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Lithostratigraphic units of the Helvetic Palaeogene: review, new definition, new classification

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Abstract The Palaeogene lithostratigraphic units of the Swiss Helvetic Alps have been revised and in parts newly defined in order to harmonise the existing nomenclature. The resulting new classification scheme of the Helvetic Palaeogene includes (1) the basal Siderolithic Group, (2) the entire nummulite succession of Euthal Formation, Bürgen Formation, Klimsenhorn Formation, Wildstrubel Formation, Niederhorn Formation, and Sanetsch Formation, (3) the Stad Formation, (4) the Muot-da-Rubi Formation, (5) the North Helvetic Flysch Group, as well as (6) South Helvetic and Ultrahelvetic (to ?North Penninic) flysch formations. The new classification further aims at simplifying the often very confusing nomenclature and the multitude of local names.

Keywords Helvetic Alps · Palaeogene · Lithostratigraphy · Biostratigraphy · Palaeogeography · Switzerland

1 Introduction

During the past approximately 150 years a huge number of lithostratigraphic names had been established for the Palaeogene deposits of the North Alpine Foreland Basin, which are today exposed in the Helvetic domain of the Swiss Alps (Fig. 1). Yet, although widely distributed in the Helvetic Alps, the corresponding deposits are frequently found in discontinuous and incoherent successions. This reflects two difficulties: (1) The relatively narrow depositional realm of the Helvetic Palaeogene sediments underwent northwestward migration through time, i.e., younger formations were not necessarily formed on top of the older ones, but often in greater distance farther northwest. (2) Deposits of the same lithostratigraphic unit are today in many cases spatially separated and situated in different tectonic units. This may have tempted locally working researchers to generate a multitude of names for very similar lithostratigraphic units. Therefore, besides classifying the lithostratigraphic units of the Helvetic Palaeogene, a further goal of our study is to simplify the existing nomenclature and to reduce the huge amount of local names (see Tables 1 and 2). To achieve such simplified and reduced nomenclature we first harmonised the literature data into a robust lithostratigraphic framework of formally defined groups, formations, members, and beds. By doing so, we basically continued the work of Herb (1988) who already aimed at a stringent nomenclature for the Helvetic Palaeogene. One major outcome of the harmonisation of lithostratigraphic terms throughout Switzerland is the further development of the internet-based lexicon at www.strati.ch as already pointed out in the editorial introduction.

1.1 Geological framework

In the present-day Alps, the Helvetic successions are present as parautochthonous cover of the basement, as largely displaced and internally deformed nappes, and as small, isolated allochthonous thrust sheets in various tectonic

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Table 1 New classification scheme of the Helvetic Palaeogene Nummulitic and Siderolithic deposits of the Helvetic Alps of Switzerland

Aktuell gültige Nomenklatur: *Gruppe* – Formation	Aktuell gültige Nomenklatur: Member – *Bank*	Alte Bezeichnungen
Stad-Formation	***Wängen-Kalk*** ***Rütenen-Konglomerat*** ***Kleintal-Konglomerat*** ***Jochstock-Konglomerat***	Globigerinenmergel, Globigerinenschiefer, Stadschiefer, Fleckenmergel
Sanetsch-Formation	**Pierredar-Kalk**	Calcaire à petites nummulites
	Tsanfleuron-Member	
	Diablerets-Member	Diablerets-Schichten
Niederhorn-Formation	**Gemmenalp-Kalk**	Hohgant-Formation NW-Fazies
	Hohgant-Sandstein	
Wildstrubel-Formation	**Schimberg-Member**	Schimberg-Schiefer, Schimbrig-Mergel, Schimberg-Mergel
	Tierberg-Member	Hohgant-Schiefer, Pektinitenschiefer
	Küblibad-Member	Obbürgen-Schicht, Glaukonitschicht von Küblibad
Klimsenhorn-Formation	**Fruttli-Member**	Discus-Schicht
	Band-Member	Obere Perforatus-Schicht
		Oberer Quarzsandstein
	Fräkmünt-Member	Complanata-Schicht
		Unterer Quarzsandstein
		Untere Perforatus-Schicht
Bürgen-Formation	**Foribach-Member**	Foribach-Schicht
	Mattgrat-Member	Bürgen-Kalk
	NW **Scharti-Member**	Bürgen-Grünsand inkl. Gallensis-Grünsand
	SE **Steinbach-Member**	Oberer Grünsand Steinbach-Fossilschicht
Euthal-Formation	**Einsiedeln-Member**	Kalke mit *N. gallensis* und *A. spira*
		Oberer Teil der Hauptmasse des grauen Nummulitenkalks
		Obsoletus-Niveau
		Distanskalk
		Kaufmanni-Kalk (= mittlerer Teil der Hauptmasse des grauen Nummulitenkalks)
		Unterer Teil der Hauptmasse des grauen Nummulitenkalks
		Granulosakalk und -mergel
		Murchisonikalk
		Mittlerer Grünsand / Pectengrünsand
	NW **Chruteren-Member**	Lithothamnienkalk mit Grünsandlagen und echinodermenbrecciöser Kalk
		Unterer Grünsand
	SE **Batöni-Member**	Batöni-Schicht
	Fliegenspitz-Member	Fliegenspitz-Schichten
Siderolithikum-Gruppe	–	Bohnerzformation, siderolithische Brekzien (u.a.)

Note that we utilise the German wording for its widespread use and in order to assure the correct lithostratigraphic terminology. The column "Alte Bezeichnungen" comprises only the most frequently used former terms, for further older synonyms see Leupold (1964), Herb (1988) and Menkveld-Gfeller (1997)

Table 2 New classification scheme of the Muot-da-Rubi Formation, the North Helvetic Flysch Group, and South Helvetic to Ultrahelvetic (?North Penninic) flysch deposits of the Helvetic Alps of Switzerland

Aktuell gültige Nomenklatur			Alte Bezeichnungen
	Gruppe – Formation	Member – *Bank*	
Ultrahelvetische (–?Nordpenninische) Flyscheinheiten			Eingewickelter Flysch p.p., Sardonaflysch
	Martinsmad-Formation		«Obere Flyschabfolge»: Supraquarzitischer Flysch, exkl. Ölquarzit
		Sardona-Quarzit	Sardonaquarzit, inkl. Ölquarzit, Batöniquarzit (? syn.)
			«Untere Flyschabfolge»: Infraquarzitischer Flysch p.p.
	Formation du Meilleret		Flysch du Meilleret, Flysch d'Aigremont (syn.), Flysch d'Ochsenweid (syn.), Höchst-Flysch (syn.)
Südhelvetische Flyscheinheiten			Eingewickelter Flysch p.p., Blattengratflysch, Blattengratschichten, Ragazer Flysch, Einsiedler Flysch
	Lavtina-Sandstein		Intermediärer Flysch, Lavtinaflysch
	Blattengrat-Sandstein		Blattengratsandstein, Blattengratschichten p.p.
	Burg-Sandstein		Burgsandstein
Nordhelvetische Flysch-Gruppe	**Matt-Formation**		Flysch von Matt-Engi, oberer Altdorfer Sandstein, Serie von Matt, Mattersandsteine, Grès de Matt, Matter-Formation
		Engi-Dachschiefer	Fish slates of Glarus, Matterschiefer, Glarner Fischschiefer, Glarner Dachschiefer, Couches à poisson du Plattenberg
		Gruontal-Konglomerat	Conglomerat du Gruontal, Conglomerat d`Altdorf, Alpennagelfluh, Gruontalkonglomerate
		Rüschenweid-Bank	Bank von Rüschenweid
	Elm-Formation	**Grès du Val d'Illiez**	Grès d'Elm, Flyschsandstein, unterer Altdorfer Sandstein, Elmer Flysch, Serie von Elm, Elmer-Formation
	Formation de Taveyannaz		Grès de Taveyanne
	Muot-da-Rubi-Formation	**Ahornen-Member**	Ahornen-Schichten
		Kistenstöckli-Member	Kistenstöcklisandstein, Kistenstöckligipfelsandstein
		Ghölzwald-Member	Ghölzwald-Schichten
		Malor-Member	Malor-Schichten
		Südelbach-Member	Südelbach-Serie

Note that we utilise the German wording for its widespread use and in order to assure the correct lithostratigraphic terminology

positions (Fig. 1; e.g., Pfiffner 2015). The basement of the Helvetic domain is exposed in the dome-shaped structures of the Aar, Gotthard, Aiguilles Rouges and Mont Blanc crystalline massifs and also includes Late Palaeozoic elongate troughs filled with Permo-Carboniferous siliciclastic and volcanic rocks. During the Late Cretaceous—Palaeocene, the former passive margin was transformed into a compressional foreland basin north(west) of the advancing orogenic wedge; continuous deposition is recorded only in the Ultrahelvetic to North Penninic depositional realm (e.g., Lihou and Allen 1996; Lihou and Mange-Rajetzky 1996). The Palaeogene foreland basin deposits are composed of neritic carbonate and siliciclastic rocks that contain larger foraminifera (mostly Nummulites and Assilinides). They formed at the northern (distal) margin of the foreland basin during Palaeocene to earliest Oligocene and overlay the Mesozoic basement unconformably and at different stratigraphic levels (Herb 1988). They are thus distributed throughout the Helvetic Alps in a rather patchy manner. They are overlain by hemipelagic to pelagic marlstone (Globigerina Marl/Stad Formation) as well as turbiditic flysch sequences.

Kempf and Pfiffner (2004) established a palinspastic restoration of the Helvetic Palaeogene deposits guided by the maps of Ferrazzini and Schuler (1979), Herb (1988), and by the restoration of numerous cross-sections of the Helvetic Alps. In these reconstructions, which we use here (Figs. 2, 3 and 4), the changing deformation directions of the Alpine arc were taken into account by lateral stretching of the restored cross-sections (for details see Kempf and

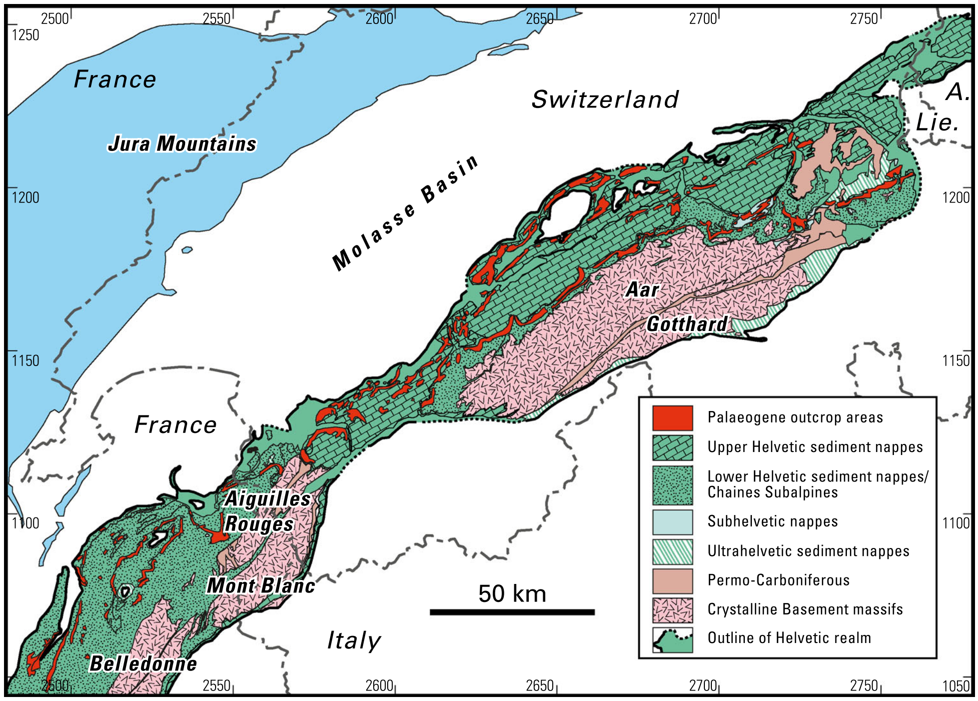

Fig. 1 Tectonic map of the Helvetic Alps of Switzerland and surrounding areas (modified from Kempf and Pfiffner 2004). Outcrop areas of the Palaeogene are highlighted in *Red*. For convenience the Swiss National Grid system is applied

Pfiffner 2004). The time frame of our study is taken from Herb (1988), Menkveld-Gfeller (1994, 1995, 1997), and Viard (1998), and is based on the chronostratigraphic chart of the ICS version 02/2014 (www.stratigraphy.org).

2 Description of the Helvetic Palaeogene formations (Palaeocene–Eocene)

2.1 Siderolithic Group

Thurmann (1836) first established the term “Siderolithicum”, while Wieland (1976) extended its use for siderolithic rocks of the Helvetic domain. The Siderolithic Group is neither subdivided into formations, nor does a type section or a type locality exist. For further descriptions see de la Harpe (1854), Renevier (1877, 1890), Lugeon (1905, 1917), Troesch (1908), Arbenz (1909), Fleury (1909), Heim (1908), van der Ploeg (1912), von Tavel (1936), Wieland (1976, 1979), Herb (1988), and Hänni (1999).

Lithology: For a considerable time siderolithic rocks were known only from the Jura Mountains. De la Harpe (1854) described the first discovery of Alpine siderolithic rocks at the foot of the Dents du Midi. Wieland (1976) used the term “Siderolithikum” to integrate the iron containing, sandy to argillaceous rocks that occur in the Helvetic nappes on the Mesozoic–Palaeogene boundary into an informal formation. Based on Wieland (1976), Herb (1988) defined the Helvetic “Siderolithikum” collectively as rock unit that comprises iron-containing, argillaceous and sandy rocks, often brecciated, often also as “Bohnerzton”, a pisolitic iron ore clay (with vadose pisoliths). However, the rock unit does not occur merely in form of infiltrates and pockets in the underlying rocks, partially disaggregating the underlying rocks into brecciated formations. But it can also form massive beds between the underlying rocks and younger transgressive rocks above (Wieland 1976). The main rock types are sandstone and claystone, which also constitute the matrix of the breccia. The red or green coloured rocks—depending on the iron oxidation state—feature elongate, mostly black pisoliths composed of hematite and chamosite. Siderolithic breccia and conglomerate beds can be locally up to 50 m thick. The siderolithic rocks are an unequivocal indicator of terrestrial conditions. The presence of deep-reaching karst pockets and caves is characteristic of regions with siderolithic formations. These can extend as much as 100 m below the base of the Palaeogene and are often bound to preexisting networks of fissures. Such karst cave systems require a certain relief and, in particular, a significant uplift of the entire region above sea level. The siderolithic rocks are restricted to regions where transgression of the Niederhorn and Sanetsch Formation had occurred at the beginning of the Priabonian. Hence, concerning the age, the rocks of the Siderolithic Group must have formed prior to the Priabonian; that is, before the deposition of the Niederhorn and Sanetsch Formation. From the autochthonous of Col-

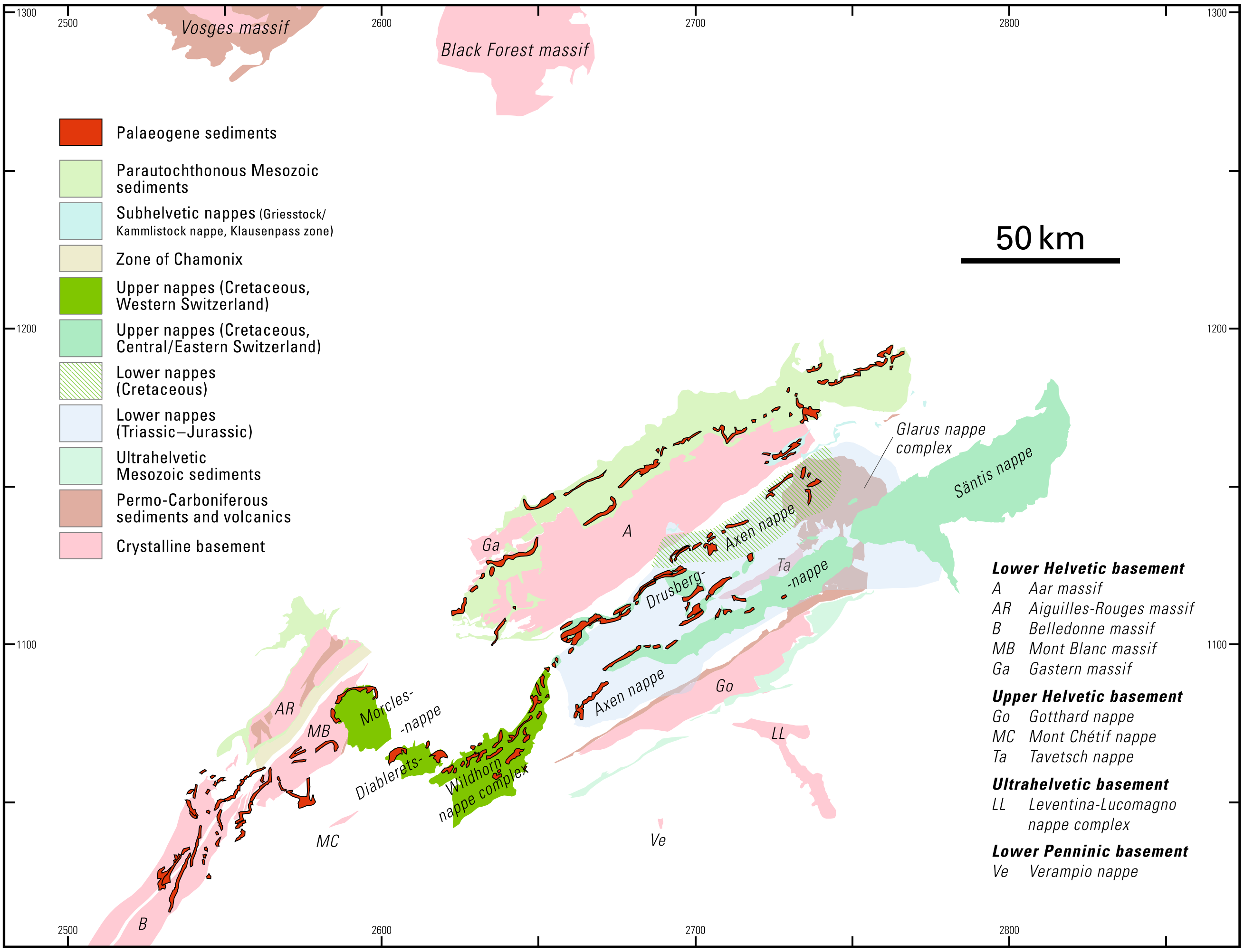

Fig. 2 Palaeogeographic reconstruction of the Helvetic realm (pre-Mesozoic basement and Mesozoic–Cenozoic sediment cover) in relation to the Black Forest massif as part of stable Europe (modified from Kempf and Pfiffner 2004)

lombey (Canton Valais), a siderolithic fissure-infilling permits dating by means of a rodent tooth of the species *Sciuroides*, which yielded a Bartonian age (Weidmann 1984). Von Tavel (1936) identified *Lucina bipartita* and *Perna lamarcki* from a siderolithic filling of a palaeokarst pocket on the Daubenhubel in the Doldenhorn nappe and assigned the latter form to the Lutetian. In addition, there is a possibility of the formation of several karst generations, which seems especially likely in the palaeogeographically northern parts of the Helvetic domain. Overlying strata: Niederhorn Formation, Sanetsch Formation; underlying strata: Quinten Formation, Öhrli Formation, Betlis Formation, Helvetischer Kieselkalk, Tierwis Formation, Schrattenkalk Formation, Garschella Formation, Seewen Formation. Biostratigraphy: older than the Priabonian, rarely direct datings: Lutetian (shells), Bartonian (rodent tooth); arguably formed mainly during the Middle Eocene. Locally, the overlying strata (e.g., the Diablerets Member of the Sanetsch Formation) lent itself to dating (Weidmann et al. 1991, Menkveld-Gfeller 1994, Schlagintweit et al. 2012). Current geographical extent: Western and Central Switzerland: Reuss valley at Altdorf to the western Swiss frontier at Champéry. Tectonic units: Western and Central Switzerland: Autochthonous of Aar and Aiguilles Rouges massives, Lower Helvetic, Parautochthonous slices, Doldenhorn, Wildhorn, and Morcles nappe, France: Morcles nappe and Chaînes Subalpines.

Remarks: The crude iron-stained weathering of the Mürren breccia (“Mürren-Brekzie”) perhaps favours an interpretation as a deposit of the Siderolithic Group. The freshly cut limestone breccia, however, shows that the sandy cement contains Nummulites, and the components of the breccia are much smaller than usual in siderolithic rocks (Stauffer 1920). Therefore, the Mürren breccia belongs to the

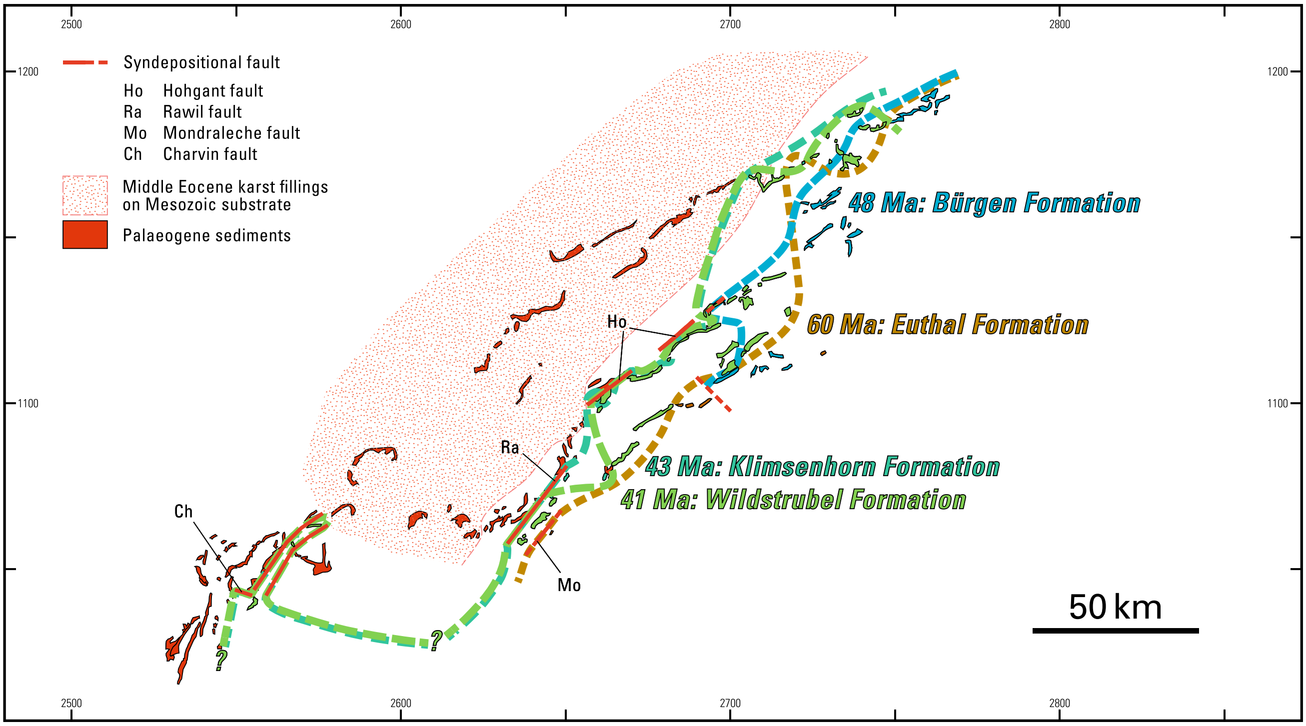

Fig. 3 Temporal and spatial distribution of the Euthal Formation, Bürgen Formation, Klimsenhorn Formation and Wildstrubel Formation during the Palaeocene–Eocene (modified from Kempf and Pfiffner 2004). *Dashed bold lines* indicate the northernmost occurrence of the different formations. Note the spatial distribution of the Siderolithic deposits (*dotted pattern*)

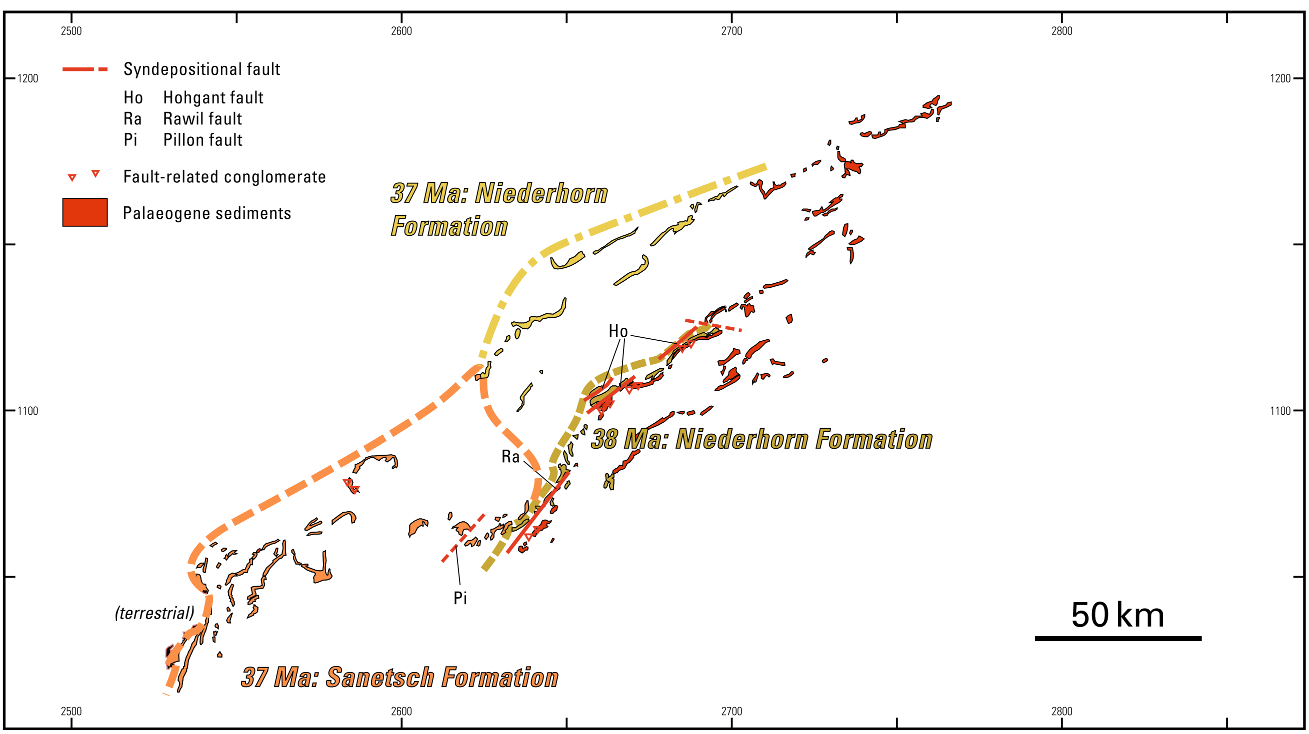

Fig. 4 Temporal and spatial distribution of the Niederhorn Formation and Sanetsch Formation during the Eocene–Oligocene (modified from Kempf and Pfiffner 2004). *Dashed bold lines* indicate the northernmost occurrence of the different formations

Palaeogene deposits and thus appears above the Siderolithic Group: the Mürren breccia is hence newly placed in the Hohgant Sandstone, a member of the Niederhorn Formation. The Grindelwald "Marble" ("Grindelwaldner Marmor", Arbenz 1909, Wieland 1976) outcrops in the valley of the lower Grindelwald glacier and is known for its use as building stone for door casings, columns and furniture tops. It is lens-like embedded in the limestone of the Öhrli Formation as colourful breccia. Components of Helvetischer Kieselkalk, Öhrli- and Quinten formations are enclosed by a sandy, dark-green or argillaceous, dark-red to violet matrix. The Grindelwald "Marble" is considered as a breccia-variety of the Siderolithic Group; the less well known Rosenlaui "Marble" equally corresponds to a breccia-variety of the Siderolithic Group. The informally named Dünden conglomerate (Dünden-Konglomerat, Zwahlen 1986), is a siderolithic conglomerate variety of the Bundstock element (Hänni 1999). In addition to large, chloritized or limonitised pisoids, the mineralised rusty-green, sandy-argillaceous matrix contains up to fist-size limestone components that are primarily assigned to the upper part of the Schrattenkalk Formation. Wieland (1976, 1979) also investigated siderolithic rocks in the Swiss Plateau and in the Jura Mountains. He realised differences in the rock composition to the Helvetic nappes: The main constituents are kaolinite, quartz and goethite as well as montmorillonite. The pisoliths from a core sample in Küsnacht exhibit a structure similar to the Helvetic rocks, but are composed of goethite and kaolinite, respectively hematite and kaolinite. The age of the rocks, however, is in agreement, although their formation may have continued somewhat longer owing to the absence of the Late Eocene marine transgression here. The discovery of mammal remains in Egerkingen (Canton Solothurn), respectively at Mormont (Canton Vaud), allows to date pockets filled with pisolithic iron ore to the Middle Eocene or, for Mormont, to the Middle to Late Eocene (e.g., Stehlin 1903). The extent of the Siderolithic Group continues irregularly in the Morcles nappe and the Chaînes Subalpines of the Haute-Savoie. No further information can be provided here regarding the extent, the lithological formation or the age of the siderolithic rocks.

2.2 Euthal Formation

The Euthal Formation, first described by U. Menkveld-Gfeller (in Funk et al. 2013), is subdivided into the Fliegenspitz Member, Chruteren/Batöni Member, and Einsiedeln Member. The type section is exposed at Steinbach, Lake Sihl (Canton Schwyz) ("Fluh" section at Fluhhof-Steinbach, Jeannet et al. 1935; Swiss coord. 2702.532/1217.150). For further descriptions see Leupold (1964, p. 322, 337), Herb and Hottinger (1965), Herb (1988), and Decrouez and Menkveld-Gfeller (2003).

Lithology: The basal Fliegenspitz Member and the two succeeding Chruteren Member and Batöni Member, respectively, have been preserved only very locally. The Fliegenspitz Member is built up as sandy marlstone, occurs palaeographically isolated and represents a first northwest-oriented transgressional phase in the Palaeogene. The Chruteren Member varies in terms of facies from glauconitic sandstone to coarse echinodermal limestone and to Lithothamnium limestone. On the other hand, the contemporaneous Batöni Member is mainly sandy and changes only in the northwest to a limestone-dominated facies towards the top. Both members formed during a second transgressional phase. The dominating element of the Euthal Formation, however, is typically a sequence of Nummulite-rich limestone above a basal glauconitic sandstone ("Grünsandstein"): the approx. 30 m thick Einsiedeln Member ("Hauptmasse des Nummulitenkalks", "Einsiedeln reefs", see Table 1). These deposits represent a third transgression, a subsequent regression followed by another transgressive phase. Overlying strata: Bürgen Formation, Stad Formation; underlying strata: Wang Formation, Amden Marl. Biostratigraphy: Selandian to earliest Lutetian, Larger foraminifera, planktonic foraminifera. Current geographical extent: Western Switzerland: Cabane des Violettes (Canton Valais); Central Switzerland: Stoos-Fronalpstock region, Einsiedeln region (Lake Sihl–Sihl valley), Lauerz; Eastern Switzerland: Weesen-Amden region, Alpstein, Fänerenspitz, Weisstannen valley. Tectonic units: Western Switzerland: southern Wildhorn nappe; Central Switzerland: Einsiedeln / Lauerz zone of tectonic slices; Eastern Switzerland: Säntis nappe, Fliegenspitz complex, Subalpine Flysch zone, Blattengrat nappe, Brülisau/Wildhaus melange.

2.2.1 *Fliegenspitz Member*

The Fliegenspitz Member, established by Menkveld-Gfeller (in Funk et al. 2013), was first described by Herb (1962; "Fliegenspitz-Schichten"). The type locality (2733.860/1224.350) and the type section are both at Fliegenspitz (Canton St. Gallen) (Herb 1962), a reference section is found at Näserinabach, Batöni (Canton St. Gallen) (Lihou 1995). For further descriptions see Arn. Heim (1910; "Lagenmergel"), Zimmermann (1936), and Herb (1988).

Lithology: The Fliegenspitz Member has been preserved today only locally as relics in form of dark-brown to grey-black sandy marlstone. It represents a first transgression at the base of the Euthal Formation, which arguably encompassed a larger area of the southeastern Helvetics. It is made up of an alternation of fine-grained, somewhat nodular limestone beds with sandy, marly slate, previously referred to as "Lagenmergel". The thickness at the type locality is approx. 12–15 m. Overlying strata: Batöni

Member, Stad Formation; underlying strata: Wang Formation. Biostratigraphy: Selandian–Thanetian (Palaeocene), Discocyclina, planktonic foraminifera. Current geographical extent: Eastern Switzerland: Weesen-Amden region (Fliegenspitz), Weisstannen valley. Tectonic units: Eastern Switzerland: Fliegenspitz complex, Blattengrat nappe.

Note: Stacher (1980) described the Middle Eocene Fliegenspitz beds as dark-brown to grey-black marlstone from the Wilerhorn region that are lithologically closely related to the Late Cretaceous Wang Formation and the Late Eocene Stad Formation ("Globigerina marl"), respectively. This marlstone, however, does not belong to the newly introduced Fliegenspitz Member. The Middle Eocene marlstone that occurs on the eastern Brienzergrat (Jost-Stauffer 1993) can neither be linked to the Fliegenspitz Member. Both occurrences arguably belong to the Tierberg Member of the Wildstrubel Formation. Kraus (1932), Oberhauser (1958) and Mohler (1966) described the sediments of the Fliegenspitz Member as Early Palaeogene Wang beds.

2.2.2 *Chruteren Member*

Established and first described by U. Menkveld-Gfeller (in Funk et al. 2013), the type locality is at Chruteren (Canton Schwyz) (2694.513/1202.526), the type section at Steinbach, Lake Sihl (Canton Schwyz) (Section "Fluh" at Fluhhof-Steinbach, Jeannet et al. 1935; Swiss coord. 2702.532/1217.150). For further descriptions see Herb and Hottinger (1965), Friedl and Zurbrügg (1988), and Hantke et al. (2013).

Lithology: The Chruteren Member comprises relic deposits of a second transgression succeeding the Fliegenspitz Member, which were largely eroded as a consequence of the transgression of the "middle" glauconitic sandstone ("Mittlerer Grünsand") of the Einsiedeln Member. It comprises highly varying lithologies as a result of rapid facies changes: "Unterer Grünsand" (Leupold 1964), Lithothamnium limestone, coarse echinodermal limestone, and glauconitic quartz sandstone, which are typically only partly preserved. To some extent, these lithologies are embedded as clasts in the upper part of the Chruteren Member. The deposition of the Chruteren Member took place in more shallow water than the Fliegenspitz Member, and it has a more limited lateral extent and a thickness of approx. 1–20 m. The Chruteren Member is palaeogeographically situated northwest of the contemporaneous Batöni Member. Overlying strata: Einsiedeln Member; underlying strata: Amden Marl, Wang Formation. Biostratigraphy: Late Thanetian to earliest Ypresian, Larger foraminifera. Current geographical extent: Central Switzerland: Stoos-Fronalpstock, Einsiedeln region (Lake Sihl), Hoch Ybrig (Fidisberg) region. Tectonic units: Central Switzerland: Einsiedeln zone of tectonic slices; Eastern Switzerland: Säntis nappe.

2.2.3 *Batöni Member*

Established by U. Menkveld-Gfeller (in Funk et al. 2013) and first described by Rüefli (1959). The type locality is at Batöni (Canton St. Gallen) (2745.742/1202.611), the type section at Oberlavtina (Canton St. Gallen) (Lihou 1995; ca. 2746.000/1202.800). For further descriptions see Oberholzer (1933), Leupold (1939), Bisig (1957), Rüefli (1959), Wegmann (1961), Leupold (1964, p. 100), Herb (1988), and Lihou (1993, 1995).

Lithology: The Batöni Member forms a relic deposit of a second transgression succeeding the transgression of the Fliegenspitz Member. The lower sandstone, 10–15 m thick, is truncated at the top by a condensation horizon, followed by a transition to the upper sandstone and, particularly in the northwestern part of the palaeogeographic extent, there is a change to limestone-dominated sediments with Corallinaceans and Echinoderms as well as Nummulites (20–50 m thick). A condensation horizon forms the top. These sediments were deposited under rapidly changing conditions and in clearly shallower water than the Fliegenspitz Member. The Batöni Member is palaeogeographically situated southeast of the contemporary Chruteren Member. Overlying strata: Einsiedeln Member; underlying strata: Amden Marl, Wang Formation, Fliegenspitz Member. Biostratigraphy: Palaeocene, Larger foraminifera. Current geographical extent: Eastern Switzerland: southeastern Weisstannen valley. Tectonic units: Eastern Switzerland: Blattengrat nappe.

2.2.4 *Einsiedeln Member*

Established by Menkveld-Gfeller (in Funk et al. 2013) and first described by Boussac (1912; "Couches de Einsiedeln"). Type locality and type section at Steinbach, Lake Sihl (Canton Schwyz) (section "Fluh" at Fluhhof-Steinbach, Jeannet et al. 1935; 2702.532/1217.150), a reference section is at Chalchweid (Canton Schwyz) along the road to Gross-Euthal (section "Kalch", Jeannet et al. 1935; 2702.226/1217.747). For further descriptions see A. Escher (in Kaufmann 1877), Heim (1908), Boussac (1912), Leupold (1937, 1964, p. 337, 341, 381, 584), Herb and Hottinger (1965), Herb (1988), and Decrouez and Menkveld-Gfeller (2003).

Lithology: After a hiatus and the linked partial karst formation of the underlying beds, a third transgression of the Euthal Formation prograded to the NNW and deposited a glauconitic sandstone to sandy limestone ("Mittlerer Grünsand"), locally with oysters, scallops

(*Pectinidae*), and rarely corals and nummulites (*N. irregularis*, cf. Herb and Hottinger 1965), max. 3 m thick. To the top the Einsiedeln Member is developed as limestone, proving a regressive tendency almost to the top of the Einsiedeln Member. Leupold (1964, p. 342) and other authors named the individual limestone banks according to the most frequently occurring Larger foraminifera species: "Murchisonikalk", "Granulosakalk", "Kaufmanni-Kalk" and "Distanskalk" as well as the "Obsoletus-Niveau" and "Gallensis-Kalk" together form the "Hauptmasse des grauen Nummulitenkalks" (see Table 1). The following "Gallensis-Grünsand" was deposited by another transgression prograding further to the northwest and is assigned to the Bürgen Formation (Menkveld-Gfeller 1997). This sequence of the Einsiedeln Member is up to approx. 30 m thick. Typically, individual horizons of these limestones are rich in hematite, glauconite or are infiltrated by siderolithic deposits, so the colour spectrum of these limestones rich in Nummulites and Assilinids varies considerably. Overlying strata: Stad Formation; underlying strata: Chruteren Member, Amden Marl, Wang Formation. Biostratigraphy: Middle Ypresian (formerly Cuisian) to earliest Lutetian, Larger foraminifera. Based on isotope ($\delta^{13}C$) analyses in the Steinbach section Letsch (2012) speculates that the Palaeocene/Eocene boundary is situated more or less at the base of the Nummulite Limestone of the Einsiedeln Member. However, Larger foraminifera data of Leupold (1964), Herb and Hottinger (1965) and Friedl and Zurbrügg (1988) suggest that the onset of the Einsiedeln Member already occurred during the Middle to Late Ypresian.

Current geographical extent: Western Switzerland, Cabane des Violettes (Canton Valais); Central Switzerland: Stoos-Fronalpstock region, Einsiedeln region (Lake Sihl–Sihl valley), Lauerz; Eastern Switzerland: Alpstein, Fänerenspitz, Weisstannen valley. Tectonic units: Western Switzerland: Southern Wildhorn nappe; Central Switzerland: Einsiedeln zone of tectonic slices, Lauerz zone of tectonic slices (?); Eastern Switzerland: Säntis nappe, Subalpine Flysch zone, Blattengrat nappe, Brülisau/Wildhaus melange.

2.3 Bürgen Formation

Established by Lutz (1988) and first described by Kaufmann (1886; "Bürgenschichten", "Bürgengrünsand"). The Bürgen Formation is subdivided into: Steinbach Member, Scharti Member, Mattgrat Member, Foribach Member. The type section is located at Bürgenstock (2671.200/1205.250—2670.950/1205.080; Menkveld-Gfeller 1997). For further descriptions see Leupold (1964, p. 165, 168, 174, 596), Frey (1965), Herb (1988), Lutz (1988), and Decrouez and Menkveld-Gfeller (2003).

Lithology: A highly condensed, partially mollusk-rich phosphorite bed established during a subsidence phase; today, it is preserved only very locally. This bed, together with overlying glauconitic sandstone containing phosphorite nodules, forms the Steinbach Member. Contemporaneous or somewhat later, during a phase of transgression, sandy, strongly glauconitic marlstone to sandstone was deposited partially with large quantities of *Assilina exponens*, the Scharti Member. A rapid decrease in quartz and glauconite content leads to the micritic limestone of the Mattgrat Member. The top of this limestone is hardground-like and disintegrated into nodules, and merges rapidly into the Foribach Member, a glauconitic-sandy micrite with nodules of the Mattgrat Member. Thickness of the whole succession is max. 54 m. Overlying strata: Klimsenhorn Formation, Wildstrubel Formation, Stad Formation; underlying strata: Seewen Formation, ?Amden Marl, Euthal Formation. Biostratigraphy: earliest to Late Lutetian, Larger foraminifera, planktonic foraminifera. Current geographical extent: Central Switzerland, Lake Lucerne region, Einsiedeln region (Lake Sihl), Reuss to Linth valley; Eastern Switzerland: Flibach near Weesen, eastern Sernf valley, Weisstannen valley, Linth valley to Rhein valley. Tectonic unit: Central Switzerland: Drusberg nappe, Einsiedeln zone of tectonic slices, Griessstock nappe, Kammlistock nappe, Klausenpass zone of tectonic slices; Eastern Switzerland: Subalpine Flysch zone, Blattengrat nappe, Brülisau/Wildhaus melange.

2.3.1 *Steinbach Member*

Established by U. Menkveld-Gfeller (in Funk et al. 2013). Type locality and type section at Steinbach, Lake Sihl (Canton Schwyz) ("Fluh" section at Fluhhof-Steinbach, Jeannet et al. 1935; 2702.532/1217.150), for further descriptions see Escher (in Kaufmann 1877; "Gastropodenschicht"), Leupold (1937, 1939, 1964, p. 69, 341, 595, 596), Herb and Hottinger (1965), Herb (1988), Lihou (1995), and Decrouez and Menkveld-Gfeller (2003, "Steinbachfossilschicht", p. 132).

Lithology: With irregular contact to the underlying bed, the Steinbach Member forms a condensed horizon: a phosphorite bed with phosphoritic gastropods and bivalves, corals, and reworked clasts of the Einsiedeln Member, in part a mere cm thick crust. Above, glauconitic sandstone ("Grünsand") partially with phosphoritic nodules follows. Max. thickness is 5 m. Herb (1988) interpreted this sequence as formed during a phase of subsidence, as proven by submarine erosion and locally preserved with condensed sediments and reworked pebbles. Based on age, the Steinbach Member corresponds approximately with the "Gallensis-Kalk" (top of Einsiedeln Member) and possibly already with the onset of the Scharti Member (see below). The palaeogragraphic regions of occurrence of these three units, however, are clearly separated. Overlying strata: Stad Formation; underlying strata: Einsiedeln Member (Euthal Formation). Biostratigraphy: earliest Lutetian, Larger foraminifera. Current geographical extent: Central Switzerland: Einsiedeln region (Lake Sihl, Fidisberg); Eastern Switzerland: Flibach near Weesen, eastern Sernf valley, Weisstannen valley. Tectonic unit: Central Switzerland: Drusberg nappe, Einsiedeln zone of tectonic slices; Eastern Switzerland: Subalpine Flysch zone, Blattengrat nappe.

2.3.2 *Scharti Member*

Established by U. Menkveld-Gfeller (in Funk et al. 2013). The type locality is at Bürgenstock (2671.200/1205.250—2670.950/1205.080; Menkveld-Gfeller 1997; "Bürgen-Grünsand" including "Gallensis-Grünsand", see Table 1).

Lithology: The base consists of massive glauconitic and calcareous sandstone. Above, finely bedded sandstone alternates with sandy limestone with variable glauconite content. Often intensely bioturbated, Assilines, and Discocyclines are frequent. Depositional depth is 50–70 m, the thickness is 5–25 m. Overlying strata: Mattgrat Member, Stad Formation; underlying strata: Seewen Formation, ?Amden Marl, Euthal Formation. Biostratigraphy: Early Lutetian (*Assilina exponens*). Current geographical extent: Central Switzerland: Lake Lucerne region, Reuss to Linth valley; Eastern Switzerland: Toggenburg to Rhein valley. Tectonic unit: Central Switzerland: Drusberg nappe, Griessstock nappe, Kammlistock nappe, Klausenpass zone of tectonic slices; Eastern Switzerland: Glarus nappe complex, Subalpine Flysch zone, Brülisau/Wildhaus melange.

2.3.3 *Mattgrat Member*

Established by U. Menkveld-Gfeller (in Funk et al. 2013). The type locality is at Bürgenstock (2671.200/1205.250—2670.950/1205.080; Menkveld-Gfeller 1997; "Bürgen-Kalk").

Lithology: Poorly to well bedded, grey, bioturbated micritic limestone with low content of quartz and glauconite sand; the glauconite portion increases towards the top. At the top the limestone is hardground-like and disintegrated to nodules. Nummulites of the *millecaput* group and the *perforatus* group (in the upper part) are frequent. Thickness is 5–13 m. Overlying strata: Foribach Member, Wildstrubel Formation; underlying strata: Scharti Member. Biostratigraphy: Middle Lutetian, nummulites of the *perforatus* group. Current geographical extent: Central Switzerland: Lake Lucerne region, Reuss to Linth valley; Eastern Switzerland: Linth valley to Rhein valley. Tectonic unit: Central Switzerland: Drusberg nappe, Griessstock nappe, Kammlistock nappe, Klausenpass zone of tectonic slices; Eastern Switzerland: Lower Helvetic.

2.3.4 *Foribach Member*

Established by R. Herb (in Bayer et al. 1983; "Foribach-Schicht"). The type locality is at Bürgenstock (2671.200/1205.250—2670.950/1205.080; Menkveld-Gfeller 1997), a reference section is at Foribach, Sarnen (2662.420/1194.500—2662.550/1194.350; Menkveld-Gfeller 1997). Note: since 1995 the Foribach Member is no longer exposed at this site.

Lithology: A bed of highly glauconitic, sandy micrite with nodules of the Mattgrat-Member-type facies is succeeded by bedded, strongly bioturbated, sandy, glauconitic micrite with greenish-grey weathering colour. Contact with the overlying strata (Klimsenhorn Formation, Stad Formation) is always distinct. Thickness is approx. 4.5–16 m. Overlying strata: Klimsenhorn Formation, Wildstrubel Formation, Stad Formation; underlying strata: Mattgrat Member. Biostratigraphy: Late Lutetian, Nummulites. Current geographical extent: Central Switzerland: Lake Lucerne region, Reuss to Linth valley. Tectonic unit: Central Switzerland: Drusberg nappe, Griessstock nappe, Kammlistock nappe, Klausenpass zone of tectonic slices.

2.4 Klimsenhorn Formation

The Klimsenhorn Formation, established by R. Herb (in Bayer et al. 1983) and first described by Schumacher (1948), is subdivided into the Fräkmünt Member, Band Member, and Fruttli Member. The type locality is at Klimsenhorn (2661.500/1204.025—2661.625/1204.100; Menkveld-Gfeller 1997), a reference section is described by Menkveld-Gfeller (1993, 1997; section Rawil 4).

Lithology: The type and reference section of the Klimsenhorn formation are distinct in terms of facies, thicknesses and age of the members: The entire sequence of the type section at Klimsenhorn is thick, very sandy, in part conspicuously coarse-grained. In the Rawil region the sequence is very thin and the sand content is restricted to a few individual horizons. At Pilatus a Middle and Late Eocene dispersal center can be identified (R. Herb in Bayer et al. 1983, Herb 1988, Menkveld-Gfeller 1994). From there the detrital material is carried to the west and east to distal regions by currents parallel to the coast. The boundaries between the "Untere Perforatus-Schicht" and the lower quartz sandstone, the lower quartz sandstone and the "Complanata-Schicht", as well as the upper quartz sandstone and the "Obere Perforatus-Schicht" are often indistinct. Therefore, a new subdivision of the Klimsenhorn Formation into three members was suggested in Menkveld-Gfeller (1997, Table 1): The Fräkmunt Member ("Untere Perforatus-Schicht", lower quartz sandstone and the "Complanata-Schicht"), the Band Member (upper quartz sandstone and "Obere Perforatus-Schicht"), and the Fruttli Member ("Discus-Schicht"). The definition of these three new members should end the previous confusion in the nomenclature (Menkveld-Gfeller 1997, Table 1). Overlying strata: Wildstrubel Formation, Küblibad Member, Niederhorn Formation; underlying strata: Schrattenkalk Formation, Garschella Formation, Seewen Formation, Amden Marl, Wang Formation, Bürgen Formation. Biostratigraphy: Late Lutetian to Bartonian, Nummulites. Current geographical extent: Western Switzerland: Rawil region; Central Switzerland: Border Chain between Lake Thun and Lake Lucerne, Schächen valley to Linth valley; Eastern Switzerland: Linth valley to Kistenpass region. Tectonic units: Western Switzerland: Wildhorn nappe (NW of the Mondralèche fault and SW of the Hohgant-Rawil fault zone); Central Switzerland: Drusberg nappe, Axen-Südlappen, Lower Helvetic; Eastern Switzerland: Lower Helvetic.

2.4.1 *Fräkmünt Member*

Established and first described by Menkveld-Gfeller (1997). The type locality is at Klimsenhorn (2661.500/1204.025—2661.625/1204.100; Menkveld-Gfeller 1997), a reference section is described by Menkveld-Gfeller (1993, 1997; section Rawil 4).

Lithology: Contact to the underlying Cretaceous formations is distinct and discordant. The base is formed by poorly bedded quartz sandstone with embedded Nummulite-rich micrite layers. Above follows massive, glauconitic bimodal quartz sandstone, in part cross-bedded; poorly banked limestone toward the top with micritic parts. Weathering colour: light to mouse grey. The thickness is 1–37 m. Contact to the overlying strata (Band Member, Wildstrubel Formation) is distinct. Overlying strata: Band Member, Wildstrubel Formation; underlying strata: Cretaceous formations (predominantly Schrattenkalk Formation, Garschella Formation, Seewen Formation). Biostratigraphy: Late Lutetian to Bartonian, Nummulites. Current geographical extent: Western Switzerland: Rawil region; Central Switzerland: Border Chain between Lake Thun and Lake Lucerne, Schächen valley to Linth valley; Eastern Switzerland: Linth valley to Kistenpass. Tectonic units: Western Switzerland: Wildhorn nappe (NW of the Mondralèche fault and SW of the Hohgant-Rawil fault zone); Central Switzerland: Drusberg nappe, Axen-Südlappen, Lower Helvetic; Eastern Switzerland: Lower Helvetic.

2.4.2 *Band Member*

Established and first described by Menkveld-Gfeller (1997). The type locality is at Klimsenhorn (2661.500/1204.025—2661.625/1204.100; Menkveld-Gfeller 1997), a reference section is described by Menkveld-Gfeller (1993, 1997; section Rawil 4).

Lithology: The base comprises a massive barren quartz sandstone bed, with often bimodal quartz grain-size distribution, which overlies Cretaceous formations or the Fräkmunt Member. It is succeeded by a relatively well-bedded alternation of calcareous sandstone to limestone, in part highly bioturbated. The contact to the overlying Fruttli Member is always distinct, the weathering colour is light-grey to dirty white. The thickness is approx. 1.5–10 m. Overlying strata: Fruttli Member, Wildstrubel Formation; underlying strata: Cretacous formations (predominantly Schrattenkalk Formation, Garschella Formation, Seewen Formation), Fräkmünt Member. Biostratigraphy: Late Lutetian to Bartonian, Nummulites. Current geographical extent: Western Switzerland: Rawil region; Central Switzerland: Border Chain between Lake Thun and Lake Lucerne, Schächen valley to Linth valley; Eastern Switzerland: Linth valley to Kistenpass region. Tectonic units: Western Switzerland: Wildhorn nappe (NW of the Mondralèche fault and SW of the Hohgant-Rawil fault zone); Central Switzerland: Drusberg nappe, Axen-Südlappen, Lower Helvetic; Eastern Switzerland: Lower Helvetic.

2.4.3 *Fruttli Member*

Established and first described by Menkveld-Gfeller (1997). The type locality is at Klimsenhorn (2661.500/1204.025—2661.625/1204.100; Menkveld-Gfeller 1997), a reference section is described by Menkveld-Gfeller (1993, 1997; section Rawil 4).

Lithology: The Fruttli Member overlies with distinct contact the Bürgen Formation or the Band Member. At the base a barren, thin quartz sandstone bank is present. Above follows either a massive sequence of marly micrite poor in sand or an alternation of fine-grained calcareous sandstone and sandy limestone, both rich in Discocyclines. The contact to the overlying strata (Wildstrubel Formation, Niederhorn Formation) is distinct. The weathering colour is greenish-grey, the thickness approx. 1.5–15 m. Overlying strata: Küblibad Member (Wildstrubel Formation), Niederhorn Formation; underlying strata: Bürgen Formation, Band Member. Biostratigraphy: Late Lutetian to Bartonian, Nummulites. Current geographical extent: Western Switzerland: Rawil region; Central Switzerland: Border Chain between Lake Thun and Lake Lucerne, Schächen valley to Linth valley; Eastern Switzerland:

Linth valley to Kistenpass region. Tectonic units: Western Switzerland: Wildhorn nappe (NW of the Mondralèche fault and SW of the Hohgant-Rawil fault zone); Central Switzerland: Drusberg nappe, Axen-Südlappen, Lower Helvetic; Eastern Switzerland: Lower Helvetic.

2.5 Wildstrubel Formation

The Wildstrubel Formation, established and first described by Menkveld-Gfeller (1993, 1994), is subdivided into the Küblibad Member (originally "Küblibad-Schicht"), Tierberg Member (originally "Hohgant-Schiefer"), and Schimberg Member. The type section is exposed along the hiking path between Rawilseeli and Wildstrubelhütte SAC (2601.810/1136.790; Menkveld-Gfeller 1994; section Rawil 8). For further descriptions see Kaufmann (1886), Lugeon (1910; "schistes arénacés à patine fauve"), Mollet (1916), Schumacher (1948), Leupold (1964, p. 634, 857), Bieri (1978), Wanner (1987), Lutz (1988), and Herb (1988; "SE-Fazies der Hohgant-Formation").

Lithology: The boundary with the underlying strata is always distinctly formed. The Küblibad Member, at the base of the Wildstrubel Formation, is exposed as discontinuous, thin, glauconitic and phosphoritic quartz sandstone. Early diagenetic, lithified phosphoritic nodules as well as partially phosphoritic matrix can be related to hardground formation. The succeeding Tierberg Member has a distinct boundary and comprises the main constituent of the Wildstrubel Formation. Here, we have highly bioturbated, fine-grained, sandy calcareous marl that was deposited on the slope of a platform (Bieri 1978). The phosphorite and glauconite content decrease rapidly, while the size of the quartz grains tends to decrease towards the top and the matrix portion increases. Horizons with fine-grained, sandy, somewhat calcareous, bioturbated marlstone containing mollusks can occur in the lower part of the Tierberg Member. Toward the top, the Tierberg Member is replaced at various locations by the Schimberg Member. This consists of partially sandy marlstone featuring local sandstone layers and conglomerate with sandstone and limestone pebbles. The transition into the Stad Formation occurs rapidly in both cases, mostly within a meter. The total thickness is up to 50 m. Overlying strata: locally Niederhorn Formation, Stad Formation; underlying strata: Schrattenkalk Formation, Garschella Formation, Seewen Formation, Amden Marl, Wang Formation, Bürgen Formation, Klimsenhorn Formation, locally Niederhorn Formation. Biostratigraphy: Bartonian to Priabonian, based on dating of the underlying strata, respectively the overlying strata, planktonic and benthonic foraminifera. Current geographical extent: Western Switzerland: east of the Sanetsch pass to the Aare valley; Central and Eastern Switzerland: Aare valley to Calfeisen valley. Tectonic units: Western Switzerland: Wildhorn nappe, east of the Sanetsch pass and southeast of the Hohgant-Rawil fault zone; Central and Eastern Switzerland: Drusberg nappe, southeast of the Hohgant-Rawil fault zone, Axen nappe, west of Muota river, Lower Helvetic between Reuss valley and Calfeisen valley.

2.5.1 *Küblibad Member*

The Küblibad Member was established by U. Menkveld-Gfeller (in Funk et al. 2013) and first described by Mollet (1916; "Glaukonitschicht von Küblibad"). The type section is exposed along the hiking path between Rawilseeli and Wildstrubelhütte SAC (2601.810/1136.790; Menkveld-Gfeller 1994; section Rawil 8). For further descriptions see Mollet (1916), Schaub (1936), Schumacher (1948), Herb (1988), and Menkveld-Gfeller (1993, 1994; "Küblibad-Schicht").

Lithology: The Küblibad Member is discontinuous, thin, and exposed as glauconitic sandy limestone to calcareous, ferruginous sandstone to phosphoritic quartz sandstone. The glauconite content is mostly less than 10 %. Accumulated shells of Discocyclines occur at many locations at the base. These were presumably carried upward from the underlying Klimsenhorn Formation by intense bioturbation. The bed succeeds the underlying strata at a clear omission surface or with a basal conglomerate horizon of washed out, early diagenetic, lithified nodules. The partially phosphoritic matrix as well as the occurrence of early lithified phosphoritic nodules are related to hardground formation. The glauconite content retreats towards the top and the sand portion increases. The Küblibad Member is overlain by the bedded calcareous sandstone of the Tierberg Member. The thickness is max. 4 m. Overlying strata: Tierberg Member; underlying strata: Cretaceous formations (predominantly Schrattenkalk Formation, Garschella Formation, Seewen Formation), Bürgen Formation, Klimsenhorn Formation. Biostratigraphy: Bartonian, based on dating of the underlying strata, respectively the overlying strata. Current geographical extent: Western Switzerland: east of the Sanetsch pass to the Aare valley; Central and Eastern Switzerland: Aare valley to Calfeisen valley. Tectonic units: Western Switzerland: Wildhorn nappe, east of the Sanetsch pass and southeast of the Hohgant-Rawil fault zone; Central and Eastern Switzerland: Drusberg nappe, southeast of the Hohgant-Rawil fault zone, Axen nappe, west of Muota river, Lower Helvetic between the Reuss valley and Calfeisen valley.

2.5.2 *Tierberg Member*

The Tierberg Member was established and first described by U. Menkveld-Gfeller (in Funk et al. 2013). The type section is exposed along the hiking path between Rawilseeli and Wildstrubelhütte SAC (2601.810/1136.790; Menkveld-Gfeller 1994; section Rawil 8). For further descriptions see Schumacher (1948), Leupold (1964, p. 857), Steffen (1981), Herb (1988), and Menkveld-Gfeller (1993, 1994; "Hohgant-Schiefer").

Lithology: The Tierberg Member comprises the main constituent of the Wildstrubel Formation. Here, we have highly bioturbated fine-grained, sandy calcareous marlstone to fine-grained calcareous quartz sandstone that were deposited on the slope of a platform (Bieri 1978). As a result of the intense bioturbation there is a clear, nodular aspect to these deposits. Phosphorite- and glauconite content decrease rapidly, while towards the top the size of the quartz grains tends to decrease and the matrix portion increases. Horizons with fine-grained sandy, somewhat calcareous, bioturbated marlstone containing mollusks, serpulids and rarely solitary, ahermatypic corals ("Pectinidenschiefer") can occur in the lower part of the Tierberg Member. An increase in marl content and the appearance of planktonic foraminifera demonstrate a rapid change into the Stad Formation, the transition occurring within 1 m. Locally, the Schimberg Member follows above the Tierberg Member. When coarser intercalations are absent, the Schimberg Member can hardly be distinguished from the Tierberg Member. The thickness is up to 50 m, whereby the thickness appears to be greatest immediately to the southeast along the Hohgant-Rawil fault zone. Overlying strata: locally Niederhorn Formation, Schimberg Member, Stad Formation; underlying strata: locally Klimsenhorn Formation, Küblibad Member. Biostratigraphy: Bartonian to ?Priabonian, based on dating of the underlying, respectively the overyling strata. Graf (1984) investigated the Dinoflagellate fauna in the Pilatus region and dated the succession from Tierberg Member to Stad Formation to NP 17–19 (Bartonian to Priabonian). Current geographical extent: Western Switzerland: east of the Sanetsch pass to the Aare valley; Central and Eastern Switzerland: Schafmatt to Calfeisen valley. Tectonic units: Western Switzerland: Wildhorn nappe, east of the Sanetsch pass and southeast of the Hohgant-Rawil fault zone; Central and Eastern Switzerland: Drusberg nappe, southeast of the Hohgant-Rawil fault zone, Axen nappe, west of Muota river, Lower Helvetic between the Reuss valley and Calfeisen valley.

2.5.3 Schimberg Member

The Schimberg Member was established by Menkveld-Gfeller (in Funk et al. 2013) and first described by Mollet (1921; "Schimberg-Schiefer"). The type locality is at Ober Loegg, Schimbrig LU (2733.860/1224.350), the type section is at Schimbrig LU, ca. 200 m NE Alp Ober Loegg (2650.650/1198.110; Eckert 1963). A reference section is at Pilatus (Canton Lucerne) (2661.775/1203.820; Bieri 1978). For further descriptions see Kaufmann (1872), Mayer-Eymar (1887), Boussac (1912), Mollet (1921), Brückner (1946), Schumacher (1948), Eckert (1963), Bieri (1974, 1978, 1982), R. Herb (in Bayer et al. 1983), and Herb (1988).

Lithology: The Schimberg Member consists of partially sandy marlstone that has occasionally sand layers and conglomerate beds with sandstone- and limestone pebbles. The reworked pebbles originate from locally-occurring units of the Cretaceous and of the Palaeogene (even of the Schimberg Member) and were washed in. As a result of the sporadic activity of the Hohgant-Rawil fault zone, shallow marine calcareous quartz sandstone to sandy limestone with a species-rich bivalve- and gastropod fauna (Mollet 1921) are embedded in the Schimberg Member (Menkveld-Gfeller in Funk et al. 2013), an interfingering of the Schimberg Member with the Hohgant Sandstone (Niederhorn Formation). Eckert (1963) had already postulated local uplift and fault activity during the deposition of the Schimberg Member, with the simultaneous onset of erosion on the footwall fault blocks and, thereby, the delivery of material for the conglomerate beds. The member is hardly distinguishable from the Tierberg Member in areas where these intercalations are absent. The transition into the Stad Formation is demonstrated by the occurrence of less- and fine-grained quartz, a decrease in feldspar content, an increase in clay content and detrital muscovite as well as a change in the foraminifera fauna to forms that occur in deeper water. The intercalation of conglomerate beds starts in the middle part of the Schimberg Member and extends into the Stad Formation (Eckert 1963, Bieri 1978). The thickness in the type region is 33–55 m. Overlying strata: locally Hohgant Sandstone (Niederhorn Formation), Stad Formation; underlying strata: Tierberg Member, locally Hohgant Sandstone (Niederhorn Formation). Biostratigraphy: Priabonian, planktonic and benthonic foraminifera. Current geographical extent: Central Switzerland, Schafmatt-Schimbrig region to Lake Lucerne. Tectonic unit: Central Switzerland: Drusberg nappe.

Remarks: Many of the horizons described as "Schimberg-Schiefer" or the like do not belong to the Wildstrubel Formation because they originate from another stratigraphic level: sediments of the Fitzligraben (Bieri 1978), of the Lammgraben near Habkern, of the Waldegg at Beatenberg (Colombi 1960, Bieri 1978), and of the Schlafegg in Kandergrund, of the Gollitschenkessel near Frutigen, as well as of the Bunderle near Adelboden (Schuler 1980, Steffen 1981).

2.6 Niederhorn Formation

Established and first described by U. Menkveld-Gfeller (in Funk et al. 2013), the Niederhorn Formation is subdivided into two members: the Hohgant-Sandstein (Hohgant Sandstone) and the Gemmenalp-Kalk (Gemmenalp Limestone). The type section is located at Wagenmoos, Gemmenalphorn region (2629.300/1177.700; Breitschmid 1978), a reference section is situated at the Niesehorn, northwest of the hiking path Iffigsee to Wildhornhütte SAC (2596.600/1135.900; Menkveld-Gfeller 1993, 1994). For further descriptions see Studer (1834b), Beck (1911), Stauffer (1920), Schumacher (1948), Colombi (1960), Leupold (1964, p. 105, 631), Breitschmid (1978), Zwahlen (1983), Bugnon (1986), Herb (1988; "NW-Fazies der Hohgant-Formation"), Gfeller (1989), Arnold (1990), Menkveld-Gfeller (1993 "Hohgant-Formation"), and Decrouez and Menkveld-Gfeller (2003).

Lithology: The Niederhorn Formation developed from the southeast to the northwest during two transgressive phases around 38–37 Ma. Shallow marine sediments have been preserved northwest of the current geographical extent of the Wildstrubel Formation from the earlier transgression, while the later transgression north thereof formed shallow marine, in part sand-dominated sediments. As a consequence of erosion, respectively absent exposure, information as to the sediments is absent between both regions. The Hohgant Sandstone is built up of coastal siliciclastic sediments with calcareous, partially brackish successions poor in sand. The succeeding Gemmenalp Limestone is predominantly composed of Discocyclines- and Corallinacean-rich limestone. The boundary with the overlying Stad Formation is typically distinct; only at the top of the reference section there is a transitional facies of Discocyclines- and Bryozoan-rich marlstone. The thickness is up to 170 m. Overlying strata: locally Schimberg Member (Wildstrubel Formation), Stad Formation; underlying strata: Quinten Formation, Öhrli Formation, Betlis Limestone, Helvetischer Kieselkalk, Schrattenkalk Formation, Klimsenhorn Formation, Wildstrubel Formation, locally Siderolithic Group. Biostratigraphy: Late Bartonian to earliest Priabonian, Larger foraminifera. Current geographical extent: Western Switzerland: Lauenen valley to Aare valley; Central Switzerland: Aare valley to Melchaa river. Tectonic units: Western Switzerland: Doldenhorn nappe, Gellihorn nappe, Jägerchrüz nappe, Wildhorn nappe, northwest of the Hohgant Rawil fault zone, respectively between Wildstrubel and Pilatus (Drusberg nappe) also locally adjoining the fault zone directly to the southwest; Central Switzerland: Lower Helvetics, Drusberg nappe, base of Axen nappe.

2.6.1 Hohgant Sandstone

Established by Menkveld-Gfeller (1993, 1994) and first described by Studer (1834b). Here, we included the "priabone Sandsteine des Nordhelvetikums" (Herb 1988) to the Hohgant Sandstone. The type section is located at Wagenmoos, Gemmenalphorn region (2629.300/1177.700; Breitschmid 1978), a reference section is situated at the Niesehorn, northwest of the hiking path Iffigsee to Wildhornhütte SAC (2596.600/1135.900; Menkveld-Gfeller 1993, 1994). For further descriptions see Studer (1834b), and Herb (1988).

Lithology: The member is built of coastal siliciclastic sediments with embedded calcareous parts poor in sand, partially brackish. Dispersal systems, presumably from the crystalline massifs in the north (Black Forest, Vosges) concentrate in the Klimsenhorn and Hohgant regions, with the sediment transport parallel to the Hohgant-Rawil fault zone towards the west. Near the dispersal centers the cyclicity of the deposits is pronounced (Breitschmid 1978, three transgression/regression cycles). More distal, e.g., in the Wildstrubel region, it only remains weakly recognizable or is entirely absent. The sandstone successions that arose during the second transgression phase were often underlain by fossil-rich horizons of former brackish water environments and/or conglomerate beds, which often fill a pre-Eocene relief or are linked to synsedimentary faults (Stauffer 1920, Zwahlen 1983, Bugnon 1986, Gfeller 1989, Arnold 1990). The Mürren breccia ("Mürren-Brekzie", Stauffer 1920, Collet and Paréjas 1931, Krebs 1925) of the Lower Helvetics also counts as part of these conglomerate beds at the base of the Hohgant Sandstone. According to Müller (1938), the Mürren breccia is located between the underlying strata (Cretaceous, Siderolithic Group) and Priabonian sediments (coal-bearing marlstone) of the overlying strata. Boulders to pebbles from the underlying Cretaceous strata in a sandy-siliceous matrix, rarely including Nummulites, occur as a result of reworking due to a transgression of the Priabonian sea (Collet and Paréjas 1931). Overlying strata: locally Schimberg Member (Wildstrubel Formation), Gemmenalp Limestone, Stad Formation; underlying strata: Quinten Formation, Öhrli Formation, Betlis Limestone, Helvetischer Kieselkalk, Schrattenkalk Formation, Klimsenhorn Formation, Wildstrubel Formation, locally Siderolithic Group. Biostratigraphy: Late Bartonian, Larger foraminifera. Nummulites of the *fabianii* group were identified in the Hohgant Sandstone in the region of the Lower Helvetic of the Titlis chain as well as in the Dolderhorn nappe of Kiental. These Nummulites originated in the latest Priabonian (Künzi 1975, Herb 1988), which is in contrast to the dating of the Hohgant Sandstone of the Wildhorn nappe (Menkveld-Gfeller 1993, 1994). It can thereby be proven that the deposition of the Hohgant Sandstone must have occurred in two pulses. Current geographical extent: Western Switzerland: Lauenen valley to Aare valley; Central Switzerland: Aare valley to Melchaa river. Tectonic units:

Western Switzerland: Doldenhorn nappe, Gellihorn nappe, Jägerchrüz nappe, Wildhorn nappe, northwest of the Hohgant-Rawil fault zone, respectively between Wildstrubel and the Pilatus area also directly adjoining southwest at the fault zone; Central Switzerland: Lower Helvetics, Drusberg nappe, base of Axen nappe.

2.6.2 *Gemmenalp Limestone*

Established and first described by Menkveld-Gfeller (1993, 1994). The type section is located at Wagenmoos, Gemmenalphorn region (2629.300/1177.700; Breitschmid 1978), a reference section is situated at the Niesehorn, NW of the hiking path Iffigsee to Wildhornhütte SAC (2596.600/1135.900; Menkveld-Gfeller 1993, 1994). For further descriptions see Beck (1911), Schumacher (1948), Colombi (1960), and Herb (1988).

Lithology: In general, Discocyclines and Corallinacean limestone facies are dominant. In the region north of Lake Thun the Gemmenalp Limestone, which is poor in or devoid of quartz sand, is mostly built as Corallinacean limestone ("Lithothamnien-Kalk"). West of the Wildstrubel the facies varies greatly: Corallinacean-rich limestone poor in quartz sand, sandy Discocyclines-rich limestone to marlstone as well as tempestite-like sediments appear. The boundary to the overlying Stad Formation is mostly distinct, solely in the reference section are planktonic foraminifera established at the top and a transition is developed in the form of a Bryozoan-rich marlstone. Overlying strata: Stad Formation; underlying strata: Hohgant Sandstone. Biostratigraphy: Priabonian, Larger foraminifera. Current geographical extent: Western Switzerland: Lauenen valley to Aare valley; Central Switzerland: Aare valley to Melchaa river. Tectonic units: Western Switzerland: Doldenhorn nappe, Gellihorn nappe, Jägerchrüz nappe, Wildhorn nappe, northwest of the Hohgant-Rawil fault zone, respectively between the Wildstrubel and the Pilatus (Drusberg nappe) also locally adjoining the fault zone directly to the southwest; Central Switzerland: Lower Helvetics, Drusberg nappe, Axen nappe.

2.7 Sanetsch Formation

The Sanetsch Formation, established and first described by Menkveld-Gfeller (1994), can be subdivided into three members: Diablerets Member, Tsanfleuron Member and Pierredar-Kalk (Pierredar Limestone). The type section is located SSW of the Sanetsch pass (2586.720/1129.395, section Lapis de Tsanfleuron 1; Menkveld-Gfeller 1993, 1994), a reference section at Sanetsch Buvette, N of Lac de Sénin (2589.010/1134.870; Menkveld-Gfeller 1993, 1994). For further descriptions see Furrer (1938), Rykken (1968), Martini (1970), and Herb (1988; "NW-Fazies der Hohgant-Formation").

Lithology: The sediments of the "überwiegend kalkige Fazies des Priabons" (Herb 1988) were named for the Sanetsch pass, north of Sion. The basal Diablerets Member fills the palaeorelief that is present at the top of the underlying Cretaceous strata and is visible only locally. The underlying strata were reworked during the onset of the transgression, which resulted in the formation of breccia and conglomerate beds exhibiting a spectrum of local pebbles. Lacustrine limestone with coal lenses, a plaster comprising oysters or microcodia, miliolida- and ostracod-rich micrite, sand-limestone and quartz sandstone as well as sandy limestone with a rich mollusk fauna ("Cerithien-Schichten") form the remaining part of this thin member (Menkveld-Gfeller 1994). A sandy facies that is already fully marine, the Tsanfleuron Member, follows discontinuously in a pre-transgressive relief over the Diablerets Member or directly on the Cretaceous deposits. The Pierredar Limestone terminates the Sanetsch Formation towards the top. It rests on Cretaceous deposits or follows above the Tsanfleuron Member. The facies, which is also described as "calcaires à petites nummulites" varies with respect to fossil content, but is always poor in or devoid of quartz sand. The boundary with the overlying formation is typically distinct; planktonic foraminifera often appear already in the uppermost section of the Pierredar Limestone and, in part, an increment of marl content in the limestone demonstrates the transition to the Stad Formation. The entire thickness is up to max. 90 m. Overlying strata: Stad Formation, underlying strata: Quinten Formation, Öhrli Formation, Betlis Limestone, Helvetischer Kieselkalk, Tierwis Formation, Schrattenkalk Formation, Garschella Formation, Seewen Formation, locally Siderolithic Group. Biostratigraphy: (?Late Bartonian) Priabonian to Rupelian, mammal remains, Larger foraminifera. Current geographical extent: France: Haute-Savoie; Western Switzerland: southwest of the Daubenhorn, west of Lauenen valley: Sanetsch, Diablerets, Dents de Morcles and Dents du Midi regions. Tectonic units: France: Morcles nappe and Chaînes Subalpines (Haut-Giffre, Platé, Bornes-Aravis, Bauges); Western Switzerland: westernmost Doldenhorn nappe, northwestern part of Wildhorn nappe, Diablerets nappe, Morcles nappe.

2.7.1 *Diablerets Member*

Established by Menkveld-Gfeller (1993, 1994) and first described by Hébert and Renevier (1854; "Faciès à Diablerets"). The type section is located SSW of the Sanetsch pass (2586.720/1129.395, section Lapis de Tsanfleuron 1;

Menkveld-Gfeller 1993, 1994). For further descriptions see Hébert and Renevier (1854), Renevier (1890), Boussac (1912), Moret (1934), Charollais (1962), Rykken (1968), Martini (1968, 1970), Doudoux and Coletta (1975; “Couches des Diablerets”), Pairis (1975), Pairis & Pairis (1975), Pairis et al. (1984; “Formation brune”), Weidmann et al. (1991), Viard (1998), and Schlagintweit et al. (2012).

Lithology: The Diablerets Member is built only locally as a filling of a palaeorelief at the top of Cretaceous deposits and reflects the onset of a transgression. The member was presumably deposited over a large area, but eroded again to a great extent (except for pockets and depressions) when the full marine transgression commenced. During the transgression the underlying Cretaceous formations were reworked and breccia or conglomerate beds were deposited with a local spectrum of pebbles. This conglomerate, which has not been assigned a lithostratigraphic unit by Menkveld-Gfeller (1993, 1994), is being newly viewed here, as suggested by Linder (2005) and Schlagintweit et al. (2012), as a basal part of the Diablerets Member. The “Roc Champion Conglomerate” (Lugeon and Argand 1937), described in detail from the Morcles nappe by Rykken (1968), also belongs to this member. The facies of the remaining part of this member varies greatly from the bottom to the top: thin, lacustrine limestone rich in Charophytes arises next to or above a marly layer, followed by a miliolid- and ostracod-rich micrite, sand-limestone and quartz sandstone as well as a more or less sandy limestone, the so-called “Cerithien-Schichten”. A rich mollusk fauna was variously described therefrom (e.g., Renevier 1890). Schlagintweit et al. (2012) demonstrated the presence of *Clypeina helvetica*, a Dascycladacean alga, in this upper part of the Diablerets Member. The thickness is max. 18 m; additionally up to 10 m, in the Morcles nappe even up to 45 m of conglomerate beds. Overlying strata: Tsanfleuron Member, underlying strata: Cretaceous formations (predominantly Schrattenkalk Formation), locally Siderolithic Group. Biostratigraphy: (?Late Bartonian–) Priabonian, mammal remains, (Weidmann et al. 1991, MP 13-20; note the difficult correlation of mammal biozones with marine biozones). Current geographical extent: France: Haute-Savoie, Western Switzerland: West of Lauenen valley: Sanetsch, Diablerets, Dents de Morcles, and Dents du Midi regions. Tectonic units: France: Morcles nappe and Chaînes Subalpines (Haut-Giffre, Platé, Bornes-Aravis, Bauges); Western Switzerland: Diablerets nappe, Morcles nappe, northwestern part of the Wildhorn nappe.

2.7.2 *Tsanfleuron Member*

Established and first described by Menkveld-Gfeller (1993, 1994). The type section is located SSW of the Sanetsch pass (2586.720/1129.395, section Lapis de Tsanfleuron 1; Menkveld-Gfeller 1993, 1994), a reference section is located at Sanetsch Buvette, north of Lac de Sénin (2589.010/1134.870; Menkveld-Gfeller 1993, 1994). For further descriptions see Boussac (1912), Martini (1970), Kunz (1982), Pairis (1975), Pairis and Pairis (1975), Pairis et al. (1984; “Formation grise”), Herb (1988), Menkveld-Gfeller et al. (1995), and Viard (1998).

Lithology: The base of the Tsanfleuron Member is commonly built as quartz sandstone to calcareous sandstone devoid of fossils, often with bimodal grain-size distribution. Frequently it fills karst fissures in the top of the underlying Cretaceous strata. Sediments of the transition to the inner shelf, sandstone to micrite, follow with the first Corallinaceans. The sand supply decreases upsection, a sandstone bed or a sandy limestone bed terminates the member towards the top. The Tsanfleuron Member is preserved discontinuously, laterally it can be represented by a conglomerate bed with a sandy matrix, by a sandstone bed with plenty of large oysters, or it can be missing. The thickness is up to 17 m. Overlying strata: Pierredar Limestone, underlying strata: Cretaceous formations (predominantly Schrattenkalk Formation), Siderolithic Group, Diablerets Member. Biostratigraphy: Priabonian, Larger foraminifera. Current geographical extent: France: Haute-Savoie; western Switzerland: west of Lauenen valley: Sanetsch, Diablerets, Dents de Morcles and Dents du Midi regions. Tectonic units: France: Morcles nappe and Chaînes Subalpines (Haut-Giffre, Platé, Bornes-Aravis, Bauges); Western Switzerland: Diablerets nappe, Morcles nappe, northwestern part of Wildhorn nappe.

2.7.3 *Pierredar Limestone*

Established and first described by Menkveld-Gfeller (1993, 1994). The type section is located SSW of the Sanetsch pass (2586.720/1129.395, section Lapis de Tsanfleuron 1; Menkveld-Gfeller 1993, 1994), a reference section is located at Sanetsch Buvette, N of Lac de Sénin (2589.010/1134.870; Menkveld-Gfeller 1993, 1994). For further descriptions see Boussac (1912; “Calcaires à petites nummulites”), Rykken (1968), Martini (1970), Doudoux and Coletta (1975), Pairis (1975), Pairis and Pairis (1975, “Les Calcaires blancs”), Kunz (1982; “Calcaires nummulitiques et Calcaires gréseux à Lithothamnion et Lithophyllum”), Pairis et al. (1984), Herb et al. (1984), Herb (1988), Menkveld-Gfeller et al. (1995), and Viard (1998).

Lithology: Pierredar-Kalk (Pierredar Limestone) represents the Sanetsch Formation in part as the sole stratigraphic member. This manifold limestone is characterised by abrupt vertical and horizontal facies changes and was deposited on a carbonate platform. Corals occur only secondarily and at few locations. Micrite, mainly built of Corallinaceans with local clusters of benthic Larger foraminifera, and marly micritic limestone with Discocyclines and many clasts of benthic

Larger foraminifera are predominant lithologies. Often the Discocyclines-rich limestone overlays the Corallinacean limestone ("Lithothaminen-Kalk"), which formed in somewhat shallower water under calm conditions. A transition of the Pierredar Limestone into the marl of the Stad Formation as a result of increasing marl content is rare. Most often the boundary is distinct, although a change in the depositional area is signalised by the appearance of planktonic foraminifera. The thickness is max. 68 m. Overlying strata: Stad Formation; underlying strata: Cretaceous formations (predominantly Schrattenkalk Formation), Siderolithic Group, Tsanfleuron Member. Biostratigraphy: Priabonian to Rupelien, Larger foraminifera. Current geographical extent: France: Haute-Savoie; Western Switzerland: southwest of Daubenhorn, west of Lauenen valley; Sanetsch, Diablerets, Dents de Morcles and Dents du Midi regions. Tectonic units: France: Morcles nappe and Chaînes Subalpines (Haut-Giffre, Platé, Bornes-Aravis, Bauges); Western Switzerland: west of Doldenhorn nappe, northwestern part of Wildhorn nappe, Diablerets nappe, Morcles nappe.

2.8 Stad Formation

The Stad Formation was first described by Kaufmann (1886) and is subdivided into several regionally occurring beds: Wängen Limestone (Wängen-Kalk), Rütenen Conglomerate (Rütenen-Konglomerat), Kleintal Conglomerate (Kleintal-Konglomerat), Jochstock Conglomerate (Jochstock-Konglomerat). "Blockmergel" (Leupold 1939, 1942, Jeannet 1941) and other similar beds are not considered as formal beds. The type section is located at Alpnachstad (2663.850/1200.875—2663.850/1201.300; Kaufmann 1886, Bolli 1951; "Stadschiefer"); note that the type section is overturned. For further descriptions see Buxtorf (1916, 1918), Anderegg (1940), Brückner (1946), Schumacher (1948), Bolli (1951), Styger (1961), Eckert (1963), Charollais et al. (1980), and Herb (1988).

Lithology: Almost entirely quartz-free, grey, slaty, platelike, clay-rich marlstone ("plattiger Mergelschiefer"), towards the top (stratigraphically into the underlying strata owing to the overturned sequence) transition into slightly sandy to sandy, grey marl ("Mergelschiefer") with, in part, well preserved foraminifera; frequently yellowish to lightgrey weathered, occasionally mica-bearing. The sand content generally decreases towards the top, before it again increases as it reaches the top of the depositional sequence. In the region of Western and Central Switzerland, sandstone- or limestone beds (Wängen-Kalk) occur at or near the base, often meters thick. Furthermore, conglomerate intercalations can occasionally be seen, which are interpreted as the result of regional, synsedimentary fault tectonics. Generally, the slaty marlstone of the Stad Formation changes its lithology from highly sandy to clayey-marly without interruption. The thickness reaches at up to more than 100 m at various locations. Overlying strata: Muot-da-Rubi Formation, North Helvetic Flysch Group, *Blattengrat Sandstone* (South Helvetic flysch), tectonic boundary; underlying strata: Sanetsch Formation, Niederhorn Formation, Wildstrubel Formation, Bürgen Formation, Euthal Formation. Biostratigraphy: Yprésien to Priabonian; highly heterochronous depositional sequence, generally becoming younger from (palaeogeographically) the southeast towards the northwest; planktonic foraminifera (cf. Herb 1988, p. 639 f., Wängen-Kalk: Fauna listing in Eckert 1963, p. 1066 f.), Early Oligocene (cf. Charollais et al. 1980). Current geographical extent: distribution area of the Helvetic sediment nappes in entire Switzerland and Haute Savoie (France). Tectonic units: France: Morcles nappe and Chaînes Subalpines (Haut-Giffre, Platé, Bornes-Aravis, Bauges); Western Switzerland: Doldenhorn nappe, Morcles nappe, Wildhorn nappe, as tectonic slices in the Habkern melange; Central Switzerland: Drusberg nappe, Axen nappe, Autochthonous-Parautochthonous, Einsiedeln zone of tectonic slices, Griessstock nappe, Kammlistock nappe, Klausenpass zone of tectonic slices; Eastern Switzerland: Säntis nappe, Subalpine Flysch zone, Blattengrat nappe, Brülisau/Wildhaus melange.

2.8.1 Wängen Limestone

Coarse-grained, bioclastic, m thick limestone beds occur at various horizons in Western and Central Switzerland in the Wildhorn nappe and in the Drusberg nappe (Herb 1988, Menkveld-Gfeller 1995).

2.8.2 Rütenen Conglomerate

Massive, coarse-grained and poorly sorted conglomerate with marly matrix. Pebbles originated from the underlying sediments of Late Cretaceous to Palaeogene age (Buxtorf 1916; Herb 1988). Occurrence near Rütenen/Beckenried.

2.8.3 Kleintal Conglomerate

The occurrence of the Kleintal conglomerate is widespread in the region of Chlital/Altdorf (Anderegg 1940). Pebbles of Cretaceous (Betlis Limestone to Schrattenkalk Formation) and Middle Eocene strata (Bürgen Formation) originate from the frontal part of the Axen nappe of Central Switzerland.

2.8.4 Jochstock Conglomerate

Conglomerate or breccia with partly coarse-grained sandy matrix composed of marlstone (Stad Formation). Pebbles of the Cretaceous (predominantly Betlis Limestone, occasionally Helvetischer Kieselkalk) and Middle Eocene strata (Klimsenhorn Formation) originate from the Axen nappe of the Jochpass region near Engelberg (Canton Obwalden) (Schumacher 1948).

3 Description of the Helvetic Palaeogene formations (Late Eocene–Oligocene)

3.1 Muot-da-Rubi Formation

The here newly established and defined Muot-da-Rubi Formation combines spatially isolated sedimentary successions that represent the transition from "Globigerina Marl" (Stad Formation) into North- and South Helvetic flysch facies. Type locality is at Muot-da-Rubi/Kistenstöckli (2720.650/1186.350); there is no type section. The Muot-da-Rubi Formation can be subdivided into several members: Ahornen Member, Kistenstöckli Member, Ghölzwald Member (all North Helvetic); Malor Member, Südelbach Member, (all South Helvetic; Table 2). For further descriptions see Soder (1949; "Südelbach-Serie"), Styger (1961), Frey (1965; "Ahornenschichten", "Kistenstöckli-Schichten", "Ghölzwald-Schichten", and "Malor-Schichten"), and Mayoraz (1995; "Brèches tertiaires").

Lithology: The Muot-da-Rubi Formation incorporates isolated members, which have in common that they show a facies transition of the silty-marly Stad Formation into flysch sediments through the appearance of turbidic sandstone beds and breccia layers. (See description of the individual members.) The Muot-da-Rubi Formation can be found in the North- and South Helvetic depositional areas. Overlying strata: Taveyannaz Formation, tectonic boundary; underlying strata: Stad Formation. Biostratigraphy: Priabonien to ?Rupelian, planktonic foraminifera (very rare). Current geographical extent: See individual members. Tectonic unit: See individual members.

3.1.1 Ahornen Member

The Ahornen Member was first described by Frey (1965; "Ahornen-Schichten") at its type locality Ahornenrus (today Malorrus) (2716.100/1192.700). For further descriptions see Styger (1961; Bodenbach section).

Lithology: The Ahornen Member that occurs at different locations of Central and Eastern Switzerland is characterized by the appearance of greenish volcanic rock fragments in the sandstone. This is in contrast to the remaining members of the Muot-da-Rubi Formation, in which such fragments are absent. The base here often consists of slaty marlstone, which already belongs to the Stad Formation. Overyling strata: Taveyannaz Formation, tectonic boundary; underlying strata: Stad Formation, Malor Member (exceptionally). Biostratiography: ?Priabonian. Current geographical extent: Central and Eastern Switzerland: Reuss valley to Linth valley. Tectonic units: Central and Eastern Switzerland: Lower Helvetic.

3.1.2 Kistenstöckli Member

The Kistenstöckli Member was described by Styger (1961; "Kistenstöckligipfelsandstein", "Kistenstöcklisandstein"), the type locality forms the peak of the Kistenstöckli (2720.650/1186.350). For further descriptions see Arn. Heim (1908) and Brückner (1952).

Lithology: A microconglomerate bed with partly rounded fragments of North Helvetic Late Jurassic and Cretaceous strata as well as Palaeogene sandy limestones follows above 100–150 m of slaty Stad Formation that become more calcareous towards the top. It is succeeded by an alternation of 100–200 m of well-bedded, mica-rich sandy limestone and fine-grained, sandy, slaty marlstone; sandstone dominates the top. The formation of the microconglomerate presumably suggests Late Eocene fault tectonics. Overyling stratum: Taveyannaz Formation; underlying strata: Stad Formation. Biostratigraphy: Priabonian, Larger foraminifera. Current geographical extent: Eastern Switzerland: Kistenpass region. Tectonic unit: Eastern Switzerland: Lower Helvetic (Parautochthonous).

3.1.3 Ghölzwald Member

The Ghölzwald Member was described by Frey (1965; "Ghölzwald-Schichten"), the type locality is at Ghölzwald, Stelli (2717.430/1194.250).

Lithology: Above the slaty marlstone of the Stad Formation follow few dm- thick beds of micaceous sandy limestone and calcareous, mica-rich sandstone. Occasionally, a weak gradation can be observed. The overall thickness of the sandy part sums up to only a few meters. Overlying strata: tectonic boundary; underlying strata: Stad Formation. Biostratigraphy: Priabonian, Larger foraminifera. Current geographical extent: Central Switzerland: Linth valley. Tectonic unit: Central Switzerland: Lower Helvetic.

3.1.4 Malor Member

The Malor Member was described by Frey (1965; "Malor-Schichten") at its type locality Ahornenrus [today Malorrus] (2716.150/1192.700).

Lithology: The Malor Member emanates from the Stad Formation by inserting fine-grained sandstone- and micaceous sandstone layers. Also, sandy limestone beds repeatedly occur in alternation with slaty marlstone.

Gradation and parallel lamination can be seen locally in the sandstones. The matrix is calcareous but can also be siliceous locally (oily gloss). In the highest layers, scattered fragments of carbonated andesite occur. The entire thickness is approx. 30–40 m. Overlying strata: Ahornen Member; underlying strata: Stad Formation. Biostratigraphy: Priabonian, Larger foraminifera. Current geographical extent: Central and Eastern Switzerland: Klausenpass to Linth valley. Tectonic units: Central and Eastern Switzerland: Lower Helvetic.

3.1.5 *Südelbach Member*

The Südelbach Member was described by Soder (1949; "Südelbach-Serie") at its type locality Südelgraben near Sörenberg (Canton Lucerne) (2643.000/1186.000). For further descriptions see Gigon (1952; Basale Flysch-Schuppe) and Eckert (1963).

Lithology: In part (primarily in the lower part) marlstone, but rapidly changing to silty marlstone in which scattered clastic graded beds appear. Equally, coarser grained polygenic breccia beds occur, as well as Corallinacean-rich limestone beds. The sequence is bounded by erosion towards the top. Underlying strata: Stad Formation (possibly tectonic boundary). Biostratigraphy: Priabonian, Larger foraminifera. Current geographical extent: Central Switzerland: Sörenberg, Habkern valley. Tectonic unit: Central Switzerland: Drusberg nappe.

3.2 North Helvetic Flysch Group

The North Helvetic Flysch Group was first described by Vuagnat (1945). There is no type locality for the entire lithostratigraphic group, however, type regions may be the Muttsee–Sernf valley in the Glarus Alps of Eastern Switzerland, and the Val d'Illiez (Canton Valais) in the western Swiss Alps. The North Helvetic Flysch Group is subdivided into Taveyannaz Formation, Elm Formation, and Matt Formation (Table 2). For further descriptions see Lusser (1826; "Alpensandstein"), Buxtorf (1912), Oberholzer (1918), Brückner (1946), Vuagnat (1952), Siegenthaler (1974), and Lateltin (1988).

Lithology: The sandstone of the Taveyannaz Formation is characterised by its high content of volcanic minerals. The Elm Formation consists of an alternation of often graded sandstone beds with slaty claystone and siltstone ("Dachschiefer"). Coarse, polygenic conglomerate beds, poorly-bedded sandstone beds and clayey-silty sediments build up the uppermost Matt Formation. Regionally, the overall thickness of the group can amount to more than 1000 m. Overlying strata: tectonic boundary; underlying strata: Muot-da-Rubi Formation, Stad Formation, tectonic boundary. Biostratigraphy: ?Priabonian to Rupelian, in part Larger foraminifera as well as vertebrate remains in the Matt Formation. Current geographical extent: western Switzerland: Rhone valley, Kander valley to Meiringen; Central Switzerland: Jochpass to Altdorf, Schächen valley to Linth valley; Eastern Switzerland: Linth valley, Sernf valley, Kistenpass to Landquart. Tectonic units: Western to Eastern Switzerland: Lower Helvetic (Autochthonous-Parautochthonous).

3.2.1 *Taveyannaz Formation*

First described by Studer (1834a; "Grès de Taveyanne"), the type locality is the Alpe de Taveyannaz (2575.600/1128.100); no type section exists. For further descriptions see Favre (1867), Vuagnat (1952), Siegenthaler (1974; Taveyannaz-Formation), Sawatzki (1975), and Lateltin (1988).

Lithology: The greenish and light-grey, speckled sandstone of the Taveyannaz Formation (Formation de Taveyannaz) is characterised by the high content of volcanic minerals (e.g., de Quervain 1928, Vuagnat 1952). The sandstone may be replaced by thick successions of slaty claystone and siltstone. Regional differences in composition led Siegenthaler (1974) to distinguish three sandstone units: Vorsteg-, Muttenberg-, and Ruchi Sandstone. The thickness is, possibly also due to tectonic accumulation, highly variable and can reach 800 m in the region of the Canton of Glarus. Overlying strata: Elm Formation; underlying strata: Muot-da-Rubi Formation, Stad Formation, tectonic boundary. Biostratigraphy: ?Priabonian to Rupelian, Larger foraminifera uncommon. Current geographical extent: France: Morcles nappe and Chaînes Subalpines (Haut-Giffre and eastern Platé, Aravis); Western Switzerland: Val d' Illiez, Rhone valley, Kander valley to Meiringen; Central Switzerand: Jochpass to Altdorf, Schächen valley to Linth valley; Eastern Switzerland: Linth valley, Sernf valley, Kistenpass to Landquart. Tectonic units: Western to Eastern Switzerland: Lower Helvetic (Autochthonous-Parautochthonous).

3.2.2 *Elm Formation*

First described by Haug (1900; "Grès d'Elm"), the type locality is the Sernftal; no type section exists. For further descriptions see Oberholzer (1933; "Flyschsandstein"), Vuagnat (1945; "Grès du Val d'Illiez"), Brückner (1946; "unterer Altdorfer Sandstein"), Staub (1954; "Elmer Flysch"), Wegmann (1961; "Serie von Elm"), Leupold (1964, p. 364, 1191), Siegenthaler (1974; "Elmer-Formation"), and Lateltin (1988; "Formation du Val d'Illiez" with "schistes marnomicacés" and "grès du Val d'Illiez").

Lithology: Intercalation of mostly well-bedded and often graded sandstone (Grès du Val d́Illiez) with thinner slaty clay- and siltstone. The sandstone contains, in contrast to the underlying Taveyannaz Formation, primarily diabase in the coarse-sand fraction (and generally less abundant amounts of volcanic fragments). Due to tectonic complications neither in the Elm-region nor in the region of the Val d'Illiez the definition of a complete type section is possible. The thickness is highly variable (tectonic accumulation?) and can reach 700–800 m in the region of Glarus (Siegenthaler 1974), and approx. 400 m in Western Switzerland (Lateltin 1988). Overlying strata: Rüschenweid Bed, Matt Formation, tectonic boundary; underlying strata: Taveyannaz Formation. Biostratigraphy: Rupelian, no autochthonous fossils. Current geographical extent: France: Morcles nappe and Chaînes Subalpines (Haut-Giffre and western Platé, Bornes, western Bauges); Western Switzerland: Val d'Illiez, Rhone valley, Kander valley to Meiringen; Central Switzerland: Jochpass to Altdorf, Schächen valley to Linth valley; Eastern Switzerland: Linth valley, Sernf valley. Tectonic units: Western to Eastern Switzerland: Lower Helvetic (Autochthonous-Parautochthonous).

The ***Val d'Illiez Sandstone*** ("Grès du Val d'Illiez") forms a member of the Elm Formation. It corresponds to the type "Grès du Val d'Illiez" that has been described from outcrops in Western Switzerland and Haute Savoie (France).

Lithology: Coarse- to fine-grained sandstone layers, which often show normal grading and bottom marks are typical for this member. A boundary between the sandstone of the underlying Taveyannaz Formation (Ruchi Sandstone) and the Val d'Illiez Sandstone is not easy to draw. However, the increase of milky quartz minerals and especially the sudden appearance of "porphyrites arborescentes" makes a differentiation possible. Single turbiditic sandstone beds can reach up to 6 m in thickness. Geographical and tectonic extent correspond to the one of the Elm Formation.

3.2.3 Matt Formation

The Matt Formation, first described by Alb. Heim (1908; "Flysch von Matt-Engi"), is subdivided into a bed (Rüschenweid-Bank) and two members (Gruontal-Konglomerat, Engi-Dachschiefer). The Sernf valley may serve as type locality of the entire formation, which is, however, neither defined nor exists a type section. The quarry "Bitzi" near Matt (2732.200/1202.600; Wegmann 1961) may act as type locality of the sandstone succession of the Matt Formation, which was first described by Vuagnat (1952; "Grès de Matt"). A type section (individual parts) may be present at Stosswand (2731.400/1201.050—2731.270/1201.500; Siegenthaler 1974). For further descriptions see Brückner (1946; "oberer Altdorfer Sandstein"), Staub (1954; "Serie von Matt"), Styger (1961), Wegmann (1961; "Mattersandsteine"), and Siegenthaler (1974; "Matter-Formation").

Lithology: Poorly-bedded, massive grey to light-grey sandstone units with thicknesses of 2–20 m separated by thin, ripple-laminated, frequently synsedimentary slumped slaty claystone and siltstone dominate above the basal Rüschenweid Bed. Regionally, numerous layers of conglomerate ("Gruontal-Konglomerat") are intercalated. The turbiditic sandstone beds in general exhibit distinct upper and lower boundaries, are fine- to coarse-grained and occasionally contain fine pebbles (<10 mm). In the Sernf valley the thickness is 400–500 m and tapers off to the south. A sequence dominated by slaty claystone and siltstone ("Engi-Dachschiefer"), which is up to 500 m thick, follows above. This sequence can reach even greater thicknesses and includes the famous "Fischschiefer" of Engi (fish slate) with a Rupelian fauna. Overlying strata: tectonic boundary; underlying strata: Elm Formation. Biostratigraphy: Rupelian, rarely planctonic foraminifera; there are macrofossils such as bone fish (teleostei), marine turtles, and remains of birds in the "Engi-Dachschiefer". Current geographical extent: Central Switzerland: Engelberg to Altdorf, Schächen valley to Linth valley; Eastern Switzerland: Linth valley, Sernf valley. Tectonic units: Central and Eastern Switzerland: Lower Helvetic (Autochthonous-Parautochthonous).

The ***Rüschenweid Bed*** was first described by Siegenthaler (1974; "Bank von Rüschenweid"). The type locality is at Rüschenweid, Sernf valley (2732.280/1203.400).

Lithology: Coarse-grained sandstone bed with orange-brown weathering colour, often laminated. It contains a rich though mostly reworked foraminifera fauna of the Middle to Late Eocene. In part, a complete Bouma sequence can be observed. The thickness is approx. 0.8 m. Overlying strata: remaining part of Matt Formation; underlying strata: Elm Formation. Biostratigraphy: Rupelian, Larger foraminifera. Current geographical extent: Eastern Switzerland: Sernf valley. Tectonic units: Eastern Switzerland: Lower Helvetic (Autochthonous-Parautochthonous).

The ***Gruontal Conglomerate*** (Gruontal-Konglomerat) was first described by Boussac (1912; "Conglomerat du Gruontal", "Conglomerat d' Altdorf"). The type locality is the lower part of the Gruontal (2690.800/1196.400—2691.500/1196.700). For further descriptions see Lusser (1829; "Alpennagelfluh"), Alb. Heim (1891), Sarasin (1892), and Buxtorf (1912; "Gruontalkonglomerate").

Lithology: Several beds of polygenic conglomerate and breccia with rock fragments of Helvetic and Penninic origin, embedded in the sandstone succession of the Matt Formation. Overlying and underlying strata: sandstone succession of Matt Formation. Biostratigraphy: Rupelian, no autochthonous fossils. Current geographical extent: Central Switzerland: very locally occurring south of Lake Lauerz, Reuss valley. Tectonic units: Central Switzerland: Subalpine Flysch zone, Lower Helvetic (Autochthonous-Parautochthonous).

The ***Engi Slate*** (Engi-Dachschiefer) was established by Siegenthaler (1974). The type locality is at Diggenwald, at Engi-Hinterdorf (base ca. 2731.500/1204.350). For further descriptions see Murchison (1849; "Fish slates of Glarus"), Heer (1865; "Matterschiefer"), Mayer-Eymar (1877, 1887; "Glarner Fischschiefer"), Wettstein (1887; "Glarner Dachschiefer"), and Boussac (1912; "Couches à poisson du Plattenberg").

Lithology: Very fine-grained section of the Matt Formation. Clayey-silty slate ("Dachschiefer") gradually predominates the sandstone succession. The boundary is assigned wherever the ratio of sandstone to claystone is <1. On the eastern side of the Sernf valley the thickness is towards 200 m, on its western side 500–1000 m. Overlying strata: tectonic boundary; underlying strata: sandstone succession of Matt Formation. Biostratigraphy: Rupelian, macrofossils such as remains of bonefish (teleostei), marine turtles and birds. Current geographical extent: Eastern Switzerland: Linth valley, Sernf valley. Tectonic units: Eastern Switzerland: Lower Helvetic (Autochthonous-Parautochthonous).

Preliminary note to: ***further flysch formations***: Unlike the North Helvetic Flysch Group, the following South Helvetic and Ultrahelvetic (in parts possibly North Penninic) flysch units were primarily described (and widely used) in a tectonic context. These flysch units comprise the "Blattengrat-Flysch", "Ragazer Flysch", and "Sardona-Flysch" as well as the "Einsiedeln flysch" (e.g., Leupold 1942). They consist of strongly deformed (folded and thrusted) sedimentary units of Late Cretaceous and Palaeogene age regardless their depositional character as schelf sediments or flysch deposits. Hence, the term "flysch" is in this context obviously misleading as it does not relate to its original meaning as a synorogenic turbiditic sedimentary succession. For that reason, we describe in the following exclusively those sedimentary units lithostratigraphically, which are intrinsically related to flysch deposition within their respective tectonic context. The remaining units are related to well-defined Helvetic formations.

3.3 South Helvetic flysch deposits (*not defined as formal group*)

There are two regions in Central and Eastern Switzerland in which South Helvetic flysch deposits occur, both tectonically separated (e.g., Leupold 1942): (a) the Burg Sandstone of the internal and external Einsiedeln zone of tectonic slices, and (b) the *Blattengrat Sandstone* and the *Lavtina Sandstone* of the Lower Helvetic nappes of Eastern Switzerland (Blattengrat nappe, Bad-Ragaz nappe).

3.3.1 Burg Sandstone

Frei (1963) described the flysch sandstone, which arises from the Stad Formation (globigerina marl) as Burg Sandstone (Formation; "Burgsandstein"), from the locality Burg (Canton Schwyz), northeast of Lake Lauerz (type locality: 2690.425/1211.260). There seems to be a normal stratigraphic contact with the Stad Formation, which is proven by load casts. Leupold (1964: p. 1112, 416, 134) and Herb (1962) parallelised the Burg Sandstone (of Einsiedeln zone of tectonic slices) with the *Blattengrat Sandstone* and the *Lavtina Sandstone* (of Blattengrat nappe and Bad-Ragaz nappe).

Lithology: The Burg Sandstone consists of well-bedded, dark- to light-grey, fine-grained sandy limestone and coarse- to fine-grained grey calcareous sandstone, which partly includes glauconite grains (Frei 1963). Occasionally, the succession is interbedded with marlstone (type "Fleckenmergel"). The thickness of the Burg Sandstone in the type section is approx. 10 m. The fauna of the Burg Sandstone is dominated by planktonic foraminifera and clasts of nummulites and discocyclines (reworked from the underlying strata). The finding of *Halkyardia* cf. *minima* indicates a Priabonian age. Underlying strata: Stad Formation; overlying strata: tectonic boundary. Biostratigraphy: Priabonian, foraminfera. Current geographical extent: Central Switzerland: very locally occurring: SW Lake Lauerz, Gätterli Pass, Ruestel (Lake Sihl). Tectonic units: Central Switzerland: Subalpine Flysch zone, Einsiedeln zone of tectonic slices.

Arn. Heim (1911) classified the complete sediment succession (tectonically) above the North Helvetic Flysch Group and below the Sardona nappe ("Sardona flysch"), as "Blattengratschichten" (Blattengrat beds), which comprises a Helvetic succession of Amden Marl, Wang Formation, Euthal Formation, Steinbach Member (Bürgen Formation), Stad Formation, and flysch ("Wildflyschgruppe"). However, only the topmost beds above the Stad formation can be assigned to true flysch deposits: Malor Member (Muot-da-Rubi Formation), Blattengrat-Sandstein (see below), and Lavtina-Sandstein ("Lavtina Flysch", see below). Oberholzer (1933) interpreted the latter as Ultrahelvetic and added this unit to the "Wildflysch" (i.e. melange), whereas for Leupold (1942) the "Lavtina flysch" belongs tectonically to the succession of the Blattengrat nappe. The "Blattengratflysch" was first described by Leupold (1942) in its type region Sernftal, east of Elm. Bisig (1957) specified a composite type section at Elm–Fanenstock (ca. 2732.600/1198.100–2733.800/1200.000), which is, however, tectonically disrupted. For further descriptions see Arn. Heim (1911) and Oberholzer (1933; "Blattengratschichten"); Leupold (1942) and Bisig (1957; "Blattengratflysch"). Jeannet et al. (1935) and

Leupold (1937, 1942) parallelised the "Blattengratschichten" with the flysch of Einsiedeln and Wildhaus; Lihou (1995).

We here define two formations, the *Blattengrat Sandstone* and the *Lavtina Sandstone*, following stratigraphically the Stad Formation.

3.3.2 Blattengrat Sandstone

Bisig (1957) first described the *Blattengrat Sandstone* (Formation; Blattengrat-Sandstein) from its type locality at Blattengrat, northeast of Elm, Sernf valley (at P. 2248: 2734.540/1201.260). For further descriptions see Arn. Heim (1911) and Oberholzer (1933; "Blattengratschichten" pro parte); Leupold (1942); Lihou (1995). The *Blattengrat Sandstone*, as true flysch deposit, is part of the so called "wrapped" flysch ("eingewickelter Flysch", Arn. Heim 1911) representing the youngest and uppermost sediment succession of the Blattengrat nappe. There is a thin, basal unit of transitional sediments—sandstone beds in marlstone—that can be related to the Muot-da-Rubi Formation. However, since this unit is not mapable at 1:25'000 scale, we consider it as part of the above following *Blattengrat Sandstone*.

Lithology: The Stad Formation, comprising here a patchy marlstone ("Fleckenmergel"), terminates with the first occurrence of sand lenses in the marlstone (i.e., representing the Muot-da-Rubi Formation). It is succeeded by mica-sandstone beds, the proper *Blattengrat Sandstone*, which alternates with thin beds of patchy, more or less siliceous limestone ("Fleckenkalk"). The *Blattengrat Sandstone* consists of coarse-grained quartz sand and mica; a Fe-bearing variety of the latter appears reddish on a weathered surface. Black slate fragments and siliceous and calcareous pebbles may additionally be present, as well as fragments of Cretaceous and Palaeogene reworked foraminifera. Priabonian foraminifera (*Heterostegina helvetica*), known from the Subalpine Flysch zone, can also occur. The thickness is a few tens of meters at most. Overlying strata: tectonic boundary; underlying strata: Stad Formation ("Fleckenmergel"), Muot-da-Rubi Formation. Biostratigraphy: Priabonian, foraminifera. Current geographical extent: Eastern Switzerland: Sernf valley. Tectonic units: Eastern Switzerland: Blattengrat nappe, Bad-Ragaz nappe.

3.3.3 Lavtina Sandstone

Leupold (1942) first described the *Lavtina Sandstone* (Formation; "Intermediärer Flysch", "Lavtinaflysch") from the type locality at Tristelrus/Unterlavtina (2746.200/1204.600). For further descriptions see Oberholzer (1933; as part of the "Wildflysch"). Like the *Blattengrat Sandstone*, the *Lavtina Sandstone* is part of the so called "wrapped" flysch ("eingewickelter Flysch", Arn. Heim 1911) representing the youngest and uppermost sediment succession in the Weisstannen valley (Blattengrat nappe). The *Lavtina Sandstone* is presumably an equivalent of the *Blattengrat Sandstone* and frequently forms individual tectonic slices.

Lithology: The *Lavtina Sandstone* comprises up to 0.5 m thick beds of grey (weathered yellow–brown) siliceous limestone and calcareous sandstone with black (weathered light-grey) slaty claystone layers in-between. "Fukoidenkalk" and "Fukoidenmergel" is frequently interbedded. The *Lavtina Sandstone*, like the *Blattengrat Sandstone*, passes gradually out of the Stad Formation (or Muot-da-Rubi Formation). Its thickness varies between "great thickness" and "in traces available" (cf. Leupold 1942). Overlying strata: tectonic boundary; underlying strata: Stad Formation ("Fleckenmergel"), Muot-da-Rubi Formation. Biostratigraphy: Middle Eocene–?Priabonian, foraminifera. Current geographical extent: Eastern Switzerland: Weisstannen valley. Tectonic units: Eastern Switzerland: Blattengrat nappe.

3.4 Ultrahelvetic (and ?North Penninic) flysch deposits (*not defined as formal group*)

Ultrahelvetic Helvetic flysch deposits occur in Western and Eastern Switzerland: (a) the Meilleret Formation ("Flysch du Meilleret", e.g., Homewood 1974) in the Meilleret nappe of Western Switzerland, and (b) the flysch deposits of the Lower Helvetic Sardona nappe of Eastern Switzerland.

3.4.1 Meilleret Formation

Lugeon (1938) described the flysch deposits of the Meilleret nappe as "Flysch du Meilleret" named after the Tête de Meilleret SW of the village Vers l'Eglise. For further descriptions see McConnell and de Raaf (1929), McConnell (1951), Homewood (1974, 1976, 1977), and Badoux and Gabus (1991). The "Flysch du Meilleret" corresponds with the "Flysch d'Aigremont" (Lugeon 1938), the "Flysch d'Ochsenweid" (Lugeon 1938; Homewood 1974), and the "Höchst Flysch" (Ferrazzini 1981). The latter contains thickly bedded coarse-grained arenite and conglomerate and, according to benthic and planktonic foraminifera as well as nannofossils, has an age of Middle to Late Eocene. Hsü and Briegel (1991) also assigned the "Adelbodner Flysch" and the "Leissigen Flysch" (both of the Lake Thun region) to Ultrahelvetic flysch deposits of Middle Eocene or probably Late Eocene age. We here define the Meilleret Formation as lithostratigraphic unit in contrast to the "Flysch du Meilleret", which may be used in a tectonic sense as well, similarly to the term “Blattengrat Flysch” etc. (see above).

Lithology: Badoux and Gabus (1991) divided four lithofacies in the type region; these are: 10–15 m basal conglomerate characterized by sedimentary clasts in a sitly-marly matrix, approx. 50 m medium- to coarse-grained arkose sandstone, 50–100 m biogenic-detritic limetone, and polygenic conglomerate with a crystalline and sedimentary clast composition and a silty-sandy matrix. Undifferentiated, the Meilleret Formation may accumulate to 60–100 m thickness. The Meilleret Formation formed as submarine fan deposits along the southern margin of the Helvetic realm (Homewood 1977) and was fed by channels from a source area further to the south. These fan deposits, characterised by highly immature terrigenous clastic and shallow marine carbonate clasts, were built up during Middle to probably Late Eocene times. Locally, the Meilleret Formation contains conglomerate layers, which comprise large boulders (“blocs exotics”), and abundantly also nummulites. Clasts of pre-Triassic basement showing a wide variety of cristalline and metamorphic rock types (similar to those of the North Penninic Niesen Flysch) as well as of Mesozoic sediments of Ultrahelvetic and North Penninic origin, and contemporaneous shallow carbonate-shelf material, form boulder-size conglomerate beds and coarse lithic arenites, which were emplaced by a wide variety of tractional turbidity current and mass-flow processes (Homewood 1976). The nummulites, orthophragmines and Corallinacean fragments of the Meilleret Formation (Lugeon 1938) thus mark an important difference to the Niesen Flysch, which, in addition, had been deposited earlier. Overlying strata: tectonic boundary; underlying strata: Aalenian deposits. Biostratigraphy: Age of the nummulites: Lutetian (Homewood 1974, Lugeon 1938), locally rare nannofossils give an age of Priabonian (Homewood 1976). Current geographical extent: Western Switzerland: Col des Mosses–Diablerets–Adelboden. Tectonic units: Western Switzerland: Ultrahelvetic.

3.4.2 Martinsmad Formation

Leupold (1942) first described the “Sardona-Flysch” (i.e., the sediment succession of the Sardona nappe) in detail and subdivided it into Seewen Formation, Amden Marl, Wang Formation, and “Wildflysch”. For further descriptions see Arn. Heim (1911), Boussac (1912) for Seewen Formation, Amden-Mergel, and Wang formation, Oberholzer (1933; Glarner «Wildflysch»), Bisig (1957; «Sardonaflysch»); Lihou (1995). Like the *Blattengrat Sandstone* and the *Lavtina Sandstone*, the flysch deposits of the Sardona nappe are part of the so called “wrapped” flysch (“eingewickelter Flysch”, Arn. Heim 1911). The strongly schistous sediment succession is intensely deformed, and Leupold (1942) subdivided the succession into an “infraquartzitic” and “supraquartzitic” flysch. Yet, this subdivision includes non-flysch deposits as well. Thus, we combine all true flysch deposits in the here defined Martinsmad Formation. “Globotruncanenkalk” (=Seewen Formation), “Globotruncanenmergel” (=Amden Marl), “Freudenbergschiefer” and “Unterer Siderolitheskomplex” (=Wang Formation) of Leupold (1942)—all belonging to the older part of the “infraquartzitic flysch”—are not further considered.

The Martinsmad Formation as defined here comprises the entire succession of true flysch deposits of the Sardona nappe. These are, sensu Wegmann (1961), the “infraquartzitic flysch” pro parte (including “Kristallinkonglomerate” and “Unterer Ölquarzithorizont”), the “Sardonaquarzit”, and the “supraquartzitic flysch” (comprising “oberer Ölquarzitkomplex”, “Fukoidenschiefer”, “Siderolitesplatten”, and “oberster sandsteinreicher Flysch”). Based on this classification, Lihou and Allen (1996) introduced a “Sardona Quartzite Formation” composed of four facies associations. Based thereon, we here define the Martinsmad Formation subdivided by the Sardona Quarzite (formal member) informally into a “lower” and “upper flysch unit”. The type locality (Leupold 1942) is east of Piz Sardona/Sardona-Hütte SAC (ca. 2739.500/1197.500), a type section may be taken from Lihou and Allen (1996). For further descriptions see Arn. Heim (1911), Oberholzer (1933), Leupold (1942), and Wegmann (1961).

Lithology: See individual members. Overlying strata: tectonic boundary; underlying strata: Wang Formation, tectonic boundary. Biostratigraphy: Maastrichtian to Ypresian (?earliest Lutetian), foraminifera. Current geographical extent: Eastern Switzerland: Sernf and Weisstannen valley. Tectonic units: Eastern Switzerland: Sardona nappe.

The member ***Sardona Quartzite*** (Sardona-Quarzit), as defined here, consists of three lithologically different units: the “Sardonaquarzit” (Leupold 1942) and, following Lihou and Allen (1996), the “lower” and “upper Ölquarzit” horizons of Wegmann (1961) below and above.

The base is formed by a 10–20 m thick slaty sandstone–claystone unit (“unterer Ölquarzithorizont”, Wegmann 1961), which can locally be missing. The following coarse-grained, white, weathered greenish quartzite is thickly bedded and distinguishable in the field, where it commonly forms a morphologically uniform ridge. The Sardona Quartzite reaches a thickness of up to >50 m and seems to taper out laterally (Wegmann 1961). The upper part comprises brown weathered, grey to green dm thick quartzite beds alternating with cm- to dm thick slaty black claystone with a total thickness of 40–50 m (“oberer

Ölquarzithorizont", Wegmann 1961). Lihou and Allen (1996) interpreted this siliciclastic flysch sequence as a deep-marine fan lobe system derived from northern and southern (crystalline boulders) sources. The Sardona Quartzite divides the sediment succession informally into a lower and upper flysch unit. In the Bad-Ragaz nappe, northeast of the Sardona nappe, develops an approx. 50 m thick nummulites-rich limestone (of Euthal and Bürgen Formation) at Batöni (Lavtina valley) into a 15 m thick rust-brown, coarse-grained, glauconitic quartz sandstone, the "Batöniquarzit", which is locally dissipated into nummulites- and Corallinacean-bearing echinodermal limestone beds (Leupold 1942). It may thus form a lateral equivalent of the Sardona Quartzite. Biostratigraphy: Thanetian to Ypresian ("Batöniquarzit": Ypresian to Lutetian), foraminifera.

Lithology: The ***lower flysch unit*** consists of the "Kristallinkonglomerate" (Leupold 1942) comprising a slaty, black, serizitic claystone complex, which incorporates coarse crystalline clasts of cm- to m-size ("exotic boulders"); these boulders may form locally m thick conglomerate beds (Wegmann 1961). It should be noted that Wegmann (1961) described flysch sandstone beds already from the Campanian "Rindermattlischichten" (transitional into flysch facies) and the Maastrichtian "Sideroliteskomplex" (equivalent to Wang Formation). Biostratigraphy: ?Late Cretaceous to Palaeocene, foraminifera.

Lithology: The ***upper flysch unit*** comprises "oberer Ölquarzithorizont", "Fukoidenschiefer" ("Mörderhornschichten" of Wegmann 1961), and "Siderolitesplatten" ("Geisseggschichten" of Wegmann 1961) of Leupold (1942), and "oberster sandsteinreicher Flysch" of Wegmann (1961). The "oberer Ölquarzithorizont" comprises brown weathered, grey to green dm thick quartzite beds alternating with cm- to dm thick slaty black claystone with a total thickness of 40–50 m. "Fukoidenschiefer" is composed of blueish (ocher when weathered) marlstone or micritic orange limestone with fucoids and helminthoids, and occasionally 2 m thick grey sandstone beds with a total thickness of at least 50 m. "Siderolitesplatten" is formed by a well-bedded alternation of grey (siliceous) limestone, fine- to coarse-grained sand-limestone with siderolites, and slaty marlstone layers. It is 50–100 m thick and forms steep cliffs. The "oberster sandsteinreicher Flysch" (Wegmann 1961) consists of gnarly irregular beds of fine-grained, dark grey (weathered brown) calcareous sandstone and polygenic conglomerate in a matrix of poorly bedded, slaty black claystone, several 100 m thick.

Remark: There is a debate whether the flysch deposits of the Sardona nappe originated palaeogeographically from the Ultrahelvetic or North Penninic realm. Both interpretations are supported by arguments: (a) Sandstone petrography (Lihou and Mange-Rajetzky 1996) indicates that the flysch of the Sardona nappe has had a different source than North Penninic flysch deposits—based on the lack of garnet from the orogenic front. (b) Age and conformable depositional sequence (Cretaceous to Palaeogene) point towards Penninic development. (c) The underlying strata (e.g., Leupold 1942) is equivalent to the (Ultra) Helvetic depositional realm. (d) The sedimentation rate of the Martinsmad Formation is much smaller than those of contemporaneous Penninic deposits (structurally controlled isolated basin, individual basin evolution; Lihou 1996, Lihou and Allen 1996).

4 Conclusions

We have formally defined the Palaeogene lithostratigraphic units of the Swiss Helvetic Alps. The hitherto existing nomenclature has been revised and was in parts harmonised and newly defined into a robust lithostratigraphic framework of formally defined groups, formations, members, and beds (Tables 1, 2).

Deposits formed by pre-Late-Eocene weathering are summarised within the Siderolithic Group ("Siderolithikum"). The suite of nummulitic deposits is classified by six formations covering the Middle Palaeocene to Eocene. These are, from old to young: The Euthal Formation including the Fliegenspitz Member, Chruteren Member, Batöni Member, and Einsiedeln Member. The Bürgen Formation subdivided into the Steinbach Member, Scharti Member, Mattgrat Member, and Foribach Member. The Klimsenhorn Formation comprising the Fräkmünt Member, Band Member, and Fruttli Member. The Wildstrubel Formation including the Küblibad Member, Tierberg Member, and Schimberg Member. The Niederhorn Formation with the members Hohgant Sandstone and Gemmenalp Limestone. The Sanetsch Formation divided into the Diablerets Member, Tsanfleuron Member, and Pierredar Limestone. The highly heterochronous Stad Formation, composed of more or less silty to sandy slaty marlstone, completes the depositional sequence towards the top.

In order to understand the complex lateral and vertical setting of the nummulitic formations and the Stad Formation, we used the palinspastic restoration of Kempf and Pfiffner (2004) of the underlying Helvetic crystalline basement and related Late Palaeozoic to Mesozoic nappes (Figs. 2, 3, 4). The resulting chronostratigraphic framework of the Palaeogene Helvetic deposits and their development through time and space is demonstrated in two palinspastically restored schematic cross-sections (Figs. 5, 6).

Regarding the various flysch deposits of the North Alpine Foreland Basin that were deposited above their Helvetic substrate, we established the Muot-da-Rubi

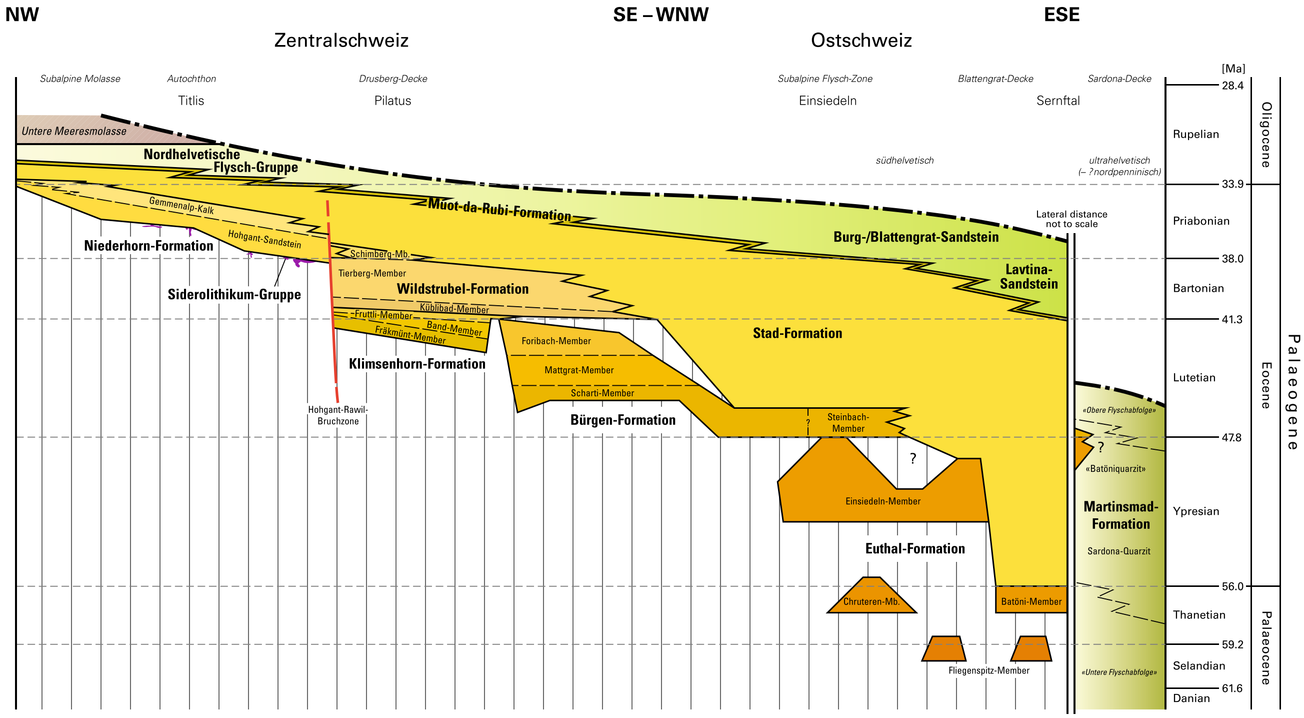

Fig. 5 Schematic cross-section of Palaeogene deposits in Central and Eastern Switzerland through space and time. Important localities and tectonic units are shown. Chronostratigraphy is based on the chronostratigraphic chart of ICS, v. 02/2014 (www.stratigraphy.org). Note that we utilise the German wording for its local use and in order to assure the correct lithostratigraphic terminology

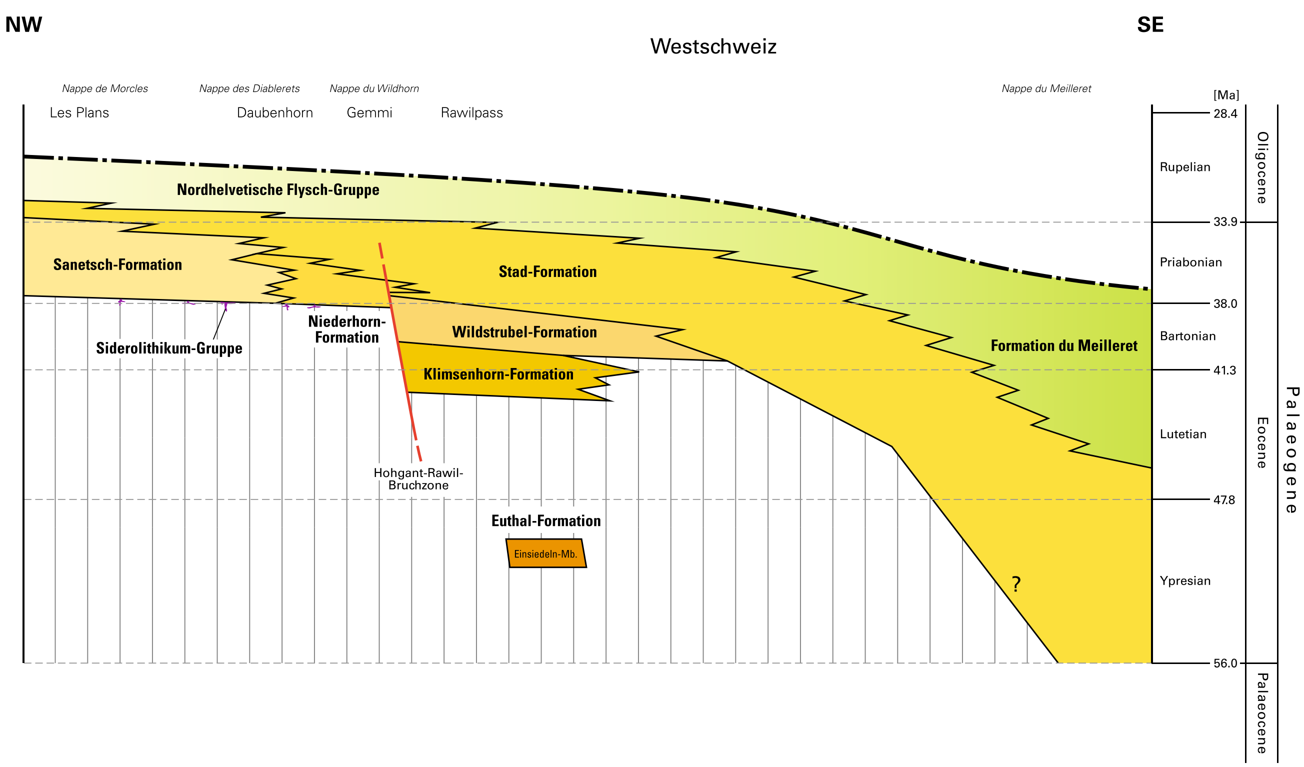

Fig. 6 Schematic cross-section of Palaeogene deposits in Western Switzerland through space and time. Important localities and tectonic units are shown. Chronostratigraphy is based on the chronostratigraphic chart of ICS, v. 02/2014 (www.stratigraphy.org). Note that we utilise the German or French wording for its local use and in order to assure the correct lithostratigraphic terminology

Formation, the North Helvetic Flysch Group as well as flysch formations of South Helvetic and Ultrahelvetic (to ?North Penninic) origin. The Muot-da-Rubi Formation covers sediment successions of different tectonic positions that represent the transition from hemipelagic marlstone deposition (Stad Formation) to turbiditic flysch deposition (e.g., North Helvetic Flysch Group). The North Helvetic Flysch Group consists of the Taveyannaz Formation at the base, the Elm Formation with the Val d'Illiez Sandstone, and the Matt Formation on top, which includes the Rüschenweid Bed and the members Gruontal Conglomerate and Engi Slate. South Helvetic flysch deposits are summarised in three formations: The Burg Sandstone of the Einsiedeln zone of tectonic slices as well as the Blattengrat Sandstone and the *Lavtina Sandstone* of the Blattengrat and Bad-Ragaz nappe. Flysch deposits of Ultrahelvetic origin comprise the Meilleret Formation of Western Switzerland (Meilleret nappe) and the Martinsmad Formation of Eastern Switzerland (Sardona nappe); the latter even may be of North Penninic origin.

Based on the formally defined classification shown here, the huge number of (confusing) lithostratigraphic names is no longer necessary. The frequently used synonyms of older publications are mentioned in the text and are related to the original papers. Brief descriptions of the newly defined lithostratigraphic units can be found at www.strati.ch.

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