strasse von Üselmatt nach Asp, unpublished profile section.

Genser, H. (1966): Schichtenfolge und Stratigraphie des Doggers in den drei Faziesbereichen der Umrandung des Südschwarzwaldes. – Oberrheinische Geologische Abhandlungen, 15(1/2): 1-60; Karlsruhe.

Geyer, M., Nitsch, E. & Simon, T. (2011): Geologie von Baden-Württemberg. 5., völlig neu bearbeitete Auflage, Verlag Schweizerbart Stuttgart 2011, 627 p.

Gonzalez, R. & Wetzel, A. (1996): Stratigraphy and paleogeography of the Hauptrogenstein and Klingnau Formations (middle Bajocian to late bathonian), northern Switzerland. Eclogae geol. Helv. 89/2, 695 - 720.

Gonzalez, R. (1993): Die Hauptrogenstein-Formation der Nordwestschweiz: (mittleres Bajocien bis unteres Bathonien). Dissertation, Geologisch-Paläontologisches Institut der Universität Basel, Basel.

Gsell, F. (1968): Geologie des Falten- und Tafeljura zwischen Aare und Wittnau und Betrachtungen zur Tektonik des Ostjura zwischen dem Unteren Hauenstein im W und der Aare im E. Univ. Zürich Inaugural-Dissertation.

Gygi, R.A. (1969): Zur Stratigraphie der Oxford- Stufe (oberes Jura- System) der Nordschweiz und des süddeutschen Grenzgebietes.- Beitr. geol Karte Schweiz. N.F. 136.

Gygi, R.A. (1977): Revision der Ammonitengattung Gregoryceras (Aspidoceratidae) aus dem Oxfordian (Oberer Jura) der Nordschweiz und von Süddeutschland. Taxonomie. Phylogenie. Stratigraphie. Eclogae geol. Helv. 70/2, 435 – 542.

Gygi, R.A. (1981): Oolitic iron formations: marine or not marine? Eclogae geol. Helv. 74/1, 233-254.

Gygi, R.A. (1991): Die vertikale Verbreitung der Ammonitengattungen Glochiceras, Creniceras und Bukowskites im Späten Jura der Nordschweiz und im angrenzenden Süddeutschland. Stuttgarter Beiträge Naturkunde (B) 179, 1 - 41.

Gygi, R.A. (2000a): Annotated index of lithostratigraphic units currently used in the Upper Jurassic of northern Switzerland.- Eclogae geol. Helv. 93/1, 125-146.

Gygi, R.A. (2000b): Integrated stratigraphy of the Oxfordian and Kimmeridgien (Late Jurassic) in northern Switzerland and adjacent southern Germany.- Denkschr. schweiz. Akad. Natwiss. 104, 1-151.

Gygi, R.A. & Rieber, H. (1989): Der Aargauer Jura zwischen Laufenburg und Wildegg. Jahresberichte und Mitteilungen des Oberrheinischen Geologischen Vereins 71, 177-188.

Hagorn, H., & Nitsch, E. (2009). Field Guide, 6th International Triassic field Workshop, September 7–11, 2009. Tübingen, p. 72.

Hagdorn, H., & Simon, T. (2005). Der Muschelkalk in der Stratigraphischen Tabelle von Deutschland 2002. Newsletters on Stratigraphy, Stuttgart, 2005(41), 143–158.

Hahn, W. (1971): Der Jura. - in Sauer, K. & Schnetter, M. (1971): Die Wutach. Bad. Landesver. Natkd. u. NAturschutz, Freiburg i.B., 117-133.

Heim, A. (1919). Geologie der Schweiz. Band 1: Molasseland und Juragebirge. Leipzig: Tauchnitz.

Herold, T. (1992): Die Geologie der "Eptinger Bucht" unter besonderer Berücksichtigung der Sedimentologie des Hauptmuschelkalks. Diploma thesis, University Basel, Basel, p. 74.

Hofmann, F., Schlatter, R. & Weh, M. (2000): Erläuterungen zu Blatt 97: Beggingen (LK 1011) des Geologischen Atlas der Schweiz 1:25'000. Bundesamt für Wasser und Geologie, Bern.

Hofmann, R. & Sander, P.M. (2014): The first juvenile specimens of Plateosaurus engelhardti from Frick, Switzerland: isolated neural arches and their implications for developmental plasticity in a basal sauropodomorph. PeerJ. 2014 Jul 3;2:e458. doi: 10.7717/peerj.458. eCollection 2014.

Hostettler, B. (2012): New lithostratigraphical units for the Callovian stage in the central Swiss Jura Mountains. – Swiss Geoscience Meetings 2012, Abstracts: 169-170.

Hostettler, B., Reisdorf, A. G., Jaeggi, D., Deplazes, G., Bläsi, H., Morard, A., et al. (2017): Litho- and biostratigraphy of the Opalinus Clay and bounding formations in the Mont Terri rock laboratory (Switzerland). Swiss Journal of Geosciences, 110, 23–37.

Jordan, P. (1982): Lias zwischen Unterem Hauenstein und Schinznach / Die Geologie um Rohr SO. Unpubl. Diplomarb. Univ. Zürich.

Jordan, P. (1983): Zur Stratigraphie des Lias zwischen Unterem Hauenstein und Schinznach (Solothurner und Aargauer Faltenjura). Eclogae geol. Helv. 76/2, 355-379.

Jordan, P. (2016): Reorganisation of the Triassic stratigraphic nomenclature of northern Switzerland: overview and the new Dinkelberg, Kaiseraugst and Zeglingen formations. Swiss Journal of Geosciences, 109/2, 241-255. doi:10.1007/s00015-016-0209-4.

Jordan, P., Malz, A., Heuberger, S., Pietsch, J., Kley J. & Madritsch, H. (2015): Regionale geologische Profilschnitte durch die Nordschweiz und 2D-Bilanzierung der Fernschubdeformation im östlichen Faltenjura. Nagra Arbeitsbericht NAB 14-105.

Jordan, P., Pietsch, J., Kündig, N., Bläsi, H.R. & Deplazes, G. (2016a): Grundlagen zur Definition und Unterteilung der Klettgau- und Bänkerjoch-Formation (vormals Oberer und Mittlerer Keuper) in der Nordschweiz. Nagra Arbeitsbericht Bericht NAB 16-062.

Jordan, P., Pietsch, J.S., Bläsi, H.R., Furrer, H., Kündig, N., Looser, N., Wetzel, A. & Deplazes, G. (2016b): The middle to late Triassic Bänkerjoch and Klettgau formations of northern Switzerland. Swiss Journal of Geosciences, 109/2, 257-284. doi: 10.1007/s00015-016-0218-3.

Jordan, P., Wetzel, A. & Reisdorf, A. G. (2008). Jurassic. Swiss Jura Mountains. In T. McCann (Ed.), The Geology of Central Europe. Volume 2: Mesozoic and Cenozoic (pp. 880–889). London: The Geological Society of London.

Kazmaier, S. (2019): Mikrofaziesanalyse des Randengrobkalks der Oberen Meeresmolasse. Unpubl. Masterarb. Eberhard Karls Universität Tübingen.

Kiefer, L., Deplazes, G. & Bläsi, H.R. (2015): Sedimentologie und Stratigraphie des Frühen Juras in der Nordschweiz: Staffelegg-Formation und sich nach Osten anschliessende Vorkommen. Nagra Arbeitsbericht NAB 14-95.

Kleiner, J. (2009): Die Paläoumwelt der Keuperschichten und der Lias-Doggerschichten zwischen Küttigen und Frick (Aargauer Jura). Masterarbeit Universität Freiburg. (unpublished)

Kozur, H. & Bachmann, G.H. (2008): Updated correlation of the Germanic Triassic with the Tethyan scale and assigned numeric ages. Berichte der Geologischen Bundesanstalt, Wien 76, 53-58.

Kuhn, O. & Etter, W. (1994): Der Posidonienschiefer der Nordschweiz: Lithostratigraphie, Biostratigraphie und Fazies. Eclogae geol. Helv., 87/1, 113–138.

Lepper, J., Rambow, D. & Röhling, H.-G. (2005): Der Buntsandstein in der Stratigraphischen Tabelle von Deutschland 2002. Newsletters on Stratigraphy, Stuttgart 2005 41, 129-142.

Looser, N., Schneebeli-Hermann, E., Furrer, H., Blattmann, T. M., & Bernasconi, S. M. (2018): Environmental changes and carbon cycle perturbations at the Triassic–Jurassic boundary in northern Switzerland. Swiss Journal of Geosciences, 111(3), 445-460.

Lusser, C. (1980): Sedimentologie und Paläogeographie des unteren Doggers im zentralen und nördlichen Jura. Diss. Univ. Basel.

Lutz, M. (1964): Stratigraphische und tektonische Untersuchungen am südwestlichen Schwarzwaldrand zwischen Wiesental und Hochrhein. Oberrh. geol. Abh. 13/1-2, 75-122.

Matter, A., Peters, T., Bläsi, H.R., Meyer, J., Ischi, H. & Meyer, C. (1988): Sondierbohrung Weiach. Geologie. Nagra Technischer Bericht NTB 86-01.

Matter, A., Peters, T., Isenschmid, C., Bläsi, H.R. & Ziegler, H.-J. (1987): Sondierbohrung Riniken. Geologie. Nagra Technischer Bericht NTB 86-02.

Mazurek, M. & Aschwanden, L. (in prep.): Multi-scale petrographic and structural characterisation of the Opalinus Clay. Nagra Arbeitsbericht NAB 19-44.

Meier, I. (2011): Sulfur isotopes of Gipskeuper and Anhydritgruppe in Northern Switzerland. Master Thesis, ETH Zürich.

Merki, P. (1961). Der Obere Muschelkalk im östlichen Schweizer Jura. Eclogae geol. Helv., 54/1, 137–219.

Meyer, C.A. & Furrer, H. (1995): Taphonomie und paläoökologische Rekonstruktionen: Beispiele aus dem Mesozoikum des Jura. Bericht über die Exkursion der Schweizerischen Paläontologischen Gesellschaft gemeinsam mit der Schweizerischen Geologischen Gesellschaft am 4. Oktober 1994. Eclogae geol. Helv. 88/3, 711–720.

Meyer, C.F. & Thüring, S. (2003): Dinosaurs of Switzerland C. R. Palevol 2, 103–117.

Moesch, C. (1857): Das Flözgebirge im Kanton Aargau.- N. Denkschr. schweiz. Ges. Natw. 15(1856).

Moesch, C. (1863): Vorläufiger Bericht über die Ergebnisse der im Sommer 1862 ausgeführten Untersuchungen im Weissen Jura der kantone Solothurn unjd Bern. Verh. schweiz. naturforschenden Ges. in Luzern 1862, 156 - 167.

Moesch, C. (1867): Geologische Beschreibung des Aargauer-Jura und der nördlichen Gebiete des Kantons Zürich. Beitr. geol. Karte Schweiz 4.

Montero-Serrano, J. C., Föllmi, K. B., Adatte, T., Spangenberg, J. E., Tribovillard, N., Fantasia, A., & Suan, G. (2015): Continental weathering and redox conditions during the early Toarcian Oceanic Anoxic Event in the northwestern Tethys: Insight from the Posidonia Shale section in the Swiss Jura Mountains. Palaeogeography, Palaeoclimatology, Palaeoecology, 429, 83-99.

Mühlberg. M. (1900): Vorläufige Mitteilung über die Stratigraphie des Braunen Jura im nordschweizerischeJuragebirge. Eclogae geol. Helv. 6/4, 293-332.

Müller, W.H., Huber, M., Isler, A. & Kleboth, P. (1984): Erläuterungen zur Geologischen Spezialkarte Nr. 121 der zentralen Nordschweiz 1:100 000 mit angrenzenden Gebieten von Baden-Württemberg. NTB 84-25. Baden: Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (Nagra) und Schweizerische Geologische Kommission.

Nagra (1992): Sondierbohrung Siblingen. Untersuchungsbericht. Nagra Technischer Bericht NTB 90-34. Nagra, Wettingen.

Nagra (2001): Sondierbohrung Benken. Untersuchungsbericht. Nagra Technischer Bericht NTB 00-01. Nagra, Wettingen.

Nagra (2014): SGT Etappe 2: Vorschlag weiter zu untersuchender geologischer Standortgebiete mit zugehörigen Standortarealen für die Oberflächenanlage. Geologische Grundlagen. Dossier II: Sedimentologische und tektonische Verhältnisse. Nagra Technischer Bericht NTB 14-02. Nagra, Wetingen.

Nitsch, E. & Zedler, H. (2009): Oberkarbon und Perm in Baden-Württemberg. LGRB-Informationen, 22: 7–102; Freiburg i.Br.

Oppel, A. & Waagen, W. (1866): Über die Zone des Ammonites transversarius. Geognost.-paläont. Beiträge 1/2, 207-318.

Paul, W. (1971): Die Trias. In: Sauer, K. & Schnetter, M. 1971: Die Wutach. Naturkundliche Monographie einer Flusslandschaft. Natur- u. Landschaftsschutzgebiete Bad.-Württ., 6, 123 - 146. Freibur i.Br.

Peters, Tj. (1964): Tonmineralogische Untersuchungen an einem Keuper-Lias-Profil im Schweizer Jura (Frick). Schweizerische Mineralogische und Petrographische Mitteilungen 44, 1-30.

Peters, Tj., Matter, A., Bläsi, H.R. & Gautschi, A. (1986): Sondierbohrung Böttstein. Geologie. Nagra Technischer Bericht NTB 85-02.

Peters, Tj., Matter, A., Meyer, J., Isenschmid, C. & Ziegler, H.J. (1989): Sondierbohrung Kaisten. Geologie. Nagra Technischer Bericht NTB 86-04.

Pietsch, J., Wetzel, A., Jordan, P., (2016): A new lithostratigraphic scheme for Schinznach Formation (Upper Muschelkalk of Northern Switzerland). - Swiss Journal of Geosciences 109, 285-307. DOI 10.1007/s00015-016-0214-7.

Pöppelreiter, M. (2002): Facies, cyclicity and reservoir properties of the Lower Muschelkalk (Middle triassic) in the NE Netherlands. https://doi.org/10.1007/BF02668077

Quenstedt, F.A. (1843): Das Flözgebirge Würtembergs mit besonderer Rücksicht auf den Jura. Verlag der H. Laupp'schen Buchhandlung, Tübingen.

Reisdorf, A.G., Wetzel, A., Schlatter, R. & Jordan, P. (2011): The Staffelegg Formation: a new stratigraphic scheme for the Early Jurassic of northern Switzerland. Swiss Journal of Geosciences 104, 97-146.

Remane, J., Adatte, T., Berger, J.-P., Burkhalter, R., Dall'Agnolo, S., Decrouez, D., Fischer, H., Funk, H., Furrer, H., Graf, H.-R., Gouffon, Y., Heckendorn, W. & Winkler, W. (2005): Richtlinien zur stratigraphischen Nomenklatur. Eclogae geol. Helv. 98/3, 385-405.

Rick, B. (1990): Geotechnische und hydrochemische Folgen der Verwitterung sulfathaltiger Gesteine (Gipskeuper des Schweizer Jura) Diss. Naturwiss. ETH Zürich, Nr. 9257.

Rieber, H. (1973): Fauna und Stratigraphie einer oolithischen Kalkbank aus dem Toarcium von Gipf (Kanton Aargau). Eclogae geol. Helv. 66/3, 657–665.

Sander, P. M. (1992): The Norian Plateosaurus bonebeds of central Europe and their taphonomy. Palaeogeography, Palaeoclimatology, Palaeoecology, 93, 255-299.

Schalch, F. (1916): Geologische Spezialkarte des Grossherzogtums Baden. Erläuterungen zu Blatt Wiechs-Schaffhausen (Nr. 145). Heidelberg: Carl Winter's Universitäts-buchhandlung.

Schindler, C. (1962): Gipsvorkommen zwischen Riepel und Staffelegg. Unpubl. Gutachten geotechnisches Büro Dr. A. von Moos für Jura-Cementfabrik Aarau-Wildegg.

Schlatter, R.K. (1975): Geologische und paläontologische Untersuchungen im unteren Lias des Donau-Rhein-Zuges. Unpubl. Diplomarb. Univ. Zürich.

Schlatter, R. (1983): Erstnachweis des tiefsten Hettangium im Klettgau (Kanton Schaffhausen, Schweiz). Mitteilungen der Naturforschenden Gesellschaft Schaffhausen, 32, 159–175.

Schmassmann. H. (1945): Stratigraphie des mittleren Doggers der Nordschweiz. PhD-thesis Univ. Basel.

Schmassmann. H. & Bayramgil. O. (1946): Stratigraphie. Pétrographie und Paläogeographie der Perm-Formation im schweizerischen Tafeljura und die Steinkohlenfrage der Nordschweiz. Tätber. Natf. Ges. Baselland 15. 17-117.

Schneebeli-Hermann, E., Looser, N., Hochuli, P. A., Furrer, H., Reisdorf, A.G., Wetzel, A., & Bernasconi, S.M. (2018): Palynology of Triassic–Jurassic boundary sections in northern Switzerland. Swiss Journal of Geosciences, 111(1-2): 99-115.

Strübin, K. (1901): Neue Aufschlüsse in den Keuper-Liasschichten von Niederschönthal (Basler Tafeljura). Eclogae geol. Helv. 7/2, 119-123.

Timescale Creator, version 7.1 (03. June 2017): Geologic TimeScale Foundation. https://engineering.purdue.edu/Stratigraphy/tscreator/. (last access: 13 November 2019)

Tröster, J. (1987): Biostratigraphie des Obertoarcium und der Toarcium/Aalenium Grenze der Bohrungen Weiach, Beznau, Riniken und Schafisheim (Nordschweiz). Eclogae geol. Helv. 80/2, 431–447.

Trümpy, R. (1980): Geology of Switzerland: a guide-book, Part A: An outline of the Geology of Switzerland. Basel (Wepf).

Urlichs, M. (1987): Revision der Gattung Ceratites de Haan 1825 (Ammonoidea, Mitteltrias). Stuttgarter Beiträge zur Naturkunde, Serie B, 128, 36 S.

Vogt, T., Ebert, A., Häring, C., Becker, J.K., Traber, D., Deplazes, G., Bläsi, H.R. & Rufer, D. (2016): Kernbohrung Lausen: Geologische, hydrogeologische und bohrlochgeophysikalische Untersuchungen (Rohdatenbericht). Nagra Arbeitsbericht, NAB 15-10.

von Alberti, F. (1864): Überblick über die Trias mit Berücksichtigung ihres Vorkommens in den Alpen. Verlag der J. G. Cottaschen Buchhandlung, Stuttgart.

Voss. H.H. (1969): Untersuchungen zur Gliederung und Fazies der Parkinsoni-Schichten (Oberes Ober-Bajocium/Unter Bathonium) in der Umrandung des südlichen Oberrheingrabens und seiner Nachbargebiete.PhD-thesis Univ. Freiburg i. Br.

Wetzel, A. & Allia, V. (2003): Der Opalinuston in der Nordschweiz: Lithologie und Ablagerungsgeschichte.- Eclogae geol. Helv. 96/3, 451-469.

Wetzel, A. & Strasser, A. (2001): Sedimentology, palaeoecology, and high-resolution sequence stratigraphy of a carbonate-siliciclastic shelf (Oxfordian, Swiss Jura Mountains). Excursion Guide, 21st IAS Meeting of Sedimentology, Davos, Switzerland, 33-51.

Widmer, T. (1991): Zur Stratigraphie und Sedimentologie der Anhydritgruppe (Mittlere Trias) in der Region Liestal - Arisdorf (Baselland, Nordwestschweiz). Beitr. Geol. Schweiz, geotechnische Serie 79, 108 p.

Wildi, W. (1976): Die Molluskenfauna des Gansinger Dolomite (Trias, Karnian, Mittlerer Keuper) im aargauischen Tafeljura (Nordschweiz). Eclogae geol. Helv. 69/3, 671-684.

Wohlwend, S., Bläsi, H.R., Feist-Burkhardt, S., Hostettler, B., Menkveld-Gfeller, U., Dietze, V. & Deplazes, G. (2019): Die Passwang-Formation im östlichen Falten- und Tafeljura: Fasiswald (SO) – Unt. Hauenstein (SO) – Wasserflue (AG) – Thalheim (AG) – Frickberg (AG) – Cheisacher (AG) – Böttstein (AG) – Tegerfelden (AG) – Acheberg (AG). Nagra Arbeitsbericht, NAB 18-11.

Wurster, P. (1964): Geologie des Schilfsandsteins. – Mitteilungen des geologischen Staatsinstitutes Hamburg, 33 1 – 140.

Würtenberger, F.J. & Würtenberger, L. (1866): Der Weisse Jura im Klettgau und angrenzenden Randgebieten. Verh. natw. Ver. Karlsruhe 2, 11-68.

Zeiss, A. 1955: Zur Stratigraphie des Callovien und Unter-Oxfordien bei Blumberg (Südbaden). Jh. geol. Landesamt Baden-Württemberg 1, 239-266.

Ziegler, B. (1977): The "White" (Upper) Jurassic in Southern Germany. – Stuttgarter Beitr. Naturkde, B, 26: 1–79, 42 Abb., 11 Taf., Stuttgart.