E&G Quaternary Science Journal
Volume 60 / Number 2–3 / 2011 / 306–328 / DOI 10.3285/eg.60.2-3.07
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

The Quaternary of the southwest German Alpine Foreland (Bodensee-Oberschwaben, Baden-Württemberg, Southwest Germany)

Dietrich Ellwanger, Ulrike Wielandt-Schuster, Matthias Franz, Theo Simon

Abstract: The Quaternary of the 'Bodensee' region comprises Early Pleistocene fluvial gravels ('Deckenschotter') and Middle and Late Pleistocene glacial and meltwater deposits of the Rhineglacier. They reflect the transformation of the alpine margin from a foothill ramp to the overdeepened amphitheatre (today's topography). The 'Deckenschotter' reflect not only fluvial incision but also, according to major differences in petrographical composition, the evolution of their alpine source area (alpine Rhine Valley). The eldest glacial till is in contact with the 'Mindel-Deckenschotter', displaying no evidence of major overdeepening in this early time slice. Most glacial and meltwater deposits are attributed to three major foreland glaciations of the Rhineglacier forming three generations of overdeepened basins. The eldest basins are directed northward to the Donau, those of the last glaciation go west towards the Rhine. This re-orientation improves the resolution of glacial sediments and landforms. The glacial deposits are traditionally described as chronostratigraphical system based upon glacial versus interglacial units. In this paper, an updated version of this chronostratigraphy is presented, supplemented by a lithostratigraphical system that primarily focusses on sediment bodies. Finally, short definitions of major lithostratigraphical units are outlined that are used by the Geological Survey of the German State of Baden-Württemberg.

[Das Quartär des südwestdeutschen Alpenvorlandes (Bodensee-Oberschwaben, Baden-Württemberg, Südwestdeutschland)]

Kurzfassung: Das Quartär der Bodensee-Region besteht aus Schottern frühpleistozäner alpiner Flusssysteme (Deckenschotter) sowie aus glazialen und Schmelzwasser-Ablagerungen der mittel- und spätpleistozänen Eiszeiten. Sie belegen den landschaftlichen Wandel von einer Art Rampe aus Vorbergen hin zur heutigen Topographie mit ineinander greifenden, übertieften Becken, sodass sich eine Art Amphitheater ergibt. Die Deckenschotter als älteste Ablagerungen dokumentieren einerseits die Eintiefung der alpinen Flüsse in diversen Terrassenstufen im Sedimentationsgebiet, andererseits durch deutliche Unterschiede im Geröllspektrum die Vergrößerung des Liefergebiets des sich entwickelnden alpinen Rheins. Der älteste Till kommt vor in Kontakt mit Mindel-Deckenschottern, es gibt jedoch keine Hinweise auf eine glaziale Übertiefung in dieser Zeit. Die meisten glazialen und Schmelzwasser-Ablagerungen werden drei großen Vergletscherungen des Rheingletschers zugeordnet. Diese Vorlandvergletscherungen sind mit drei Generationen glazialer Becken verknüpft. Die ältesten Becken sind zur Donau orientiert, die aus der letzten Vereisung entwässern zum Rhein. Diese Reorientierung bewirkte die hervorragende räumliche Auflösung der Sedimente und Formen. Traditionell wurden die Sedimente in einem chronostratigraphischen System aus glazialen und interglazialen Stufen beschrieben. Unsere Ziele in dieser Arbeit sind, eine Aktualisierung des chronostratigraphischen Systems vorzustellen, das neue, beim geologischen Dienst von Baden-Württemberg angewandte, lithostratigraphische Schema zu erklären und die wichtigsten neuen Einheiten kurz zu beschreiben.

Keywords: *Pleistocene, Rhineglacier, chronostratigraphy, lithostratigraphy, Deckenschotter, glacial deposits, overdeepening*

Addresses of authors: **Dr. D. Ellwanger, Dr. U. Wielandt-Schuster, Dr. Matthias Franz, Prof. Dr. Th. Simon,** Regierungspräsidium Freiburg (Abteilung 9 LGRB), Albertstrasse 5, D-79104 Freiburg i. Br. E-Mail: dietrich.ellwanger@rpf.bwl.de

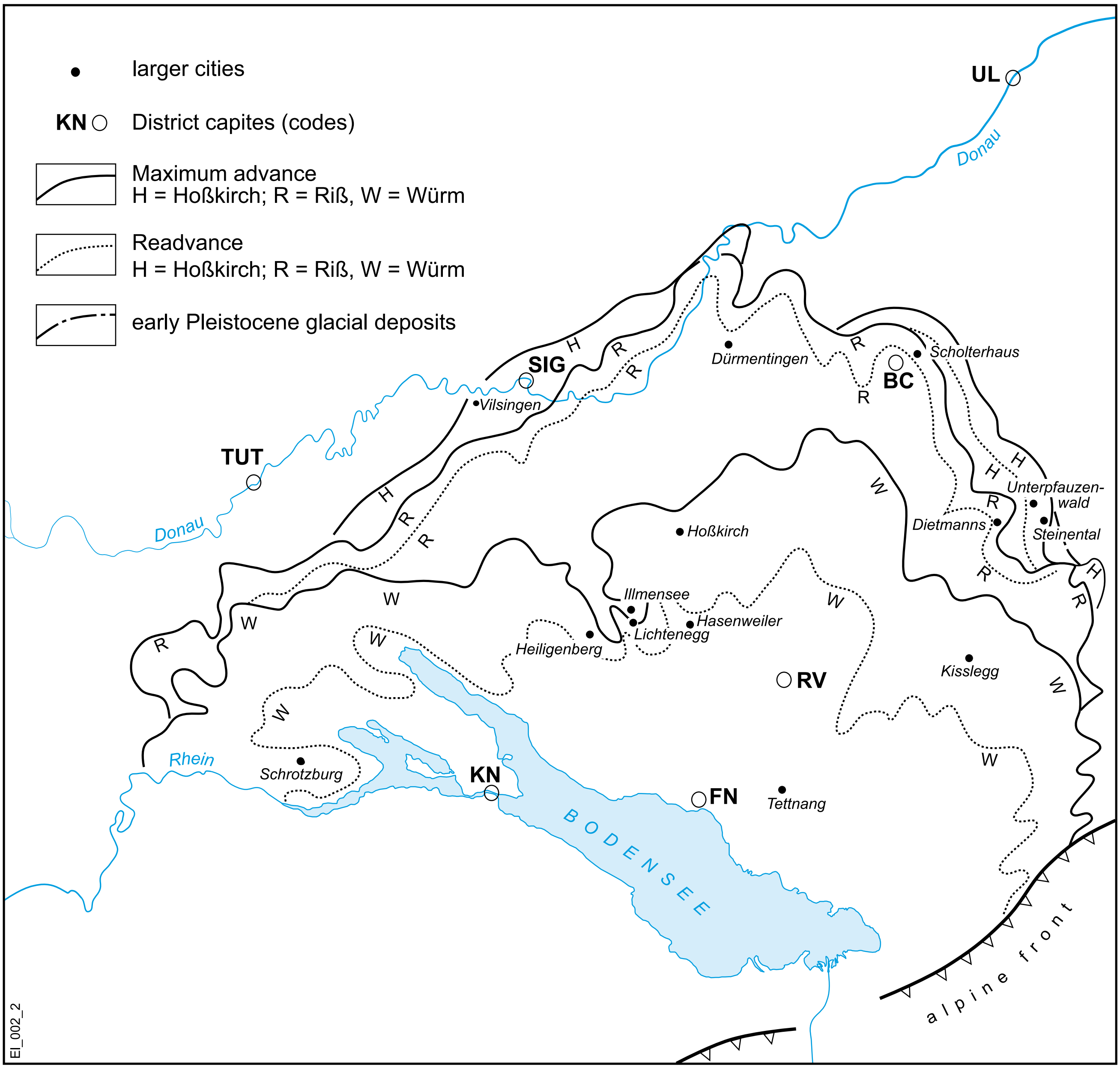

Fig. 1: Major cities and locations of the area between the Bodensee and Donau Valley, including locations referring to the formations and members of the new lithostratigraphical terms (ch. 4). – Also included are the major terminal moraine walls of the Rhineglacier; continuous lines: maximum advances of the Würmian (W), Rissian (R), and Hosskirchian (H) glaciations; dashed lines: readvances embracing glacially overdeepened basins. Cf. Fiebig 1995, 2003, LGRB 2005, Ellwanger 2003.

Abb. 1: Wichtige Städte in der Bodenseeregion und dem Donautal sowie die namengebenden Orte der neuen lithostratigraphischen Einheiten (siehe Kapitel 4). Die Hauptmoränenendwälle des Rheingletschers der Würm-, Riss- und Hosskirch-Eiszeiten sind als durchgezogene Linien dargestellt (W, R und H). Die Moränenwälle der Wiedervorstöße (gepunktete Linien) umranden die glazial übertieften Becken. Siehe hierzu auch Fiebig 1995, 2003, LGRB 2005, und Ellwanger 2003.

1 Introduction

The topography of the southwest German Alpine Foreland is the result of erosion (mainly of Tertiary bedrock) and deposition in the Quaternary (of mainly fluvial, glacial and lacustrine sediments). The major landforms were shaped by ice and meltwaters of the Rhineglacier in the Middle and Late Pleistocene. Before that, the area hosted several great rivers that are reconstructed using remnants of their fluvial sediments. Remnants of the eldest 'Deckenschotter' ('Donau-Deckenschotter') are found only in the nearby Bavarian and Swiss parts of the Alpine Foreland.

The area may be subdivided in four parts (Figs. 1, 2, 3):

- A deep "central foreland basin" (the 'Bodensee-Stammbecken') forms the core of the amphitheatre like modern topography. It is the prolongation of the overdeepened alpine Rhine Valley and surrounded by overdeepened "branch basins". All are filled with lacustrine sediments. There are highlands between the branch basins covered by drumlin moraines. An end moraine wall that represents a major readvance of the ice engulfs the branch basins and drumlin fields. Concentrically outside this inner moraine wall, a till plain with relics of the ice decay extend towards an outer end moraine. Principally the same holds for all

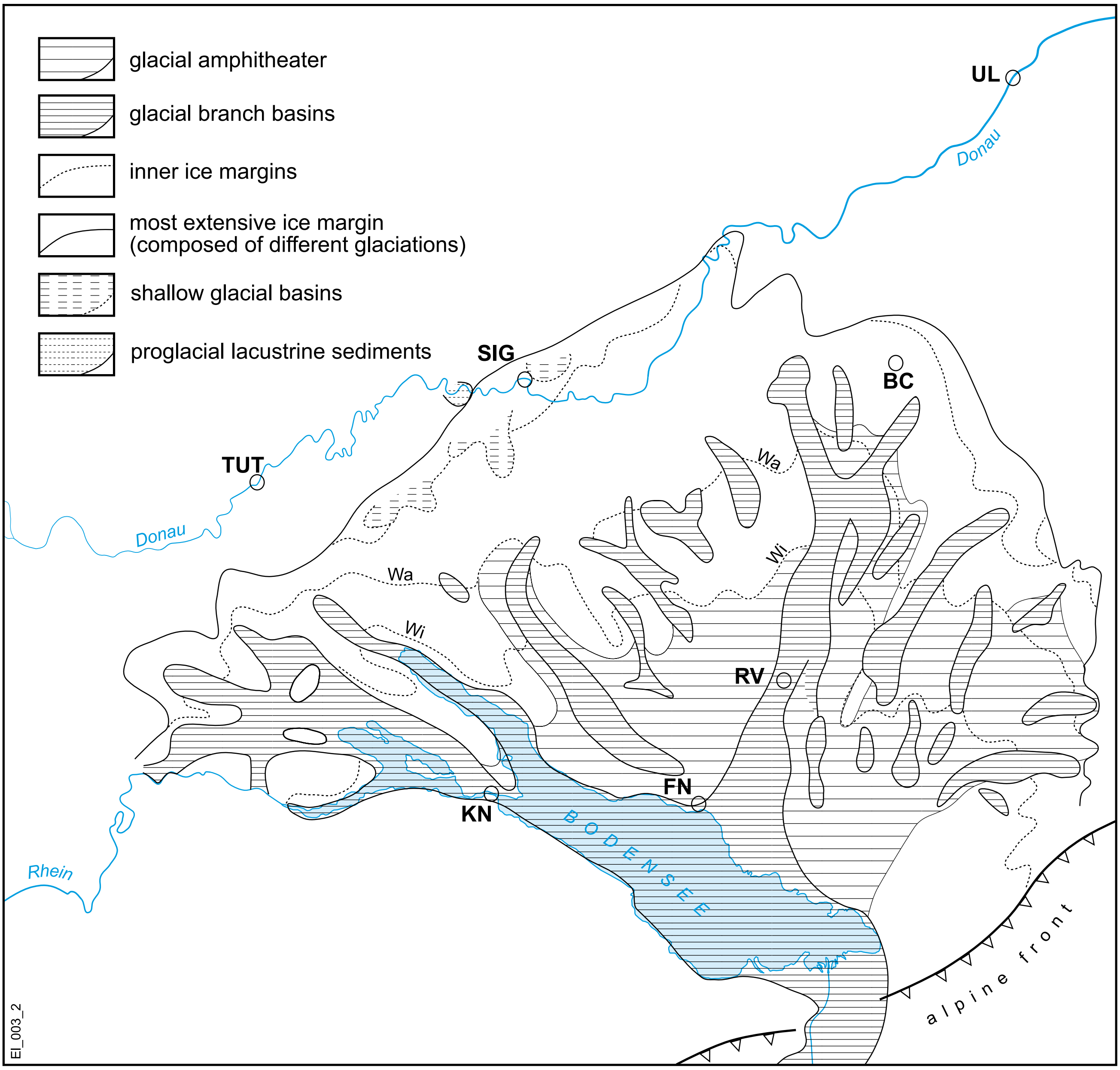

Fig. 2: Compilation of overdeepened basins of the Rhineglacier (north and west of the Bodensee) and the diachronous most extensive ice margin. Cf. Ellwanger et al. 1995, 2011.

Abb. 2: Zusammenstellung aller glazial übertieften Becken des Rheingletschers (nördlich und westlich des Bodensees) und der sich aus mehreren Gletschervorstößen ergebenden maximalen Eisbedeckung. Siehe hierzu Ellwanger et al. 1995, 2011.

three large foreland glaciations. The amphitheatre therefore results from the backstepping overdeepening towards the Alps in each glaciation.

- Northeast of the amphitheatre follows a series of fluvial terraces ('Iller-Riss-Platte') representing river and meltwater systems tributary to the Donau (Danube).

- Northwest of the amphitheatre there are elderly moraines with no or only shallow basins. Here, the alpine ice cover extended even beyond the Jurassic of the Swabian Alb.

- To the west, some deeply incised valleys are located in continuation of the central foreland basin. Deposits include moraines and gravels that further extend towards the Hochrhein Valley (between Basel and the Bodensee) and finally to the Upper Rhine Graben (URG).

The actual central basin hosts the Bodensee (Lake Constance), the largest lake north of the Alps. In some parts the base of Quaternary reaches down below sea level. This overdeepened surface has evolved from a pre-glacial, ramp-like topography with pre-alpine mountains and foothills and valleys of the alpine 'Deckenschotter' rivers. The present topography northeast and northwest of the amphitheatre still preserves a northern part of the ramp. The transformation of this ramp into the overdeepened topography is the "golden thread" of the Quaternary story of this area.

The transformation goes along with a hydrological reorientation of the area from the Donau system to the Rhine system i.e. from the Mediterranean to the North Sea. As an effect of the reorientation, each one of the three major glaciations has its own pattern of large landforms and sediment units. This is a "high-resolved" geomorphology that is often (not always) helpful to identify the stratigraphy of relief units (accommodation space) and sediment bodies (infill). This situation is unique, as in many other areas, the different ice advances keep following the same valleys.

East and west of the Bodensee amphitheatre, i.e. the Bavarian Alpine Foreland and the Swiss Midlands, the foreland topography is quite different. In Bavaria, wide fluvial gravel fields prevail, all directed towards the Donau. The glacial basins are smaller and located close to the alpine margin (Doppler et al. 2011). As opposed to this, the Swiss midlands were completely covered by ice. A mountainous topography prevails that includes Molasse highlands and strongly overdeepened valleys. This area is part of the Rhine system (Preusser et al. 2011).

Key areas for correlation with the Bavarian and Swiss Quaternary stratigraphy are the landsystems northeast and west of the Bodensee amphitheatre. I.e. the 'Deckenschotter' and meltwater terraces of the 'Iller-Riss-Platte' serve to correlate with the Bavarian terrace plains, as do the glacial basins towards the Hochrhein Valley to correlate with the Swiss midlands. An additional control is to use independent sedimentary evidence from its major sediment trap in the southern Upper Rhine Graben. To relate the special features of the neighbour regions with the high-resolved patterns of the Bodensee amphitheatre remains, up to now, a major challenge.

The actual chrono- and lithostratigraphy of the 'Bodensee-Oberschwaben' area is primarily based on three data sources: (1) the results of a century of geological mapping and research, (2) new key observations, (3) time markers. All data are evaluated focussing the actual chrono- and lithostratigraphical concepts and are summarized in a morphogenetical scenario.

Use of terms: Chronostratigraphy refers primarily to a (relative) time scale, lithostratigraphy to spatial correlation. Glaciation refers to ice advances in intervals of cold climate between interglacial periods.

2 The Basics: Observations and concepts

2.1 Traditional mapping and research

The stratigraphical tradition in the Alpine Foreland goes back to the first (and so far only) synopsis of the alpine Quaternary: Penck & Brückner's (1901/09) "circumalpine subdivision of the ice-age" (Die Alpen im Eiszeitalter) came out at the beginning of the 20th century. The four units 'Günz', 'Mindel', 'Riss' and 'Würm' were introduced that, ever since, were referred to as "alpine" units of the Quaternary.

Originally, the alpine units represented four terrace stages in prealpine valleys, i.e. this is a morphostratigraphical system referring to fluvial landforms:

- 'Niederterrasse' ('Würm', Late Pleistocene),
- 'Hochterrasse' ('Riss', Middle Pleistocene),
- 'Jüngere Deckenschotter' ('Mindel', Early Pleistocene),
- 'Ältere Deckenschotter' ('Günz', Early Pleistocene).

Penck & Brückner argued that the Würmian 'Niederterrasse' and the Rissian 'Hochterrasse' are correlated with adjoining (end-) moraines. They further argued that terraces outgoing from moraines were meltwater terraces. Both, moraines and terraces, were regarded as elements of a "glacial complex" ("Glaziale Serie"). Analogue to the Würmian and Rissian terraces, the 'Deckenschotter' terraces ('Günz' and 'Mindel') were also interpreted as elements of glacial complexes ('Glaziale Serien'). This is the basic consideration how the "tetra-glacial system of the alpine Quaternary stratigraphy" had been established.

In the decades to come, many authors have contributed to work out the alpine system in more detail. Primarily, additional terraces were identified, though on a more or less local level and definitely not "circumalpine". In parts of the Bodensee area, the four original units were mapped more precisely, some units were subdivided, new units added. Some deposits were even classified as 'Günz'- and 'Mindel' aged moraines. Additional terrace units permanently established were the 'Donau-Deckenschotter' (Eberl 1930, Löscher 1976) and the 'Biber-Deckenschotter' (Schaefer 1965). Following the system of the glacial complexes, they were both introduced as pre-'Günz'-glaciations of the so-called 'Ältestpleistozän' ("most early Pleistocene" or "earliest Pleistocene").

As correlation between the different gererations of units became more and more confusing, a "revision of nomenclature" was felt to be necessary. It ended up with a major re-interpretation of the 'Riss/Mindel', 'Mindel/Günz', and 'Günz/Donau' boundaries (Graul 1962, Schädel & Werner 1963).

After revision, more units were added: the 'Haslach-Deckenschotter' (between 'Günz' and 'Mindel', Schreiner & Ebel 1981, GLA 1995), the 'Jungriss'-Glaciation and the 'Saulgau'-Glaciation (both between Riss and Würm, Schreiner 1989, 1997, Frenzel 1991, cf. Habbe 1994, 2003, 2007). Again, the new units were only identified in few locations, but this lack of evidence was felt to be a lack of exposure or of thorough mapping. In an effort to cover possibly still unidentified units in all places, the concept of complex-units was introduced. The latest terms include 'Würm-Komplex', 'Riss-Komplex', 'Mindel-Komplex' (or 'Haslach-Mindel-Komplex'), 'Günz-Komplex', 'Biber-Donau-Komplex' etc.

All this is only a rough summary of the history of the morphostratigraphical terms and concepts, to illustrate some of the pitfalls to be avoided when using all these highly valuable data from elderly sources. This includes the use of the geological maps in scale 1:25.000: Its last sheets have recently been completed using the latest generation or terms, but production of the first sheets had started even before Penck & Brückner's circumalpine nomenclature was established. I.e. this dataset includes almost all the above add-ons, revisions and subdivisions.

In our actual approach, many results of the morphostratigraphical maps and papers are further used after being transformed accordingly. This includes terminal moraines, patterns of terrace stratigraphy, but also features related to the relief as fossil soil successions or periglacial sediment covers ("pedostratigraphy"). Some large relief elements, e.g. glacial basins serving as major sediment traps, are now much more focussed upon than before. Other elements of the morphostratigraphical approach had to be re-interpreted or even abandoned. This includes the use of Penck's "glacial complex" regarding the 'Deckenschotter'

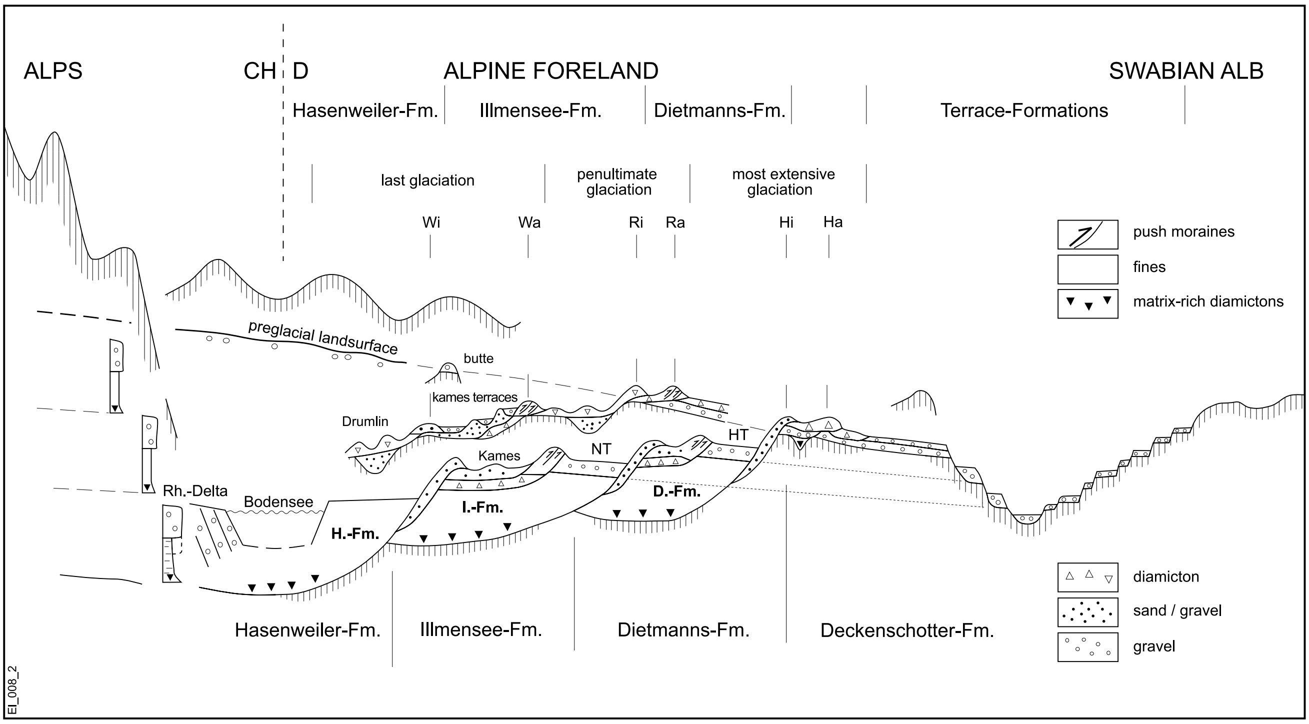

Fig. 3: Schematical cross section of the amphitheatre of the Bodensee area, from the alpine front in the south, to the terrace-landscape and Donau Valley in the north: – Top, 3rd backdrop: surface of the former foothills in the Early Pleistocene (Gelasian super stage), acting as watershed between the Bavarian 'Donau-Deckenschotter' and the Swiss 'Höhere Hochrhein-Deckenschotter' i.e. between the valleys of Donau and Rhine. – Upper middle, 2nd backdrop: niveau of an Early Pleistocene 'Deckenschotter' valley (Calabrian super stage), representing the evolving valley of the alpine Rhine. – Lower middle, 1st backdrop: Bodensee amphitheatre, niveau of the surface of three generations of Middle and Late Pleistocene highs between glacial basins (Hasenweiler-, Illmensee-, and Dietmanns-Fm.), covered by drumlins, kames, kame terraces etc. – Front (main section): Bodensee-amphitheatre, niveau of the surface of three generations of overdeepened glacial basins (Dietmanns-, Illmensee- and Hasenweiler-Fm.) The actual Bodensee marks the central basin where deposition is still ongoing. – North of the amphitheatre, the "old surface" of the Early Pleistocene 'Deckenschotter' is only modified by fluvial erosion shown by fluvial terrace levels towards the Donau Valley.
This landsystem exhibits an overall negative sediment budget. Its thickest and best-resolved sediment successions are hosted within the overdeepened glacial basins. Together with correlative terminal moraines (of the readvances of the Hosskirchian = Hi, Rissian = Ri, and Würmian = Wi stages), the unconformities are used to subdivide the sediment succession into formations. Cf. Fiebig 1995, 2003, LGRB 2005, Ellwanger 2003, Ellwanger et al. 2011.

Abb. 3: Schematischer Schnitt durch das Amphitheater des Bodenseegebiets von den Alpen im Süden (links) bis zur Terrassenlandschaft des Donautals im Norden (rechts): – Oben, 3te Kulisse: Ehemalige Vorberge des Unteren Pleistozän (Gelasium). Sie trennten als eine Wasserscheide die Abflüsse Richtung Donau und Rhein und somit die Donau-wärtigen Deckenschotter Bayerns von den „Schweizer" Höheren Hochrhein-Deckenschottern. – Obere Mitte, 2te Kulisse: Niveau des unterpleistozänen Deckenschottertales (Calabrium), des sich entwickelnden Alpenrheins. – Untere Mitte, 1te Kulisse: Bodensee Amphitheater, Schnitt durch die Hochgebiete des Mittleren und Oberen Pleistozän (drei Generationen: Hasenweiler-, Illmensee-, und Dietmanns- Formationen) zwischen den Glazialbecken; Die Landshaft ist geprägt von Drumlins, Kames und Kamesterrassen etc. – Vorne (Hauptschnitt): Bodensee-Amphitheater, Schnitt durch die übertieften Glazialbecken der Dietmanns-, Illmensee- and Hasenweiler- Formationen) Der Bodensee selbst stellt das zentrale Becken der letzten Vergletscherung dar, in dem die Ablagerung unvermindert fortdauert. – Nördlich des eigentlichen Amphitheaters wird die „alte" Oberfläche der frühpleistozänen Deckenschotterlandschaft nur durch fluviale Erosion überprägt, was sich in den Flußterrassen Richtung Donautal ausdrückt.
Dieses Landschaftssystem ist durch ein generell negatives Sedimentbudget charakterisiert. Die Glazialbecken enthalten die mächtigsten und hochauflösendsten Sedimentabfolgen. Die basalen Diskontinuitätsflächen und ihre zugehörigen Endmoränen (der Wiedervorstöße der Hosskirch = Hi, Riss = Ri, und Würm = Wi Eiszeiten) werden herangezogen um die Abfolgen in Formationen zu gliedern. Siehe auch Fiebig 1995, 2003, LGRB 2005, Ellwanger 2003, Ellwanger et al. 2011.

units and the position of some stratigraphical boundaries.

The first steps towards lithostratigraphy were the observations of Schädel (1950, 1953) that the 'Deckenschotter' gravels in the Bodensee area differ not only in position, but also in petrographical composition: He found out that the higher niveaus are poor in crystalline pebbles (< 5 %) but rich in dolomite (highest terrace, e.g. 'Donau'-aged), respectively rich in helvetic limestones (middle level, e.g. 'Günz'-aged). Only the 'Mindel'-aged gravels of the lowest terrace are rich in crystalline (> 10 %, sometimes up to 35 %). Obviously, this reflects differences in sediment provenance.

2.2 New key observations and re-interpretations

Improved information on Quaternary sediments became available as drilling activities increased. Cores and samples come from both, research projects and studies of Applied Geology (e.g. Hydrogeology, Raw Materials, Engineering Geology). The identification of the geometry of sediment bodies and the correlation of sedimentary units were used to supplement the traditional morphostratigraphical correlation. To make Quaternary stratigraphy serve as a correlation tool further on, an updated system will have to focus more strongly on sediments, i.e. it has to be shifted towards lithostratigraphy. The mere inclusion of drilling results into the old concepts is not enough; we strongly believe that some conceptual re-adjustments are also inevitable.

The basic considerations are:

- More emphasis than before is given to Penck & Brückner's basic distinction of 'Deckenschotter' (Günzian, Mindelian) and "terrace gravels" (Rissian, Würmian). Terrace gravels are related to large foreland glaciations where terminal moraine walls and other morainic landforms and sediments are hosted in an amphitheatre topography that also includes the overdeepened glacial "branch-" basins. There is no evidence of a likewise overdeepened topography related to the 'Deckenschotter' units. They are suggested to represent an alpine fluvial system (Fig. 2 and Fig. 8) that is preserved in buttes, large gravel-filled channels and gravel terraces (Fig. 3 and Ellwanger 2003).

- A series of deep core drillings into the glacial basin of Hosskirch (Fig. 1) revealed sub- and proglacial deposits grading up into interglacial deposits of Holsteinian age at the bottom of the basin, well below of a butte of 'Mindel-Deckenschotter'. Here, a new major alpine glacial unit had to be introduced between the 'Mindel-Deckenschotter' and the Rissian unit (Ellwanger et al. 1995, Ellwanger 2003). It has been labelled 'Hosskirch glaciation'. Hosskirchian glacial and periglacial sediments were also mapped elsewhere: either outside of the Rissian terminal moraines, or beneath the Rissian till sheets. Alike to the setting of the 'Hosskirch' Basin, the stratigraphical identification of Hosskirchian sediments is best if a Holsteinian time marker is available. – Including the Hosskirchian unit, there is evidence of three major glaciations in the Bodensee area (Hosskirchian, Rissian, Würmian).

- All three major glaciations (Würmian, Rissian, Hosskirchian) turn out to be twincycles (Figs. 1 & 4) that include two major ice advances (Fiebig 1995, 2003, STD 2002). Each advance is represented by (Fig. 3) a till sequence, sometimes associated with other sediments of advancing and/or downmelting ice. The overdeepened basins usually contain a succession of glaciolacustrine, lacustrine and peri- to postglacial deposits; they clearly indicate the final downmelting of the ice (there is no subglacial till). There are three types of assemblages: (a) bold terminal moraines (often push moraines) associated with a till sequence that is dominated by sands and gravels of downmelting stagnant ice (kames and eskers), (b) terminal moraines associated with drumlinized till (drumlin fields) featuring advancing ice, and (c) terminal moraines more or less closely engulfing the overdeepened basins (their infill again featuring downmelting). The terminal moraines in (b) and (c) represent the same ice advances.

- The major erosion is a matter of huge sediment discharge from inside and outside of the alpine margin. The mass deficit has to be complemented with a mass surplus elsewhere. The Upper Rhinegraben (URG) serves as the first major sediment basin of the Rhine system between the Alps and the North Sea. At its southern end is a huge fan of alpine debris. Here, numerous drillings reveal a sediment succession that includes in its upper part two impressive horizons with coarse components in a poorly sorted matrix. They are suggested to be correlative with the basin erosion unconformities of the glacial basins at the alpine margin, reflecting the high sediment transport dynamics of the erosion events (erosion-accumulation-systems, Ellwanger 2003). This scenario is directly applied for the last and penultimate glaciation. Regarding the prepenultimate generation of glacial basin (Hosskirchian), the correlative sediment patterns in the Upper Rhine Graben (URG) become more complicated. There was probably less sediment input from the Rhine Glacier (that was still more directed towards the Donau valley), and increased subsidence (in the URG) and uplift (at the margin) have to be considered (e.g. Gabriel et al. 2008).

- The correlation of basin erosion events with the coarse horizons in the URG implies huge sediment volumes to be transferred through the Hochrhein Valley in a short time. In this process, the valley suffered strong morphogenesis. Large terrace levels were created mainly by erosion. Only in some wide parts of the valley, accumulation sporadically continued, e.g. the massive coarse horizon in Wyhlen (cf. Geotop Wyhlen 2007). There are two main terrace levels ('Hochterrasse', 'Niederterrasse'). Their gravel bodies are often composed by multiple gravel cycles that may even comprise quite elderly accumulation periods, e.g. of older glacial cycles. If at all, only the terrace surfaces may be considered as element of a "glacial series", not the gravel body.

Combining the above with the "traditional" approach to Quaternary forms and sediments, the distinction between glacial and non-glacial sedimentary environments (i.e. fluvial, lacustrine) becomes more specific. Not only the 'Deckenschotter' gravels, but also parts of the Middle and Late Pleistocene terrace gravels are now considered to be of fluvial i.e. non-glacial origin. This is a major difference to the classical concept still using the "glacial series". We now interpret fluvial sediments as fluvial sediments, and not as an indirect proof of a glacial source; this is less hypothetical than the classical approach. In consequence, a glacial setting now has to be primarily identified by subglacial deposits (e.g. till).

The above results may be combined with time markers to set up a chronostratigraphical system updating the traditional morphostratigraphy, or they may be used to establish a lithostratigraphy of unconformity-bounded sediment units. The latter would be basically a sequence stratigraphic approach that also includes the potential to predict certain features, as sediment successions or the range of future ice advances. Both systems are "state-of-the-art"; it depends on the issue to be solved, which is more appropriate.

2.3 Time markers

The incorporation of time markers is inevitable in chronostratigraphy and quite helpful to control correlation in lithostratigraphy. The time markers used here come from biostratigraphy and palaeomagnetism; they comprise the "European Neogene Mammal Zone 17" (MN17), the pollen assemblages of the north-west-European warm periods of the Bavelian, the Holsteinian and the Eemian, and the Matuyama Epoch of the palaeomagnetic record.

For various reasons, physical age estimates, e.g. luminescence datings (OSL), are not included. That is because, up to now, there are too few "state of the art" studies delivering reliable physical ages of the Rhineglacier area, to be competitive with the biostratigraphical markers. Still we quote some actual studies of different units as examples:

- Würmian: luminescence datings by Kock et al. (2009) and Frechen et al. (2010) deliver inconsistent ages although identical samples were taken ('Niederterrassenschotter', Hochrhein-valley).

- Rissian: luminescence dating by Dehnert et al. (2010), Swiss midlands, discussed by Preusser et al. (2011).

- Holsteinian: luminescence dating by Klasen (2008) and the palynological interpretation by Müller (2001) may or may not be consistent, depending on the "absolute" age of the Holsteinian" (cf. discrepancy of STD 2002 and Cohen & Gibbard 2010).

- 'Deckenschotter': burial age dating by Häuselmann et al. (2007). This study refers to 'Deckenschotter' in Bavaria, further discussed by Doppler et al. (2011).

The "absolute" ages will be needed to estimate sedimentation rates or transport volumes. Presently we use the STD (2002) to transform biostratigraphical markers and sediment units into a geochronological frame (e.g. Neeb et al. 2004). In this way some preliminary estimates of sedimentation rates can be achieved already today. Any more detailed quantitative scenario will need a more accurate time frame.

The stratigraphical markers used here are listed in the context of their sediment succession and interpreted with regard to the chronostratigraphy of the sediments (locations cf. Fig. 1).

2.3.1 Neogene Mammal Zone MN 17

The MN 17 marker is known from a series of overbank fine sediments overlying some of the eldest 'Deckenschotter' remnants east and west of the Bodensee area in the Bavarian and Swiss Alpine Foreland: In Bavaria the 'Uhlenberg-Deckenschotter' ('Biber-Donau-Deckenschotter', cf. Schädel 1950, Ellwanger, Fejfar & von Koenigswald 1994, Doppler & Jerz 1995, Doppler 2003), in Switzerland the 'Irchel Deckenschotter' ('Höhere Deckenschotter', cf. Verderber 1992, 2003, Graf 1993, 2009, Bolliger et al. 1996). Accordingly the 'Donau'-aged 'Deckenschotter' represents the Gelasian super-stage of the Early Pleistocene (STD 2002, Cohen & Gibbard 2010).

2.3.2 Pollen assemblages

2.3.2.1 The Early Pleistocene pollen sequence of Unterpfauzenwald

The peat of Unterpfauzenwald ("Iller-Riss-Platte" near Leutkirch) is associated with an isolated till unit. The sediment succession begins with a gravel-unit of crystalline-poor 'Ältere Deckenschotter' with a weathered palaeosol-surface. Next follows a lower till sequence grading into fines and a peat containing the pollen flora. One or two till sequences of an upper till unit and strongly weathered periglacial sediments cover the peat. Both till-units contain > 10 % of crystalline pebbles i.e. they postdate the crystalline-poor 'Ältere Deckenschotter'.

(4) Periglacial fine sediments, strongly weathered;
(3) Upper till unit;
(2) Lower till unit grading into peat, pollen assemblage;
(1) Gravel of 'Ältere Deckenschotter', palaeosol.

The pollen assemblage includes *Tsuga*, *Pterocarya* and *Ostrya* that allows for correlation with the Early Pleistocene Bavelian stage (Hahne et al. 2010). An earlier interpretation by Göttlich (1974) suggested a Holsteinian age that is not compatible with *Tsuga* and *Ostrya*. W. Bludau suggested an age "Cromerian or older" (Bibus et al.1996).

Accepting the correlation with the Bavelian, the lower till unit represents an Early Pleistocene ice advance, either as cold period within the Bavelian or as an equivalent of the northwest European Menapian cold stage.

2.3.2.2 Holsteinian Pollen assemblages

Pollen assemblages that are attributed to the Holsteinian interglacial period were identified in various deep basins of the first generation, but also in some shallow basins and, in one case, within a gravel succession formerly attributed to the penultimate glaciation. The pollen assemblages include *Abies* almost continuously in various values, and in many cases (not always) *Fagus & Pterocarya* in the upper part of the succession (Hahne 2010).

In the deep basins, the succession usually begins with diamicton grading up into glaciolacustrine fine sediments with few pebbles (dropstones) and further up into laminated and massive lacustrine fines. This is where the pollen faunas usually occur. Depending on the position of the basin, the fines may be covered by glacial sediments or by meltwater sediments of the next younger glaciation.

(4) Sediments of the penultimate glaciation (Rissian), e.g. till or meltwater sediments;
(3) Lacustrine fine sediments, Holsteinian pollen assemblage;
(2) Glaciolacustrine sediments of the prepenultimate glaciation (Hosskirchian);
(1) Diamicton.

This kind of sediment succession including reliable Holsteinian pollen assemblages was identified in the glacial basins of Tannwald and Hosskirch (det. Bludau, Ellwanger et al. 1995, cf. Hahne 2010). In the Singen Basin (det. Bludau, Hahne 2010) the pollen-rich sediments were more sand-dominated and are probably less reliable (see Fig. 7). Also in the Waldburg basin Holsteinian pollen assemblages were found, but, in this case, not in a succession proper (Fiebig 1995).

Another reliable Holsteinian pollen flora is described from the "shallow basin" at Bittelschiess (Bludau in Schirmer 1995, Bibus & Kösel, 1996, Müller 2001, outcrop evolution cf. Ellwanger et al. 2011). It occurs within the finegrained bottom sets of an otherwise gravely delta unit. Another Holsteinian datum comes from fluvial gravels at Schmiecher See (det. Grüger 1995, cf. Hahne in Ellwanger, Simon & Ufrecht 2009).

2.3.2.3 Eemian Pollen assemblages

Only few Pollen assemblages that are attributed to the Eemian interglacial have yet been detected in the second generation of deep glacial basins. Best in the area of the Rhineglacier is the succession in the deep glacial basins of Bad

Wurzach (Wurzach Basin, Grüger & Schreiner 1993) that includes, beside of the Eemian, a succession of interstadials of the early and middle Würmian. Two Eemian deposits are reported from the Hosskirch Basin (det. Bludau, Ellwanger et al. 1995, Hahne 2010), and from the Singen Basin (det. Bludau, Szenkler, Bertleff, & Ellwanger 1997, and Szenkler & Bock 1999).

Most Eemian deposits are from shallow intramoraine basins on the till plains of the penultimate glaciation. They are usually not covered by till, though some controversies still remain open. Examples are the shallow basins from Krumbach (Frenzel & Bludau 1987), Füramoos (Müller 2001) and Jammertal (Müller, 2000)

2.3.2.4 Holocene Pollen assemblages

The infill of the last generation of glacial basins ends up with fine sediments that are commonly believed to represent the Holocene. This is usually not controlled but has exemplarily been verified in the Hasenweiler Basin (det. Knipping).

2.3.3 The palaeomagnetic records of Lichtenegg and Altheiligenberg

2.3.3.1 Lichtenegg

The succession of till and lacustrine sediments at Lichtenegg and at Schienerberg are the only two sites in the Rheinglacier area where glacial deposits follow after, and are overlain by gravels of the 'Deckenschotter' (for the 'Jüngere Deckenschotter' at Schiener Berg cf. Schreiner 2003 and Graf 2009).

There are several descriptions of the unique sediment succession of Lichtenegg that include a discussion of the palaeomagnetical results (Ellwanger et al. 1995, Ellwanger, Fiebig, & Heinz 1999, Bibus & Kösel 2003). A detailed description of the lithofacies is provided by Menzies & Ellwanger 2010. The succession starts with about 5 m of grey and brown gravels, sand and fines (including up to 10 % of crystalline pebbles). It is followed by several sequences of almost steel-grey subglacial and glaciolacustrine till (30–40 m), grading into lacustrine sediments (20 m). With an unconformity a brown sand-dominated succession with a palaeosol follows and is overlain by still another till sequence (15 m). Another unconformity follows as basis of quite coarse gravels (8 m). They are finally overlain by a package of > 20 m of massive gravels, very coarse and quite proximal ('Jüngere' = 'Mindel-Deckenschotter').

Analyses of the magnetic orientation of some fine-grained layers come to the result that several reliable samples are inversely magnetised (Fromm 1989, Rolf 1992). Although some questions regarding subglacial and diagenetic deformation are still in discussion, the sediment succession should be deposited in a period of inverse magnetic polarity, probably the Matuyama epoch.

2.3.3.2 Altheiligenberg

The deposits at Altheiligenberg represent the upper part of the crystalline-poor 'Heiligenberg Schotter' that is clearly appertained to as 'Älterer Deckenschotter' (Schädel 1950, Ellwanger et al. 1995). At Altheiligenberg, the gravels alternate with some sand- and silt-dominated horizons. Their magnetic orientation was again analysed by Fromm (1989) and Rolf (1992). The samples from the silt-horizon showed clearly an inverse magnetisation and probably also represent the Matuyama Epoch.

2.3.3.3 Summary of the time markers

The presently available time markers, as relevant of the Bodensee area, are subsumed in Tab. 1: They represent the Gelasian and Calabrian stages of the Early Pleistocene, the Holsteinian of the Middle Pleistocene, the Eemian of the Late Pleistocene and the Holocene. No evidence of the Cromerian stage of the early Middle Pleistocene has yet been recorded.

3 Chronostratigraphy of the Quaternary of the Rhineglacier area

Following Litt (2007, et al. 2005) and STD (2002), the definition of chronostratigraphical units (stages) of the Quaternary can be based upon the glacial-interglacial patterns, terrace stratigraphical levels (morphostratigraphy) and time markers. In the Bodensee area this leads to a succession as shown in Tab. 1 (right column). The basic division again subsumes two elements: an elderly system of Early Pleistocene alpine river gravels ('Deckenschotter'), and a younger system of foreland glaciations of the later Middle and Late Pleistocene. There is a gap in the early Middle Pleistocene as no evidence of sediments of this time slice has yet been identified in the Bodensee area (Tab. 2). This pattern follows the classical scheme of Penck & Brückner (1901/09), who describe a "great interglacial" (Grosses Interglazial) in the position of the gap.

Going into more detail, the 'Deckenschotter' and the "great glaciations" are further differentiated relying on morphostratigraphy: In case of 'Deckenschotter' supplemented by sediment petrography, in case of the glacial deposits by typical lithofacies successions. In both cases, the classification is controlled by time markers (Tabs 1 & 2).

3.1 Early Pleistocene 'Deckenschotter' (alpine river system)

There are three 'Deckenschotter' units: The 'Donau-Deckenschotter' ('Biber-Donau'), the 'Günz-Deckenschotter', and the 'Mindel-Deckenschotter' (Tab. 1). As outlined above, their identification refers to morphostratigraphy and petrographical composition. The yet available 'Deckenschotter' time markers refer to the record of the Neogene Mammal Zones, the palaeomagnetic record, and the palynostratigraphical record.

The Bavarian 'Donau-Deckenschotter' ('Ältestpleistozän', 'Eopleistozän', earliest Pleistocene), and the Swiss 'Irchel Deckenschotter', host the Mammal Zone MN 17 that represents the Gelasian stage, formerly late Pliocene, now Early Pleistocene (STD 2002, Cohen & Gibbard 2010).

The inverse magnetic inclination from Altheiligenberg and Lichtenegg suggests that the 'Günz' stage and the

Tab. 1: Time markers (2.3) and local chronostratigraphical stages (3) of the Bodensee area (in brackets '()': not recorded).

Tab. 1: Zeitmarken (2.3) und lokale chronostratigraphische Stufen (3) der Bodenseeregion (in Klammern '()': nicht überliefert).

<table>
<tr><th colspan="3"></th><th colspan="3">Time markers</th><th colspan="2" rowspan="2">Chronostratigraphy of the Bodensee area</th></tr>
<tr><th colspan="3">Standard Stages</th><th>Palynostratigraphy</th><th>Mammal Zones</th><th>Palaeomagnetics</th></tr>
<tr><td colspan="4">Holocene</td><td rowspan="11">(MNQ1)</td><td rowspan="7">(Brunhes)</td><td colspan="2"></td></tr>
<tr><td rowspan="12">Pleistocene</td><td rowspan="2">Late</td><td rowspan="2">Tarantian</td><td></td><td rowspan="6">Glacial and inter-glacial units (stages)</td><td>Würmian</td></tr>
<tr><td>Eemian</td><td>Eemian</td></tr>
<tr><td rowspan="4">Middle</td><td rowspan="4">Ionian</td><td></td><td>Rissian</td></tr>
<tr><td>Holsteinian</td><td>Holsteinian</td></tr>
<tr><td></td><td>Hosskirchian</td></tr>
<tr><td>(Cromerian)</td><td></td></tr>
<tr><td rowspan="6">Early</td><td rowspan="4">Calabrian</td><td>Bavelian</td><td rowspan="6">Matuyama</td><td rowspan="6">Great alpine rivers Deckenschotter</td><td rowspan="2">Jüngere Deckenschotter (Mindel)</td></tr>
<tr><td>(Menapian)</td></tr>
<tr><td>(Waalian)</td><td rowspan="2">Ältere Deckenschotter (Günz)</td></tr>
<tr><td>(Eburonian)</td></tr>
<tr><td rowspan="2">Gelasian</td><td>(Tiglian)</td><td rowspan="2">MN 17</td><td rowspan="2">Älteste Deckenschotter (Donau)</td></tr>
<tr><td>(Pretiglian)</td></tr>
</table>

Tab. 2: Comparison of chronostratigraphical terms used in Switzerland, Bavaria and Baden-Württemberg; formerly used terms in brackets '()'.

Tab. 2: Vergleich der chronostratigraphischen Begriffe der Schweiz, Bayerns und Baden-Württembergs; früher verwendete Begriffe stehen in Klammern '()'.

<table>
<tr><th colspan="2">Chronostratigraphy</th><th>Swiss alpine foreland</th><th>Bodensee area</th><th>Bavarian alpine foreland</th></tr>
<tr><td colspan="2" rowspan="2">Late Pleistocene</td><td>Last Glaciations / LGM / Birrfeld</td><td>Würmian</td><td>Würm (-Komplex)</td></tr>
<tr><td>Eem sensu Welten</td><td>Eemian</td><td>Eem (Riss/Würm-Interglacial)</td></tr>
<tr><td rowspan="7">Middle Pleistocene</td><td rowspan="5"></td><td>Penultimate Glaciation / Koblenz</td><td>Rissian</td><td rowspan="3">Riss (-Komplex)</td></tr>
<tr><td>Meikirch-Interglacial</td><td></td></tr>
<tr><td>Habsburg</td><td></td></tr>
<tr><td>Holstein Pterocarya</td><td>Holsteinian</td><td>Holstein (Mindel /Riss-Interglacial)</td></tr>
<tr><td>Major Glaciation</td><td>Hosskirchian</td><td>Mindel</td></tr>
<tr><td rowspan="2">Cromerian</td><td></td><td></td><td>Günz/Mindel-Interglacial</td></tr>
<tr><td>MEG / Möhlin</td><td></td><td>Günz</td></tr>
<tr><td colspan="2" rowspan="5">Early Pleistocene (Calabrian)</td><td>Morphotectonic Event</td><td></td><td></td></tr>
<tr><td rowspan="2">Tiefere Deckenschotter</td><td>(Jüngere)
Mindel-Deckenschotter</td><td rowspan="3">Donau</td></tr>
<tr><td>(Ältere)
Günz-Deckenschotter</td></tr>
<tr><td rowspan="2">Höhere Deckenschotter</td><td>(Älteste)
Donau-Deckenschotter</td></tr>
<tr><td></td><td>Biber</td></tr>
</table>

'Mindel' stage are part of the Matuyama epoch (Fromm 1989, Rolf 1992). They postdate the 'Donau-Deckenschotter' representing younger intervals of the Early Pleistocene. This is supported by the identification of the Bavelian warm period in the peat of Unterpfauzenwald. The peat overlies an isolated deposit of crystalline-rich till ('Mindel' stage, Tab. 1). This view corresponds well with the stratigraphical classification by Graf (2009) of "upper and lower" 'Deckenschotter' of Switzerland, but is opposed to the interpretation of the 'Deckenschotter' of the Bavarian Alpine Foreland according to which the 'Mindel' stage and part of the 'Günz' stage are already part of the Middle Pleistocene (Doppler 2003).

The chronostratigraphy of the 'Deckenschotter' interval as suggested here (Tabs. 1 & 2) seems conclusive, also regarding available time markers. It covers the Early Pleistocene in poor resolution, but this is not surprising in a terrace stratigraphical setting that is primarily controlled

E&G / Vol. 60 / No. 2–3 / 2011 / 306–328 / DOI 10.3285/eg.60.2-3.07 / © Authors / Creative Commons Attribution License

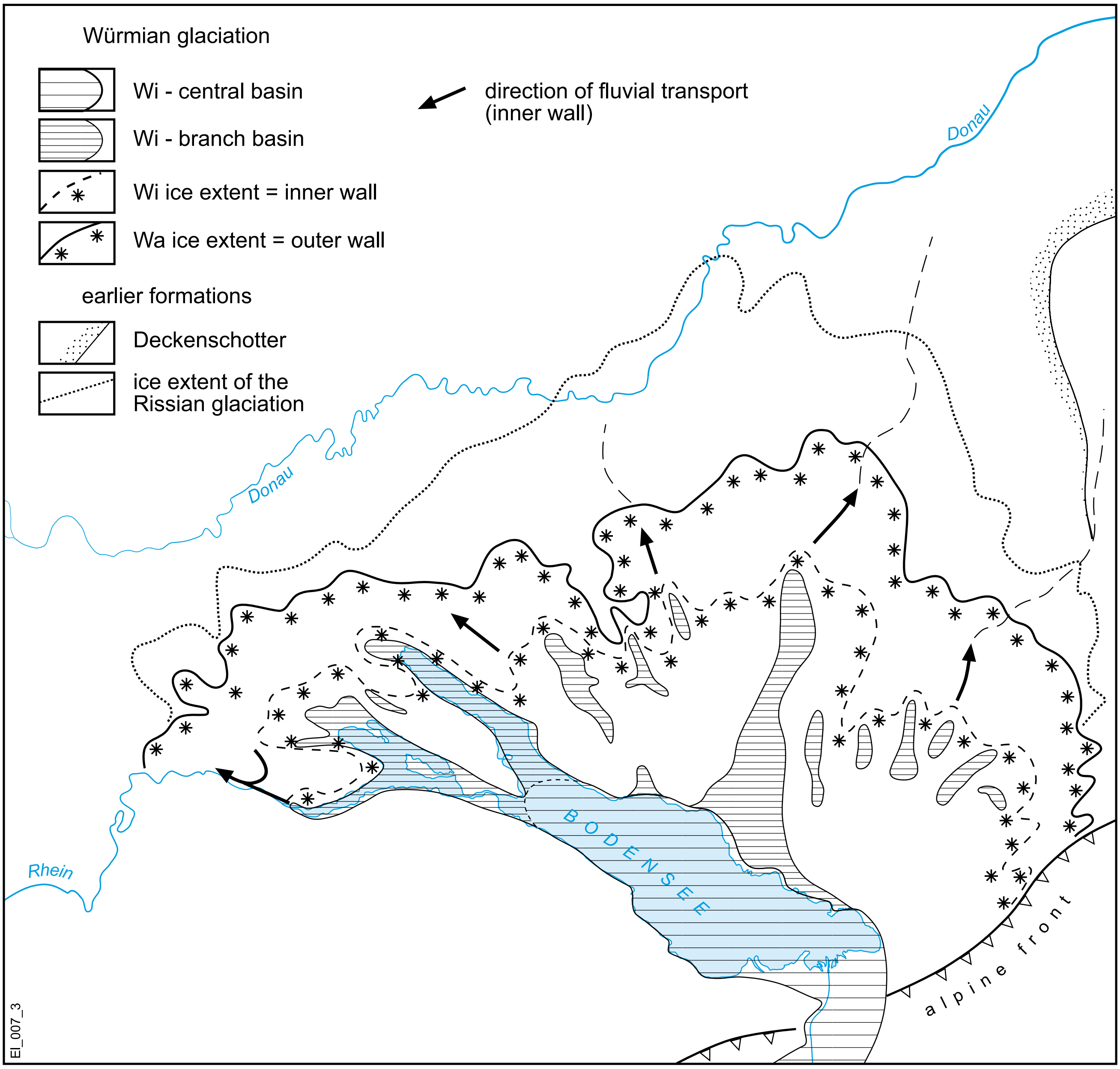

Fig. 4: Endmoränen und Glazialbecken der Würm-Eiszeit als ein Beispiel für glaziale Doppelzyklen: Das übertiefte Bodenseebecken im Zentrum und davon radial ausgehende langgestreckte Zweigbecken, die vom Endmoränenwall des Würm-Wiedervorstoßes umrahmt werden. Die tiefeingreifende Beckenerosion entsteht beim Wiedervorstoß. Dagegen bedeckt der Gletscher des ersten Vorstoßes zur Äußeren Würmendmoräne (Wa) eine wesentlich größere Fläche. Siehe hierzu auch Fiebig 1995, 2003, Ellwanger et al. 2011.

Abb. 4: Terminal moraines and glacial basins of the Würmian stage, as an example of a twincycle glaciation: The overdeepened Bodensee Basin in the centre, radially embraced by elongated branch basins that are encircled by the terminal moraine wall of the Würmian readvance. Deep basin erosion corresponds to this readvance. Whereas the first Würmian ice advance to the outer Würmian moraine (Wa) covered a much wider area. Cf. Fiebig 1995, 2003, Ellwanger et al. 2011.

by tectonics. A far better resolution of this time slice has been identified in the nearby Heidelberg Basin of the Upper Rhine Graben (Gabriel et al. 2008).

3.2 Middle and Late Pleistocene ice advances of the Rhineglacier

The chronostratigraphical record of the Middle and Late Pleistocene glaciations of the Rhineglacier comprises the three "glacial" stages Hosskirchian, Rissian and Würmian, and the "interglacial" stages Holsteinian and Eemian (their palynological records also serving as time markers). In geological mapping the sediment surfaces are also differentiated by the thickness of their cover of weathered and periglacial sediments (Schreiner & Haag 1982, Bibus & Kösel 1996). The cover averages about 1 m overlying Würmian sediment surfaces, about 2–3 m including the "Eem" fossil soil in the Rissian and about 3–4 m or more including several fossil soils in pre-Rissian surfaces.

All three glacial units are composed of sediments of two major ice-advances. Their extend is marked by an outer and an inner wall of terminal moraines (twin-cycle, cf. Fiebig, 1995, 2003, STD 2002). Each of the ice margins engulfs a glacial landsystem of different subglacial to proglacial sediments and landforms (Fig. 4): within the margin of the first ice advance (usually the outer = "maximum" margin), elements of downmelting ice prevail at the land surface, as eskers, kames and kames terraces. They are best preserved in the Würmian = last glacial maximum, LGM. Within the margin of the readvance there are two different systems of sediments and landforms: one is primarily related to active ice (frequently drumlins), the other subsumes the deeply incised glacial basins and their sediment infill (Fig. 3).

In spite of their highly resolvable erosion and sedimentation patterns, the two advances of the twin-cycles are subsumed in only one substage in the chronostratigraphical record (e.g. late Würmian, 'Oberwürm'). This substage marks the culmination of a series of earlier cold-warm variations that have far less effects regarding erosion and sedimentation (e.g. the substages of the early and middle Würmian, Grüger & Schreiner 1993). Most of the cold phases of the record are considered to represent periglacial cold climate, but some were also suggested to possibly represent additional ice advances (cf. Frenzel 1991, LGRB 1995, 2002, STD 2002; "single cycles" sensu Fiebig 1995, 2003).

This "state-of-the-art" chronostratigraphical scheme goes well beyond the classical glacial/interglacial scheme as introduced by Penck & Brückner (1901/09), in spite of the continuous use of the terms 'Riss' and 'Würm' that were originally more closely focussed upon sediments and landforms (morphostratigraphy). However, the refocus of the morphostratigraphical approach towards chronostratigraphy was also initiated by Penck & Brückner introducing an early 'Würm' oscillation called 'Laufenschwankung'.

3.3 Chronostratigraphical summary

The stratigraphical succession of the Early, Middle and Late Pleistocene begins with the Early Pleistocene 'Deckenschotter'. They are interpreted in terms of an alpine fluvial system. Its terrace patterns and lithology are suggested to reflect the changing local palaeotopography, not climate, and it contains huge hiatuses. The oldest yet known till deposits of an early Rhineglacier are related to the "youngest" 'Deckenschotter' subunit ('Mindel').

The Middle and Late Pleistocene comprise three glacial units in post-'Deckenschotter' position, Hosskirch, Riss und Würm. Each unit shows good evidence of two ice advances of the Rhineglacier. The interglacial record comprises the Holsteinian, the Eemian and the Holocene (Tab. 1).

The Quaternary chronostratigraphy of the Rhineglacier area as presented here is in parts quite different from systems used in neighbouring areas. The main differences concern the early Middle Pleistocene time interval. Here, a hiatus is suggested in the Rhineglacier area, which is correlated with various stratigraphical units in the schemes of Bavaria and Switzerland (Tab. 2):

- In the Bavarian scheme, the early Middle Pleistocene is represented by the 'Günz'-, 'Haslach'- and 'Mindel-Deckenschotter' (Doppler 2003). The transition from 'Deckenschotter' units to the Rissian stage (elderly moraines and high terraces, "Hochterrasse") is marked by the Holsteinian interglacial stage (Samerberg II, Grüger 1983).

- In the Swiss scheme, the early Middle Pleistocene is represented by the "most extensive" and the "extensive" glaciation. Here, the transition from 'Deckenschotter' to the glaciations is marked by a "morphotectonic event", probably still in the Early Pleistocene (Preusser 2009, Graf 2009).

Obviously, the schemes of Bavaria and Switzerland reflect extreme positions that will be difficult to correlate with each other. The Rhineglacier chronostratigraphical scheme comes almost as a compromise between the extremes, but it is primarily an attempt to meet the different evidences of the Bodensee area.

To resolve the highly differentiated sediments and landforms of the three twincycle ice advances, the twincycle substages are often subdivided into a couple of lithofacies units (e.g. the late Würmian = 'Oberwürm' substage in the geological map 1:25.000 sheet 8225 Kisslegg). Here, an approach might be more consistent that is based on a lithostratigraphical scheme.

4 Lithostratigraphy and lithostratigraphical definitions of the Quaternary of the Rhineglacier area

The lithostratigraphical division of the Quaternary of this area is designed to define and correlate geological units primarily based upon sedimentary features. With regard to the negative sediment budget of the Alpine Foreland, the sediment units are unconformity-bounded. Their first order unconformities are the major erosion surfaces that cause the deepening of the landsystems at the alpine margin, their second order unconformities are related to ice advances or large fluvial terrace-systems.

Following the recommendations of Steininger & Piller (1999) and LGRB (2005), the "formation" (Fm.) serves as the central unit in the lithostratigraphical scheme. Units of higher order are supergroup, group and subgroup; the formation will be subdivided in member, key horizon resp. lithofacies unit and finally bed or layer. The elements "key horizon"- resp. "facies unit" are here informally used (advised by E. Nitsch, Freiburg, pers. comm.), e.g. to cover correlative continuities of erosion events (following the concept of "dual lithostratigraphy" by Lutz et al. 2005). Lithostratigraphical symbols follow the SEP 3 standards (Denino-Thiessen et al. 2002, LGRB 2011, E. Nitsch, pers. comm.). The formations refer to the four areas outlined above, i.e. to the various sedimentary environments and to sediment preservation.

- Central part of the Rhineglacier area, between Bodensee and Donau Valley: This is a primarily glacial environment, covered by three formations that also include fluvial and lacustrine deposits. Three major unconformities generate the boundaries of the formations, they refer to the three generations of overdeepened basins and, basically, the Bodensee amphitheatre as outlined above (Hasenweiler-Fm., Illmensee-Fm., Dietmanns-Fm.).

- Each formation is subdivided into members representing different combinations of glacial, fluvial and lacustrine sediments. Regarding different till assemblages, there are "glacial" members labelling different parts of till sequences:

- Succession with active ice sediments lying below sands and gravels of downmelting stagnant ice;

- drumlinized till featuring advancing ice, and its

- correlative downmelting sediments deposited as infill of glacial basins.

- Terminal moraine sediments marking the turning point from active to downmelting ice sediments are addressed as key horizons. Finally, there are fluvial sediments representing both, meltwater and non-glacial systems. They are often unspecific with regard to the glacial cyclicity and from there subsumed as "fluvial" member.

- Isolated glacial deposits: this formation comprises deposits that predate the Dietmanns-Fm. and further isolated deposits along the Hochrhein Valley.

- The pre-Dietmanns deposits are subsumed as members of the Steinental-Fm. Their common feature is that they are all embedded in or covering the landsurface of the 'Deckenschotter' landsystem, with no evidence of subglacial overdeepening.

- The glacial deposits along the Hochrhein Valley are subsumed as Haseltal-Fm. They are attributed to Middle Pleistocene ice advances of the Rhone Glacier (Valais Glacier) into the Hochrhein Valley.

- The nonglacial or periglacial fluvial environment is covered by three formations: the Oberschwaben-Deckenschotter-Fm., the Hochrhein-Deckenschotter-Fm., and the Rheingletscher-Terrassenschotter-Fm.

- The Oberschwaben-Deckenschotter-Fm. is subdivided in different members according to differing petrographical composition of the gravels. The 'Hochrhein-Deckenschotter' and the 'Rheingletscher-Terrassenschotter' are subdivided into members by means of terrace levels ('Höhere Hochrhein-Deckenschotter', 'Tiefere Hochrhein-Deckenschotter', 'Rheingletscher-Hochterrassenschotter', 'Rheingletscher-Niederterrassenschotter'). This goes along with different amounts of surface weathering (e.g. 'Hochterrasse' ~2 m, 'Niederterrasse' ~1 m).

- The southern URG acts as the "final" sediment trap for coarse alpine debris between Rhine and Rhone. Its succession has been subdivided in Neuenburg-Fm. and Breisgau-Fm.

- The Neuenburg-Fm. is reflected in the huge sediment fan located between the mouth of the Hochrhein Valley and the Kaiserstuhl volcanoe. The succession consists of two cycles of fluvial gravels, each including a coarse basal event horizon (key horizon) that is suggested to represent a correlative continuity of the erosion unconformities of the Bodensee area. This deposit is suggested to be input- i.e. climate-controlled.

- The composition of the gravel beds of the underlying Breisgau-Fm. ranges between well and poorly sorted. The diamictic beds include altered, weathered or even decomposed pebbles, often bearing evidence of palaeosol processes. With regard to the sediment thickness of up to 200 m, their preservation will primarily depend on subsidence.

To follow, some short definitions of the formations are introduced that are suggested to constitute a lithostratigraphy of the Quaternary of the southwest German Alpine Foreland, including sub-units as members, facies units (informally introduced) and key horizons. The full definitions will be published in the internet-based "Litholex" of the German Stratigraphic Commission (DSK 2011 ff.).

4.1 Hasenweiler-Formation

Hasenweiler-Fm. (qHW, Tab. 3, Fig. 5): unconformity-bounded lithostratigraphical unit, comprising all glacial, fluvial and lacustrine sediments deposited above the "Hasenweiler unconformity" (D1-unconformity). The sediments represent only one ice advance. Its active-ice- and downmelting sediments are deposited in two different locations (~ members, qHWT, qHWb). The outward boundary of the Hasenweiler-Fm. is marked by the terminal moraines of the 'Innere Jungendmoräne' (IJE, key horizon) that reflect the maximum of the ice advance.

- Sediment infill of overdeepened basins of the Hasenweiler-Fm. ('Hasenweiler Beckensedimente', qHWb-Mb). Lower boundary: D1-unconformity. The typical succession reflects downmelting ice, beginning with (1) coarse-grained diamicton, grading up into (2) matrix-rich diamicton (waterlain till) and ending up with (3) laminated and massive fines. The succession terminates with (4) postglacial clay-rich or organic fines. The succession may be disrupted by intervals of diamicton (slumps) or substituted by deltaic gravels, but there is no subglacial till (cf. qHWT). Sedimentation may still be ongoing, e.g. in the actual Bodensee Basin. Sediment thickness: average 50 m, maximum > 100 m.

- The Tettnang-Mb. (qHWT) refers to the till cover of the areas between the basins of the Hasenweiler-Fm. This is primarily a deformation till featuring active ice, its surface shows frequently (though not always) a drumlin relief. The till consists largely of cycles of diamicton that may be substituted by gravel-dominated sediment packages, often at the ice-up side of drumlin-landforms. Resulting from a "deformable bed", the unit displays the D1-unconformity. It is the most widespread glacial unit of the Rhineglacier area, reaching from the Bodensee to the IJE terminal moraine. Sediment thickness: average 10 m, maximum 30 m.

- Throughout the Hasenweiler-Fm., deposits of fluvial sands and gravels are subsumed as 'Hasenweiler Schotter' (qHWg). They are mainly in contact with the IJE, but there are also some locally scattered downmelting gravels in large interdrumlin depressions (Tettnang-Mb.), and the quite continuous gravel-infill along larger valleys that are usually eroded below the D1-unconformity (e.g. Argen, Wolfegger Ach).

Important sub-units of the members of the Hasenweiler-Fm. are:

- IJE terminal moraine (key horizon of the qHWT) marking the outward boundary of the qHW-Fm. i.e. the turning point from ice advance to downmelting. They

Tab. 3: Lithofacies units of the Hasenweiler-Formation.

Tab. 3: Lithostratigraphische Einheiten der Hasenweiler-Formation.

Chronostratigraphy	Formation	Member		Key horizons
Holocene	Hasenweiler-Fm. qHW	Hasenweiler-Beckensediment qHWb		
Innenwall-Würm			Tettnang-Till qHWT	IJE
	D1-unconformity			

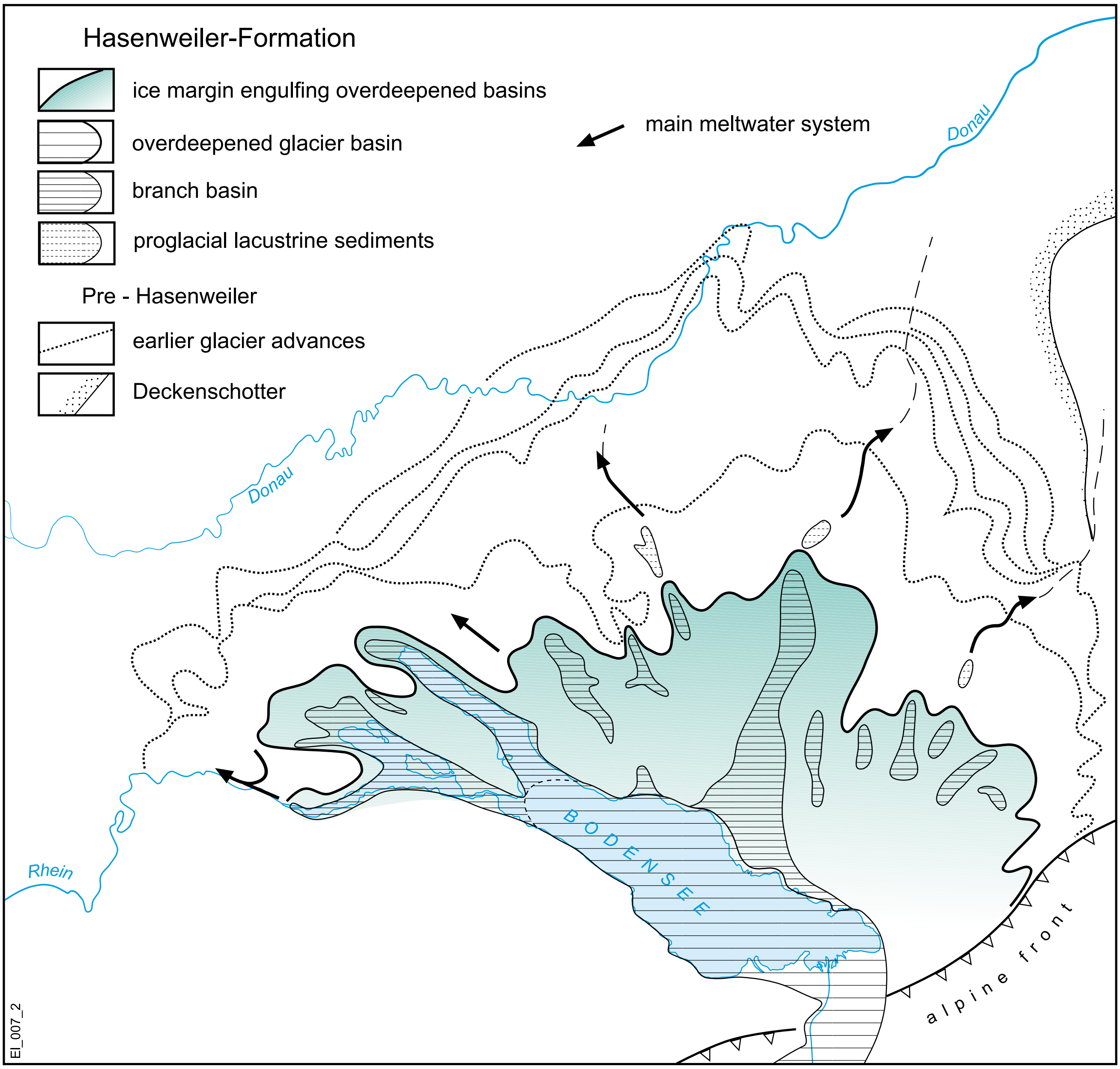

Fig. 5: Glacial basins and terminal moraines of the Hasenweiler-Formation. Although the branch basins are still radially orientated, this system is almost completely focussed towards the Rhine Valley i.e. to the west. This is also indicated by the NW elongation of the central Bodensee Basin ('Bodensee-Stammbecken'). – The highs between the branch basins are largely covered by drumlins (Tettnang-Mb.). Cf. Ellwanger *et al. 2011.*

Abb. 5: Glazialbecken und Endmoränen der Hasenweiler-Formation. Obwohl die Zweigbecken nach wie vor radial orientiert sind, ist Ihre Hauptausrichtung zum Rhein gerichtet, also nach Westen. Auch die Längserstreckung des zentralen Bodenseebeckens (Bodensee-Stammbecken) weist nach NW. – Die Hochgebiete zwischen den Zweigbecken sind weiträumig von Drumlins bedeckt (Tettnang-Subformation).

are inconspicuous landforms consisting of diamictons, gravels and sands from downmelting ice. Only few push moraines are yet known.
- Bodensee-Sediment (local "facies unit" of the qHWb).
- Eskers and related hills consisting of gravels deposited in ice-dammed channels, reflecting conspicuous landforms and sediment bodies (local "facies unit" of the qHWb).

4.2 Illmensee-Formation

Illmensee-Fm. (qIL, Tab. 4, Fig 6): unconformity-bounded lithostratigraphical unit, comprising all glacial, fluvial and lacustrine sediments deposited between "Illmensee unconformity" (D2-unconformity) and "Hasenweiler unconformity" (D1-unconformity). Its sediments comprise evidence of two ice advances. Regarding the first advance, active-ice- and downmelting sediments are again deposited in two different locations (~ members, qILD, qILb); the sediments of the last advance lie in stratigraphical succession (~ one member, qILK). There are two terminal moraine walls (key horizons): the 'Altmoränen-Innenwall' (last ice advance of the penultimate glaciation) marking the outward boundary of qIL, and the 'Äussere Jungendmoräne' (ÄJE), marking approximately the so-called "last glacial maximum" (LGM).

- Sediment infill of overdeepened basins of the Illmensee-Fm. (qILb-Mb., 'Illmensee Beckensedimente'). Lower boundary: D2-unconformity. The typical succession re-

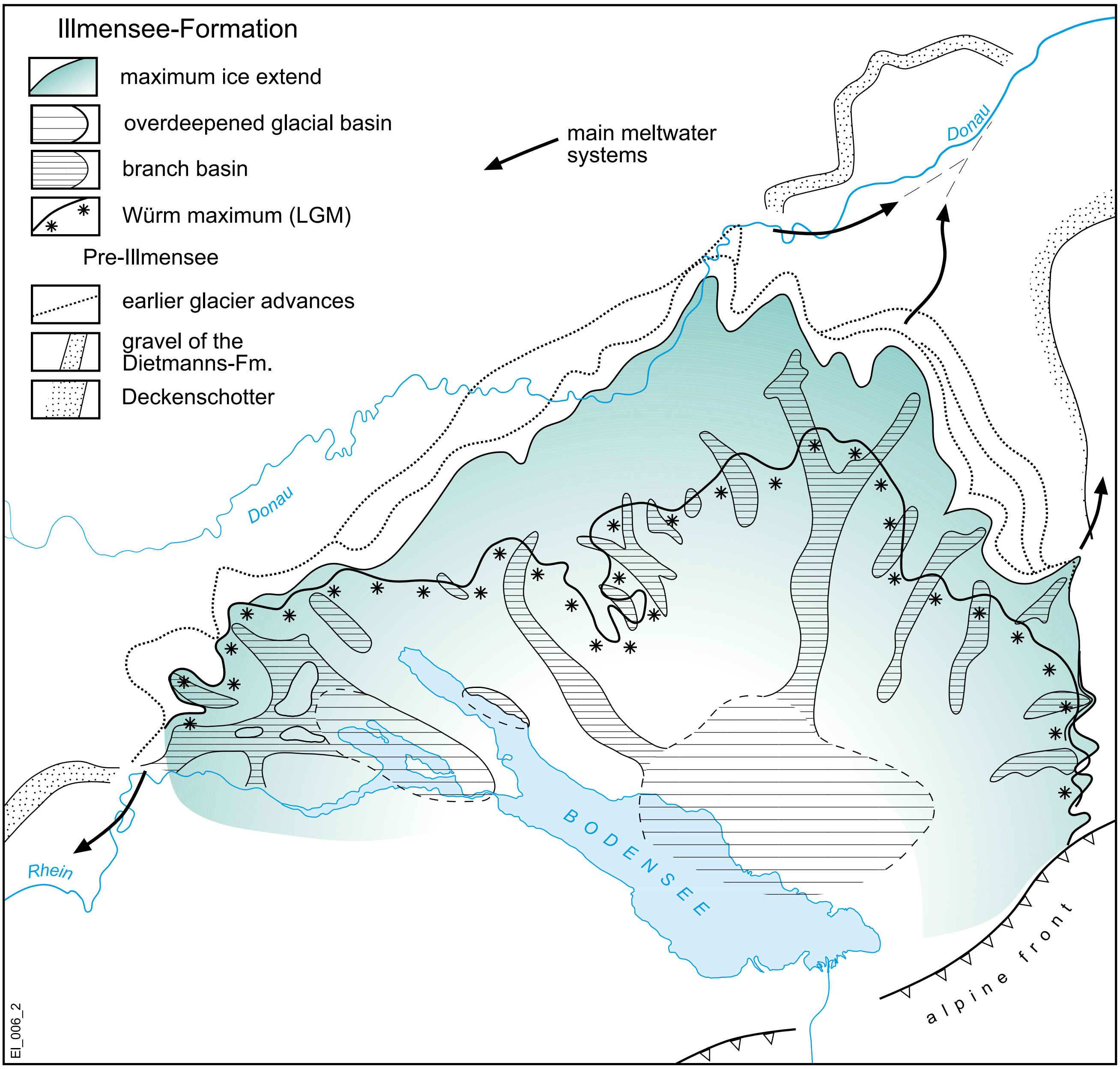

Fig. 6: Glacial basins and terminal moraines of the Illmensee-Formation. There are two central basins, one at the outlet of the overdeepened alpine Rhine Valley, the other in the westernmost part of the Bodensee area, leading over to the topography of the adjoining Swiss Midlands. The two central basins were probably parted by a Molasse high (its remnants are still present at the actual shore of the Bodensee). – Many of the branch basins of the Illmensee-Fm. are related to the valleys that go out from the LGM terminal moraine wall and where the 'Rheingletscher-Niederterrassenschotter' were deposited.

Abb. 6: Glazialbecken und Endmoränen der Illmensee-Formation. Es entstanden zwei Stammbecken, eines an der Talmündung des übertieften alpinen Rheintals, das andere im westlichen Bodenseegebiet, das zur Topographie des angrenzenden Schweizer Mittellandes überleitet. Die beiden Zentralbecken (Stammbecken) waren höchstwahrscheinlich durch ein Molasse-Hochgebiet voneinander getrennt, dessen Reste am Ufer des Bodensees noch heute vorhanden sind. – Viele Zweigbecken der Illmensee-Formation stehen in Verbindung mit den Tälern, die von der Äußeren Jungendmoräne ausgehen und in denen Niederterrassenschotter abegelagert wurden.

flects downmelting ice. It begins with (1) coarse-grained diamicton, grading up into (2) matrix-rich diamicton (waterlain till) and ends up with (3) laminated and massive fines. Again, coarser diamictic slumps or deltaic gravels may be included. Next unit to follow are sand to gravel with clay-rich or organic-rich fines (4) that may contain pollen reflecting the Eemian or early Würmian warm climate. Further up, proglacial fines (5) continuing qILb, or gravels (qIlg) or diamicton of the Kissleg-Mb. (qILK) may follow. Push moraines of the 'Äussere Jungendmoräne' (ÄJE), displaying the most conspicuous terminal moraine wall of the Alpine Foreland (key horizon), are frequently lobbing across the basins.

- The Dürmentingen-Mb. (qILD) refers to the sediment cover of elevated areas adjoining the basins of the Illmensee-Fm. outside of the ÄJE terminal moraine. Largely, this unit features again active ice, showing a moderately drumlinized surface, with cycles of deformed diamicton. Close to the margin of the correlative qILb basins, very coarse diamicton with large boulder-blocks (correlative to the D2-unconformity) may substitute the till. With increasing distance to the basins, downmelting sediments may become more frequent. They include sands and gravels and, within small interdrumlin basins, downmelting successions with fines and postglacial organic-rich sediments.

- The Kisslegg-Mb. (qILK) refers to the till sequence and correlative deposits that cover completely the area between IJE and ÄJE. Depending on the local topography it continues within the IJE underlying sediments of the Tettnang-Mb. Immediately outside of the ÄJE, it intercalates with qILg gravels. The succession begins with deformed and sheared diamicton (active-ice deposit) and continues with diamicton, sand, gravels and fines (downmelting deposits). Depending on the underlying relief, the land surface may be structured in a "kame and kettle" topography or in kames terraces.

- Throughout the Illmensee-Fm., deposits of fluvial sands and gravels are subsumed as qILg-Mb. They are most frequently outgoing from the ÄJE within the qILb-basins (correlative to the qRTN outside of the basins), but also locally consist of scattered downmelting deposits (large kames terraces, channel fill etc.).

Important sub-units of the members of the Illmensee-Fm. are:

- 'Altmoränen-Innenwall', the terminal moraine of the qILD ice advance (key horizon, qILDe), consisting of diamictons, gravels and sands, occasionally push moraines.
- 'Äußere Jungendmoräne' (ÄJE), the most conspicuous terminal moraine wall of the Alpine Foreland (key horizon, qILKe), frequently push moraines.
- Eskers and related hills consisting of gravels deposited in ice-dammed channels, reflecting conspicuous land forms and sediment bodies (local "facies unit" of the qILK).

4.3 Dietmanns-Formation

The Dietmanns-Fm. (qDM, Tab. 5, Fig. 7) is an unconformity-bounded lithostratigraphical unit, comprising all glacial, fluvial and lacustrine sediments deposited between the "Dietmanns unconformity" (D3-unconformity) and the "Illmensee unconformity" (D2-unconformity). Its sediments again show evidence of two ice advances. The first advance again comprises a till sequence (qDMV) and the infill of glacial basins (qDMb), the second just a till sequence (qDMS). There are two ice margins, both with terminal moraines that include push moraines (Fig. 7)

- Sediment infill of overdeepened basins of the Dietmanns-Fm. (qDMb-Mb., Dietmanns Beckensedimente). Lower boundary: D3-unconformaty. They represent the eldest of the yet known three generations of glacial basins. Some basins are quite deep, e.g. the Tannwald Basin at Schneidermartin almost 200 m. The typical succession reflects downmelting ice. It begins with coarse-grained diamicton, grading up into matrix-rich diamicton (waterlain till) and ends up with laminated and massive fines. Again, coarser diamictic slumps or deltaic gravels may be included. Next unit to follow are sand to gravel with clay-rich or organic-rich fines that may contain pollen reflecting the Holsteinian warm climate. The sediments to follow are mostly attributed to other members, e.g. till sequences beginning with the qDMS-Mb. On several occasions the relief of this generation of glacial basins was reversed by the overlying sediments (e.g. Waldburg-Basin).

- The Vilsingen-Mb. (qDMV) refers to the till cover of the elevated areas between the Dietmans basins and outside of the 'Altmoränen-Aussenwall'. The Vilsingen deposits are diamicton cycles that are often covered by several

Tab. 4: Lithofacies units of the Illmensee-Formation.

Tab. 4: Lithostratigraphische Einheiten der Illmensee-Formation.

<table>
<tr><th>Chronostratigraphy</th><th>Formation</th><th colspan="3">Member</th><th>Key horizons</th></tr>
<tr><td>Aussenwall-Würm</td><td rowspan="5">Illmensee-Fm.
qIL</td><td>Illmensee-Schotter
qILg</td><td colspan="2">Kisslegg-Mb.
qILK</td><td>ÄJE</td></tr>
<tr><td>Mittelwürm</td><td colspan="2" rowspan="4">Illmensee-Beckensediment
qILb</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Frühwürm</td></tr>
<tr><td>Eemian</td><td rowspan="3">Dürmentingen-Mb.
qILD</td><td></td></tr>
<tr><td rowspan="2">Innenwall-Riss</td><td rowspan="2">Altmoränen-Innenwall</td></tr>
<tr><td colspan="3">D2-unconformity</td></tr>
</table>

Tab. 5: Lithostratigraphische Einheiten der Dietmanns-Formation.

Tab. 5: Lithofacies units of the Dietmanns-Formation.

<table>
<tr><th>Chronostratigraphy</th><th>Formation</th><th colspan="3">Member</th><th>Key horizons</th></tr>
<tr><td>Aussenwall-Riss</td><td rowspan="4">Dietmanns-Fm.
qDM</td><td>Dietmanns-Schotter
qDMg</td><td colspan="2">Scholterhaus-Mb.
qDMS</td><td>Altmoränen-Außenwall</td></tr>
<tr><td>early Rissian</td><td colspan="2" rowspan="3">Dietmanns-Beckensediment
qDMb</td><td></td><td></td></tr>
<tr><td>Holsteinian</td><td rowspan="3">Vilsingen-Mb.
qDMV</td><td></td></tr>
<tr><td rowspan="2">Innenwall-Hosskirch</td><td rowspan="2">Pflummern-Till</td></tr>
<tr><td colspan="3">D3-unconformity</td></tr>
</table>

E&G / Vol. 60 / No. 2–3 / 2011 / 306–328 / DOI 10.3285/eg.60.2-3.07 / © Authors / Creative Commons Attribution License

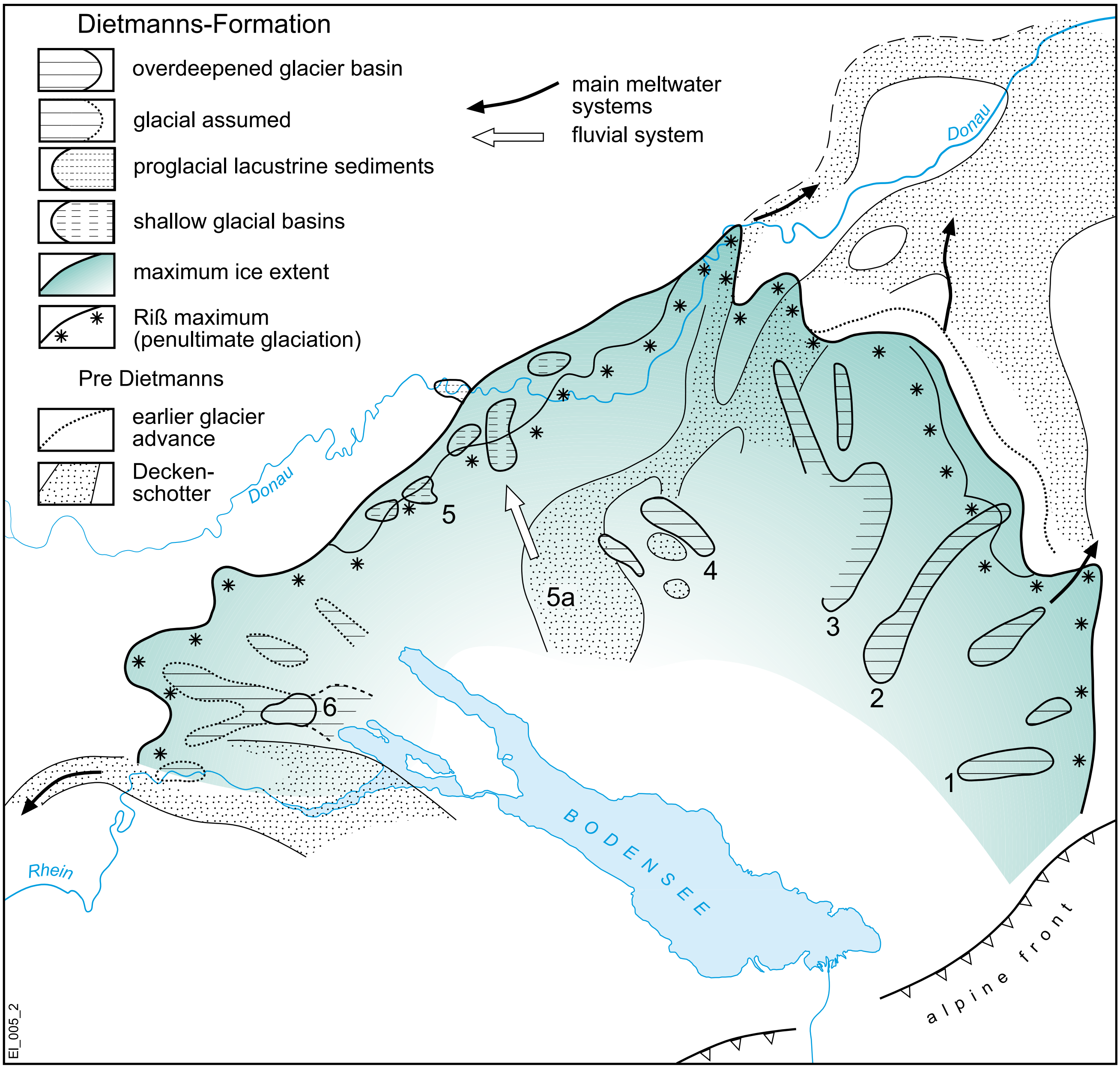

Fig. 7: Glacial basins and terminal moraines of the Dietmanns-Formation. It is suggested that this time slice marks the onset of overdeepening in the area. There are radial branch basins in the eastern part of the Rhineglacier area but no central basin alike to the present Bodensee Basin can be recognized. There are also no deep basins in the northwest, where the character of the "old" surface of a prealpine ramp still prevails. – The major branch basins are: 1 the Isny Basin (HGK 2010), 2 the Waldburg-Wurzach Basin (Fiebig 1995, 2003, Ellwanger 2003), 3 the Tannwald Basin (Ellwanger et al. 1995, Ellwanger 2003, Hahne 2010), and 4 the Hosskirch Basin (Ellwanger et al. 1995, Hahne 2010). 5, several shallow basins in the northwest follow the ice margin, including 5a delta deposits of the Holsteinian interglacial, serving as evidence for the up-river absence of deep basins (Bludau 1995, Müller 2001, Ellwanger, Fiebig & Heinz 1999, Ellwanger et al. 2011). 6 the Singen Basin (Szenkler & Bock 1999).

Abb. 7: Glazialbecken und Endmoränen der Dietmanns-Formation. In diesem Zeitabschnitt setzte die Übertiefung in der Region ein. Es gibt radial ausgerichtete Zweigbecken im östlichen Rheingletschergebiet, aber keine Hinweise auf ein zentrales Stammbecken, vergleichbar mit dem heutigen Bodenseebecken. Es gibt auch keine tiefen Becken im Nordwesten, dort blieb der Charakter der „alten" Rampen-artigen Landschaft mit außeralpinen Vorbergen erhalten. – Die großen Zweigbecken sind: 1 das Isny Becken (HGK 2010), 2 das Waldburg-Wurzach Becken (Fiebig 1995, 2003, Ellwanger 2003), 3 das Tannwald Becken (Ellwanger et al. 1995, Ellwanger 2003, Hahne 2010), und 4 das Hosskirch Becken (Ellwanger et al. 1995, Hahne 2010). 5, mehrere flache Becken entlang des Eisrands im Nordwesten. Darin enthalten sind Delta-Schüttungen (5a), in denen das Holstein Interglazial pollenstatigraphisch nachgewiesen ist. Diese Sedimente sind der Nachweis für das Fehlen von tiefen Becken weiter proximal (Bludau 1995, Müller 2001, Ellwanger et al. 1999, 2011). 6 das Singen Becken (Szenkler & Bock 1999).

meters of weathered periglacial sediments. They are rarely exposed.

- The Scholterhaus-Mb. (qDMS) refers to the till sequence and correlative deposits inside of the 'Altmoränen-Aussenwall'. The Biberach-Scholterhaus gravel pit is the classical exposure of this till in a succession of qDMg-gravels. The till sequence consists of deformed and sheared diamicton as active-ice deposit and diamicton, sand, gravels and fines as downmelting deposits.

- Throughout the Dietmanns-Fm., deposits of fluvial sands and gravels are subsumed as Dietmanns-Schotter (qDMg-Mb.). In the adjoining periglacial area they are correlated with the Rheingletscher-Hochterrassenschotter. In the central Rhineglacier area, several gravel-cycles are in stratigraphical succession. In the east and west Rhineglacier area these cycles correlate with two or more terrace levels (Iller Valley, Klettgau Valley).

Important sub-units of the members of the Dietmanns-Fm. are:

- 'Altmoränen-Aussenwall', the terminal moraine of the qDMS ice advance (key horizon, qDMSe), consisting of diamictons, gravels and sands, quite often as push moraines.
- Pflummern Till (qDMP), an isolated deposit of diamicton, sand and gravel located north of Riedlingen. It is suggested that it represents a sub-unit of the qDMV-Mb.

4.4 Isolated glacial deposits

Various isolated glacial deposits of the Rhineglacier area (Fig 8) and along the Hochrhein Valley are subsumed as Steinental-Fm. (Tab. 6) and Haseltal-Fm. (Tab. 7). The Steinental-Fm. subsumes pre-Dietmanns deposits of the Rhineglacier area, the Haseltal-Fm. refers to alpine deposits of the Rhone Glacier (Valais Glacier) along the Hochrhein Valley.

Steinental-Fm. (qST): lithostratigraphical unit comprising four isolated glacial deposits. There is no evidence that any of these deposits may be related to glacial overdeepening, so they are suggested to be part of the "fluvial" landsystem of the 'Deckenschotter'.

- The Steinhausen-Till (qSTH) refers to a diamicton that is suggested to represent the uppermost unit of glacial till in a small stripe outside the till of the Vilsingen-Mb. between Biberach and Aitrach ('Mindel' moraines sensu Schreiner & Ebel 1981). It is covered by several meters of weathered periglacial sediments and only poorly exposed. It has also been identified in several wells beneath the qDMV deposits (e.g. Schreiner 1982).

- The Unterpfauzenwald-Till (qSTU) refers to a glacial diamicton near Steinental ('Haslach' moraines sensu Schreiner & Ebel 1981). It represents the only yet known Early Pleistocene till sequence at the landsurface of the Rhineglacier area. (cf 2.3.2.1)

Tab. 7: Lithofacies units of the Haseltal-Formation.

Tabelle 7: Lithostratigraphische Einheiten der Haseltal-Formation.

Chronostratigraphy	Formation	Member	
Middle Pleistocene	Haseltal-Fm. qHT	Haseltal-Becken-sediment qHTb	Birndorf-Mb. qHTB

- The Lichtenegg-Till (qSTL) refers to a succession of diamicton, sand and gravel within 'Mindel-Deckenschotter' in the central part of the Rhineglacier area. A detailed description has been provided by Menzies & Ellwanger (2010). (cf 2.3.3.1)

- The Schrotzburg-Till (qSTS) refers to a succession of diamicton, sand and gravel that within the 'Tiefere Hochrhein-Deckenschotter' in the western part of the Rhineglacier area. A detailed description has been provided by Graf (2009).

The Haseltal-Fm. (qHS) is a lithostratigraphical unit comprising alpine glacial and lacustrine sediments along the Hochrhein Valley. It includes glacio-lacustrine and glacial sediments (qHSb, qHSB) related to different lobes of the Rhone Glacier (Valais Glacier) that overflew the Swiss Jura mountains towards the Black Forest.

- The unit Haseltal-Beckensediment (qHSb) refers to glaciolacustrine and gravitative deposits in overdeepened basins and ice dammed lakes of the Rhone Glacier.

- The Haseltal Basin is one of several glacial basins that are carved into crystalline and Permian rocks of the Black Forest. Lower boundary: D3-unconformity. The succession begins with diamicton reflecting downmelting ice, grading up into red and grey laminated and massive fines, and terminates with organic-rich fines that include pollen spectra of the Holsteinian (Hahne 2010). It includes packages of local debris (mainly Permian red sandstone).

- In the Klettgau Valley is another deposit of fine sediments of an ice-dammed lake overlying the gravels of the 'Rheingletscher-Hochterrassenschotter' (Verderber 1992, 2003).

- The Birndorf-Mb. (qHSB) subsumes deposits of alpine debris (diamicton, gravel, sand and fines) at the southern slopes of the Black Forest. They consist of isolated kames terraces, small ice-dammed lake deposits, but also till or debris covering parts of the slopes. Their preservation depends on the local topography.

4.5 The pre- and periglacial fluvial environment

The Quaternary of the fluvial environment of large valleys in the southwest German Alpine Foreland (Tab. 8) is referred to in three formations: The 'Oberschwaben-Deckenschotter' (qpDO) covering the 'Deckenschotter' remnants in the area between Bodensee and Donau Valley, the 'Hochrhein-Deckenschotter' (qpHD) covering the western Bodensee and Hochrhein areas, and the 'Rheingletscher-Terrassenschotter' (qRT) covering gravels of the 'Hoch'- and 'Niederterrasse' in both areas. They all consist of coarse fluvial gravels.

Tab. 6: Lithofacies units of the Steinental-Formation.

Tab. 6: Lithostratigraphische Einheiten der Steinental-Formation.

Chronostratigraphy	Formation	Member			
Middle Pleistocene (OIS12?)	Steinental-Fm. qST	Steinhausen-Till qSTH			
Early Pleistocene (Calabrian)			Unterpfauzenwald-Till qSTU	Lichtenegg-Till qSTL	Schrotzburg-Till qSTS

E&G / Vol. 60 / No. 2–3 / 2011 / 306–328 / DOI 10.3285/eg.60.2-3.07 / © Authors / Creative Commons Attribution License

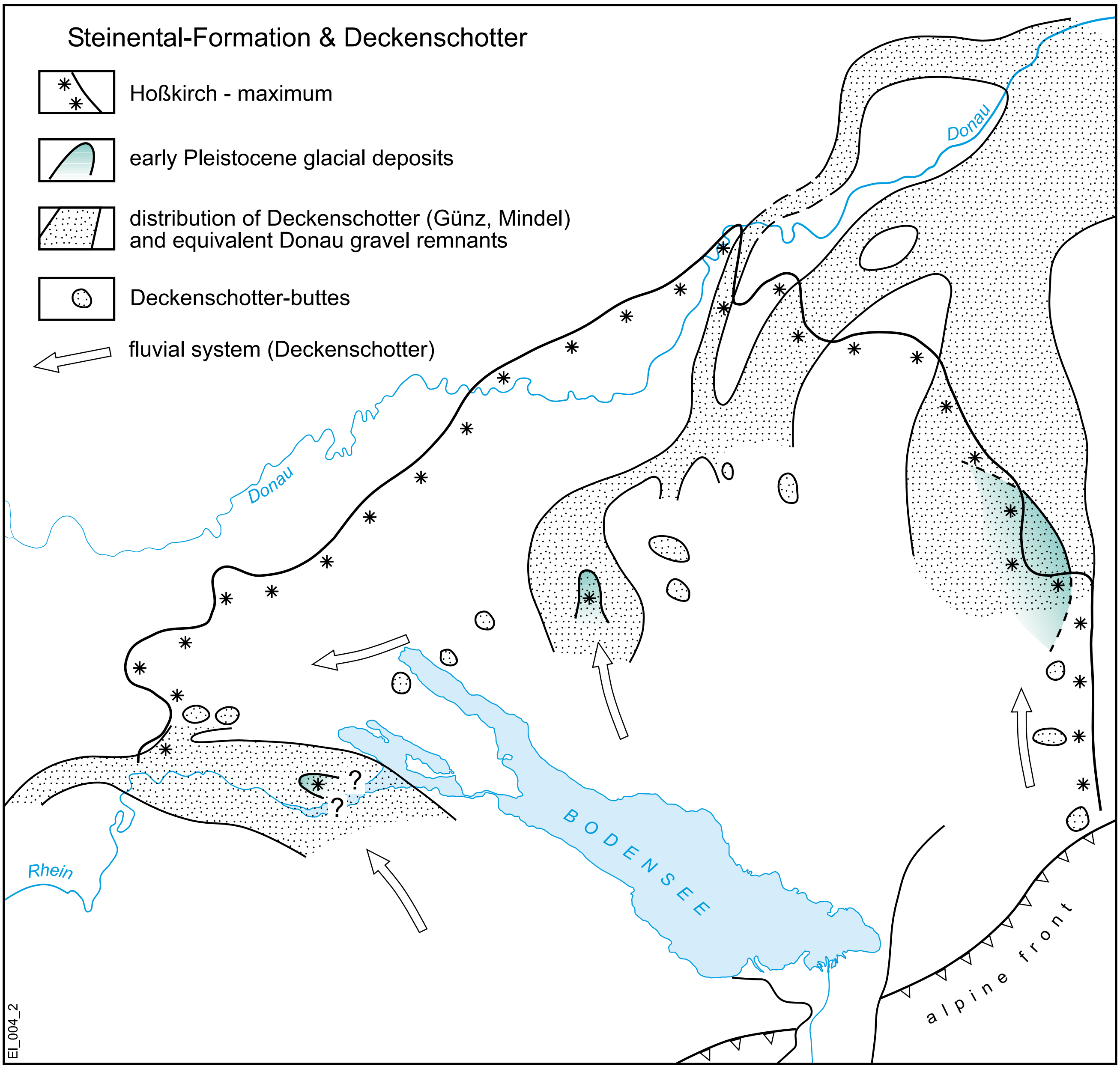

Fig. 8: 'Deckenschotter', till and terminal moraines of the Steinental-Formation. No indication for glacial overdeepening is known. The till deposits are believed to be the remnants of valley-glaciers.

Fig. 8: Deckenschotter, Till und Endmoränen der Steinental-Formation. Sie sind die ältesten eiszeitlichen Relikte und deuten auf eine nur geringe glaziale Umformung der voreiszeitlichen Landschaft hin.

The 'Oberschwaben-Deckenschotter' (qpDO) Formation consists of three members featuring different petrographical composition:

- 'Donau-Deckenschotter' (qpODD), poor in crystalline (< 5 %) but rich in Dolomite, probably reflecting a source area still east of the actual valley of the alpine Rhine.
- 'Günz-Deckenschotter' (qpODG), poor in crystalline but rich in limestone from nappes that are located close to the alpine margin. This composition is suggested to reflect the beginning of the incision of the alpine Rhine Valley.
- 'Mindel-Deckenschotter' (qpODM), rich in crystalline (10–30 %). The composition of the gravels now reflects the modern course of the alpine Rhine, but before the valley became glacially overdeepened. The inner-alpine catchment area of the Rhine is now sufficiently large to enable ice advances even into the Alpine Foreland (e.g. members of the qST-Fm.).

'Hochrhein-Deckenschotter' (qpHD): This unit is two-parted by means of terrace stratigraphy. Both subunits, the 'Höhere-Hochrhein-Deckenschotter' (qpHDh) and the 'Tiefere-Hochrhein-Deckenschotter' (qpHDt), consist of up to three accumulation cycles in stratigraphical succession (Verderber 1992, 2003, Graf 1993, 2009). There are again differences in petrographical composition, but they refer primarily to the different Swiss alpine valleys (Limmat, Reuss, Aare, Rhone). – Although the thickness of the 'Deckenschotter' along the Hochrhein Valley amounts up to several tens of meters, a much larger sediment volume has been transported through the valley into the southern URG (Breisgau-Fm.). I.e. the valley erosion and 'Deckenschotter' deposition depend largely on base level variations in the URG that are probably primarily controlled by tectonics (Ellwanger 2003).

'Rheingletscher-Terrassenschotter' (qRT): This unit subsumes two members: the 'Rheingletscher-Hochterrassenschotter' (qRTH) and the 'Rheingletscher-Niederterrassenschotter' (qRTN). Again, both subunits locally consist of two or more accumulation cycles in stratigraphical succession that may, elsewhere, correspond with different terrace levels. – The 'Terrassenschotter' are traditionally suggested to be meltwater deposits, correlative with sub- and proglacial gravels (Dietmanns- and Illmensee-gravels) and with no direct connection to the alpine sediment source area because the lake basins at the alpine margin lie in between. In this scenario, the sediment input terminates abruptly when the ice melts down, and only eventually restarts after the basins are again filled up with sediments. Preliminary results from luminescence dating indicate that this sediment input could have restarted at about 70 ka ("maximum" ages taken from Frechen et al. 2010 but doubted by Kock et al. 2009. Both papers also suggest different geological interpretations). – Again a much larger sediment volume has been transported through the valley into the URG (Neuenburg-Fm.).

4.6 The Upper Rhine Graben, southern part.

All alpine sediments that are deposited in the URG (Tab. 9) were beforehand transported through the Hochrhein Valley. In the southern URG, coarse gravels, pebbles and even blocks are deposited that are often coarser than gravels of the valley terraces. The coarse event layers were suggested

Tab. 8: Lithofacies units of the pre- and periglacial fluvial environment in the southwest German Alpine Foreland.

Tab. 8: Lithostratigraphische Einheiten der Prä- und Periglazial-Gebiete des Südwestdeutschen Alpenvorlands.

Chronostratigraphy	Formation	Member	Key horizon (e.g.)
Holocene	Rheingletscher-Terrassenschotter qRT	Rheingletscher-Niederterrassenschotter qRTN	Talauenschotter
Late Pleistocene			Niederterrassenschotter
Middle Pleistocene			Äpfingen Schotter
		Rheingletscher-Hochterrassenschotter qRTH	Baltringen Hochterrasse
			Ältere Hochterrasse
early Middle Pleistocene			
Early Pleistocene (Calabrian)	Oberschwaben-Deckenschotter qpOD	Mindel-Deckenschotter qpODM	
		Günz-Deckenschotter qpODG	
Early Pleistocene (Gelasian)		Donau-Deckenschotter qpODD	
Early Pleistocene (Calabrian)	Hochrhein-Deckenschotter qpHD	Tiefere Hochrhein-Deckenschotter qpHDt	
Early Pleistocene (Gelasian)		Höhere Hochrhein-Deckenschotter qpHDh	

Tab. 9: Lithofacies units of the southern Upper Rhine Graben.

Tab. 9: Lithostratigraphische Einheiten des südlichen Oberrheingrabens.

Chrono-stratigraphy	Formation	Member		Key horizons
Late Pleistocene	Neuenburg-Fm. qNE	Hartheim-Mb. qNEo	Zarten-Mb. qNEZ	Eventlayer
Middle Pleistocene		Nambsheim-Mb. qNEu		Eventlayer
Middle Pleistocene	Breisgau-Fm. qBR	Balgau-Mb. qBRo	Wasser-Mb. qBRW	Riegel-Horizont qBRR
Pliocene to Early Pleistocene		Weinstetten-Mb. qBRu		Hergheim-Schichten qBRH
	Iffezheim-Fm. qIF			

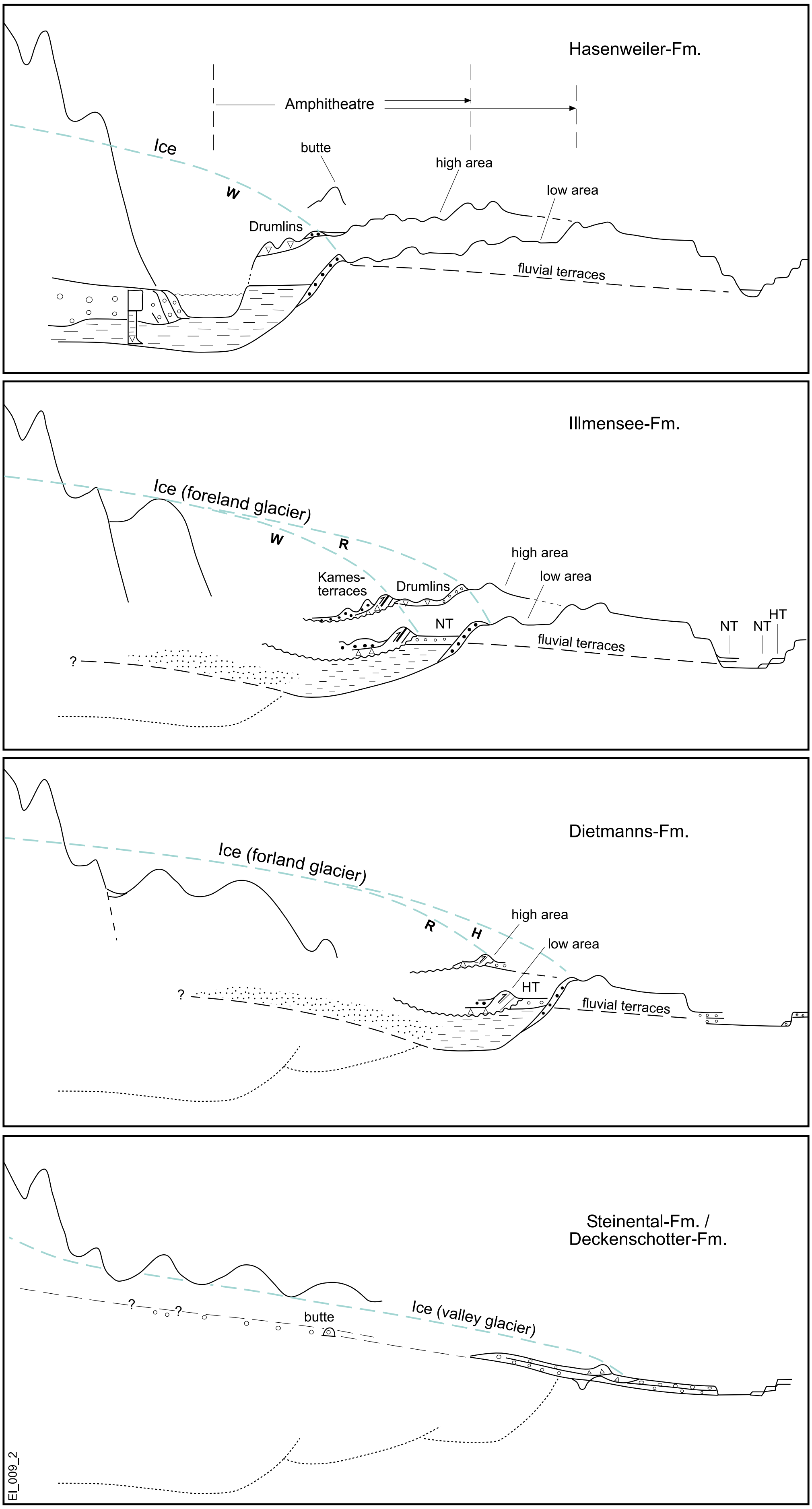

Fig. 9: Cartoon illustrating four steps of Pleistocene surface evolution of the Bodensee area, from a kind of ramp-topography to the present amphitheatre. Cf. Ellwanger *et al. 2011.*

Fig. 9: Schrittweise Entwicklung der Landschaft im Pleistozän von einer Art Rampe hin zum heutigen Amphitheater (vgl. Ellwanger *et al. 2011).*

to be correlative to morphogenetic reshaping of the valley and to the subglacial basin erosion at the alpine margin (Ellwanger 2003). The alpine input in the southern URG is referred to in two formations, the Breisgau-Fm. (qBR) and the Neuenburg-Fm. (qNE); they are further subdivided into members. The underlying Iffezheim-Fm. (qIF) is of local, non-alpine provenance. The boundary between qIF and qBR is diachronic, that is why both units begin in the Pliocene and go far up into the Pleistocene, in spite of their stratigraphical superposition.

The Breisgau-Fm. largely consists of graded alpine and local gravels. Esp. the local gravels are often altered, weathered or even completely disintegrated, indicating low sedimentation rates and possibly gravitative redeposition. Its thickness varies strongly, depending on the varying depth of the lower boundary that is primarily a matter of tectonical subsidence, supported by compaction of underlying fines. – This unit is suggested to be correlative to the 'Deckenschotter'.

The Neuenburg-Fm. (qNE) is reflected by the huge sediment fan located between the mouth of the Hochrhein Valley and the Kaiserstuhl volcanoe. The succession consists of two cycles of coarse fluvial gravels (Hartheim-Mb., qNEo, and Nambsheim-Mb., qNEu), each including a coarse basal event horizon (diamictic with pebbles and blocks). The sediment is usually unweathered. Its thickness averages between 30 m and 50 m; a large part of this is owed to the fan surface, some to compaction. – This unit is suggested to represent a correlative continuity of the erosion unconformities of the Bodensee area; it is input- i.e. climate-controlled.

According to sediment petrographical composition and heavy minerals, the sediment source of the lower and middle part of the Breisgau-Fm. are the Swiss Alps, that of the uppermost Breisgau-Fm. and the Neuenburg-Fm. is the Rhineglacier area (Hagedorn 2004).

5 Summary of relief evolution & discussion

Both, the chronostratigraphy and the lithostratigraphy of the Bodensee area that are presented here are suitable tools to describe the evolution of landforms and sediments during the Quaternary. However, the transformation of the topography from pre-alpine highlands into the actual amphitheatre landsystem with its overdeepened lake basins is better matched using the lithostratigraphical approach.

We distinguish seven steps (Figs. 3, 5, 6, 7, 8, cartoon Fig. 9):

1. The earliest Quaternary landsurface represents foothills and prealpine highlands acting as watershed between the 'Donau-Deckenschotter' of the Donau system in the east (Schädel 1950, Doppler 2003), and the eldest 'Hochrhein-Deckenschotter' of the Rhine system in the west (Schreiner 1992, Verderber 1992, 2003, Graf 1993, 2009). – Chronostratigraphy: According to Ellwanger, Fejfar & von Koenigswald, 1994 and Bolliger et al. 1996, both deposits represent the Gelasian stage.

2. The first 'Deckenschotter' remnants related to the actual Rhine Valley at the alpine margin are known as 'Günz-Deckenschotter'. They are incised below the level of the 'Donau-Deckenschotter'. Their petrographical composition reflects Helvetic and Ultrahelvetic nappes i.e. indicates the onset of erosion of the alpine Rhine Valley. This catchment area would be too small to enable an ice advance into the Alpine Foreland. – Chronostratigraphy: Early Pleistocene, according to Fromm (1989) and Rolf (1992).

3. The 'Mindel-Deckenschotter' are often (not always) incised below the 'Günz' level. Their petrographical spectra include crystalline pebbles from the central Alps, already reflecting the actual alpine Rhine Valley. This catchment area is large enough to enable ice advances into the Alpine Foreland. – Chronostratigraphy: Early Pleistocene, according to Fromm (1989) and Rolf (1992).

4. The eldest till deposits of the Rhineglacier area (subsumed in the Steinental-Fm.) show no evidence for glacial overdeepening. They are the Lichtenegg-Till, the Schrotzburg-Till, the Unterpfauzenwald-Till and the Steinhausen-Till (first advance of the Hosskirchian glacial stage. – Chronostratigraphy: Lichtenegg-Till, Early Pleistocene (Fromm 1989, Rolf 1992); Unterpfauzenwald-Till, grading into Bavelian peat (Hahne 2010); Steinhausen-Till, Hosskirchian stage (Hahne 2010).

5. The first deep basin erosion is related to the Dietmanns-Fm. There are radial branch basins in the eastern part of the Rhineglacier area but no central basin can be recognized. In the northwest, the character of the "old" surface of a prealpine ramp still prevails. Ice advance and meltwater discharge are still largely directed to the Donau Valley. – Chronostratigraphy: Hosskirchian to Rissian stage.

6. The deep basin erosion continues in the Illmensee-Formation. Now there are two central basins, one at the outlet of the overdeepened alpine Rhine Valley, the other in the westernmost part of the Bodensee area. Ice advance and meltwater discharge are now partly directed to the Donau Valley, partly to the Hochrhein Valley. – Chronostratigraphy: Rissian to Würmian stage.

7. The deep basin erosion of the Hasenweiler-Formation results in the NW elongated central Bodensee Basin ('Bodensee-Stammbecken'). Its branch basins are still radially orientated, but the system is now almost completely focussed towards the Rhine Valley i.e. to the west. – Chronostratigraphy: Würmian stage to Holocene.

The amount of Quaternary erosion since the 'Donau-Deckenschotter' seems larger in the Bodensee area than in both neighbouring areas, both downward and laterally (1 km resp. 70 km). This may be related to the reorientation of the system from the Donau to the Rhine, a setting that is unique in the Alpine Foreland. The erosion/sedimentation pattern of an eventual future ice advance is of course a matter of speculation, but most likely it will be the first Rhineglacier advance to be focussed towards the Hochrhein Valley alone. In this case, a new "most extensive" ice margin may result.

Lithostratigraphy proved to be very useful to understand and describe the morphodynamics of the Rhineglacier and to correlate with the close-by depocentres for resediments. This is due to the high spatial resolution in the Bodensee area. However, at least up to now, it does not match the difficulties of a supra-regional correlation, partly because of the insufficient knowledge on the sequence stratigraphical conditions in other glacial areas. To meet this obstacle, the chronostratigraphic approach seems more suitable.

Acknowledgement

First of all, we want to thank Prof. Dr. Ralph Watzel, President of the LGRB, for his permission to publish this paper. Our colleagues Inge Neeb and Christa Szenkler did a great job in completion of the geological maps, they also helped to update and redesign the legends. Dr. Edgar Nitsch greatly supported the formalizing of the lithostratigraphical units. Jürgen Crocoll did the excellent implementation of the figures. We enjoyed working together with you all; and we offer our most sincere thanks to you. Two anonymous reviewers superbly commented the manuscript, thank you so much for your most helpful critics and suggestions. Finally we want to remember our families: this paper would not have been possible without your patience and loving support. Most cordial thanks!

References

Bibus, E. & Kösel, M. (1996): Paläopedologische Klimazeugen zur Untergliederung des Rißeiszeiten-Komplexes im Rheingletschergebiet. – Eiszeitalter und Gegenwart, 46: 65–90; Hannover.

Bibus, E. & Kösel, M. (2003): Rezente und fossile Böden als Gliederungskriterium der Rheingletscherablagerungen am Höchsten. – Zeitschrift der Deutschen Geologischen Gesellschaft. 154: 343–356; Stuttgart.

Bibus, E., Bludau, W., Ellwanger, D., Fromm, K., Kösel, M. & Schreiner, A. (1996): On Pre-Würm glacial and interglacial deposits of the Rhine Glacier (South German Alpine Foreland, Upper Swabia, Baden-Württemberg). – In: Turner, Ch. (ed.): The early Middle Pleistocene in Europe: 195–204, Rotterdam (Balkema).

Bolliger, T., Fejfar, O., Graf, H. R. & Kälin, D. (1996): Vorläufige Mitteilung über Funde von pliozänen Kleinsäugern aus den höheren Deckenschottern des Irchels (Kt. Zürich). – Eclogae geologicae Helvetiae, 89, 3: 1043–1048; Basel.

Cohen, K.M. & Gibbard P.L. (2010): Global chronostratigraphy correlation table for the last 2.7 million years v. 2010. – IUGS International Commission on Stratigraphy's (ICS) Subcommission on Quaternary Stratigraphy (SQS). – Internet-Publ.: http://www.quaternary.stratigraphy.org.uk/charts/

Dehnert, A., Preusser, F., Kramers, J. D., Akçar, N., Kubik, P. W., R. Reber & Schlüchter, Ch. (2010): A multi-dating approach applied to proglacial sediments attributed to the Most Extensive Glacia-tion of the Swiss Alps. – Boreas, 39: 620–632. DOI: 10.1111/j.1502-3885.2010.00146.x.

Denino-Thiessen, D., Dominik, M., Haertlé, T., Hoffers, B., Hofmann, M. & Preuss, H. (2002): Anleitung zur Erfassung von Bohrungs- und Schichtdaten mit SEP 3. – Tagbuch-Nr. 32690/02, Niedersächsisches Landesamt für Bodenforschung, Fachinformationssysteme Angewandte Geologie, 39 S., NLfB (Hannover). – Internet-Publ.: http://www.gdfb.de/pdf/C39468303_L20.pdf

Doppler, G. (2003): Zur Gliederung von Ältesten Periglazialschottern und Älteren Deckenschottern im Rot-Günz-Gebiet (Oberschwaben und Bayerisch Schwaben). – Zeitschrift der Deutschen Geologischen Gesellschaft, 154, 2/3: 255–286; Stuttgart.

Doppler, G. & Jerz, H. (1995): Untersuchungen im Alt- und Ältestpleistozän des bayerischen Alpenvorlands – Geologische Grundlagen und stratigraphische Ergebnisse. – Geologica Bavarica, 99: 7–35; München.

Doppler, G, Kroemer, E., Rögner, K., Wallner, J., Jerz, H. & Grottenthaler, W.: Stratigraphic Classification of the Quaternary in Southern Bavaria. – Eiszeitalter und Gegenwart / Quaternary Science Journal, 60/2: 122–158; Hannover.

DSK (2011 ff.): LithoLex, Lithostratigraphisches Lexikon Deutschland im Internet. – Deutsche Stratigraphische Kommission. – Internet Publikation: http://www.bgr.bund.de/litholex

Eberl, B. (1930): Die Eiszeitenfolge im nördlichen Alpenvorland. – 427 S.; Augsburg (Vilser).

Ellwanger, D. (2003), unter Mitarbeit von Neeb, I. & Lämmermann-Barthel, J.: Eine landschaftsübergreifende Lockergesteinsgliederung vom Alpenrand zum Oberrhein. – In: Schirmer, W. (ed.): Landschaftsgeschichte im europäischen Rheinland. – GeoArchaeoRhein, 4: 81–124; Münster.

Ellwanger, D., Bibus, E., Bludau, W., Kösel, M. & Merkt, J. (1995): Baden-Württemberg. – In: Benda, L. (ed.): Das Quartär Deutschlands: 255–295; Berlin, Stuttgart, New York.

Ellwanger, D., Fejfar, O. & Koenigswald, W. von (1994): Die biostratigraphische Aussage der Arvicolidenfauna vom Uhlenberg bei Dinkelscherben und ihre morpho- und lithostratigraphischen Konsequenzen. – Münchner Geowissenschaftliche Abhandlungen, A 26: 173–191; München.

Ellwanger, D., Fiebig, M, & Heinz, J. mit Beiträgen zur Pollenanalyse von Bludau, W. (1999): Quartärgeologie des mittleren Rheingletschergebietes (Bittelschiess, Höchsten, Hoßkirch, Ostrach). – Jahresberichte und Mitteilungen des oberrheinischen Geologischen Vereins, N.F., 81: 217–230; Stuttgart.

Ellwanger, D, Simon, T. & Ufrecht, W. (2009): Die Lockersedimentfüllung des Blautals: Ergebnisse der neuen Forschungs-Kernbohrung am Kindergarten in Blaubeuren. – Laichinger Höhlenfreund, 44: 157–176, Laichingen

Ellwanger, D., Kimmig, B., Simon, T. & Wielandt-Schuster, U. (2011): Quartärgeologie des Rheingletschergebiets, Exkursion I. (29.04.2011). – Jahresberichte und Mitteilungen des oberrheinischen Geologischen Vereins, N.F., 93: 115–217; Stuttgart.

Fiebig, M. (1995): Pleistozäne Ablagerungen im süddeutschen und im neuseeländischen Alpenvorland – ein Vergleich). – Inaugural Dissertation Universität Freiburg: 122 S.; Freiburg.

Fiebig, M. (2003): Lithofazielle Untersuchungen an pleistozänen Sedimenten im östlichen Rheingletschergebiet. – Zeitschrift der deutschen Geologischen Gesellschaft, 154, 2/3: 301–342; Stuttgart.

Fiebig, M., Ellwanger, D., & Doppler, G. (in print): Pleistocene Glaciations of Southern Germany. – In: Ehlers, J, Gibbard, P.L. & Hughes, P.D. (eds.): Glaciations-Extent and Chronology. A closer look. Chapter 14; Amsterdam (Elsevier).

Frechen, M., E. A. Oches, & K. E. Kohfeld (2003): Loess in Europe – mass accumulation rates during the Last Glacial Period, Quaternary Science Reviews, 22: 1835–1857; Amsterdam.

Frechen, M., Ellwanger, D., Hinderer, M., Lämmermann-Barthel, J., Neeb, I. & Techmer, A. (2010): Late Pleistocene fluvial dynamics in the Hochrhein Valley and in the Upper Rhine Graben: chronological frame. – International Journal of Earth Sciences, 99, 8: 1955–1974. DOI: 10.1007/s00531-009-0482-9

Frenzel, B. (1991): Über einen frühen letzteiszeitlichen Vorstoß des Rheingletschers in das deutsche Alpenvorland. – In: Frenzel, B. (Hrsg.): Paläoklimaforschung, 1, Klimageschichtliche Probleme der letzten 130000 Jahre: 377–400; Stuttgart (Fischer).

Frenzel, B. & Bludau, W. (1987): On the duration of the interglacial to glacial transition at the end of the Eemian interglacial (deep sea stage 5e): Botanical and sedimentological evidence. – In: Berger, W. H. & Labeyrie, L. D. (eds.): Abrupt climatic changes – Evidence and implications. – NATO ASI, Series C: Mathematics and Physical Sciences, 216: 151–162; Dordrecht (Reidel).

Fromm, K. (1989): Paläomagnetische Altersbestimmungen an eiszeitlichen Quartärablagerungen bei Heiligenberg (Oberschwaben). – Niedersächsisches Landesamt für Bodenforschung – Geowissenschaftliche Gemeinschaftsaufgaben, Bericht Ar.-Nr. 105863, 19 S.; Hannover.

Gabriel, G., Ellwanger, D., Hoselmann, Ch., & Weidenfeller, M. (2008): The Heidelberg Basin Drilling Project. – Eiszeitalter und Gegenwart, Quaternary Science Journal 57, 3/4: 432 S.; Hannover.

Geotop Wyhlen (2007), http://www.geologie-des-dinkelbergs.de/geotourismus.html)

GLA (1995): Symbolschlüssel Geologie (Teil 1) und Bodenkunde Baden-Württemberg. – Geol. Landesamt Baden-Württ., Informationen, 5: 68 S. Freiburg i. Br.

Göttlich, K. (1974): Vorrißzeitliche Interglazialvorkommen in der Altmoräne des östlichen Rheingletschergebiets. – Geologisches Jahrbuch, A 18: 49–79; Hannover.

Graf, H.R. (1993): Die Deckenschotter der zentralen Nordschweiz. – Dissertation ETH Zürich – 151 S.; Zürich.

Graf, H.R. (2009): Stratigraphie und Morphogenese von frühpleistozänen Ablagerungen zwischen Bodensee und Klettgau. – Eiszeitalter und Gegenwart / Quaternary Science Journal, 58/1: 12–53; Hannover.

Graul, H. (1962): Eine Revision der pleistozänen Stratigraphie des schwäbischen Alpenvorlandes (mit einem bodenkundlichen Beitrag von K. Brunnacker). – Petermanns geographische Mitteilungen, 1962, 4: 253–271; Gotha.

Grüger, E. (1983): Untersuchungen zur Gliederung und Vegetationsgeschichte des Mittelpleistozäns am Samerberg in Oberbayern. – Geologica Bavarica, 84: 21–40; München.

Grüger, E. (1995): Pollenanalytische Untersuchungen an Sedimenten des Schmiecher Sees. – In: German et al. (1995): Die Entstehung des Schmiecher Sees aufgrund der Bohrung „Schmiecher See 1". – Beihefte zu den Veröffentlichungen für Naturschutz und Landschaftspflege in Baden-Württemberg, Landesanstalt für Umweltschutz Baden-Württemberg,, 78, 74–83; Karlsruhe.

Grüger, E. & Schreiner, A. (1993): Riss-Würm und würmzeitliche Ablagerungen im Wurzacher Becken (Rheingletschergebiet). – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 189: 81–117; Stuttgart.

Habbe, K.H. (1994): Das deutsche Alpenvorland. – In: Liedtke, H. & Marcinek, J. (Hrsg.): Physische Geographie Deutschlands: 439–475; Gotha (Perthes).

Habbe, K.A. (2003): Gliederung und Dauer des Pleistozäns im Alpenvorland, in Nordwesteuropa und im marinen Bereich – Bemerkungen zu einigen neueren Korrelierungsversuchen. – Zeitschrift der deutschen Geologischen Gesellschaft, 154, 2/3: 171–192; Stuttgart.

Habbe, K.H. (2007), unter Mitarbeit von Ellwanger, D. & Becker-Haumann, R.: Stratigraphische Begriffe für das Quartär des süddeutschen Alpenvorlandes. – Eiszeitalter und Gegenwart / Quaternary Science Journal, 56, 1/2: 66–83; Hannover.

Hagedorn, E.-M. (2004): Sedimentpetrographie und Lithofazies der jungtertiären und quartären Sedimente im Oberrheingebiet. – Dissertation Universität zu Köln, – 248 S., Köln (Internet-Publ. – http://kups.ub.unikoeln.de/volltexte/2004/1253/)

Hahne, J. (2010): Kommentare zu Pollendiagrammen von W. Bludau. – Interner Bericht, Az. 4762//10_2414, Landesamt für Geologie, Rohstoffe und Bergbau im Regierungspräsidium Freiburg; Freiburg.

HGK (2010): Hydrogeologische Karte Baden-Württemberg, Argen-Aach-Rinne Isnyer Becken. – 142 S.; Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg / Regierungspräsidium Freiburg – Landesamt für Geologie, Rohstoffe und Bergbau; Karlsruhe/Freiburg.

Häuselmann, Ph., Fiebig, M., Kubik, P.W. & Adrian, H. (2007): A first attempt to date the original 'Deckenschotter' of Penck & Brückner with cosmogenic nuclides. – Quaternary International, 164–165, 33–42. DOI: 10.1016/jh.quaint.2006.12.013

Klasen, N. (2008): Lumineszenzdatierung glazifluvialer Sedimente im nördlichen Alpenvorland. – Dissertation Universität zu Köln, – 209 + VIII S., Köln (Internet-Publ. – http://kups.ub.uni-koeln.de/volltexte/2008/2293/)

Kock, S., Huggenberger, P., Preusser, F., Rentzel R., & Wetzel, A. (2009): Formation and evolution of the Lower Terrace of the Rhine River in the area of Basel. – Swiss Journal of Geoscience, 102, 2: 307–321, DOI: 10.1007/s00015-009-1325-1

LGRB (2005): Symbolschlüssel Geologie Baden-Württemberg, Verzeichnis geologischer Einheiten; Freiburg. – Internet-Publ.: http://www.lgrb.uni-freiburg.de

LGRB (2011): Symbolschlüssel Geologie Baden-Württemberg. Verzeichnis geologischer Einheiten; Freiburg. – Internet-Publ.: http://www.lgrb.uni-freiburg.de

Litt, T., Ellwanger, D., Villinger, E. & Wansa, S. (2005): Das Quartär in der Stratigraphischen Tabelle von Deutschland 2002. – Newsletters on Stratigraphy, 41: 385–399; Stuttgart.

Litt, T. (2007): Das Quartär als chronostratigraphische Einheit. – Eiszeitalter und Gegenwart / Quaternary Science Journal, 56, 1/2: 3–6; Hannover.

Löscher, M. (1976): Die präwürmzeitlichen Schotterablagerungen in der nördlichen Iller-Lech-Platte. – Heidelberger Geographische Arbeiten, 45: 157 S.; Heidelberg.

Lutz, M., Etzold, A., Käding, K,. Lepper, J., Hagdorn, H., Nitsch, E. & Menning, M. (2005): Lithofazies und Leitflächen: Grundlagen einer dualen lithostratigraphischen Gliederung. – Newsletters in Stratigraphy, 41, 1–3: 211–223, Berlin – Stuttgart.

Menzies, J. & Ellwanger, D. (2004): Micromorphological Analysis of Complex Till Stratigraphy near Lichtenegg, Höchsten, Baden-Württemberg, Germany. – Deuqua Abstracts; Nijmegen.

Menzies, J. & Ellwanger, D. (2010): Insights into subglacial processes inferred from the micromorphological analyses of complex diamicton stratigrahy near Illmensee-Lichtenegg, Höchsten, Germany. – Boreas, 10.1111/j.1502-3885.2010.00194.x. ISSN 0300-9483.

Müller, U.C. (2000): A Late Pleistocene pollen sequence from the Jammertal, SW-Germany with particular reference to location and altitude as factors determining Eemian forest composition. – Vegetation History and Archaeobotany, 9, 2: 125–131.

Müller, U. (2001): Die Vegetations- und Klimaentwicklung im jüngeren Quartär anhand ausgewählter Profile aus dem südwestdeutschen Alpenvorland. – Tübinger Geowissenschaftliche Arbeiten, Reihe D, 07, 118 S.; Tübingen.

Neeb, I., Lämmermann-Barthel, J., Hinderer, M., Ellwanger, D., & Frechen, M. (2004): Sediment budget of Pliocene and Quaternary unconsolidated deposits of the Rheingletscher area, Swiss Midlands and the Upper Rhine Graben. – In: DFG (Hrsg.) Abstract Volume, IODP - ICDP Joint Colloqium, 17.–19. March 2004, University Bremen: 4 S.

Penck, A. & Brückner, E. (1901/09): Die Alpen im Eiszeitalter, 1199 S.; Leipzig (Tauchnitz).

Preusser, F. (2009): Stratigraphische Gliederung des Eiszeitalters in der Schweiz. – Jahresberichte und Mitteilungen des oberrheinischen Geologischen Vereins, N.F., 92: 83–98; Stuttgart.

Preusser, F., Graf , H.R., Keller, O., Krayss, E. & Schlüchter, Ch. (2011): Quaternary glaciation history of northern Switzerland. – Eiszeitalter und Gegenwart / Quaternary Science Journal, 60/2: 282–305; Hannover.

Rolf, C. (1992): Statistische Untersuchungen zur Zuverlässigkeit magnetischer Untersuchungen mit dem Spinnermagnetometer an Sedimentproben aus Oberschwaben. – Niedersächsisches Landesamt für Bodenforschung – Geowissenschaftliche Gemeinschaftsaufgaben, Bericht Ar.-Nr. 110230, 11 S.; Hannover.

Schädel, K. (1950): Untersuchungen über das Altdiluvium des Rheingletschers zwischen Iller und Bodensee. – Dissertation Universität Tübingen: 169 S.; Tübingen.

Schädel, K. (1953): Die Stratigraphie des Altdiluvium im Rheingletschergebiet. – Jahresberichte und Mitteilungen des oberrheinischen Geologischen Vereins, N.F., 34: 1–20; Stuttgart.

Schädel, K. & Werner, J. (1963): Neue Gesichtspunkte zur Stratigraphie des mittleren und älteren Pleistozäns im Rheingletschergebiet. – Eiszeitalter und Gegenwart, 14: 5–26; Öhringen.

Schaefer, I. (1965): The Succession of fluvioglacial Deposits in the Northern Alpine Foreland. – University of Colorado Studies, Series of Earth Sciences, 7: 9–14; Boulder.

Schirmer, W. (1995): Regional field trips: Rhein-Traverse. – Quaternary field trips in Central Europe: 475–558; München.

Schreiner, A. (1982): Sedimente aus vier Eiszeiten in der Altmoräne des Rheinvorlandgletschers in der Forschungsbohrung Seibranz 1981 (Baden-Württemberg). – Jahreshefte des Geologischen Landesamts Baden-Württemberg, 24: 121–130; Freiburg.

Schreiner, A. (1989): Zur Stratigraphie der Rißeiszeit im östlichen Rheingletschergebiet (Baden-Württemberg). – Jahreshefte des Geologischen Landesamts Baden-Württemberg, 31: 183–196; Freiburg.

Schreiner, A. (1992): Geologische Karte von Baden-Württemberg 1:50.000. Erläuterungen zu Blatt Hegau und westlicher Bodensee. – 290 S.; Freiburg, Stuttgart (Landesvermessungsamt Baden.Württemberg).

Schreiner, A. (1997): Einführung in die Quartärgeologie. – 257 S.; Stuttgart (Schweizerbart).

Schreiner, A. (2003): Deckenschotter im Hegau und am westlichen Bodensee. – Zeitschrift der Deutschen Geologischen Gesellschaft, 154, 2/3: 357–368. Stuttgart.

Schreiner, A. & Ebel, R. (1981): Quartärgeologische Untersuchungen in der Umgebung von Interglazialvorkommen im östlichen Rheingletschergebiet (Baden-Württemberg). – Geologisches Jahrbuch, A 59: 3–64; Hannover.

Schreiner, A. & Haag, T. (1982): Zur Gliederung der Rißeiszeit im östlichen Rheingletschergebiet (Baden-Württemberg). – Eiszeitalter u. Gegenwart, 32: 137–161, Hannover.

STD (2002): Stratigraphische Tabelle von Deutschland 2002. – Deutsche Stratigraphische Kommission (Hrsg.), Potsdam (GeoForschungsZentrum); Frankfurt a. M. (Forschungs-Institut Senckenberg). Internet-Publ.: http://www.stratigraphie.de/std/index.html

Steininger, F.F. & Piller, W.E. (eds.) (1999): Empfehlungen (Richtlinien) zur Handhabung der stratigraphischen Nomenklatur. – Courier Forschungsinstitut Senckenberg, 209: 19 S., Frankfurt.

Szenkler, C., Bertleff, B. & Ellwanger, D. (1997): Glacial sedimentology, glaciotectonics and erosional events in the Singen basin complex and its hydrogeological consequences (South German Alpine Foreland, Lake Constance area). – Gaea heidelbergensis, 3: 328–329; Heidelberg.

Szenkler, Ch. & Bock, H. (1999): Quartärgeologie und Rohstoffgeologie im Singener Beckenkomplex. Westliches Rheingletschergebiet (Hegau, Lkrs. Konstanz). – Jahresberichte und Mitteilungen des oberrheinischen Geologischen Vereins, N.F., 81: 183–216; Stuttgart.

Verderber, R. (1992): Quartärgeologische Untersuchungen im Hochrheingebiet zwischen Schaffhausen und Basel. – Dissertation Universität Freiburg: 183 S.; Freiburg i. Br.

Verderber, R. (2003): Quartärgeologie im Hochrheingebiet zwischen Schaffhausen und Basel). – Zeitschrift der Deutschen Geologischen Gesellschaft, 154, 2/3: 369–406; Stuttgart.