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Geology of the Gurnigel area
(Prealps, Switzerland)

With 67 figures, 2 tables and 5 plates

Foreword by the Geological Commission

In the spring of 1979 Dr. J. van Stuijvenberg presented the Geological Commission with the manuscript of his thesis "Geology of the Gurnigel area", in the hope that this work would be included in the "Matériaux" series.

The thesis, which was produced under the combined supervision of Professors C. Caron, R. Herb and A. Matter of the Geological Institutes of Fribourg and Berne, is concerned with the stratigraphic, structural and sedimentological description of a part of the eastern Gurnigel area.

In comparison with prevailing works on this region (for example, the map sheet Gurnigel of the "Geological Atlas of Switzerland 1:25000" published in 1961) the author has succeeded, thanks to his intensive biostratigraphical research, which he combined with exact field observations on sedimentology and tectonics, to limb the Gurnigel Flysch complex in a new and far more detailed manner than hitherto. The clearly outlined lithological profiles, together with the sedimentological analysis, form a valuable starting point for a more extensive research in the neighbouring areas. The reference on the paleogeography and paleotectonics of the Gurnigel Flysch should be taken into consideration when working on other flysch complexes, for example, the Habkern Flysch, Schlieren Flysch and the Wägital Flysch.

In their March 1979 session the Geological Commission decided to include this carefully prepared thesis in the "Matériaux" series. The manuscript was submitted for printing in the middle of July 1979.

The author will personally cover a considerable part of the printing costs of his thesis, and for this the Commission extends their thanks to him.

The reference material for the work submitted is to be found in the Geological Institute, Fribourg. The author alone is responsible for the contents of the texts and illustrations.

Berne, in October 1979

For the Swiss Geological Commission

The President:
Prof. Dr. W. Nabholz

Foreword by the author

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1. Introduction, historical summary, and scope of study

1.1 Geological and geographical situation

The External Prealps (Switzerland) can be subdivided into two tectonic units:

- At the base: a complex unit, with wildflysch (Upper Eocene), and Ultrahelvetic Mesozoic rocks (Triassic to Upper Cretaceous). The size of these Mesozoic rocks varies from cm blocks to km elements.
- At the top: the South Penninic (s.l.) Gurnigel nappe (CARON 1976), with 1.5 km thick Gurnigel Flysch (Maastrichtian to Middle Eocene). It is most extensive of the two units.

There is an important lateral variation: on one given traverse, one of the two units generally dominates (Fig. 1).

Below the External Prealps, slices of North Helvetic, Subalpine Flysch (Oligocene) are found, especially where the wildflysch and the Gurnigel nappe are less well developed.

The following monography is a contribution to the geology of the eastern part of the Gurnigel nappe, with additional observations on the wildflysch (Fig. 2).

1.2 Existing maps

The following maps have been used:

Geological maps:

- TERCIER & BIERI (1961): Geological Atlas of Switzerland 1:25000, sheet Nr. 36 Gurnigel.
- BECK & GERBER (1925): Geological map Thun–Stockhorn, 1:25000, special map Nr. 96.
- Maps from BLAU (1966), SCHMID (1970), FURRER (1952, 1953a, 1953b), and WINKLER (1977) have also been consulted.

Topographical maps:

- Maps 1:25000, Swiss federal topographic service, sheets Nr. 1206 Guggisberg (1975), Nr. 1207 Thun (1975), and Nr. 1226 Boltigen (1974).
- Maps 1:10000, Vermessungsamt des Kantons Bern, sheets Nr. 1206.2 Rüschegg (1976), Nr. 1206.4 Gantrisch (1976), Nr. 1207.1 Wattenwil (1975), Nr. 1207.3 Amsoldingen (1976), and Nr. 1226.2 Oberwil i. S. (1972). See Figure 2.

The toponomy of the 1:25000 map sheets cited is followed. Where a more precise location is necessary, toponomy of 1:10000 map sheets is used. Names figuring on older topographical bases of geological maps are used where appropriate.

1.3 Historical summary

1.3.1 Introduction and subdivision

A complete historical study of the discovery, description and interpretation of the Gurnigel Flysch would be outside the scope of this work. Therefore only a characterization of its history is given here, with some additional historical information in the chapters on stratigraphy, structure
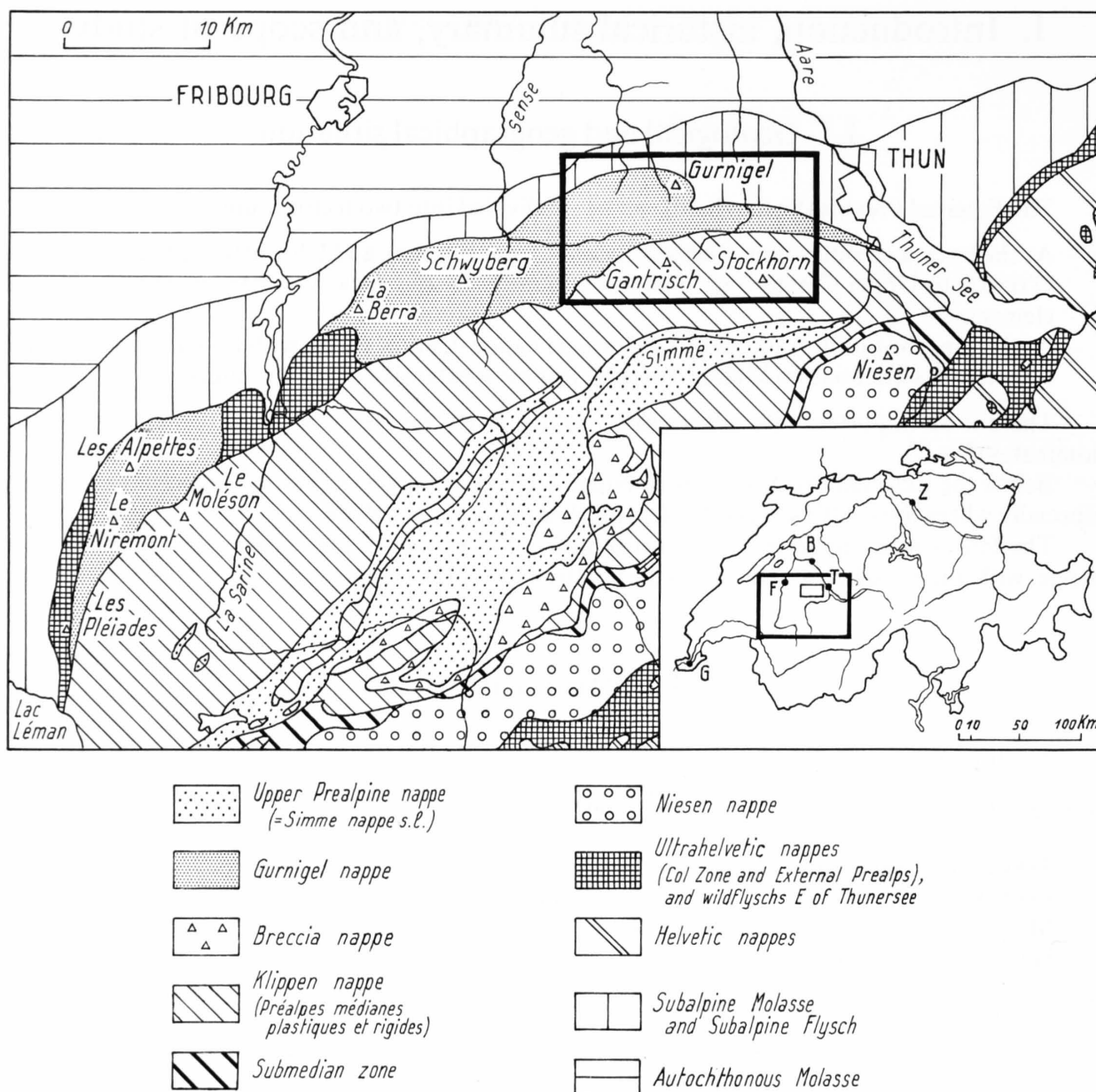
Fig. 1: Diagrammatic map of the Prealps, showing the location of the study area. Slightly modified after SPICHER (1972).

and sedimentology. More general historical reading may be found in BAILEY (1935, reprint 1968) and MASSON (1976) where the Prealps are concerned, and in GILLIÉRON (1885), GERBER (1925) and BLAU (1966) for the Gurnigel Flysch.

The history of the study of the Gurnigel Flysch may be subdivided into four periods:

1. "Autochthonous Period", up to 1893.
2. "Revolutionary Period", 1893–1920. Reinterpretation following introduction of the "nappe theory".
3. "Traditional Period", 1920–1972. Period of accumulation of general or detailed information.
4. "Period of reinterpretation", 1972–? Second radical reinterpretation following accumulation of precise data over the preceding period.

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1.3.2 "Autochthonous Period", up to 1893

During this period, only an autochthonous origin of the alpine rocks including the Gurnigel Flysch was taken into account.

STUDER (1825, p. 32) defined the "Gurnigelsandstein" as:

"Sandstein von sehr feinem, kleinem und grobem Korn. Körner von Quarz, dichtem Kalk, Feldspath u.s.w. mit Kalkcement. Anlage zu schiefriger und dünnschiefriger Absonderung. Im Querbruch uneben ins Splittrige, oft mit schwachem Glasglanz schimmernd. Bräunlichgrau, blaulichgrau, nicht selten ziemlich dunkel. Hart und schwer zersprengbar. Öfters, besonders auf den Absonderungen, weisse Glimmerblättchen, oft auch verkohlte Pflanzenteile. Nicht selten von Kalkspathadern durchzogen. Spec. Gew. 2,6–2,7. Sehr deutlich abgesonderte Schichten bildend, dickere oft mit dünnschiefrigen abwechselnd und zahnartig hervorstehend."

The same author gave three descriptions of the "Gurnigelsandstein" (STUDER 1825, 1834 and 1853), ranging the latter under the heading "Flysch" in 1853. STUDER introduced the word "Flysch" into geological literature in 1827 (HSÜ 1971). In his 1853 description he tried to explain the presence of granite components in the Gurnigel Flysch by the existence of a former basement swell, which delivered material into a marine basin (STUDER 1853, p. 387–388). The autochthonous swell disappeared during the folding of the Prealps. Later GÜMBEL (1892) called this swell "Vindelician".

A Tertiary age of the Gurnigel Flysch was postulated during the autochthonous period (RÜTIMEYER 1848, DE LA HARPE 1880) even if some authors had different opinions: Malm (BOUÉ 1830), Rhaetian (VON FISCHER-OOSTER 1870).

GILLIÉRON (1885) mapped the Gurnigel region on a 1:100000 scale, and provided an accurate description. He followed STUDER's hypothesis of a vindelician swell.

At the end of the autochthonous period some doubt arose concerning the Vindelician swell. SCHARDT (1884) suggested glacial transport for the granitic components, SARASIN (1892), who demonstrated the southern alpine character of the Habkern Granite, followed this explanation.

1.3.3 "Revolutionary Period", 1893–1920

SCHARDT (1893) proposed an entirely new explanation for the origin of the Prealps. He advocated the allochthony of the Prealps, and suggested that the Gurnigel and Niesen Flysch resulted from the debris accumulated at the front of this advancing nappe. This revolutionary idea kindled a period of passionate discussion (BAILEY 1935, MASSON 1976). Where the allochthony of the Median Prealps was concerned, all opposition was squashed by SCHARDT (1898) and LUGEON's synthesis (1902). As for the precise origin of the Gurnigel Flysch, a satisfactory solution was not yet found. LUGEON's comment illustrated the doubt on this subject (1902, p. 75):

"Je me suis demandé quelquefois si ce flysch de la zone externe n'appartenait pas aux Préalpes médianes. En effet, ce flysch est le même que celui que l'on trouve sous les Klippes de la Suisse allemande. Or, celles-ci ne sont que des fragments de la nappe des Préalpes médianes, comme l'ont montré MM. Hugi et Tobler. Ainsi ce flysch est toujours lié avec ces dernières. Si le même terrain qui recouvre les Préalpes médianes, dans les synclinaux, ne se différenciait pas de celui de la zone externe, on serait tenté de considérer celui-ci comme le flanc renversé de la nappe de ces Préalpes. En marchant la nappe aurait entraîné des fragments de la zone interne, qui auraient pénétré en écaille dans le Flysch étranger à elles-mêmes. Ainsi, dans cette manière de voir, la zone externe serait très complexe."

In the same publication he confirmed the allochthonous origin of the Median Prealps.

The following publications contributed to the classical solution of the supposedly similar origin of the Zone des Cols (Internal Prealps) and External Prealps:

SARASIN & COLLET (1907) tried to relate the Gurnigel Flysch with the Median Prealps, as a tectonic slice. Their picture was so incomprehensible that this suggestion did not gain much following; from this time, the hypotheses relating Internal and External Prealps dominated.

BUXTORF (1908, 1910), BECK (1912), and BOUSSAC (1912) realized the allochthony (in relation to the underlying Helvetic nappes) of the "Wildflysch"–Schlieren Flysch complex, which they regarded as one continuous series of Maastrichtian to Lutetian (wildflysch) and Lutetian–Priabonian (Schlieren Flysch) age; BOUSSAC (1912) regarded the Gurnigel Flysch as Lutetian (possibly Auversian), on evidence from nummulites.

BECK (1912) created a single Niesen–Habkern nappe, comprising Col Zone and Gurnigel Flysch, following SCHARDT's (1893) suggestion.

LUGEON (1914 a, b) finding crystalline slices at the basis of the Niesen nappe, postulated a central Penninic (Bernhard crystalline) origin of this nappe; thus he separated the Niesen nappe from the group of nappes with internal roots (Canavese) and from those with external roots (Rhone valley).

LUGEON (1916) proclaimed the discovery of "Habkern-Granite" in the Zone des Cols, thus tending to prove the Gurnigel Flysch to be related to this Col Zone, originating in the external root-zone (Rhone valley). This was the end of a long discussion. However, the granites mentioned by LUGEON, are not Habkern Granites (MERCANTON 1963, P. Homewood pers. comm.), which negates the basis of the classical solution.

In the same publication LUGEON suggested that the flysch was derived from a granitic swell, reviving the Vindelician land in a new position.

BUXTORF (1918), mainly following LUGEON's ideas, clarified the relationships "Wildflysch" – Schlieren Flysch in Central Switzerland, with the Internal and External Prealps, classing the Niesen Flysch as a tectonically higher unit.

ARNOLD HEIM (1920) dotted the *i* of the classical solution: he showed the similitude between the Mesozoics of the External and Internal Prealps, and created the word "Ultrahelvetic" for the provenance of the two zones.

Thus, after a long period of discussion, the classical solution for the Ultrahelvetic was born: the Median and Upper Prealpine nappes had overthrust the Helvetic realm. They passed over a part of the Ultrahelvetic, leaving this thereby behind e.g. in Internal Prealpine position (Col Zone), and pushed another part forward into an External Prealpine position (Gurnigel Flysch and Mesozoic slices). This elegant solution proved to be extremely successful: it was generally accepted for more than 50 years.

1.3.4 "Traditional Period", 1920–1972

Two basic publications delimit this period: HEIM's "Geologie der Schweiz" (1921) at the beginning, and the Swiss 1:500000 Tectonic and Geological maps (SPICHER 1972) at the close. In both of them the classical picture was followed. In between, no new hypotheses concerning the origin of the Gurnigel Flysch gained acceptance but an ever growing number of publications illustrated the advance in detailed knowledge: regional work, stratigraphy, and sedimentology.

Regional work

Progress was achieved by GERBER in the Gurnigel area: regional description (GERBER 1925) and 1:25000 map (BECK & GERBER 1925), and by TERCIER in the Berra area: regional description (TERCIER 1928), with unpublished 1:25000 map. His regional description remains the most complete ever published on the Gurnigel Flysch to date. A part of the map served as a base for the map sheet Gurnigel (Nr. 36) of the Swiss Geological Atlas 1:25000 (TERCIER & BIERI 1961).

Origin

TERCIER's ideas show an interesting evolution. In a preliminary note he suggested a lower Austroalpine origin of the Gurnigel Flysch (1925, p. 11): "...le Flysch de la Berra se rattache au complexe inférieur des nappes austro-alpines, et plus spécialement à la nappe du Falknis. ..., la zone des Préalpes externes serait composée à la fois de terrains ultrahelvétiques et de terrains austroalpins". In his thesis (TERCIER 1928), he changed his mind, and postulated an Ultrahelvetic origin for the Gurnigel Flysch, still derived however from Austroalpine elements. Then having visited the Rheno-Danubian Flysch (1936), he was finally convinced of the Ultrahelvetic origin of the exotic elements (red granites) of the Gurnigel Flysch, as suggested by LUGEON (1916). When TERCIER (1943) remarked the close resemblance between what he believed to be the Flysch of the Median Prealps at Estavannens

and the Gurnigel Flysch [1], he did not change his mind on the origin of the Gurnigel Flysch, but on the provenance of the Median Prealps (TERCIER 1945).

LEUPOLD (1943) described the swell from which the sediments of the Gurnigel Flysch were derived as the South-Helvetic swell.

CROWELL (1955) confirmed the existence of this feature on the base of flute-cast measurements. Finding different directions in the Schlieren Flysch, HSÜ (1960) started a discussion concerning the existence of a Habkern swell within the Ultrahelvetic realm (TRÜMPY 1960, HERB & LEUPOLD 1966, HUBERT 1967, and HSÜ & SCHLANGER 1971), its Ultrahelvetic location was not questioned.

Biostratigraphy

TERCIER (1928) arrived at similar results to those of BOUSSAC (1912) and BUXTORF (1918) in Central Switzerland: wildflysch and Gurnigel Flysch are one stratigraphical sequence with wildflysch being Lutetian and Gurnigel Flysch younger. LOMBARD (1940) found a Thanetian to Priabonian age for the Gurnigel Flysch of the Voirons area. LEUPOLD (1943) and VONDERSCHMITT & SCHAUB (1943) realized that the wildflysch in Central Switzerland had a Priabonian age, and the overlying Schlieren Flysch a Maastrichtian to Eocene age, thus separating the two units.

SCHAUB (1951) showed the Upper Cretaceous to Eocene age of the Schlieren Flysch from the study of larger benthonic Foraminifera. His work is a milestone in the Schlieren Flysch – Gurnigel Flysch research: ever since detailed subdivision and dating has been possible.

HEKEL (1968 b) (following the results of HAY & SCHAUB 1960 in the Schlieren Flysch) showed the possibility of the biostratigraphic resolution of the Gurnigel Flysch by study of calcareous nannofossils. He discovered three tectonic units, and showed that the Hellstätt Series is the Upper Cretaceous base of the Gurnigel Flysch, followed by Paleocene and Lower Eocene strata.

Sedimentology

A number of papers dealing with parts of the sedimentology of the Gurnigel Flysch were published during the second half of the "traditional period". CROWELL (1955) recognized turbidites, and measured current directions. These were later added by HSÜ (1960). BROUWER (1965) described a *Rhabdammina* fauna from the shales of the Gurnigel Flysch, and HUBERT (1967) stated petrographic data.

SPICHER (1972) published the Swiss Geological and Tectonic maps 1:500 000 following the classical paleogeographic interpretation as far as the Gurnigel Flysch is concerned. The publication of this standard map coincided with the first publication of a new series, casting doubt on the Ultrahelvetic origin of the Gurnigel Flysch (CARON 1972). This marks the end of the "traditional period", and the start of a second period of reinterpretation.

1.3.5 "Period of reinterpretation", 1972–?

CARON (1972) proposed a subdivision of the upper prealpine nappes, and compared the lowest of them (Sarine nappe, Reidigen Series) with the basal Schlieren Flysch in the Habkern region. As the basal Schlieren Flysch is the equivalent of the Hellstätt Series in the Gurnigel Flysch, an entirely new origin of the Gurnigel Flysch was thus suggested (Ultrabriançonnais, Southern Penninic to Austroalpine). His work was confirmed independently by HOMEWOOD (1974), who rejected the relationship Ultrahelvetic Flysch – Gurnigel Flysch on the basis of his work in the Col Zone.

KAPELLOS (1973) correlated calcareous nannofossils and nummulites in the Schwyberg area of the Gurnigel Flysch. He found a complete series from Maastrichtian to Lutetian, and introduced a new correlation nummulites–nannofossils for the Middle Eocene. He suggested that the Gurnigel Flysch was originally the stratigraphical cover of the Niesen Flysch.

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[1] Similar observations had been made by BACHMANN (1876), GILLIÉRON (1885), and LUGEON (1902).

VAN STUIJVENBERG (1973) showed the presence of six tectonic slices in, and in the continuation of, the area studied by HEKEL (1968 b).

CARON (1976) defined the Gurnigel nappe in the Prealps and summed up the arguments against an Ultrahelvetic origin of the Gurnigel Flysch suggesting a South Penninic, or Ultrapenninic origin. This publication summarizes the arguments leading to a new discussion on the origin of the Gurnigel Flysch.

1.4 Area and scope of study

The limits of the studied area are indicating on Figures 1 and 2. These limites are:

- to the north: front of the Gurnigel nappe,
- to the east: last outcrops west of Lake Thun,
- to the south: front of the Median Prealps,
- to the west: N–S line (593.750), middle of Guggisberg map sheet.

The main effort of the study was directed towards the following problems:

a) Biostratigraphy of the Gurnigel Flysch by nannofossil dating, and eventually lithostratigraphic subdivision.
b) Structure of the Gurnigel Flysch based on the stratigraphic information. Interpretation of the structure.
c) Sedimentology of the Gurnigel Flysch.
d) Origin, paleogeography and structural evolution affecting the Gurnigel Flysch, comprising a study of the associated wildflysch.
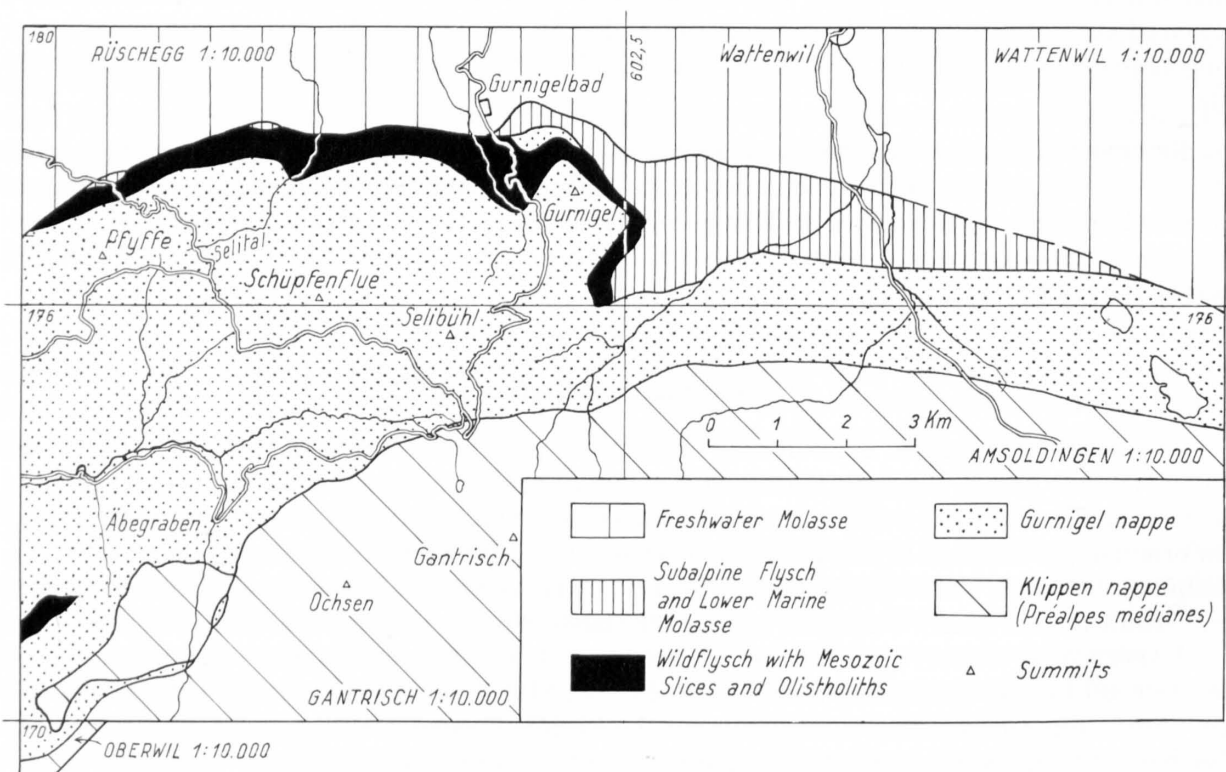
Fig. 2: Tectonic sketch map of the study area, compiled from TERCIER & BIERI (1961), BECK & GERBER (1925), SCHMID (1970), and BLAU (1966, and pers. comm.). The limit of the 10000 map sheets used are also indicated.

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2. Stratigraphy

2.1 Introduction: Biostratigraphy and lithostratigraphy

The usual approach of the general geological study of an area is that of mapping *lithostratigraphic* formations (HEDBERG 1976). For a number of reasons, however, this method was difficult, if not impossible to apply within the eastern part of the Gurnigel nappe:

- The outcrop conditions are generally poor.
- The whole series of the Gurnigel Flysch consists of an apparently monotonous succession of turbiditic sandstones and shales. In the field, many outcrops can only be ascribed to "Gurnigel Flysch".
- Lateral facies changes are highly probable.
- The tectonic complications in the studied area are considerable (HEKEL 1968, KAPELLOS 1973, VAN STUIJVENBERG 1973). The given stratigraphic position of one outcrop does not often allow a precise attribution of the next outcrop.

A	B	C	D	E		F	G
	L. EOC.	(LATTORFIAN) PRIABONIAN	Priabona-	NP 20	Sphenolithus pseudoradians Zone		
–39–41				NP 19	Isthmolithus recurvus Zone		
8 my	M. EOCENE	(BIARRITZIAN) LUTETIAN	Biarritz -- Barton --|	NP 18	Chiasmolithus oamaruensis Zone		
				NP 17	Discoaster saipanensis Zone		
				"NP 16"	Reticulofenestra umbilica Zone		IV
–47–49			Lutetia --|	NP 15	C. alatus = Nannotetrina fulgens Zone		
	EARLY EOCENE	CUISIAN		NP 14	Discoaster sublodoensis Zone		
6 my			Cuise -- Ieper ----	NP 13	Discoaster lodoensis Zone		
				NP 12	M. tribrachiatus = T. orthostylus Zone		III
	YPRESIAN s.l.	ILERDIAN	Campo ---	NP 11	Discoaster binodosus Zone		
				NP 10	M. contortus = T. contortus Zone		
–53–55				NP 9	Discoaster multiradiatus Zone		
			Thanet --|	NP 8	Heliolithus riedeli Zone		IIb
	PALEOCENE	THANETIAN		NP 7	Discoaster gemmeus (= mohleri) Zone		
				NP 6	Heliolithus kleinpelli Zone		
10 my				NP 5	Fasciculithus tympaniformis Zone		
		(MONTIAN) DANIAN		NP 4	Ellipsolithus macellus Zone		
				NP 3	Chiasmolithus danicus Zone		
			"Dan"---	NP 2	Cruciplacolithus tenuis Zone		IIa
				NP 1	Markalius inversus Zone		
–63–65			Maastricht|	26	Nephrolithus frequens Zone		II I II
7 my	CRETACEOUS	MAASTRICHTIAN	L	25	Arkhangelskiella cymbiformis Zone	c b a	
			E	24	Reinhardtites levis Zone		
–72				23	Tranolithus phacelosus Zone		

Fig. 3: Diagram of stratigraphic correlations. For explanation see text.

On the other hand, an extensive *biostratigraphic* control is facilitated by reasonably well preserved calcareous nannofossils, as shown by HEKEL (1968*b*). The method is easy and rapid, and precise information may be gained from the smallest outcrops.

The biostratigraphical approach was therefore the obvious choice, and once a sufficiently dense cover of precisely dated outcrops was established, the general structure of the area became apparent, providing a satisfactory basis for the sedimentological study.

The correlation of chronostratigraphic, biostratigraphic and lithostratigraphic units is shown on Figure 3. This figure will be discussed later (Stratigraphic correlations, p. 29) in so far as not previously reviewed.

2.2 Biostratigraphy of the Gurnigel Flysch

2.2.1 Previous work

SCHAUB (1951) gave a detailed biostratigraphy of the Schlieren Flysch based on *nummulites* and showed its Maastrichtian to Eocene age. KAPELLOS (1973) was later able to apply the same method in parts of the Gurnigel Flysch.

HAY & SCHAUB (1960) showed the usefulness of a second biostratigraphic tool in the study of the Schlieren Flysch: *calcareous nannofossils*.

In the Gurnigel Flysch HEKEL (1968*b*) was the first to study calcareous nannofossils, finding Maastrichtian to Cuisian ages in the Selital area. This confirmed the ideas of the Basel group about the age of the Gurnigel Flysch (see TERCIER 1946, p. 500–501; SCHAUB 1951, p. 82–83).

C. Caron (unpublished, cited in HEKEL 1968*b*) obtained similar results, based on displaced planktonic Foraminifera.

From that time a number of biostratigraphic–micropaleontological papers on the Gurnigel Flysch followed: KAPELLOS (1973), combining nummulites and nannofossils, VAN STUIJVENBERG (1973 and this work), WEIDMANN et al. (1977) and MOREL (1978).

In the meantime, a third micropaleontological tool was developed by the Geneva school: *dinoflagellate* stratigraphy (JAN DU CHÊNE et al. 1975).

2.2.2 Calcareous nannofossils

2.2.2.1 *Introduction*

The great practical use of calcareous nannofossils for biostratigraphical dating may be illustrated by its rapid development. The first hint on stratigraphic zones was given by BRAMLETTE & RIEDEL (1954), a first general zonation was proposed by STRADNER (1963), and in 1970 MARTINI presented a standard zonation for the Tertiary during the 2nd Planktonic Conference held in Rome (MARTINI 1971). This standard zonation is mainly based on European land sections and subdivises the Tertiary into 46 zones, labelled NP 1 to NP 25 for the Paleogene. Another zonation was proposed by BUKRY (1973), mainly based on JOIDES results, and valid for low latitudes. For the Cretaceous system, SISSINGH (1977) has recently published a synthetic subdivision of 26 zones. For further reference, see HAY (1977) and GARTNER (1977).

The study and dating of calcareous nannofossils in the present work has been carried out with one intent and that is the general analysis of the Gurnigel Flysch. Therefore the practical standard zonation has been chosen as a basis for all stratigraphical determination. This zonation had already been tested for its practical use (VAN STUIJVENBERG 1973). Thus, the method consisted of determining the presence or absence of the guide fossils of the chosen zonation in the light microscope.

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The reader interested in the systematics and morphology of the species concerned is referred to KAPELLOS (1973), who published abundant illustrations; his species concepts have not been followed here. Dr. Katharina Perch-Nielsen (Zürich) kindly read and criticized the nannofossil chapter, and checked the determinations on Plate I.

2.2.2.2 *Sample preparation*

The preparation of the calcareous nannofossil samples was the following:

– In the field, collection of small samples of fresh marls: a moderate percentage of clay protects the nannofossils from recrystallisation; pure limestones give poor results, as do – obviously – limefree claystones.
– In the laboratory: scratching of some grams of marl from a fresh surface; cleaning during 2 minutes by ultrasonic treatment in 5% Na-hexametaphosphate; concentration by centrifugation and straining off of the clay-sized fraction; bringing the concentrate into suspension by stirring with water; sedimentation of the coarse (> 50 μ) fraction; pipetting from the suspension containing now the appropriate fraction 2–50 μ; drying on a slide, and covering with Caedax or Entellan. To prevent laboratory contamination, fingers and scratch knife were dipped in 5% HCl between each sample.

Some remarks may be added to this preparation method:

– During sedimentation, a selection takes place: a shorter or longer duration of the sedimentation of the suspension causes changes in the relative abundance of the species present. For the purpose of this study, this was not important, but concentration of the samples was necessary.
– The cleaning of the nannofossils from clay particles by sodium hexametaphosphate (or H_2O_2) may cause some etching. The generally very poor (etched) state of preservation of the material studied makes this factor relatively insignificant.
– Smear-slides were not used.

2.2.2.3 *Characteristics of each zone of calcareous nannofossils in the Gurnigel Flysch*

The zonations of SISSINGH (1977, Maastrichtian), and MARTINI (1971, Tertiary), as shown on Figure 3, column *E* (p. 15) are followed. The important nannofossil species are illustrated on Plate I.

About 2300 samples have been studied, comprising those studied previously (VAN STUIJVENBERG 1973); ⅓ was sterile, ⅓ yielded some nannofossils, allowing determination, and ⅓ yielded enough nannofossils for precise determination. Preservation is rather poor: dissolution and etching phenomena are frequent, overgrowth may also be observed.

– 25–26, *Arkhangelskiella cymbiformis* and *Nephrolithus frequens* zones: Maastrichtian.
The combination of these two zones can be recognized in a large number of preparations from the Gurnigel Flysch. The "*Arkhangelskiella cymbiformis* association" (STRADNER 1963) is characteristic. This comprises *A. cymbiformis* (large) (Plate I, 2), *Micula staurophora* (Plate I, 1), and the usual Late Cretaceous species, belonging to *Prediscophaera, Watznaueria, Cribrosphaerella, Bidiscus, Microrhabdulus,* and others. A subdivision of the *Arkhangelskiella cymbiformis* association did not seem to be feasable: *Lithraphidites quadratus* (defining subzone 25c), and *Nephrolithus frequens* (Plate I, 3) (defining zone 26) are present in few samples only. *A. cymbiformis* (large) is present in all samples, fixing the oldest samples in the subzone 25b at least.

– NP 1 – NP 4: *Markalius inversus, Cruciplacolithus tenuis, Chiasmolithus danicus* and *Ellipsolithus macellus* zones.

Here again, the recognition of a group of zones (four) was possible for a large number of samples, but a more precise subdivision into one particular zone generally impossible. The change between the Late Cretaceous *A. cymbiformis* association and the following Tertiary coccoliths is striking (BRAMLETTE & MARTINI 1964). The Danian association of the Gurnigel Flysch is dominated by the species *Ericsonia cava* (Plate I, 4), and *Cruciplacolithus tenuis* and *C. notus* (Plate I, 5). Other forms, such as *M. inversus, Chiasmolithus danicus* and *C. bidens* (Plate I, 6) are comparatively rare, whereas *Biantholithus sparsus* and *Thoracosphaera* are very rare. The marker of NP 4 *Ellipsolithus macellus* appears to be lacking. A particular feature of the Danian is the extensive reworking of Upper Cretaceous species.

– NP 5 – NP 7: *Fasciculithus tympaniformis, Heliolithus kleinpelli* and *Discoaster mohleri* (= *gemmeus*) zones.

These zones are characterized by the bloom of calcareous nannofossils. During NP 5 the genera *Fasciculithus* (Plate I, 7) and *Sphenolithus* appear, NP 6 is defined by the apparition of the genus *Heliolithus* (Plate I, 8), and NP 7 by the apparition of the genus *Discoaster* (Plate I, 9).

The three zone defining genera are easily recognizable, and allow reliable determination. In poor samples usually only a few *Fasciculithus* sp. were found – the genus *Fasciculithus* appears to be reasonably solution resistant.

Apart from genera mentioned, others, such *Prinsius* and *Toweius,* developed during the Paleocene.

– NP 8: *Heliolithus riedeli* Zone.

This zone is defined by the apparition of *Heliolithus riedeli,* which is difficult, or even impossible, to recognize in many regions (PERCH-NIELSEN 1974, in CARO et al. 1975). Another marker, *Discoaster nobilis,* was therefore proposed.

In the Gurnigel Flysch, both forms are present. *Heliolithus riedeli* was useful in the Voirons area (JAN DU CHÊNE et al. 1975, with illustration), the Fayaux area (VAN STUIJVENBERG et al. 1976), and the Gurnigel area (this study). The determination of *H. riedeli* (often problematic) was kindly confirmed by K. Perch-Nielsen. In Plate I, one specimen is from the Voirons area (Fig. 12), and one from the Gurnigel area (Fig. 11). The alternative marker, *D. nobilis,* is also to be found (Plate I, 10). Frequently, however, both markers appear to be rather rare, so that NP 8 was not normally distinguished from NP 7. On the whole, NP 8 shows the fully developed spectrum of Paleocene nannoplankton: *Discoaster (helianthus, mohleri, nobilis,* and others), various *Fasciculithus, Chiasmolithus, Sphenolithus, Ericsonia, Toweius,* and others.

– NP 9: *Discoaster multiradiatus* Zone.

Discoaster multiradiatus (Plate I, 13) has all the characteristics of a perfect marker: easily recognizable, a synchronous, apparently worldwide, apparition, and often fairly abundant. I found this species frequently in the Gurnigel Flysch of this area. The accompanying association is similar to that of NP 8.

– NP 10: *Tribrachiatus (= Marthasterites) contortus* Zone.

This zone is defined by means of the evolutionary lineage: *Tribrachiatus bramlettei* → *T. contortus* → *T. orthostylus* (alternative nomenclature: *Marthasterites bramlettei* → *M. contortus* → *M. tribrachiatus*), described in detail by HEKEL (1968a). The beginning of NP 10 is marked by the apparition of the genus *Tribrachiatus,* and the close by the last presence of the transitional species of *T. contortus;* if *T. orthostylus* is solely present, NP 11 is reached.

In the Gurnigel area, the lower part of NP 10 is characterized by *Rhomboasper cuspis* (Plate I, 14), and only to a minor extent by the related *T. bramlettei* (JAN DU CHÊNE et al. 1975, Plate III, 8), and the upper part of the zone by *T. contortus* (Plate I, 15). *D. multiradiatus* is also present, tending to have 20–25 rays, while *D. multiradiatus* in NP 9 tends to have 25–30 rays.

The upper limit of the zone is difficult to apply: the negative definition by extinction of *M. contortus* is not valid due to ubiquitous reworking.

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A further characteristic of NP 10 in the study area is the constant reworking of upper Cretaceous nannofossils.

– NP 11: *Discoaster binodosus* Zone.
NP 11 is defined by the sole presence of *Tribrachiatus orthostylus* (Plate I, 17) following its evolution from *T. contortus*. This zone is present in a large number of samples from the studied area. However, a number of samples determined as belonging to NP 10 could be the time equivalent of lower NP 11 due to reworking. The nannofossil association takes a more "Eocene" character: development of Prinsiaceae of *C. gammation* group, presence of *Discoaster binodosus*, development of *Chiasmolithus grandis*, and reduction of typical Paleocene genera such as *Fasciculithus*, *Heliolithus* and others.

– NP 12 – NP 13: *Tribrachiatus orthostylus* and *Discoaster lodoensis* zones.
The base of zone NP 12 is defined by the apparition of *D. lodoensis* (Plate I, 16), leading to the co-occurrence *D. lodoensis* and *T. orthostylus*. After extinction of *T. orthostylus*, the presence of *D. lodoensis* alone defines NP 13. The first limit, base of NP 12, is well defined and easily determinable. The second limit (similarly to the limit NP 10/NP 11) is compromised by the eventual reworking of *T. contortus*.
In the Gurnigel area, I was frequently able to recognize both zones. The association of the accompanying nannofossils is "Eocene" with discoasters such as *D. binodosus*, *D. deflandrei*, *D. gemmifer*, *D. barbadiensis*, and coccoliths such as *Neococcolithus dubius*, *Reticulofenestra*, *C. pseudogammation*, *Toweius callosus*, amongst others.

– NP 14: *Discoaster sublodoensis* Zone.
The lower limit of this zone is defined by the apparition of *D. sublodoensis* (Plate I, 18), which was applicable in this area. However, the relative paucity together with the generally poor state of conservation, sometimes made it difficult to recognize the presence of *D. sublodoensis* with certainty. The association of this zone is characterized by the presence of *Reticulofenestra dictyoda*, with a size of about 8–10 µ. In the highest part of the zone, *D. lodoensis* and *D. sublodoensis* disappear, leading to some difficulty in certain cases.

– NP 15: *Nannotetrina fulgens* (= *Chiphragmalithus alatus*) Zone.
The base of this zone is defined by the appearance of the typical genus *Nannotetrina*.
In the Gurnigel Flysch, *Nannotetrina* is mostly found as the species *N. cristata* (Plate I, 19), less frequently as *N. fulgens*. The accompanying association is of normal Middle Eocene character with *Reticulfenestra dictyoda* (8–12 µ), *Chiasmolithus grandis*, large *Coccolithus pelagicus* and other forms. Within the upper part of the zone, *Nannotetrina* disappears.

– "NP 16": *Reticulofenestra umbilica* Zone.
Many authors have already suggested the usefulness of *R. umbilica* as a marker within the Middle Eocene (BUKRY 1973; ROTH, BAUMANN & BERTOLINO 1971). R. Morel and I were also able to use this limit in the Gurnigel Flysch: an evolutionary lineage seems to exist with the following members: *Toweius callosus* (NP 13) → *Reticulofenestra dictyoda* (NP 14, NP 15) → *R. umbilica* ("NP 16") (Plate I, 20–22). The limit between *R. dictyoda* and *R. umbilica* has been chosen by size: if the species is 12.5 µ or bigger, it is *R. umbilica* (see LEVIN 1965). This provided an useful criterion for the zone "NP 16" which worked in the Pléiades area (WEIDMANN et al. 1977), in the Niremont area (MOREL 1978) and in the Gurnigel area. The lineage should be checked in detail in the Schwyberg area where a thick sequence of relatively undeformed Lutetian is present.
The definition of the base of "NP 16", the *Discoaster tani* Zone (MARTINI 1971) is the extinction of the rather atypical *Rhabdosphaera gladius*. Moreover LOCKER (1967), author of *R. gladius*, described this species from late Eocene beds. For these reasons "NP 16" as used here is only approximatively time-equivalent with the original zone NP 16 defined by MARTINI (1971).

– NP 17 – NP 20: These were not found within the Gurnigel Flysch of the study area, they are however discussed in the paragraph on wildflysch (p. 25 ff.).

2.2.2.4 *Further observations on nannofossils of the Gurnigel Flysch*

Pelagic sediment – turbiditic sediment

The bulk of the Gurnigel Flysch was deposited below the Carbonate Compensation Depth (CCD, see 4. Sedimentology), so that little or no calcite and thus no calcareous nannofossils are to be found in the pelagic sediment. Practically all samples containing nannofossils were taken in resedimented turbiditic shales. However during the Ilerdian, the sediment surface of the Flysch of the Selital area was apparently above the CCD. Thus, calcareous nannofossils have been preserved in the pelagic sediment as well. A comparison between nannofossils of the pelagic and the redeposited sediments first showed that the associations are different; samples from both the Schwarzenbühl quarry and from the Selital road outcrops, showed a much richer content of discoasters in the pelagic sediments than in the turbiditic deposits. Secondly, the age of each association is apparently the same, i. e. within a given zone. There is one doubtful exception from the Selital (NP 10 in the hemipelagics and NP 9 in the turbiditic shale). Both samples are very poor, and this discrepancy might only be apparent.

Reworking

As stated above, the bulk of the nannofossil samples was taken in resedimented turbiditic marls. Two types of reworking of nannofossils may be observed.

a) *Small scale reworking:* Within a depositional area, every turbidity current erodes the underlying strata to some extent (e. g. flute casts); in channeled areas this erosion might be quite important. It is the resultant reworking which hinders the use of zones defined by the extinction of certain species. However, the facts that (*a*) various samples could in practice be assigned to this type of zone (NP 11, NP 13), (*b*) those pelagic turbiditic samples compared gave the same age, and (*c*) the nannofossil zonation in general works so well in a turbidite sequence such as the Gurnigel Flysch, all suggest that this type of reworking is not too important. Accepting that 20% of eroded nannofossils are added to the nannofossils carried by a turbidity current, this turbidite will contain 20% reworked nannofossils. In the next bed, only 20% of 20%, i. e. 4% will be left, and after 10 beds (some meters of sediment), only 0.000002% is left. Even if more extensive erosion may take place in channels, the effect of this small-scale reworking will be of minor importance.

b) *Large scale reworking:* It is possible that older marls are eroded, due to tectonic processes, sea level changes, etc. This is of some importance in the Gurnigel Flysch:
The Upper Cretaceous species *Micula staurophora* is ubiquitous throughout the sequence, and therefore Upper Cretaceous beds must have been continually eroded in the source area. During two particular stages, this erosion appears to have been very important. Some samples of Danian age contain up to 99% (or more) of Cretaceous forms, causing difficulties in determinations (all the more so because the Tertiary nannoplankton evolution started from scratch); and samples from the Ilerdian (NP 10) often contain abundant reworked Cretaceous species.

As a consequence, all nannofossil ages have to be taken as minimum values only.

2.2.3 Other biostratigraphic results

Dinoflagellates

Dr. R. Jan du Chêne (Bordeaux) kindly determined a number of samples from outcrops where nannofossils were not found. These samples mainly come from the Selibühl–Zigerhubel area, and from the Uebeschi quarry (eastern part of the study area).

The Early Eocene age of the Uebeschi quarry, suggested by BLAU (1966), citing RUTSCH (1947) and K. Schmid (unpublished) on the base of nummulites and discocyclines is given more precisely as Cuisian. This age, as well as the lithology support BLAU's attribution of this quarry to the Gurnigel Flysch.

Nummulites

These were not used for stratigraphic purposes. Their distribution over the Gurnigel area is irregular: they are fairly rare in the NE part but are frequent to the NW. The oldest small nummulite was found in thin section (Selital 16, NP 10), and confirmed by Prof. R. Herb (Berne). As for the Schwyberg area, KAPELLOS (1973) stated that nummulites are lacking in strata of Ilerdian age.

Other stratigraphic methods

They have been tested, but so far without much success:

- Planktonic Foraminifera are not completely absent, but give poor results. They are found in turbiditic sandstones and shales.
- Pollen and spores are found in the palynological preparations; they allowed some comparisons (cf. JAN DU CHÊNE et al. 1975).
- Magnetostratigraphy has been tried in cooperation with the Geophysics Department of the ETH-Zürich (Prof. W. Lowrie and Dr. J. Channell). The results so far obtained do not have any stratigraphic value.

2.3 Lithostratigraphy

2.3.1 Introduction

TERCIER (1928) was the first to propose a lithostratigraphic subdivision of the wildflysch – Gurnigel Flysch, which he considered as a continuous stratigraphic sequence. He distinguished:

1. wildflysch,
2. tectonic slices of Mesozoic rocks,
3. Gurnigel Flysch, with the Hellstätt Series being a local facies variation of the Gurnigel Flysch.

TERCIER & BIERI (1961) distinguished both a Mesozoic series and a Flysch. They subdivided the latter into wildflysch, Hellstätt Series, and Gurnigel Sandstone.

WEIDMANN et al. (1977) recently developed a lithostratigraphical subdivision of the Gurnigel Flysch of the Pléiades area. To avoid an unnecessary multiplication of terms for one single Flysch, M. Weidmann, R. Morel and the present author refer to informal lithostratigraphic units (Fig. 3, column *G*), on the understanding that formal terms will be defined taking the entire nappe into account.

2.3.2 Lithostratigraphy of the Gurnigel area

2.3.2.1 *Hellstätt Series (Flysch I)*

The Hellstätt Series was defined by TERCIER (1928, p. 55):

"Les schistes marneux prédominent manifestement; ils sont généralement de teintes sombres, quelquefois brun-rouge. Des bancs de grès s'y intercalent, mais sans dominer nulle part. Ce sont surtout des grès très durs, verdâtres ou noirâtres, à grain très fin, à ciment essentiellement siliceux. De telles roches apparaissent sporadiquement dans le Grès du Gurnigel, plus communément dans le Wildflysch; à Hellstätt, elles abondent. Près de Martene, on aperçoit 2 à 3 bancs d'une petite brèche. Plus caractéristiques encore sont les calcaires. Déjà en remontant les divers ruisseaux de la zone, on les observe à plus d'un endroit. Mais c'est surtout entre Untere Hellstätt et Hellstätt-hahnen qu'on les voit le mieux. Les calcaires sont marneux, clairs, gris-bleuâtre extérieurement; leur surface est couverte de Fucoïdes. Ils forment des bancs schisteux de 20 à 80 cm d'épaisseur."

The type-locality is the Hellstätt chalet [1] (591.60/175.60/1400 m), just west of the study area. Figure 4 shows the "Hellstätt" profile, which crops out in direct continuation with the Hellstätt type sequence. HEKEL (1968 b) discovered the Maastrichtian age of this series, which is the basal sequence of the Gurnigel Flysch. KAPELLOS (1973) informally proposed to call this series "Basaler Gurnigel-flysch", but his suggestion is generally not followed.

The Hellstätt Series shows a regular alternation of various types of turbidites (conglomerates, sandstones, marls, and limestones), and subordinate green hemipelagic shales.

Fig. 4: "Hellstätt" profile (595.70/177.40); base of the Pfyffe slice, in continuation with the Hellstätt type locality. Bed numbers correspond to those of Figures 16 and 18.

– The *conglomerates* are polymictic. They are invariably the T_a division of a Bouma turbidite cycle. Maximum thickness is 50 cm (generally less); the clasts which may attain 2 cm or more, are generally less than 1 cm. Conglomerates are subsubordinate and are not present in all out-crops.

– The *sandstones* always appear as well developed turbidites – Bouma cycles $T_{bc(d)}$ and $T_{c(d)}$. Paleocurrent measurements (corrected for dip only) gave two general directions: NW to SE, and E to W. No thickening-up or thinning-up cycles have been observed. Sandstones form the

[1] Spelled Hällstett on the 1975 edition of the map sheet Guggisberg 1:25000.

second most important rock type of the Hellstätt Series after the marls. They are generally fairly thin, 2–50 cm, but may measure up to 2 m.

– The *marls* are the dominant lithology of the Hellstätt Series by volume. They show a wide variety of types: from white-weathering, albarese type marls, to greyish, reddish and black marls. They may occur as the upper part of a sandstone bearing turbidite or form an independent bed.

– The *limestones* are characteristic but rare. They show a typical bluish-white, massive, fine grained aspect, with a fine fissure system (hammer bearing bed, Fig. 4; thin section photograph: Plate IV, 6).

– The *green hemipelagic shales* are mostly lime-free, and are to be found at the top of the turbiditic marls. Normally they measure only a few cm, often less. Although they are volumetrically unimportant, they can be found at most outcrops.

Profiles are difficult to measure in the Hellstätt Series as the base of the Gurnigel Flysch is always highly tectonized and the predominance of marls creates poor outcrop conditions. Three profiles measured in the Hellstätt Series are discussed in Chapter 4 (Sedimentology, Fig. 16/27). The overall thickness of the series may be estimated as 100–300 m.

Comparisons. – The Hellstätt Series is present in each outcrop area of the Gurnigel Flysch between Lake Geneva and Lake Thun, generally with the same lithology (Pléiades, WEIDMANN et al. 1977; Niremont, MOREL 1978; Berra, KAPELLOS 1973; Kapfberg, C. Caron, pers. comm.; Hellstätt; Gurnigel).

To the east, the outcrops at Bohlberg (Habkern area) show a very similar facies (CARON 1972). SCHAUB's (1951) description of the lower (Cretaceous) part of the Basal Schlieren Flysch suggests similar facies. The Reidigen Series (PAGE 1969, CARON 1972, 1976) at the base of the Upper Prealpine nappes, shows entirely similar facies.

2.3.2.2 Tertiary Gurnigel Flysch: Flysch IIa, IIb, III and IV

Flysch IIa

The predominantly marly Hellstätt Series is overlain by a fairly thin unit (100 m) characterized by an alternance of thin sandstones, black and grey, often lime-free turbiditic shales, and green shales which are completely lime-free. The sandstones are often carbonate-cemented, but may be quartz-cemented ("Ölquarzit"); they are sometimes rich in glauconite. Conglomerates are very rare. Minor thickening-up cycles may be observed. The paleocurrent-direction is generally from the NW, exceptionally from the E.

The Einberg profile (Fig. 15) may be taken as representative. Other sections can be found in the lower part of the Louetli profile (Fig. 22), north of Cheesere, north of Luterbühl, and int the southwest face the Schüpfenflue. The age of Flysch IIa is Danian (NP 1 – NP 4).

Comparisons. – Similar facies are found in the lower Fayaux quarry, near Vevey (VAN STUIJVENBERG et al. 1976), and in the Berra area (KAPELLOS 1973). In the Schlieren Flysch, the upper (Danian) part of the "Basaler Schlierenflysch" (SCHAUB 1951) shows comparable facies. The flysch outcrop near Weissenburgbad above the Median Prealps (described by FLÜCK 1973) shows similar facies.

Flysch IIb (Série de la Gebrannte Egg, TERCIER 1928, p. 55)

This unit is characterized by a predominance of sandstones, and often forms cliffs and summits above the depressions of the Maastrichtian–Danian rocks. Such summits are Zigerhubel, Selibühl (the highest summit of the Gurnigel nappe at 1750 m), Schüpfenflue, Pfyffe and Berra. A number of quarries are worked in this unit: Louetli, Schwendi, Schwarzenbühl, Zollhaus, Fayaux.

In the southern part of the area, this unit is thinner, and less dominates the morphology (Hengstcheeren, steep slope south Sägerei, Marchgraben). Maximum thickness of this series is ~200 m to the N and ~150 m to the S.

These facies are characterized by thick sandstone beds (up to or more than 5 m), which show thickening-up sequences (lower part), and thinning-up sequences (upper part). Relatively shaly intervals (up to 10 m thick) appear between these thick sandy sequences. The lithology of these shaly intervals is very similar to that of Flysch IIa. The sandstones are sometimes conglomeratic; besides thick turbidites, deposits resulting from other mechanisms are present (see Sedimentology, p. 42). In the lower part of the series, the shales are often completely lime-free (as in Flysch IIa), but in the upper part (northern area) both the grey and black turbiditic shales and the interbedded green shales are lime-bearing. The age of this series is Thanetian and Earlier Ilerdian (NP 5 – NP 9). Profiles from this series have been measured at Louetli, Kurhaus, Schwarzenbühl, Selital (lower part), Schüpfenflue and Oschoube (lower half).

Comparisons. – This series is widely represented (lower Zollhaus quarry, Berra summit, cliffs in the Veveyse de Fégire, and the upper Fayaux quarries). In the Schlieren Flysch, the similar Guber Sandstone (SCHAUB 1951) is coarser, thicker and still more sand dominated. The Flysch at Estavannens (TERCIER 1942), which overlies the Median Prealps is very similar.

Flysch III

The previous sandstone dominated Flysch is followed by a shale dominated series, with interbedded sandstones and conglomerates. The shale dominated intervals show a typical alternance of thin sandstones, grey turbiditic shales (lighter than those of IIa and IIb), and green hemipelagic shales. The interbedded sandstones are often calcarenitic, with a high proportion of shallow shelf derived components. They may show thinning-up cycles. Thin coarse sandstones may be observed. In one case (Gouchheit), thin turbiditic limestone is present. These limestones, beige-brown coloured are of different facies than those of the Hellstätt Series.

Flysch III is well developed in the southern part of the area, especially in the Äbegraben region, where both the green shales and the turbiditic shales are lime-free.

In the northern outcrop area (Selital, Süfternen, Oschoube), the series appears to be truncated as the upper part (NP 13, NP 14) is lacking, probably removed by erosion or by tectonics. This may explain the rarity of nummulites in the northern area (Selital, Graben south-west of Selibühl, Ober Gurnigel).

The thickness of this series may be estimated as 200 m in the northern area, and up to 500 m in the southern area. Age is Ilerdian, Cuisian, and Earliest Lutetian (NP 10 – NP 15). Profiles were measured at Selibühl (upper part), Oschoube (upper half), Gouchheit, Äbegraben I–IV, Grätli I–II, and Stäckhüttenwald.

Comparisons. – Similar facies are to be found in the Schwyberg area (Höllbach, KAPELLOS 1973), in the Pléiades area (WEIDMANN et al. 1977), and in the Uebeschi area (easternmost outcrops of the Gurnigel Flysch, BLAU 1966).

In the Schlieren Flysch, the Schoni Sandstone and Upper Schlieren Sandstone (SCHAUB 1951) are similar.

Flysch IV

The outcrops in the Wannelsgrabe area, southwest of Schwefelberg, and south of Stäckhütte, suggest a new facies dominated by lime-rich marls, and where green shales are rare. In the upper Schwyberg area, Niremont area (MOREL 1978), and Pléiades area (WEIDMANN et al. 1977) similar facies are to be found. Thickness may attain 100–150 m, and age is Lutetian (NP 15, "NP 16").

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2.4 Wildflysch

2.4.1 Introduction, previous work

The term "Wildflysch" was defined by KAUFMANN (1886, p. 553) in the Habkern area. The wildflysch was considered to be the stratigraphic base of the Gurnigel Flysch by TERCIER (1928). He ascribed a Lutetian–Priabonian age to the Gurnigel Flysch, since he found Lutetian nummulites in the "Wildflysch".

LEUPOLD (1943) and VONDERSCHMITT & SCHAUB (1943) recognized that the Schlieren Flysch (Habkern area) is of Maastrichtian to Eocene age, and thus forms a higher tectonic unit than the Priabonian "Wildflysch". TERCIER (1946, p. 500) admitted the Late Paleocene age of the Zollhaus quarry, but did not accept, however, that "Wildflysch" and Gurnigel Flysch made up two superimposed, independent tectonic units. He suggested a lateral transition between Gurnigel Flysch and "Wildflysch" within the same basin. GUILLAUME (1957) followed this opinion, considering the wildflysch to be of Maastrichtian–Priabonian age. CORMINBŒUF (1959) further suggested lateral continuity with the Subalpine Flysch, which he considered to be Paleocene.

With the first precise dating of the entire Gurnigel Flysch sequence as Maastrichtian to Eocene (HEKEL 1968 b), and the evidence for a Priabonian age of the wildflysch (KAPELLOS 1973, VAN STUIJVENBERG 1973), the Gurnigel Flysch–wildflysch relationship was shown to be similar to that of the Schlieren Flysch–Habkern Wildflysch.

2.4.2 General description of the wildflysch

Wildflysch tends to form topographic lows, and shows poor outcrops. At many places, isolated Mesozoic rocks or conglomerates are visible, but the shaly matrix can only rarely be observed.

By far the best outcrops are found in the Seligraben (see photographs in KAPELLOS 1973, p. 44, 45) and east of Zigerhubel (Gurnigelbruch). Other outcrops are found in the region east, northeast and north of Ober Gurnigel, north of Luterbühl, at Gross Louetli, in the Schwarzwasser valley, and north of Schwarzenbühl. The wildflysch of this zone was mapped by TERCIER & BIERI (1961), BECK & GERBER (1925), BLAU (1966), SCHMID (1970) and FURRER (1952, 1953 a and b).

A second wildflysch zone appears at Ladengrat in the SW of the area studied (TERCIER & BIERI 1961, WINKLER 1977). Moreover, some outcrops in the Gürbe valley may be considered as wildflysch (see below).

2.4.2.1 *Matrix of wildflysch*

This is composed of black shales, siltstones and very fine-grained sandstones. These are highly tectonized with frequent calcite scars. Green marly shales are often folded with the matrix for which they may easily be mistaken: I had the impression that they form a part of the matrix, whereas in wildflysch of the Pléiades area (P. Homewood, pers. comm.) these marls are considered to be a component, and not a part of the final matrix. HERB (1962) has described a similar occurrence of several varieties of marls and shales in the wildflysch of the Amden area.

2.4.2.2 *Mesozoic rocks*

The most important components in the wildflysch by volume are blocks of various Mesozoic rock types of different size. The largest amongst them measures 300 m according to GERBER (1925) and TERCIER & BIERI (1961): this is the Malm north of Ober Gurnigel.

Triassic

Gypsum, dolomites, green and red dolomitic shales together with rare red quartzitic sandstones have been observed. The dolomitic rocks are comparable with those of the "Médianes Plastiques"

nappe. Gypsum is frequent, often layered and folded. The red sandstones are comparable with the Helvetic facies.

Rhaetian

Some coquinoid silty marls may be of Rhaetian age.

Liassic

There are several outcrops of Liassic biosparites, some of considerable extent. They were discovered and described by GILLIÉRON (1885), and mapped by TERCIER & BIERI (1961). GILLIÉRON considered their facies as typical of the Median Prealps; W. Winkler (pers. comm.) confirmed this opinion. WINKLER (1977) has described Liassic facies of Median Prealps type from the wildflysch in the Ladengrat area (Schwendi).

Dogger

Dark silty marls and fine sandstones, with abundant *"Posidonomya alpina"* have been found NE of Ober Gurnigel. GERBER (1925) showed their Bajocian age based on ammonites (*Sauzei* Zone). This facies resembles that of the Median Prealps ("Zoophycus-Dogger", W. Winkler, pers. comm.), as well as that of the Bulle area attributed to the Ultrahelvetic by MORNOD (1949). The similarity between matrix of the wildflysch and tectonized Dogger shales may sometimes have caused confusion.

Malm

The majority of the larger blocks north-east of the Ober Gurnigel summit are Upper Jurassic limestones. They show a variety of rock types with nodular limestones, calcarenites, calcirudites and micritic limestones ("calcaires sublithographiques"). According to W. Winkler (pers. comm.) some of them are highly comparable with the Malm of the Median Prealps of the Gantrisch area. Others are different and might be similar to Ultrahelvetic facies of the Montsalvens area. In the wildflysch of the Ladengrat area, TERCIER (1928) and WINKLER (1977) described Malm of typical Median Prealps facies at the Schwendi locality.

Lower Cretaceous

The "Gitzi" stones, isolated limestone blocks in the Gurnigelbruch, have Helvetic facies. They are described and dated as Barremian by GERBER (1925) who found *Desmoceras* cf. *neumayeri,* and mapped by TERCIER & BIERI (1961) and BECK & GERBER (1925). GERBER (1925) also found Helvetic Valanginian marls which are no longer exposed. The mottled limestones sometimes found in the wildflysch are of typical Montsalvens (Ultrahelvetic) facies (R. Morel, pers. comm.). Some chert-bearing thin bedded limestones may be of Median Prealps origin (Neocomian, W. Winkler, pers. comm.).

Upper Cretaceous

Rare small slices of green to grey pelagic limestones of Ultrahelvetic ("Leimern"-) facies have been observed with a *Globotruncana* fauna as well as some *Pithonella*. They are dated as Turonian–Coniacian (M. Caron, pers. comm.).

At one outcrop (N of Tröli, TERCIER & BIERI 1961) they show a red facies similar to Couches rouges (Median Prealps).

2.4.2.3 *Conglomerates*

Conglomerates form a special group of components of the wildflysch. They are thick polymictic "organized" conglomerates (up to 5 m), often showing grading and contain Habkern Granite elements. Clasts, frequently of cobble size, may reach 1 m. Wildflysch conglomerates have been observed in the lower part of the Seligraben, in the Schwarzwasser-Tröli area (TERCIER & BIERI 1961),

north-east of the Brunnerennegg (BECK & GERBER 1925, FURRER 1952, 1953 *a, b*), and as isolated "outcrops".

Most of these conglomerates are of Maastrichtian age, or are surrounded by Maastrichtian shales, as nannofossil dating revealed. A Maastrichtian conglomerate, grading into sandstone and marls is illustrated by Figure 5. The coarsest conglomerates (602.200/177.800/1290 m), have not been dated. They may be related to surrounding shales, but GERBER (1925) was able to observe tectonic contacts between the two in an excavation which he dug for this purpose.

The origin of these Maastrichtian conglomerates is problematic. They may well be a proximal equivalent of the Hellstätt Series, but further study is necessary to confirm or deny this hypothesis.

Gürbe valley outcrop

An outcrop of the Gürbe Valley (602.75/175.75/1125 m), situated within the Gurnigel Flysch area, shows an irregular conglomerate bed, some thick sandstone beds, and tectonized shales, dated as Maastrichtian. As Maastrichtian conglomerates of this type are usually found in the wildflysch, I have mapped this outcrop as such (Plate V). FURRER (1952, 1953 *a, b*) found two springs of sulfate rich water (typical of wildflysch groundwater) in the same area.

Ladengrat conglomerate

At Ladengrat (southwestern wildflysch zone) a coarse, nummulite bearing conglomerate, mainly composed of rounded Malm blocks, crops out (TERCIER 1928, WINKLER 1977). This conglomerate is different from the Maastrichtian conglomerates usually found in the wildflysch.

Berra area

Attribution to conglomerates to either Hellstätt Series or wildflysch is also problematic in the Berra area. KAPELLOS (1973) dated some coarse, turbiditic conglomerates north of Sus Cressin as Maastrichtian, and showed their biostratigraphic continuity with the overlying Paleocene Gurnigel Flysch of the Berra summit. His conclusion that all the wildflysch mapped in this area by TERCIER (1928, and unpublished map) belongs to the Hellstätt Series is only justified for the outcrops north of Sus Cressin.

Fig. 5: Conglomerate grading into sandstone and shale, dated at * as Maastrichtian. Seligraben wildflysch.

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2.4.2.4 *Crystalline blocks*

The Seligraben has furnished large amounts of Habkern Granite which have been used for road construction in the Gurnigelbad area. Today the larger remaining blocks measure more than 1 m in diameter. They are mostly isolated, showing no visible relationships with the matrix. Smaller blocks, cobbles and pebbles may be found in the conglomerates. They are well rounded, and show a spectrum of red and white granites of Habkern type, sometimes with the typical association of beige-brown-olive quartz, and red orthoclase. Acid volcanic porphyries are also present. Prof. T. Hügi (Berne) kindly confirmed these observations. This spectrum is similar to that described by SARASIN (1892, 1894).

2.4.3 Age of the wildflysch by nannofossil dating

Black shales (wildflysch matrix) sometimes gave a (Lutetian–) Priabonian age but were often sterile. Green shales frequently gave a (Lutetian–) Priabonian age with following nannofossil zones (cf. Fig. 3, column *E*).

– NP 17 – NP 18: *Discoaster saipanensis* and *Chiasmolithus oamaruensis* zones.
The marker of NP 18, *Chiasmolithus oamaruensis*, is apparently rather rare in the area, so an alternative marker, *Dictyococcites bisectus* (Plate I, 23) was used. This species developed near the NP 17/NP 18 limit, being slightly heterochronous (EDWARDS & PERCH-NIELSEN 1975, p. 480, BUKRY 1973). *D. bisectus* is nearly always present in the samples studied; large specimens of *Reticulofenestra umbilica* (Plate I, 22) are also ubiquitous. A minimum age of upper NP 17 / lower NP 18 (Uppermost Lutetian) can be concluded for the older samples of green shale.

– NP 19: *Isthmolithus recurvus* Zone.
I. recurvus, which defines NP 19, was only found in 3 or 4 samples (Plate I, 24). It shows heavy overgrowth and is rare, and therefore may have been overlooked in samples of poor quality. The presence of this species proves the Priabonian or younger age of these samples.

– NP 20: *Sphenolithus pseudoradians* Zone.
NP 20 is defined by the presence of *S. pseudoradians*. This species (*S.* cf. *pseudoradians*, Plate I, 25) was determined in only one or two samples, along with *I. recurvus*, suggesting the presence of Upper Priabonian.

– NP 21: *Ellipsolithus subdistichus* Zone.
NP 21 (Lowermost Oligocene) is defined by the extinction *Discoaster barbadiensis* (Plate I, 26) and *D. saipanensis* (Plate I, 27). These discoasters are always present in better preserved samples, suggesting a Late Eocene age for the youngest of them. However it is possible that Priabonian nannofossils have been reworked into Lowermost Oligocene wildflysch matrix.

To sum up their biostratigraphy, the wildflysch shales show a nannofossil association with *D. bisectus*, *R. umbilica*, *C. formosus*, *D. barbadiensis* and sometimes *I. recurvus*, which indicates a Priabonian age at the oldest. This confirms the results of KAPELLOS (1973), who discovered Priabonian nummulites in the Seligraben, and those of the present author (VAN STUIJVENBERG 1973). The presence of Maastrichtian conglomerates within the wildflysch, and the presence of conglomerates in the Hellstätt Series which frequently lies just above the wildflysch may explain why GUILLAUME (1957) concluded a Maastrichtian to Lutetian–Priabonian age for this formation.

Some further observations

Samples from the Subalpine Flysch, which may be mistaken for wildflysch in tectonized areas, show a similar association to that of the wildflysch shales (reworked, NP 18 – NP 20). Oligocene species eventually present may not have been recognized.

Whereas marls associated with the conglomerates always revealed a Maastrichtian association, older Mesozoic nannofossils were found in some dark, tectonized shales (Dogger?, Oxfordian?) indistinguishable from wildflysch matrix in the field.

2.4.4 Summary

The wildflysch of the Gurnigel area (map Plate V) is composed of a shaly, intensively sheared matrix surrounding a wide variety of tectonic slices and/or sedimentary olistoliths: Mesozoic rocks of at least Helvetic, Ultrahelvetic and "Subbriançonnais" (Median Prealps) origin, Maastrichtian (Gurnigel related?) conglomerates, crystalline blocks, Gurnigel Flysch, and Tertiary conglomerates, as well as imbricate slices of Subalpine Flysch.

The age of the wildflysch is Priabonian at least, and its formation will be discussed later (5. Origin of the Gurnigel Flysch).

2.5 Stratigraphic correlations and map legend

Figure 3 (p. 15) sums up chronostratigraphic, biostratigraphic and lithostratigraphic units referred to in this text.

Column A: Apparent ages and duration of intervals after CAVELIER & POMEROL (1977). The period of sedimentation of the present Gurnigel Flysch lasted about 66 my to about 46 my (i. e. 20 my or more).

Column B: The *Paleocene/Eocene* limit is not yet universally agreed upon. The present tendancy is to follow the recommendation of the "Colloque sur l'Ilerdien" (Paris, 18th November 1974; 1975), and to include the Ilerdian within the Early Eocene. This limit is the dashed line of Column *B* and *C*. The full line follows a proposition of POMEROL (1977), to enlarge the Ilerdian. It coincides with the base of the *Discoaster multiradiatus* Zone (NP 9) (MARTINI 1971), and has been mostly used in the recent literature on the Gurnigel Flysch: JAN DU CHÊNE et al. (1975), VAN STUIJ-VENBERG et al. (1976), WEIDMANN et al. (1977), and MOREL (1978). On the other hand, VAN STUIJVEN-BERG (1973), and KAPELLOS (1973), following SCHAUB (1951, 1965) considered the Ilerdian as Late Paleocene.

The limit *Early Eocene/Middle Eocene* needs some discussion. Two approaches exist in the literature: one starting from planktonic Foraminifera: apparition of *Hantkenina aragonensis* = Middle Eocene, and the other starting from the definition Lutetian = Middle Eocene, and thus from the content of the Lutetian strata in the Paris basin.

To compare the first apparition of *H. aragonensis* with that of *Nannotetrina fulgens*, the nearest important nannofossil event, the following references may be cited: GARTNER (1971, Blake Plateau), BERGGREN (1972), POMEROL (1973), and CITA (1975, Possagno, with discussion). These authors describe the first appearance of *Nannotetrina* slightly before that of *Hantkenina*. In the Klippen Flysch (Flysch des Préalpes médianes), Dr. Monique Toumarkine and the author (unpublished data) arrived at a similar result.

In the Paris basin (type area of the Lutetian) the nummulite *N. laevigatus* is generally accepted as indicating the base of the Middle Eocene. In the Gurnigel Flysch of the Schwyberg area, KAPELLOS (1973) found that *Nummulites obesus* (time equivalent of *N. laevigatus* in a parallel nummulite lineage) appears slightly after *Nannotetrina*. KAPELLOS & SCHAUB (1974) arrived at similar results in the Campo section, where *N. laevigatus* is present.

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Thus from either definition, the base of the Middle Eocene (Lutetian) lies just above the apparition of *Nannotetrina* (base of NP 15). For practical purposes these limits may be considered to be synchronous.

However, BOUCHÉ (1962), who studied the nannofossils of the Lutetian type area, concluded that it may be attributed to the *Discoaster sublodoensis* Zone (labelled NP 14 by MARTINI 1971). Many authors have followed BOUCHÉ's conclusion, and put the limit somewhere within NP 14, see for instance BERGGREN (1972), POMEROL (1973) and CITA (1975). As I suggested in 1975 (footnote in JAN DU CHÊNE et al.), BOUCHE's interpretation is questionable for several reasons:

1. *D. sublodoensis* is found only very rarely in two samples and is absent in all younger, Middle and Late Eocene samples studied by BOUCHÉ.
2. BOUCHÉ's *Coccolithus*? sp. is in fact *Reticulofenestra dictyoda* (measuring up to 12 μ on BOUCHÉ's pictures) and was equated by a number of authors (e. g. MARTINI 1969) with *Reticulofenestra umbilica*. This species indicates, to my mind, that the nannofossils of the Lutetian type area belong to NP 15, or even "NP 16" as used here.
3. In a shallow continental sea, such as the Lutetian Paris basin, the nannofossil assemble may very well be somewhat endemic (without *Nannotetrina,* and with many specimens of *Braarudosphaera*).
4. *Discoaster sublodoensis* might be reworked.

To sum up, if one equates the three important markers, *Nannotetrina, Hantkenina* and *N. laevigatus,* a simple and coherent picture arises for the base of the Lutetian and the Middle Eocene; this limit has been drawn on Figure 3.

The *Middle Eocene/Late Eocene* limit is drawn after the results of the Possagno studies (CITA 1975, PROTO DECIMA et al. 1975), according to which the lower limit of the Priabonian lies within the upper part of NP 18. This modifies the usual nannofossil tradition which equates the base of NP 18 with the Late Eocene.

Column C: The Danian/Thanetian limit is chosen as the NP 5 datum, which is arbitrary. The Thanetian/Ilerdian limit follows POMEROL's (1977) proposition. The Ilerdian/Cuisian limit is that which is generally accepted; the Cuisian/Lutetian limit and the Lutetian (s. l.)/Priabonian limits are discussed above. The position of the Lattorfian follows CAVELIER's (1972, 1975) suggestions.

Column D: The repartition of the calcareous nannofossils in a number of stratotypes is indicated, as found in the current literature. K. Perch-Nielsen (pers. comm.) suggested continuation of the Danian into NP 4. The position of the "Lutetia" area is modified after BOUCHÉ (1962).

Column E: Calcareous nannofossils after MARTINI (1971), and SISSINGH (1977): however "NP 16" was modified as discussed above.

Column F: Biostratigraphic units and map legend
In order to represent the stratigraphic results on a map (Plate V) the ages found in the Gurnigel Flysch were grouped into six biostratigraphic units:

 – *"Maastrichtian",* defined by Maastrichtian nannofossils.
 – *"Danian",* defined by Earliest Tertiary nannofossils (NP 1 – NP 4).
 – *"Thanetian",* defined by the apparition of *Fasciculithus tympaniformis* (NP 5 – NP 8).
 – *"Ilerdian",* defined by the apparition of *Discoaster multiradiatus* (NP 9 – NP 11).
 – *"Cuisian",* defined by the apparition of *Discoaster lodoensis* (NP 12 – NP 14).
 – *"Lutetian",* defined by the apparition of *Nannotetrina fulgens* (NP 15 – "NP 16").

The biostratigraphic units thus defined coincide with stages, apart from the "Ilerdian"/ "Cuisian" limit chosen here: the lower part of NP 12 is found in the stratotype area of the Ilerdian. All the chosen limits are based on apparition of reliable nannofossil markers.

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For the wildflysch and Subalpine Flysch, a seventh unit, *"Priabonian"*, was defined by the presence of *Dictyococcithes bisectus*.

On a biostratigraphic data map, the dated outcrops are shown as coloured dots; the same biostratigraphic units figure on the "interpreted" geological map (Plate V). The biostratigraphic data map is deposited in the Geological Institute Fribourg.

Column G: Lithostratigraphic units
The lithostratigraphic units are indicated as discussed above (2.3 Lithostratigraphy).

3. Structure

3.1 Introduction

3.1.1 Previous work

Few authors have paid close attention to the internal structure of the Gurnigel nappe, as a precise stratigraphical control was lacking; the sections drawn by GAGNEBIN (1924), GERBER (1925), and TERCIER (1928) do not show much detail.

Although TERCIER (1928, p.55) suggested the presence of two slices in the Hellstätt area, the Hellstätt Series has been drawn on the Gurnigel map sheet (TERCIER & BIERI 1961) as a formation.

Sections through (or touching) the Gurnigel nappe in the study area have been drawn by BIERI (1925), GERBER (1925), BLAU (1966), and SCHMID (1970).

More detailed structural results were obtained following the study of nannofossil stratigraphy: HEKEL (1968b) discovered the presence of several slices in the Selital area, and VAN STUIJVENBERG (1973) showed these to number at least six. KAPELLOS (1973) emphasized the complicated structure of the Seligraben, however on the base of data differing from those presented here. The sections drawn by WINKLER (1977) were also based on biostratigraphic data, as far as the Gurnigel Flysch is concerned.

3.1.2 Method

Continuous observation was generally not possible, as the Gurnigel area is poor in outcrops. This difficulty is partly compensated by the possibility of dating smallest outcrops.

Regional structural trends and architecture have been ascertained by combining dip and strike measurements with the biostratigraphical datations. The results are illustrated by a structural map (Fig. 7) and by sections (Fig. 9), whereas the "Interpreted geological map" (Plate V) shows the combination of the biostratigraphic data, structural data, and other field evidence, e. g. morphology.

3.2 Regional description

3.2.1 Structural elements: thrusts, faults and folds

The identification of structural elements as described below was mainly based on indirect criteria, as outcrop conditions rarely permitted direct identification.

3.2.1.1 *Thrust surfaces and slices*

Any traverse of the Gurnigel nappe in the study area reveals a number of thrust planes subdividing the nappe into a number of slices. These surfaces show a fairly constant strike to the E or NE. Dip values (S or SE) are not easy to estimate, but rarely exceed 45°.

The slices generally show a normal polarity, but an inverted polarity has sometimes been observed. Slices may show the complete stratigraphic profile of the Gurnigel Flysch, but are more frequently incomplete. In the western part of the study area, 5 to 6 slices are developed; they wedge out towards the Seligraben area. In the eastern part, from Gürbetal to Uebeschi, only one or two slices make up the entire Gurnigel Flysch.

3.2.1.2 *Faults*

Two groups of faults may be distinguished: major faults or fault zones and minor faults.

Major faults delimit the different slices laterally; they tend to strike in a N direction (N 15 W, N 10 E, N 40 E), and may be (sub)vertical strike slip faults, more often sinistral than dextral.

Minor faults are numerous. They dictate a certain compartimention within the slices; when N striking and vertical they generally show a sinistral throw; others are E–W striking reverse faults within the slices.

3.2.1.3 *Folds*

Two groups of folds may be distinguished: major folds which involve the slices as a whole, and minor folds involving only a part of a slice.

Major folding is a rather subordinate feature, only evident in the Selital–Schwarzwasser area and the Selibühl–Zigerhubel area.

Minor folds are a frequent feature, particularly in the "Maastrichtian"; the same often holds for the "Eocene" part of the slices.

Two groups of other folds may complicate the picture: *a)* some of the folds in the Eocene strata could be explained as synsedimentary slump features; *b)* important (sub)recent sliding and creep are often localized in tectonically complicated areas; this might erroneously lead to suggest alpine folding in some cases.

3.2.1.4 *Distinguishing faults, thrust surfaces and folds*

A clear distinction between different tectonic styles is not always possible from the available data, as illustrates Figure 6.
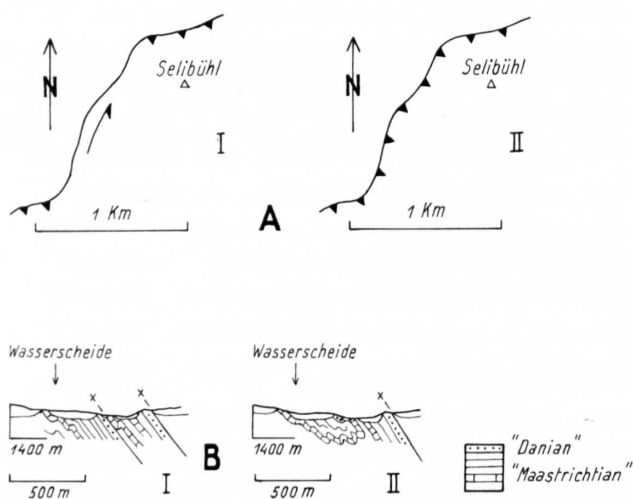
Fig. 6: Examples of different interpretations of the same data. For explanation see text.

Figure 6*A* shows two interpretations of the area SW of Selibühl. (I) is a combination of strike-slip fault and thrusting, and (II) is simple thrusting with an arcuate trace.

Different interpretations are also possible in the Wasserscheide area (Fig. 6*B*): some small isolated Maastrichtian and Danian "outcrops" are visible without lateral continuity. The outcrops are too small to allow polarity control. (I) is an interpretation with a thrust surface separating two slices, and (II) the same as a synclinal fold.

On the maps and on section 3, I have chosen the solution *A*(II) and *B*(I). Alternative solutions would have been possible in other cases as well.

3.2.1.5 *Cleavage*

Cleavage has only been observed in one outcrop, north of the Schüpfenflue.

3.2.2 Description of slices

For practical reasons, the slices are described in a "cylindristic" way, as indicated on Figure 8. This does not necessarily imply, however, the presence of continuous slices, as the following description of slices and faults will show.

I. *"Grätli slice"*

An apparently continuous zone of slices is found along the front of the Median Prealps. It is formed by the youngest Gurnigel Flysch on any traverse. From W to E, the Grätli slice contains:

I*a* Grätli–Wannelsgraben area: normal sequence of (S)E dipping "Cuisian" and "Lutetian" (NP 12 – "NP 16"), locally with minor folding.

I*b* Area E of Stäckhütte: complicated and poorly outcropping area. "Cuisian" is present, probably together with "Lutetian".

I*c* Hengstschlund–Schwefelberg–(Wasserscheide?)–Chueberg–Upper Gürbe valley area: this zone contains a number of outcrops, generally belonging to the "Lutetian" (NP 15, "NP 16"); the Chueberg area, at least, also shows some Cuisian strata. The general polarity is normal, with some minor folding. Outcrops are lacking across fairly wide zones.

I*d* Area N of Langenegg–Grätli: here again Eocene Gurnigel Flysch is present (NP 9 – NP 15), generally in an inverted position. Minor folding is present.

I*e* Uebeschi area (not represented on Fig. 8): in the eastern part of the study area, the outcrop at Uebeschi (Cuisian) can be ascribed to the Grätli slice; the same holds for the nummulite bearing outcrops at "Uesseres Gländ" – Rüdismatt.

I*f* Area S and E of Stäckhütte syncline: the Lutetian outcrops S, SE and E of the Stäckhütte "syncline" (Median Prealps, see maps) may also be ascribed to the Grätli slice.

II. *Selibühl slice*

This second zone of slices shows an extreme lateral variety; stratigraphically, only "Maastrichtian" and "Paleocene" appear to be present.

II*a* Area S of Ladengrat Wildflysch and Marchgrabe area: very few outcrops can be attributed to the Selibühl slice; they are made up of some isolated Maastrichtian and Danian strata (S of Ladengrat), and two outcrops of "Maastrichtian" and "Thanetian" (NP 5) (Marchgrabe). The contact with the Ladengrat Wildflysch and with the Schüpfenflue slice (III) is clear, but the limit
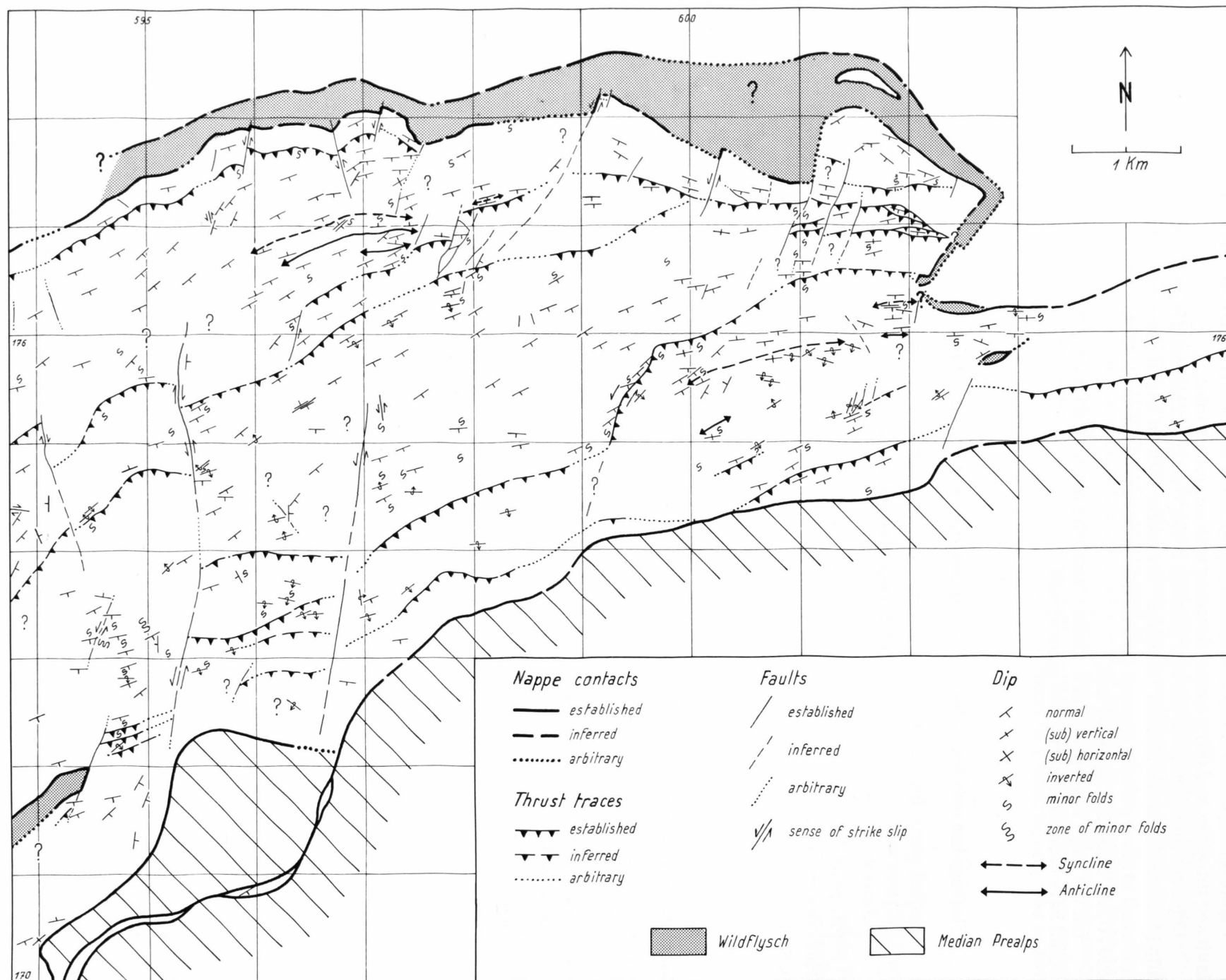
Fig. 7: Structural map of the Gurnigel area.
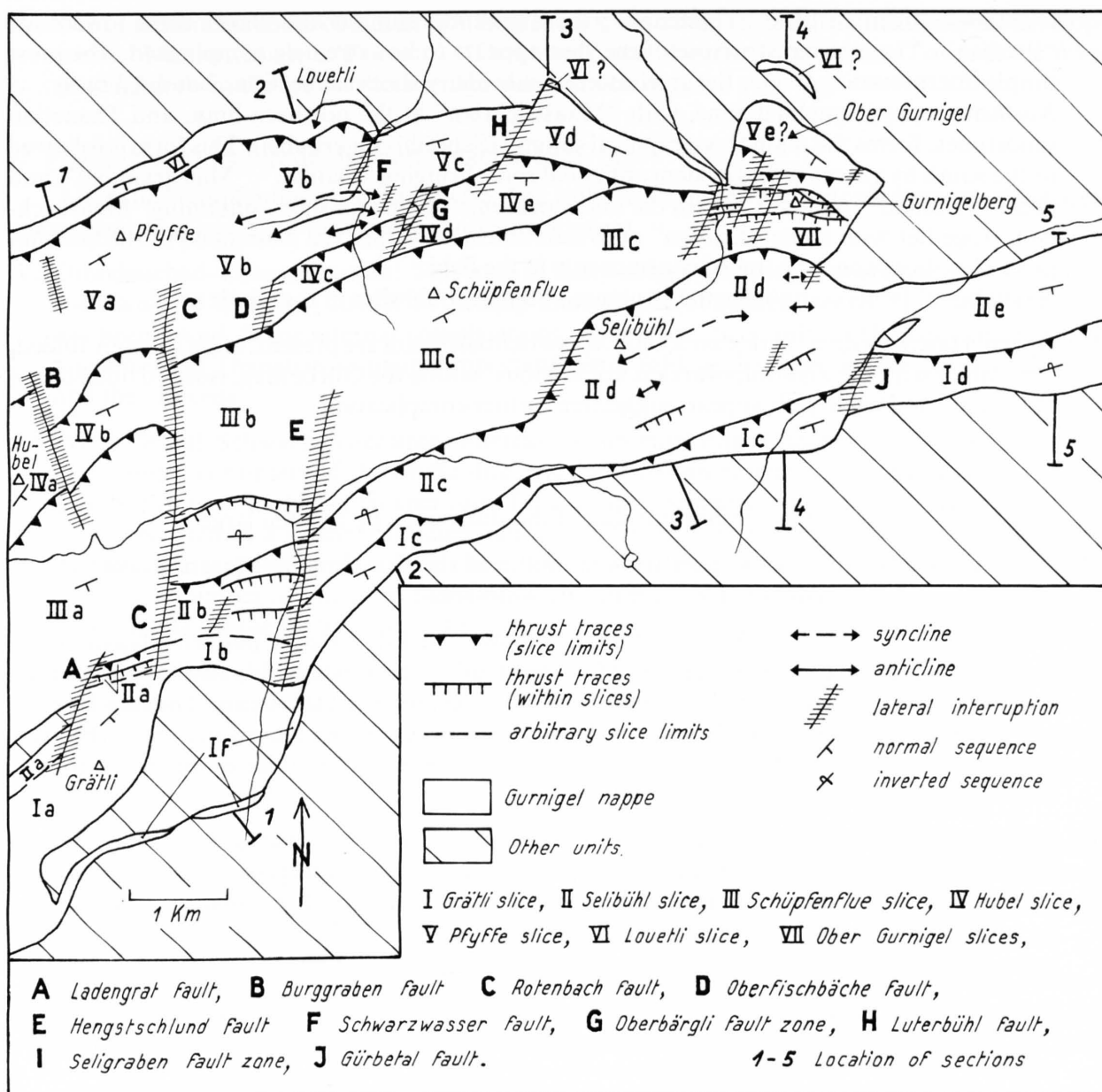
Fig. 8: Location of slices, faults, and sections as described in the text.

with the overlying Grätli slice (I) is not visible: this part of the Selibühl slice might be alternatively interpreted as the tectonically reduced base of the Grätli slice.

IIb Area N and NE of Stäckhütte: a complicated series of minor slices relays the Selibühl slice as far as the Hengstschlund valley. These slices, which contain Maastrichtian, Danian and Thanetian strata, allow more than one interpretation (folds, slices). The limit with the underlying Schüpfenflue slice is evident from nannofossil data, whereas the limit with the overlying Grätli slice has to be inferred through lack of outcrops.

IIc Stierenmoos area: in this area, the slice is made up of "Maastrichtian", "Danian" and "Thanetian"; the entire segment is inverted; intensive minor folding is present.

IId Selibühl–Zigerhubel area: after an important interruption of outcrops due to moraine cover of Sense valley, the Selibühl slice shows its most complete development. The strata contain "Maas-

trichtian", "Danian" and "Thanetian"; the Zigerhubel summit also shows some lowermost "Ilerdian". The internal structure of the slice appears to be extremely complicated. The most simple interpretation divides the area into two subsidiary slices (cf. sections 3 and 4, Fig. 9):
Northern area: a synclinal zone, with "Maastrichtian" at the northern limit, and Thanetian sandstones, forms the main topographical summit (Selibühl–Zigerhubel). This form is followed to the south by a more or less evident anticlinal zone, bringing "Danian", "Maastrichtian", and finally "Danian" to the surface. In the *southern area,* a secondary slice, containing "Maastrichtian" together with some "Danian" at Wasserscheide, overlies the main mass of the Selibühl slice. This slice cannot be traced continuously in the field.
A number of faults complicate the structure of the Selibühl slice in the whole area.

II*e* Gürbe–Hasenegg area: in this area, only Maastrichtian strata are present, often strongly folded. Continuity with the Zigerhubel area is not obvious; within the Gürbe area, isolated outcrops of "Danian", and wildflysch appear, suggesting further complication.

III. *Schüpfenflue slice*

As a whole, this is the most important slice of the study area, up to 2 km large.

III*a* Marchgrabe–Äbegrabe area: polarity is normal, and the slice contains Maastrichtian to Lutetian stages. Faults, folds, and folded zones are widespread.

III*b* Dürretannen area: here the Schüpfenflue slice shows a slightly different pattern. Maastrichtian to Cuisian stages are present, but the "Maastrichtian" is more extensively developed, showing important minor folding; the Dürretannen area is composed of Danian and Thanetian strata, which are partly inverted and N dipping. Lack of outcrops prevents a clear picture of this area. South of the Sense, the Eocene part forms an independent, inverted limb, which is not to be found in either the western or eastern extremities of the slice.

III*c* Schüpfenflue area: here the picture is fairly simple, with a widespread Maastrichtian to Cuisian (NP 12 – ? NP 13) sequence. In the "Maastrichtian", minor folding is present as usual. North of the Sense the "Eocene" sometimes shows minor folding with a southward overturn, which may be explained by creep or slumping. In the Seligraben area, the slice is highly reduced; a few outcrops of "Thanetian" between 1400 and 1450 m might be ascribed to the Schüpfenflue slice.

East of the Seligraben in the Gurnigel area, the Schüpfenflue (III), Hubel (IV), and Pfyffe (V) slices are replaced by a complicated group of minor slices. These will be dealt with separately (V*e* and VII).

IV. *Hubel slices*

Between the major Schüpfenflue (III) and Pfyffe (V) slices, a series of discontinuous, minor slices appears, grouped here as Hubel slices.

IV*a* Hubel area, NW Sangerboden: crossing the limit of the area studied, the Hubel hill is formed by an eastward dipping element, containing "Maastrichtian", "Danian" (?), and "Thanetian". This quasi-transversal slice shows up fairly well in the morphology.

IV*b* Grossottenlüje area: the Hubel slice contains only Maastrichtian, and Danian strata in this area, with ubiquitous minor folding.

IV*c* Süfternen area: after an interruption, the Hubel slice reappears as a minor element, containing some "Maastrichtian", "Danian", and lower "Thanetian".

IV*d* Bärgli slices area: in the area of Oberbärgli, a number of very small slices, containing either "Maastrichtian", or "Thanetian", or "Cuisian", interrupts the Hubel slices.

IV*e* N of Lischboden and S of Luterbühl, the Hubel slices attain their fullest stratigraphic development. "Maastrichtian", "Danian", "Thanetian" and "Eocene" are present. Towards the Wyssenbachgraben, the Hubel slices wedge out completely.

V. *Pfyffe slice* (= Ecaille de Hellstätt, Tercier 1928, p. 55)

After the Schüpfenflue slice, the Pfyffe slice is the most important tectonic element of the area studied, but once again lateral discontinuities are evident.

V*a* Ottenleuebad–Cheeseren area: This area is fairly simple, showing a normal series of "Maastrichtian" to "Cuisian". Just W of the map limit (Fig. 8), at Milkenvorsass, "Lutetian" (NP 15) has been found. Some internal complications are present: two faults at Horbühl interrupt the alignement of Thanetian summits; important minor folding characterizes the "Maastrichtian" and the "Eocene".

V*b* Pfyffe–Selital–Schwarzwasser area: whereas the summital ridge Cheeseren–Pfyffe–Gägger suggests simple continuity of the Pfyffe slice, the deformation pattern south of this chain is completely different: in the Selital area some folds appear, bringing two "Cuisian" zones to the surface, separated by a mainly "Ilerdian" anticline. To the west, these folds disappear, and in the Fischbach area, "Ilerdian" only has been found, overthrust by the Schüpfenflue (III) slice. To the east, a number of folds and faults limit this segment of the Pfyffe slice. N striking sinistral minor faults cut the Pfyffe slice north of the folded area and east of the Schwarzwasser valley.

V*c* Grosslouetli area: here, the Pfyffe slice is reduced to a "Thanetian" and "Eocene" element, not well marked morphologically, which is limited to the west by the Schwarzwasser zone (faults and folds), and to the east by a mainly covered zone which precludes direct connection with the Luterbühl area. The "Eocene" shows minor folding of a different style from the Selital–Schwarzwasser folds.

V*d* Luterbühl–Seligraben area: in this area, the Pfyffe slice appears to have been rotated slightly: the normal series dip SSW. "Maastrichtian" to lower "Cuisian" (NP 12) are present. There are 3 or 4 faults, which cause a marked block pattern within the slice; not all limbs show the complete Maastrichtian to Cuisian series visible at Luterbühl.

V*e* Ober Gurnigel area: the most northerly element of the Gurnigelberg slices has no direct connection with the Luterbühl area. However, this flat SW-dipping element may be compared with the Pfyffe slice, suggesting a sinistral displacement greater than 500 m.

VI. *Louetli slice* (= Ecaille de la Gebrannte Egg, Tercier 1928, p. 51)

This is a fairly continuous feature generally consisting of Thanetian sandstones, locally with some "Danian" and "Ilerdian". A number of minor sinistral faults interrupt the slice.

In a way, the small outcrop N of P. 1265 (N Luterbühl), and the isolated slice E of the Stockhütte might be regarded as minor equivalent of the Louetli slice.

VII. *Gurnigelberg slices zone*

In the area between Seligraben and the eastern limit of the Gurnigel Flysch, a mosaic of minor, stratigraphically incomplete slices, often limited by folds and faults appears. Attribution to the Schüpfenflue (III), or Hubel (IV) slices is impossible. The northernmost Ober Gurnigel area, however, might be related to the Pfyffe (V) slice.

3.2.3 Description of major faults (Fig. 7 and 8)

Presence of major faulting is deduced more from lack of continuity, and independence of deformational style in adjacent compartments than from direct evidences.

A. The Ladengrat fault limits the internal wildflysch zone, and displaces the Grätli slice with a left-lateral throw.

B. The Burggraben fault separates the elements IV*a* and IV*b* of the Hubel slices by dextral displacement, and also implicates the Pfyffe slice (V*a*).

C. The Rotenbach fault is an important strike slip fault, affecting five slices. The segments I*a*, II*a* and III*a* of the Grätli, Selibühl and Schüpfenflue slices each are different from the I*b*, II*b* and III*c* segments. The segment IV*b* of the Hubel slices is cut off, and the southern part of the Pfyffe slice shows different contents in the segments V*a* and V*b*. The southern part of the Rotenbach fault has a sinistral throw, but the northernmost part is apparently dextral.

D. The Oberfischbäche fault cuts off the western part of segment IV*c* of the Hubel slices.

E. The Hengstschlund fault is an important strike slip fault, separating different segments of three slices: I*b* and I*c* of the Grätli slice, II*b* and II*c* of the Selibühl slice, and III*b* and III*c* of the Schüpfenflue slice where 500 m of sinistral movement can be deduced.

F. The Schwarzwasser fault limits the Louetli slice (VI), and separates the segments V*b* and V*e* of the Pfyffe slice.

G. The Oberbärgli fault zone delimits a series of minor slices (IV*d*), separating the segments IV*c* and IV*e* of the Hubel slices. These faults lie in the continuation of the Hengstschlund fault.

H. The Luterbühl fault separates the segments V*c* and V*d* of the Pfyffe slice.

I. The Seligraben fault zone is formed by a number of faults, giving rise to a series of minor slices. The Schüpfenflue slice is cut off, the Pfyffe slice may be left-laterally displaced up to 1 km.

J. The Gürbetal fault separates two different segments I*c* and I*d* of the Grätli slices, and might be related to the presence of wildflysch in the Gürbe valley, between segments II*d* and II*e* of Selibühl slices. Other slices are lacking on this traverse.

3.2.4 Comments on the sections (Fig. 9)

Section 1, Ottenleuebad–Stäckhüttenghürn: a complete sequence, with slices I–IV and the outcrops S of the Stäckhütte "syncline". The Selibühl slice (II) is reduced. The Schüpfenflue (III) shows the internal complication of the Eocene part as mentioned; the Hubel slice (IV) is exaggerated by rather oblique projection.

Section 2, Schwarzenbühl–Schwefelbergbad: the complete suite of six slices. The Selibühl slice (II) is completely inverted, the Schüpfenflue slice (III) shows some folds with southern overturn (possibly due to superficial creep or slumping). The folds of the Selital area are visible in the Pfyffe slice (V).

Section 3, the Grätli slice (I) (much reduced), the Selibühl slice (II) (well developed but internally complicated), the Schüpfenflue slice (III) (complete and normal), the Hubel slice (IV) (developed to maximum) and the Pfyffe slice (V) (fairly complete). A possible equivalent of the Louetli slice (VI) has been shown.

Section 4, Ober Gurnigel–Gürbe: the most complicated section, leaving much room for different interpretations. This section is drawn with the idea of at least partial tectonical continuity of underlying Subalpine Flysch (Goldegg Sandstone and Jordisboden Marls), and overlying wild-

SECTIONS THROUGH THE EASTERN
PART OF THE GURNIGEL NAPPE
by Jan van Stuijvenberg
1978

Klippen nappe (Préalpes médianes)
"Dogger"   ×× Nappe contacts
"Lias"   × Slice contacts
"Trias"

I Grätli slice, II Selibühl slice,
III Schüpfenflue slice,
IV Hubel slice, V Pfyffe slice
VI Louetli slice, VII Ober Gurnigel
                      slices

Gurnigel nappe
"Eocene"
"Thanetian"
"Danian"
"Maastrichtian"

Change of direction

Wildflysch
(Priabonian-(?) Oligocene)

Subalpine Flysch
Jordisboden Marls, Goldegg Sandstone
(Lattorfian-Rupelian)

Subalpine Molasse
Seftigschwand Fm (Aquitanian)
Rossboden Fm (Chattian)
Wolfsegg Fm (Rupelian)

LOCATION
OF SECTIONS

With data from BLAU (1964),
GERBER (1925), SCHMID (1970),
TERCIER & BIERI (1961),
and WINKLER (1977)

Fig. 9: Sections through the Gurnigel nappe.

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flysch–Gurnigel Flysch. The Grätli slice (I) and Selibühl slice (II), comparable with section 3, are visible as well as the highly imbricated Gurnigelberg slices zone (VII). The Ober Gurnigel may be comparable with the Pfyffe slice (V) and the isolated Gurnigel Flysch segment in front with the Louetli slice (VI).

Section 5, Gürbe–Langeneggrätli only shows the Grätli slice (I) (inverted) and the Selibühl slice (II) (widespread but poorly outcropping).

3.3 Interpretation

The interpretation discussed here, is strongly influenced by the ideas of PLANCHEREL (1976, 1979), who studied the structures of the Median Prealps and adjoining zones on a regional scale.

3.3.1 Younger deformations

Slices

As seen above, the main characteristic of the structure described is the presence of imbricated slices. Their genesis may be explained by underthrusting of the Gurnigel nappe below the Median Prealps, as illustrated in Figure 10.

During an earlier stage (as far as the Gurnigel nappe is concerned), the Grätli slice (I) may have been thrust under the front of the Median Prealps. In the next stage, the thrust surface shifted ahead, accreting the Grätli slice to the overthrusting mass of the Median Prealps; the Selibühl slice (II) was then underthrust ("overridden"). The process continued, creating further slices in the Gurnigel
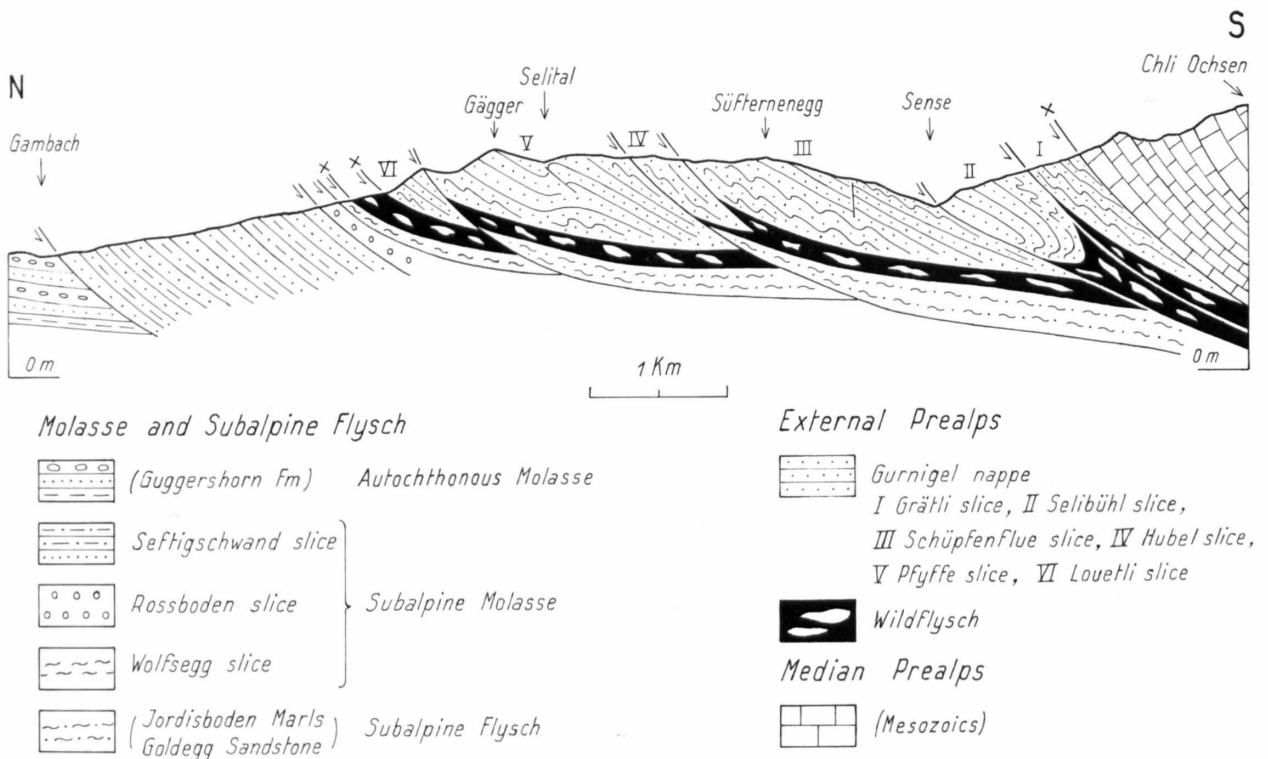
Fig. 10: Interpretation of structural section resulting from crustal subduction.

nappe, and then in the Molasse, until finally the Gibelegg slice was formed. Sedimentation of part of the Molasse may have been synchronous with the slice formation. The imbricated thrust slices may thus be explained by crustal subduction (TRÜMPY 1975). A shortening of 20–40% has been drawn on Figure 10.

Wrench faults

A further characteristic of the study area is the presence of strike slip (wrench) faults. They are generally N–S striking (N 10° E, Rhine Graben direction) with left-lateral throw. Independent deformation of the imbricated slices has taken place on either side of the important wrench faults. This implies that these wrench faults are essentially contemporaneous with the formation of the slices: older faults would have been deformed by thrusting, whereas younger faults would displace more or less equally deformed segments. The wrench faults may be superficial expression of deep wrench zones.

Eastern area

The eastern part of the study area (Gürbe valley – Uebeschi–(?) Lake Thun) is characterized by an extreme surface reduction of the Gurnigel nappe. Underthrusting apparently dominated the deformation here, as opposed to wrenching.
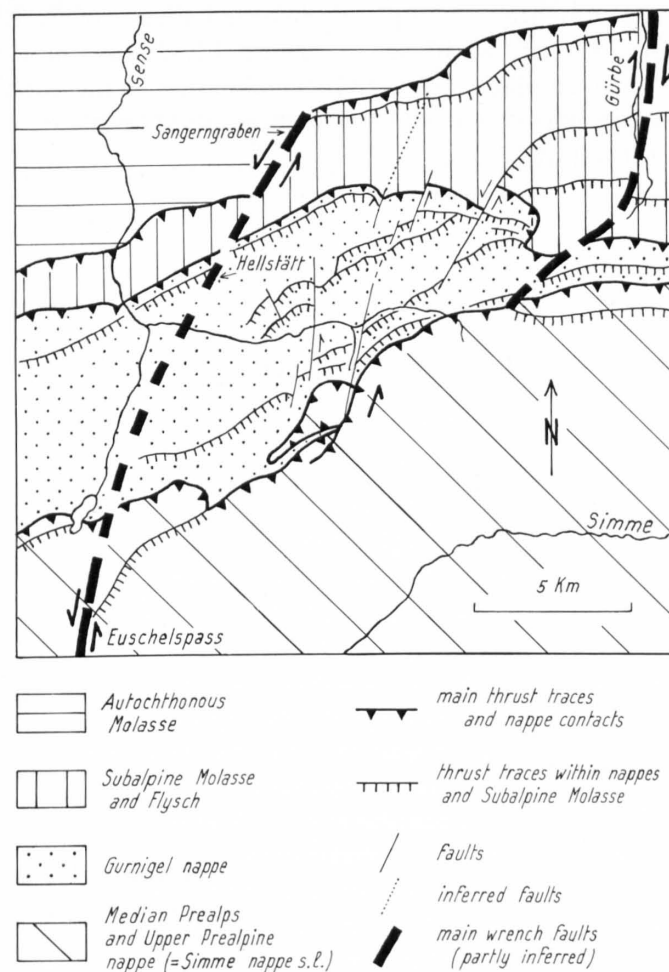
Fig. 11: Map interpretation of the structure of the study area being a relay between two major wrench faults. Inspired by PLANCHEREL (1979).

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The western part of the study area shows a complicated mosaic of slices and faults. As suggested on Figure 11 (mainly after PLANCHEREL 1979), this mosaic may be explained as a relay between two important wrench zones: the Gürbe line (inferred after PAVONI 1977) to the NE, and the Euschelspass (– ? Hellstätt – ? Sangerngraben) fault zone in the SW. Within this relay, both underthrusting and wrenching have taken place.

Age of deformation

The age of the younger deformations is difficult to establish. They may have started by the end of the Oligocene, or more likely during the Miocene. As the Gibelegg slice built up of upper Miocene rocks is involved, they have certainly continued during the Mio-Pliocene, if not until quite recently.

3.3.2 Older deformations

The Gurnigel Flysch is of internal alpine origin. Important movement has therefore taken place between the close of sedimentation, and the younger deformations which took place at the front of the alpine chain. The formation of the wildflysch can be related to this probably Priabonian–Oligocene phase. It is difficult to attribute structural properties of the actual Gurnigel nappe to the older deformation. The presence of two main slices (Schüpfenflue and Pfyffe), might be due to arrival as two main masses. Does the presence of completely inverted slices suggest older large scale folds? Does the relation Subalpine Flysch – wildflysch – Gurnigel Flysch (as found in the Gurnigel area), suggest an early arrival ("mise en place") of the Gurnigel nappe on the Subalpine Flysch? Further analysis of the Gurnigel nappe may reveal which structures might be inherited, and which structures are due to the younger deformations alone.

4. Sedimentology

4.1 Introduction

4.1.1 Previous work

TERCIER's 1948 paper may be considered as the first "modern" publication on the sedimentation of the Gurnigel Flysch. He suggested the deep-water character of flysch sedimentation in general, influenced by his experience in the Indonesian Archipelago.

KUENEN & CAROZZI (1953) and CROWELL (1955) recognized the Gurnigel Flysch as an accumulation of turbidites.

CROWELL's (1955) paleocurrent measurements (flute-casts and other directional properties) were made partly in the Gurnigel area. These implied that the Gurnigel Flysch had been accumulated from the NW, with clastics derived from a crystalline swell. CROWELL suggested the presence of a canyon – deep-sea fan system (1955, p. 1370) – to explain the scattering flute-cast directions.

BROUWER (1965) described a rich association of agglutinated benthonic Foraminifera in the shales of the Gurnigel Flysch (the *Rhabdammina* fauna) and he emphasized its deep-water character. Similar results were obtained by WEIDMANN (1967).

HUBERT (1967) studied the petrography of the Gurnigel Flysch and distinguished green hemipelagic shales from grey turbiditic shales.

SCHÜPBACH & MOREL (1974) explained the sedimentation of the Gurnigel and Schlieren Flysch by progradation of a single fan from the Voirons area (proximal) to the Schlieren Flysch area (distal).

4.1.2 Modern trends in sedimentology of turbidite facies

Over the last few years, considerable progress in description and understanding of turbidite sequences has been achieved in three ways: theoritical and experimental study of depositional mechanisms, recognition and definition of different facies and facies associations, close study of present day deep-sea fans.

4.1.2.1 *Depositional mechanisms*

MIDDLETON & HAMPTON (1973) summarized four possible depositional mechanisms of sediment gravity flows ("turbidites s.l."): turbidity currents, fluidized sediment flows, grain flows and debris flows.

In the case of the Gurnigel Flysch, turbidity currents are the most important of these sediment gravity flow mechanisms. It is more difficult to imagine that each of the latter three mechanisms could have made a major contribution to the sedimentation.

Some criticism and precisions concerning fluidized flows, grain flows, and debris flows have since been enounced (LOWE 1976 *a, b;* HAMPTON 1975; ENOS 1977). It is likely that combinations of mechanisms should appear. To cite MIDDLETON & HAMPTON (1973, p. 30):

"It might be expected, in other words, that most sediment gravity flows would be of two main types: (i) highly concentrated flows, where sediment is supported by a range of different mechanisms, including turbulence, and (ii) relatively low concentration flows, with sediment supported by turbulence (turbidity currents). The density of the highly concentrated flows might be expected to be only slightly less than those of unconsolidated sediment (perhaps 1.5 to 2.4 gm/cc), whereas the density of the relatively low concentration turbidity currents might be expected to be in the ranges 1.03–1.2 gm/cc."

This two-fold subdivision is reminiscent of an older subdivision based on rock sequences: turbidites and fluxoturbidites (DZULYNSKI, KSIASKIEWICZ & KUENEN 1959).

4.1.2.2 *Facies subdivision*

MUTTI & RICCI LUCCHI (1972, 1975) gave a subdivision of "turbidite facies", mainly based on field observations in the Apennines, and the Southern Pyrenees.

Facies A is characterized by very thick, and very coarse beds. Two subfacies may be distinguished: facies A_1 with "organized" conglomerates, pebbly sandstones, and very coarse to coarse sandstones, and facies A_2 with "disorganized" conglomerates, and pebbly mudstones, measuring 0.5–15 m. Depositional mechanisms would be grain flows, high density turbulent flows, and sandy debris flows.

Facies B includes thick, medium to coarse sandstones, with plane laminae throughout the bed. Thicker beds (30–200 cm) are named B_1, thinner beds (20–80 cm) B_2. Depositional mechanisms would be fluidized flows, high density turbulent flows (B_1), or highly concentrated, overloaded dispersions, leaving behind a tractional lag deposit (by-passing) (B_2).

Facies C comprises the complete classical ("Bouma-cycle") turbidites, that is, with T_a division. C_1: coarse to fine sandstones, with poor sorting. C_2: medium to fine sandstones, with moderate to poor sorting. Turbidity currents are thought to be the depositional mechanism.

Facies D comprises incomplete classical ("Bouma-cycle") turbidites, that is, without the basal T_a subdivision. Three subfacies, D_1, D_2 and D_3 are distinguished by their sand/shale ratio: D_1 (sand/shale high, > 1), D_2 (low to very low, < 1), and D_3 (nil). Turbidity currents are considered to be the depositional mechanism.
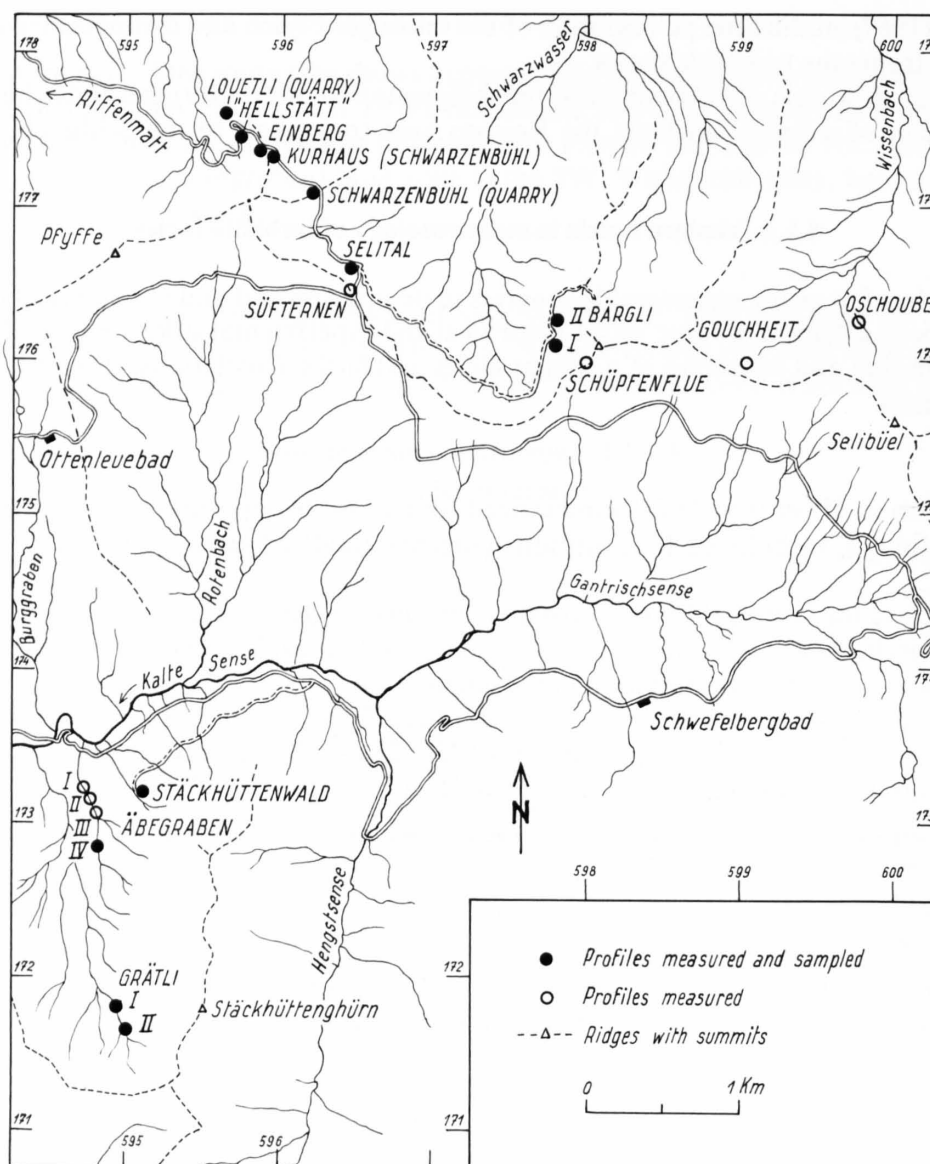
Fig. 12: Location of measured profiles.

Facies E are thin-bedded (3–20 cm), coarse grained beds, with high sand/shale ratio, irregular bed geometry, frequent sharp tops, and high-angle cross-laminae. Facies E are thought to be lag deposits of by-passing high concentration flows, and are thus related to facies *B*.

Facies F includes all chaotic deposits due to slumping s.l. A transition to facies A_2 is possible.

Facies G represents the normal, basinal ("hemipelagic") deposits, interbedded with "turbidites". Settling from surface waters or from nepheloid layers is considered to be the depositional mechanism.

4.1.2.3 *Deep-sea fans*

An organisation of turbiditic sediments in deep-sea fans has been described both from ancient deposits (MUTTI & RICCI LUCCHI 1972, KRUIT et al. 1972, RICCI LUCCHI 1975, MUTTI 1977), and from recent sediments (HANER 1971, NELSON & KULM 1973). In spite of different approaches and

study of different basins, the resultant models are reasonably similar. Two areas may be recognized within a deep-sea fan:

  a) a mainly distributary, channelized *Inner Fan;*
  b) a mainly depositary, non-channelized *Outer Fan.*

Within the *Inner Fan,* channel-fill and overbank sediments are found. With certain restrictions (RICCI LUCCHI 1975, MARTINI & SAGRI 1977) channels tend to be characterized by so called positive, fining- and thinning-up cycles. A more detailed study reveals the presence of channel axis facies, channel margin facies, levee facies and inter-channel facies (MUTTI 1977). At the mouth of a channel, a channel mouth bar may be built up. The lower part of the channellized inner fan may be called middle fan; it shows a larger number of smaller channels. The *Outer Fan* is the area where sedimentation is more important than sediment transport and distribution. The sedimentation is characterized by a number of depositional, prograding sandstone lobes, showing so called negative, thickening- and coarsening-up cycles. Between the lobes, areas with finer grained and thinner beds (lobe fringes) may be found. *Basin Plain* deposits are characterized by an association of "distal" turbidites, and hemipelagic interbeds. Theoretically no trends should be observed.

4.2 Field observations

4.2.1 General description of rock types

As mentioned in the paragraph on Lithostratigraphy (2.3), four rock types build up the series of the Gurnigel Flysch: shales, sandstones, conglomerates and limestones.

Sandstones: STUDER's (1825) definition of the Gurnigel Sandstone took only this rock type into account, but it may represent some 40–50% of the Gurnigel Flysch. These are hard, well cemented, carbonate-rich, blue to grey, brown weathering sandstones, well bedded, with sharp lower, sometimes sharp upper surfaces. The lower surfaces often show sole marks: flute casts, trace fossils,

		Selital area	Schüpfenflue area	Äbengraben area
LUTETIAN	NP 15			I II
				Grätli
	NP 14			I IV I I
CUISIAN	NP 13	I Süfternen		
	NP 12			I III I Stäckhüttenwald
	NP 11		I Gouchheit	I II Äbegraben
ILERDIAN	NP 10			I I
	NP 9	I Selital	Oschoube	
	NP 8	Schwarzenbühl		
	NP 7			
THANETIAN	NP 6	Louetli		
	NP 5		I Schüpfenflue	
	NP 4	I Kurhaus		
	NP 3			
DANIAN	NP 2	I Einberg		
	NP 1			
MAASTRICHTIAN		I "Hellstätt"	I Bärgli I	
			I Bärgli II	

Fig. 13: Stratigraphic position of measured profiles.

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
I	Bed numbers, samples
23	bed number (corresponds to sample number)
●	heavy mineral sample
○	shale sample : clay minerals and nannofossils
✳	nannofossil sample
T	poorly visible

II	Lithology
	conglomerate
	sandstone
	grey shale
	green shale
	limestone
	alternation of shales and minor sandstones ("minor" depends on scale)
●●	clay chips
~~	erosive surface
⊠	covered

III	Structure, grain size
	no structure visible, massive
	parallel lamination
	wavy bedding
	ripples (C,D beds)
	ripples (E beds)
	cross bedding (A beds)
◡◡	dish structures
	ball structures

	reworked Gurnigel sandstone
Ω	convolute bedding
⌐ᴗ	load cast
	flute cast
Sand	Wentworth scale

IV	Interpretation of beds
E A,B,F C,D G	facies subdivision of MUTTI & RICCI LUCCHI (1975)
b.g.	"background noise" : alternation of D and G

V	Further observations
	folds, tectonisation
	fault
x——x	continuation of profile in other compartment of outcrop
✳ NP9	nannofossil dating
290 gr 110	groove cast direction
135	flute cast direction
	abundant burrows (s.l.)
—ⵁ	separation by plant fragments layer

VI	Interpretation of environment
	thickening up sequence (lobe)
	thinning up sequence (channel fill)
	channelized bed

Fig. 14: Legend of sedimentological profiles.

groove casts, prod casts and load casts. They are sometimes pebbly and measure between 0.5 cm and 500 cm, mostly between 5 cm and 50 cm. Internal structures are parallel lamination, small ripples, convolute bedding, and grading. Components are quartz, pink and white feldspars, various litho-clasts, glauconite, mica, bioclasts (numerous nummulites, algae, bryozoans), frequent coal fragments. The bulk of the sandstones may have been deposited by classical ("Bouma type") turbidity currents.

Conglomerates are relatively rare (up to 5%); most of them are pebbly sandstone. They are often massive, may show some ball structures, clay chip levels, cross-bedding or grading.

Shales form the most frequent rocks: up to 50%. They can be subdivided into several types:

– Grey shales are the most common, and show a wide variety of grey, brown, pink or white weathering types; carbonate content varies between 0 and 50%. They sometimes show parallel lamination, and may be deposited from turbidity currents. Fucoid burrowing is frequent.

– Green shales are fairly rare (10% of the shales); they are always found at the top of, or just

below, a Bouma-cycle. They have a very low carbonate content (usually nil), show abundant Fucoid burrows, and appear to be the basinal, hemipelagic sediment.

Limestones are extremely rare. A hard, micritic, bluish-white limestone with a characteristic fine fissure pattern occurs in the Hellstätt Series. Fucoids are present and some lamination or grading may be observed. They are probably turbiditic. In one Eocene profile (Gouchheit), a beige-brown turbiditic limestone has been observed.

4.2.2 Description of profiles

The location of the 19 measured profiles is shown on Figure 12; their stratigraphic position on Figure 13, and their legend on Figure 14. The profiles belong to three groups:

1. *Selital area:* These profiles belong to the Louetli and Selital slices; they may represent the more proximal facies in the Gurnigel area.
2. *Schüpfenflue area:* These profiles belong to the eastern part of the Schüpfenflue slice; they may represent intermediate facies.
3. *Äbegraben area:* These profiles belong to the western part of the Schüpfenflue slice, and the Grätli slice. They may represent the more distal facies.

Figure 51 (p. 65) gives composite profiles of the three areas.

4.2.2.1 *Profiles from the Selital area* (Fig. 15–30)

"Hellstätt" lies in the structural continuation of the type locality of the Hellstätt Series, at the base of the Pfyffe slice. The profile shows a sequence of marly shales, some sandstones, and one typical limestone (bed 8), without a sequential order. It may well represent a basin plain environment (Fig. 4, photo; Fig. 16, profile; Fig. 18, detailed profile). In this profile, Bouma-cycles include T_d division (often visible in the basin plain sequences). Elsewhere (lobes, channelized) T_d is often lacking. The explanation of the T_d division in terms of flow regime is difficult (BLATT et al. 1972, p. 123). The relation T_d division – basin plain might give a solution: the waning turbidity current has to deposit its silt and mud load where no surface inclination remains.

Einberg was measured along a forest road to the Einberg hut. It also shows a basin plain association, with more frequent sandstones, and C turbidites. The dark grey shales and carbonate-free green shales sometimes show a green transitional layer (e. g. bed 10). The profile is shown on Figures 15 and 19 (detailed), and shows the only Danian flute casts with an E to W paleocurrent direction (dip corrected).

Kurhaus is a fairly poor road outcrop just N of the Schwarzenbühl Kurhaus. The profile shows a progradational trend, coming just after the Einberg basin plain profile (Fig. 17). In the field, the presence of one main progradational cycle is fairly evident.

Louetli is one of the most complete profiles, situated in an abondonned quarry (Fig. 20, 21, 22 and 23). The lower part of the profile (Fig. 22, column *A*) has the same stratigraphic position as the Einberg and Kurhaus profiles (see Fig. 13); this part is shown at a larger scale. The Louetli profile provides an instructive sequence: basin plain at the base, a progradational succession (20–50 m), and a channelized interval. The latter interval shows a number of positive sequences (channel fills), and some interchannel areas. The shales are mostly carbonate-free. Some beds (51, 52) show minor slumping, which might indicate levees.

Schwarzenbühl is an abandonned quarry (being progressively hidden by growing vegetation). There is a two-fold division of the profile: the lower 13 m are sandstone dominated, the upper 3 m (and more, now covered) are shale dominated. The sandstone dominated part of the profile may be interpreted as channelized, but without obvious trends. Levees or "proximal" overbank facies may be present. The prominent bed 31 is clearly channelized cutting the underlying beds 28, 29 and 30.
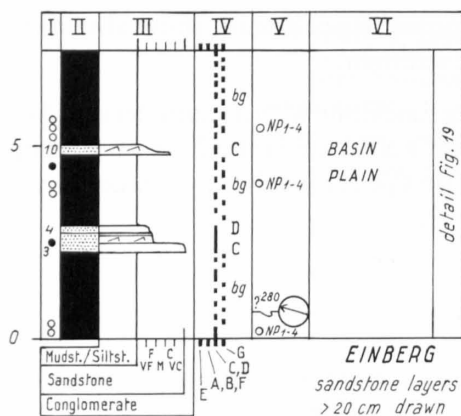
Fig. 15: Einberg profile.
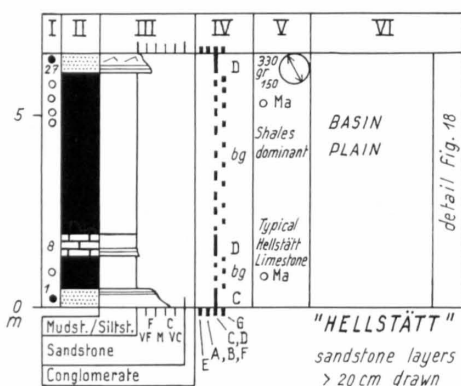
Fig. 16: "Hellstätt" profile.
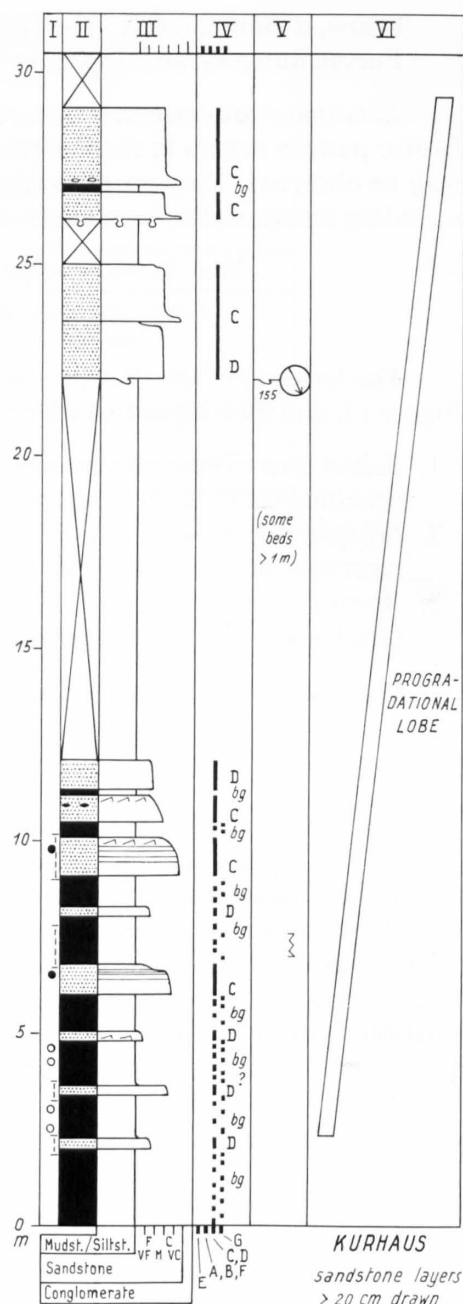
Fig. 17: Kurhaus profile. →

These three beds may represent an "overbank–interchannel progradation", and thus foreshadow the arrival of the channel. The upper 3 m are shale dominated, but some poorly visible conglomerate beds indicate continuation of a channeled environment. The green shales of the Schwarzenbühl profile contain some carbonate. The profile is shown on Figures 24, 25 and 26.

Selital is a poorly outcropping longer road outcrop, locally completely covered. The lower part of the profile shows a series of probable channels (up to bed 13), separated by covered interchannel (?) facies. The upper part of the profile shows a regular, rather monotonous succession of sandstones and shales, with many D and G, and some C beds. It is difficult to interpret the upper part of the profile as the continuation of a prograding fan. The profile is drawn on Figure 27, with a detail from the upper part on Figure 29. Reworked Gurnigel Sandstone can be observed in bed 5; one lump shows soft sediment deformation (Fig. 28). The poorly visible structure between beds 28 and 29 could be explained by slumping or by flexure.
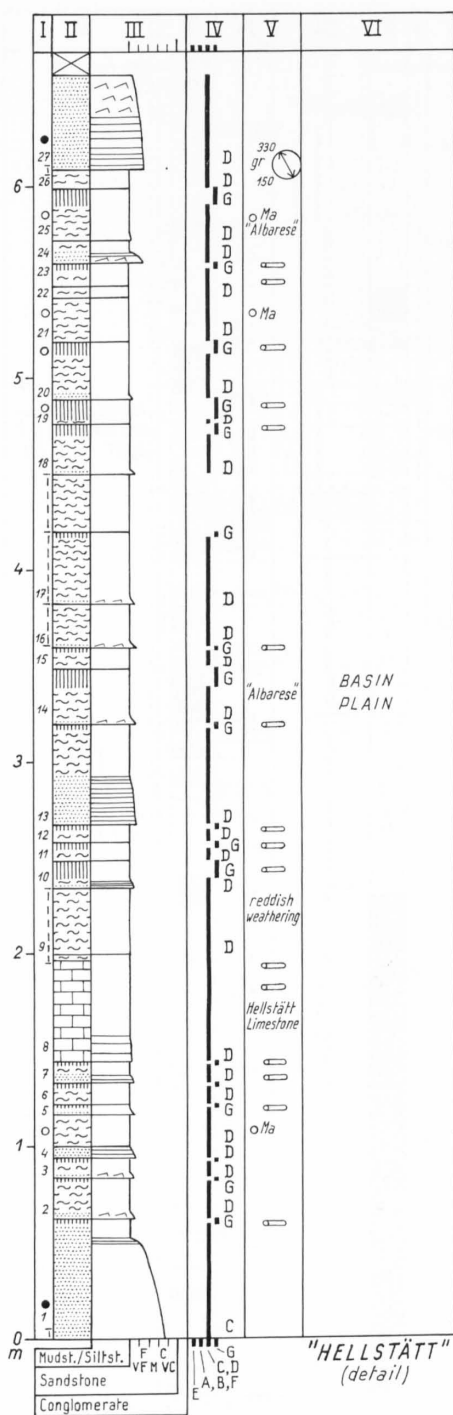
Fig. 18: "Hellstätt", detailed profile.
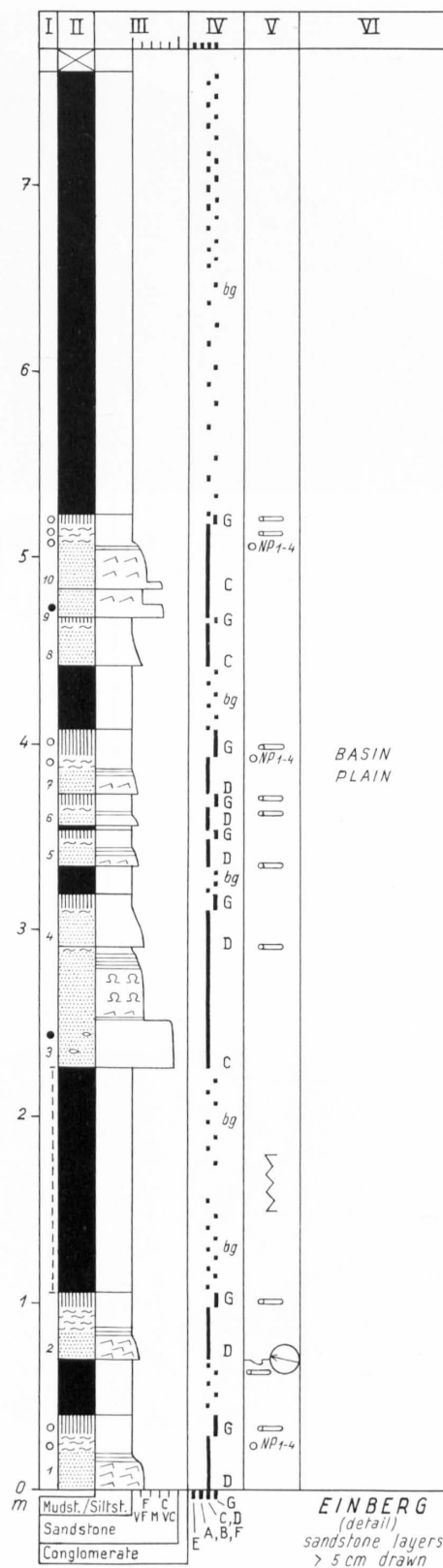
Fig. 19: Einberg, detailed profile.
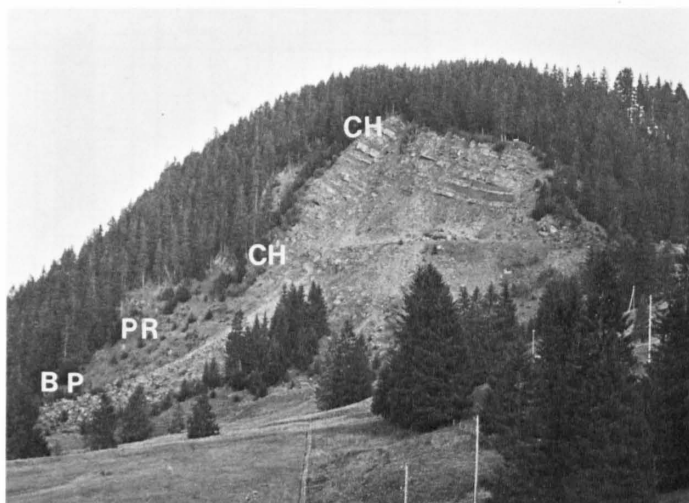
Fig. 20: Louetli quarry. The profile measures 150 m. *BP* = Basin plain, *PR* = Progradational lobes, *CH* = Channelized sequence. "Danian" and "Thanetian".

Fig. 21: Louetli profile. Sandstone bed 42 is eroded by conglomeratic bed 43. Bed numbers correspond to Figure 23. "Thanetian".
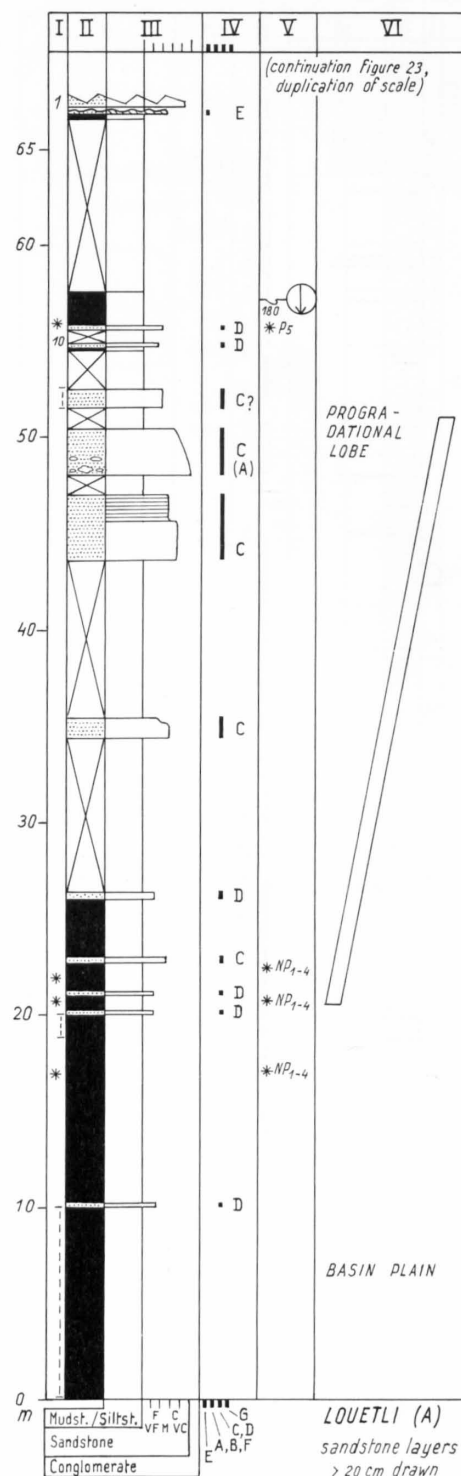
Fig. 22: Louetli profile (*A*) (scale half of normal).

Fig. 23: Louetli profile (*B* and *C*). →

50

LOUETLI (B)
sandstone layers
> 20 cm drawn

LOUETLI (C)
sandstone layers
> 20 cm drawn

51
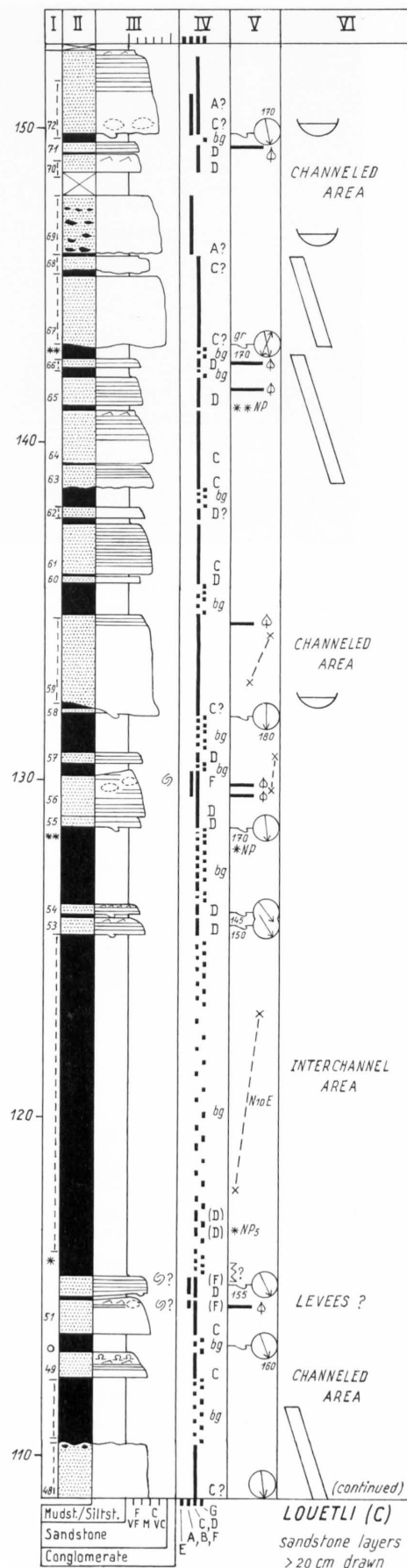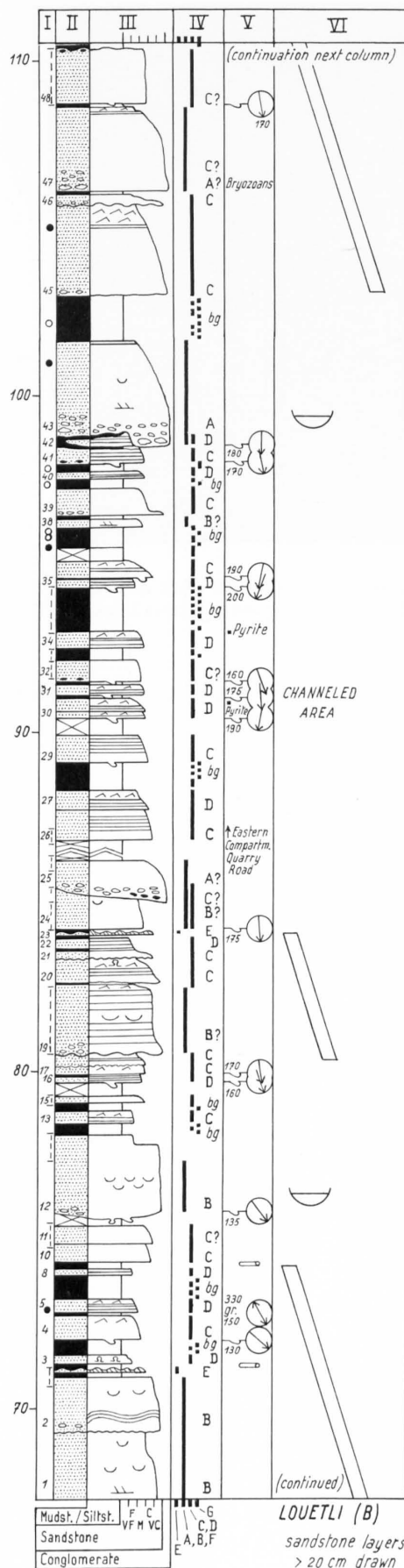
Fig. 24: Schwarzenbühl quarry. Up to bed 31 sandstone dominated, after that shale dominated. Bed 31, with ball structures, cuts off underlying beds. Bed numbers correspond to Figures 25 and 26. Lower "Ilerdian".
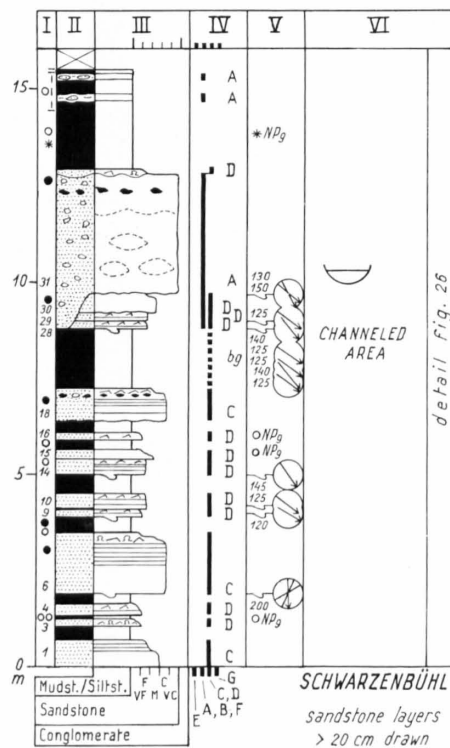
Fig. 25: Schwarzenbühl profile.
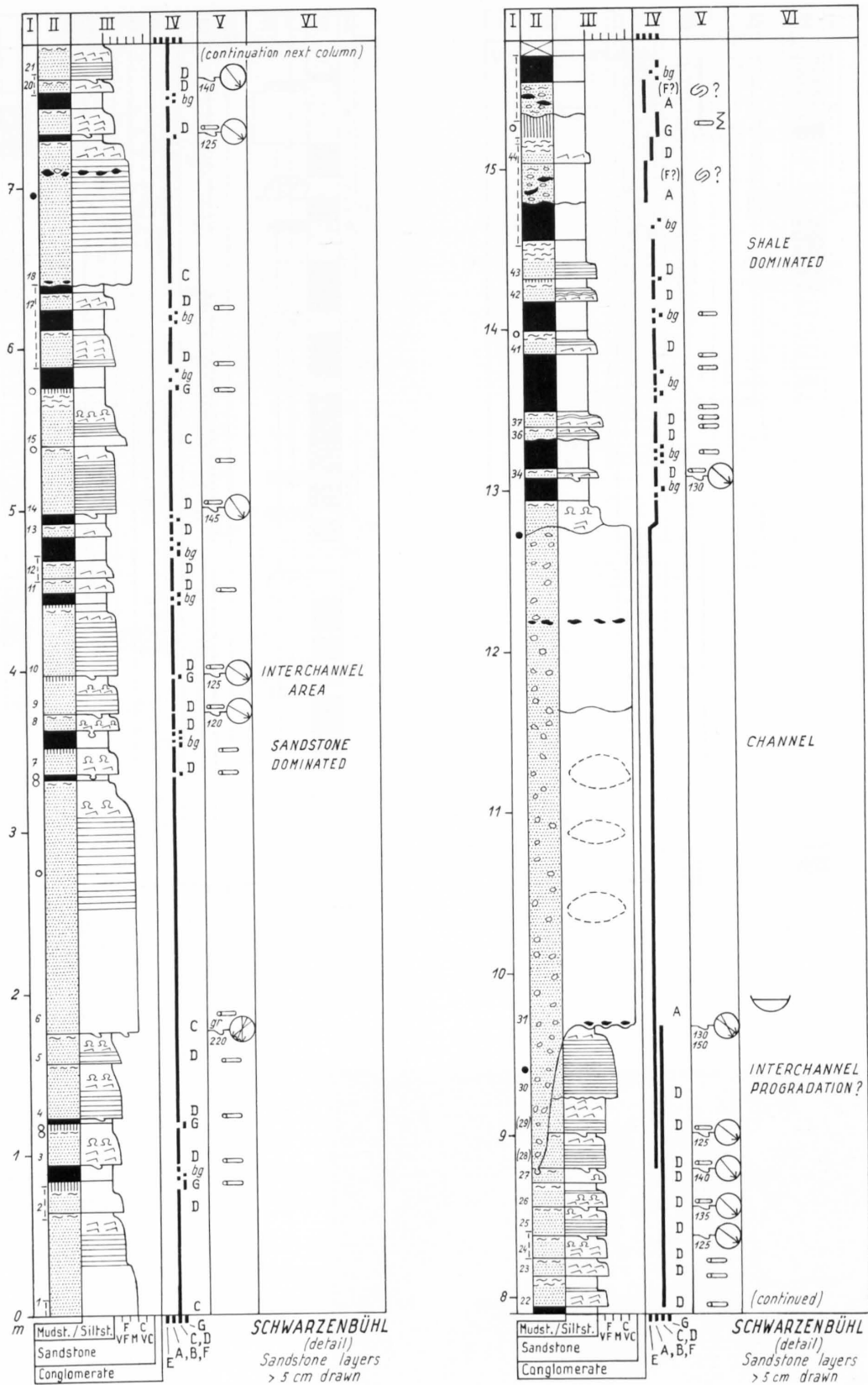
Fig. 26: Schwarzenbühl, detailed profile.
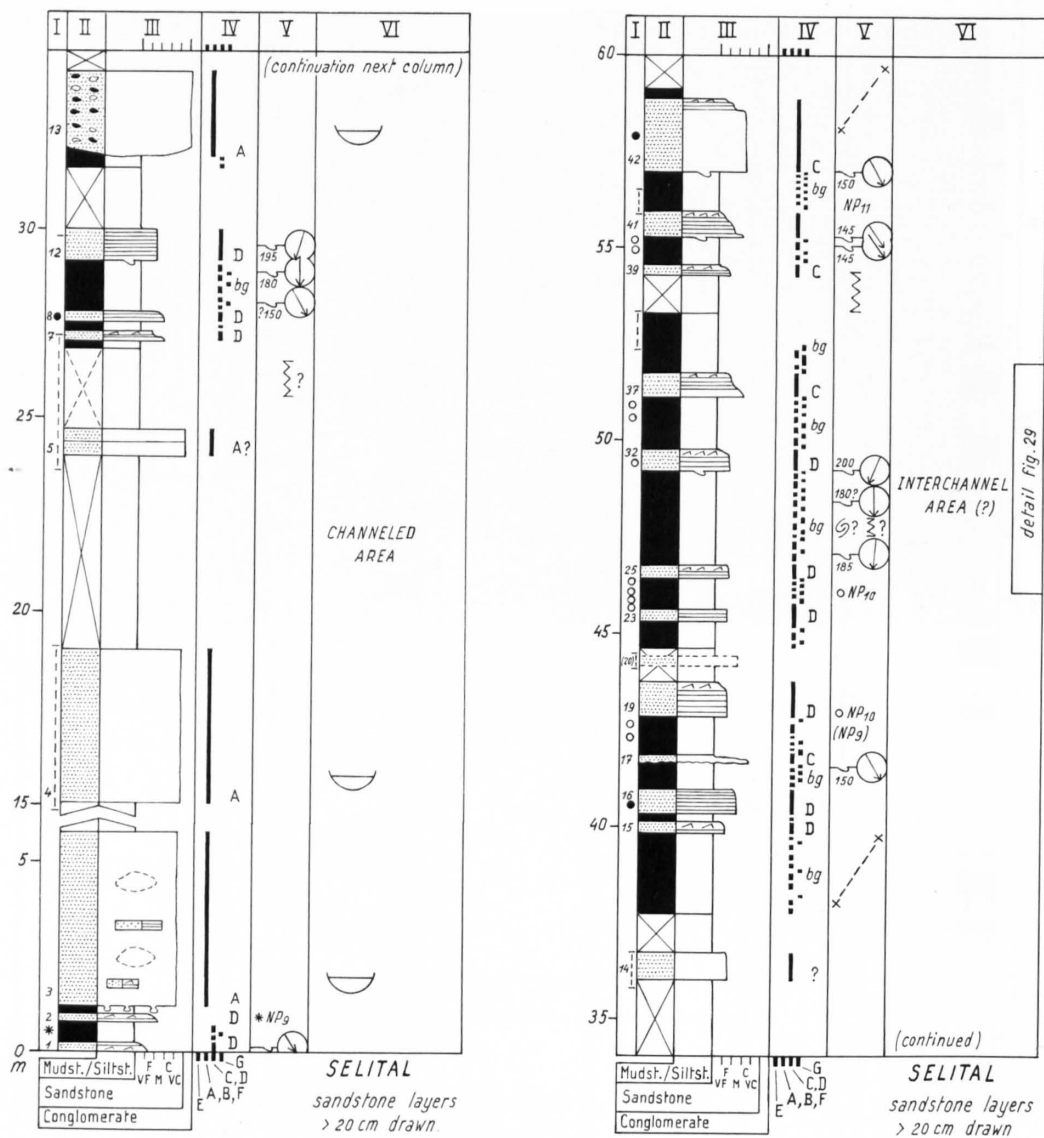
Fig. 27: Selital profile.

Fig. 28: Selital profile. Soft sediment deformation of an eroded Gurnigel sandstone bed in the conglomeratic bed 3 (corresponds to Fig. 27). Lower "Ilerdian" (photograph: S. Thompson III).

Fig. 30: Süfternen profile (A) and detailed
profile (B).

← Fig. 29: Selital, detailed profile.

Süfternen is a short profile showing interchannel facies typical of the "Eocene": alternating *D* and *G* facies, with some *E* beds. Figure 30*A* and *B* (detail).

The Selital area (Fig. 51, p. 65) may be summarized as follows: during the Maastrichtian and Lower Danian, basin plain conditions prevailed, followed by a marked sandstone progradation during the mid-Paleocene. Sandstone dominated channels followed, continuing until the Lower Ilerdian (NP 9). In the course of the Ilerdian (NP 10), a break in the development took place, leading to shale dominated sedimentation. During the Cuisian, modest channels and predominant interchannel shales characterize the sedimentation. The lower half of the sequence was probably deposited under or near the CCD: the green shales are carbonate-free, and contain *"Rhabdammina"* fauna (p. 80). During the Ilerdian, the CCD was reached, and the green shales retain some carbonate; later during the Eocene, sedimentation again took place below the CCD.

55

Fig. 31: Schüpfenflue from the west. *B-II* = Bärgli II profile; *B-I* = Bärgli I profile; *SC* = Schüpfen-flue profile. Between the basin plain deposits of Bärgli II and I, and the major progradational lobe of the Schüpfenflue, some minor progradational lobes can be observed in the woods. "Maastrichtian" to Lower "Thanetian".
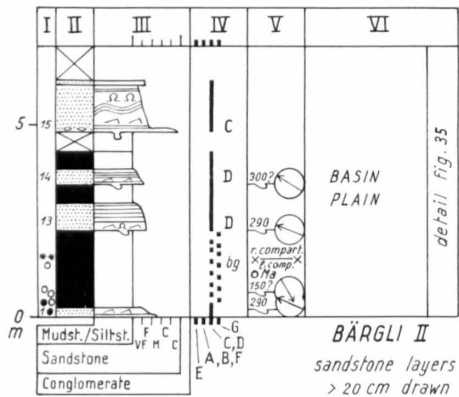
Fig. 32: Bärgli II profile.
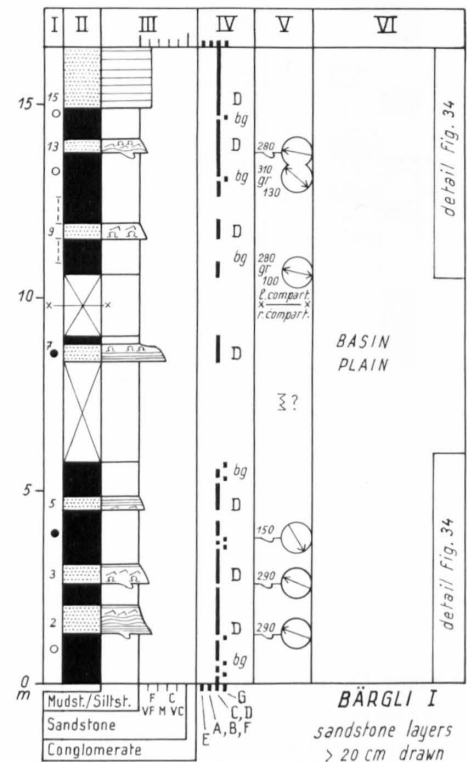
Fig. 33: Bärgli I profile. →
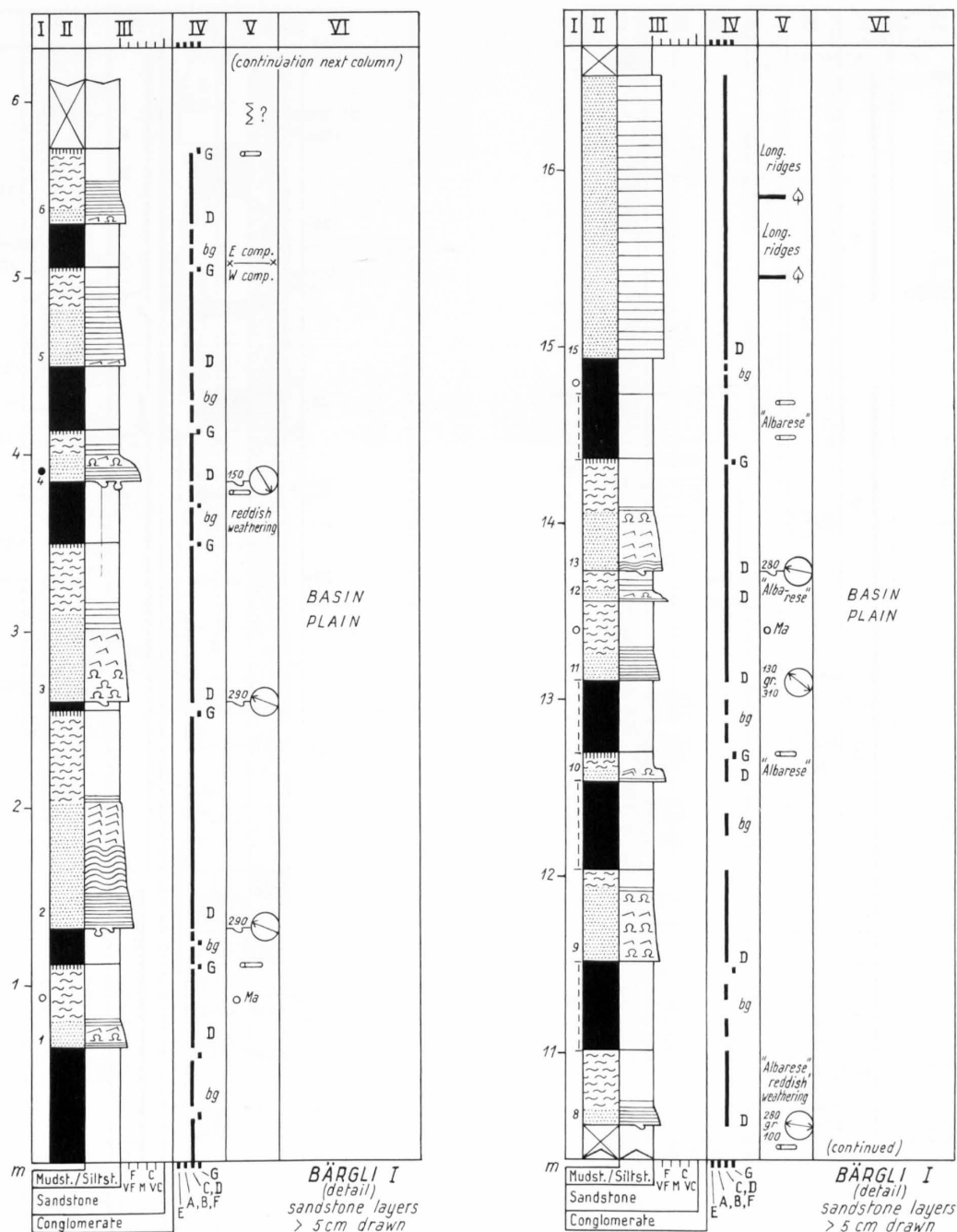
Fig. 34: Bärgli I, detailed profile.

4.2.2.2 Profiles from the Schüpfenflue area (Fig. 31–40)

Figure 31 shows the NW face of the Schüpfenflue with location of the Bärgli II, I and Schüpfenflue profiles.

Bärgli II is a rather small, folded outcrop on a forest road. It shows a basin plain association, with sandstones, shales, and one conglomerate layer, a T_a division of a Bouma-cycle. The Bouma division T_d is also present in the turbidites of this profile, Figures 32 and 35 (see remark "Hellstätt" profile).

Fig. 35: Bärgli II, detailed profile.

BÄRGLI II
(detail)

BASIN
PLAIN

Fig. 36: Schüpfenflue profile.
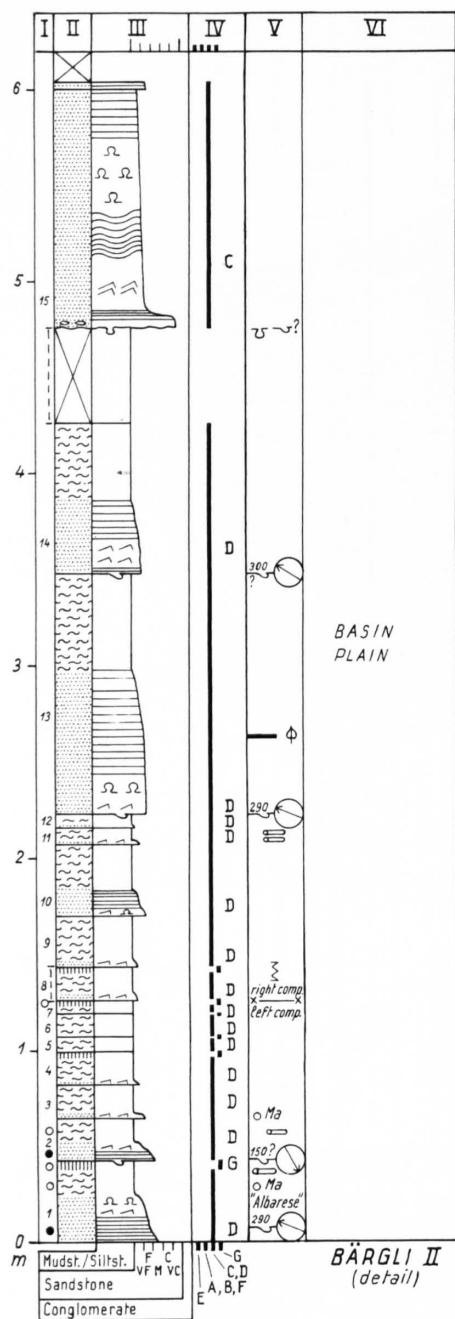
SCHÜPFENFLUE
sandstone layers
> 20 cm drawn
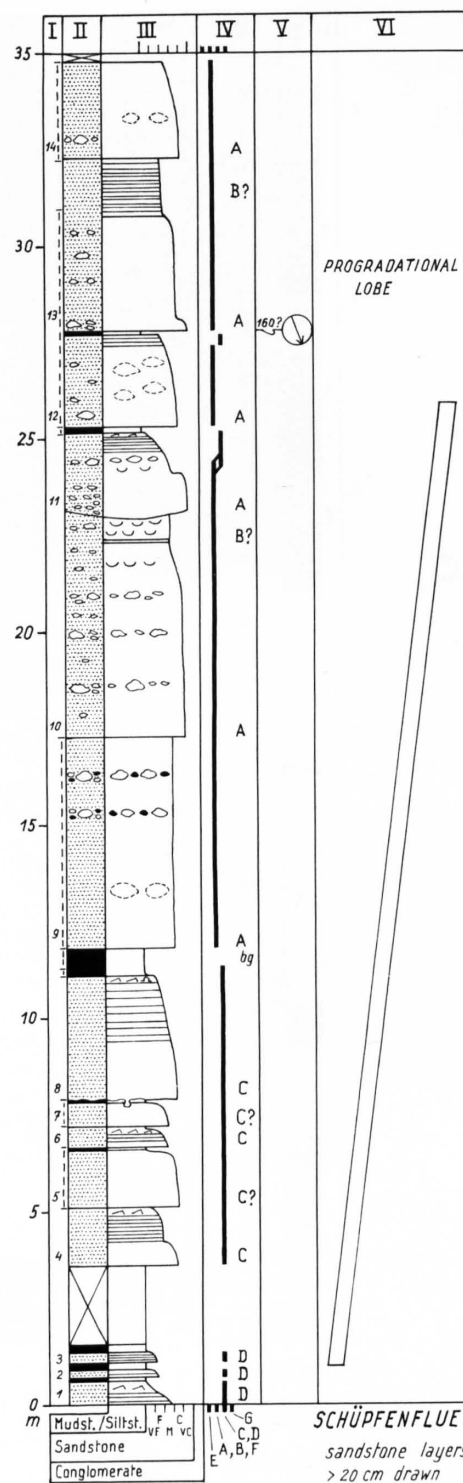
PROGRADATIONAL
LOBE

← Fig. 37: Schüpfenflue profile. Dish structures
from upper part of bed 10 (bed number corre-
sponds to Fig. 36). Lower "Thanetian".

Fig. 38: Oschoube profile (A and B). →

OSCHOUBE (A)
sandstone layers
> 20 cm drawn

OSCHOUBE (B)
sandstone layers
> 20 cm drawn

59
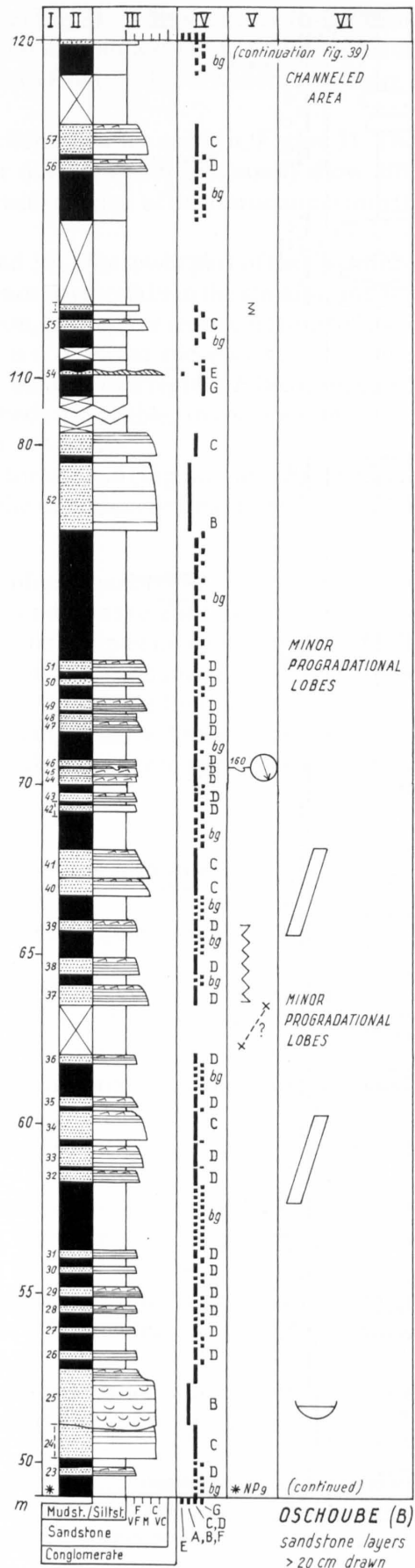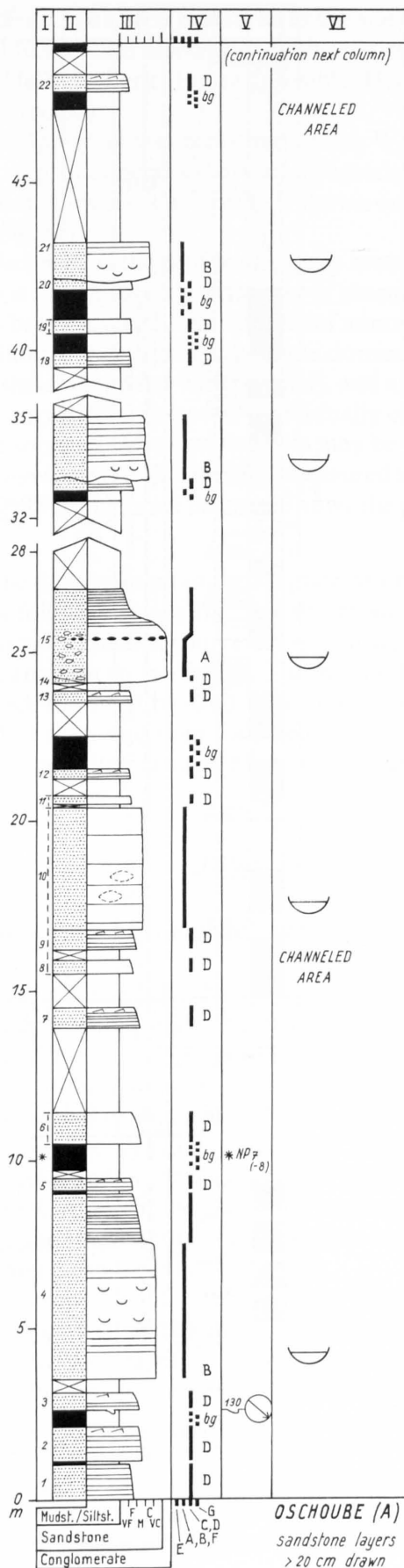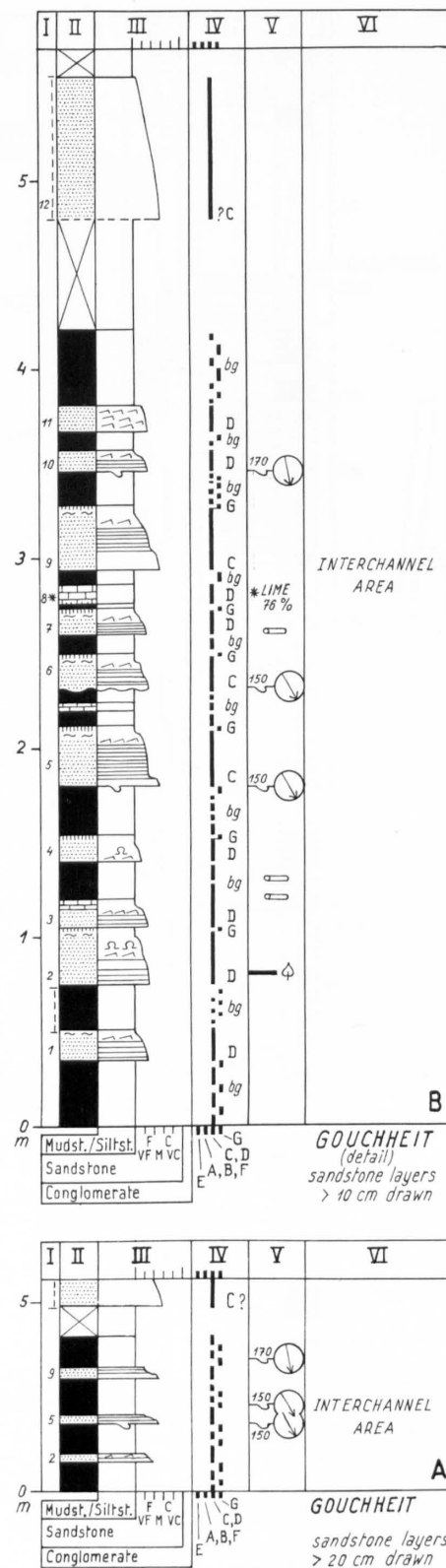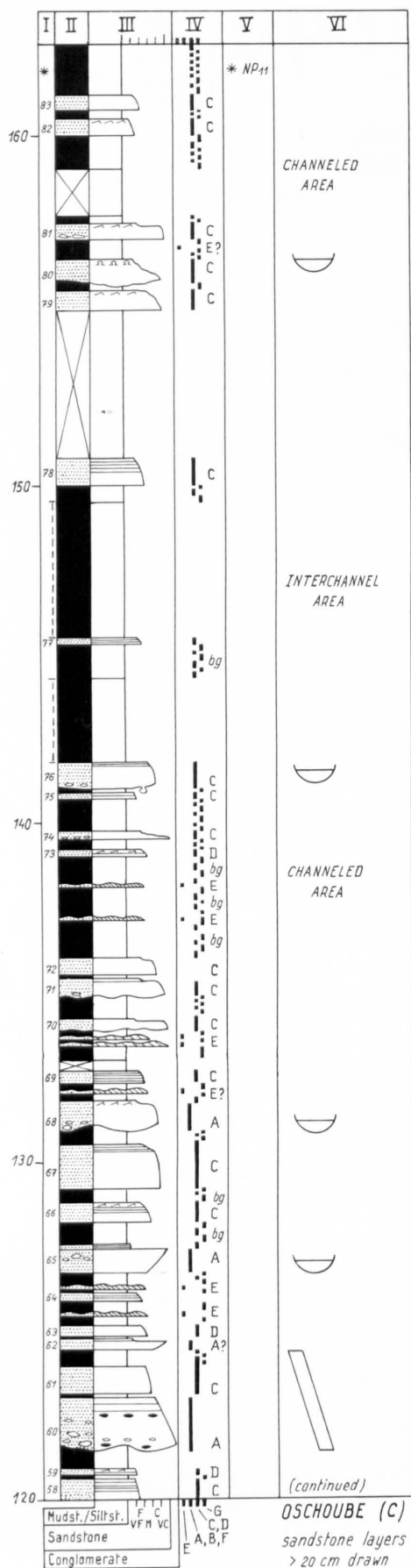
Fig. 39: Oschoube profile (*C*).

Fig. 40: Goucheit profile (*A*), and detailed profile (*B*).

Bärgli I has been measured at the site of a landslide (Fig. 31). This sequence (Fig. 33 and 34) is a typical basin plain association with a variety of shales and sandstones. The multiple source character of the Hellstätt Series is clearly visible. Here the turbidites from the E dominate those from the NW (dip corrected).

Schüpfenflue was measured on the W slope of the Schüpfenflue summit, Figure 31. The profile shows a pronounced sandstone progradation. Lower outcrops (not measured) show minor progradational cycles. The profile is shown on Figure 36, with a detail of dish structures from the upper part (Fig. 37).

Oschoube is the profile of a steep brook (Fig. 38 and 39). The lower part of the Oschoube profile (50 m) is most probably a number of channel-fill sequences (waterfalls in the stream), and interchannel (?) beds (covered). An interval of minor progradation, with active sedimentation follows. After a 30 m interruption (probably shale dominated), there is a different succession: numerous beds of green shales (together with one red), and an important number of irregular E beds, suggesting passage of strong flows. Several individually channelized beds are visible. In the uppermost part of the profile some interchannel deposits may be present (p.p. covered).

Gouchheit is a short profile measured along an old forest road (Fig. 40 A and B). The section may represent interchannel facies; it shows the position of the only Eocene limestones found in the study area.

The development of the sedimentation of the Schüpfenflue area (Fig. 51, p. 65) may be summarized as follows: during the Maastrichtian, basin plain conditions reigned, with sedimentation from at least two different source areas; during the Danian, the basin plain environment continued, but with transition to fan fringe. During the Lower Thanetian a pronounced sandstone progradation occurred, followed by sandstone deposition in channels. During the Ilerdian this pattern was interrupted at first, and then followed by renewed active channelized sedimentation, now shale dominated (Upper Ilerdian and Cuisian). The green shales of this area are extremely poor in carbonate or completely lime-free.

4.2.2.3 *Profiles from the Äbegraben area* (Fig. 41–51)

Äbegraben I ("Ilerdian") shows a small progradational cycle, which is shown on Figures 43 and 46.

Äbegraben II ("Ilerdian") shows a series of small positive ("channel") cycles, which show a general progradation: each channel is bigger than the precedent. Dr. P. Homewood pointed out this feature to me. This "prograding channelized sequence" might to be the reactivation of a starved channel, or the arrival of a major channel on a smoothed, but still inclined surface. Sedimentation is predominantly channelized at the end of this profile (Fig. 44 and 47).

Äbegraben III (Lower "Cuisian") (Fig. 42) shows an (inter)channel environment. The profile starts with a bed probably deposited by debris flow.

Stäckhüttenwald has a similar age, and facies association as Äbegraben III (Fig. 41; Fig. 48, detail). It shows an active, fairly regular sedimentation, sometimes interrupted by debris flow beds, indicating a channeled environment.

Äbegraben IV (Upper "Cuisian") is poorly exposed. It shows a channel facies association (Fig. 45), with some channel fill sequences; a number of E beds witness passage of important flows. The directional properties are rather irregular.

Grätli I has the same age as Äbegraben IV, and also shows some sandstone dominated channelized sequences (Fig. 49). These form a series of waterfalls in the upper part of the Marchgraben. The positive cycles show up on the profile.

Grätli II ("Lutetian"), was measured in a small brook. Interchannel, and channel facies may be present (Fig. 50 A; and 50 B, detail). Bed 7 is rather remarkable: it may be one composite event, a debris flow, a slump (?), and a turbidity current. The lithology of this profile is similar to that of the

Fig. 41: Stäckhüttenwald profile.

Fig. 42: Äbegraben III profile.
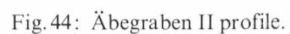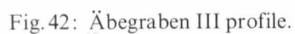
Fig. 43: Äbegraben I profile.

Fig. 44: Äbegraben II profile.

STÄCKHÜTTENWALD

sandstone layers
> 20 cm drawn

ÄBEGRABEN III

sandstone layers
> 20 cm drawn

ÄBEGRABEN I

sandstone layers
> 20 cm drawn

ÄBEGRABEN II

sandstone layers
> 20 cm drawn

Mudst./Siltst.
Sandstone
Conglomerate

CHANNELED AREA

detail Fig. 48

CHANNELED AREA

PROGRADATIONAL LOBE

"CHANNEL PROGRADATION"
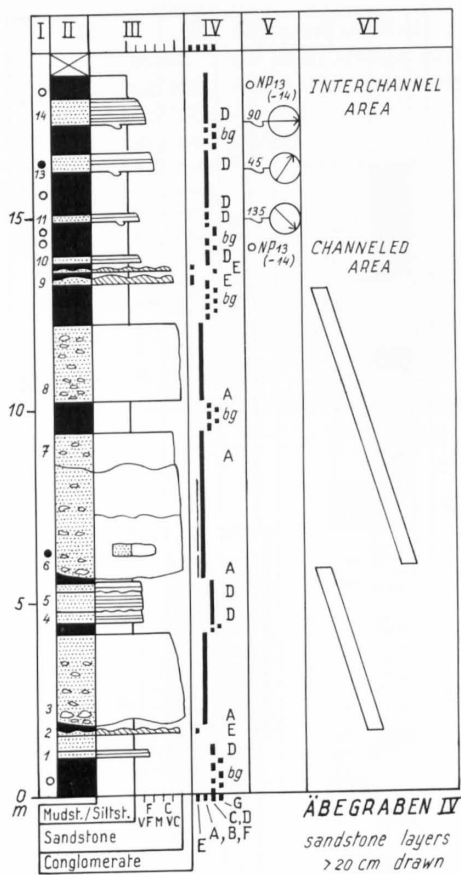
Fig. 45: Äbegraben IV profile.
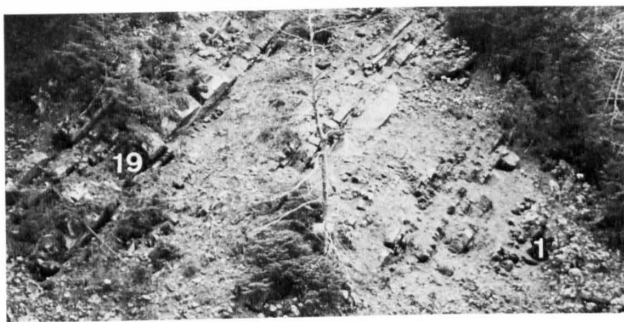
Fig. 46: Äbegraben I profile. Minor progradational lobes (~3 m). Bed numbers correspond to Figure 32. "Ilerdian".
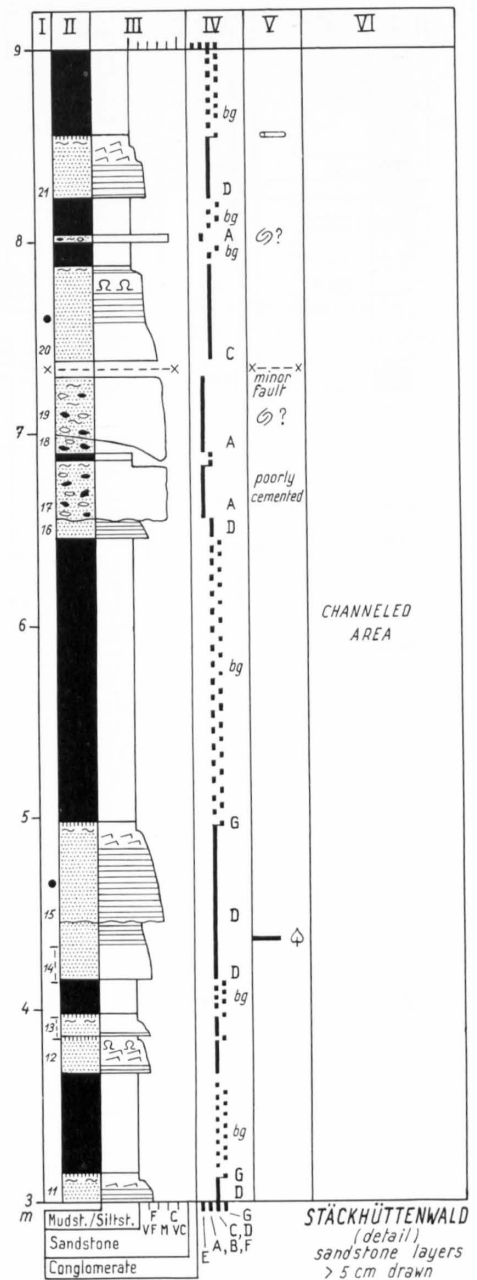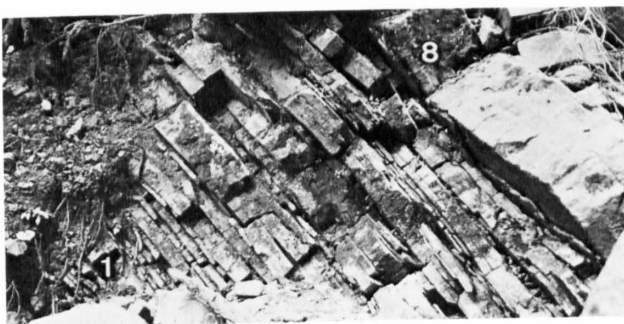
Fig. 48: Stäckhüttenwald, detailed profile.

← Fig. 47: Lower part (~15 m) of Äbegraben II profile, showing a series of thinning-up cycles, each thicker than the precedent ("Channel progradation"). Bed numbers correspond to Figure 44. Upper "Ilerdian".

63
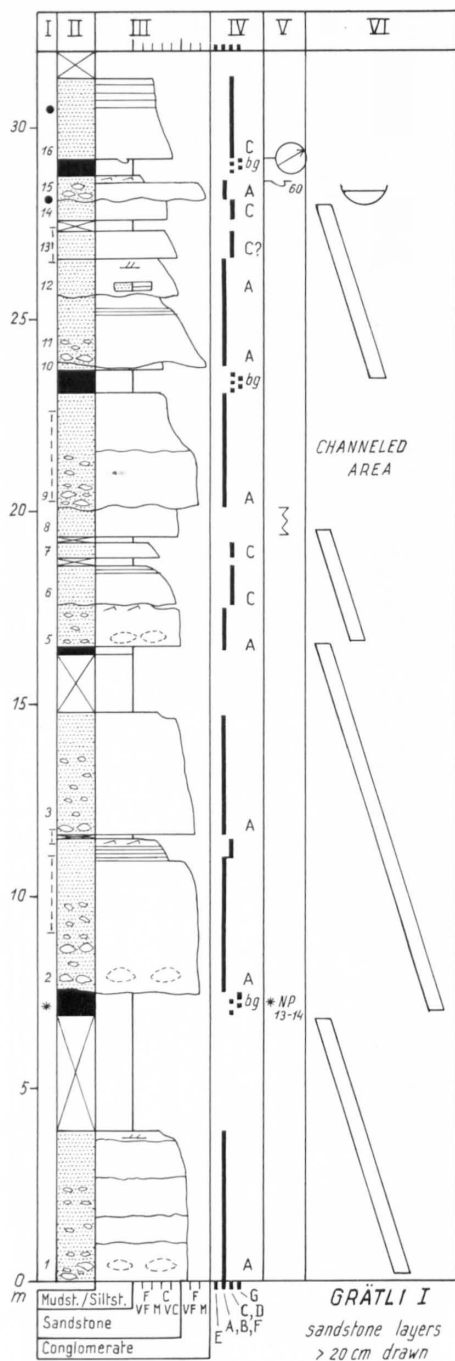
Fig. 49: Grätli I profile.
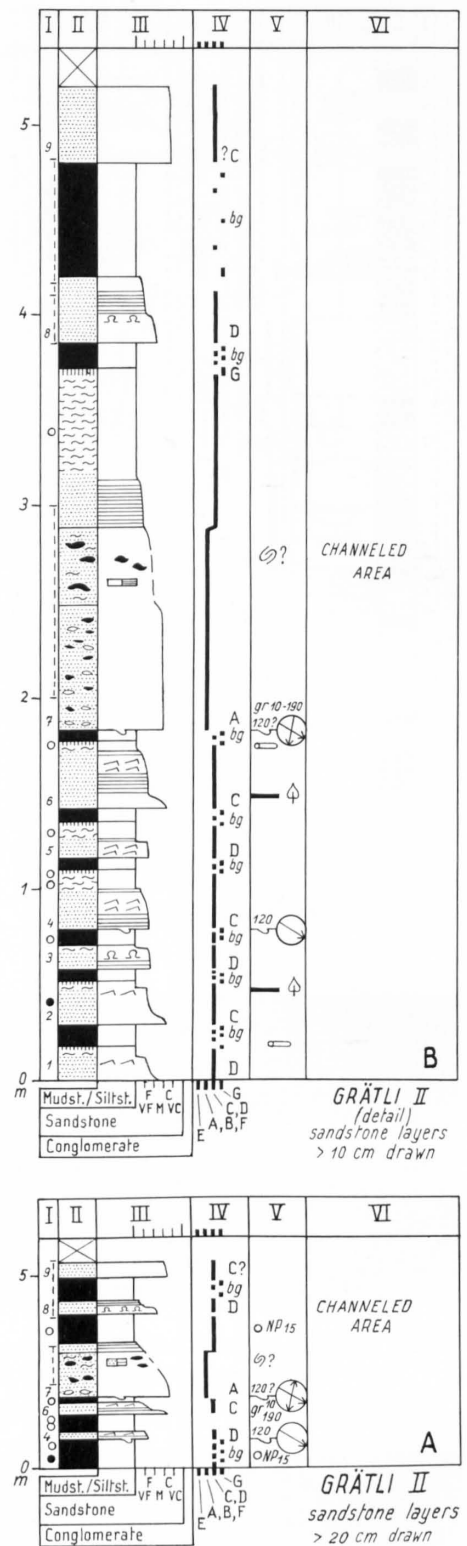
Fig. 50: Grätli II profile (*A*), and detailed profile (*B*).

Lithology

▭ thick bedded sandstones
▬ thin bedded sandstones and shales
⬚ conglomerates and pebbly sandstones
⬚ limestones

Measured profiles

1	"Hellstätt"	11	Oschoube
2	Einberg	12	Gouchheit
3	Louetli	13	Äbegraben I
4	Kurhaus	14	Äbegraben II
5	Selital	15	Äbegraben III
6	Schwarzenbühl	16	Stäckhüttenwald
7	Süfternen	17	Äbegraben IV
8	Bärgli II	18	Grätli I
9	Bärgli I	19	Grätli II
10	Schüpfenflue		

Biostratigraphic units: see biostratigraphy, chapter 2

ÄBEGRABEN area

SELITAL area

SCHÜPFENFLUE area
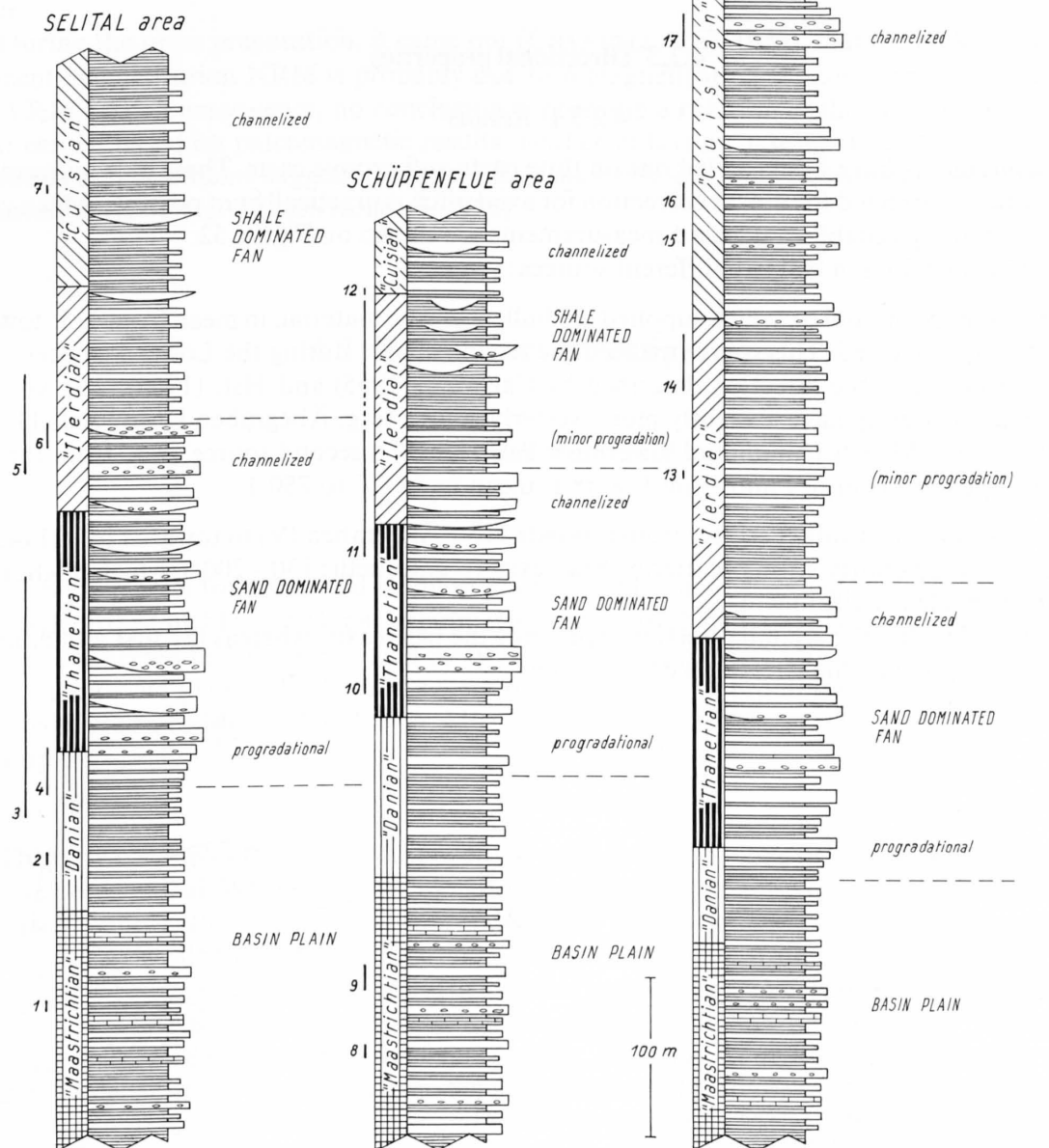
Fig. 51: Composite profiles of the eastern area of the Gurnigel Flysch.

65

Lower "Eocene" of the Äbegraben; in the younger ("NP 16") Wannelsgraben section lithological differences appear (see 2.3, Lithostratigraphy, p. 21).

The evolution of the sedimentation in the Äbegraben area (Fig. 51) may be summarized as following. During the Maastrichtian, basin plain conditions prevailed with abundant shales, some sandstones, conglomerates and limestones. During the Danian, basin plain conditions still reigned, with sandstones and dark shales, followed by a sandstone dominated progradation during the Thanetian. The sandstone predominance was not as marked as the Selital and Schüpfenflue area. The progradation was soon followed by channelized deposits. During the Ilerdian a slackening of the sedimentation occurred, and shales and some sandstones accumulated. Minor progradation took place, again followed by a channeled environment, with many shale dominated interchannel areas. Some slumping may have taken place at this point. This channeled environment continued during the Early Lutetian.

An extreme low carbonate content is present over the whole Äbegraben area: the green shales are carbonate-free, the grey shales often do not contain any carbonate either.

4.2.3 Directional properties

4.2.3.1 *Results*

Measurements have been carried out on flute casts and groove casts. These paleocurrent data have only been corrected for dip, as correction for axial pitch is practically not possible. Mean values from those outcrops enabling at least 5 measurements are shown on Figure 52.

The Gurnigel Flysch had two different sources:

NW: This is the main source, which supplied the bulk of clastic material, in mean from 315° towards 145°, dip corrected. This source masked the second source during the Lower Paleocene, and corresponds to the direction described by CROWELL (1955) and HSÜ (1960). The youngest strata apparently have a slightly more westerly source (e. g. Äbegraben IV towards 113°).

E: During the Maastrichtian (and lowermost Paleocene?) a second source area, from the E, is also apparent (Bärgli I and II on Fig. 38*A*, mean from 80° to 280°).

The outcrop mean values scatter from towards 113° (Äbegraben IV) to towards 167° (Louetli); within the outcrops fairly strong scattering may exist (e. g. Louetli: 130°–200°), which might be expected in channeled environments.

It is possible that the second direction represents the basin axis, whereas the first and dominating direction represents the lateral fan development.
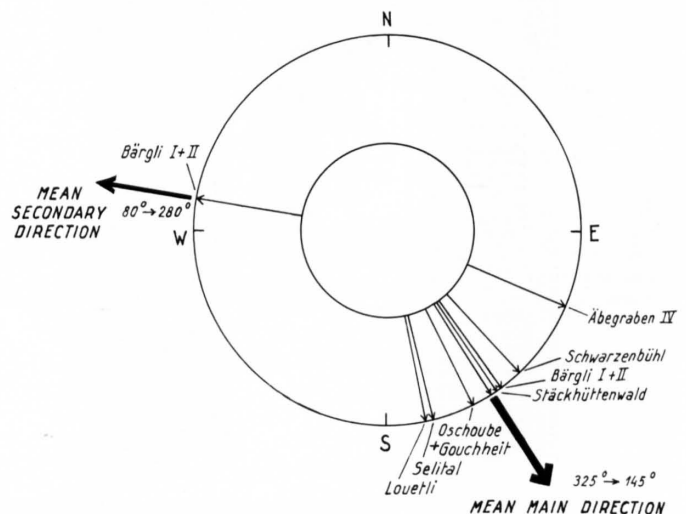
Fig. 52: Directional properties. Outcrop mean values of flute cast and groove cast measurements, showing a major and a minor source.

4.2.3.2 *Paleomagnetic results*

In a structurally complicated area, rotations, whether of slices or of the whole nappe, cannot be excluded. To test this possibility, measurements of natural remanent magnetization (NRM) have been carried out in cooperation with the Geophysics Department ETH Zürich, Prof. W. Lowrie and Dr. J. Channell. The results will be published in detail later (CHANNELL et al. 1979).

All outcrops studied show a consistent paleomagnetic direction, differing (after dip correction) about 90° from the present day N–S direction. This direction may be explained by:

1. Tectonics: clockwise rotation of the Gurnigel nappe by about 90°.
2. Sedimentation: orientation of magnetic grains by currents.
3. Remagnetization: all directions would be mainly due to the present earth field.
4. An unidentified control (e.g. diagenesis).

A 90° rotation would imply serious paleogeographic consequences as the Gurnigel Flysch would then not have a northwestern as generally accepted, but would be derived from a southwestern source.

During the press preparation, it came out (CHANNELL et al. 1979), that the bulk of the natural remanent magnetization NRM is probably due to remagnetization (viscous remanent magnetization, VRM). As a consequence, no conclusion concerning a rotation of the Gurnigel nappe (or its slices) can be based on paleomagnetic results, neither in favour, nor against. On the other hand, anisotropy measurements suggested alignment of magnetic grains by turbidity currents (parallel to the current direction, cf. ARGENTON et al. 1975).

4.3 Laboratory investigations

4.3.1 Heavy minerals

4.3.1.1 *Method*

Heavy minerals from fine and medium grained sandstones have been studied according to the method described by MATTER (1964). About 250 grams of fresh material of each sample was crushed, and then immersed in 10% acetic acid at 70° C, until all carbonate was dissolved. The remaining grains were sieved (0.06–0.4); 10 grams were then immersed in bromoform. Heavy minerals thus separated were embedded in Aroclor Nr. 4465 (n = 1.66). Dr. H. Maurer (Berne) kindly determined the samples.

4.3.1.2 *Results*

Thirty-two samples from measured profiles, and one from a block below the Schüpfenflue summit have been studied. Where possible a hundred transparent grains (garnet excluded) were counted from each sample, the corresponding proportion of garnet grains was noted separately. From 33 samples, 24 revealed 100 grains (+ garnet), 9 less (in mean 0.3% from 10 grams separated grains). The complete results of the heavy mineral determinations are listed in Figure 53. The countings have been separated into four groups: a Maastrichtian group (6 samples from "Hellstätt", Bärgli II and Bärgli I), a Paleocene group (9 samples from Einberg, Kurhaus, Louetli and Schüpfenflue), a northern lowest Eocene group (8 samples from Schwarzenbühl and Selital), and a southern Eocene group (10 samples from Stäckhüttenwald, Äbegraben IV, Grätli I and Grätli II). The heavy mineral spectrum of the Gurnigel Flysch consists of tourmaline, garnet and zirkon, with the TiO_2 group, apatite, and some accessory minerals.

4.3.1.3 *Characteristics of the heavy minerals*

H. Maurer characterized each of the heavy minerals encountered as follows:

- *Tourmaline* (42%) is generally well rounded, sometimes with neogenic growth (overgrowth, rarely authigenesis). Two colour varieties are present: brownish and olive green. The relative frequency of these varieties is given in Figure 53 according to a colour index after FÜCHTBAUER (1964): number of olive green grains / number of all other grains.
- *Garnet* (28%): Etched surfaces show a staircase like form, sometimes with inclusions.
- *Zircon* (27%) appears under two types: one with idiomorphic habitus, partly with zonal structure; the second, rarer type is rounded. Both types are generally elongated.
- *TiO$_2$ group* (12%):
  Rutile, stalked-columnar, high refractive index, reddish, rarely yellow.
  Anatase, tabular or pyramidal habitus, partly with anormal interference colours.

	1 Ga	2 Ep	3 Ap	4 To	5 Zi	6 Ru	7 Ti	8 St	9 Mo	10 Br	11 An	12 TC	13 NG
LOUETLI 45	13	2	0	50	26	3	0	6	1	6	6	1,27	100
LOUETLI 43	4	0	2	33	36	10	2	0	.6	1	10	0,74	100
LOUETLI 37	10	1	2	56	27	8	0	2	0	2	2	0,34	100
LOUETLI 5	8	2	0	44	32	14	0	0	3	3	2	1,75	100
SCHÜPFENFLUE	6	0	2	74	11	6	2	0	0	0	5	1,00	100
KURHAUS 4	27	3	10	30	23	9	1	10	8	5	1	1,14	100
KURHAUS 3	26	4	24	32	20	1	2	10	0	5	2	1,13	100
EINBERG 9	60	2	66	9	19	3	0	0	0	1	0	0,80	100
EINBERG 3	57	0	33	4	7	3	0	20	0	1	0	3,00	68
PALEOCENE MEAN		38 To, 23 Zi, 12 TiO2 (7 Ru), 16 Ap, 6 St, Rest 5, + 24 Ga										

	1 Ga	2 Ep	3 Ap	4 To	5 Zi	6 Ru	7 Ti	8 St	9 Mo	10 Br	11 An	12 TC	13 NG
BÄRGLI I/7	13	4	0	48	19	11	0	1	0	3	14	0,66	100
BÄRGLI I/4	77	0	41	19	30	0	2	0	4	2	2	1,71	100
BÄRGLI II/2	46	1	1	33	40	7	2	0	0	0	16	0,43	100
BÄRGLI II/1	28	0	2	33	8	2	0	1	0	0	9	0,83	55
"HELLSTÄTT" 27	61	0	0	68	14	16	1	0	0	1	0	1,16	100
"HELLSTÄTT" 1	6	0	0	37	48	1	2	2	7	3	0	0,85	100
MAASTRICHTIAN MEAN		43 To, 28 Zi, 16 TiO2 (7 Ru), 7 Ap, 1 St, Rest 5, + 42 Ga										

	1 Ga	2 Ep	3 Ap	4 To	5 Zi	6 Ru	7 Ti	8 St	9 Mo	10 Br	11 An	12 TC	13 NG
GRÄTLI II/2	8	1	0	12	23	0	0	0	3	0	4	1,0	43
GRÄTLI I/16	11	2	2	10	38	7	1	0	5	0	3	3,5	68
GRÄTLI I/14	3	0	2	22	17	0	0	0	0	2	0	1,0	43
ÄBE. IV/15	3	0	4	20	31	2	0	0	0	4	1	0,43	62
ÄBE. IV/16	10	0	1	19	38	1	0	1	4	3	0	0,73	67
STÄCK. 37	19	1	0	48	21	0	0	2	2	2	1	0,60	77
STÄCK. 35	6	0	12	29	35	5	0	2	9	6	2	0,38	100
STÄCK. 27	3	0	0	59	23	4	0	0	2	12	0	0,90	100
STÄCK. 20	31	0	0	37	42	7	0	0	8	2	4	1,47	100
STÄCK. 15	10	0	0	67	19	2	0	0	4	6	2	0,63	100
SOUTHERN AREA EOCENE MEAN		42 To, 37 Zi, 11 TiO2 (4 Ru), 3 Ap, 1 St, Rest 6, + 14 Ga										

	1 Ga	2 Ep	3 Ap	4 To	5 Zi	6 Ru	7 Ti	8 St	9 Mo	10 Br	11 An	12 TC	13 NG
SELITAL 42	56	2	20	27	33	3	0	7	3	0	5	1,45	100
SELITAL 32	17	3	6	55	16	6	2	4	0	0	8	0,62	100
SELITAL 16	67	1	39	40	18	0	0	2	0	0	0	1,0	100
SELITAL 8	32	1	0	47	9	2	1	4	0	3	3	0,52	70
SCHWARZ. 31	54	3	19	47	17	3	1	0	1	1	0	1,47	100
SCHWARZ. 30	27	0	8	34	23	2	0	11	7	9	6	1,00	100
SCHWARZ. 18	31	0	0	61	8	1	0	12	4	13	1	0,74	100
SCHWARZ. 6	16	7	8	43	23	1	1	7	0	2	8	1,39	100
LOWERMOST EOCENE MEAN		46 To, 19 Zi, 10 TiO2 (2 Ru), 13 Ap, 7 St, Rest 5, + 39 Ga										

1 Ga : Garnet
2 Ep : Epidote (Pistacite)
3 Ap : Apatite
4 To : Tourmaline
5 Zi : Zircon
6 Ru : Rutile
7 Ti : Titanite = Sphene
8 St : Staurolite
9 Mo : Monazite
10 Br : Brookite
11 An : Anatase
12 Tc : Tourmaline Color Index (FÜCHTBAUER 1964)
13 NG : Number of grains counted (without Garnet)

OVERALL MEAN: 42 To | 27 Zi | 12 TiO2 R BA | 10 Ap | 4 St 5 R + 28 Ga (33 samples)

COMBINED MEAN from FÜCHTBAUER (1964) + GASSER (1967): 48 To | 26 Zi | 13 TiO2 R BA | 11 Ap | 1 St 1 R + 7 Ga (8 samples)

0 — 50 — 100 %

To Tourmaline
Zi Zircon
TiO2 - Groupe; R Rutile BA Brookite + Anatase
Ap Apatite
St Staurolite
R Remainder (Monazite, Epidote, Titanite = Sphene)
+ 17 Ga 17 % Garnet, on 100 other grains
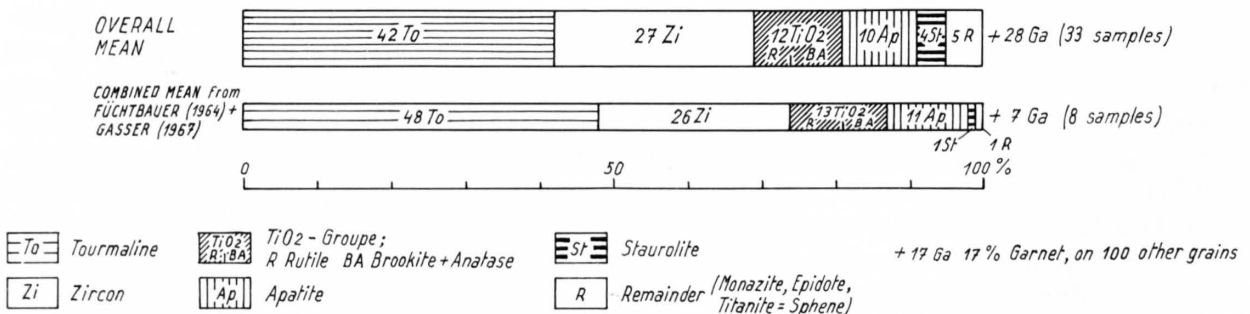
Fig. 53: Tables of heavy mineral counts of the Gurnigel Flysch of the study area.

Brookite, tabular, high refraction index, weak pleochroism. Anatase and brookite are often difficult to separate and therefore grouped on Figure 53.
- *Apatite* (10%) appears with a characteristic yellow rim; partly limonite skin and ore inclusions. May sometimes be authigenic.

The accessory minerals contain staurolite (4%), strongly pleochroic, most grains with cock's cant contour, monazite (3%), titanite (= sphene), and epidote (pistazite, not clinozoisite).
The state of preservation of the heavy minerals is good to very good.

4.3.1.4 *Statistical analysis*

In spite of the apparently monotonous and homogenous heavy mineral spectrum, some statistical analysis has been carried out. Dr. U. Gasser † (Berne) kindly introduced me to this subject, and placed computer and programmes of the Berne University at my disposal.
Two problems have been considered:

- first: Do the 33 samples studied contain groups of samples (factors), with different heavy mineral content? If so, do these groups have a geological sense (stratigraphic position, paleocurrent direction)? With respect to this, a factor analysis has been carried out.
- second: Is the subdivision into four groups valid, or do certain samples show more affinity to one of the other groups? To answer these questions an analysis of discrimination has been carried out.

Factor analysis and discriminant analysis are described by KRUMBEIN & GRAYBILL (1965).

Factor analysis

In a main component or factor analysis[1] the *n* (here 33) samples are regarded as *n* vectors in the *m*-dimensional space built up of *m* (here = 11) variables. The cosinus of the angle between the vectors is the correlation coefficient between the samples; best correlation is achieved if $r = 1$, no correlation if $r = 0$.
Now if groups of highly correlative vectors (samples) so called factors, are present, the number of dimensions (coordinate axis) can be strongly reduced, without a too strong falsification of the correlations between the vectors.
As a result one obtains a lower dimensional, better surveyable space, the main component or factor space. A certain loss of information obviously occurs at every dimension lowering step.
For the present study, a main component analysis in *Q* mode with oblique axis rotation has been carried out according to the COVAP programme (MANSON & IMBRIE 1964), with 33 samples and 11 variables (heavy minerals present) and with a percentage range transformation (= all samples recalculated to the same number of grains)[2].
As the calculation showed, one factor would represent 56.9% of the available information; 4 factors 83%, 5 factors 87.7%, 6 factors 91.3% and 7 factors 94.3%. With 11 factors all available information would have been taken into account. Too many factors from 33 variables would be difficult to interpret; less than 4 factors would cause too great a loss of information. Diagrams with 4, 5, 6 and 7 factors have therefore been drawn, and these are shown on Figure 54.
Some samples are always correlated (underlined on Fig. 54) and therefore appear together in the different factors; others are intermediate ("labile") and thus be linked to one, or to another factor.
Comparing the 4, 5, 6 and 7 factors, following samples invariably appeared together, and are obviously related (Table 1):

---

[1] In a *factor* analysis the mean values of groups of samples (factors) are calculated; in a *main component* analysis, extreme samples are chosen as main components, and the remaining samples are assigned. For the geological practise, the difference is negligible.

[2] The same calculations have been carried out with 12 variables, including the tourmaline colour index. No important difference resulted.

Table 1: *Groups of sandstones with related heavy minerals*

1	2	3	4	5
Stäckhüttenwald 27	Selital 32	Selital 16	Grätli I/16	Bärgli II/1
Stäckhüttenwald 15	Selital 8	Einberg 9	Grätli II/2	Bärgli I/7
Grätli I/14	Schwarzenbühl 6	Selital 42	Äbegraben IV/6	
Stäckhüttenwald 37	Kurhaus 3 —— *		"Hellstätt" I	
Äbegraben IV/15	Schüpfenflue		Stäckhüttenwald 20	
	"Hellstätt" 27		Louetli 43	

* Separation in case of 7 factors.

Two groups of the five might have a geological sense:

– *Group 1* includes Eocene samples from the southern area alone. This would imply a certain independance of the area.

4 Factors 83 %	5 Factors 87,9 %	6 Factors 91,3 %	7 Factors 94,3 %
STÄCK. 27	STÄCK. 27	GRÄTLI I/14	GRÄTLI I/14
STÄCK. 15	SCHWARZ. 18	ÄBE IV/15	ÄBE IV/15
GRÄTLI I/14	STÄCK. 15	STÄCK. 27	STÄCK. 27
SCHWARZ. 18	GRÄTLI I/14	LOUETLI 37	STÄCK. 15
LOUETLI 45	SCHWARZ. 30	STÄCK. 15	STÄCK. 37
STÄCK. 37	STÄCK. 37	LOUETLI 5	LOUETLI 37
ÄBE. IV/15	ÄBE. IV/15	STÄCK. 37	EINBERG 9
SCHWARZ. 30	LOUETLI 45	SCHÜPFENFLUE	SELITAL 16
LOUETLI 37	SCHÜPFENFLUE	SELITAL 32	SELITAL 42
LOUETLI 5	SELITAL 32	SELITAL 8	KURHAUS 3
SCHÜPFENFLUE	KURHAUS 3	KURHAUS 3	SCHWARZ. 6
SELITAL 32	SELITAL 8	"HELLSTÄTT" 27	SELITAL 32
SELITAL 8	SCHWARZ. 6	BÄRGLI II/2	SELITAL 8
"HELLSTÄTT" 27	"HELLSTÄTT" 27	SCHWARZ 6	SCHWARZ. 31
BÄRGLI II/2	EINBERG 3	EINBERG 9	GRÄTLI I/16
SCHWARZ. 6	SELITAL 16	SELITAL 16	LOUETLI 43
KURHAUS 3	EINBERG 9	EINBERG 3	"HELLSTÄTT" 1
BÄRGLI II/1	SCHWARZ. 31	BÄRGLI I/4	GRÄTLI II/2
BÄRGLI I/7	SELITAL 42	SCHWARZ. 31	ÄBE. IV/6
EINBERG 3	BÄRGLI I/4	SELITAL 42	STÄCK. 20
SELITAL 16	GRÄTLI I/16	GRÄTLI I/16	BÄRGLI II/2
EINBERG 9	GRÄTLI II/2	"HELLSTÄTT" 1	BÄRGLI I/4
SCHWARZ 31	"HELLSTÄTT" 1	GRÄTLI II/2	LOUETLI 5
SELITAL 42	ÄBE. IV/6	STÄCK. 35	BÄRGLI I/7
BÄRGLI I/4	STÄCK. 35	LOUETLI 43	BÄRGLI II/1
GRÄTLI I/16	STÄCK. 20	ÄBE. IV/6	LOUETLI 45
GRÄTLI II/2	LOUETLI 43	KURHAUS 4	SCHWARZ. 30
ABE. IV/6	KURHAUS 4	STÄCK. 20	SCHWARZ. 18
"HELLSTÄTT" 1	BÄRGLI II/2	BÄRGLI I/7	STÄCK. 35
STÄCK. 35	BÄRGLI I/7	BÄRGLI II/1	KURHAUS 4
STÄCK. 20	BÄRGLI II/1	LOUETLI 45	EINBERG 3
LOUETLI 43	LOUETLI 37	SCHWARZ. 18	"HELLSTATT" 27
KURHAUS 4	LOUETLI 5	SCHWARZ. 30	SCHÜPFENFLUE

Fig. 54: Tables of factors of heavy mineral samples (COVAP, main component analysis in Q-mode, oblique axis projection, 33 samples, 11 variables, percentage range transformation). Underlined samples are always correlated; they form the groups of Table 1.

– *Group 5* includes two Maastrichtian samples, from which one (Bärgli II/1) was sedimentated from E (as the other might also be). This group 5 might therefore represent the secondary, eastern source of the Gurnigel Flysch (cf. 4.2.3.3). The composition of this group is: To 55, Zi 17, TiO_2 23 (R 7, B + A 16), Ap 2, St 1, + 32 Ga.

Discriminant analysis

Analysis of discrimination is a procedure which looks for so called discriminance functions, separating given groups optimally. The groups are then tested on their significant variance, and finally the samples are re-assigned according to the parameters found.

The calculations have been carried out with the programme "DISK" (FABER & NOLLAU 1969), with the 4 groups defined from the 33 samples, with 11 variables, and with main axis transformation[1].

Figure 55 shows the projection of the 33 samples and 4 groups from the three dimensional discriminance space. No significant separation of the four groups is apparent. Three samples have been re-assigned to other groups. The group of the Eocene samples of the southern area is the most distinct.

This latter result is similar to that achieved by the Factor Analysis. This might be due to the stratigraphic position (youngest samples), or to lateral supply of this area, compared with the Selital and Schüpfenflue areas.
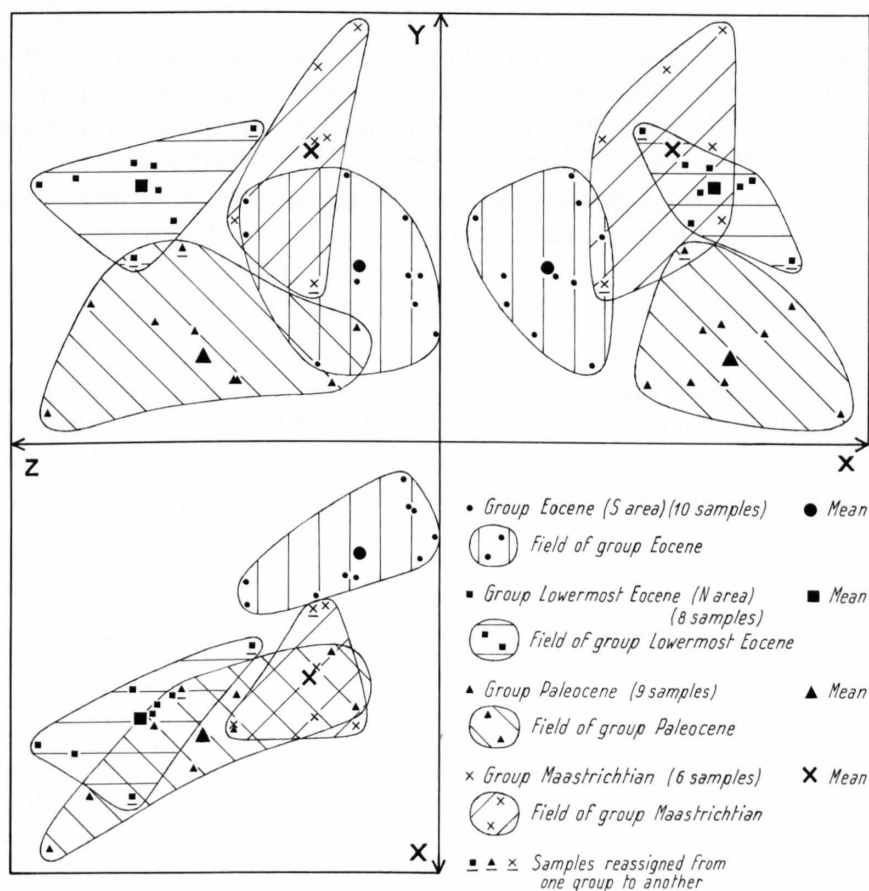
Fig. 55: Projection of heavy mineral samples and groups of samples from the discriminance space. The fields of the groups intersect: no significant separation of the groups has been achieved.

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[1] The calculations have also been carried out with 12 variables, and without main axis transformation. The results were similar.

With the same procedure, the discriminant functions show the order in which each variable contributes to the separation of the groups. This order is apatite, staurolite, tourmaline, rutile, anatase, sphene, etc.

To summarize, the statistical analysis of the heavy minerals from the Gurnigel Flysch of the study area shows one main result: the heavy mineral spectrum is homogenous, subdivision into groups is somewhat arbitrary.

4.3.1.5 *Interpretation*

A number of factors controls the heavy mineral spectrum as it is found today in the sediment. Besides variations due to sampling, grain size differences, and preparation, the following influences have played a role:

1. Source area.
2. Chemical and mechanical processes between the source area and the final sedimentation in the basin (weathering, fluviatile transport, preliminary sedimentation on a shelf with possibly diagenetic influences).
3. Diagenetic or metamorphic processes after sedimentation: intrastratal solution, authigenesis.

The last factor might be of minor importance; the sandstones were fairly rapidly cemented (cf. 4.3.5), and never underwent either a high stage of diagenesis (cf. 4.3.2) or metamorphism which would have caused important authigenesis. However, some tourmaline and apatite may be due to neogenic growth.

The spectrum encountered probably reflects the source area and the influences before and during the sedimentation into the flysch basin. The fact that no very unstable and unstable heavy minerals (PETTIJOHN, POTTER & SIEVER 1972, p. 305) remained, suggests a fairly important weathering and abrasion before the final sedimentation. The residual spectrum indicates the presence of a continental crustal source area, with granitic and metamorphic rocks (+ reworked sediments?). The presence of ophiolitic rocks can be excluded. This is in agreement with the petrography of lithic clasts (cf. 4.3.5).

4.3.1.6 *Comparisons*

Gurnigel Flysch

FÜCHTBAUER (1964) and GASSER (1967) have carried out 8 analysis in the Gurnigel area. Their combined results are shown on Figure 53; they fit in well with the results obtained here.

MOREL (1978) studied heavy minerals from the Niremont area where a high apatite content is characteristic. Apart from this, the spectrum observed by MOREL generally fits with the spectrum observed here.

Schlieren Flysch

FÜCHTBAUER (1964) and GASSER (1967) analysed 5 samples which show a spectrum comparable to that of the Gurnigel Flysch.

Other Flysch of the Prealps

FLÜCK (1973) studied heavy minerals from Prealps Flysch in great detail. Among these, one group shows a similar heavy mineral spectrum to the Gurnigel Flysch, i. e. the "Klippenflysch" (external zone): Bäder, Weissenburg, Mursbrunnen, Stockensee (with 1–2% spinel, however), and Estavannens. These outcrops may be attributed to the Reidigen Series (PAGE 1969), and thus to the Sarine nappe (CARON 1972). Heavy mineral analysis thus confirms CARON's (1972, 1976) suggestion of the relationship between Reidigen Series and Hellstätt Series – Gurnigel Flysch.

The Prealpine Flysch units ascribed by FLÜCK (1972) to the "Klippenflysch" (internal zone), Breccia nappe, and Plattenflysch (Helminthoid Flysch) show a heavy mineral spectrum comparable to that of the Gurnigel Flysch, apart from the lower garnet content.

4.3.2 Clay minerals

4.3.2.1 *Introduction*

The study of the clay mineral fraction from the shales of the Gurnigel Flysch has been carried out with the following purposes:

- establishment of assemblages,
- establishment of possible differences between grey supposedly turbiditic, and green supposedly hemipelagic shales,
- establishment of diagenesis stage.

Prof. T. Peters (Mineralogical Institue Berne), Prof. M. Frey (Mineralogical Institute Basle), and Dr. T. Küpfer (Mineralogical Institute Fribourg) kindly helped to interpret the diagrams, placed the diffractometer of the Mineralogical Institute of Berne at my disposal, and critically read this paragraph.

4.3.2.2 *Methods*

Sampling: 33 samples from grey shales and 28 from green shales, have been studied. In some layers, differentiation of shale types is not unequivocal (cf. 4.4).

Sample preparation: The samples have been prepared in the Geological Institute Berne according to the following method: 25 grams of fresh shale were pulverized during 20–30 seconds in a swinging disk mill; the clay fraction ($< 2 \mu$) was separated in a sedimentation cylinder; the carbonate was eliminated by 2n HCl, and the suspension neutralized by centrifuging with distilled water; the material was saturated with Ca^{2+} by a 2% $CaCl_2$ solution, and neutralized again; oriented samples were made by drying the clay-water suspension on a glass slide under an infrared lamp.

Diffractometer: The samples have been x-rayed on the Philips-diffractometer of the Mineralogical Institute, Berne, at the following conditions: 40 kV, 22 mA, CuK_α radiation, Ni-filter, window 1°, 0.2, 1°, goniometer velocity 2°/minute, paper velocity 1600 mm/h, time constant = 0.5 sec. Each sample has been x-rayed three times: air dried, ethylenglycol saturated (swelled), and after heating at 550° C during one hour.

Estimation of relative amounts of clay minerals has been carried out by surface integration of the peaks of the diagrams of the glycolated samples. To calculate the kaolinite/chlorite ratio, peak height ratio at 25° (2θ) has been used. The relative amount of illite and montmorillonite in the mixed-layer illite/montmorillonite has been estimated after MacEwan et al. (1961, in Brown 1961, p. 417, Fig. XI, 17).

The crystallinity of illite, named I.C. in the following text, has been measured after Kubler (1967) as the width at half height (in mm) of the first illite basal reflexion at 10 Å (8.8°, 2θ). The limits diagenesis/anchimetamorphism, and anchimetamorphism/epimetamorphism are at 7.5 and 4, respectively, at the given conditions.

Due to technical problems, I.C. measurements have been carried out at time constant (TC) = 0.5 sec, instead of usual TC = 2 sec. A higher TC causes a slightly broader peak, and thus slightly higher I.C. values. A test series revealed that this difference is in the order of 0.5 (mean: scattering between 0 and 1). I have therefore added 0.5 to all measured I.C. values. This correction seems to be acceptable, as the Gurnigel Flysch generally shows high I.C. values so that a difference of 0.5 does not have much influence.

4.3.2.3 *Results*

The estimated relative amounts of clay minerals and I.C. values are listed in Figures 56, 57 and 58. Some typical x-ray diagrams on Figure 59.
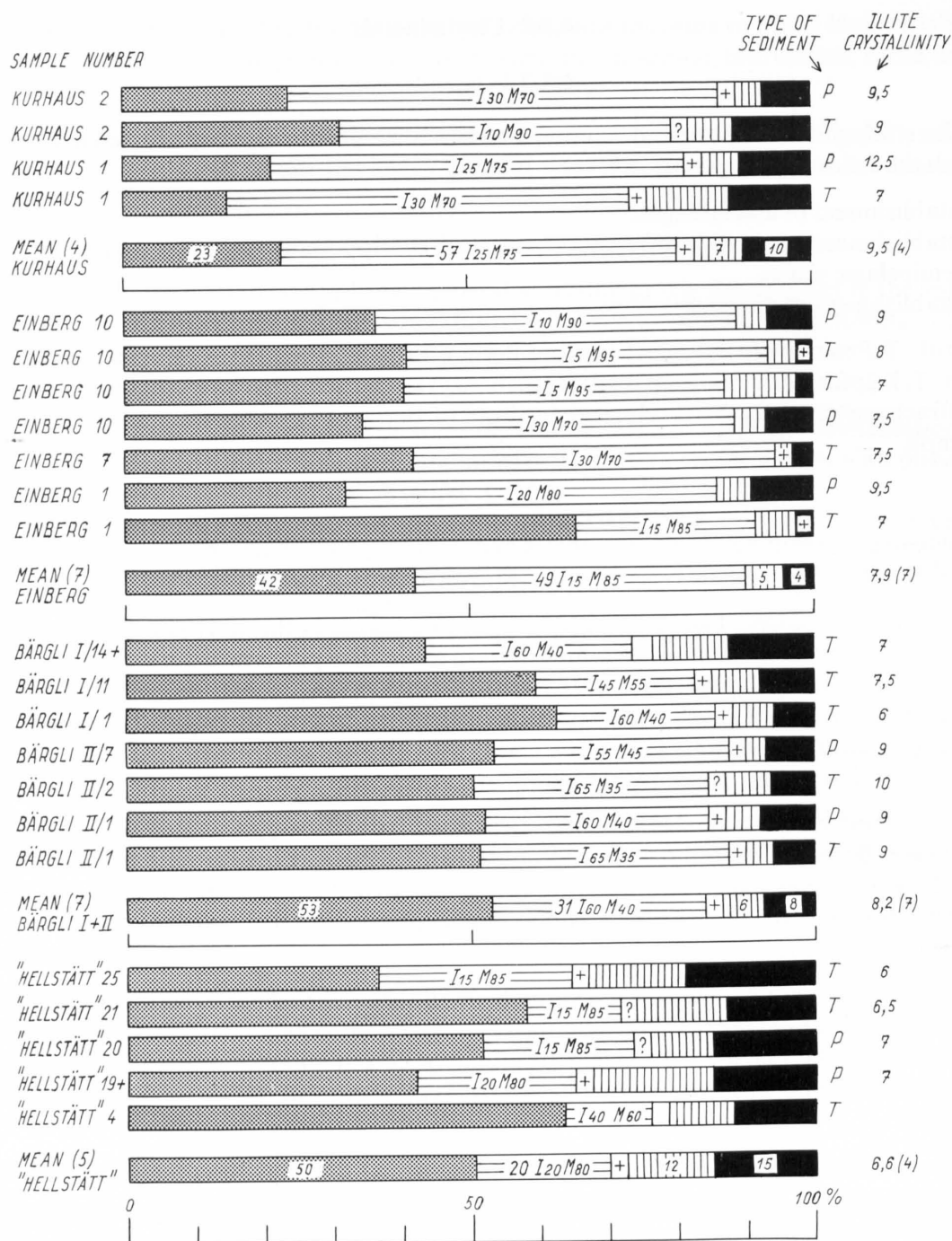
Fig. 56: Estimated relative amounts of clay minerals from "Hellstätt", Bärgli, Einberg and Kurhaus profiles. Legend see Figure 58.

Illite, a term grouping various clay minerals with muscovite structure, is identified by its first basal reflexion at 10 Å, not markedly influenced by glycolation. It shows poor to modest crystallinity, with a rather wide scattering (cf. 4.3.2.5). Illite is the dominating clay mineral with a share of 50%, minimum 23% (Kurhaus), and maximum 64% (Grätli II). Illite is a common detrital clay mineral, or may form during diagenesis.

Mixed-layers I/M show an I:M ratio varying from 5:95 to 75:25, with a mean of 45:55. By glycolation, the broad I/M shoulder between 11–15 Å moves to 13–16 Å. By heating the shoulder
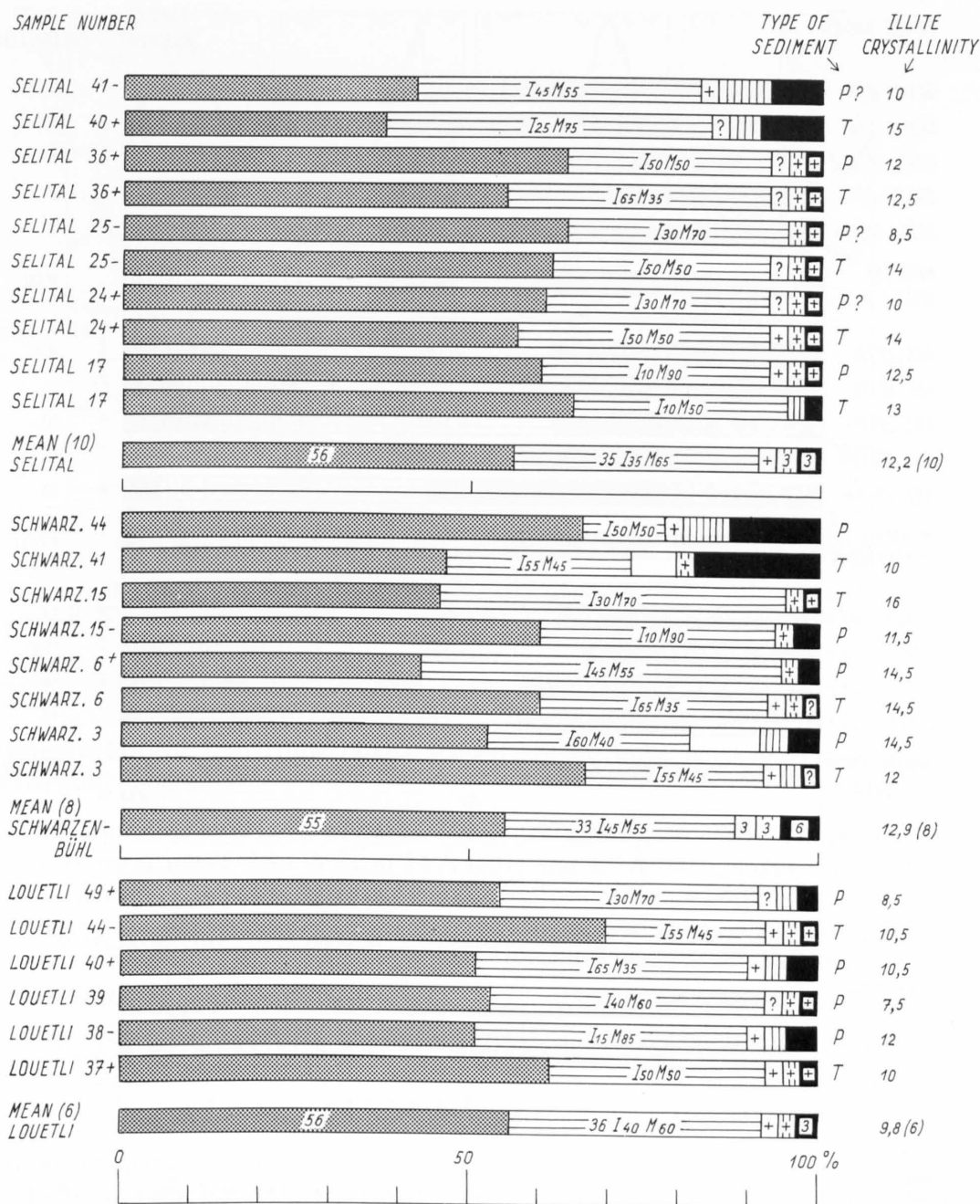
Fig. 57: Estimated relative amounts of clay minerals from Louetli, Schwarzenbühl and Selital profiles.
Legend see Figure 58.

disappears. The mixed-layers are irregular (random) (CARROLL 1970, p. 38 and Table 9). They comprise 35% of the clay minerals, with minima of 20% ("Hellstätt") and 25% (Grätli II), and a maximum of 58% (Kurhaus). They may be formed by weathering processes (detritic), or as an intermediate stage of illitisation of montmorillonite (diagenetic).

Montmorillonite[1] is identified by the (001) peak at 15 Å, moving to 17 Å after glycolation. If many mixed-layers with a high montmorillonite content are present, the distinction between mont-

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[1] Montmorillonite s.l. = smectite.

TYPE OF SEDIMENT   ILLITE CRYSTALLINITY

GRÄTLI. II/7 — I70M30 + ? — T — 10,5
GRÄTLI II/6 — I75M25 + — P — 9,5
GRÄTLI II/5 — I55M45 + — T — 8
GRÄTLI II/4 — I70M30 ? + — T — 8
GRÄTLI II/3+4 — I75M25 + — P — 9
MEAN (5) GRÄTLI II — 64 — 26 I70M30 + 5 — 9 (5)

ÄBE. IV/14 — I70M30 — T — 8,5
ÄBE. IV/12 — I70M30 — T
ÄBE. IV/11- — I65M35 — P — 10
ÄBE. IV/10+ — I70M30 ? — T — 10,5
ÄBE. IV/1+ — I70M30 + — P — 10
MEAN (5) ÄBEGRABEN IV — 45 — 32 I70M30 — 4 — 9 — 10 — 9,7 (4)

STÄCK. 32+ — I65M35 + — P — 13
STÄCK. 29+ — I70M30 + — P — 15,5
STÄCK. 28+ — I70M30 + — T — 14
STÄCK. 24+ — I65M35 + — T — 11
MEAN (4) STÄCK HÜTTENWALD — 39 — 33 I70M30 + — 23 — 13,4 (4)

0 — 50 — 100 %

MEAN (61) — 50 — 35 I45M55 + 5 7 — 10,1 (58)
MEAN PROBABLY PELAGIC SAMPLES (28) — 49 — 37 I45M55 + 4 8 — 10,2 (27)
MEAN PROBABLY TURBIDITIC SAMPLES (33) — 51 — 34 I45M55 + 6 7 — 10 (31)

0 — 50 — 100 %

Illite
Mixed Layers { Illite-Montmorillonite: estimated ratio
Montmorillonite s.ℓ. (Smectite)
Chlorite
Kaolinite

[+] Trace (0-2,5%, drawn as 2,5%)
[?] Trace supposed (drawn as 2,5%)
P Hemipelagic sediment (e±), field evidence
T Turbiditic sediment (eP), field evidence
STÄCK. 24±: Sample level under/over bed STÄCK. 24

Fig. 58: Estimated relative amounts of clay minerals from Stäckhüttenwald, Äbegraben IV and Grätli II profiles. Mean values of estimated relative amounts of clay minerals. Legend.

morillonite and mixed-layers is arbitrary. A trace of montmorillonite is present in most samples. It may be of detrital origin or be developed from volcanic glass in a very early diagenesis stage.

Kaolinite is identified by its (001) and (002) peaks at 7 Å and 3.6 Å (the latter enables distinction from chlorite). It represents 7% of the clay minerals, with a maximum of 23% in Stäckhüttenwald,
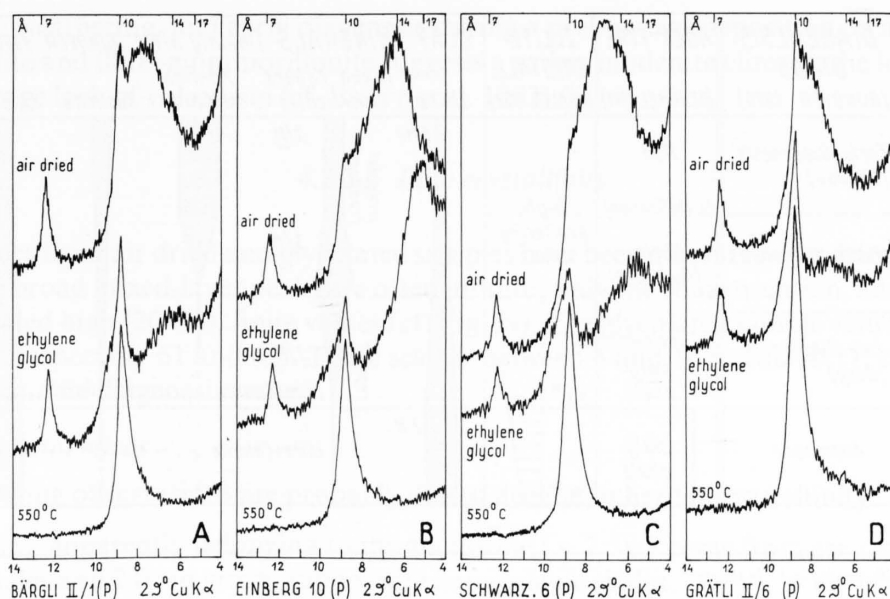
Fig. 59: Typical x-ray diagrams of clay minerals from the Gurnigel Flysch. – *A*: "Maastrichtian". *B*: "Danian". *C*: "Ilerdian". *D*: "Lutetian". *A, B, C* = Selital area, *D* = Äbegraben area near Median Prealps.

and only traces in Louetli, Selital (lower part), Schwarzenbühl (lower part), and Grätli II, kaolinite is a common detrital mineral.

Chlorite is identified by a series of peaks: (001), (002), (003), and (004). The peaks at 7 Å (002) and 3.5 Å (004) are stronger than those at 14 Å (001) and 4.7 Å (003), suggesting the presence of Fe-chlorite (CARROLL 1970, p. 33). After heating generally only a trace of (001) survives; glycolation has no influence. Chlorite represents 5% of the clay minerals, with a maximum of 12.5% in "Hellstätt"; in Louetli, Schwarzenbühl, Selital and Stäckhüttenwald only traces are present. Chlorite is a common diagenetic and detrital clay mineral.

In some samples, quartz and feldspar (alkalifeldspar and/or plagioclase) are present.

4.3.2.4 *Interpretation*

Figure 60 summarizes the general development of mudstones during diagenesis (DUNOYER DE SEGONZAC 1970; M. Frey, lectures 1975/76). A comparison between this diagram and the results obtained herein reveals:

- no slaty cleavage is present (with one local exception N of Schüpfenflue); the shales are lithified;
- illite, random mixed-layers (I : M = 1), montmorillonite, kaolinite and chlorite are present;
- illite shows a poor to modest crystallinity, with a wide scattering (see below).

These observations suggest the middle diagenesis DUNOYER (1970), equivalent of the lowest part of the deep burial stage (MÜLLER 1967). Temperatures may not have been higher than 70° or 90° and an important burial under a pile of nappes can practically be excluded.

Source of detrital clay minerals

As no important diagenesis influenced the clay minerals, these probably still reflect the source area, where three factors may have had an influence: source rocks (crystalline basement and Me-

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DIAGENESIS STAGE (MÜLLER 1967)	DIAGENESIS STAGE (DUNOYER 1970)	ROCK TYPE (SCHAMEL 1971)	ILLITE CRISTALL. (KÜBLER 1967)	CLAY MINERALS (mainly after DUNOYER 1970) Illite	Mixed Layers (k-rich)	Montmorillonite	Kaolinite	Chlorite	GURNIGEL FLYSCH
Shallow-burial stage	Early Diagenesis (Shallow)	Mud (Lithification)	high, scattering values	1 Md	J/M				
Deep-burial stage	Middle Diagenesis	Shale (Mudstone)			J/M				
	Late Diagenesis (Deep)	incipient slaty shale	7,5*		J/M Illite+Chlorite		Dickite		
	Anchizone	slaty shale	4*	2 M	Illite+Chlorite				
Epimetamorphism									

(Mixed Layers column labels: irregular (random); regular)

* Scale of Berne Mineralogical Institute

Fig. 60: Diagram of diagenesis stages of mudstones, and supposed diagenesis stage of the shales from the Gurnigel Flysch.
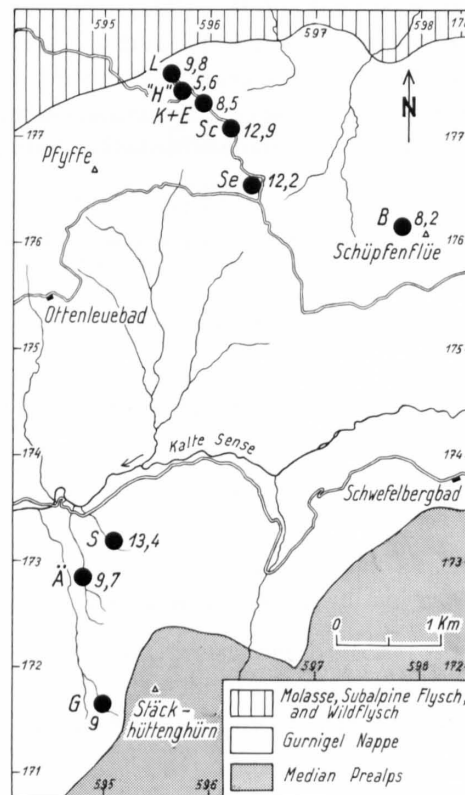
Fig. 61: Areal distribution of outcrop mean values of illite crystallinities, measured in glycolated samples.

sozoic cover), weathering, and early diagenesis during a preliminary deposition on a shelf. The dominance of illite and illite–montmorillonite suggests a rather moderate climate, the low montmorillonite percentage lack of volcanism (cf. BLATT et al. 1972).

4.3.2.5 *Illite crystallinity*

Generalities

I. C. indices from air dried and glycolated samples have been measured. Air dried sample values (including the broad mixed-layer peak) are often infinite; only the Maastrichtian, and some Eocene outcrops revealed high (20–70), finite values (cf. Fig. 59). The glycolated sample values are indicated on the figures (especially 61 and 62). These scatter between 6 and 16 (mean 10.1); they agree with the suggested middle diagenesis stage.

Influence of detrital micas

The following observations are probably due to detrital, inherited crystallinity:

– Of 9 values, apparently belonging to the anchizone (< 7.5), 7 come from grey, supposedly turbiditic shales and 2 from green, supposedly hemipelagic shales.
– The mean of grey shale samples is 10, of green shale samples 10.2.
– The values of the green shale samples are slightly less scattering, than the values of grey shale samples (Fig. 62 B).

A stratigraphic trend?

The I. C. values plotted on a composite stratigraphic column (Fig. 62) apparently show a stratigraphic trend. "Maastrichtian (and "Paleocene") crystallinity" is better than "Eocene crystallinity".
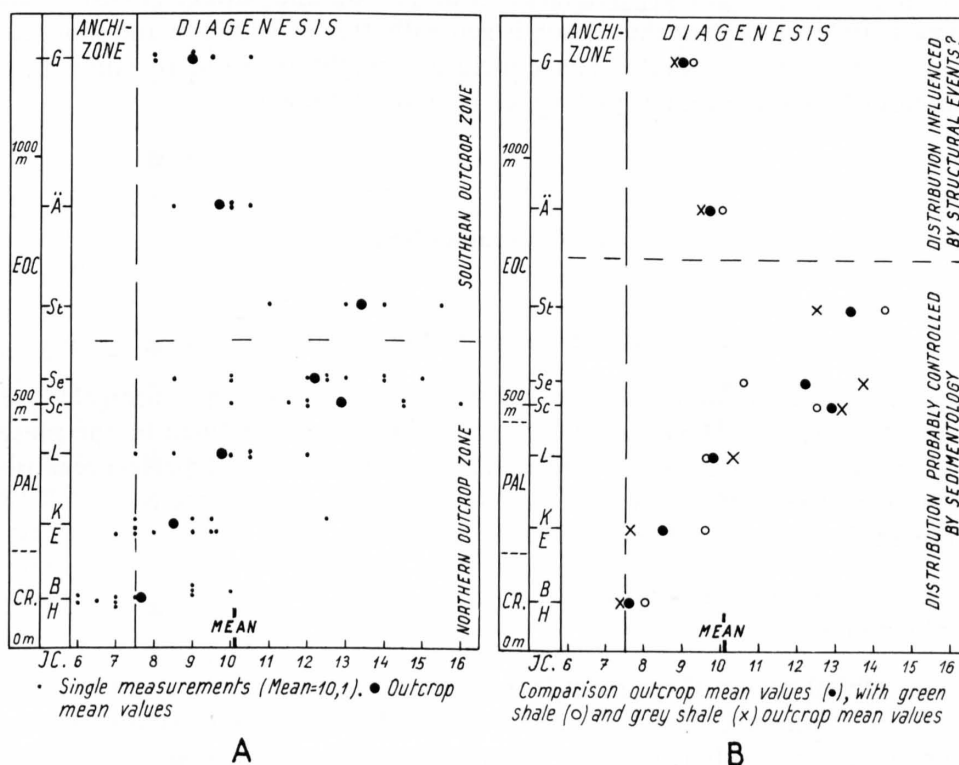
Fig. 62: Stratigraphic distribution of illite crystallinities from the Gurnigel Flysch. Composite stratigraphic column. *A* = single measurements. *B* = outcrop mean values split up in mean values from green shale, and from grey shale samples.

In the samples from the Maastrichtian shales, air dried values are measurable (40–70; cf. Fig. 59); some montmorillonite, and random mixed-layers are present; I.C. values are widely scattered and most measurements have been carried out in grey shale samples (heritage). For these reasons the trend may only be apparent. However, for the Maastrichtian strata, a burial of up to 1500 m consolidated sediment during 20 my or more can be imagined. This may have enabled enrichment of K in the illite lattices, resulting in better crystallinity, as suggested by T. Peters.

Tectonic influence?

The youngest Eocene outcrops (Äbegraben IV and Grätli II) show better crystallinity than the underlying ones (Fig. 61 and 62). The scattering of the I.C. values (glycolated) is less, and I.C. values of air dried samples range between 20 and 25 (Diagram *D* of Fig. 59). The illite content of Grätli II (64%) is the highest of the area studied.

These observations may be explained by younger structural events. This suggestion agrees with the observations of WINKLER (1977), who measured air dried values of 20–25 in the overlying "Rhätian", and 40–45 in the "Dogger" (Median Prealps), apparently in continuation with the Gurnigel Flysch values.

Aberrant values

Some samples show extremely low I.C. values (e. g. 2). They have been omitted on the figures. Presence of calcite scars in one of these samples suggest bed parallel tectonic movements which may have caused higher temperatures locally.

4.3.2.6 *Comparisons*

In the Gurnigel Flysch, VAN STUIJVENBERG et al. (1976), and MOREL (1978) obtained similar results. KUBLER's (1970) statement that flysch is generally free of kaolinite and montmorillonite is not confirmed by the present study. His conclusion might be valid to some extent for the (par)autochthonous North-Helvetic Flysch which he mainly studied.

4.3.3 Foraminifera

4.3.3.1 *Introduction, method and samples*

Since BROUWER's study (1965) it has been known that the shales of the Gurnigel Flysch are characterized by the presence of a *Rhabdammina* fauna. This fauna is defined by the presence of agglutinated Foraminifera, amongst which single-chambered and uniserial species are most abundant. WEIDMANN (1968) and VAN STUIJVENBERG et al. (1976) achieved similar results.

For the present work, two problems have been studied:

– influence of the type of sedimentation,
– stratigraphic trend.

A minimum of 250 grams of sediment from the samples taken for clay mineral analysis were studied for their foraminiferal content. A number of samples contained less than 250 grams, some of these have been omitted or combined, so that 58 samples remained. It is sometimes difficult to obtain sufficient material from only one sediment layer, specially in the case of green shales.

Determinations and counts were kindly carried out by Dr. Michèle Caron (Fribourg) and Dr. Angela Grünig (Berne).

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	Type of sediment (Field evidence)	single–chambered	uniserial	bi-,tri-and multiserial	small benthonic	small planctonic	Radiolarians	Fish Teeth	Other fossils (mainly mollusc tests)	Association R Rhabdammina I Insignificant
LOUETLI 49+	P	+	–	–	–	–	–	–	–	I
LOUETLI 44–	T	–	–	–	–	–	–	–	+	I
LOUETLI 40+	P	●	+	–	–	–	–	–	–	R
LOUETLI 39	P*	+	–	–	–	–	–	–	–	I
LOUETLI 38–	P	●	•	–	–	–	–	–	–	R
LOUETLI 37+	T	•	o	+	–	–	–	+	+	R
KURHAUS 2	P*	●	o	–	–	–	–	–	–	R
KURHAUS 2	T	•	o	–	–	–	–	+	–	R
KURHAUS 1	P	●	+	–	–	–	–	+	–	R
KURHAUS 1	T	–	–	–	–	–	–	–	–	I
EINBERG 10	P	●	•	–	–	–	–	+	–	R
EINBERG 10	T	+	–	+	+	•	+	–	–	O
EINBERG 10	T	–	–	–	–	+	–	–	–	I
EINBERG 7	P	•	•	–	–	–	–	+	–	R
EINBERG 7	T	+	–	–	–	–	–	–	–	I
EINBERG 1	P	●	•	–	–	–	–	+	–	R
EINBERG 1	T	+	–	–	–	–	–	–	–	I
BÄRGLI I/14	T	–	–	–	–	–	–	–	–	I
BÄRGLI I/11	T	o	–	–	–	–	–	–	–	I
BÄRGLI I/1	T	–	–	–	–	–	–	–	–	I
BÄRGLI II/7	P	●	•	–	–	–	–	+	–	R
BÄRGLI II/6	P	•	+	+	+	–	–	–	–	O
BÄRGLI II/2	T	+	–	–	+	+	+	–	–	I
BÄRGLI II/1	P	●	•	–	–	–	–	–	–	R
BÄRGLI II/1	T	–	–	–	o	+	–	–	–	I
"HELLSTÄTT" 25	T	–	–	+	–	+	–	–	–	I
"HELLSTÄTT" 21	T	–	+	–	–	+	–	–	–	I
"HELLSTÄTT" 20	P	●	•	–	–	–	o	+	–	R
"HELLSTÄTT" 19	P	●	•	–	–	–	–	–	–	R
"HELLSTÄTT" 4	T	+	–	–	–	–	–	–	–	I

	Type of sediment (Field evidence)	single–chambered	uniserial	bi-,tri-and multiserial	small benthonic	small planctonic	Radiolarians	Fish Teeth	Other fossils (mainly mollusc tests)	Association R Rhabdammina I Insignificant
GRÄTLI II/7	T	o	–	–	+	+	–	–	–	O
GRÄTLI II/5	T	–	–	+	+	•	o	–	+	O
GRÄTLI II/3+4	P*	•	o	–	+	o	–	–	–	O
GRÄTLI II/4	T	o	+	–	+	•*	o	–	–	O
ÄBE. IV/14	T	o	–	–	o	+	–	–	–	O
ÄBE. IV/12	T	–	–	–	+	–	–	–	–	I
ÄBE. IV/10	T	o	–	+	+	–	o	–	–	O
ÄBE. IV/1–	P	•	–	–	–	–	o	+	–	R
STÄCK. 32+	P	●	+	–	–	–	–	–	–	R
STÄCK. 29+	P*	●	+	–	+	–	–	+	–	R
STÄCK. 28+	T	o	–	–	–	–	+	–	–	I
STÄCK. 24+	T	●	–	–	–	–	–	–	+	R
SELITAL 41–	P?	•	+	–	+	–	–	–	–	R
SELITAL 40+	T	o	–	–	–	–	–	–	–	I
SELITAL 36+	P	•	+	–	–	–	–	+	–	R
SELITAL 36+	T	o	–	–	–	–	–	–	–	I
SELITAL 25–	P?	+	+	–	+	+	–	–	+	I
SELITAL 25–	T	–	–	+	+	+	–	–	–	I
SELITAL 24+	P?	o	–	–	–	–	–	–	–	I
SELITAL 24+	T	–	–	–	–	–	–	–	–	I
SELITAL 17	P	•	–	–	+	–	–	–	–	R
SELITAL 17	T	•	–	–	o	–	–	–	+	O
SCHWARZ. 44	P	●	–	–	+	+	–	–	–	R
SCHWARZ. 41	T	–	–	–	+	+	+	–	+	I
SCHWARZ. 15	P	●	+	+	o	o	–	–	–	O
SCHWARZ. 15	T	o	–	o	•	o	–	–	+	O
SCHWARZ. 9	P	o	+	+	–	–	–	–	–	R
SCHWARZ. 3	T	+	–	–	–	–	–	–	+	I

– Absent + Present (1–4 Specimen) o Rare (5–9)
• Frequent (10–19) ● Very frequent (20–)

Remarks:
Pyritized traces and small spines (Radiolarians, Sponges) neglected.
P* Contaminated with small amount of turbiditic Sediment.
* with three big Globigerinas.

Fig. 63: Tables of Foraminifera counts.

4.3.3.2 Results

Foraminiferal Number and representative value

The samples contained a mean of 17 specimens, a Foraminiferal Number (F. N.; number of Foraminifera per gram dry sediment) of about 0.1. This is a low value, compared to 4.7–44 stated by BROUWER (1965). Green shales, F. N. 0.3, contain considerably more Foraminifera than grey shales, F. N. 0.03.

The low number of Foraminifera counted lessens the representative value of the material studied, and only general trends may be inferred from the data.

Species observed

The results are listed on Figure 63, whereas Plate II illustrates some of the Foraminifera observed.

Single-chambered Foraminifera contain species from the genera *Rhabdammina/Bathysiphon* (difficult to separate, cf. BROUWER 1965, p. 317), *Psammosphaera, Ammodiscus,* and *Glomospira.* The bulk of the Foraminifera belongs to this group: 67% (75% in the green shales, and 52% in the grey shales).

Uniserial agglutinated Foraminifera contain the genera *Hormosina, Reophax, Rzehakina, Haplophragmoides,* and *Trochamminoides.* They represent 15% of the Foraminifera (19% in green shales and 6% in grey shales).

Biserial agglutinated Foraminifera are extremely rare: 2% of the counted Foraminifera (1% in green shales, and 6% in grey shales). Species belonging to the families Textulariidae and Trochamminidae have been found.

Calcareous Foraminifera, small benthonic and small pelagic forms (*Globigerina*) are present in a number of samples, often in a comparable number. They represent 16% of the Foraminifera (5% in green shales and 36% in grey shales).

Single - chambered forms

Uniserial forms   A   Biserial, triserial, and multiserial forms

▼ *Eocene (S area) (12 samples)*
▲ *Lowermost Eocene (N area) (16 samples)*
+ *Paleocene (N area) (17 samples)*
. *Maastrichtian (N area) (13 samples)*

● *Overall mean (58 samples)*
○ *Mean of supposed hemipelagic samples (26)*
× *Mean of supposed turbiditic samples (32)*

Single - chambered forms

Uniserial forms   B   Biserial, triserial, and multiserial forms

. *Samples from supposed pelagic sediment*
× *Samples from supposed turbiditic sediment*
□ *Mean of all 22 samples with Rhabdammina fauna R*
● *Mean of all (58) samples*

Fig. 64: Distribution of agglutinated Foraminifera from the Gurnigel Flysch in triangles after BROUWER (1965). *A* = mean values of all samples of groups listed in the text. *B* = single values of samples with *Rhabdammina* fauna.

Other fossils: Other than Foraminifera, the following have been found: various mollusc shell fragments, echinoid spines, fish teeth, pyritized radiolarians (Plate II, 1), and sponge spines. Pyritized traces are fairly frequent (Plate II); these can be mistaken for *Rhabdammina*, however, the latter is never pyritized.

Green shales and grey shales

The agglutinated Foraminifera observed are represented on triangles (Fig. 64 *A* and *B*) after BROUWER (1965). In Figure 64 *A*, mean values from outcrops (grouped as for heavy mineral analysis) and mean values from all green and from all grey shales, are plotted. In Figure 64 *B*, single sample values from all samples containing *Rhabdammina* fauna are given.

The data has been analysed (Table 2) to show up possible differences between samples from green shales (supposedly hemipelagic) and from grey shales (supposedly turbiditic, see 4.4.2). The samples are divided into three groups:

I: *Insignificant*, less than 10 Foraminifera.

R: *Rhabdammina fauna* (BROUWER 1965), 90% of the species observed are agglutinated Foraminifera. These samples are indicated on Figure 64 *B*.

O: *Other*, more than 10% of the species observed are not agglutinated, but calcareous (benthonic or planktonic Foraminifera).

Table 2: *Distribution of Foraminifera groups*

R	O	I	Group
22	11	25	All samples (58)
19	3	4	Samples from green shales (26)
3	8	21	Samples from grey shales (32)

The *Rhabdammina* fauna is generally present in the green shale samples, whereas an insignificant, that is diluted association (sometimes of *Rhabdammina* fauna, sometimes of "other", reworked calcareous Foraminifera) may be observed in the grey shale samples.

Stratigraphic trends

No obvious stratigraphic trend can be observed in the distribution of the Foraminifera: in practically all profils green shales are characterized by *Rhabdammina* fauna (cf. Fig. 63 and 64).

– *Maastrichtian.* From foraminiferal evidence, the sedimentation of the Gurnigel Flysch started in a deep-water, *Rhabdammina* fauna environment.

– *Upper Paleocene/Lowermost Eocene.* The *Rhabdammina* fauna is generally present in the green shales. Green shales contain *Globigerina* and benthonic Foraminifera, as well as some biserial agglutinated Foraminifera in the Schwarzenbühl profile alone. Samples from this locality show a certain carbonate content (cf. 4.4), and contain nannofossils. This might be explained by a certain filling up of the basin, or a change in the CCD (cf. 4.4). In the more southerly slices, this tendency was not observed.

– *Lutetian.* One green shale sample (combined from two layers) only was available (profile Grätli II). In spite of low carbonate content (no nannofossils), some small calcareous Foraminifera were found. Allowing that no contamination occurred, this might indicate a certain filling of the basin. There is, however, no other evidence for this suggestion.

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Other Foraminifera

Only Foraminifera from the shales have been taken into consideration. Furthermore, a wide variety of resedimented Foraminifera is present in the sandstones (turbidites), and among these, nummulites and other benthonic Foraminifera have recently been studied by KAPELLOS (1973).

4.3.3.3 *Comparisons*

The results obtained here agree with those obtained in the Gurnigel Flysch by BROUWER (1965), WEIDMANN (1968), VAN STUIJVENBERG et al. (1976), and MOREL (1978).

In other Prealpine Flysch, particularly the Fouyet Series (Simme nappe), WEIDMANN (1968) obtained similar results. These compare with the study by BROUWER (1965), which comprised the Schlieren Flysch and many extra-alpine sequences.

Comparable faunas of agglutinated Foraminifera have been described from the Eastern Alps, where benthonic Foraminifera have been closely studied for some time (e. g. GEROCH 1960, SAMUEL 1977, GRÜN in FAUPL et al. 1970, and PFLAUMANN 1967).

4.3.4 Carbonate content

4.3.4.1 *Method*

Carbonate content of sandstones, shales and limestones has been measured on the Passon apparatus (Sedimentology Laboratory of Geological Institute Berne). The apparatus measures gas pressure developed by the reaction of HCl with carbonate of the pulverized sample. Precision is to within several percent.

The calcite/dolomite ratio was measured (after MILLIMAN 1974) by x-ray analysis of pulverized samples on a Philips-diffractometer (Mineralogical Institute, Berne).

4.3.4.2 *Results*

Sandstones

Eighteen samples were measured; the mean carbonate content is 36%, with a range of 18 to 45%. No stratigraphic trend was evident.

Grey shales

Sixteen samples were measured. They yielded 20% carbonate, ranging between 7%–40%. The values from "Paleocene" samples tend to be lower than the values from the "Maastrichtian" and "Eocene" samples. A part of the grey shales is carbonate-free (HCl reaction in the field).

Green shales

Eleven samples were measured. They contained a mean of 2.8% carbonate, with a range between 0 and 9%. Most green shales tested in the field are carbonate-free.

Limestones

Three limestones from the Hellstätt Series yielded 79% carbonate; the lower Eocene limestone of Gouchheit 71%. A Cuisian limestone from the Mortive (Niremont area, MOREL 1978) yielded 73%. The results obtained are summarized in Figure 65.

Dolomite/calcite ratio

Powder preparations of all samples have been x-rayed. No dolomite peak was found in any, although thin section analysis revealed some dolomite (see below). A dolomite/calcite ratio less than 1:20 does not furnish an identifiable peak.

e^p —— ■ 3%

e^t —— 20%

d

c —— 36%

b

a

0 10 20 30 40 50%

Bouma-Cycle   CARBONATE CONTENT
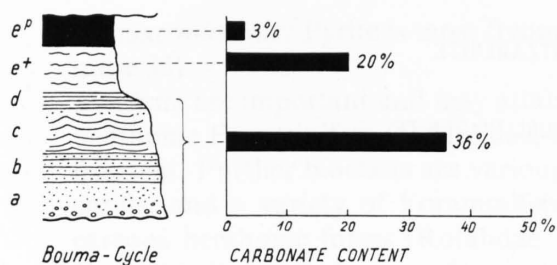
Fig. 65: Mean carbonate contents of sandstones (T_{abcd}), grey shales (T_{et}) and green shales (T_{ep}) from the Gurnigel Flysch.

4.3.4.3 *Discussion*

Figure 65 strongly suggests that the sedimentation of the Gurnigel Flysch took place in a deep, carbonate-free environment, into which carbonate-bearing turbidites (sandstones and shales) were fed. Post-depositional leaching of carbonate from the upper part of the grey shales has also taken place. The explanation of these observations by interstitial fluid flow through the sandstones overlying the shales is not valid. Green shales are by far more frequent in thin-bedded sequences, and are often absent under thick sandstones.

Similar observations and conclusions have been made in the Helminthoid Flysch of the Apennine (SCHOLLE 1971), and in the Rheno-Danubian Flysch (HESSE 1975).

4.3.5 Thin section observations

4.3.5.1 *Limestones*

Limestones from the Hellstätt Series are very fine micritic Fe-bearing mudstones (Plate III, 6). In the lower, laminated and coarser part of "Hellstätt" 8, small current selected chambers of *Globigerina* or *Hedbergella,* some quartz, clay, and organic fragments are present.

The Gouchheit Limestone is a wackestone with 0.150 mm clasts (recrystallized radiolarians, *Globigerina,* some quartz, muscovite and glauconite) in a micritic, Fe-bearing matrix.

4.3.5.2 *Sandstones*

Composition has been estimated visually, and is shown on Figure 66, in a Quartz–Feldspar–Rock Fragment triangle after FOLK (1968).

Quartz

Quartz comprises all types of quartz including metaquartzite (Chert is grouped with rock fragments).

- *Common quartz* is dominant (cf. Plate III, 1–4). It may be monocrystalline or polycrystalline. Undulatory extinction is frequent.
- *Volcanic quartz* is present in all thin sections, but less frequent than common quartz. Sharp extinction and habitus are characteristic (cf. Plate IV, 2).
- *Sedimentary quartz,* rarely present, shows old overgrowths.
- *Quartzite* and *dike quartz* are rare.

Quartz grains are generally subangular to angular, sometimes (well-)rounded. Overgrowths, other than inherited, have not been observed.

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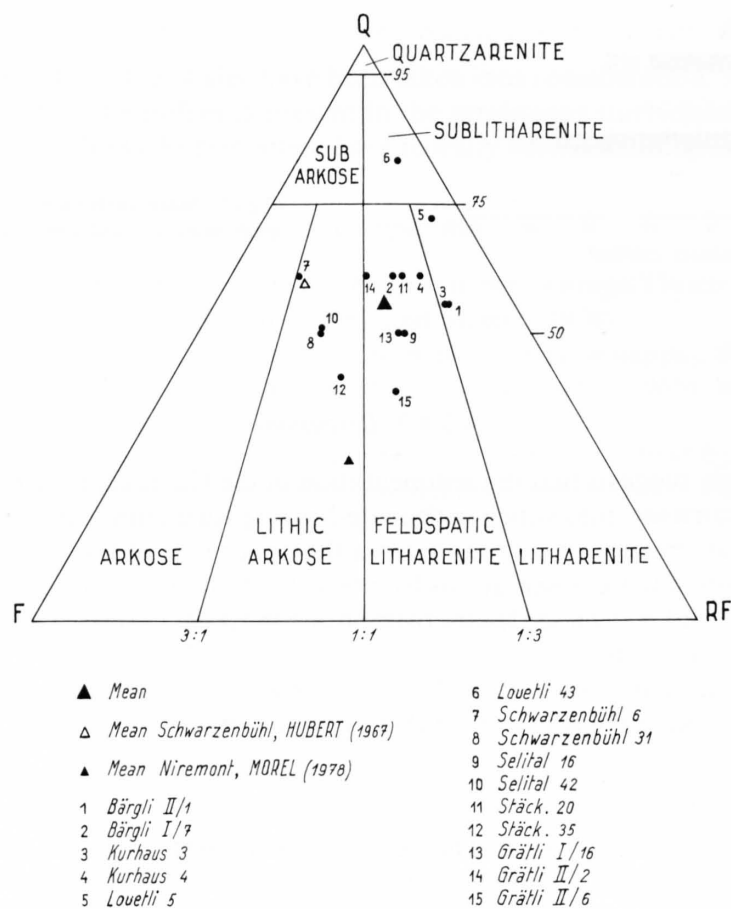
Fig. 66: Composition of sandstones from the Gurnigel Flysch; triangle after FOLK (1968).

Legend:

▲ Mean

△ Mean Schwarzenbühl, HUBERT (1967)

▲ Mean Niremont, MOREL (1978)

1	Bärgli II/1	6	Louelli 43
2	Bärgli I/7	7	Schwarzenbühl 6
3	Kurhaus 3	8	Schwarzenbühl 31
4	Kurhaus 4	9	Selital 16
5	Louelli 5	10	Selital 42
		11	Stäck. 20
		12	Stäck. 35
		13	Grätli I/16
		14	Grätli II/2
		15	Grätli II/6

Feldspar (together with granite and gneiss fragments)

– *Orthoclase* is perthitic. According to Dr. T. Küpfer, who checked determinations of granitic and volcanic components, they are of typical plutonic character. A myrmekitic structure (K-feldspar/Q) was observed in one thin section (Selital 42).

– *Plagioclase* (albite and oligoclase) is less frequent than orthoclase.

– *Granite* fragments are more frequent than *Gneiss* fragments. Some feldspars are weathered, whereas others are fresh.

Rock fragments

– *Volcanic rocks:* acide porphyrites with quartz and feldspar phenocrysts (Plate IV, 2). Smaller grains, showing porphyrite matrix only, may sometimes be confused with chert fragments.

– *Metamorphic schists* are rare.

– *Sediments* are common: cherts, dolomites, sparitic and micritic limestones of a wide variety, e.g. *Radiolaria–Globochaete–Saccocoma* biomicrite (typical Malm facies), *Globotruncana* biomicrite (Upper Cretaceous). Shales and mudstones are very frequent; they are often difficult to distinguish from clay matrix.

Other components

– *Mica* is ubiquitous but rare (1–2%). Muscovite is much more common than biotite (sometimes chloritized, Plate IV, 1).

– *Glauconite* is also ubiquitous but rare (1–2%). More glauconite is present in the Paleocene sandstones than in the others.

– *Opaque minerals:* Pyrite is most frequent, normally rare, but exceptionally up to 20% (Stäck-hütte 35).

– *Bioclasts* are important and may attain 20% or more in some thin sections. Bryozoans, larger benthonic Foraminifera (Orbitoidae, Nummulitidae), and algae (*Lithothamnium*) are the most frequent. Further bioclasts are various shell fragments, echinoderms, gastropods, some single corals, and a variety of Foraminifera: planktonic forms (*Globigerina, Globotruncana*), calcareous benthonic forms (Rotalidae, rare Miliolidae), and agglutinated forms. Dr. Michèle Caron kindly verified a part of these determinations.

Cement and matrix

Cement and matrix make up 15–20% of the sandstones. Distinction of the two is sometimes difficult, as micritic matrix may be recrystallized. The same holds for the distinction clay matrix –shale fragments (cf. DICKINSON 1970). Volumetrically, cement is more important than matrix.

The cement has a blocky texture, and consists of Fe-calcite (Plate III, 1–2). In coarser sands, cement is generally more abundant than in finer sandstones which have more matrix.

The matrix ranges between 0 and 10% (or more) in proportion and consists of clay, quartz, shale, and limestone fragments (Plate III, 3–4). The matrix content is more important than suggested by HUBERT (1967), and RECH-FROLLO (1959), who only commented on the presence of cement.

Diagenetic phenomena

General observations only are given here. Prof. A. Matter kindly checked the observations on diagenetic phenomena, and on cement/matrix problems.

– *Compaction* is demonstrated by bending of mica's (Plate IV, 1) and by frequent solution of bioclasts (Plate IV, 3).

– *Overgrowth:* Some echinoid fragments show overgrowth rims, whereas bioclasts exceptionally show an early drusy cement of iron-free calcite (Plate IV, 4).

– *Cementation* is probably related to the solution of bioclasts and limestone fragments (Plate IV, 3). The abundance of pyrite suggests formation in reducing conditions. The presence of re-worked lithified blocks of Gurnigel Sandstone in some thick beds is an argument in favour of early cementation.

– *Replacement:* Quartz and feldspar have apparently been replaced by calcite cement at a later stage (Plate IV, 2); quartz has also been precipitated as chalcedony in nummulites and other bioclasts (Plate IV, 5–6).

– *Dolomite formation:* Dolomite rhombohedrons have sometimes grown within the cement (Plate III, 5).

Summary and comparisons

The Gurnigel Sandstones are mineralogically and texturally immature. According to FOLK's (1968) classification, they are immature feldspathic litharenites, lithic arkoses, and litharenites (+ one sublitharenite) (Fig. 66).

The values stated here for the mean composition of the sandstones of the Schwarzenbühl quarry fit well with the values stated by HUBERT (1967) for the same outcrop.

The sandstones of the Niremont area (MOREL 1978, HUBERT 1967) have a noticeably lower quartz content than those of the Gurnigel area.

4.3.5.3 Conglomerates

Lithoclasts of 10 pebbly sandstones and conglomerates have been studied in thin section. Dr. M. Weidmann (Lausanne) kindly checked the results, which revealed the same rock types as in the sandstones; according to M. Weidmann, none of these are specific for a particular alpine paleogeographic realm.

Lithoclast types

The following components can be listed:

- Basement: granites, gneisses, and crystalline schists.
- Permo-Triassic (?): acid volcanic porphyrites.
- Triassic: dolomites, arkoses, quartzites, certain limestones (?).
- Liassic, Dogger: shales (?) and limestones (?).
- Malm, Lower Cretaceous: pelagic limestones, cherts.
- Upper Cretaceous: pelagic limestones of "Couches rouges" or "Scaglia" type.

Further research in better suited areas (with more abundant conglomeratic facies, e.g. Berra–Schwyberg or Voirons), should reveal a more complete series of basement and Mesozoic rocks.

4.4 Interpretation

4.4.1 Sedimentation rate

Due to imprecision of thicknesses measured and apparent ages, an overall value only can be given: 1200 m in 20 my, or 6 cm/1000 years. This is based on actual hardrock (compacted) data, and may therefore have been double during sedimentation. The contribution of the hemipelagic sedimentation (green shales) to this value is less than 5%, or about 0.3 mm/1000 years. Comparable values have been found in the Schwyberg area (KAPELLOS 1973), in the Niremont area (MOREL 1978), and in the Pléiades–Fayaux area (WEIDMANN et al. 1977).

4.4.2 Sedimentary environment

The characteristics of the green shales (capping turbidite cycles, extremely low carbonate content, *Rhabdammina* fauna, green colour) confirm the hypothesis that they are the basinal, "hemipelagic" sediment of the Gurnigel Flysch, as suggested by HUBERT (1967).

The green shales have been deposited in a (bathyal-)abyssal environment, below the Carbonate Compensation Depth (CCD). Globigerinas and nannofossils have been dissolved, and only clay "rainfall" and some radiolarians reached the bottom, where agglutinated Foraminifera and some trace fossils found sufficient living conditions. The environment was reducing as indicated by the presence of organic matter, pyrite, and the green colour of the shales. Occasionally the sediment/water interface reached the CCD (or the CCD was lowered). This suggests that deposition took place not too far below the CCD. The position of the CCD varied during the Tertiary (BERGER & WINTERER 1974), but a sedimentation depth between 2.5 and 5 km seems reasonable.

The green colour can be explained by the presence of clay minerals such as illite and chlorite; whereas the grey colour of the turbiditic shales could be due to the presence of scattered organic matter and finely disseminated pyrite (cf. discussion in BLATT et al. 1972, p. 398). This explanation confirms WEIDMANN's (1967) observations. A reddish colour of the shales would have resulted in the case of an oxidizing environment.

The distinction between green shale and grey shale as indicative of hemipelagic sedimentation may sometimes be misleading; green shales may have been eroded and resedimented by turbidity currents; some turbidites may be poor in organic matter; if organic matter is graded, it may be absent in the uppermost part of the turbiditic shale; bioturbation can lessen the differences, which may also be masked by weathering.

Comparisons. – Very similar reasoning has been made for the Helminthoid Flysch of the Apennines (SCHOLLE 1971), and for the Rheno-Danubian Flysch (HESSE 1975).

4.4.3 Sedimentary controls and evolution of sedimentation

Composite sedimentological profiles are shown on Figure 51; Figure 67 illustrates the development of the sedimentation.

Three factors have controled the sedimentation of the Gurnigel Flysch: 1) tectonics, 2) sea level changes, and 3) growth of deep-sea fan system.

4.4.3.1 *Tectonics*

The Gurnigel Flysch was deposited in a deep oceanic [1] basin over a period of more than 20 my. In the source area, the "Habkern massif", a Mesozoic sedimentary series and its crystalline basement were subjected to erosion. This general situation might be explained by tectonic influence causing uplift in the source area, and subsidence of the basin. It is an open question as to whether this was due to progressive installation of a compressional regime or not, and as to whether the Habkern massif was deformed (underthrusted) during an Upper Cretaceous tectonic phase, to be later subjected to uplift during the Tertiary.

4.4.3.2 *Sea level changes*

Two sea level changes may be inferred from the accumulation of the Gurnigel Flysch: sea level lowering during the Danian (Lower Paleocene), and sea level rise during the Ilerdian (Lowermost Eocene).

The Danian sea level lowering is mainly documented by the general sandstone progradation during the Paleocene. The shelf became emerged, and sand was transported from the (high relief) land-mass strait into the basin. Several detailed observations fit with this picture: reworking of Cretaceous nannofossils into the Danian shales; reworking of Cretaceous (?) glauconite, first abraded by wave action and then re-deposited as Paleocene turbidite sandstones. Additional modifications are the change from kaolinite–chlorite-bearing clay minerals to practically kaolinite–chlorite-free clay minerals during the Thanetian (change from chemical to mechanical erosion?), and higher content of staurolith in the heavy minerals of the Paleocene sandstones.

The Ilerdian sea level rise is illustrated by the change of lithology; sandstones give way to shales. It is suggested here that a shelf area was submerged during the Ilerdian, and a wide neritic sea with nummulites, bryozoans, algae, etc. came into existence [2]. Sand was less abundant (lower relief), and was trapped on the shelf. The type of sedimentation of the Gurnigel Flysch thus changed. When a new equilibrium was reached (end of the Ilerdian), sedimentation continued with organoclastic sands and mud (the presence of amber in the Ilerdian of the Gurnigel Flysch fits into the picture with destruction of coastal vegetation by the transgressive sea).

Remark: Plate tectonics furnish an explanation of sea level changes by acceleration or slackening of spreading rates (HAYS & PITTMAN 1973). According to these authors a period of accelerated sea floor spreading creates a wider surface of younger, shallower ocean; the oceans overflow, and transgression occurs on the continental margins. On the other hand, long periods of low sea floor spreading rates would lead to continued sinking of ocean floors, resulting in a regressive tendency on the margins. As a result, changes in spreading pattern of the Atlantic Ocean (PITTMAN & TALWANI 1972;

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[1] Oceanic in sedimentological sense: the basement is not known.

[2] The evolution of nummulites during the Early Eocene may be related to widespread development of shallow shelves, amongst other factors such as a warmer climate.

now visible

High stand sea level

PENNINIC-LIGURIAN OCEAN

wide shelf

CCD

HABKERN MASSIF

Oceanic basin

slope

Continental crust (granites, gneisses, micaschists), acid volcanics, and mesozoic sedimentary cover.

4. CUISIAN

now visible

Sea level rise

PENNINIC-LIGURIAN OCEAN

Flooding of shelf

CCD

HABKERN MASSIF

Oceanic basin

slope

Continental crust (granites, gneisses, micaschists), acid volcanics, and mesozoic sedimentary cover.

3. ILERDIAN

now visible

Low stand sea level

PENNINIC-LIGURIAN OCEAN

narrow shelf

CCD

HABKERN MASSIF

Oceanic basin

slope

Continental crust (granites, gneisses, micaschists), acid volcanics, and mesozoic sedimentary cover.

2. DANIAN - THANETIAN

now visible

High stand sea level

PENNINIC-LIGURIAN OCEAN

wide shelf

CCD

HABKERN MASSIF

Oceanic basin
Basement not known

slope

Continental crust (granites, gneisses, micaschists), acid volcanics, and mesozoic sedimentary cover.

1. MAASTRICHTIAN -DANIAN

Fig. 67: Evolution of sedimentation of the Gurnigel Flysch. For explanation see text.

DEWEY et al. 1973) may have had a double influence on alpine sedimentation: by change of the tectonic conditions (tensional, lateral or compressive), and also by sea level variations.

In the case of the Gurnigel Flysch, the changes of plate movements at 63 my (Cretaceous/Tertiary boundary), and 53 my (Ilerdian) (DEWEY et al. 1973) therefore may have influenced the tectonic framework, as well as the relative sea level.

4.4.3.3 Deep-sea fans

Deep-sea fan systems developed under this control of tectonics and sea level changes.

- During the Maastrichtian and Danian, basin plain conditions ruled, with sedimentation from two sources dispersed by classical turbidity currents. These also brought some conglomerates into the basin so that the slope may not have been far away.
- During the Paleocene, sandstone progradation took place by outbuilding of submarine fans. These sands derived from one source. Progradational lobes were followed by channels, bringing sand still further into the basin. By the end of the Paleocene, a sandstone dominated Mid Fan environment was emplaced.
- During the Ilerdian, the development of the fan slackened, as stated above. By the end of the Ilerdian, minor progradation (Oschoube, Äbegraben I), and "channel progradation" (Äbegraben II) illustrate renewal of fan activity. A warmer climate and the change from mechanical to chemical weathering both explain the kaolinite increase (top Schwarzenbühl, top Selital, Stäckhütte, cf. Fig. 57 and 58), and possibly the diminishing amount of staurolith among the heavy minerals.
- During the Cuisian, channelized Mid Fan conditions ruled, in a now shale dominated environment. These conditions were maintained during the Lutetian.

How many fans?

SCHÜPBACH & MOREL (1974) suggested a single fan between Voirons and Schlieren Flysch. This is, however, difficult to reconcile with the more recent data. The development of both the Gurnigel and the Schlieren Flysch sedimentation is extremely similar to that of the Voirons Flysch, which does have a more proximal character. A system of several minor fans would more easily explain the simultaneous response to changes of conditions. This suggestion is supported by the petrographic differences between Gurnigel and Niremont (quartz content, heavy mineral content), and the petrographic particularities of the Gurnigel area (abundant granites) and the Berra area (abundant porphyrites) as stated by SARASIN (1892, 1894). No major channels relating the Gurnigel area and the Schlieren Flysch area may be inferred from the available data. Certainly none existed during the Maastrichtian and Danian.

4.4.3.4 Other factors

Additional controls, climatic changes in particular, but also changes of CCD or of current pattern in the basin and Coriolis effect (e.g. RUPKE 1977) may be imagined. They are generally considered to have been of minor importance.

4.4.3.5 Comparisons

Within the *Gurnigel Flysch*, a comparable evolution of the sedimentation took place in the Niremont–Pléiades area (MOREL 1978, WEIDMANN et al. 1977). In the Schwyberg–Berra area, the scarce available data also suggests a similar sequence.

In the *Voirons* area, the Maastrichtian and Paleocene are similar; during the Eocene, however, differences appear with the development of a conglomeratic Inner Fan environment.

The *Schlieren Flysch,* generally more sandy, shows a very similar sequence, as far as can be judged from SCHAUB's (1951, 1965) observations, as well as from WINKLER's (thesis in preparation) preliminary data.

The *Reidigen Series* and associated structural slices at the base of the Upper Prealpine nappes show a similar development of Maastrichtian, Danian and Thanetian sections.

4.4.4 Width of basin and source area

On a given transect of the study area, 5 of 6 slices have been distinguished. Admitting a length of 3 km for each slice, the Gurnigel Flysch as at present represents a width of at least 15 km. The real figure is probably considerably larger for several reasons:

- gaps between the slices are probably present;
- clasts of possible Gurnigel Flysch facies have been observed in the Molasse (Chattian to Tortonian) (SCHMID 1970; cf. Ultrahelvetic relief, STAUB 1934, and GASSER 1968);
- remnants of the Gurnigel Flysch are still present in the synclines of the Median Prealps ("Sarine nappe");
- the most proximal facies (Inner Fan), and the most distal facies (Eocene basin plain) of the Gurnigel Flysch have not been preserved.

For these reasons the Gurnigel Flysch may have originally covered a strip of 40 km width or more. The thickness of the Gurnigel Flysch being 1200 m (study area), the width of the eroded continental area (Habkern massif) may be estimated as 50 km (eroded 1 km deep), or 25 km (eroded 2 km), possibly more. A shelf area of 0–20 km may have been situated between land and basin. Width of basin, shelf, and source area thus may have been some 75–100 km. This is, of course, a rough approximation, based on many uncertanties and suppositions. HSÜ & SCHLANGER (1971) arrived at comparable figures: 130 km for the couple southern half of the Habkern Island, and Gurnigel Flysch basin. Their calculations were mainly based on comparison with dimensions of modern basins.

5. Origin of the Gurnigel Flysch

5.1 Introduction, previous work

Until recently, the Gurnigel Flysch was generally thought to be of Ultrahelvetic or North-Penninic origin (TRÜMPY 1960, KLAUS 1966, HERB & LEUPOLD 1966). CROWELL (1955), on the base of flute cast measurements, confirmed the presence of a crystalline South-Helvetic swell, separating Helvetic and Ultrahelvetic, and shedding clasts towards the SE into the Ultrahelvetic (or even North-Penninic) realm, thus feeding the Gurnigel Flysch (LEUPOLD 1943). HSÜ (1960) suggested the existence of a Habkern swell within the Ultrahelvetic realm, south of the South-Helvetic on the basis of different current directions in the Schlieren Flysch and Gurnigel Flysch. The two sequences were deposited to the north and to the south of this Habkern swell. TRÜMPY (1960) suggested a lateral change of current directions, with both flysch being sedimented S of the Habkern massif. HUBERT (1967) followed TRÜMPY's opinion (1960) whereas HSÜ & SCHLANGER (1971) followed HSÜ's ideas. HSÜ (1972) placed the so-called Ultrahelvetic flysches in a "mediterranean plate tectonic framework".

Recently, CARON (1972, 1976) and HOMEWOOD (1974, 1977) showed the incompatibility of an Ultrahelvetic, or North-Penninic origin for the Gurnigel Flysch. CARON (1972, 1976) pointed out the close relationship of the Gurnigel nappe, and the Sarine nappe (lowermost element of the Upper Prealpine nappe, = Simme nappe s.l.), suggesting an ultra-Briançonnais, or ultra-Penninic origin of the Gurnigel nappe.

5.2 Origin of the Gurnigel Flysch

5.2.1 The South-Penninic–Ligurian realm as origin of the Gurnigel nappe

With the elimination of the Ultrahelvetic and North-Penninic realms as a possible origin of the Gurnigel Flysch, the Briançonnais (e. g. Median Prealps) and the Pre-Piemontais (Breccia nappe) have to be left out of consideration as well on account of their Upper Cretaceous and Tertiary pelagic limestones ("Couches rouges"). The origin of the Gurnigel Flysch has thus to be looked for in the broad South-Penninic (Piemont) – Ligurian realm. Many problems concerning the paleogeography of this realm have still to be resolved (TRÜMPY 1975b, 1976; DEBELMAS 1975a, 1975b; DAL PIAZ 1974). Most authors agree that an important Cretaceous orogeny (eo-alpine phase) has taken place (TRÜMPY 1975b, DAL PIAZ et al. 1972, J. M. CARON 1977). This orogenesis consisted of subduction of a part of the South-Penninic–Ligurian Ocean under the South-Alpine foreland. Abrasion of the Habkern massif and sedimentation of the Gurnigel Flysch took place within the context of the paleogeography formed after this eo-alpine phase.

5.2.2 Possible basins

Two (para)oceanic basins can be taken into consideration as possible areas for the accumulation of the Gurnigel Flysch: the Canavese and the Piemont (cf. DEBELMAS 1975b, Fig. 3). The Canavese has undergone Upper Cretaceous high pressure metamorphism (DAL PIAZ et al. 1972, HUNZIKER 1974), and may therefore be eliminated. In the Piemont, the zone Saas Fee–Zermatt has also undergone Upper Cretaceous high pressure metamorphism, whereas the Combin zone was spared. The original relationship between these two zones has not been preserved.

5.2.3 Possible Habkern massifs

Taking the possibility of important tectonic rotations of a rootless unit such as the Gurnigel nappe into consideration, three possibilities for the location of the Habkern massif can be envisaged: the northern margin of the Piemont–Ligurian "Ocean", its southern margin, or an intra-oceanic continental craton.

1. If the Gurnigel Flysch has indeed been deposited from a northern margin as the current directions suggest, the Monte Rosa nappe, Gran Paradiso and Dora Maira, as well as a possible former continuation as Corsica (cf. ALVAREZ 1976, WESTPHAL et al. 1976) can be considered. Red granites are absent within the Monte Rosa nappe, and Tertiary limestones (Couches rouges) have been deposited in the Breccia nappe which may represent some of its sedimentary cover. This solution is therefore fairly improbable. Corsica, where red granites, and a Tertiary shelf (neighbouring the Ligurian "Ocean") are known, merits serious consideration as a possible "Habkern" massif.

2. If the Gurnigel Flysch was deposited from a southern margin, the Insubrian zone might be a possible source. Clastics could have been furnished into the Canavese basin, or more likely (ac-

cepting subduction of Canavese, Sesia, and Dent Blanche during the Upper Cretaceous, DAL PIAZ et al. 1972, HUNZIKER 1974) directly into the remaining part of the Piemont "Ocean". Within this context, the underthrusting of the Sesia – Dent Blanche would have caused the uplift of the "Insubrian ridge" (DEBELMAS 1975 a, p. 1008), and red granites which have been compared to the Habkern Granite (SARASIN 1892) are well known from the Southern Alps. As rocks of the Ivrea zone, which are absent in the Gurnigel Flysch, might not yet have been subjected to erosion during the Eocene, this solution cannot be ruled out "a priori".

3. The Dent Blanche – Sesia could have served as intra-oceanic craton between Piemont and Canavese (DEBELMAS 1975 a). Red granites do exist in the Dent Blanche nappe (P. Bearth, pers. comm. 1977). This solution seems very unlikely, as it would be incompatible with the well documented Upper Cretaceous high pressure metamorphism and subduction (DAL PIAZ et al. 1972). The lack of rocks of Valpelline type in the Gurnigel Flysch is relevant in this respect.

In the case of each of the possibilities evoked, remnants of the Habkern massif should still be visible. Other solutions are possible, if one accepts the possibility of complete disappearance of the Habkern massif craton by erosion, by subduction, or by lateral movements (DEBELMAS 1975 a, TRÜMPY 1976).

5.3 The Gurnigel nappe

Expulsion of the nappe

At the end of the Eocene, the residual Tethyan Ocean was completely consumed, and continental collision of the South-Alpine Insubrian Plate and the European foreland took place (DEWEY et al. 1973). During this phase, the Gurnigel Flysch was detached from its basement, along with other (upper) Prealpine nappes.

Gravity sliding and formation of wildflysch

A phase of probably gravity controlled sliding towards the external, Helvetic realm then followed. During this phase, formation of the wildflysch took place in a deep-water environment (SCHARDT 1893, CARON 1966). Elements of Briançonnais, Ultrahelvetic "diverticules", and Helvetic origin which are present in the wildflysch, were dragged along with the Gurnigel nappe. Traces of this passage are still preserved in the synclines of the Klippen nappe (Median Prealps).

Arrival and more recent deformations

After this sliding phase the Gurnigel nappe came to rest somewhere on the (North-)Helvetic realm, followed by the other Prealpine nappes. During the Neogene further deformation led to the actual situation.

6. Conclusions

The flysch of the eastern part of the Gurnigel nappe (Prealps) consists of a 1200 m thick series of alternating sandstones and shales, with intercalated conglomerates and limestones. These were deposited from Maastrichtian to Middle Eocene in a deep-marine basin. Agglutinated Foraminifera (*Rhabdammina* fauna) populated the floor of this basin, below the CCD.

Clastics were delivered from a shelf and from a land area (Habkern massif), consisting of continental crust and its Mesozoic cover. Larger benthonic Foraminifera (e. g. nummulites), bryozoans and algae flourished on the shelf. Intensive weathering in a moderate to subtropical climate took place on the landmass.

During the Maastrichtian, the Gurnigel Flysch of the area studied was deposited in a basin plain environment. During the Paleocene, a sand dominated deep-sea fan system developed, connected with a sea level fall causing increased erosion and sand production. The sandstone dominance and fan activity was broken off during the Ilerdian, due to a sea level rise causing flooding of the shelf, and decreasing erosion and sand production. By the end of the Ilerdian, fan activity was renewed, now characterized by shales and organoclastic sandstones.

The paleogeographic situation of the basin and the Habkern massif has not yet been established in detail. Corsica, the Insubrian ridge, or some other continental area may be identified with the Habkern massif, which fed clastics into the remnant of the Piemont "Ocean" left after the Cretaceous eo-alpine orogeny.

Expulsion of the Gurnigel nappe from its basin took place by the end of the Priabonian, during the meso-alpine orogeny. After that the nappe slid, probably gravity controlled, forward to the North-Helvetic realm, where it arrived during the Oligocene. On the way the wildflysch was formed.

After its arrival (mise en place), the Gurnigel nappe underwent younger deformations (neo-alpine orogeny), resulting in the present sliced and faulted series.

Summary

This geological study of the External Prealps covers a surface of 60 km^2 in the cantons of Berne and Fribourg, Switzerland. The main effort focussed on stratigraphic, structural, and sedimentological analysis of the Gurnigel Flysch, although the underlying wildflysch was also investigated.

Stratigraphy

The Gurnigel Flysch is formed by a more than 1000 m thick sequence of sandstones and shales with subordinate conglomerates and limestones. The sequence, dated as Maastrichtian to Lutetian, has been subdivided into six mapped biostratigraphic units by means of calcareous nannofossils. An informal lithostratigraphy is proposed.

Structure

The stratigraphic subdivisions combined with structural observations reveal the tectonics of the Gurnigel nappe. The latter is composed of six thrust sheets, which are laterally interrupted by faults. The general structure is interpreted as the result of "crustal subduction" and contemporary wrench faults.

Sedimentology

The sedimentology was established through field observations (mainly measured profiles), laboratory investigations (heavy minerals, clay minerals, carbonate content, and thin section observations), as well as from a comparative study of the Foraminifera. The Gurnigel Flysch is shown to have been deposited in a deep-marine basin below the Carbonate Compensation Depth (CCD). Agglutinated foraminifers of *Rhabdammina* fauna typical of this environment are described. Sedimentary environment evolved from a deep-marine basin to a deep-sea fan. This evolution was controlled by tectonic influences and sea level changes. The source of detritus of the Gurnigel Flysch was formed by a shallow-marine shelf and a land area (Habkern massif), comprising both continental crust and a Mesozoic cover.

Wildflysch

The wildflysch is dated as Priabonian at the oldest (possibly Early Oligocene) by means of calcareous nannofossils. Matrix and components of the wildflysch (Mesozoic slices and/or olistoliths, conglomerates, granites and others) are briefly described.

Paleogeographic origin

The Piemont–Ligurian realm is suggested to be the paleogeographic origin of the Gurnigel nappe, whereas more precise, but hypothetical locations are discussed.

Résumé

Cette étude géologique des Préalpes externes couvre une superficie de 60 km², à la limite des cantons de Berne et Fribourg, Suisse. Les efforts ont été concentrés sur l'analyse stratigraphique, structurale et sédimentologique du Flysch du Gurnigel; une partie concerne le wildflysch sous-jacent.

Stratigraphie

Le Flysch du Gurnigel se compose d'une série épaisse de plus de 1000 m, formée de grès, calcaires argileux et argilites, avec des conglomérats et calcaires subordonnés. A l'aide des nanno-fossiles calcaires, la série, datée du Maastrichtien au Lutétien, a pu être subdivisée en six unités bio-stratigraphiques, cartographiées. Une subdivision lithostratigraphique informelle est établie.

Structure

La subdivision stratigraphique jointe aux observations tectoniques permettent une subdivision structurale de la nappe du Gurnigel. Celle-ci est formée de six écailles qui sont latéralement interrompues par des failles. Ces structures sont interprétées comme le résultat d'une "subduction crustale" et de décrochements contemporains ("wrench-faults").

Sédimentologie

Les recherches sédimentologiques comprennent des levés de terrain (essentiellement des levés de coupes), des recherches de laboratoire (minéraux lourds, minéraux argileux, calcimétrie et observations de coupes minces), ainsi qu'une étude comparative des foraminifères. Le Flysch du Gurnigel a été déposé dans un bassin marin profond en dessous du niveau de compensation des carbonates (CCD). Des foraminifères agglutinés d'une faune à *Rhabdammina* typiques de ce milieu y sont décrits. La sédimentation a évolué d'une plaine sous-marine ("Basin plain") à un cône sous-marin profond ("Deep-sea fan"). Ce développement a été contrôlé par des influences tectoniques et des variations du niveau de la mer. La source des apports du Flysch du Gurnigel était constituée par un plateau continental (shelf) et une région émergée (massif de Habkern) comportant croûte continentale et couverture mésozoïque.

Wildflysch

A l'aide des nannofossiles calcaires, le wildflysch est daté du Priabonien (éventuellement de l'Oligocène inférieur). La matrice et les composants du wildflysch (écailles et/ou olistolithes mésozoïques, conglomérats, granites et autres) sont décrits brièvement.

Origine paléogéographique

Le domaine piémontais–ligure est proposé comme origine paléogéographique de la nappe du Gurnigel. Des attributions plus précises mais hypothétiques sont esquissées.

Zusammenfassung

Die vorliegende geologische Beschreibung der "Préalpes externes" bezieht sich auf ein Gebiet von 60 km², das in den Kantonen Bern und Freiburg, Schweiz, gelegen ist. Schwerpunkte der Arbeit bilden stratigraphische, strukturelle und sedimentologische Untersuchungen des Gurnigel-Flyschs, wobei aber auch der liegende Wildflysch berücksichtigt wurde.

Stratigraphie

Der Gurnigel-Flysch besteht aus einer über 1000 m mächtigen Abfolge von Sandsteinen, Mergeln und Tonsteinen, mit untergeordneten Konglomeraten und Kalken. Mit Hilfe der kalkigen Nannofossilien konnte die als Maastrichtien bis Lutétien datierte Abfolge in sechs biostratigraphische Kartiereinheiten gegliedert werden. Eine informelle lithostratigraphische Gliederung wird aufgestellt.

Struktur

Die stratigraphische Unterteilung, kombiniert mit tektonischen Beobachtungen erlauben eine strukturelle Gliederung der Gurnigel-Decke. Diese ist aus sechs Schuppen aufgebaut, welche seitlich durch Brüche versetzt sind. Diese Strukturen werden interpretiert als das Ergebnis von "Crustal subduction" und gleichzeitigen Blattverschiebungen ("wrench faults").

Sedimentologie

Die sedimentologischen Untersuchungen umfassen Feldaufnahmen (hauptsächlich Profilaufnahmen), Laboruntersuchungen (Schwermineralien, Tonmineralien, Calcimetrie und Dünnschliff-Beobachtungen) sowie vergleichende Studien an Foraminiferen. Der Gurnigel-Flysch wurde in einem tiefmarinen Becken unterhalb der Kompensationstiefe für Karbonate (CCD) abgelagert. Agglutinierte Foraminiferen einer für dieses Milieu typischen *Rhabdammina*-Fauna werden beschrieben. Die Sedimentation entwickelte sich von einer Beckenebene ("Basin plain") zu einem "Deep-sea fan". Dieser Vorgang wurde von tektonischen Einflüssen und Meeresspiegel-Schwankungen kontrolliert. Das Liefergebiet für den Gurnigel-Flysch bestand aus einem Schelf und einem Landgebiet (Habkern-Massiv), aufgebaut aus kontinentaler Kruste und deren mesozoischer Bedeckung.

Wildflysch

Mit Hilfe der kalkigen Nannofossilien lässt sich der Wildflysch als Priabonien (eventuell als Unteroligozän) datieren. Die Matrix und die Komponenten des Wildflyschs (mesozoische Schürflinge und/oder Olistholithe, Konglomerate, Granite usw.) werden kurz beschrieben.

Paläogeographische Herkunft

Als paläogeographischer Herkunftsort der Gurnigel-Decke wird der piemontesisch-ligurische Bereich angenommen. Weitergehende, jedoch hypothetische Zuordnungen werden kurz angedeutet.

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Plate I

Calcareous nannofossils from the Gurnigel Flysch

Enlargement × 2000

Fig. 1. *Micula staurophora* (GARDET) STRADNER, VS 76/866, G. F., Einberg 1, "Danian", NP 1–4 (reworked).

Fig. 2. *Arkhangellskiella cymbiformis* VEKSHINA, VS 76/754, G. F., Honeggwald (Gürbe valley), "Maastrichtian".

Fig. 3. *Nephrolithus frequens* GORKA, VS 69/0028, G. F., northwest of Rotmoos, "Maastrichtian".

Fig. 4. *Ericsonia cava* (HAY & MOHLER) PERCH-NIELSEN, VS 76/866, G. F., Einberg 1, "Danian", NP 1–4.

Fig. 5. *Cruciplacolithus notus* PERCH-NIELSEN, VS 74/105, G. F., north of Ober Gurnigel, "Thanetian", NP 5.

Fig. 6. *Chiasmolithus bidens* (BRAMLETTE & SULLIVAN) HAY & MOHLER, VS 76/359, G. F., Einbergstrasse, "Thanetian", NP 5.

Fig. 7. *Fasciculithus involutus* BRAMLETTE & SULLIVAN, VS 76/639, G. F., southwest of Schaleberg, "Thanetian", NP 5.

Fig. 8. *Heliolithus kleinpelli* SULLIVAN, VS 8611/0905, G. F., Höllbach road south of Allmet (Schwyberg area), "Thanetian", NP 6.

Fig. 9. *Discoaster gemmeus* STRADNER = *D. mohleri* BUKRY & PERCIVAL, VS 75/272, G. F., Wissenbach, Gouchheit area, "Thanetian", NP 8.

Fig. 10. *Discoaster nobilis* MARTINI, VS 76/822, G. F., Schwarzenbühl 15, "Ilerdian", NP 9.

Fig. 11. *Heliolithus* cf. *riedeli* BRAMLETTE & SULLIVAN, VS 75/272, G. F., Wissenbach, Gouchheit area, "Thanetian", NP 8.

Fig. 12. *Heliolithus riedeli* BRAMLETTE & SULLIVAN, RJC 1286, G. F., Voirons area.

Fig. 13. *Discoaster multiradiatus* BRAMLETTE & RIEDEL, VS 76/822, G. F., Schwarzenbühl 15, "Ilerdian", NP 9.

Fig. 14. *Rhomboaster cuspis* BRAMLETTE & SULLIVAN, VS 76/0043, G. F., east of Schwarzenbühl quarry, "Ilerdian", NP 10.

Fig. 15. *Marthasterites contortus* (STRADNER) DEFLANDRE (= *Tribrachiatus contortus*), VS 76/845, G. F., Selital 25, "Ilerdian", NP 10.

Fig. 16. *Discoaster lodoensis* BRAMLETTE & RIEDEL, VS 69/0020, G. F., uppermost Selital area, "Cuisian", NP 12.

Fig. 17. *Marthasterites tribrachiatus* (BRAMLETTE & RIEDEL) DEFLANDRE = *Tribrachiatus orthostylus* SHAMRAI, VS 6811/0906, G. F., Gurnigel road south Chaltweh, "Cuisian", NP 12.

Fig. 18. *Discoaster sublodoensis* BRAMLETTE & SULLIVAN, VS 76/271, G. F., southeast Ottenleuebad, "Cuisian", NP 14.

Fig. 19. *Nannotetrina cristata* (MARTINI) PERCH-NIELSEN, VS 6811/10.06, G. F., southwest Schwefelbergbad, "Lutetian", NP 15.

Fig. 20. *Toweius callosus* PERCH-NIELSEN, VS 76/271, G. F., southeast Ottenleuebad, "Cuisian", NP 14.

Fig. 21. *Reticulofenestra dictyoda* (DEFLANDRE & FERT) STRADNER, VS 76/700, G. F., southwest Schwefelbergbad, "Lutetian", "NP 16".

Fig. 22. *Reticulofenestra umbilica* (LEVIN) MARTINI & RITZKOWSKI, VS 76/481, wf., green shale, northeast Ober Gurnigel, "Priabonian", NP 19–20.

Fig. 23. *Dictyococcithes bisectus* (HAY, MOHLER & WADE) BUKRY & PERCIVAL, VS 76/481, idem.

Fig. 24. *Isthmolithus recurvus* DEFLANDRE, VS 76/481, idem.

Fig. 25. *Sphenolithus* cf. *pseudoradians* BRAMLETTE & WILCOXON, VS 76/481, idem.

Fig. 26. *Discoaster barbadiensis* TAN SIN HOK, VS 69/0019, G. F., uppermost Selital area, "Cuisian", NP 12.

Fig. 27. *Discoaster saipanensis* BRAMLETTE & RIEDEL, VS 69/0098, wf. shale, south of Fettbeder, "Priabonian", NP 18–20.
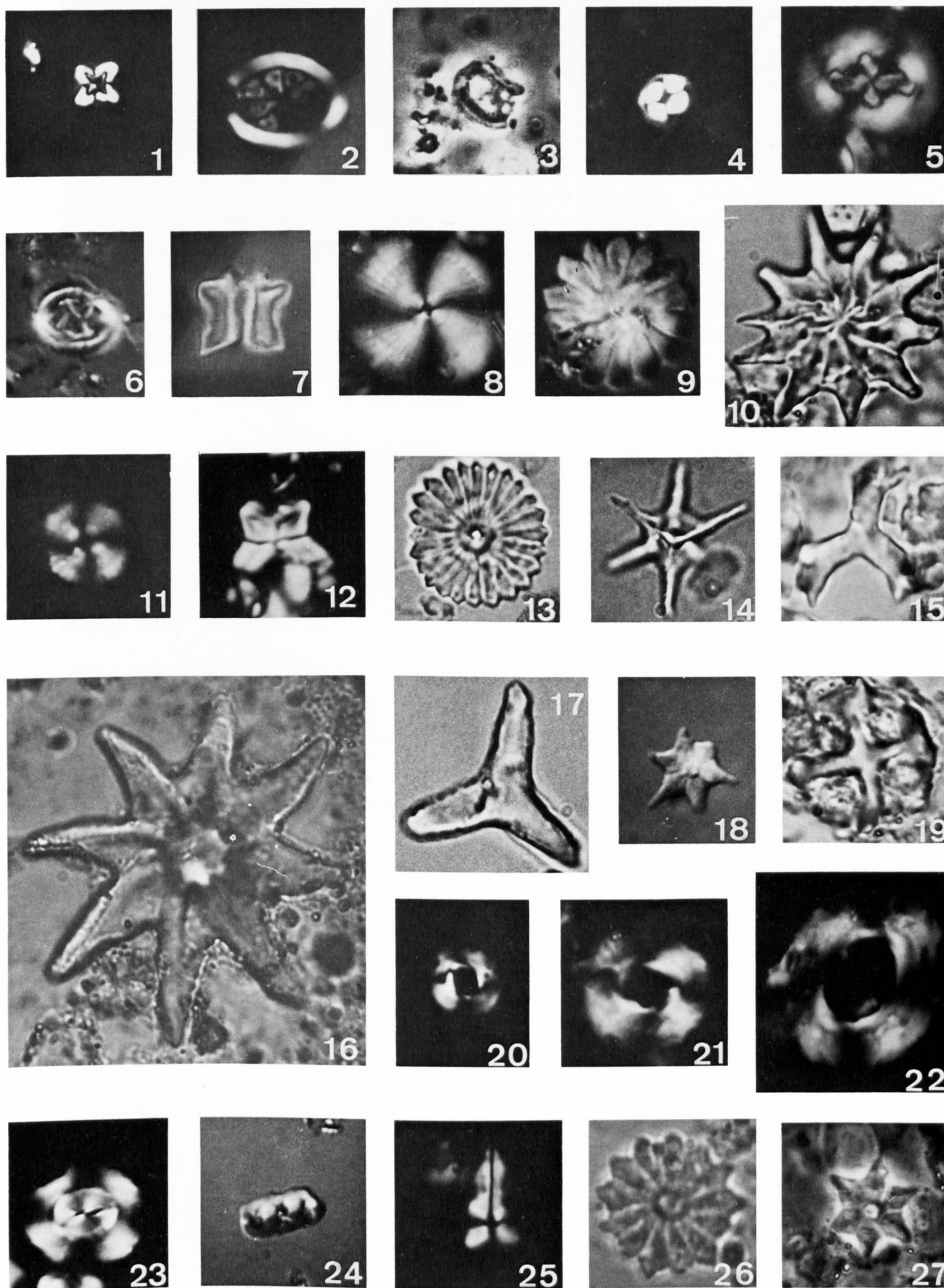

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Plate II

Foraminifera, Radiolaria and burrow from the Gurnigel Flysch

Fig. 1. Pyritized burrow (Fucoid?), × 33, Bärgli I/1, "Maastrichtian".

Fig. 2. *Rhabdammina* cf. *cylindrica* GLAESSNER, × 33, "Hellstätt" 20, "Maastrichtian". – Fig. 2a: idem, detail, × 267.

Fig. 3. *Bathysiphon* ex gr. *robustus* (GRZYBOWSKI), × 33, Grätli II/4, "Lutetian".

Fig. 4. *Kalamopsis grzybowskii* (DYLAZANKA), × 67, Louetli 38, "Thanetian".

Fig. 5. *Kalamopsis grzybowskii* (DYLAZANKA), × 33, "Hellstätt" 18.

Fig. 6. *Hormosina ovulum* (GRZYBOWSKI), × 67, Bärgli II/1, "Maastrichtian".

Fig. 7. *Glomospira gordialis* (JONES & PARKER), × 33, Kurhaus 2, "Danian".

Fig. 8. *Glomospirella* sp., × 33, Kurhaus 2, "Danian".

Fig. 9. *Ammodiscus siliceus* (TERQUEM), × 67, Bärgli II/1, "Maastrichtian".

Fig. 10. *Glomospira charoides* (JONES & PARKER), "Hellstätt" 19, "Maastrichtian".

Fig. 11. *Haplophragmoides kirki* WICKENDED, × 67, Bärgli II/1, "Maastrichtian".

Fig. 12. *Trochamminoides irregularis* WHITE, × 33, Kurhaus 2, "Danian".

Fig. 13. *Recurvoides* sp., × 33, "Hellstätt" 20, "Maastrichtian".

Fig. 14. *Rzehakina epigona* (RZEHAK), × 67, Louetli 38, "Thanetian".

Fig. 15. *Rheophax duplex* GRZYBOWSKI, × 33, Kurhaus 2, "Danian".

Fig. 16. *Rheophax pilulifer* BRADY, × 33, "Hellstätt" 20, "Maastrichtian".

Fig. 17. *Spiroplectammina spectabilis* (GRZYBOWSKI), × 67, Schwarzenbühl 15, "Ilerdian".

Fig. 18. *Textularia* sp., × 33, Bärgli II/6, "Maastrichtian".

Fig. 19. *Gaudryina* sp., × 67, "Hellstätt" 25, "Maastrichtian".

Fig. 20. *Globigerina* sp., × 67, Grätli II/4, "Lutetian".

Fig. 21. *Dictyomitra striata* LIPMAN, × 133, "Hellstätt" 20, "Maastrichtian".

Photographs made on Scanning Microscope of Geological Institute, Fribourg.
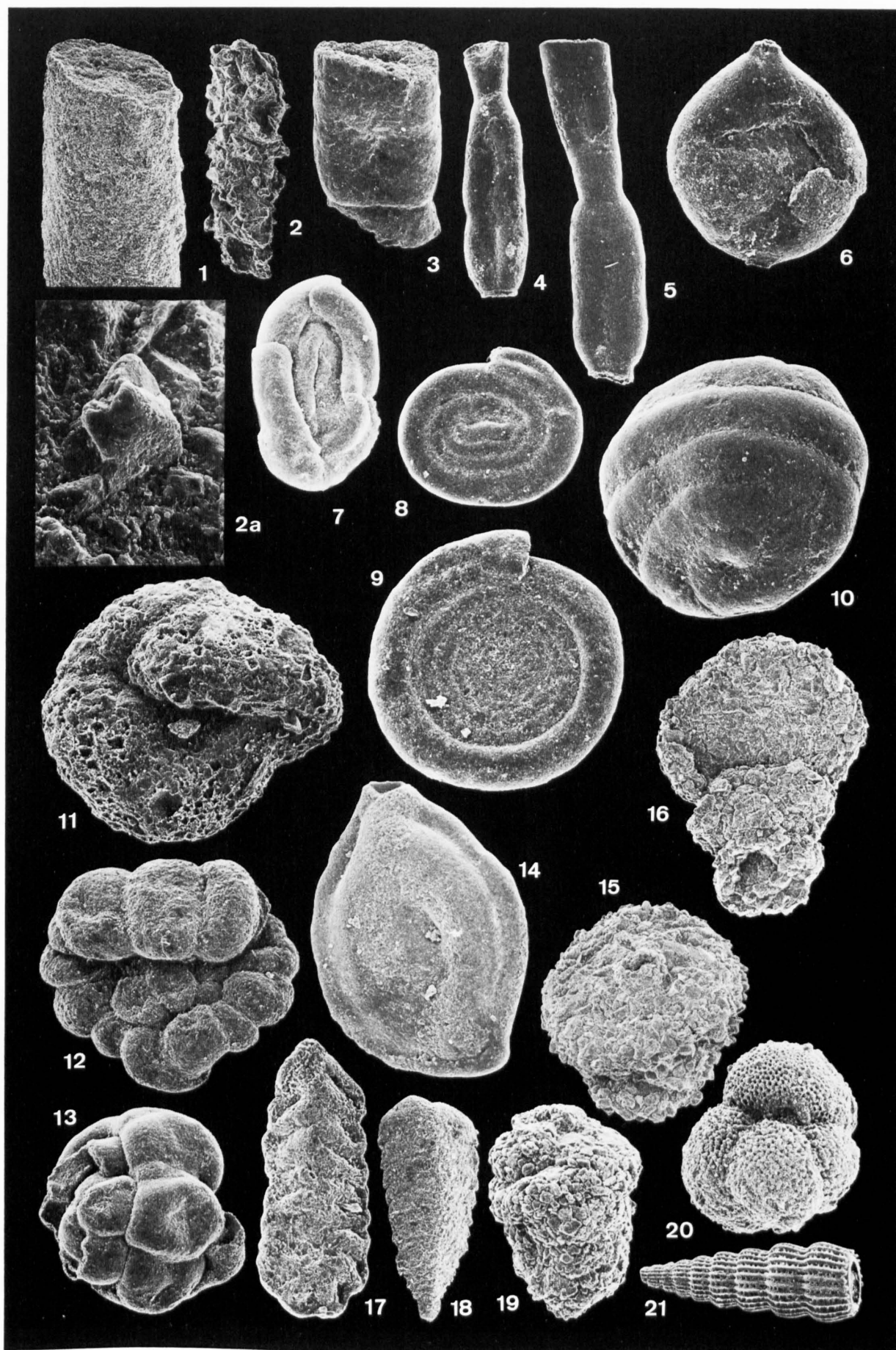
106
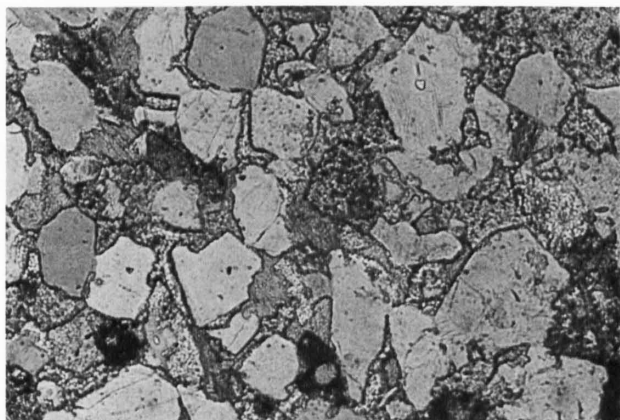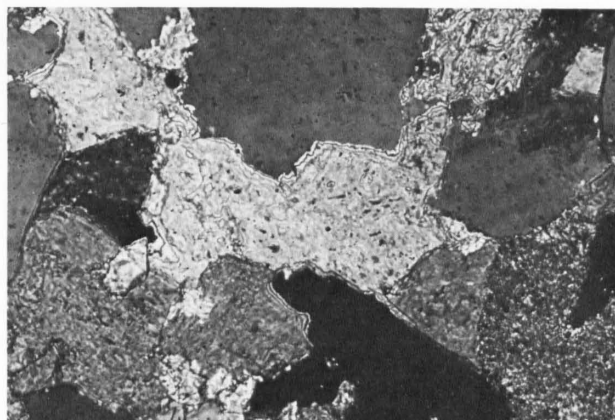
PLATE II

Plate III

Thin section photomicrographs from the Gurnigel Flysch (1)
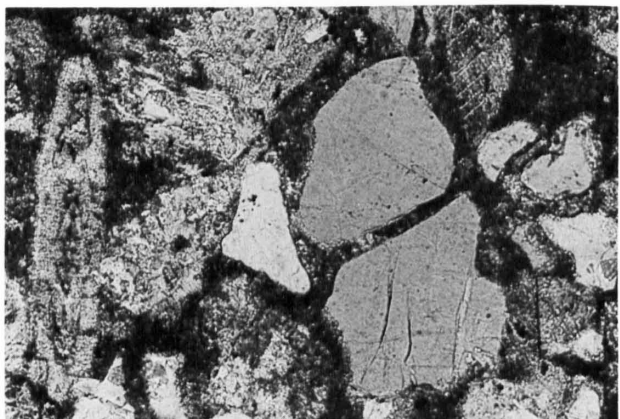
Fig. 1.   Calcite cemented sandstone, × 62.5 (Bärgli I/7).
Fig. 2.   Quartz grains attacked by calcite cement, × 192 (Bärgli I/7).
Fig. 3.   Sandstone with micritic matrix, × 62.5 (Grätli II/6).
Fig. 4.   Matrix-rich sandstone, × 62.5 (Bärgli II/1).
Fig. 5.   Dolomite rhombohedron in calcite cement, × 160 (Bärgli I/7).
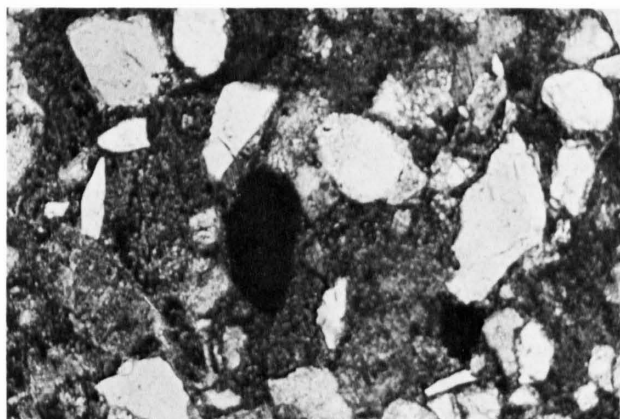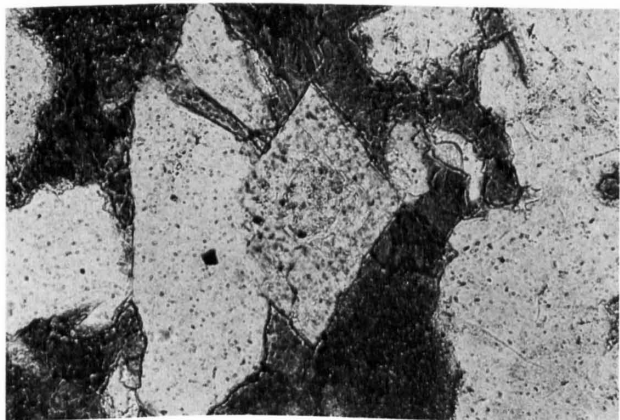Fig. 6.   Hellstätt Limestone, × 75 ("Hellstätt" 8, top).
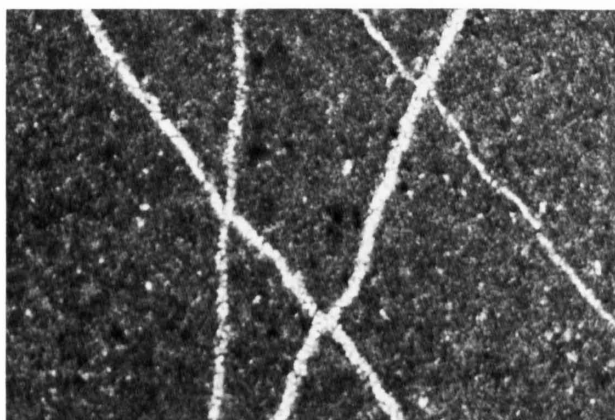
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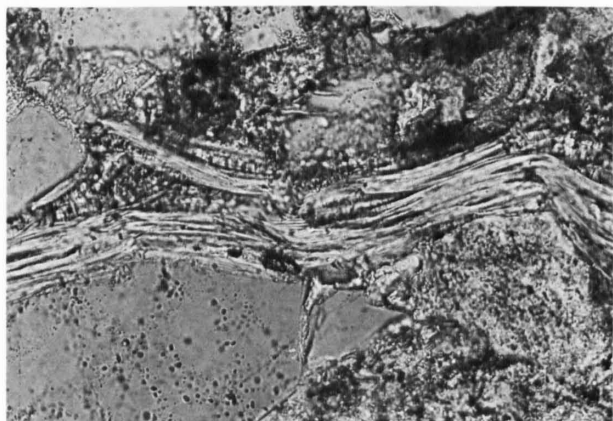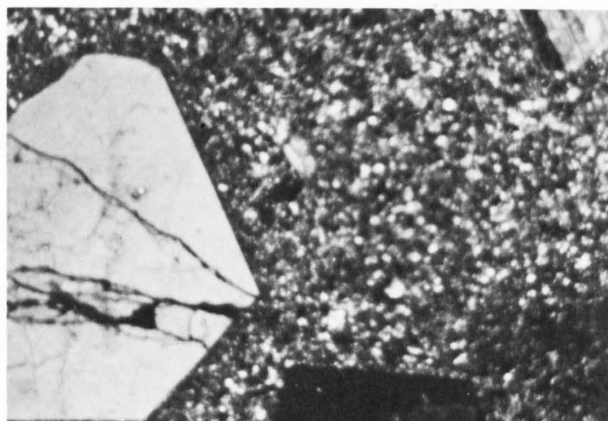## Plate IV

Thin section photomicrographs from the Gurnigel Flysch (2)
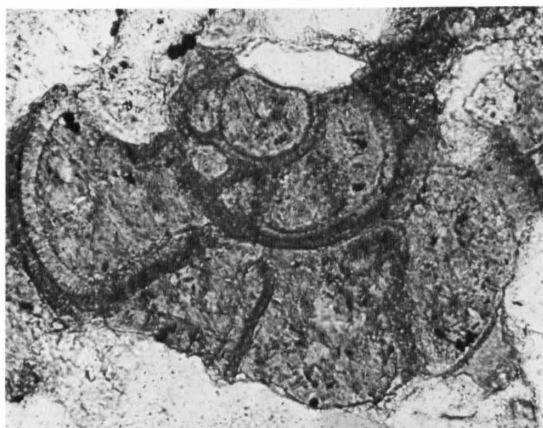
Fig. 1.   Bended muscovite, × 160 (Stäckhüttenwald 20).

Fig. 2.   Acid porphyrite, × 30 (Louetli 43).

Fig. 3.   Calcite cemented benthonic Foraminifera, partly dissolved by pressure solution, × 192 (Louetli 43).

Fig. 4.   Iron-free drusy, and iron-bearing blocky cement in bryozoan, × 75 (Louetli 43).

Fig. 5.   Nummulite with neogenic growth of chalcedony; left chamber filled with mud, × 62.5 (Grätli I/16).
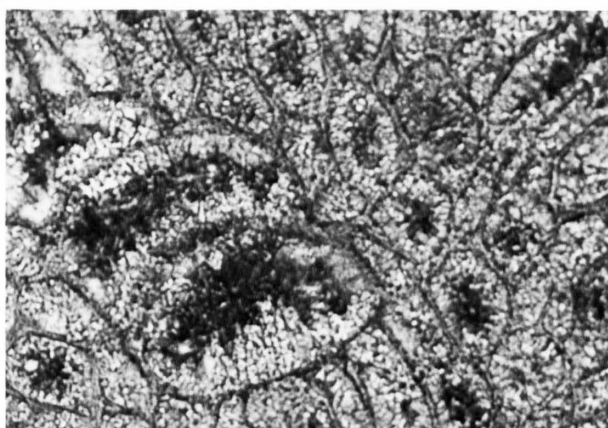
Fig. 6.   Idem, crossed nicols.

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6

J. VAN STUIJVENBERG: Geology of the Gurnigel area

Matér. Carte géol. Suisse, n.s., 151e livr., 1979. PLATE V

Legend:

Gurnigel nappe
(biostratigraphic units as commented in text)

- "Lutetian"
- "Cuisian"
- "Ilerdian"
- "Thanetian"
- "Danian"
- "Maastrichtian"

Wildflysch
- "Priabonian"

Nappe contacts
- established
- inferred
- .... arbitrary

Slice limits and other thrust traces
- established
- inferred
- .... arbitrary

Faults
- established
- inferred
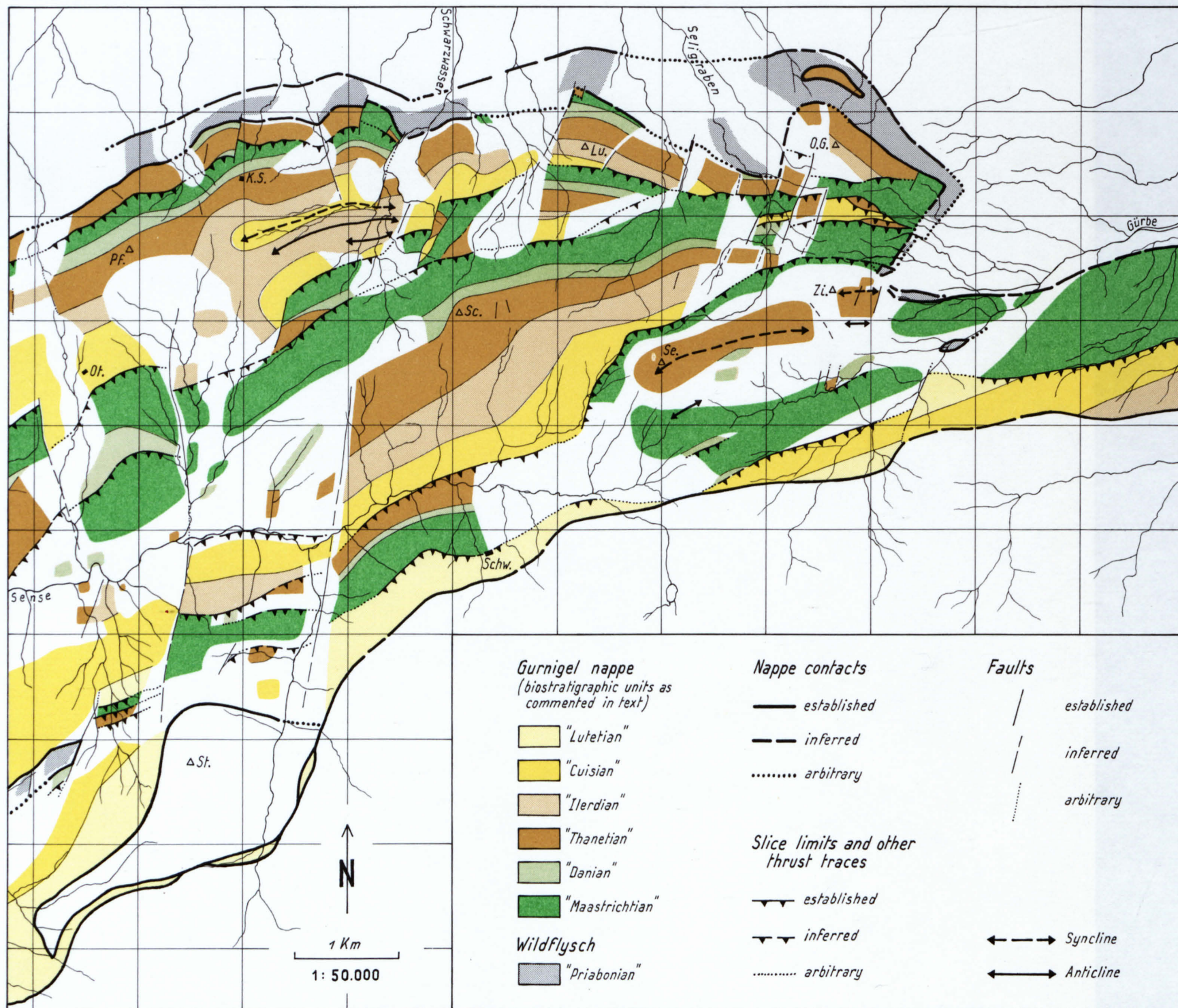- arbitrary
- ←----→ Syncline
- ←——→ Anticline

N

1 Km

1 : 50.000

K.S. = Kurhaus Schwarzenbühl
Lu. = Luterbühl
O.G. = Ober Gurnigel
Ot. = Ottenleuebad
Pf. = Pfyffe
Sc. = Schüpfenflue
Schw. = Schwefelbergbad
Se. = Selibühl
St. = Stäckhüttenghürn
Zi. = Zigerhubel

Interpreted geological map

of the eastern part of the Gurnigel nappe

By J. van Stuijvenberg