SEPTEMBER 5TH

PALEOCENE AND EARLY EOCENE FACIES OF RHENODANUBIAN FLYSCH AND HELVETICUM & TERTIARY MOLASSE

By H. Egger and L. R. Wagner with contributions by I. Draxler, C. Heilmann-Clausen, M. Homayoun and H. Peresson

Stop 2.1: Kohlbachgrabensection NE of Anthering (Rhenodanubian Flysch)
Topic: Mudturbidites, black shales and bentonites from the Paleocene/Eocene - boundary (Literature: EGGER, 1995; EGGER, 1996; EGGER et al., 1997)

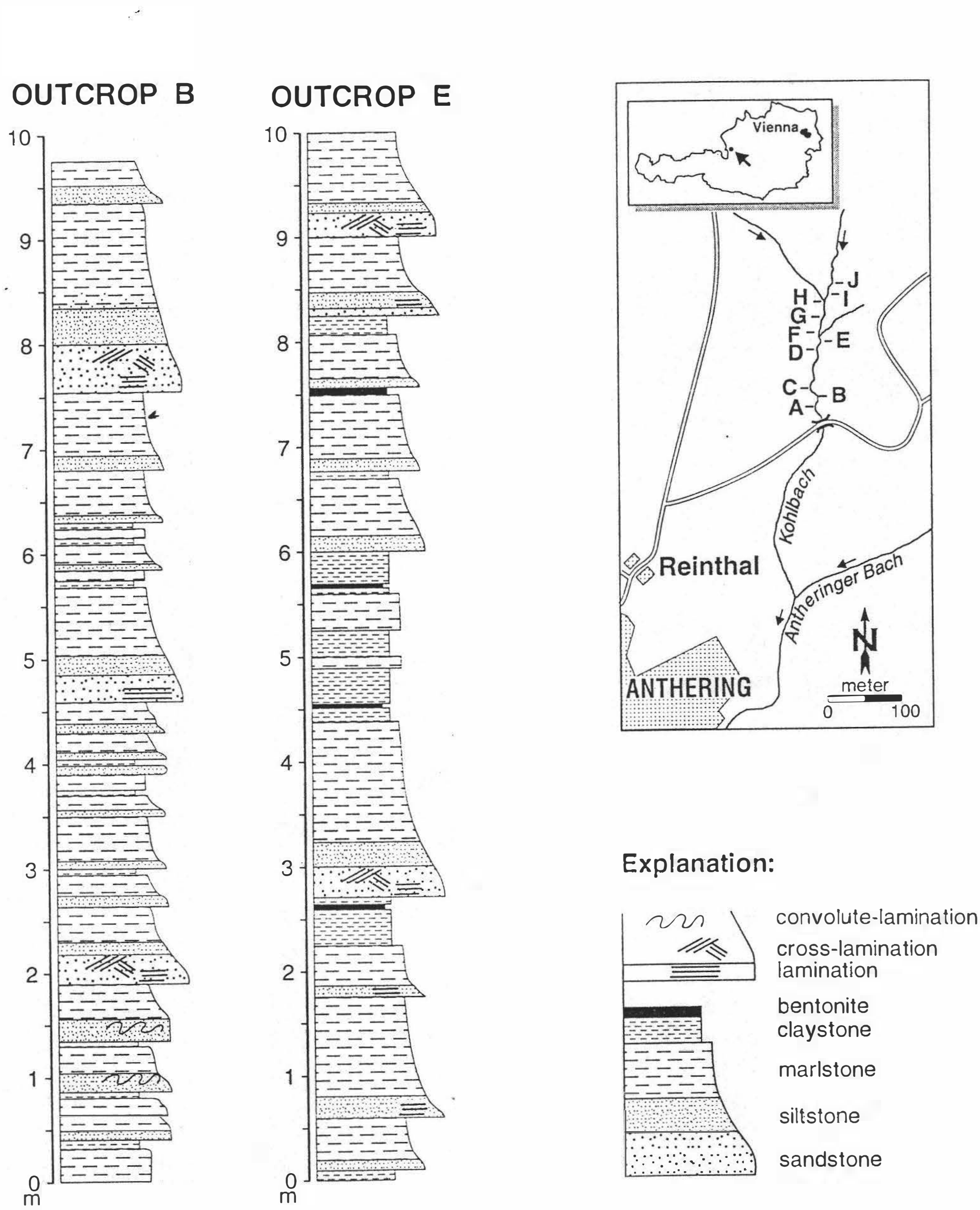

Fig. 23 Location of outcrops and examples of the sedimentary facies of the Anthering formation (thickness of bentonites exaggerated).

In the area north and northeast of Salzburg the Anthering Formation (EGGER, 1995) forms the youngest part of the Rhenodanubian Flysch. The type locality of this formation is situated in the small gully of the Kohlbach 15km north of Salzburg (fig. 1). A quarternary moraine covers the southern sector of the valley. The first outcrop of the Paleogene is located about 50m upstream of the small roadbridge displaying sediments from the Early Eocene (nannoplankton-zone NP11). Unfortunately there is no continously exposed section from here on upstream but there are a number of adjacent outcrops owing to the erosion at the outside bends of the meander loops. In all the exposures the beds are dipping steeply to southsouthwest.

The Anthering flysch section is considered to be a stratigraphic section of the NP9/NP10 nannoplankton zonal boundary. This boundary is often used in marine sections as a proxy for the Paleocene/Eocene boundary and is dated with 55.0 Ma (SWISHER & KNOX, 1991). On the other hand planktonic foraminiferal specialists usually correlate the P5/P6 zonal boundary (BERGGREN et al, 1995) which is estimated at 54.7 Ma with the Paleocene/Eocene boundary. More recently the major d13 C spike at 55.5 Ma has been suggested as providing a useful means of correlation between marine and terrestic stratigraphies. In the deep sea this significant d13 C excursion is associated with a world wide benthic foraminiferal extinction. Lacking a clearly defined Global Stratotyp Section and Point (GSSP) the Paleocene/Eocene boundary still awaits a clear definition (see discussion in BERGGREN & AUBRY, 1996).

LITHOLOGY

The dominant rocktypes of the Anthering section are soft graded silty marls and marls (fig.23 and fig.24).They display average carbonate contents of approximately

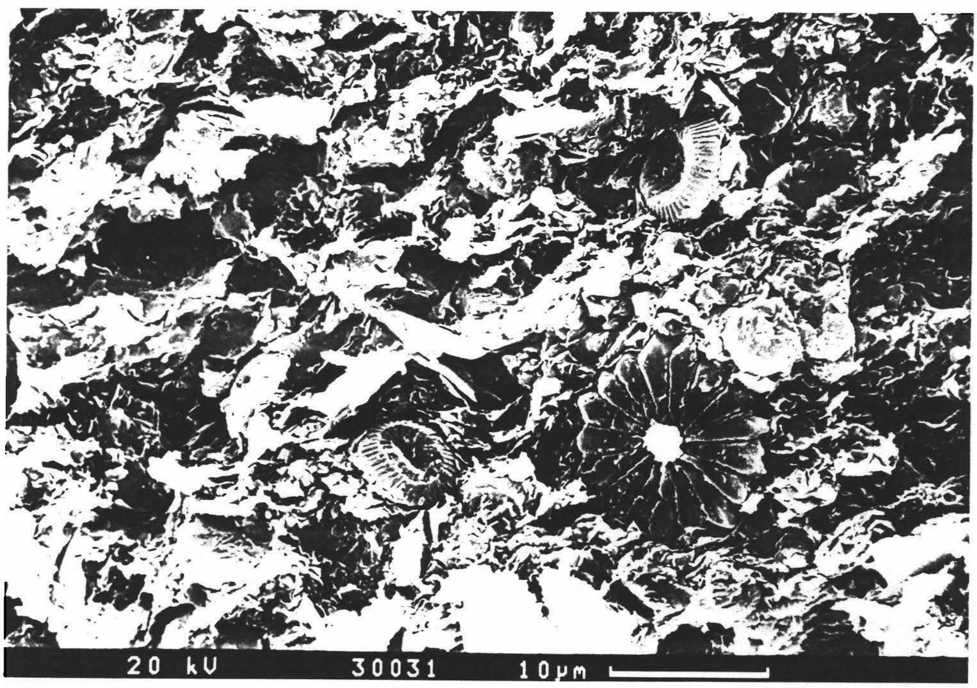

Fig.24 REM image of a mudturbidite from the Anthering formation with abundant calcareous nannoplankton

40% and average contents of organic carbon of 0.49%. Occasionally these light grey coloured marls change into thin sandy layers towards their base. These usually display base-truncated BOUMA-sequences. Therefore these marly rocks can be interpreted as **mudturbidites**.The single turbidite layers reach thicknesses up to 2m. Sandy to silty hardbeds (calcareous greywackes) with complete BOUMA-sequences occur only sporadically within the section. They usually show well developed flute casts, which are indicating a sediment transport parallel to the basin axis from southwest to northeast. Therefore we can assume a deepening of the basin in that direction. Heavy mineral associations of these beds (det. W. SCHNABEL) are dominated by turmaline (31 %), apatite (25%), zircone (17%) and garnet (17%). Very unusual for the Rhenodanubian flysch are high contents of apatite which indicate magmatic sources.

Usually the **hemipelagic claystones** of the Anthering formation are bioturbated, contain abundant agglutinated foraminifera and show green colour. Only within a short division of the Anthering section (outcrop E and a single layer in outcrop D - fig. 23) the light coloured turbidites contrast with alternating dark grey to black claystones. The single layers of these claystones can reach thicknesses up to 40cm. No fine scale lamination is visible in the claystones. From this homogenous fabric a continous accumulation of the clay particles can be implied. The dark colour of the claystones is a result of a relatively high content of organic carbon (0.94% on average) and of abundant pyrite. Under the electron microscope the studied samples of black shales from the Anthering section show abundant framboids and minute crystals of pyrite. Due to the weathering of sulphide the surfaces of the claystones show a rusty appearance and sometimes tiny gypsum crystals can be observed there. A strong sulphuric smell was noticed when grinding the samples. Contrary to the turbiditic marls, which contain abundant foraminifera and calcareous nannoplankton, the claystone does not contain any planktonic organisms except pyritized remains of diatoms and radiolaria. There are also no hints of benthic

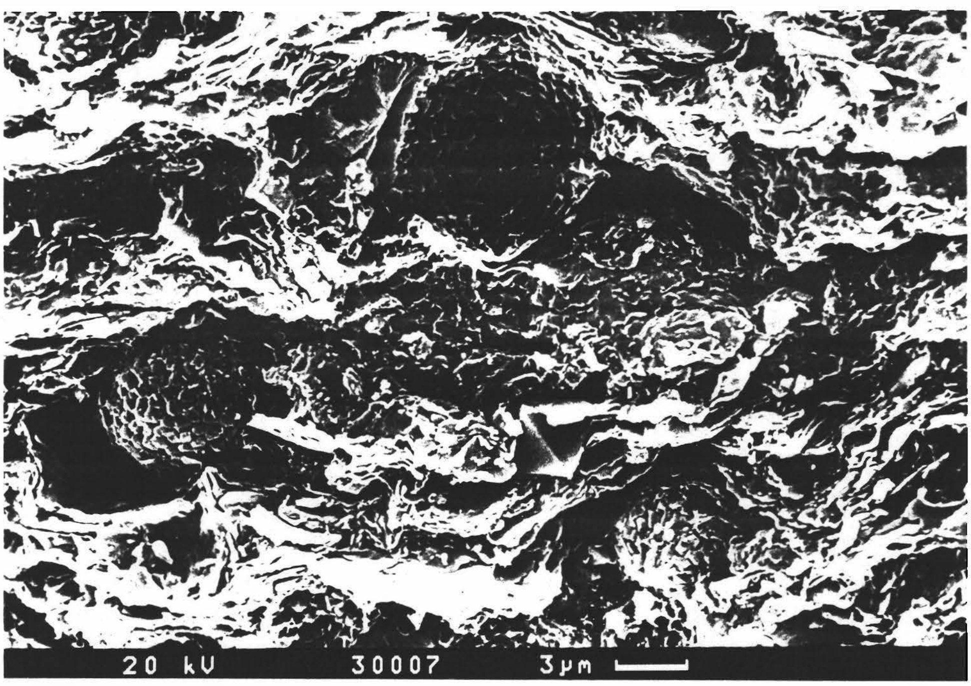

Fig. 25 REM image of a black shale from the Anthering formation (outcrop E). The homogenous fabric consists of parallel orientated platy particles of clay minerals with occasional pyrite framboids and pyrite octahedra.

foraminiferas or of bioturbation. All these features led to an interpretation of these claystones as a hemipelagic sediment of an oxygen-deficient environment. This hypothesis is supported also by the comparison of some geochemical data of black shales and green shales.

	BLACK SHALES (outcrop E)			GREEN SHALES (outcrop B)		
	85	87	89	58	59	60
toc %	0,98	1,02	1,17	0,15	0,19	0,15
S %	2,52	3,28	2,28	0,1	0,12	0,03
Fe (tot) %	6,64	7,27	6,02	2,86	3,87	3,78
Fe (pyr) %	4,39	5,71	3,97	0,17	0,21	0,05
DOP	0,66	0,78	0,65	0,14	0,11	0,03
U ppm	3,1	2,9	2,6	1,6	2,4	2,8
V ppm	306	327	305	142	127	143

Tab. 1 A comparison of some geochemical data of black shales and green shales from the Anthering section

Claymineral studies display that the turbiditic marls as well as the hemipelagic claystones consist of smectite, illite, kaolinite and minor amounts of chlorite (fig. 26). The most remarkable feature is the high contents of authigenic smectite. Around 30 pure **Fe-montmorillonite layers** (bentonites) occur in the section which are interpreted as ashes of air fall derivation. These layers are restricted to a short part of the section (upper part of outcrop H to upper part of outcrop E) whereas smectite is common in the pelitic rocks of the entire section. The bentonites are seen as products of a short period of strongly increased explosive volcanic activity.

Claymineralogy, siliciclastics, carbonates and sheetsilicates								
Sample	Smectite	Illite-mica	Kaolinite	Chlorite	Quartz	Feldspar	Carbonate	Sheetsilicates
1*	79%	15%	6%	0%	15%	0%	53%	32%
2	73%	21%	6%	0%	25%	2%	0%	73%
25*	48%	44%	5%	3%	20%	5%	13%	62%
27*	24%	36%	40%	0%	16%	2%	44%	38%
30*	71%	21%	8%	0%	15%	2%	47%	36%
80*	89%	7%	2%	2%	20%	0%	29%	51%
81*	90%	7%	3%	0%	7%	0%	44%	49%
82	98%	2%	0%	0%	10%	7%	0%	83%
83	93%	3%	2%	2%	17%	0%	0%	83%
84	81%	8%	11%	0%	15%	0%	0%	85%
85	78%	15%	5%	2%	23%	0%	0%	77%
89	81%	16%	0%	3%	17%	0%	2%	81%
12	25%	35%	40%	0%	40%	5%	4%	51%
13*	64%	30%	6%	0%	20%	2%	38%	40%
14	94%	2%	0%	4%	18%	3%	8%	71%
58	58%	36%	0%	6%	42%	14%	4%	40%
59	63%	10%	0%	27%	24%	5%	22%	49%
60	69%	14%	0%	17%	22%	4%	0%	74%
75*	79%	16%	3%	2%	18%	20%	43%	19%

Tab. 2 Mineralogical composition of turbidites (*) and hemipelagites from the Anthering formation

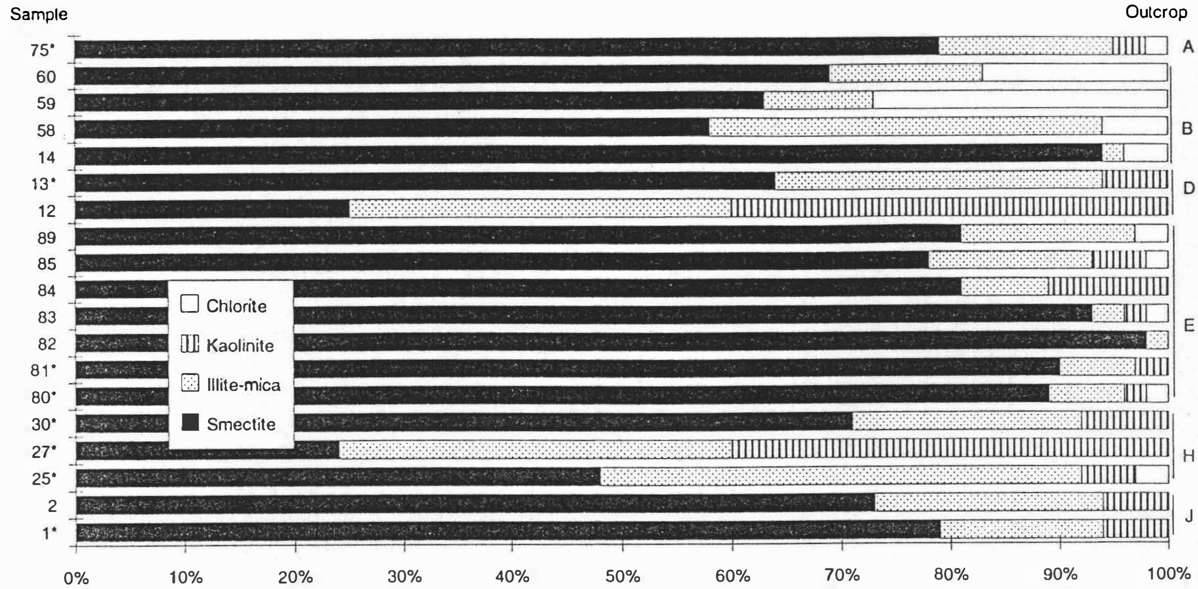

fig. 26 Claymineral composition of turbidites (*) and hemipelagites of the Anthering formation

The white to yellowish weathered bentonites can achieve thicknesses up to 3cm but usually they are only a few millimeters thick. Therefore it was not possible to observe any sedimentary structures (e.g. graded bedding) within these layers in the field. Due to the fine-grained composition of the bentonites it was also not possible to analyze any isolated volcanic components or relicts. With SiO_2 values ranging from 56% to 65% the bulk sample major-element analyses of the bentonite layers refer to an andesitic to dacitic composition of the ash material. Due to the total conversion of the ashes to smectitic clay however the original chemical composition of the layers has strongly changed. Therefore only immobile elements can be used as indicators for the original material.

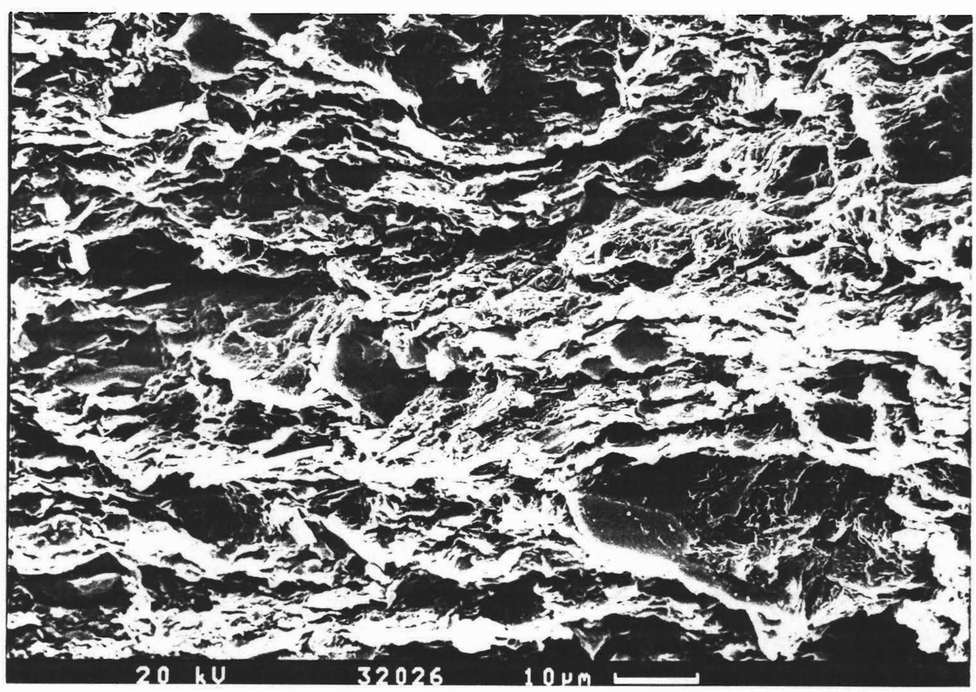

Fig. 27 REM image of a bentonite from the Anthering section

In the Zr/TiO2-Nb/Y diagram, the first group of ashes plot in the alkali basalt field the composition of the sporadic thicker layers, however, falls into the trachyte field. So it is obvious that that the bentonites of the Anthering section display mainly basaltic compositions and only a few highly evolved alkaline ashes are present as well.

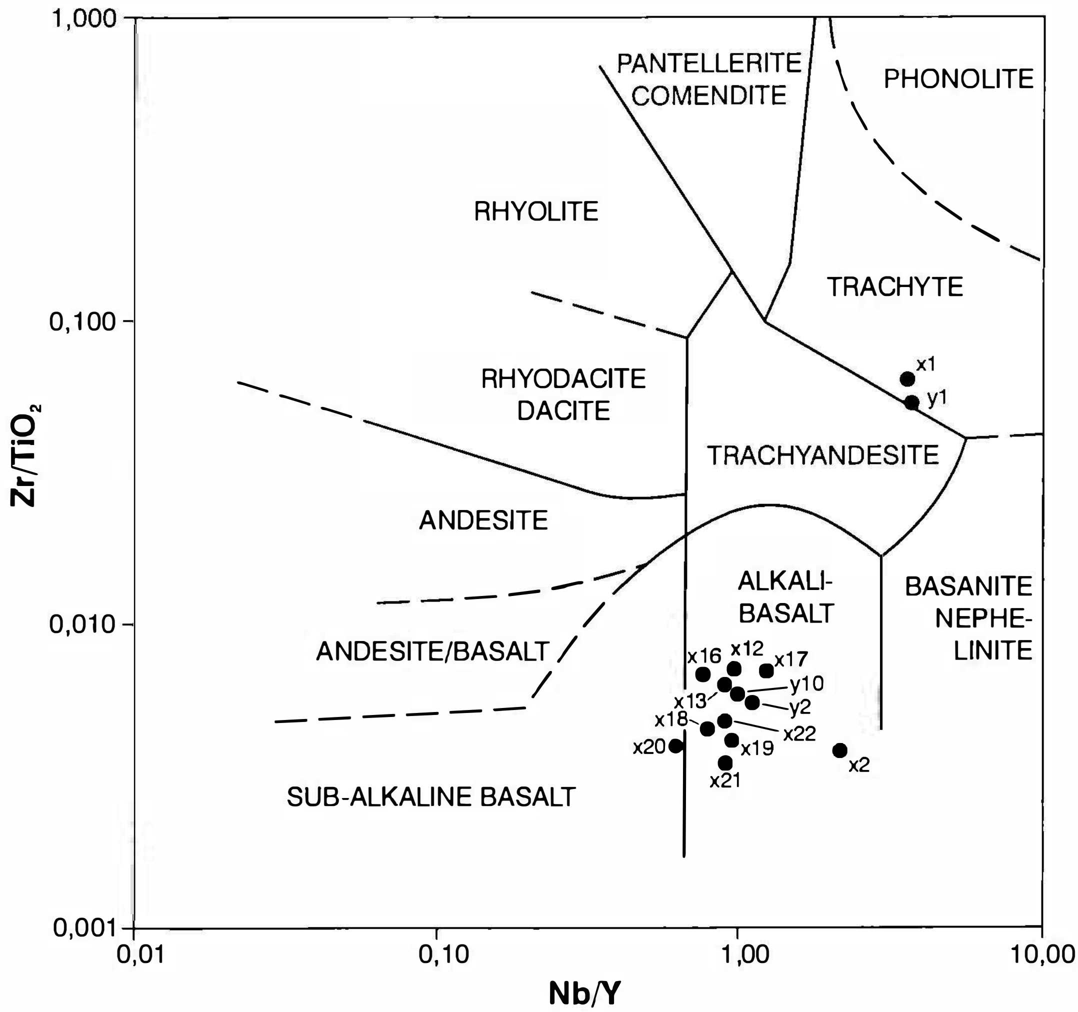

Fig. 28 Magma origin of different ash layers of the Anthering formation by means of immobile element distribution (see WINCHESTER & FLOYD, 1977)

STRATIGRAPHY

Calcareous nannoplankton

Calcareous nannofossils were examined with a Zeiss photomicroscope. In the studied samples both diversity and abundance of calcareous nannoplankton is generally high, the majority of the samples are showing only moderate preservation however. All samples display contents of reworked species mainly from the Campanian and Maastrichtian but also Lower Cretaceous species were observed. A detailed inventory of the observed species will be published in a separate paper. Here we will refer only to the biostratigraphic important taxa which are used for determining the age of the ash series.

The beginning of the ash series lies in the uppermost part of outcrop H. In the samples of the marls adjoining the oldest bentonites (layers x1, x2 and x3) beside common *Discoaster multiradiatus* specimens *Tribrachiatus bramlettei* and *Discoaster diastypus* do already occur. Therefore it is obvious that the beginning of the increased explosive volcanic activity lies within NP 10. In the lower part of outcrop H (approximately 10m below layer 1) specimens questionably assignable to *T. bramlettei* were observed. There seems to be a evolutionary transition between the genus Tribrachiatus and Rhomboaster and therefore the first occurrence of Tribrachiatus is very difficult to recognize. As no specimens of Tribrachiatus were observed in outcrops I and J the NP9/NP10 boundary is drawn in the lower part of outcrop H. Around the NP9/NP10 boundary *Transversopontis pulcher* is a common species in a few samples *Rhabdosphaera solus* is also common.

In this older part of the section (J, I, lower H) a large number of redeposited specimens was observed. This is probably an effect of low plankton productivity in the uppermost Paleocene because in that part of the section claystones are very common whereas mudturbidites are rare. Beside Tribrachiatus and Rhomboaster stratigraphically important species are *Fasciculithus involutus, F. schaubii, Toweius eminens, Campylosphaera eodela, Ellipsolithus distichus, E. macellus* and *Heliolithus kleinpelli.* Except of F.schaubii all named taxa were found also in the samples of outcrops G, F and E. Therefore we can assume that these taxa cross the NP9/NP10 boundary and have their last occurrence in the early NP10. *Discoaster binodosus* has its first appearance in the samples of the outcrop G.

T. bramlettei is rare also in the younger sediments farther downstream and becomes more common in the upper part of outcrop E and especially in the lower part of outcrop D. Bentonites are still common in outcrop E but none of them were found in outcrops D, C, B and A. The first occurrence of *T. contortus* is within outcrop D 3m to 4m above the ash series. Together with *T. contortus* a smaller representative of the genus Tribrachiatus appear. This is described as *T. digitalis* by AUBRY (in press). According to this author *T. digitalis* has a narrow stratigraphic range immediately before the first appearance of *T. contortus.* In our samples however, T. digitalis co-occurs with *T. contortus.* This is may be an effect of redepostion but it is also often very difficult to distinguish between both morphotypes. Therefore we prefer the name *T. contortus* for both variations which we call A (=digitalis) and B (=contortus). It is obvious that the first appearance of *T. contortus* postdates the ash series which is therefore restricted to the lowermost part of NP 10.

Sediments from NP 10 are exposed also in outcrops C and B where *T. contortus* co-occurs with *T. orthostylus.* It is remarkable that *Sphenolithus editus* has its first appearance in that part of the section. The total thickness of NP 10 comes up to 60m in the Kohlbach section. Within outcrop B lies the boundary to NP 11 where T. contortus has vanished and only T. orthostylus was observed. As in all other outcrops of the Anthering section *Discoaster multiradiatus* and *Chiasmolithus bidens* are common species.

Sporomorphes (by Ilse Draxler)

A detailed study of the sporomorphs of Anthering is in preparation (DRAXLER). Some preliminary results are presented below. Till now samples from outcrop J and E have been studied. In the pelagic claystones pollen and spoes are badly preserved and show low diversity. This might be an effect of the position of the sedimentary basin far away from the next land mass. Additionally the anoxic conditions at the basin floor the dinoflagellates and sporomorphs are often filled with pyrite.Therefore the preservation of the palynomorphs is poor. Owing to their fragile exines they are usually damaged and corroded and therefore especially the pollengrains are often undeterminable. Additional damage may be caused by mechanical abrasion during the long distance transportation of the grains. In general the thickwalled fern spores are better preserved than the pollengrains.

The sporomorphes are dominated by angiosperms and pteridophytes whereas gymnospermes are less important. Due to their bad preservation the pollengrains very often could not be determined or only the family or genus could be identified using the scanning electron microscope.

The pollen assemblage of the samples from Anthering is dominated by many triporate juglandaceous pollentypes belonging to Carya (*Caryapollenites sp.*), Platycarya, Engelhardia (*Momipites quietus*) and Myricaceae (*Triatriopollenites bituitus*). Most of the representatives of this group have their first appearance in the late Paleocene. Angiospermes are also represented by specimens of the families Fagaceae (*Tricolporopollenites cingulum*), Mastixiaceae (*Tricolporopollenites cf. edmundi*) Betulaceae (*Alnus sp.*), Olaeceae, Tiliaceae (*Intratriporopollenites sp.*), Verbenaceae, Icacinaceae (*Compositoipollenites sp.*), Anacardiaceae (*Rhus sp.*), Platanaceae, Aquifoliaceae (*Ilex sp.*) and Sapotaceae (*Tetracolporopollenites sp.*). Plamae occur with *Monocolpopollenites tranquillus* and *Arecipites sp.*. Representatives of the Normapolles group, which had its highest diversity in the early Paleocene, are rare (*Pompeckjoidaepollenites subhercynicus* , *Plicapollis pseudoexcelsus*).

Spores of gymnosperms include the families Pinaceae (*Pinus sp., Abies sp.*) and Taxodiaceae (*Taxodaceaepollenites hiatus)* Pteridophytes are represented by the families Gleicheniaceae (Concavisporites sp.) and Schizeaceae (*Lygodium sp.*, *Cicatricosisporites dorogensis*, *Varirugosporites sp.*).

The pollen assemblage contains elements of paleotropical vegetation like Icacinaceae, Mastixiaceae, Sapotaceae, Taxodiaceae and Engelhardia which actually have their representatives in Southeast-Northamerica and Southeast Asia. Therefore similar paleoclimatic conditions are implied for the early Tertiary of the alpine area.

Dinoflagellates (by Claus Heilmann-Clausen)

A detailed study of the dinoflagellates in the Anthering section is ongoing (HEILMANN-CLAUSEN & EGGER). The preliminary results are briefly presented below. So far samples from outcrops D (lower part) to J have been studied, while samples from outcrops A to C and K to M are being processed at the moment. Mainly pelagic layers have been sampled, but a number of turbidite samples are also included in the study.

The aim of the study is mainly to compare the biostratigraphy of the Anthering section with ash-bearing transitional Paleocene-Eocene sections from the North Sea Basin. The comparison is primarily with Denmark where the classical exposures of the 'negative' and the 'positive' ash-series of BØGGILD (1918) occur. The upper part of this ash-series is also known as the North Sea 'Ash Marker'. KNOX (1996) recently described the Paleocene-Eocene pyroclastic phases.

A direct (first order) biostratigraphical correlation is an independent means to establish whether the ash-series at Anthering is contemporaneous with that of the North Sea Region (and thus possibly identical) or of a different age.

Dinoflagellates are (in contrast to other marine microfossils) richly represented and well preserved in the non-calcareous strata of the Paleocene-Eocene transition in the Northwest European Tertiary Basin. Here they have been intensely studied in relation to oil-exploration, and their stratigraphical distribution is well known.

General characteristics of the dinoflagellate assemblages at Anthering

All samples contain dinoflagellates of moderate to good preservation. *Apectodinium* spp. are common to abundant throughout outcrops D (lower part) to J. There is a general upwards decrease from very high frequencies (usually about 50% of the total dinoflagellate assemblage) in outcrop J and JA to somewhat less in outcrop I and higher strata. On this basis the studied samples can all be referred to the "association á *Wetzeliella* (now *Apectodinium) homomorphum"* defined by JAN DU CHENE et al. (1975) in the Western Alps, where the association spans most of the interval of NP 9, NP 10 and NP 11.

A number of stratigraphically interesting taxa occur in the samples, some are sporadic and rare, others are more consistently present. They include: *Homotryblium tenuispinosum, "Homotryblium" bifurcatum, Phthanoperidinium crenulatum, Muratodinium fimbriatum, Adnatosphaeridium robustum, Deflandrea oebisfeldensis, "Wetzeliella" unicaudalis, Lingulodinium machaerophorum* (very rare) and *Hystrichokolpoma* aff. *rigaudae* in HEILMANN-CLAUSEN & COSTA (1989). Most of these allow a general comparison to the transitional Paleocene-Eocene strata of Northwest Europe. In particular, *Hystrichokolpoma* aff. *rigaudae* seems to be restricted to the main ash phase in the North Sea Basin (where it is rare). On the other hand *Homotryblium tenuispinosum* is unknown at the Paleocene-Eocene transition of Northwest Europe, but common in younger strata (NP 11 and upwards), and has also been recorded in a few Late Paleocene samples (older than those at Anthering) in North Germany (KÖTHE,1990). *"Wetzeliella" unicaudalis* and *"Homotryblium" bifurcatum* are previously described from the Pyrenees (CARO, 1973), but are unknown from the North Sea Basin.

A prominent event: the LAD of *Apectodinium augustum*

Apectodinium augustum, the morphologically most extreme species in the genus, occurs commonly and with typical morphology in the pelagic and most of the turbiditic samples of outcrops J and JA. It has not been observed in the samples of outcrop I, H, E and D. At Anthering the uppermost occurrence (LAD) of this species is, therefore, a conspicuous event.

Typical *A. augustum* has hitherto only been documented from the North Sea Basin and the Norwegian-Greenland Sea. The range in Denmark and the central North Sea is from the base of the 'negative' ash series of BØGGILD (1918) and up to ash layer -19b (HEILMANN-CLAUSEN 1985, 1994). The range approximately coincides with pyroclastic Phase 2.1 of KNOX (1996) in the lower part of the Sele Formation of the North Sea. This is a phase of relatively few and usually thin ash layers. The North Sea strata with *Apectodinium augustum* are, furthermore, characterized by a marked peak-occurrence of *Apectodinium* spp.

In the North Sea Basin the LAD of A. augustum is generally considered as a most prominent and reliable event for correlation.

Conclusion

Apectodinium augustum has been recorded for the first time in the Tethyan Realm. The LAD of this species is a prominent feature both at Anthering and in the North Sea Basin. It coincides with an upwards decrease in abundance of *Apectodinium* spp. in both areas. These features strongly suggest that the outcrops J and JA at Anthering may be synchronous with the lower part of the 'negative' ash series of BØGGILD (1918) and approximately correlate with pyroclastic Phase 2.1 of KNOX (1996). The ash-bearing outcrops E-H at Anthering may, therefore, be synchronous with the upper part of the 'negative' ash series and/or the 'positive' ash series in the North Sea region. This is the main ash-phase (Phase 2.2 of KNOX, 1996) with the thickest and most abundant layers, considered to coincide with the onset of seafloor spreading between Greenland and Scotland- Norway.

In the North Sea Basin the FAD of the genus *Wetzeliella* is a prominent feature above the main ash phase (HEILMANN-CLAUSEN, 1994). The absence of true *Wetzeliella* in the studied part of Anthering suggests that the ash sequence is no younger than the main phase of the North Sea region.

STOP 2.2: Kroisbach
TOPIC: Oiching formation (Silty to sandy marls, Paleocene of the South-Helvetic shelf)

The Kroisbach section is the most complete outcrop of South-Helvetic rocks between Salzburg and Vienna. Unfortunately the access to the outcrops is not the best. Therefore we will see only the older part of the section whereas the younger part will be shown at the next stop.

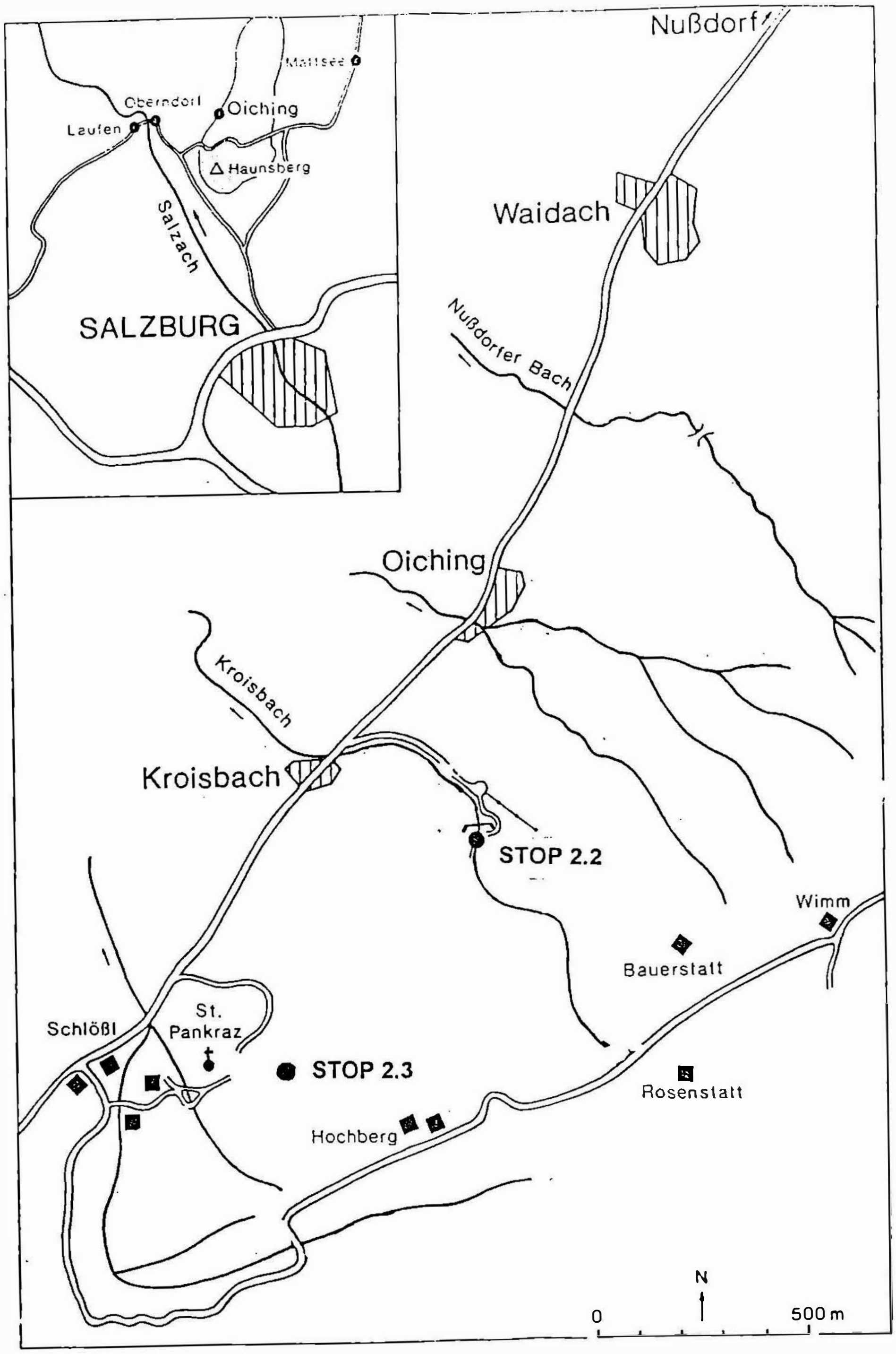

Fig. 29 Sketch map of the outcrops in the Helveticum N of Salzburg

In contrast to the coeval sediments of the Rhenodanubian flysch the early Eocene rocks of the Helvetic zone display a shallow water marine facies. In the Helvetic realm the water depth increased from north to south. Due to the regression at the end of the Cretaceous the northern part of the Helvetic realm emerged above sea-level and was affected by erosion. Approximately at the beginning of the Eocene the sea returned with a transgression. Owing to the deepening of the depositional area to the south the stratigraphic gap at the unconformity between Tertiary and Cretaceous increases from south to north. In the southernmost part of the Helvetic area a continuous marine sedimentation persisted.

Grey marls (Gerhartsreith formation - not exposed in the Kroisbach) are the dominating rocks of the Maastrichtian in the South-Helvetic zone. They display high amounts of kaolinite. At the K/T-boundary silty to sandy clays and marly clays occur (Oiching formation) which are free of kaolinite but have high contents of chlorite (fig. 30 and tab. 3). This change in sedimentary facies is seen as a consequence of the regression at the end of the Cretaceous which led to increasing erosion of the southern part of the European continental plate.

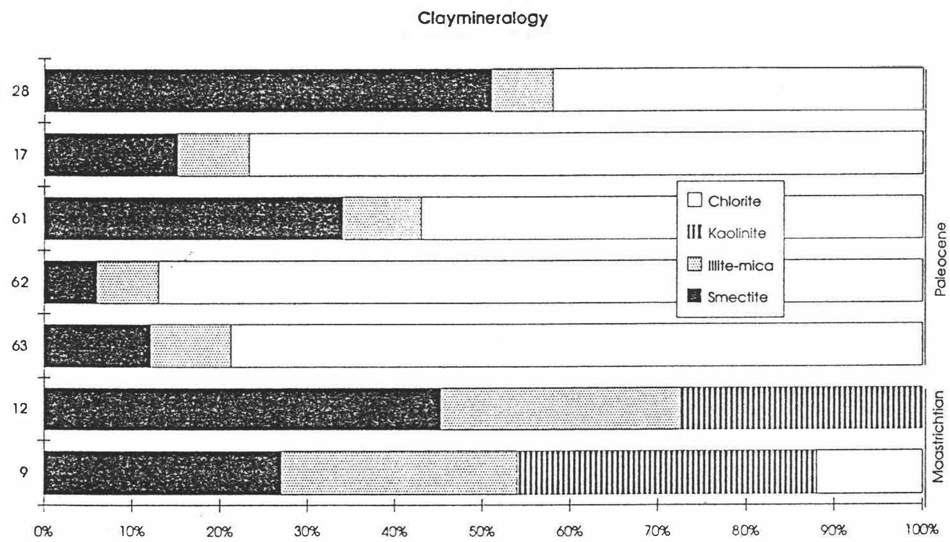

Fig. 30 Claymineral composition of pelitic rocks of the Oiching formation

Claymineralogy, siliciclastics, carbonates and sheetsilicates								
Sample	Smectite	Illite-mica	Kaolinite	Chlorite	Quartz	Feldspar	Carbonate	Sheetsilicates
9	27%	27%	34%	12%	9%	22%	49%	20%
12	38%	23%	23%	0%	16%	2%	40%	42%
63	12%	9%	0%	78%	58%	7%	0%	35%
62	6%	7%	0%	87%	42%	3%	2%	53%
61	34%	9%	0%	57%	61%	11%	2%	26%
17	15%	8%	0%	76%	59%	8%	0%	33%
28	51%	7%	0%	42%	29%	7%	4%	60%

Tab . 3 Mineralogical composition of pelitic rocks of the Oiching formation

Especially in the older part of the Kroisbach section the rocks of the Oiching formation display dark grey colours and show often rusty crusts on their surfaces. Chemical analyses prove contents of 0.92% organic carbon, 0.70% of sulphur and 2.84% of iron. The degree of pyritization (DOP - according to RAISWELL & BERNER, 1985) points to a sedimentation of the Oiching formation under oxic conditions (DOP=0.35).

Detailed studies of the foraminifera of the Oiching formation were carried out by KUHN (1992). The rich and high diverse benthonic foraminiferal assemblages correspond to middle/outer shelf depth in the early and middle Paleocene. The estimated water depth for these assemblages did not exceed 200m. In the late Paleocene shallow water conditions existed. At that time glaukonitic sand was deposited with the pelitic rocks which often display intensive bioturbation. The sandstone beds often contain a large number of fossils (mainly brachiopods, bivalves and gastropods). The siliziclastic sequence is superimposed by an algal limestone ("Lithothmanienkalk") which underlies nummulitic limestones.

STOP 2.3: St. Pankraz, Schlößlbruch
TOPIC: South-Helvetic facies (shallow-water facies with nummulitic limestones and intercalated quarz-arenitic sand) of early Eocene age
(Literature: EGGER & SCHULTZ, 1991).

The outcrop at St. Pankraz is part of the South-Helvetic unit. The dominating rocks are reddish-brown to grey arenitic limestones (Roterzschichten and Schwarzerz-schichten) which contain small amounts of detrital quartz and sedimentary iron-ores. Intercalated in this facies are a few meters of fine- to middlegrained quartz-arenitic yellowish sand (Mittelschichten).

The calcareous facies is extremely rich in fossils: nummulites and a large number of different species of gastropods, bivalves and echinids are described from this outcrop. Remarkable is the occurrence of a tortoise (Manouria (Hadrianus) sp.), the jaw-bone of a crocodile and remains of a tapire (Lophiodon oecitanum CUVIER) and of other mammals. Interesting are the findings of fossil fruits (Palaeophytocrene sp.) of the family Icacinaceae which has its representatives exclusively in tropical regions (TICHY, 1980).

The depositional environment of the early Eocene rocks is interpreted as a shallow shelf-area with a strong terrigenous influence. Beginning from the middle Eocene an intensive deepening of the South-Helvetic realm led to the deposition of Globigerina marls (Stockletten) which form the youngest sediments of this unit.Their sedimentation ends in the uppermost Eocene.

Very significant brittle tectonic features are densely spaced faults which cut through the Lower Eocene beds. Two dominating sets of subvertical faults strike NNW-SSE and NNE-SSW. Mainly subhorizontal lineations on both sets identify them as strike-slip faults (Fig.31a). The NNW-SSE striking faults show dextral and the NNE-SSW striking faults show sinistral displacement which can be obtained from well developed shear sense indicators at the fault surfaces like Riedel-shears and calcite fibers. Both sets form a typical cogenetic conjugate strike-slip fault system which originated under N-S directed compression. This compression direction in the lower (European plate) of the alpine orogen mirrors the general N-S directed convergence direction between the Adriatic and European plates during the Tertiary (PERESSON & DECKER, 1997a).

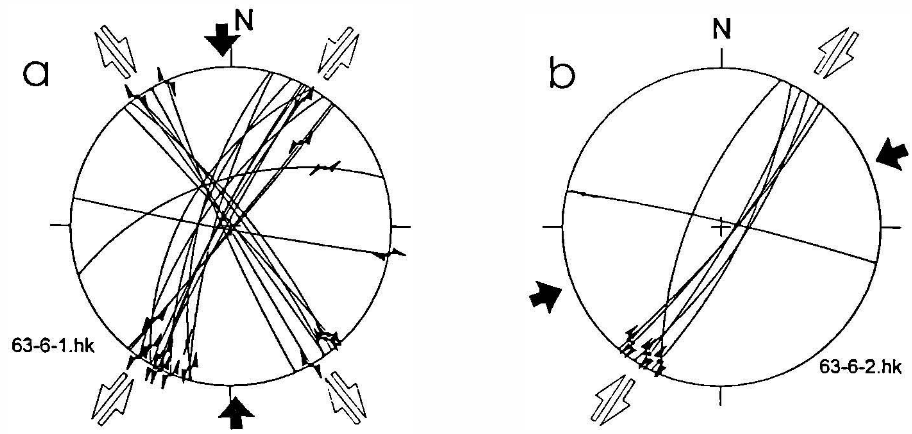

Fig 31a,b a: Conjugate strike-slip faults indicating N-S directed compression b: Reactivation and shear sense reversal on NNE-SSW striking faults due to younger ENE-WSW compression

Some younger reactivations of the faults with shear sense reversals occured due to changing paleostress directions. Riedel shears on the NNE-SSW striking sinistral faults are commonly overgrown by calcite fibers indicating younger dextral movements along the faults. The NNW-SSE striking faults also show some signs of shear sense reversals. The responsible compression direction for reactivation was directed ENE-WSW (Fig. 31b). Offsets during reactivation of the faults were much smaller than during the previous event. These reactivations can be correlated to a Late Miocene E-W compressional event which affected the whole Alpine-Carpathian-Pannonian system (PERESSON & DECKER, 1997b).

Stop2.3: Lukasedt-Dreimühlen (outcrop in the Oichten valley, approx. 1.3 km E of Oberndorf, approx. 300m N of Lukasedt, at the NW side of the Oichten creek)
Topic: Reworked sediments from the top of the Molasse Imbrications.
Lithostratigraphic unit: Hall Group - Lukasedt Formation (Lower Miocene = Eggenburgian to Ottnangian (Lit.: ROETZEL, RUPP & STEININGER, 1991).

The outcrop between the upper and lower mill in the N of Lukasedt is approx. 35 m long and 6 to 8 m high. At the northwestern side of the Oichten valley the section dips with 45° to 70° to the NW.

The sequence starts with approx. 8 m thick, grey, pebbly, silty sands and silts. The well rounded pebbles consist of quartz, quartzite and dark and light carbonates.The silty matrix contains up to 80 cm large clasts of fine grained sandstone. Fossil fragments (gastropods, bivalves, scaphopods, corals, balanides, and foraminifera) are abundant in the pebbly mudstone.

The overlaying 3.7 m predominantly laminated and ripple bedded, brown and grey beds are rich in fragmental plant remains in the upper 1.5 m. The internal 0.2 to 0.4m thick bedding starts usually with a thin graded layer with rip up mud clasts at the base. At the top of the outcrop are brown and grey, micaceous sandstones with calcareous cement.

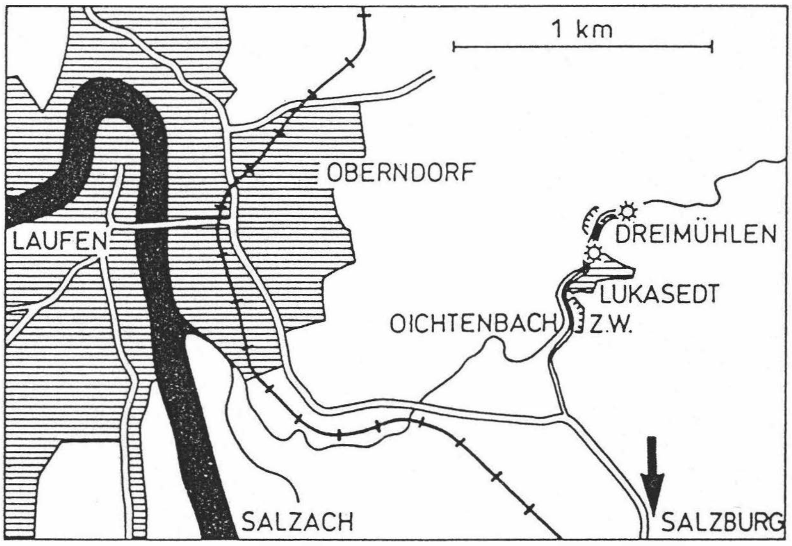

Fig. 32 Location of the outcrop Lukasedt-Dreimühlen

Interpretation:
The oldest sediments of the Hall Group the light grey, micaceous, calcareous sandstones, siltstones, sandy pelites and darker muddy conglomerates with plant fragments of the Lukasedt Formation are restricted to the SW in Salzburg. The Lukasedt Formation was deposited on top of the Molasse Imbrications in a relative narrow erosional channel, which was filled by slides, slumps, turbidites and contourites. On top of the Perwang imbricates the Eggenburgian Lukasedt Formation and slides of the upper Oligocene Ebelsberg formation were sedimented in a minimum water depth of at least 500 m. They were uplifted with the Imbricates and subsequently (Eggenburgian to Ottnangian time) moved large parts again down the flanks. In the present, the Lukasedt sediments crop out at an elevation of 500 m N of Salzburg. This corresponds to an uplift of 1000 m during the last 20 million years.

Molasse section along the river Traun (Bavaria).

The most complete section of marine Oligocene Molasse sediments outcrop in the river Traun valley between Siegsdorf and Traunstein. The section was studied by geoscientists since the early 19th century (for a complete reference list see REISER & WENGER 1987).
Topic: Sequence of Oligocene to Miocene deep water sediments.
Lithostratigraphic units: Lower Marine Molasse, Thalberg beds, Rogatsboden Formation, Puchkirchen Formation.
Tectonic unit: Molasse Imbrications in front of Helveticum nappes.
Age: Oligocene and Miocene - Kiscellian to Egerian

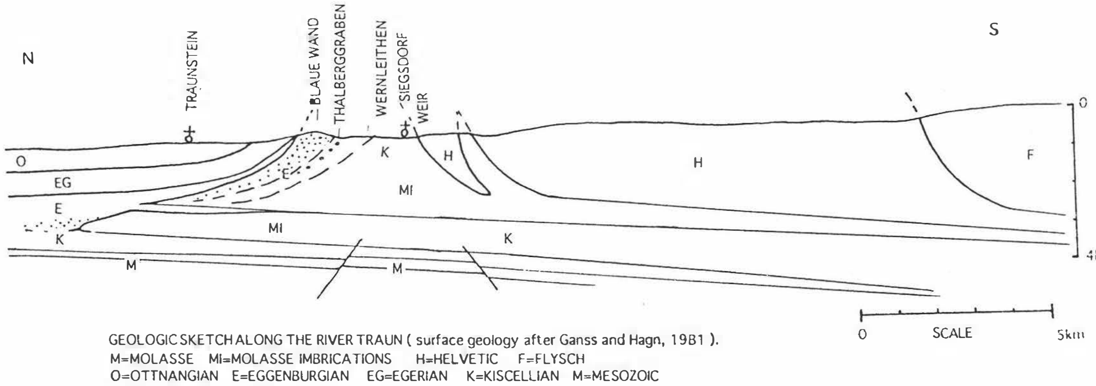

Fig. 33 Geologic sketch along the river Traun

Stop2.5: Traunsection
Topography: Thalberggraben, approx. 2.5 km **N** of Siegsdorf, approx. 300 m **E** of the road Siegsdorf to Traunstein.
Age: Oligocene - Lower Egerian.

The forest road in the Thalberggraben of the Hochberg cuts through bluish grey, silty, micaceous, folded, pebbly shales, muddy and sandy conglomerates. The folded beds dip with 20° to WNW. The mega and microfauna and flora was found in the pelitic section and contains shallow and deeper water assemblies.

Interpretation:
The matrix supported conglomerates are mass movement sediments. More than 90% of Lower Puchkirchen Formation, which is the equivalent in the subsurface in Austria, is made out of such slide material.

Stop 2.6: Traunsection
Topography: Blaue Wand, approx. 3 km **N** of Siegsdorf, roadcut on E-side of main road Siegsdorf to Traunstein.
Age: Miocene - Upper Egerian.

Along the road are bluish grey muddy, silty and sandy conglomerates with thin shale and sandstone layers exposed. The pebbles contain mainly quartz and cystalline with dark and light carbonates and single pebbles of Gosau and lower Tertiary.
Interpretation:

Also this outcrop belongs to the massflow sediments of the Upper Puchkirchen Formation. Even the shales are slides. Some of the thin bedded sandstone could either be by bottom currents reworked sands or turbidites. The soft brown fishshales (Ebelsberg Formation in Austria) further upsection at the Egerian - Eggenburgian boundary represent a slide from the northern slope.

Stop 2.7: Traunsection :
Topography: depending on the water level and distribution of the gravel banks in the rivers red and white Traun a) weir at Wernleiten or b) park approx. 600 m **N** of Siegsdorf between red and white Traun in the **N** of the public swimming pool.

In the river beds of the white and red Traun outcrop N- dipping, dark grey, bluish grey and brown thin bedded shales with soft folded shale layers above submarine erosion planes. In direction to the confluence of the rivers the intercalations of sandstone layers and lenses increase stratigraphically upsection.

The sandstones fill the lows of the submarine erosion planes above the shalebeds. The internal structures of the sandstones are slump structures, ripple lamination, starved ripples, sharp lower and upper contacts and laminations. The association of the foraminifera indicates a bipolar distribution of shallow to brakish and deeper water fauna. The Oligocene - Kiscellian to Lower Egerian age of the section was determined by Microfauna and Nannoplancton.

Interpretation: The hard shales are probably the very distal portions of turbidites in the S. The pelitic slide layers moved in from the **N**. Bottom currents eroded the surface of the shale layers and the lows were filled by reworked sands (contourites). This is the equivalent to the Rogatsboden Formation and the southern part of the Zupfing Formation in Austria.

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