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ORIGINAL PAPER

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Paleogeography of the Upper Rhine Graben (URG) and the Swiss Molasse Basin (SMB) from Eocene to Pliocene

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Abstract Twenty paleogeographic maps are presented for Middle Eocene (Lutetian) to Late Pliocene times according to the stratigraphical data given in the companion paper by Berger et al. this volume. Following a first lacustrine-continental sedimentation during the Middle Eocene, two and locally three Rupelian transgressive events were identified with the first corresponding with the Early Rupelian Middle Pechelbronn beds and the second and third with the Late Rupelian ≪ Serie Grise ≫ (Fischschiefer and equivalents). During the Early Rupelian (*Middle Pechelbronn beds*), a connection between North Sea and URG is clearly demonstrated, but a general connection between North Sea, URG and Paratethys, via the Alpine sea, is proposed, but not proved, during the late Rupelian. Whereas in the southern URG, a major hiatus spans Early Aquitanian to Pliocene times, Early and Middle Miocene marine, brackish and freshwater facies occur in the northern URG and in the Molasse Basin (OMM, OSM); however, no marine connections between these basins could be demonstrated during this time. After the deposition of the molasse series, a very complex drainage pattern developed during the Late Miocene and Pliocene, with a clear connection to the Bresse Graben during the Piacenzian (Sundgau gravels). During the Late Miocene, Pliocene and Quaternary sedimentation persisted in the northern URG with hardly any interruptions. The present drainage pattern of the Rhine river (from Alpine area to the lower Rhine Embayment) was not established before the Early Pleistocene.

Keywords Rhine Graben · Molasse · Paleogene · Neogene · Paleogeography

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Introduction

Several paleogeographic reconstructions were published for the URG and the Molasse Basin during the last 10 years (Berger 1996; Kuhlemann and Kempf 2002; Schlunegger and Pfiffner 2001; Sissingh 1998, 2003). Here, we present the results of 4 years of research carried out in the frame of the EUCOR-URGENT project, giving a very detailed paleogeographic frame of the studied area for Middle Eocene to Late Pliocene times. These maps were prepared according to the stratigraphic data published by Berger et al. in this volume. To avoid repetition and redundancy between the two papers, references pertaining to stratigraphic and facies data are generally not repeated here but can be found in the companion paper by Berger et al. (2004).

Eocene (Maps 1–3)

Map 1 Lutetian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: Steinbach/Gallensis Formation, Bürgen Fm. and ?Klimsenhorn Fm., Siderolithic

Plateau and Jura Molasse: Siderolithic

Southern and middle URG: Siderolithic, Eozäner Basistone, URG-conglomerates and breccias (“Steingang”), Bouxwiller Fm. (= Planorbenkalke and Calcaires d’eau douce “Lutétiens”), Green Marls (= Lymneenmergel, Marnes vertes, Grüne Mergel), Salifère inférieur, Lower Salt Fm.

Northern URG and Mainz Basin: Messel Formation, Eozäner Basiston, Unreine Sand- und Tonschichten, Ältere Eisenberger Tonfolge, Green Marls (=Lymneenmergel, Grüne Mergel, Eisenberger Grünton) (see Fig. 1).

Map 2 Bartonian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: Wildstrubel and Klimsenhorn Formation, ?Globigerinenmergel, Hohgant Formation (base), Siderolithic

Plateau and Jura Molasse: Siderolithic

Southern and middle URG: URG-conglomerates (“Steingang”), Green Marls (=Lymneenmergel, Marnes vertes, Grüne Mergel), Salifère inférieur, Lower Salt Fm.

Northern URG and Mainz Basin: ?Eozäner Basiston, Green Marls (=Lymneenmergel, Grüne Mergel, Eisenberger Grünton) (see Fig. 2).

Map 3 Priabonian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse:Wildstrubel Formation (top), Globigerinenmergel, Flysch sudhelvétique, Marnes à foraminifères, Hohgant Fm., Calcaires à petites nummulites, Cerithium beds, Couches à Cérithies,Couches à Diablerets, Sanetsch Fm., ?Siderolithic?

Plateau and Jura Molasse: Siderolithic, ??base Gelberde and Raitsche

Southern and middle URG: URG-conglomerates (“Steingang”), ?Conglom. de Porrentruy, Green Marls (=Lymneenmergel, Marnes vertes, Grüne Mergel with Melanienkalke), Salifère inférieur, Lower Salt Fm., Rote Leitschicht, Zone dolomitique, Lower Pechelbronn beds

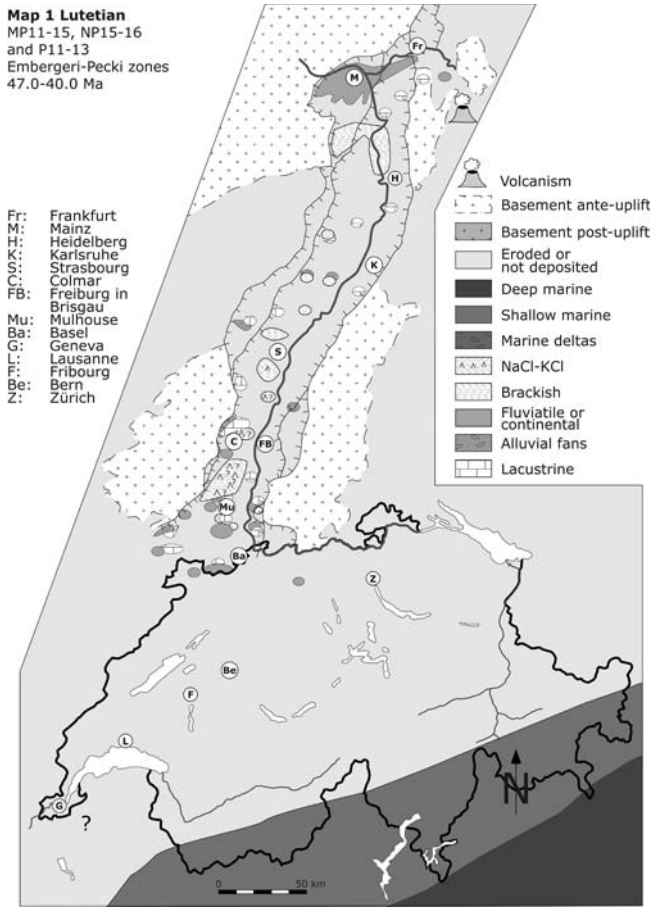

Fig. 1 Paleogeographic map of the Lutetian

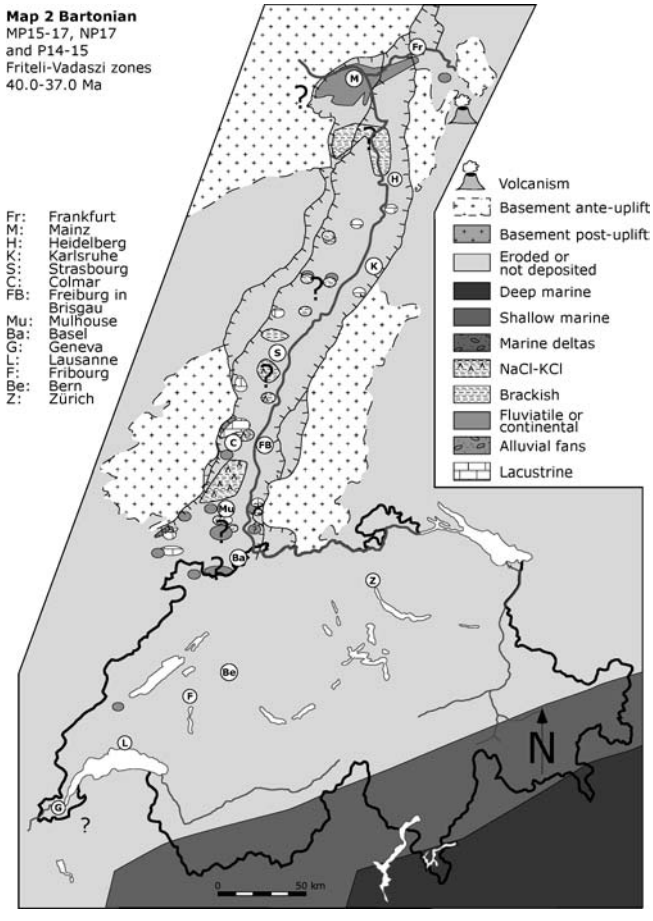

Fig. 2 Paleogeographic map of the Bartonian

Northern URG and Mainz Basin: Green Marls (=Lymneenmergel, Marnes vertes, Grüne Mergel, Eisenberger Grünton), Rote Leitschicht (incl. Sandige Eisenberger Decktone), Lower Pechelbronn beds and Eisenberger Klebsand (see Fig. 3).

During the Lutetian, the Alpine sea was located in the area northern Italian and southern Switzerland, with its northern shoreline about 70 km south of Bern (Sissingh 1998). The Alpine front was probably situated about 300 km south of its present position (Dèzes et al. 2004). Most of the area of present Switzerland was dominated by erosion (marked by local siderolithic deposits). In the URG, sedimentation occurred locally, with small lakes (e.g. Messel or Bouxwiller) and local fluviatile deposits. The first halites accumulation (mainly in the Mulhouse–Colmar area) probably began at this time.

They are no major changes during the Bartonian. In the URG, it is not clear whether sedimentation was persistent or was interrupted at this time, as postulated by Sissingh (1998).

During the Priabonian, the URG was affected by a first rifting phase that was responsible for the development of large conglomeratic fans along both the eastern and western, as well as the southern graben margins.

The axis of the evolving URG was occupied by the Salt basins in its southern, brackish (with local salt) to lacustrine in its middle-, and fluviatile to lacustrine in its northern part, as well as in the Mainz Basin.

Early Oligocene, Rupelian (Maps 4–6)

Map 4 Early Rupelian

Lithostratigraphy (for details, see Berger et al. 2004, this volume):

Helvetic and Subalpine Molasse: UMM Meletta shales, Taveyannaz and Aldorf sandstones, Val d'Illiez Fm.

Plateau and Jura Molasse: Calcaires inférieurs, Krustenkalk, Gelberde, Raitsche,

Southern and middle URG: Conglom. de Porrentruy, URG-conglomerates and breccias ("Steingang"), Middle Pechelbronn beds (=Zone fossilifère), Plattige Steinmergel, Marnes et calcaires en plaquette, ? Salifere moyen, ?Middle Salt Fm.

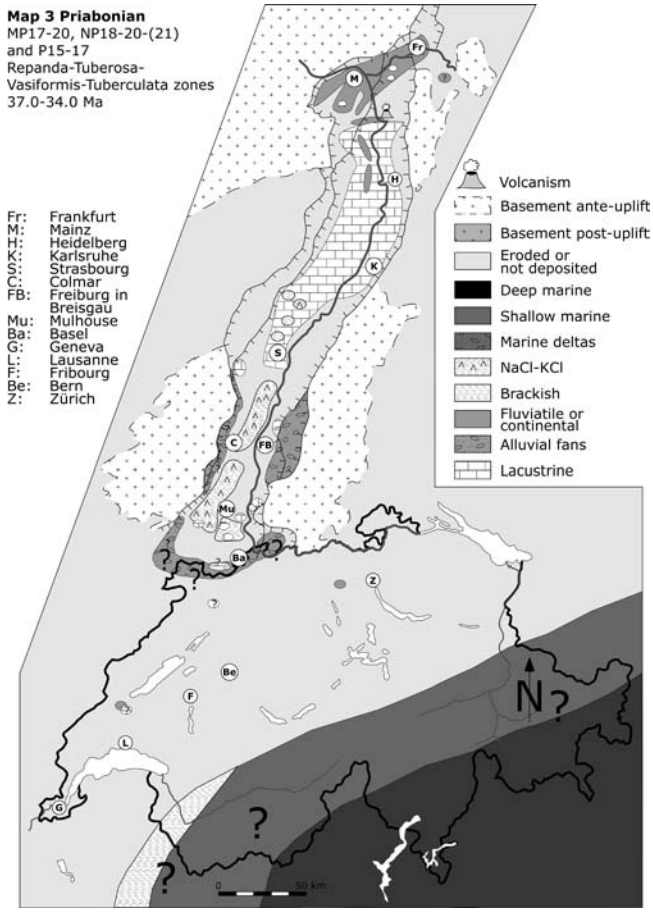

Fig. 3 Paleogeographic map of the Priabonian

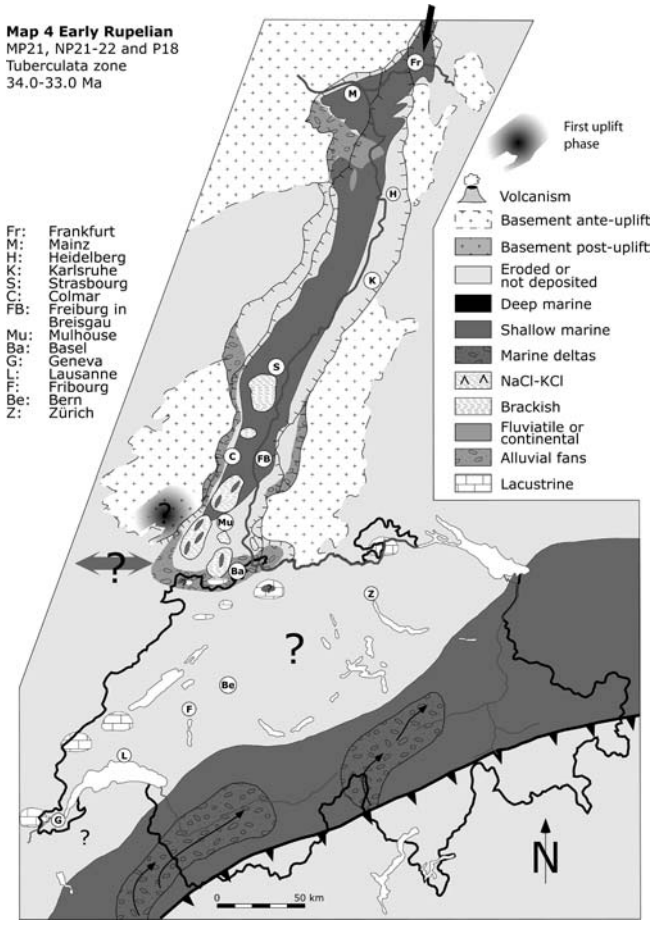

Fig. 4 Paleogeographic map of the Early Rupelian

Northern URG and Mainz Basin: Middle Pechelbronn beds and Ebertsheim Fm (see Fig. 4).

Map 5 Middle Rupelian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: UMM Vaulruz Fm., Grisiger Mergel and Horwer Sandstein

Plateau and Jura Molasse: Calcaires inférieurs, Krustenkalk, Gelberde, Raitsche

Southern and middle URG: ??Conglom. de Porrentruy, URG-conglomerates and breccias (''Steingang''), Salifere sup., Upper Salt Fm., Haustein (pars), Upper Pechelbronn beds

Northern URG and Mainz Basin: Upper Pechelbronn beds (see Fig. 5).

Map 6 Late Rupelian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: UMM Vaulruz Fm., Grisiger Mergel & Horwer Sandstein, USM Molasse rouge, Beichlen Fm.

Plateau and Jura Molasse: Calcaires inférieurs, Krustenkalk, Molasse alsacienne, Fischschiefer, Septarienton, Meeressand, Foraminiferenmergel,UMM ?Vaulruz Formation, Horwer Sandstein?, USM untere Bunte Mergel

Southern and middle URG: Molasse alsacienne, URG-conglomerates (''Steingang''), ''Serie grise'', (Rupelton, Foraminiferenmergel, Fischschiefer, Melettabeds, Cyrenenmergel, etc.), Alzey Fm., Bodenheim Fm.

Northern URG, Mainz and Hanau Basins: ''Serie grise'', (Rupelton, Foraminiferenmergel, Fischschiefer, Oberer Rupelton, Meletta beds, Cyrenenmergel), Alzey Fm, Bodenheim Fm., Stadecken Fm., Sulzheim Fm. (pars) (see Fig. 6).

The beginning of the Rupelian (Map 4) was marked by a general transgression coming from the North Sea, corresponding to the Middle Pechelbronn beds. The sea ended in the southern URG, where the Streifige Mergel and the Haustein show the transition from marine to brackish and then to lacustrine conditions. The Molasse of the Jura Mountains was apparently not affected by this transgression. Moreover, no connection existed at this time between the marine Pechelbronn beds and the

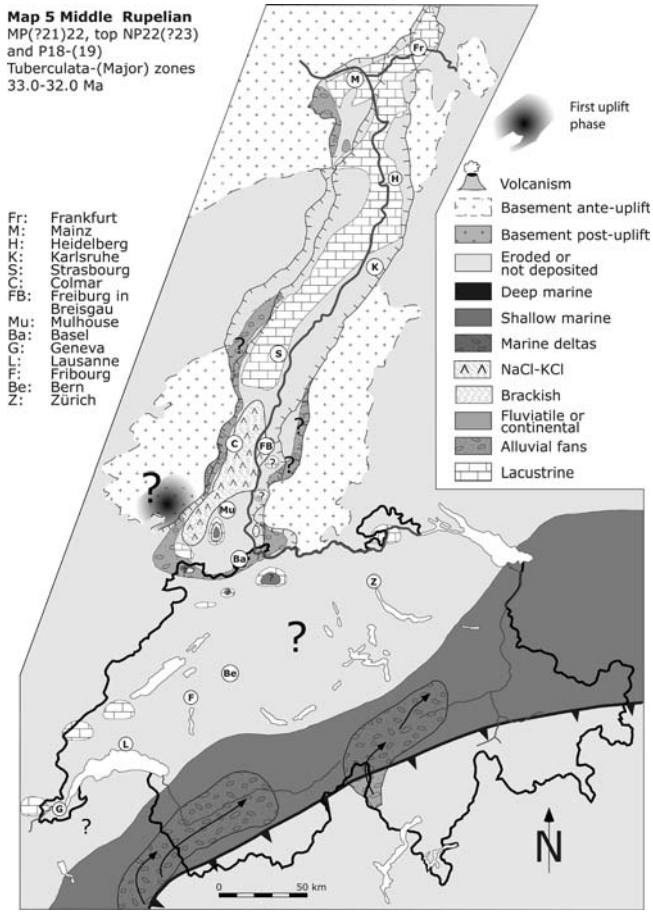

Fig. 5 Paleogeographic map of the Middle Rupelian

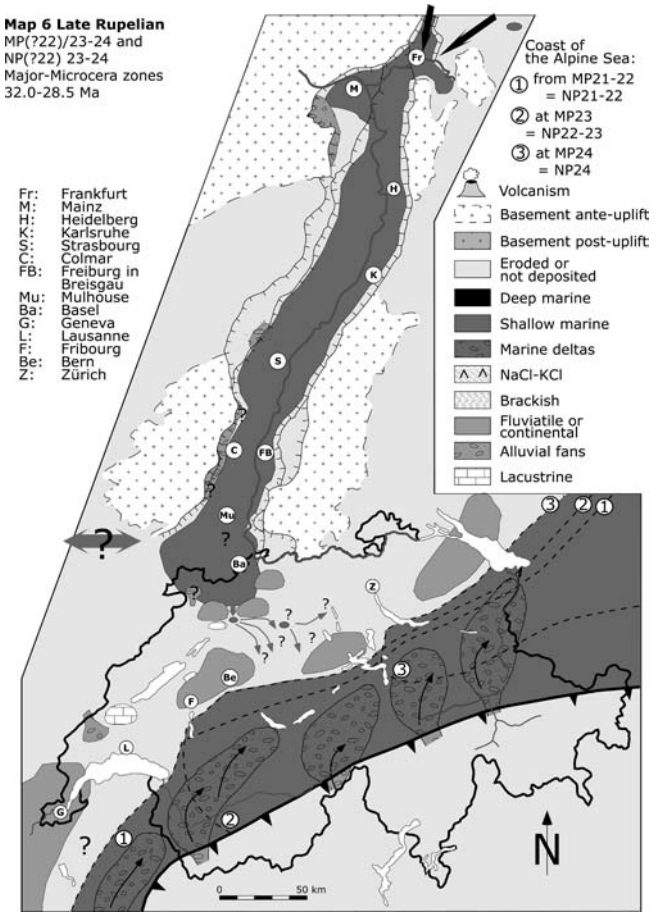

Fig. 6 Paleogeographic map of the Late Rupelian

Perialpine marine Molasse. This is perhaps due to the relief along the southern margin of the URG, as evidenced by the occurrence of large amounts of conglomerates (e.g. in the area of Porrentruy). At this time, the first pebbles derived from the Vosges basement were observed, indicative of uplift of the southern Vosges massif (Picot et al. 2004).

During the Middle Rupelian (Map 5), marine connections between the North Sea and the URG were interrupted, leading to the development of lacustrine (in the North) and brackish basins (South), with the well-known Upper salt basins (KCl). During this time, the perialpine sea (UMM) was not connected with the Rhine graben.

A general marine transgression invaded then the entire URG-basin during the Late Rupelian (Map 6), giving rise to the deposition of the ≪ Série grise ≫ (Meletta shales, Fischschiefer and other synchronous formations, see Berger et al., this volume). During this time, the Alpine sea regresses towards the East. It is likely that during this time a marine connection existed between the Alpine foreland and the URG (perhaps during NP 23?) but its precise position is not known (see Berger 1996; Kuhlemann and Kempf 2002). As shown on Map 6, the regression of the Alpine sea occurred between 32 Ma and 29 Ma (see also Diem 1986; Berger 1995; Picot 2002). Thus, a marine connection between URG and Molasse Basin was only possible via the central and eastern part of the Swiss Molasse Basin (corresponding to the coast lines 2 and 3 on Map 6), as its western part was already covered by fluviatile sediments (USM, with mammals, see Berger 1992 and 1996).

Kuhlemann et al. (1999) proposed Late Rupelian transport of clastic material from the Molasse Basin into the Southern Rhine graben, based on fission tracks-cooling age spectra of detrital apatites and zircon crystals. The precise stratigraphic position of this transport is unfortunately still insufficiently constrained.

Late Oligocene, Chattian (Maps 7–9)

Map 7 Early Chattian

Lithostratigraphy (for details, see Berger et al. 2004, this volume):

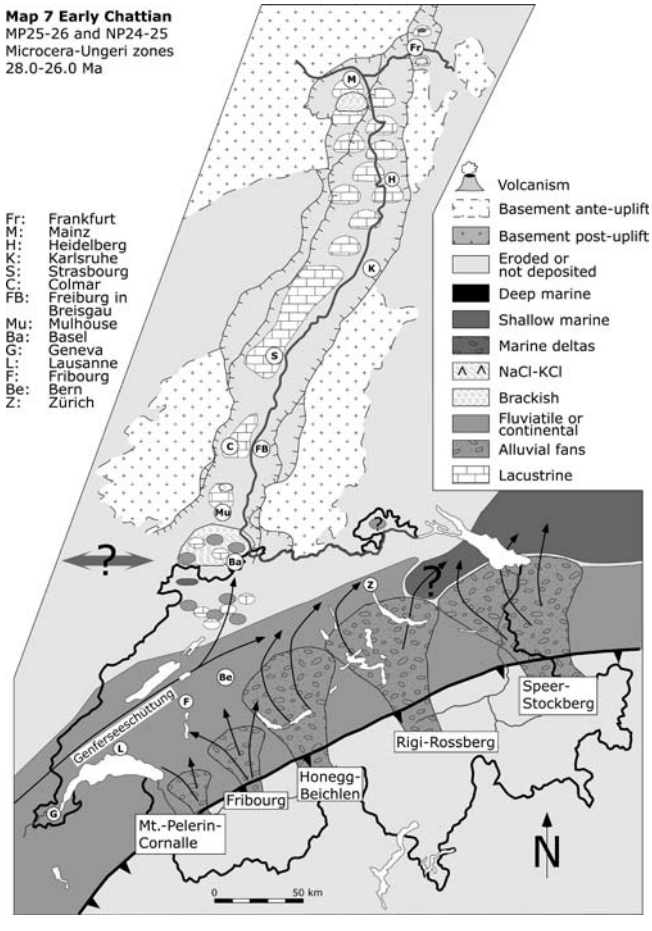

Fig. 7 Paleogeographic map of the Early Chattian

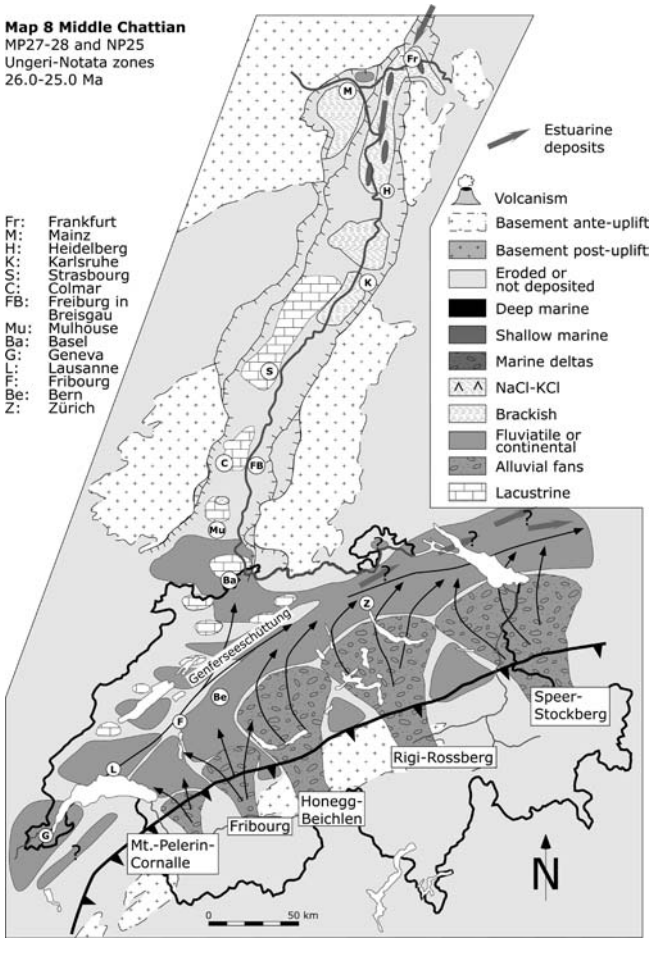

Fig. 8 Paleogeographic map of the Middle Chattian

Helvetic and Subalpine Molasse: USM Molasse rouge, Uerscheli Formation, Schwändibach conglom., Granitic Molasse Formation, Homberg beds

Plateau and Jura Molasse: UMM Top Bausteinschichten, Calcaires inférieurs, Krustenkalk, Molasse alsacienne, Top Septarienton, USM untere Bunte Mergel

Southern and middle URG: Molasse alsacienne, Niederroedern beds, Freshwater beds, Lower Cerithium beds

Northern URG, Mainz and Hanau Basins: Niederroedern beds, Budenheim-Fm., Sulzheim Fm. (pars) (see Fig. 7).

Map 8 Middle Chattian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: USM Molasse rouge, Mt. Pelerin Fm., Losenegg Fm., ?Schwändibach conglom., Thun conglom., Honegg marls

Plateau & Jura Molasse: ??Calcaires inférieurs, Molasse alsacienne, ? Calcaires delémontiens? (base), USM untere Bunte Mergel

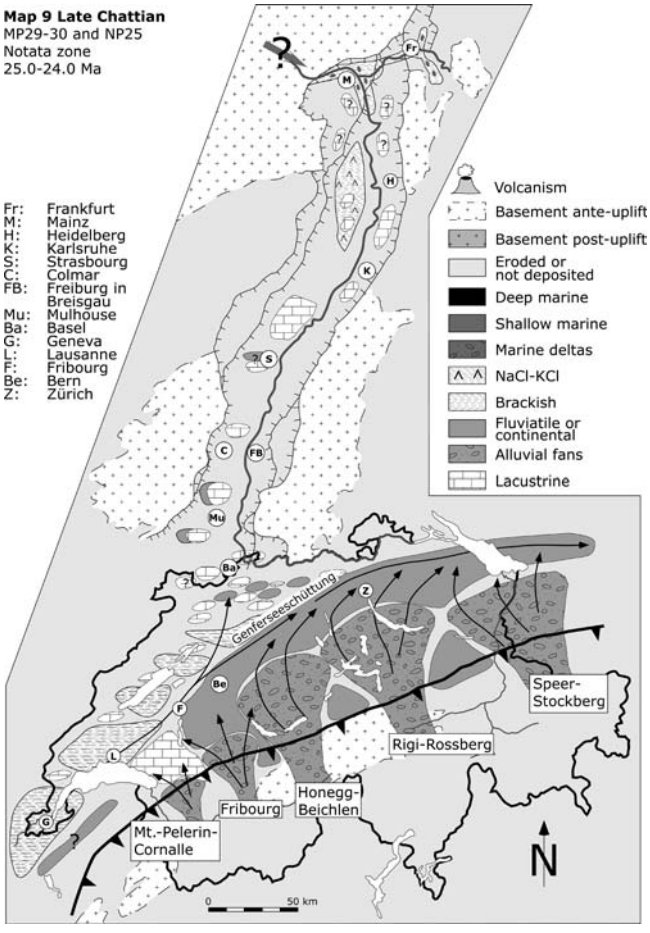

Fig. 9 Paleogeographic map of the Late Chattian

Southern and middle URG: Niederroedern beds, Freshwater beds, Lower Cerithium beds, Tüllingen Formation (base)

Northern URG, Mainz and Hanau Basins: ? Niederroedern beds, Lower Cerithium beds, Budenheim Formation, Sulzheim Fm (pars) (see Fig. 8).

Map 9 Late Chattian

Lithostratigraphy : (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: USM Conglomerates, Honegg marls, Gitzischöpf conglom., Molasse à charbon

Plateau and Jura Molasse: USM Calcaires et Dolomies??, USM Grès et Marnes grises à gypse (GMGG), Calcaires delémontiens

Southern and middle URG: Tüllingen Fm., Middle Cerithium beds, Upper Cerithium beds (pars)

Northern URG, Mainz and Hanau Basins: Middle Cerithium beds and Landschneckenkalk, Oppenheim Fm (see Fig. 9).

During the Early Chattian (Map 7), following the regression of the UMM towards the East, fluvial sediments prevailed in the Swiss Molasse Basin. Alluvial conglomeratic fans derived from the Alps were drained by a SW–NE fluviatile system referred to as the Genferseeschüttung. Part of this system invaded the southern URG through the Jura Molasse, as attested by heavy minerals of the so-called Molasse Alsacienne (Picot 2002). Lacustrine sediments prevailed in the Middle URG, whereas its northern part, including the Mainz basin, was dominated by brackish and lacustrine sediments.

During the Middle Chattian (Map 8), conditions as established during the Early Chattian prevail in the Swiss Molasse Basin. In the Northern URG, a brackish to marine ingression, probably derived from the North Sea, is recognized (Reichenbacher 2000; Sissingh 2003).

The Late Chattian (Map 9) shows an important decrease in clastic supply to the western Molasse Basin, resulting in the development of lacustrine and brackish conditions, as attested by the accumulation of lacustrine limestones and gypsiferous marls (Molasse à charbon, Calcaires et Dolomies, Grès et marnes gris à gypse). The southern and middle part of the URG were dominated by lacustrine conditions (Niederroedern beds, Lower Cerithium beds) whereas the in the northern URG brackish sediments, with local important salt accumulations, prevailed.

The differences observed between the map of Kuhlemann and Kempf (2002) (plate 2) and the maps presented here (Maps 7–9) are principally an effect of time resolution: the map of Kuhlemann and Kempf presents a combination of our Maps 7–9 and is more interpretative (e.g. concerning the connection with the Bresse Graben).

Early Miocene, Aquitanian and Burdigalian (Maps 10–13)

Map 10 Early Aquitanian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic ans Subalpine Molasse: end of USM conglomerates (e.g. Gitzischof congl.)

Plateau and Jura Molasse: USM Grès et Marnes grises à gypse (GMGG), Calcaires delémontiens?

USM Molasse grise de Lausanne (and local conglomerates), Gunten Quartzite conglom., Granitische Molasse, obere Bunte Mergel (and sandstones)

Southern and middle URG: Upper Cerithium beds, Oberrad Formation

Northern URG, Mainz and Hanau Basins: Upper Cerithium beds, Oberrad Formation (see Fig. 10).

Map 11 Late Aquitanian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: USM Molasse grise de Lausanne (and local conglomerates), Gunten Quartzite conglom., Granitische molasse, obere Bunte Mergel (and sandstones), Calcaires de La Chaux, OMM

Southern and middle URG: Inflata beds and Lower Hydrobia beds

Northern URG, Mainz and Hanau Basins: Rüssingen Fm. (= Inflata beds) and Wiesbaden Formation (see Fig. 11).

Map 12 Early Burdigalian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: OMM (Sense Fm. and Luzern Fm.) and Freshwater proximal conglomerates (e.g. Gunten Quartzite Conglom.)

Southern and middle URG: ?Lower Hydrobia beds, ?Landscheckenmergel

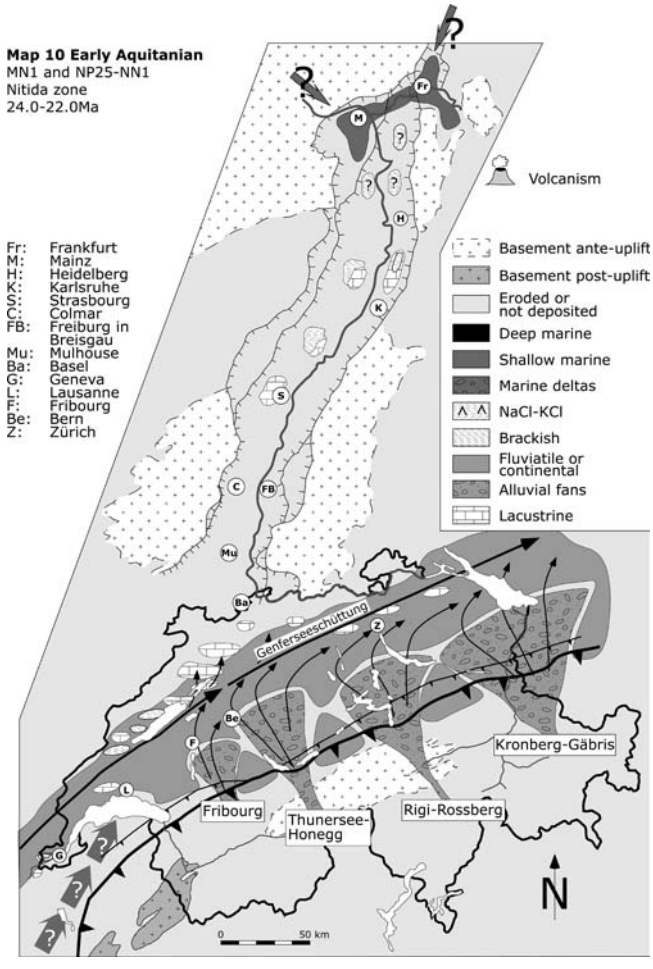

Fig. 10 Paleogeographic map of the Early Aquitanian

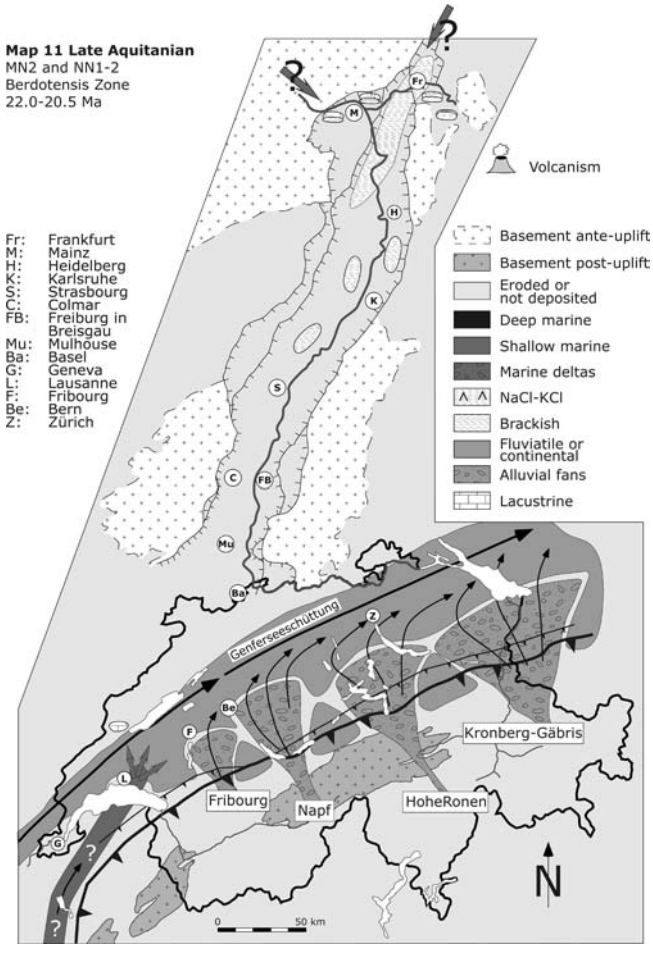

Fig. 11 Paleogeographic map of the Late Aquitanian

Northern URG, Mainz and Hanau Basins: Wiesbaden Formation, Upper Hydrobia beds, Niederrad Formation (= Landscheckenmergel), Jungtertiär I (base) (see Fig. 12).

Map 13 Late Burdigalian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: OMM (?top of Belpberg Fm., St.-Gall Fm.), OSM (conglomerates), OMM-OSM transition, Marnes rouges, Rote Mergel, Helicidenmergel, Graupensandrinne

Southern and middle URG: JungTertiär I

Northern URG and Hanau Basin: Praunheim Formation, JungTertiär I (see Fig. 13).

During the Aquitanian (Maps 10 and 11), accumulation of alluvial clastic continued in the Swiss Molasse Basin, with local lacustrine and brackish deposits prevailing in its distal parts. The occurrence of a marine ingression in its western parts is attested by mammal faunas (MN2a) trapped in tidal deposits (Berger 1985). Marine ingressions coming from the North are clearly evident in the northern URG (Rüssingen Fm. and basal Wiesbaden Fm.).

Kuhlemann and Kempf (2002) proposed in their plate 3 brackish and lacustrine facies in the southern URG and Bresse grabens. We do not agree with this interpretation, as no dated sediments are known from this area during this time, which probably corresponds to a period of erosion (Becker 2003; Berger et al. (2004), this volume).

During the Burdigalian (Map 12), a marine ingression originating from W is evident in the entire Molasse Basin. Modalities of this transgression were discussed in detail by several authors (Berger 1985, 1996; Kuhlemann and Kempf 2002).

In contrast to Kuhlemann and Kempf (2002) (plate 4), most of the northern URG sediments of this interval are brackish, as attested by the Wiesbaden-Fm and Upper Hydrobia beds dated as MN3 (see Berger et al. (2004), this volume).

During the Late Burdigalian (Map 13), the Molasse Sea probably regresses towards the distal part of the basin, where brackish conditions prevailed (Marnes rouges, Helicidenmergeln, see Becker 2003). An impor-

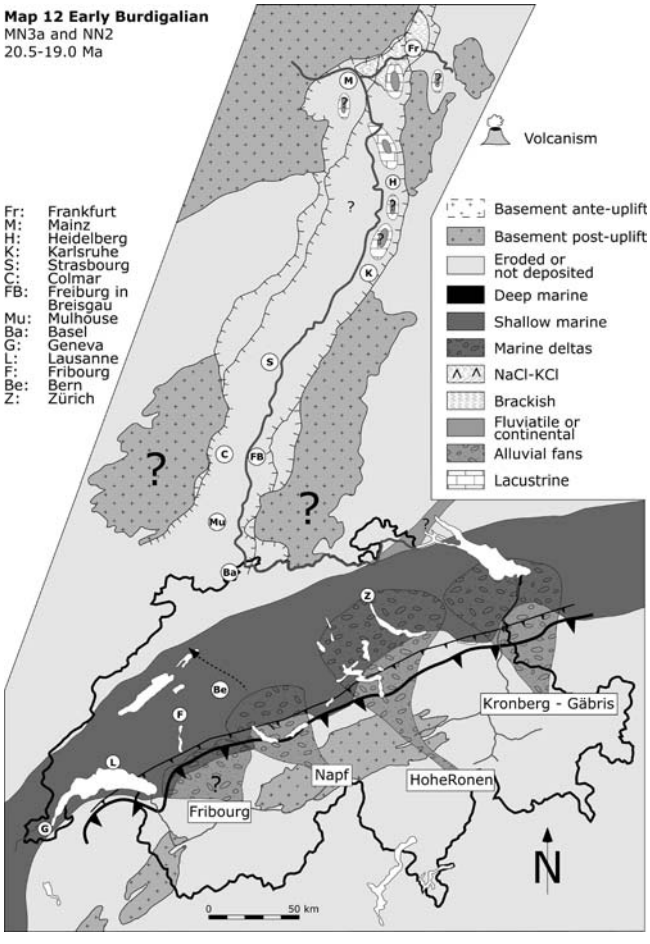

Fig. 12 Paleogeographic map of the Early Burdigalian

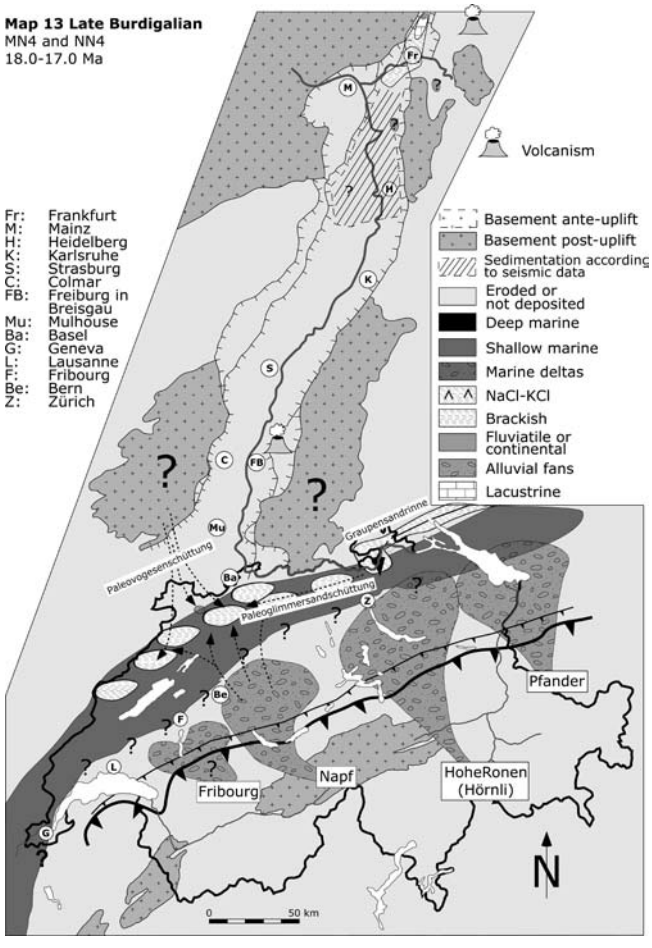

Fig. 13 Paleogeographic map of the Late Burdigalian

tant estuary is evident in the NE, the so-called Graupensandrinne (see Reichenbacher et al. 1998).

In the northern parts of the URG, fluviatile, lacustrine and brackish sediments are attributed to the Jungtertiär I (North URG) and the Praunheim Formation (Hanau Basin). In the Mainz Basin, late Burdigalian sediments are missed.

Reflexion seismic data, calibrated by wells, show that south of the city of Speyer, a regional erosional unconformity of about mid-Burdigalian age cuts southward progressively deeper into Early Burdigalian and Oligocene sediments. This unconformity is related to uplift of the Vosges-Black Forest arch, including the southern part of the URG (Roll 1979; Dèzes et al. 2004).

Middle to Late Miocene (Maps 14–17)

Map 14 Late Langhian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: OSM (conglomerates), OMM–OSM transition, Marnes rouges, Rote Mergel, Helicidenmergel, OSM (base Glimmersand), Calcaires de Vermes

Southern and middle URG: JungTertiär II (basal part)

Northern URG and Hanau Basin: Staden Fm, Main Trapp, Bockenheim Fm., Salzhausen beds, JungTertiär II (basal part) (see Fig. 14).

Map 15 Early Serravallian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: OSM (conglomerates), OSM Glimmersand, JuraNagelfluh s.l.

Southern and middle URG: Heubergschotter?

Northern URG and Hanau Basin: ?JungTertiär II (basal part) (see Fig. 15).

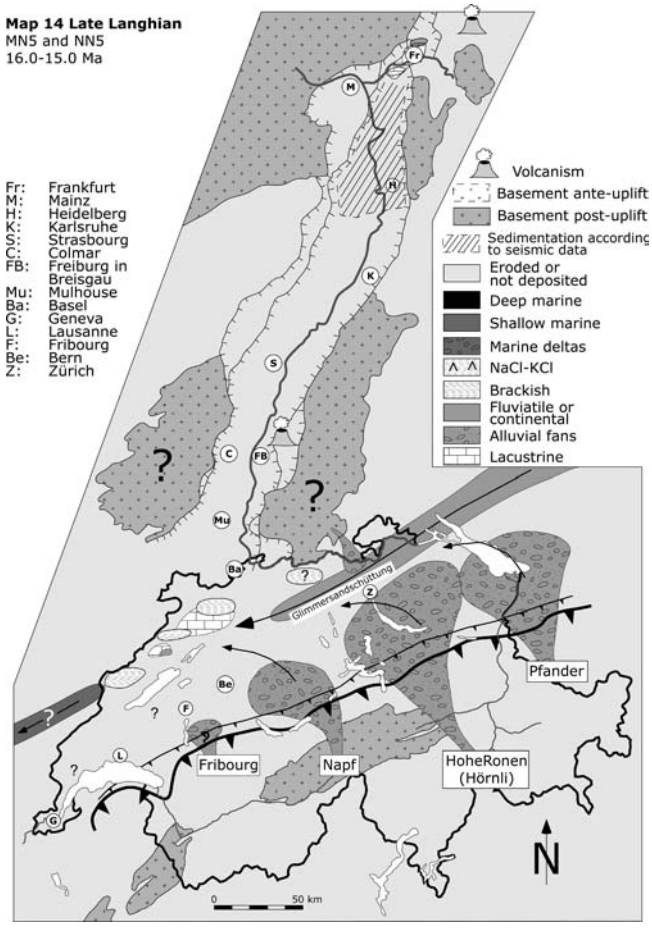

Fig. 14 Paleogeographic map of the Late Langhian

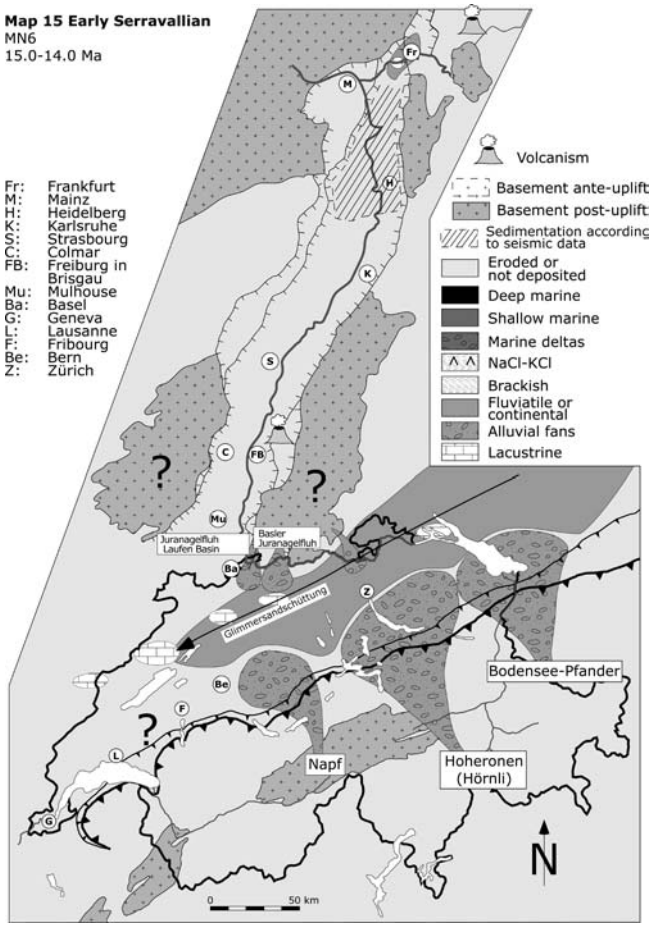

Fig. 15 Paleogeographic map of the Early Serravallian

Map 16 Middle Serravallian

Lithostratigraphy (for details, see Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: OSM (conglomerates), OSM (“Oeningian”) and ?Glimmersand (top), Anwilerkalke, JuraNagelfluh s.l.

Southern and middle URG: Heubergschotter?

Northern URG, Mainz and Hanau Basins: no sedimentation (see Fig. 16).

Map 17 Tortonian

Lithostratigraphy (see more details in Berger et al. 2004, this volume)

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: Hegau and Höwenegg serie, Vogesensande, Hipparionsande, Dinotheriensand, ?Wanderblock Fm. ?

Southern and middle URG: Heubergschotter?, Hipparionsande, Dinotheriensand,

Northern URG, Mainz and Hanau Basins: Lautersheim Fm., Dinotheriensand, Dorn-Dürkheim Fm., Bohnerzton (see Fig. 17).

These maps were already discussed by D. Becker and J.P. Berger (submitted) in the frame of the EEDEN program; here, we repeat only the principal events occurring during this time span.

During the Langhian (Map 14), a NE-SW fluviatile drainage (so-called Glimmersand) drained the distal part of the Molasse Basin. Alluvial fans coming from the Alps (Napf, Hörnli and Bodensee-Pfander) are only evident in central and eastern Switzerland and adjacent Bavaria (see Kuhlemann and Kempf 2002). All these deposits form the OSM.

Equivalent sediments are unknown for the western part of the Molasse Basin when 2,000 m of Miocene sediments were probably eroded during the Plio-Pleistocene (Kuhlemann and Kempf 2002).

Only punctual relicts of Langhian deposits occur in the western Jura Molasse (see Kälin et al. 2001) displaying a brackish-marine facies (NN4-NN5). In the northern URG, the sedimentation is essentially continental, brackish and lacustrine. In the Mainz Basin, Langhian sediments are missed.

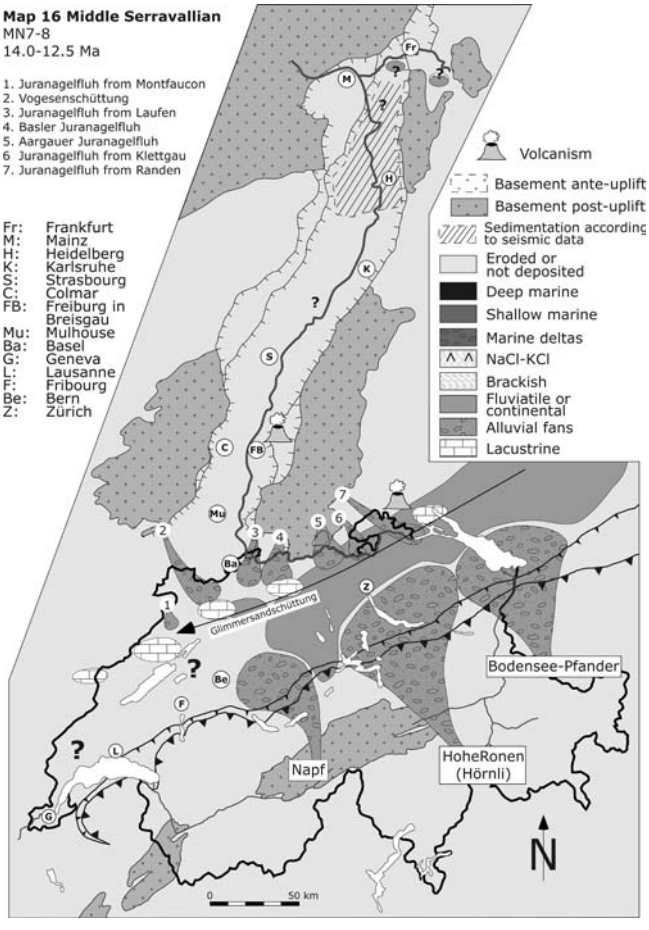

Fig. 16 Paleogeographic map of the Middle Serravallian

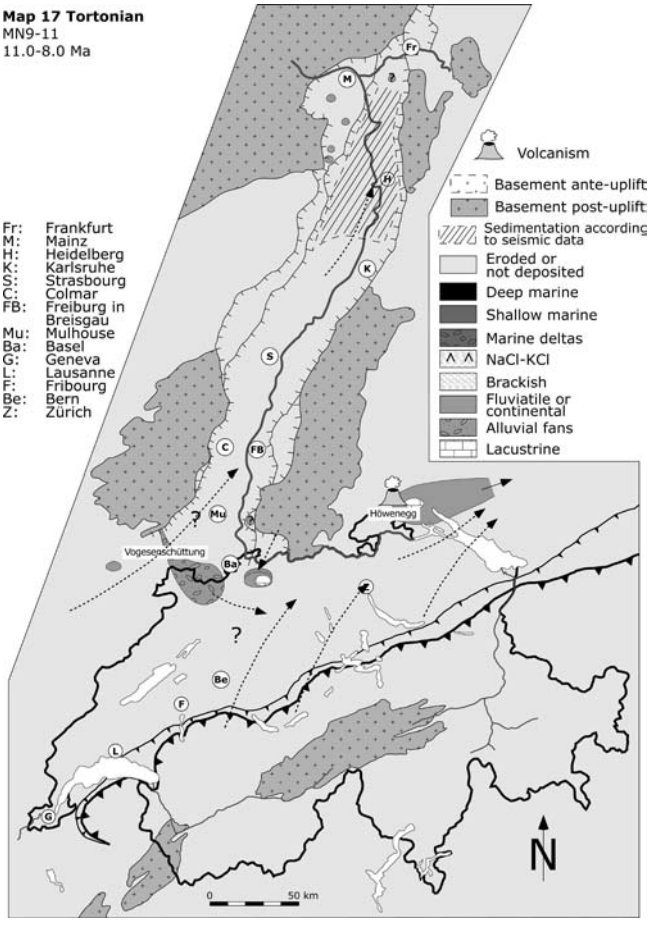

Fig. 17 Paleogeographic map of the Tortonian

In conjunction with progressive uplift of the Vosges-Black Forest arch, the central and southern part of the URG were subjected to erosion.

During the Serravallian (Maps 15–16), the fluviatile sedimentation of the OSM continued, with an important clastic supply coming from the Vosges and Black Forest massifs, confirming continued uplift during this time.

Although no sediments dated as Middle and Late Serravallian are known in the URG (?possible remnants near Frankfurt ?), their presence in its northern parts is indicated by reflection seismic data.

The Tortonian (Map 17) is principally known by conglomeratic and sandy alluvial deposits coming from the Vosges and Schwarzwald massifs (fossil localities Charmoilles, Nebelberg, Höwenegg) in the southern URG, by the Dinotheriensand and by the Dorn-Dürkheim beds (only Mainz Basin). The Dinotheriensande of the northern URG and the Mainz Basin were deposited by an Upper Rhine coming from the northern Vosges and Schwarzwald massifs (Bartz 1961; Abele 1977).

The Tortonian drainage pattern is very difficult to reconstruct; a general W–E drainage of the Molasse basin was proposed by several authors (Giamboni et al. 2004; Kuhlemann and Kempf 2002; Liniger 1966; Petit et al. 1996; Schlunegger et al. 1998), generally based on the uplift of the western and central parts of the Molasse Basin in conjunction with folding of the Jura Mountains.

Pliocene (Maps 18–20)

Map 18 Early Pliocene (Early Zanclean)

Lithostratigraphy : ?51, see Berger et al. 2004, this volume

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: ?Wanderblock Form. ?

Southern and middle URG: ''Pliocene not differentiated''

Northern URG, Mainz and Hanau Basins: Karst infills, White Mio-Pliocene, Klebsand, ''Pliocene not differentiated'', Jungtertiär II (see Fig. 18).

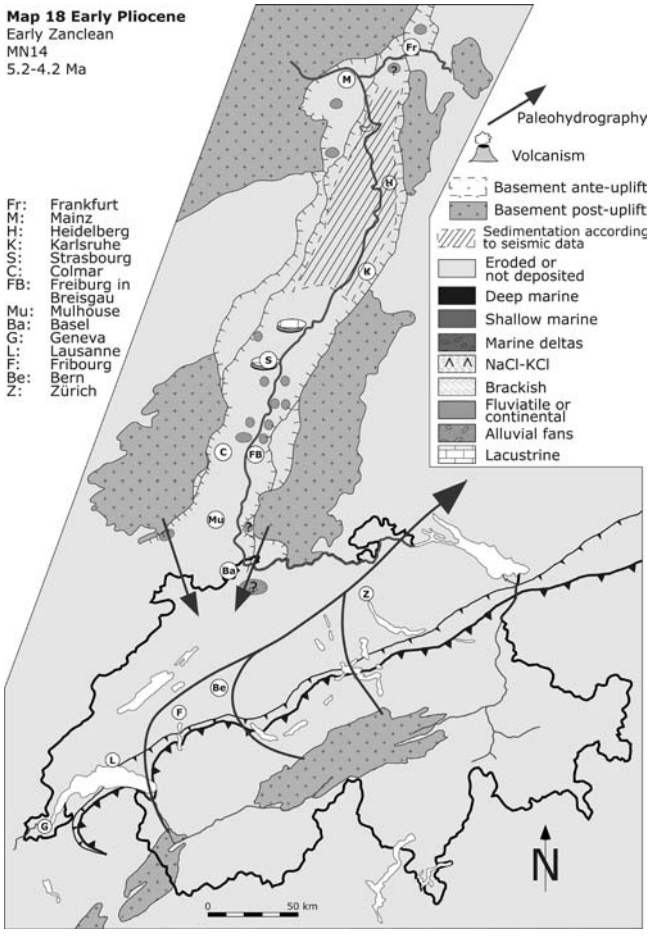

Fig. 18 Paleogeographic map of the Early Pliocene

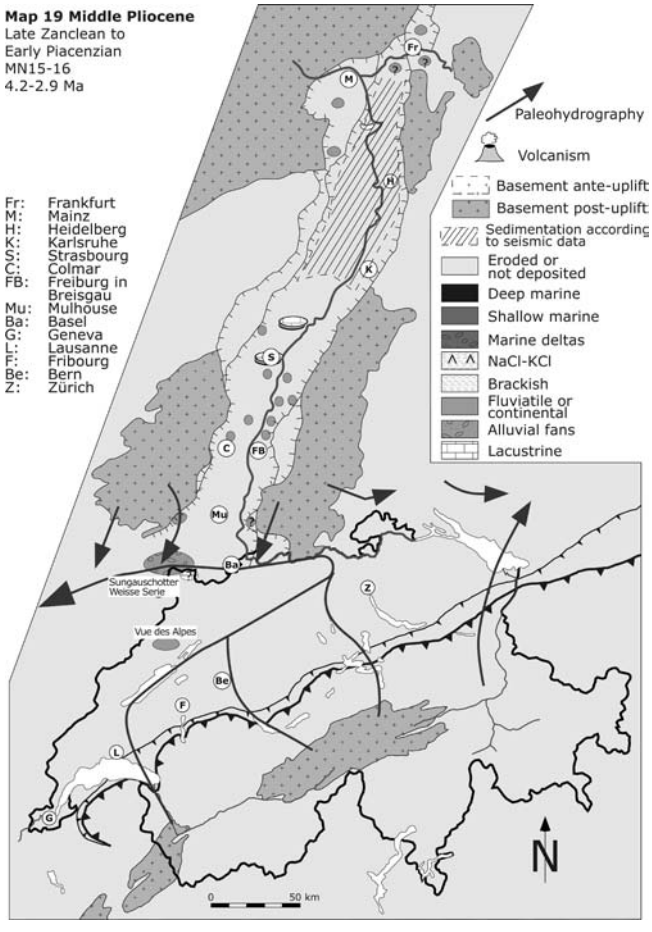

Fig. 19 Paleogeographic map of the Middle Pliocene

Map 19 Early to Late Pliocene (Late Zanclean to Early Piacenzian)

Lithostratigraphy : 24, 31, 51, see Berger et al. 2004, this volume

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: Karst Vue des Alpes, Sundgauschotter and Argiles de Bonfol, Weiße Serie

Southern and middle URG: Sundgauschotter and Argiles de Bonfol, Weiße Serie, ''Pliocene not differentiated''

Northern URG, Mainz and Hanau Basins: Karst infills, arvernensis-Schotter, Pliozän I-III, ''Pliocene not differentiated'', Jungtertiär II (see Fig. 19).

Map 20 Late Pliocene (Late Piacenzian to Early Gelasian)

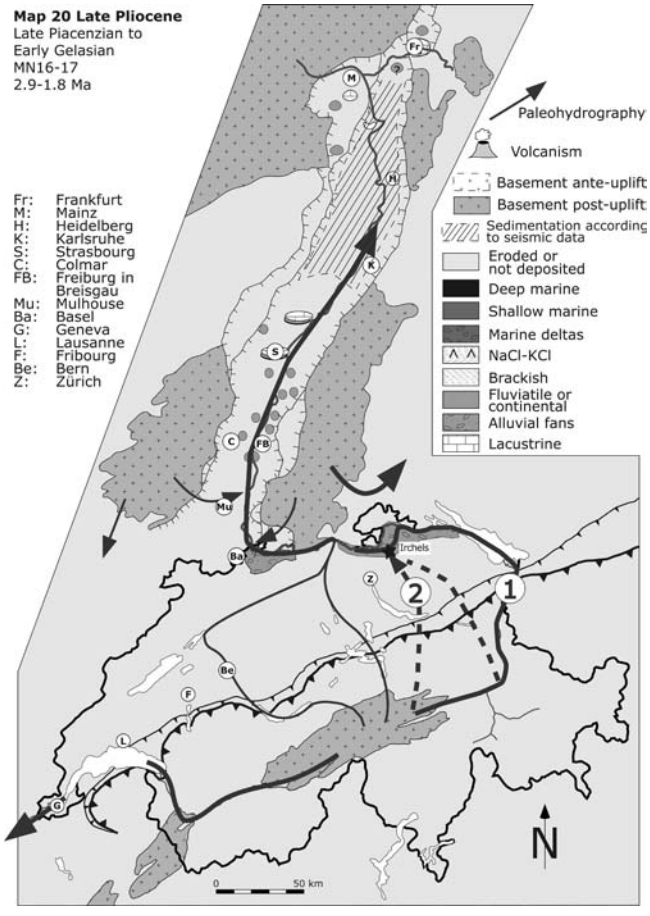

Fig. 20 Paleogeographic map of the Late Pliocene

Lithostratigraphy : 50, 51, see Berger et al. 2004, this volume

Helvetic and Subalpine Molasse: no sedimentation

Plateau and Jura Molasse: Ältere Deckenschotter

Southern and middle URG: ''Pliocene not differentiated''

Northern URG, Mainz and Hanau Basins: Karst infills, arvernensis-Schotter, Ältere Weisenauer Sande, ''Pliocene not differentiated'', Jungtertiär II (see Fig. 20).

Messinian sediments were not identified in the whole URG region as well as in the Molasse. Probably, some Bohnerz clays were deposited in the Mainz Basin.

During the Early Pliocene (Map 18), the continental conditions probably prevailed; as no fossil localities are known from this time, it is not possible to detail depositional environments, areas of sedimentation and the drainage pattern. In the URG, important sediments considered as ≪ Pliocene ≫ in the literature are known from several areas, (mainly between Colmar and Strasbourg) although they are not precisely dated (see Berger et al. 2004 in this volume).

During the Late Zanclean–Early Piacenzian (Map 19), an abrupt change of the drainage pattern is marked by the occurrence of the Sundgau gravels in the south, as well as by the arvernensis gravels in the north. Most of the Alpine-derived deposits were transported towards the North and Northeast area, then towards the West into the Bresse Graben. The Eastern part of the Alpine system was probably still drained towards the East (Giamboni et al. 2004; Liniger 1966; Petit et al. 1996).

The drainage pattern presented on Map 20 is still being disputed: most of the authors (Giamboni et al. 2004; Müller et al. 2002; Petit et al. 1996) proposed a general pattern of the Thurtal-Rheintal-Glatttal Schüttung towards the West and then into the URG, according to the data of the Höhere Deckenschotter (Bolliger et al. 1996; Graf 2003) and heavy mineral investigations in the northern URG (Semmel 1983; Boenigk 1982). However, some authors (D. Ellwanger, oral communication) do not agree with this interpretation and argue that this drainage pattern was only established with the deposition of the Lower Freiburg beds circa 800,000 years ago.

Note that first Alpine heavy minerals appear in the Lower Rhine graben at the Plio-Quaternary transition (Boenigk 2002; Heumann and Litt 2002).

Conclusion

The maps presented here have to be considered as a working document. Several questions are still open, as for example

– the precise timing, localisation and origin of the Salt deposits during the Eocene

– the precise relationships between the different formations occurring in the South URG between the Late Eocene and the Early Oligocene (and especially the prolongation of the Pechelbronn beds towards the South)
– the relationships between URG, Molasse and Bresse Graben during the Late Rupelian
– the lack of sedimentation in the South URG during the Early and middle Miocene
– the drainage pattern during the Late Miocene and Early Pliocene

It is to be noted that no map was proposed here for the Messinian, a crucial period for the circum Mediterranean area. It was not possible, at this state of knowledge, to distinguish between a possible effect of the regressive erosion on the Molasse basin and the tectonic uplift generally proposed for this period.

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References

Abele G (1977) Morphologie und Entwicklung des Rheinsystems aus der Sicht des Mainzer Raumes. Mainzer geographische Studien 11:245–259 Mainz

Bartz J (1961) Die Entwicklung des Flußnetzes in Südwestdeutschland. Jahreshefte des Geologischen Landesamtes Baden-Würtemberg 4:127–135 Freiburg i. Br

Becker D (2003) Paléoécologie et paléoclimats de la Molasse du Jura (Oligo-Miocène): apport des Rhinoceratoidea (Mammalia) et des minéraux argileux. Thèse Univ Fribourg, Geofocus 9:1–327

Berger JP (1985) La transgression de la Molasse marine supérieure (OMM) en Suisse occidentale. Münchn geowiss Abh A5:1–207

Berger JP (1992) Paléontologie de la Molasse de Suisse occidentale. Thèse d'habilitation Univ Fribourg 25.05.1992, pp 1–450

Berger JP (1995) Des nannofossiles calcaires aux rhinocéros: déplacés au remaniés?. Eclogae geol Helv 88(3):657–680

Berger JP (1996) Cartes paléogéographiques-palinspastiques du bassin molassique Suisse (Oligocène inférieur-Miocène moyen). N Jb Min Geol Pal Abh 202(1):1–44

Berger JP, Reichenbacher B, Becker D, Grimm M, Grimm K, Picot L, Storni A, Pirkenseer C, Schaefer A (2004) Eocene-Pliocene time scale and stratigraphy of the Upper Rhine Graben (URG) and the Swiss Molasse Basin (SMB). Int J Earth Sci, this volume

Boenigk W (1982) Der Einfluß des Rheingraben-Systems auf die Flußgeschichte des Rheins. Zeitschrift für Geomorphologie, Supplementband, vol 42. Stuttgart, Berlin, pp 167–175

Boenigk W (2002) The Pleistocene drainage pattern in the Lower Rhine Basin. In: Rift tectonics and syngenetic sedimentation; the Cenozoic Lower Rhine Basin and related structures. Netherlands J Geosci 81(2):201–209

Bolliger T, Fejfar O, Graf H, Kaelin D (1996) Vorläufige Mitteilung über Funde von pliozänen Kleinsäugern aus den höheren Deckenschottern des Irchels (Kt. Zürich). Eclogae geol Helv 89(3):1043–1048

Dèzes P, Schmid S, Ziegler PA (2004) Evolution of the European Cenozoic Rift System: interaction of the Alpine and Tyrenean orogens with their foreland lithosphere. Tectonophysics (in press)

Diem B (1986) Die Untere Meeresmolasse zwischen der Saane und Ammer. Eclogae geol Helv 79(2):493–559

Giamboni M, Ustaszewski K, Schmid SM, Schumacher ME, Wetzel A (2004) Plio-Pleistocene transpressional reactivation of paleozoic and paleogene structures in the Rhine-Bresse transform zone (northern Switzerland and eastern France). Int J Earth Sci (accepted)

Graf HR (2003) Geschichte des unteren Thurtales. Mitt der Thurgauischen Naturforsch Ges 59:7–30

Heumann G, Litt T (2002) Stratigraphy and paleoecology of the Late Pliocene and Early Pleistocene in the open-cast mine Hambach (Lower Rhine basin). In: Schaefer A, Siehl A (eds) Rift tectonics and syngenetic sedimentation; the Cenozoic Lower Rhine Basin and related structures. Geologie en Mijnbouw. Neth J Geosci 81(2):193–199

Kälin D, Weidmann M, Engesser B, Berger J-P (2001) Paléontologie et âge de la Molasse d'eau douce supérieure (OSM) du Jura neuchâtelois. Mémoires suisses de paléontologie 121:65–99

Kuhlemann A, Kempf O (2002) Post-eocene evolution of the North Alpine Foreland Basin and its response to Alpine tectonics. Sediment Geol 152:45–78

Kuhlemann J, Spiegel C, Dunkl I, Frisch W (1999) A contribution to the middle Oligocene paleogeography of Central Europe: new evidence from fission tracks ages of the Southern Rhine graben. N Jb Geol Palaeontol Abh 214:415–432

Liniger H (1966) Das plio-altpleistozäne Flussnetz der Nordschweiz. Regio Bas 7(2):158–177

Müller WH, Naef H, Graf HR (2002) Geologische Entwicklung der Nordschweiz, Neotektonik und Langzeitszenarien Zürcher Weinland. NAGRA technischer bericht 99–08, p 237

Petit C, Campy M, Chaline J, Bonvalot J (1996) Major paleogeographic changes in Alpine Foreland during the Pliocene—Pleistocene. Boreas 25:131–143

Picot L (2002) Le Paléogène des synclinaux du Jura et de la bordure sud-rhénane: paléontologie (Ostracodes), paléoécologie, biostratigraphie et paléogéographie. Thèse Univ Fribourg, Geofocus 5, pp 1–240

Picot L, Becker D, Lapaire F, Ustaszewski K, Hug WA, Berger JP (2004) Sédimentologie, paléontologie et paléoenvironnements côtiers de la région de Porrentruy (sud - rhénan): implications géodynamique. Eclogae geol Helv (accepted)

Reichenbacher B (2000) Das brackish-lakustrine Oligozän und UnterMiozän im Mainzer Becken und Hanauer Becken: Fischfaunen, Paläoökologie, Biostratigraphie, Paläogeographie. Cour Forschung Senckenberg 222:1–143

Reichenbacher B, Böttcher R, Bracher H, Doppler G, von Engelhardt W, Gregor HJ, Heissig K, Heizmann EPJ, Hofmann F, Kälin D, Lemcke K, Luterbacher H, Martini E, Pfeil F, Reiff W, Schreiner A, Steininger FF (1998) Graupensandrinne—Ries-Impakt: Zur Stratigraphie der Grimmelfinger Schichten, Kirchberger Schichten und Oberen Süsswassermolasse (nördliche Vorlandmolasse, Süddeutschland). Z dt geol Ges 149(1):127–161

Roll A (1979) Versuche einer Volumenbilanz der Oberhreingrabens und seiner Schultern. Geol Jb Riehe A, vol 52. p 82

Schlunegger F, Pfiffner A (2001) The sedimentary response of the North Alpine Foreland basin to changes in erosional processes in the Alps. IAS 2001, 21st Meeting, Davos, 3–5 September 2001. Excursion guides, pp 85–99

Schlunegger F, Slingerland R, Matter A (1998) Crustal thickening and crustal extension as controls on the evolution of the drainage network of the central Swiss Alps between 30 Ma and the present: constraints from the stratigraphy of the North Alpine Foreland Basin and the structural evolution of the Alps. Basin Res 10(2):197–212

Semmel A (1983) Die plio-pleistozänen Deckschichten im Steinbruch Mainz-Weisenau—Geologisches Jahrbuch Hessen 111:219–233 Wiesbaden

Sissingh W (1998) Comparative Tertiary stratigraphy of the Rhine graben, Bresse graben and Molasse basin: correlation of Alpine foreland events. Tectonophysics 300:249–284

Sissingh W (2003) Tertiary paleogeographic and tectonostratigraphic evolution of the Rhenish Triple Junction. Paleogeogr Paleoclimatol Paleoecol 196:229–263