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Age and geographic distribution of the youngest Upper Freshwater Molasse (OSM) of eastern Switzerland

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Key words: Upper Freshwater Molasse, Miocene, lithology, stratigraphy, biozonation, structure
Schlüsselworte: Obere Süsswassermolasse, Miozän, Lithologie, Stratigraphie, Biozonierung, Struktur
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ABSTRACT

Systematic field work within the Upper Freshwater Molasse (OSM) of Eastern Switzerland (Cantons of Zürich, Thurgau and St.Gallen) led to the discovery of a fine grained breccia equivalent to the Hörnli-breccia. This layer is used as a local lithological correlation horizon within the youngest Hörnli Molasse. New findings of small mammals help to better constrain the age of the selected profiles, to characterize them, and to attempt correlations. A map with the distribution of the youngest OSM in Eastern Switzerland is presented here. There are indications that N of the Schauenberg and NE of Wil, sediment thickness decreases notably, at least in the younger parts of the OSM. Along the line Schneitberg (ZH)-Wellenberg (TG)/Imenberg (TG)-Ottenberg (TG) a depression exists with erosional relics being preserved up to at least MN8, even below an elevation of 700 m above sea level.

Faunas with an unambiguous age of MN9 have not been reported until now. If ever, MN9 would be expected in the layers at higher altitude of Ottenberg, Wellenberg, Altenberg and in the uppermost Schnebelhorn area. In the latter fossiliferous marls are extremely rare. E of the Bernrain-Amriswil region, up to now there are not enough paleontological data for or against normal faulting of a possible Bodenseegraben. The same is to be reported for the hypothetic existence of a "Thurgraben" as proposed by previous authors.

ZUSAMMENFASSUNG

Systematische Geländebegehungen in der Oberen Süsswassermolasse (OSM) der Ostschweiz (Kantone Zürich, Thurgau und St. Gallen) führten zur Entdeckung einer zur Hörnlibrekzie äquivalenten Feinbrekzie. Diese wird nun in den jüngeren Hörnlischichten regional als lithologischer Bezugshorizont herangezogen. Neue Kleinsäugerfunde liefern einige neue Erkenntnisse zur Altersstellung ausgewählter Profilgebiete, erlauben sie zu charakterisieren und schliesslich untereinander zu korrelieren. Die jüngsten Molasseanteile der OSM werden auf einer Übersichtskarte dargestellt. Es ergeben sich Hinweise, dass sich nördlich des Schauenberges und nordöstlich Wil zumindest in den jüngeren Schichten der OSM, eine deutliche Verringerung der Sedimentmächtigkeit einstellt. Auf einer Linie Schneitberg (ZH)-Wellenberg (TG)/Imenberg (TG)-Ottenberg (TG) liegt eine Senke vor, in der in heutigen Erosionsrelikten, selbst unterhalb von 700 m über Meer, jüngste Anteile (bis mindestens MN8) erhalten bleiben konnten.

Säugerfaunen eines eindeutigen MN9-Alters konnten bisher nirgends nachgewiesen werden. Wenn überhaupt, so ist MN9 am ehesten in den höchsten Partien am Ottenberg, Wellenberg, Altenberg und in der höchsten Schnebelhornregion zu erwarten. In letzterer sind fossilhaltige Mergelhorizonte jedoch kaum vorhanden. Östlich Berlingen-Amriswil konnte die vermutete Grabenabsenkung zum Bodensee paläontologisch bis heute nicht widerlegt, aber auch nicht sicher verifiziert werden. Gleiches gilt für die hypothetische Existenz eines von früheren Autoren angegebenen Thurgrabens.

RESUME

Les travaux de terrain dans la molasse d'eau douce supérieure (OSM) de la Suisse orientale (cantons de Zurich, Thurgovie et St.Gall) ont mis à jour une brèche fine, équivalent de la brèche du Hörnli, qui est utilisée comme niveau de corrélation stratigraphique régional pour les parties les plus jeunes de la Molasse du Hörnli. De nouvelles découvertes de micromammifères ont permis de caractériser les profils étudiés, de fixer leur âge et de les corréler. Les parties les plus jeunes de l'OSM sont présentées et corrélées sur un plan d'ensemble. Au N du Schauenberg et au NE de Wil l'épaisseur de l'OSM (au moins dans ses parties plus jeunes) semble diminuer clairement. Sur une ligne Schneitberg(ZH)-Wellenberg(TG)/Imenberg(TG)-Ottenberg(TG) se trouve une dépression ayant préservé des reliefs constitués d'OSM très jeune (MN8 ou même plus jeune) situées à moins de 700 m d'altitude.

Des faunes de mammifères d'âge MN9 n'ont pas été mises en évidence. Des arguments lithostratigraphiques laissent supposer que des sédiments de cet âge pourraient néanmoins se trouver au sommet de l'Ottenberg, du Wellenberg, de l'Altenberg ainsi que dans la région supérieure du Schnebelhorn. Malheureusement, l'espoir de trouver des marnes fossilifères dans ce type de sédimentation reste très faible. A l'E de Berlingen-Amriswil la structure de graben dans la région du lac de Constance n'a pu être mise en évidence par les analyses paléontologiques. Il en va de même pour l'éxistence hypothétique d'un «Thurgraben» proposé par les anciens auteurs.

1. Introduction, previous investigations

The Molasse Basin of Switzerland is the western North Alpine foredeep which developed during the formation of the Alpine orogenic belt. Sedimentation started during Oligocene times and ended in the Late Miocene at around 11 Ma (million years). In the south of the basin, the oldest Molasse sediments are marine to brackish (Lower Marine Molasse, UMM) with a duration from about 35 to 28 Ma (Frei 1979; Berger 1992).

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Later, under a fluviatile regime, sedimentation was prograding northward (Lower Freshwater Molasse, USM). Different origins of clasts can be recognized (Schlunegger et al. 1993, 1996; Kempf 1998), allowing to distinguish various alluvial fans. From about 22 to 18 Ma a narrow marine gulf expanded from the Rhone valley eastwards through the Swiss Molasse Basin into southern Germany (Berger 1985; Keller 1989). After retreat of the sea, large alluvial fans (Napf, Hörnli) of the Upper Freshwater Molasse (OSM) developed, prograding occasionally far north (Bürgisser 1980; Bolliger 1992a, 1997). The Molasse sediments are mainly composed of clastic material derived from the forming Alps. Subsidence rates fluctuated slightly, but remained comparable across larger areas of the basin ending up in similar lithological successions. After deposition, uplift was much stronger in the western part of the sedimentary basin. Thus, due to stronger erosion, lower Molasse formations are outcropping there.

For many decades, geologists were working on the sedimentology, stratigraphy, paleontology and tectonics of the Upper Freshwater Molasse (OSM) of eastern Switzerland. Especially Tanner (1944), Hofmann (1951, 1956, 1960, 1965), Pavoni (1952, 1955, 1956, 1957, 1959), Hantke (1953), Rutsch (1956), Büchi (1957, 1958, 1959), Büchi et al. (1961, 1965), Bürgisser (1980, 1981) and Bolliger et al. (1988) contributed to a detailed lithostratigraphic framework.

Bürgisser (1980) reinvestigated the sediments of the unique Hüllistein conglomerate and its distal equivalents and highlighted its vast fan-wide stratigraphic value. He interpreted these sediments as the result of a mass flow, caused by a catastrophic outbreak of debris after the collapse of a natural dam of an inneralpine lake. This lake had supposedly formed after a huge landslide, possibly ensuing from earthquake.

At first, only a single bentonite horizon was known and was considered as a marker bed. Consequently, larger faulting was suggested. Later, it became evident, that there were at least three bentonite horizons in the Zürich area (Pavoni & Schindler 1981), and some of these were dated with different methods (Fischer et al. 1987; Fischer 1988; Gubler et al.1992). In the Molasse of St.Gall, K/Ar-dating of biotite from the bentonite of Bischoffszell was carried out by Gentner et al. (1963). Although dated in a different way, the Bischoffszell bentonite revealed a younger age than the Küsnacht bentonite and is therefore probably equivalent to the Leimbach or Riedhof bentonite. Thus, theories about larger fault structures in the region of Zürich were successively rejected. Hofmann (1970, 1973, 1974, 1975) concentrated on finding new volcanic ash layers in the OSM of northeastern Switzerland and recognized a marl layer with clasts of Upper Jurassic limestone as being the result of an impact which most probably was identical to the event of the Ries-impact in Germany.

Biostratigraphic work based on small mammal teeth was mainly done by Hünermann (1981, 1984, 1987), Bürgisser et al. (1983), Bolliger & Eberhard (1989) and Bolliger (1994a, 1996). Bolliger (1992a+b) attempted to elaborate a biostratigraphy of the more proximal part of the western Hörnli alluvial fan. Engesser (1972, 1989) and Kälin (1993, 1997) contributed to a better understanding of mammal chronology of the Swiss OMM and OSM focusing on the more western parts of Switzerland. Swiss correlations were amended by basin-wide correlations (Bolliger 1994b). The most recent summary on the OSM-biostratigraphy of Switzerland was provided by Bolliger (1997), a magnetostratigraphic correlation of the Hörnli area was carried out by Kempf et al. (1997). All mentioned biostratigraphically working authors used the MN-units (neogene mammal units, Mein 1975; Lindsay et al. 1989) for correlation. This convention will also be followed here.

An overview of the paleogeographic development within the Swiss Molasse was recently given by Berger (1996).

The study area of this paper is situated between the Lake Zurich (Zürichsee) and the Lake Constance (Bodensee) (Fig.1). The Swiss national grid system is indicated at the borders of Figure 1. Thus, localities mentioned in the text will mostly be located by approximate coordinates in angular brackets (coordinates in kilometers, horizontal first) for a rapid orientation.

2. Lithology, facies evolution

The center of the Hörnli alluvial fan between the Pfannenstiel in the west [693/239] and the Altenberg in the east [731/250] is dominated by conglomerates. They extend more westwards in the older parts of the OSM and more north- to northeastwards in the youngest parts. In an area north of Zürich-Winterthur-Frauenfeld-Ottenberg, the radial fan deposits are interfingering with sediments of a basin-axial river system (Bürgisser 1980, 1981). These are the so called "Glimmersande der Ost-West-Schüttung" (Hofmann 1960), composed of sandy river-sediments which are relatively rich in mica. During MN5 the Glimmersand river system was running in a wide depression across the Schienerberg [711/283] and the Rodenberg [701/281] to the Irchel [687/266]. During MN6 this basin-axial Glimmersand river system moved temporarily southwards. Near Zürich, as well as in the Winterthur region, a southward migration of the Glimmersand river system is observed during an earlier MN6 (Sagentobel near main mammal site [686/249]; Rümikon above main mammal site [701/262]). During MN8 the system moved northward again and was temporarily situated even farther north than at the Schienerberg [711/283]. At this time, gravels of the Hörnli alluvial fan reached northward to the Ottenberg [727/272], Wellenberg [716/269] and Seerücken [719/278]. This shifting of the basin-axial stream occurred due to a variation in activity of the diverse river systems and/or because of tectonic movements; it was also influenced by the fluvial behaviour of the river which was braided to meandering (Bürgisser 1980; Bolliger 1994a). Büchi et al. (1965) discussed a southwestern continuation of an elevated zone with well developed calcretes (Albsteinschwelle) from Ulm (Germany) down to the region of Winterthur that could be responsible for a first channelization of the basin-axial river system after the retreat of the OMM-sea.

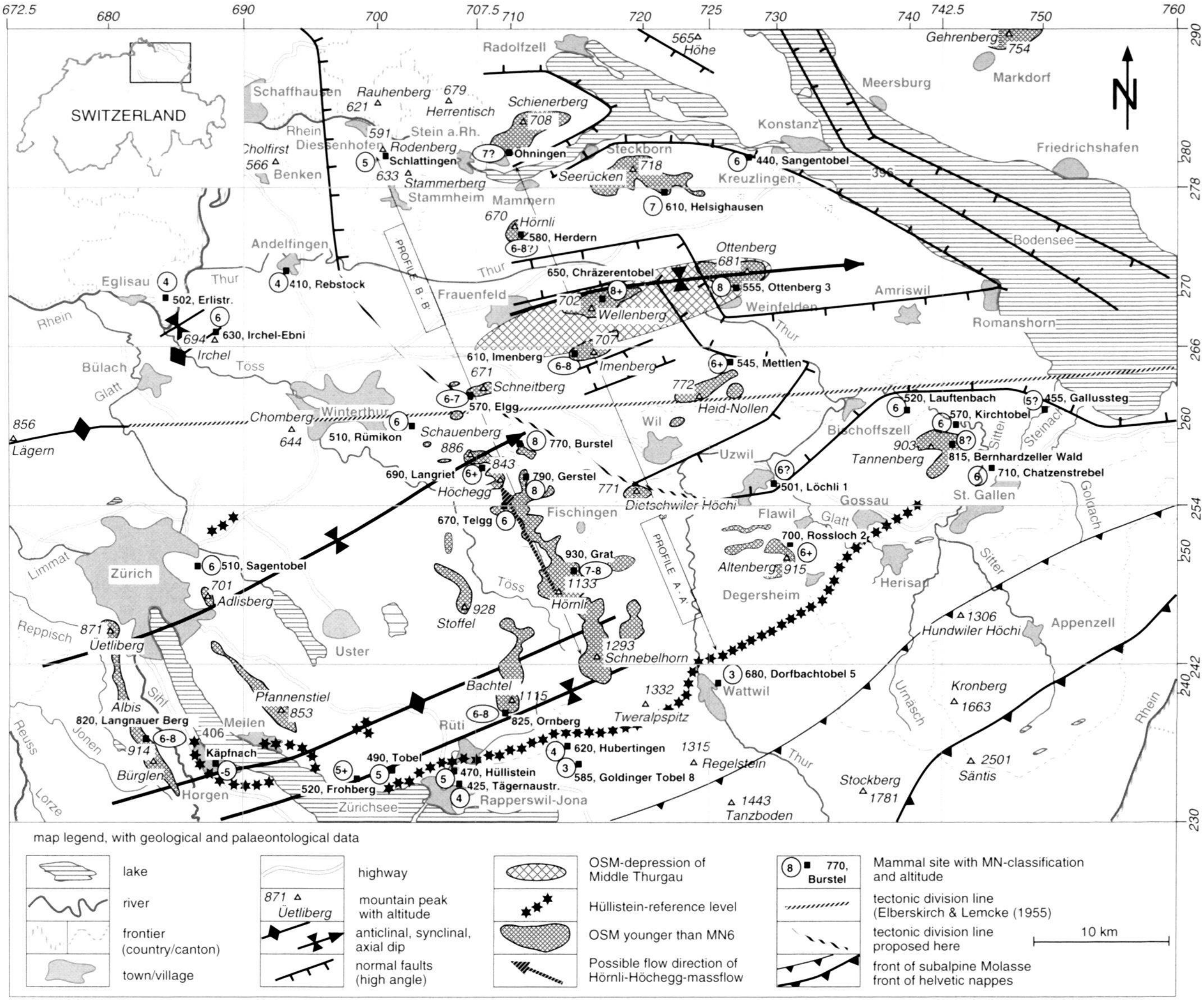

Fig.1. Map of outcrops of OSM sediments younger than MN6. The Hüllistein marker bed is drawn after Bürgisser (1980). As to tectonic structures, only the main foldstructures and some high angle normal faults are shown (after Schuppli 1952; Hofmann 1993). The mammal sites are placed with MN-reference according to Table 1, Fig. 5, Bolliger (1992a+b, 1997) and Kälin (1997). The OSM-depression of Middle Thurgau is especially marked. The grid reference is given according to the division of Swiss topographic maps (1:25'000). Profile A-A' refers to Fig. 2, profile B-B' to Fig. 7.

From Albis [683/235] south of Zürich westwards to the Lindenberg (outside Fig.1), the OSM-sediments become finer grained and show abundant limnic influence. This area is located between the alluvial fans of the Napf (in the west outside Fig.1) and the Hörnli [714/247]. The alluvial fan situated east of the Hörnli alluvial fan, named Bodensee alluvial fan ("Bodenseeschüttung"; Hofmann 1957), is represented by yellow marls and sandstones in the Tannenberg area [742/258].

A decrease of sediment thickness of the OSM is observed north of Schauenberg [707/258], north of Wil [721/258] and probably northeast of Tannenberg [742/258]. The generally lower sediment thickness of the Bavarian OSM with respect to the Swiss OSM has been discussed by Bolliger (1994b).

Lithological correlation horizons are the Hüllistein-massflow and the Hörnli-Höchegg-massflow (see discussion in chapter 4.). They are unique in the Hörnli alluvial fan. Rare is also the occurrence of ophiolitic conglomerates and sandstones (Hofmann 1951, 1993; Pavoni 1957). They seem to be abundant during middle and higher MN6 (Kaabach [718/263], Telgg [709/254], Mettlen [727/265], Fischingen [716/252]). However, as already shown by Pavoni (1957), they also locally occur in much older sediments of early MN5, thus their value as corre-

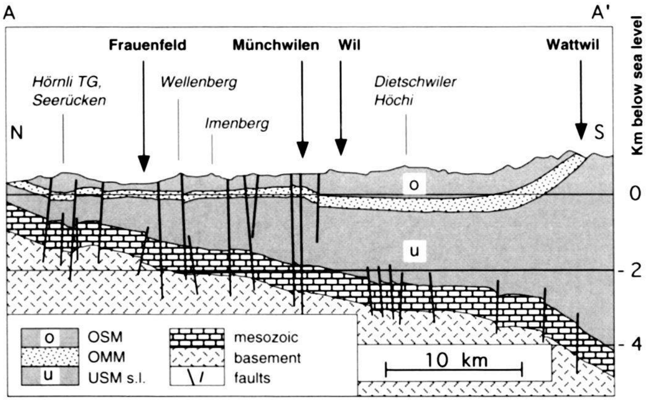

Fig. 2. Simplified cross-section drawn after Pfiffner et al. (1997). A northern, fault-dominated zone is followed by a southern, slightly folded area. Suggestions of Elberskirch and Lemcke (1955) are in agreement with this cross-section. Note vertical exaggeration.

lation horizons is restricted. Formation of these sediments remains somewhat unclear, but as they contain larger quantities of heavy minerals, it may be concluded that separating effects during transportation must have influenced their formation beside a derivation from a special catchment area. The origin of the ophiolithic components is supposedly from high Penninic nappes (Habicht 1987).

Important correlation horizons are the bentonites which show wide lateral distribution within the OSM (from the Lindenberg west of Zürich to a region near Landshut, east of Munich in Bavaria, Germany; both outside Fig.1). In contrast, tuff-layers are restricted to an area surrounding the Hegau volcanoes west of Lake Constance. Thus, in eastern Switzerland, tuffs were found at the Seerücken [719/278] and the Wellenberg [716/269], and are consequently related to the Hegau volcanism (Hofmann 1975). According to Ulbig (1994), the bentonites in Bavaria possibly also originate from the Hegau volcanoes, whereas Unger et al. (1990) rather suggest a rhyolitic source in Hungary. However, locally these layers serve as correlation horizons. In each case, isotopic dating and careful chemical analysis of volcanic minerals would be very helpful for a possible wider correlation. Until now, it seems certain, that tuffs and bentonites are not related to the Ries-impact, in agreement with Hofmann (1973) and Heissig (1986). Angular upper Jurassic limestones of which some show shatter-cones, are found in a marl at Bernhardzell [743'100/260'530/510m], Hofmann (1973). They represent probably a westernmost equivalent of the "Brockhorizont", a boulder horizon in the german OSM (Heissig 1986, 1989), which is considered to be the impact-ejecta of the collision of an extraterrestrial body which produced the Nördlingen crater. The Nördlingen and Steinheim craters situated NE of Ulm (Germany, outside Fig. 1) are well studied and were recognized as impact structures by Shoemaker & Chao (1961). Hofmann (1973) suggested a third contemporaneous crater in the Lake Constance region. Biostratigraphically, contemporaneousity of the german boulder horizon with the ejecta at Bernhardzell was indicated by Bolliger (1994b).

3. The structure of the eastern Swiss Plateau Molasse

The structure of the Molasse Basin of the eastern Swiss Plateau Molasse was studied by Schmidle (1931), Hofmann (1951), Schuppli (1952), Elberskirch & Lemcke (1955), Büchi et al. (1965), Lemcke (1973), Naef et al. (1985), Stäuble & Pfiffner (1991) and Pfiffner et al. (1997). Schuppli (1952) summarized earlier results with respect to petroleum research. Naef et al. (1985), as well as Stäuble & Pfiffner (1991) and Pfiffner et al. (1997) were taking up the subject regarding the structure of the Molasse Basin and published their interpretation mainly based on seismic lines (Fig.2). Structural interpretation from outcrop studies is given in the explanation to the geological map of Wil (Hofmann 1993).

Elberskirch and Lemcke (1955) divided the autochthonous Molasse Basin with respect to tectonics in two parts, consisting of a fold-influenced, compressive southern Molasse and an extensive northern Molasse, which shows horst-graben-structures. These authors suggested a separation along a line from the easternmost Jura-fold of Lägern [673/259] to Rorschach [754/261] and Bregenz in adjacent Austria, south of Lake Constance (see Fig. 1). However, in a geologically interpreted section recently given by Pfiffner et al. (1997) for an area north of Münchwilen [717/260], widespread faulting is suggested (Fig.2), whereas a synclinal-like structure is shown between Wil and Wattwil [724/240], with its deepest part right south of Wil. This subdivision into a fold-dominated and a fault-dominated part roughly supports the observations of Elberskirch & Lemcke (1955), but a division seems rather to run from Schaffhausen (along the already by Schuppli (1952) proposed southern continuation of the "Randenverwerfung"), to Andelfingen, further to Uzwil, and via Tannenberg to the southern Lake Constance (Fig. 1).

3.1. Faulting

A general basin-parallel (WSW-ENE) normal faulting of the basement was supposed to have already started during the middle Miocene, especially in the subjurassic region, coinciding with early folding of the Jura mountain belt (Naef et al. 1985).

NW-SE-trending normal faulting around Lake Constance was already proposed by Schmidle (1911, 1931) and later authors followed this model of a deep graben-structure, although there was poor evidence concerning the amount of vertical and/or horizontal movements. Stäuble & Pfiffner (1991) and Pfiffner et. al. (1997) contributed data from new seismic profiles, but the resolution of these deep seismic lines was only sufficient enough to show approximately where the structures are situated within the OSM, but not to clarify the exact amount of vertical block movement. Moreover, Hofmann

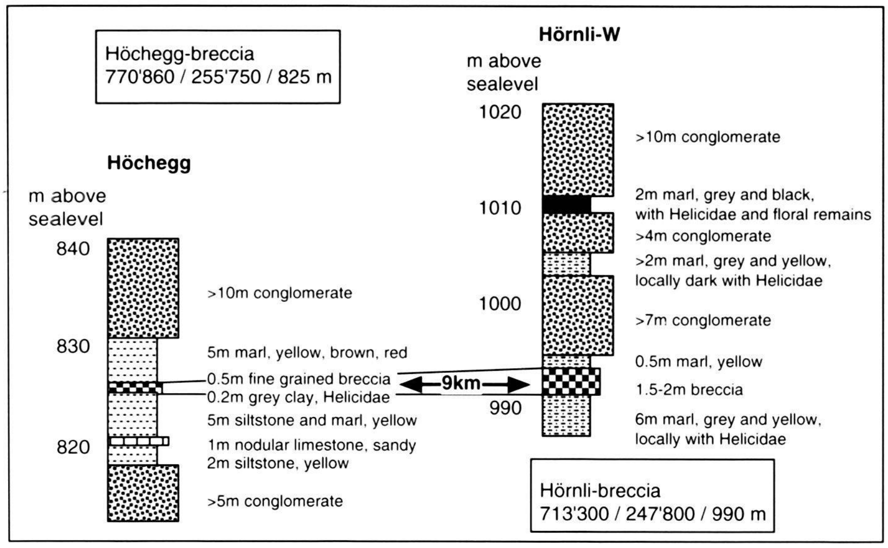

Fig. 3. Profiles of both known outcrops of the breccia layer within the youngeest Hörnli-Molasse (MN 8). (see Fig.1 for location).

(1951, 1993) observed that many blocks N and E of Wil are slightly tilted northwards, such as south of Imenberg [716/266] along the valley of the Kaabach, along the valley south of Mettlen in the Heid-Nollen-region, and at the Tannenberg.

Schmidle (1931) proposed a Graben-like depression along "Rheintal-Eschenz-Mammern-Müllheim-Weinfelden-Amriswil-Romanshorn". Hofmann (1951) followed the proposal of Schmidle (1931) concerning the existence of a then named "Thurgraben-system". He arranged the boundaries in a way that no Molasse outcrops are found to prove the postulate. Hofmann (1993) additionally reported a normal fault structure along the Lauchetal, south of Imenberg, indicating a vertical displacement of ca. 80 m. However, according to the profiles given by Stäuble & Pfiffner (1991) and Pfiffner et al. (1997), no clear Thurgraben can be seen along their seismic line, but several high angle faults reaching to the surface with offsets of maybe up to 150 m are reported by them, without giving precise localizations. The already mentioned problem of resolution of these seismic profiles has therefore to be considered. In the discussed area between Seerücken and Wellenberg, faulting is abundant, but displacement is probably mainly of rather minor amounts, following Naef et al. (1985) and Pfiffner et al. (1997; see also Fig.2). Naef et al. (1985) mention evidence for faults and a graben-structure of the Lake Constance area and indicate a possible vertical block movement up to about 400 m for the eastern flank and more than 100 m for the western flank of Lake Constance. It is probable, that these fault structures formed mainly during the active phase of Hegau volcanoes from about 16 to 7 Ma (Naef et al. 1985). Movement along these faults is suggested by recent earthquakes, as already mentioned by Schmidle (1931). Two earthquakes of march 1976 are reported by Pavoni (1987) in the area of Lake Constance suggesting dextral horizontal movement along the axis of Lake Constance. These earthquakes probably originated in a depth of 8–10 km.

3.2. Folding

Folding (see Fig.1) occurred in the area of Lake Zurich (von Moos 1946; Pavoni 1957) and is also evident in the Irchel region (Bendel 1923, Schuppli 1952). Supposedly as a kind of an eastern continuation of the easternmost Jura-fold (Lägern), an anticlinal structure can be followed eastwards across Eschenberg [679/260], Winkel [684/261] to the region of Embrach [687/262] southeast of Bülach. Fold structures are also observed in the Schauenberg region southwest of Winterthur (Büchi 1958).

Folding remains uncertain northeast of the line Schauenberg-Uzwil-Tannenberg. But, as already mentioned above, northward tilting of the Molasse strata is repeatedly found south of a line along Schneitberg-Wellenberg/Imenberg-Ottenberg, whereas at the Seerücken, a slight southward dip is observed. Schuppli (1952) named this structure Synclinal of Märstetten and postulated that it was a easternmost continuation of the "main-synclinal". More westwards, the Üetliberg-Schauenberg-synclinal is considered to be the "main-synclinal" by Schuppli (1952).

4. Results of litho- and biostratigraphy

Lithostratigraphic correlation received a new impulse with the discovery of a sandy, fine grained and matrix supported microbreccia horizon in the profile at Höchegg [770'860/255'750/825m], Figures 3 and 4. It is very likely, that this peculiar layer correlates with the breccia horizon from Chlihörnli [713'300/247'800/990m], which was first discovered by Tanner

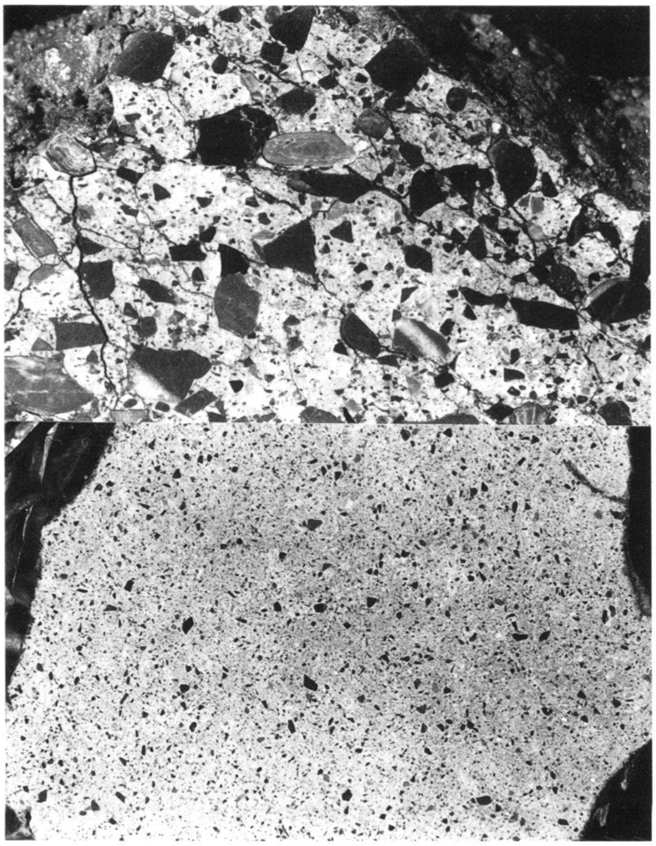

Fig. 4. Hörnli-breccia (a) and Höchegg-breccia (b). The decreasing grain-size from Hörnli to Höchegg (9 km distance) is obvious. The matrix-supported breccia is interpreted as a debris flow with angular components. The distal fine-grained breccia should rather be designated as a mud-flow; components are sandgrain-sized and angular and supported by a muddy matrix. Approximate width of both pictures: 55 mm.
The pictured specimens are deposited at the Geological Institute, ETH Zürich.

(1944) and later interpreted as massflow event by Bolliger (1992a). The base of this massflow seems not to be erosive, although in its more proximal part at Hörnli, reworked marly components have been found (Bolliger 1992a). In fact, there are now two markerpoints available, placed within the youngest OSM (MN8). There is a decrease of about 165 m of elevation within 9 km distance from Hörnli to Höchegg (Figs. 3 and 5). On the assumption, that this massflow event was well channelized in a former river bed, an approximate flow direction of 333 degrees NNW is estimated and would be in accordance to general flow directions in the Hörnli fan (Bürgisser 1980, 1981, 1984). Flow directions of the younger OSM (MN8) were mostly less pointed in western direction than general flow directions in older portions of the OSM (MN5 to MN6), as reported by Bürgisser (1980) and Bolliger (1987). Thus a diminished W-dip or increased N-dip of the Molasse Basin in a younger period of the OSM is assumed, resulting in conglomerates reaching as far north as Ottenberg, Schienerberg and Seerücken (Hofmann 1967). Yet, the topographic gradient between both breccia outcrops can only be estimated. According to Bürgisser (1980) an original fluvial dip in the Hörnli alluvial fan of about 25–110 m along 9 km is likely to occur. The observed 165 m thus must also include differences in later tectonical movements, if the two breccias represent the same massflow event. Detailed sedimentological studies and eventual further additional findings in-between the two known outcrops of the breccia could possibly give more answers. Besides, the study of the decrease of layer-thickness from about 1.5–2 m to approximately 0.4 m and of the decrease of grain sizes from up to 2 cm to below 2 mm downstream could eventually add details to the mechanism and rapidity of the event. The profiles of the two breccia sites are displayed in Figure 3. Figure 4 shows the striking ressemblance of grain shape and grain content, as well as the differences in grain size of both breccia layers. The composition of components is yet to be studied in detail.

New investigations of the OSM of eastern Switzerland (cantons of Zürich, Thurgau and St. Gallen) revealed numerous new small mammal sites (Tab. 1). Some of them displayed a rich fauna and enabled an accurate MN-classification which in turn allowed a detailed age interpretation. Other sites still need further sampling for more reliable data. Already a total of about three tons of sediment have been treated.

The regional profiles of Table 2 and Fig.5 are each composed of several individual local profiles. The aim is to give a bio- and lithostratigraphical framework and to arrive at an optimal correlation.

In the profile-region ZH1 the OMM/OSM contact is exposed (not shown in Fig.5), and a lower MN6 is evident in the youngest parts of the OSM at the Irchel. ZH2, ZH3, ZH5 and ZH6 were already investigated bio- and lithostratigraphically by Bolliger (1992a). The youngest part especially of ZH6 is poorly fossiliferous, but the occurence of MN8 is proofed at the sites Grat and Hörnli 1000. ZH4 und TG1 overlap. A lower MN6 is found there at Rümikon and a higher MN6 at Telgg and Langriet. At Burstel-Haselberg MN8 is assured with *Deperetomys hagni*. The previously mentioned breccia at Höchegg is situated in the region ZH4 whereas the formerly known Hörnli breccia is situated in the region ZH6. In correlation with neighbouring mammal sites (Burstel, Gerstel, Grat, Hörnli), both breccia layers are located within the unit of MN8, and thus further constrain their concurrence. Mammal sites of the highest parts of TG2 display MN6–8 (Imenberg), which yet has to be clarified with more fossils. TG3 revealed the first *Collimys* of Eastern Switzerland at the site Chräzerentobel 650 m. This site is provisionally located in a higher MN8. The base of the profile TG3 should be in MN6, because the profile TG6 nearby contains the reference site Mettlen 4 in a comparable position (higher MN6). The occurrence of MN8 in TG5 was already described by Bolliger (1996) at Ottenberg 3. MN9 is likely to occur there since sediments with a thickness of ca. 100 m exist above the site. Although, sedimentation rates and occurence of hiatuses are yet unknown. However, only mollusc containing marls have been found so far. In SG1 at

site (community)	Swiss coordonates	teeth	kg	MN-unit
Lauftenbach (St. Pelagiberg)	739'680 / 261'390 / 520 m	11	20	6 (lower)
Kirchtobel (Bernhardzell)	743'170 / 260'000 / 570 m	9	30	6 (lower)
Sagentobel 475 (Zürich)	686'725 / 249'670 / 475 m	3	15	6 (lower)
Irchel-Ebni	687'030 / 267'650 / 630 m	10	30	6 (lower)
Sangentobel, (Ermatingen)	722'910 / 280'510 / 440 m	18	40	6 (lower)
Löchli 1 (Niederuzwil)	729'470 / 255'700 / 503 m	1	15	6 ?
Löchli 2 (Niederuzwil)	729'500 / 255'500 / 520 m	1	30	6 ?
Sorntal	735'670 / 259'450 / 518 m	6	40	6 ?
Rossloch 1 (Flawil)	731'600 / 251'650 / 675 m	?	15	6 ?
Rossloch 2 (Flawil)	731'400 / 251'530 / 700 m	50	150	6 (higher)
Telgg (Oberhofen)	708'510 / 254'025 / 670 m	54	150	6 (higher)
Mettlen 4 (Mettlen)	726'500 / 265'000 / 545 m	>> 1000	> 2000	6 (higher)
Bernrain 2 (Kreuzlingen)	728'870 / 277'700 / 485 m	1	30	?
Gallussteg FH24	749'760 / 261'200 / 455 m	23	30	5-8 ??
Herdern 580 (Herdern)	710'800 / 274'625 / 580 m	4	15	6-8 ??
Rossloch 3 (Flawil)	731'400 / 251'530 / 725 m	11	30	7-8 (?)
Burstel-Haselberg (Bichelsee)	710'660 / 258'350 / 770 m	8	30	8
Schauenberg 845	707'200 / 257'600 / 845 m	1	30	8
Chräzerentobel 655	716'560 / 269'100 / 650 m	70	300	8

Table 1:
New recently discovered mammal sites in the OSM of eastern Switzerland. The separating line indicates the division in older (MN6) and younger (MN7 and MN8) faunas.

Table 2. The grouped profiles or profile-areas (see also Fig. 5).

Canton of Zürich (ZH):	
ZH1: Tössegg-Irchel	ZH2: Zürichsee-Uetliberg-Albis
ZH3: Zürich-Pfannenstiel-Stäfa	ZH4: Tösstal-Schauenberg
ZH5: Bachtel-Rüti	ZH6: Schnebelhorn-Hörnli
Canton of Thurgau (TG):	
TG1: Bichelsee	TG2: Imenberg
TG3: Wellenberg	TG4: Seerücken
TG5: Ottenberg	TG6: Nollen-Bischoffszell
Canton of St.Gall (SG):	
SG1: Thur-/Glattal-Altenberg	SG2: Tannenberg-St.Gallen
SG3 : Wattwil-Degersheim	SG4: Jona-Goldinger Tobel

Löchli, a lower MN6 and at Rossloch 2 a higher MN6 was found, as well as a probable MN7/8 at the site Rossloch 3 with the shrew *Dinosorex pachygnathus*. MN8 to MN9 may be expected at the Altenberg (915 m), because almost 200 m of sediment are overlying the site Rossloch 3. In SG2, a lower MN6 was found at several sites (Lauftenbach, Kirchtobel, Chatzenstrebel [746/257]). Here, the occurence of an impact layer (Hofmann 1973), and some decameters higher the outcrops of the lithostratigraphically correlated bentonites of Bischoffszell and Waldkirch/Mollen (Hofmann 1973) display time-markers (Figs.5 and 6). The bentonite of Bischoffszell and Waldkirch/Mollen respectively, was dated to 14.6 Ma by Gentner et al. (1963) and to 14.4 Ma by Fischer et al. (1987). Furthermore, good exposures allow a continuous connection to the Hüllistein-horizon down-section (Hofmann 1951). The age of the mammal site at Bernhardzeller Wald (743/258, Falkner & Ludwig 1904; Hofmann 1951) is unclear since the site could not yet be rediscovered (MN8?). SG3 and SG4 are restricted to sediments with fauna older than MN6 and are not further considered here.

The correlation of the discussed profiles is given in Figure 5. There are clear indications that a decrease in sediment thickness occurs northwards and eastwards. At the Tannenberg (SG2) thicknesses are comparable to slightly smaller to the ones at Albis-Üetliberg near Zürich (ZH2). At Schnebelhorn-Hörnli the OSM reaches its greatest thickness, about 800 m of OSM are present there above the Hüllistein marker bed. Figure 6 gives a summary of the current knowledge concerning faunal succession within the OSM of eastern Switzerland. Correlation with dated bentonites and geomagnetic profiles reveals an approximate average sediment accumulation rate of about 20–50 m/100,000 years in intermediate to proximal alluvial fan areas. The ages in million years are added after the global magnetic time scale.

Public seismic lines show only doubtful evidence for trench faulting in the area close to the Lake Constance due to peculiar features, which are difficult to explain. No matter how, these signs can be interpreted in different ways, but give vague indications of larger fault structures. Besides the abundant occurrence of tectonic slickensides (Rutschharnische) in Molasse marls east of the line Berlingen [719/281] – Amriswil [740/268] no direct evidence was observed. The existence of possible chestnut-leaves (*Castanea jacki*), found at Bernrain [729/278] near Kreuzlingen (Würtenberger 1906), suggests an age around MN8 or younger of these sediments. *Castanea jacki* represents probably leafs of a *Quercus (Oak)* species. These leafs are the only known remains of this kind in Switzerland so far. Similar leafs were found in a very young floral assemblage within the german OSM at Achldorf, possibly of a MN9 age (Unger 1986). If this fossil is time-sensitive, it would give clear evidence of normal faulting since the mammal-site of Sangentobel [723/280] at Ermatingen nearby revealed a lower MN6. Yet, there is no biostratigraphic indication of faulting along the southwestern margin of Lake Constance, as the small mammal assemblage of Gallussteg [750/261] in the Steinach valley north

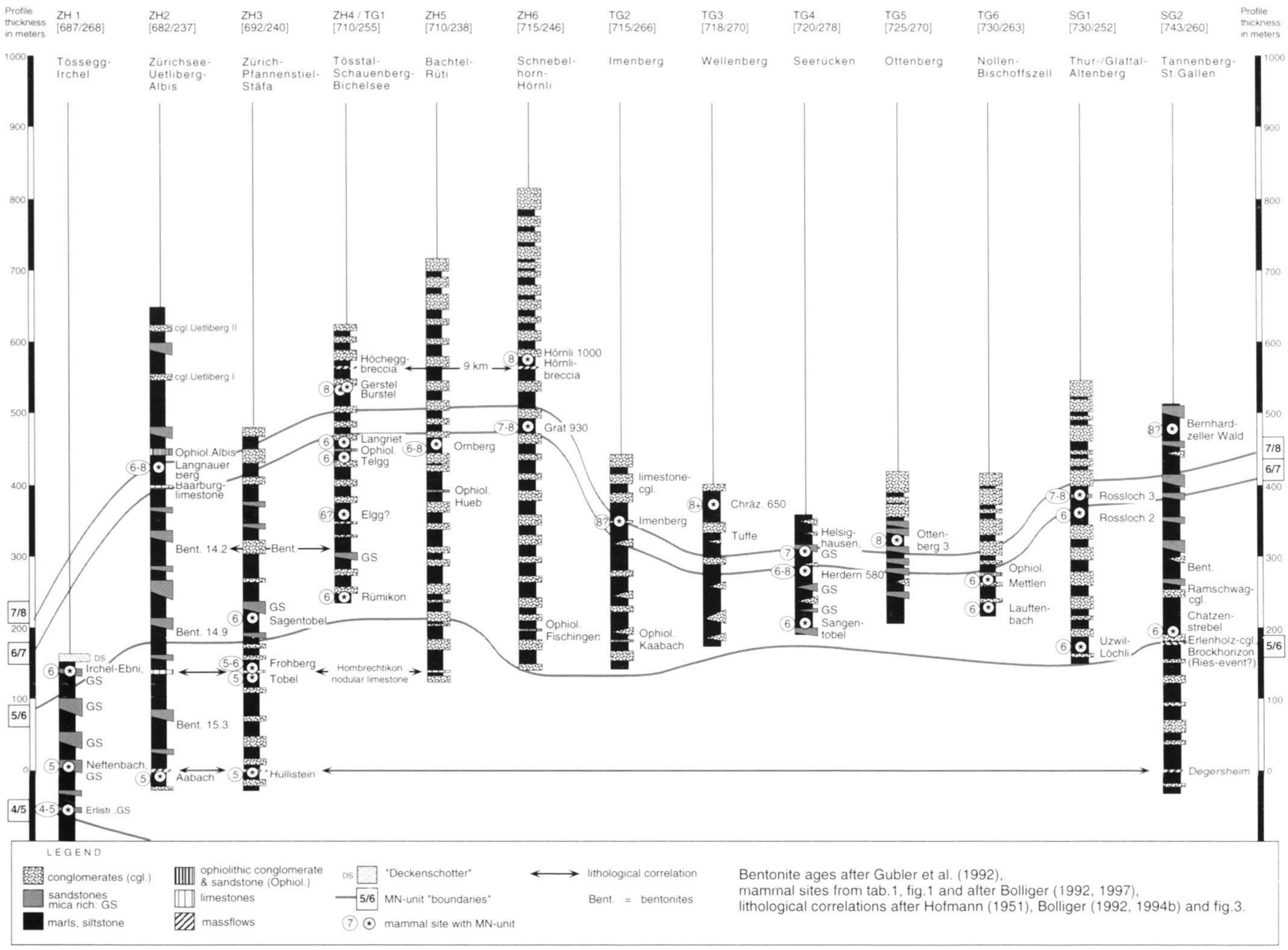

Fig. 5. Litho- and biostratigraphical correlations of the discussed profile-areas.

of St. Gallen is still too poor for a MN-correlation. The locality of Kirchtobel at Bernhardzell 5 km more in the west (743/260) and situated at a higher elevation is of a lower MN6.

As a result, there is not yet enough biostratigraphic data available to support the hypothesis of a graben-structure and we are still far away from understanding the exact amount of such vertical movements.

Faunas of the youngest OSM (MN8) are found within a narrow belt from Wellenberg to Ottenberg at low altitudes, (lowest at Ottenberg) and suggest a "depression" with an eastward dipping axis (Fig.7). It is probable, that this structure is neither a synclinal nor a tectonic graben, but rather a depression that was formed by a series of slightly tilted blocks. This depression is informally named OSM-depression of Middle Thurgau ("Mittelthurgauische OSM-Senke"). It corresponds perhaps partly to the Märstetten-syncline of Schuppli (1952) and partly to the Thurgraben of Hofmann (1951). The OSM-depression of Middle Thurgau can be traced westwards, however increasingly with less certainty. In the region of Winterthur, the syncline of the Schauenberg (Büchi 1958), and near Zurich the synclinal structure of Uetliberg (679/245, Pavoni 1957) are related to the depression of Middle Thurgau, regarding their role as the "Hauptsynklinale" according to Schuppli (1952). However, this "Mittelthurgauische OSM-Senke" was not the basin axis during the time of sedimentation, because the contemporaneous radial alluvial sediments of the Hörnli rivers reached further to the north to Seerücken and Schiener Berg, where they interfingered with the basin-axial Glimmersand river system (The direction of this stream was from ENE to WSW).

Distribution of Mammal sites of various ages are shown in the schematic cross-section along Rodenberg-Schauenberg-Hörnli (Fig.7), visualizing this depression.

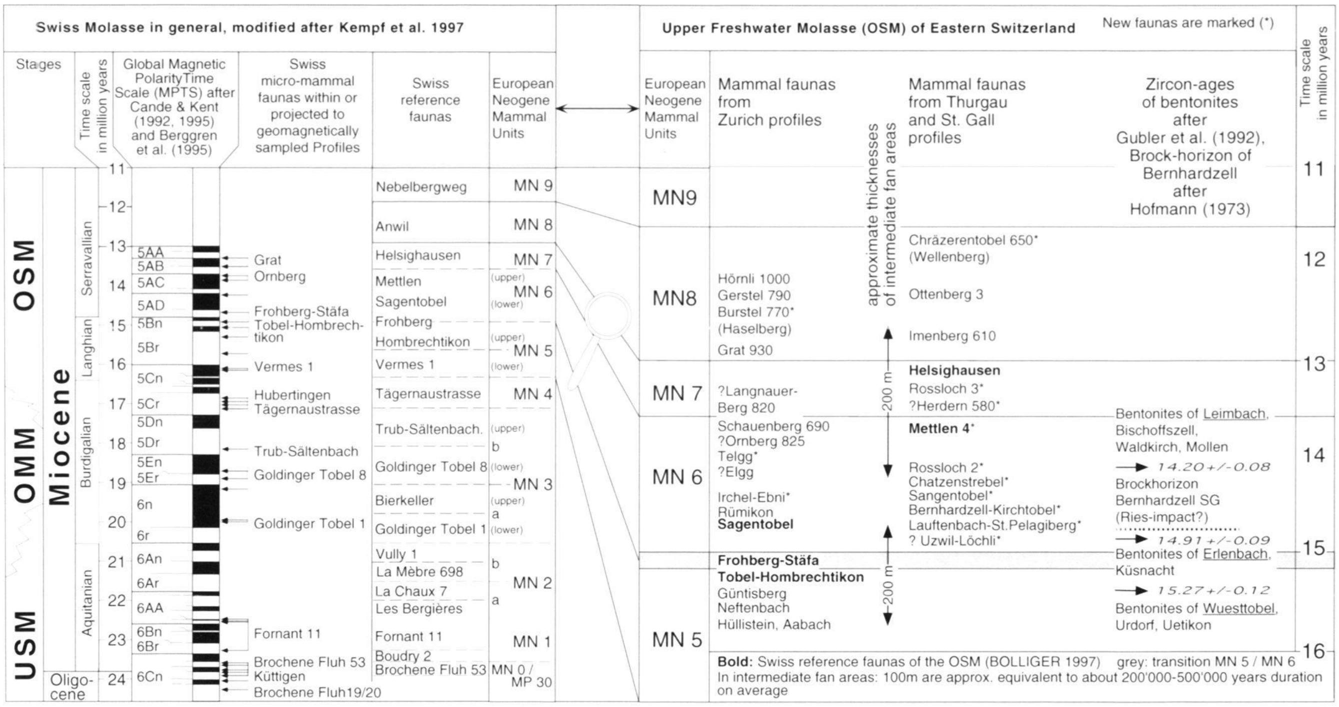

Fig. 6. Correlative chart of the faunal succession and magnetostratigraphy of the eastern Swiss Molasse basin.

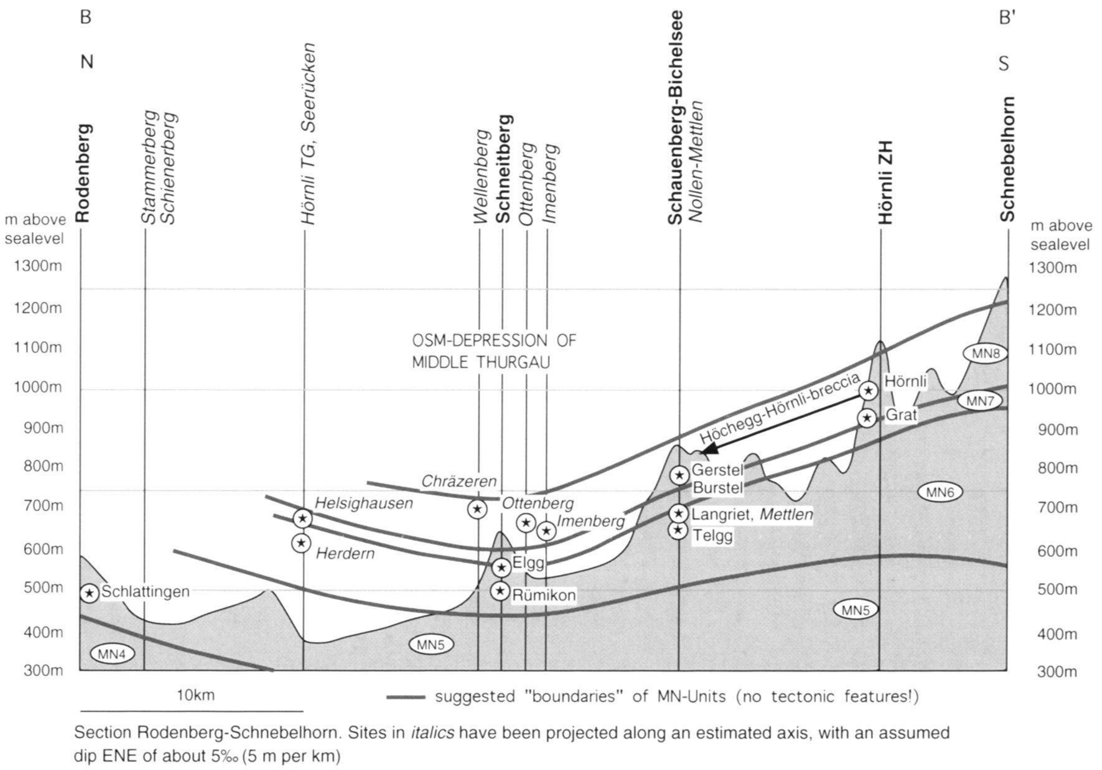

Fig. 7. An idealized cross-section from Rodenberg to Schnebelhorn depicts the location of the OSM-depression of the central Thurgau (Mittelthurgauische OSM-Senke), sediment-thickness and distribution of MN-units. The presence of MN7 is restricted to a zone of about 50 m thickness or less. (For location see Fig. 1).

5. Occurrence and distribution of sediments younger than ca. 13.5 million years

As shown in Figure 1, the regions with faunas younger than MN6 occur in a rather irregular pattern. Nevertheless, some reasons that lead to this distribution of younger OSM in eastern Switzerland are discussed in the following. The center of the conglomeratic Hörnli alluvial fan was prone to erosional resistance. Especially the hills of Albis, Pfannenstiel, Tannenberg, Ottenberg, Imenberg, Wellenberg, Seerücken, and the Irchel are relics of post-molassic erosion. The Irchel is covered by Deckenschotter (Bendel 1923; Graf 1993) of Plio-/Pleistocene age, as proven by micro-mammal biostratigraphy (Bolliger et al. 1996). At this time, younger parts of the OSM were already eroded at the Irchel. This so called "Zeugenberg" was formed during the Quaternary period after the deposition of Deckenschotter. The ultimate shape and distribution of most of the hills of the flat lying Molasse of eastern Switzerland was presumably achieved mainly during the largest phase of glaciation of the latest ice-age. In western direction, outside the map of Figure 1, only at the top of the Lindenberg (878 m), to the west of the Reuss river, sediments younger than MN6 may occur. The Lindenberg also represents an erosional relic, but showing the typical facies between two alluvial fans (Napf and Hörnli), consisting of marls, sand-, silt- and limestones.

The youngest sediments of the eastern Swiss OSM are first expected to occur at Wellenberg-Ottenberg, further also around the Dietschwiler Höchi [719/254], at the Altenberg, in the Schnebelhorn area and at the Tannenberg. To strengthen this proposal, intense investigations in order to gain more micromammal fossils have to be realized.

However, faunas of MN9 like in Hammerschmiede near Kaufbeuren in Bavaria, Germany (Mayr & Fahlbusch 1975) could not (yet) be found in eastern Switzerland.

6. Conclusion and perspective

A first new investigation showed a wide distribution of OSM deposits with an age younger than about 13.5 Ma to about 12 Ma (MN7–8), as indicated by various new mammal sites. The irregular pattern of distribution is caused by Pleistocene uplift and erosion. According to the distribution of small mammal sites, a depression structure along Wellenberg-Ottenberg is found. Normal faulting along the Lake Constance is likely to occur, but yet poorly strengthened by first paleontological data. The breccia layers at Höchegg and Hörnli are interpreted as the product of the same sedimentological event and represent the first lithological reference layer in the youngest Hörnli-Molasse.

New mammal sites should be searched in the uppermost parts of the OSM-hills with drillsticks, since natural outcrops are usually not present. Using this method, the youngest fossils of the OSM in eastern Switzerland will be found. To wash adequate amounts of sediment, a professional washing equipment with an expert team of collaborators is essential for success, because fossils occur in rather low density and can easily be missed. Thus, large quantities of sediment have to be treated. Careful paleontological investigation (preferably small mammal remains) could eventually allow to estimate the amounts of vertical block movements along Lake Constance. It remains to hope that the breccia layer of Hörnli and Höchegg may be found elsewhere in the Hörnli area (most probably in-between the two known outcrops), to support their concurrence and to allow study of flow-mechanisms of this exceptional event. Further research should include detailed chemical and structural analysis and dating of all available volcanic minerals (in bentonites and tuff-layers).

A detailed discussion of the small mammal findings mentioned in this paper will be the subject of a later publication.

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