

## **Fundamental research of the unconventional hydrocarbon potential in the Waschberg Zone, Lower Austria**

Projekttitel	<b>Grundlagenuntersuchungen zur Potentialabschätzung unkonventioneller Kohlenwasserstoff-Lagerstätten in der Waschbergzone</b>
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## **Abstract**

The Oligocene Menilite Formation is the most important source rock in the Carpathians and may have also contributed to hydrocarbon accumulations in the Czech part of the Vienna Basin. The main aim of the present contribution is to examine if Oligocene rocks in the Waschberg Zone in Austria hold a similar hydrocarbon potential.

The Oligocene succession in the Waschberg Zone comprises the Lower Oligocene Ottenthal Formation and the Upper Oligocene Thomasl Formation. The Ottenthal Formation is subdivided from base to top into marls and shales (Ottenthal Mb.; NP21-22), diatomaceous rocks (Galgenberg Mb.; NP22) and the Dynow Marlstone (lower NP23).

The study is based on 74 samples from an outcrop section near Ottenthal (“Waldweg section”), which has been studied paleontologically by Rögl et al. (2001) and on 50 core and cuttings samples representing the Thomasl Formation in wells Thomasl and Poysdorf (see also Fuchs et al., 2001). In order to characterize the samples and to determine their petroleum potential, the following methods were applied: (i) measurements of total organic carbon (TOC), total inorganic carbon, total sulphur contents, (ii) Rock-Eval pyrolysis, (iii) biomarker analysis, (iv) organic petrography, (v) stable carbon isotopy of carbonate minerals, (vi) atomic absorption spectrometry to determine biogenic silica contents, (vii) scanning electron microscopy, and (viii) X-ray diffractometry.

Low TOC contents and low hydrogen index values show that the Ottenthal and Thomasl formations in the “Waldweg section” is a poor source rock and is not considered a potential play for unconventional hydrocarbons. In contrast, the Thomasl Formation, encountered in the Thomasl and Poysdorf boreholes, holds a fair to good hydrocarbon potential (~2.2-2.5 %TOC; type III and type II kerogen) and may generate 1.0 to 1.6 tons of hydrocarbons per m<sup>2</sup>. Nevertheless its shale gas/shale oil potential is considered low. This is mainly due to the very deep position of the maturity cut-off values for shale oil (0.8 %Ro; ~4000 m) and shale gas (1.2 %Ro; ~5000 m), and the complex geological setting.

Obviously TOC contents of borehole samples are significantly higher than in outcrop samples. Because a detrimental effect of weathering on the samples from the “Waldweg section” cannot be excluded, it is suggested to drill a shallow borehole in the Ottenthal area.

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## 1. INTRODUCTION

The aim of the study “Grundlagenuntersuchungen zur Potentialabschätzung unkonventioneller Kohlenwasserstoff-Lagerstätten in der Waschbergzone” was to assess the unconventional (and conventional) petroleum potential of the Oligocene Ottenthal and Thomasl formations. These formations are equivalents of the Oligocene Menilite Formation, which is the most important source rock in the Carpathians (Sachsenhofer et al., 2017) and may have also contributed to hydrocarbon accumulations in the Czech part of the Vienna Basin .

The study is based on the investigations of surface samples (“Ottenthal Waldweg”; Rögl et al., 2001) and core and cuttings samples from boreholes Thomasl 1 and Poysdorf 2 (Fuchs et al., 2001; see Fig. 1a for sample position).

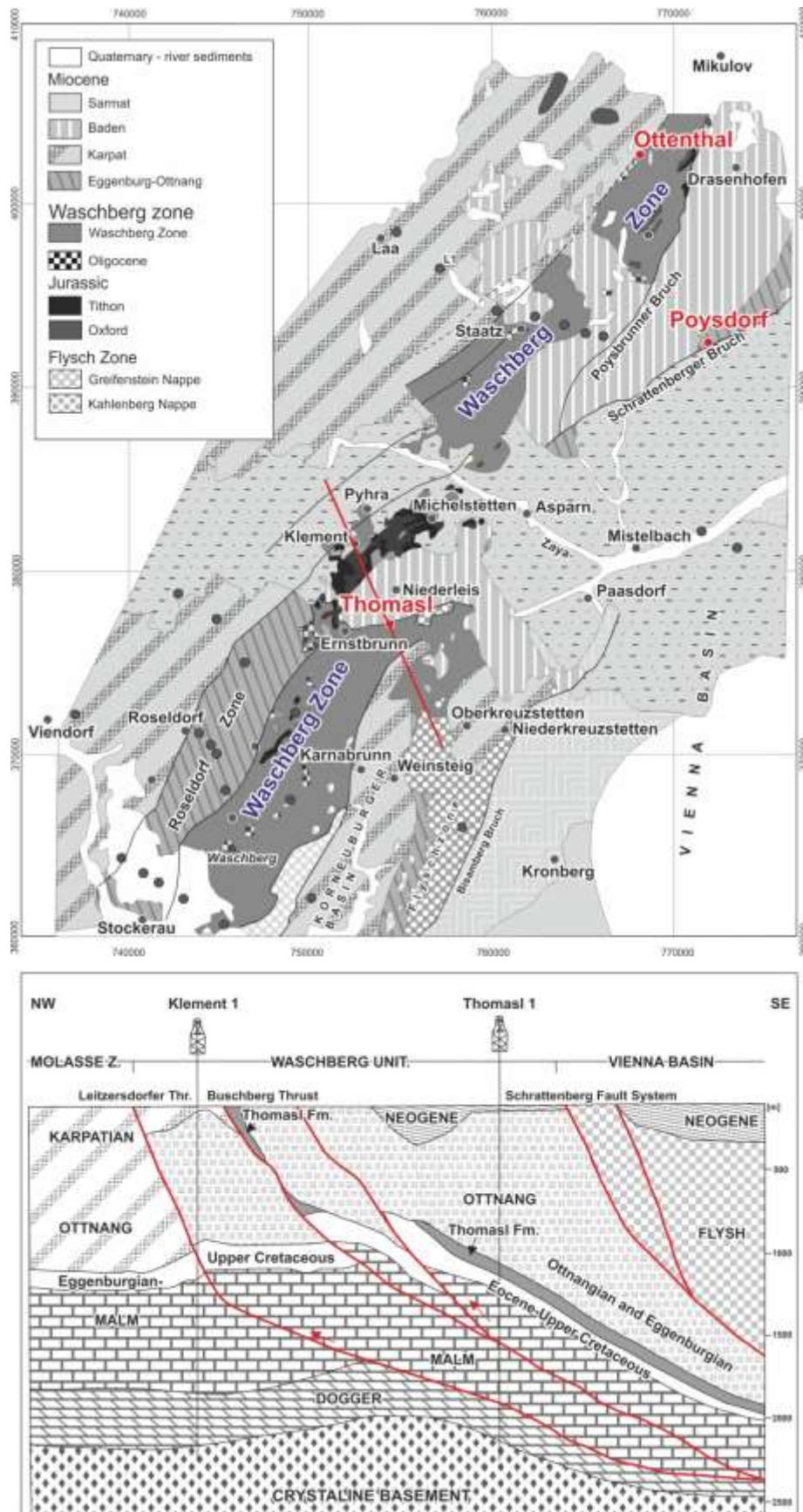
To reach the goal, it was planned to determine (i) total organic carbon (TOC), sulphur and calcite equivalent percentages, (ii) to perform RockEval pyrolysis and (iii) to measure stable isotope ratios of carbonate minerals on c. 125 samples. Furthermore it was planned to investigate biomarker and maceral compositions of 48 samples.

Beyond the agreed methods, atomic absorption spectroscopy (SiO<sub>2</sub> content), X-ray diffraction (bulk mineralogy), and scanning electron microscopy (texture and chemical composition) have been used to characterize the rocks in more detail.

## 2. GEOLOGICAL SETTING

The Waschberg Zone in Lower Austria extends over ca. 50 km from the river Danube near Stockerau to the Czech border in the north (Fig. 1) and continues into the Zdanice and Pouzdrany units in southern Moravia. Its width varies from 4 to 12 km. The Waschberg Zone overthrusts (para-)autochthonous Molasse sediments and is overthrust by the Rhenodanubian Flysch (Granado 2016). It comprises mainly Lower Miocene sediments with imbricated Jurassic, Cretaceous and Paleogene rocks. Ottnangian rocks prevail in an outer unit (Roseldorf Subzone; Fig. 1; Rögl et al., 2012).

The Oligocene succession in the Waschberg Zone comprises the Lower Oligocene Ottenthal Formation and the Upper Oligocene Thomasl Formation (Fig. 2).



**Fig. 1:** a) Tectonic map of the Waschberg Zone (simplified from Wessely, 2006), showing location of the Otenthal “Waldweg section” and the Thomasl 1 and Poysdorf 2 wells. b) Cross section through the Waschberg Zone after Fuchs et al. (2001).

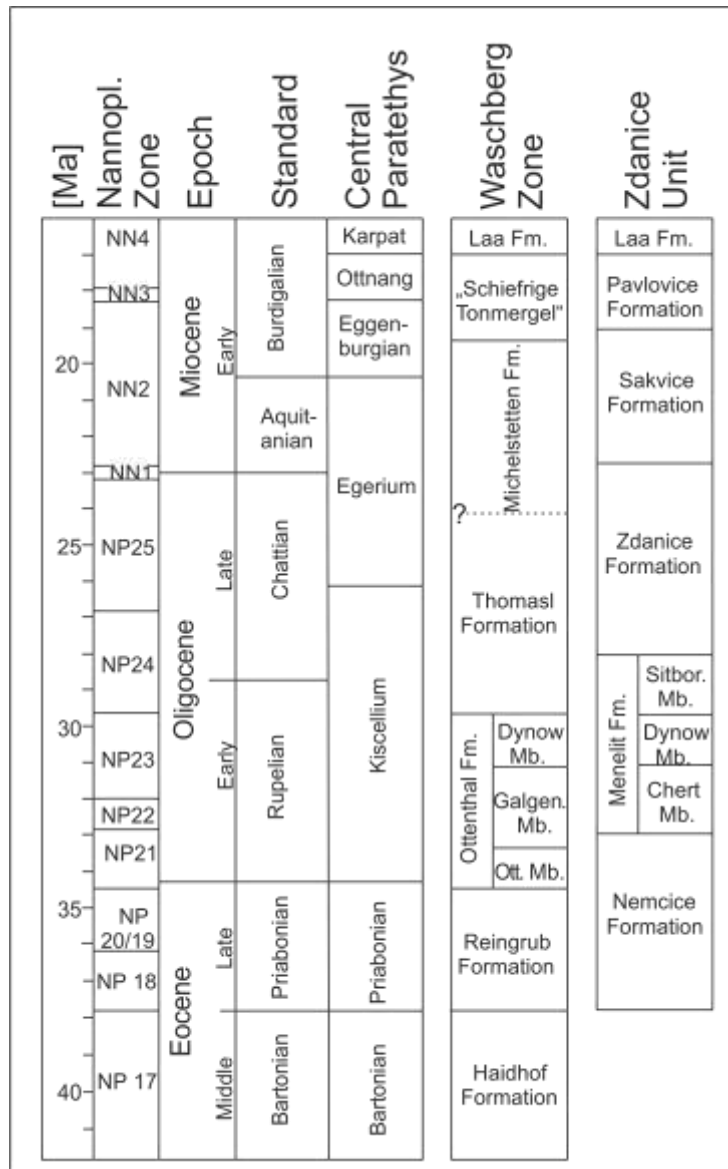


Fig. 2: Stratigraphy of the Waschberg Zone and the Zdanice Unit (after Fuchs et al. 2001).

## 2.1 Ottenthal Formation

The Ottenthal Formation includes from base to top the Ottenthal Member (Seifert, 1982), the Galgenberg Member and the Dynow Member (Rögl et al., 2001; Fig. 2). The lower part of the Ottenthal Member (NP21-22; Rögl et al., 2001) consists of *Globigerina*-marls and banded marls interbedded with bituminous clay. Sandy or silty layers of limonitic laminae are common. The Galgenberg Member (NP22 to lower NP23) includes diatomites and cherts. The Dynow Member (NP23) comprises light grey, partly silicified coccolithic marls. A strong decrease in salinity is recorded within the diatomites of the Galgenberg Member and salinity remained low during deposition of the Dynow Member (Rögl et al., 2001).

The Ottenthal Formation has been studied in the “Waldweg section” located east of the village Ottenthal. This section is approximately 55 m long, but heavily tectonized. Rögl et al. (2001) distinguished twelve tectonic wedges (labelled by Roman numbers), which are separated by faults (Fig. 3).

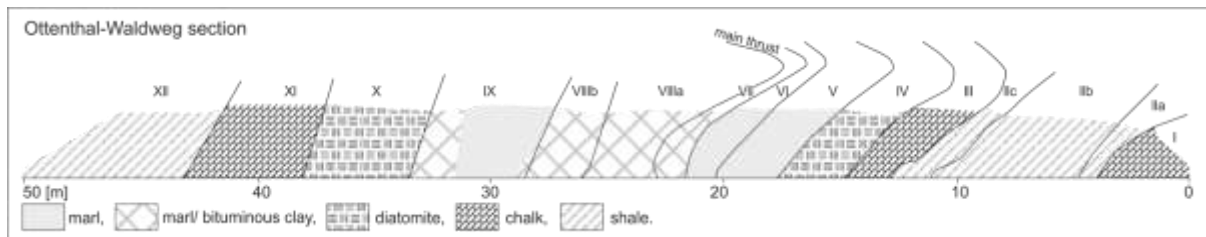


Fig. 3: Wedges of the “Waldweg section” near Ottenthal (after Rögl et al., 2001).

## 2.2 Thomasl Formation

The Upper Oligocene Thomasl Formation (upper NP23-NP25) overlies the Ottenthal Formation and consists of sandy shales and sandstones. Single layers of gypsum and jarosite are present in outcrop samples. Following deposition of the low-salinity Dynow Member, a gradual but fluctuating return to normal conditions is observed within the Thomasl Formation (Rögl et al., 2001). Slump bodies of shales, gravels and sands represent the “Sitborice event” (Krhovský & Djurasinovic, 1993) at the base of the formation. The sedimentary character of the Thomasl Formation hints towards a deep marine depositional setting. The autochthonous foraminifera argue toward an upper to middle bathyal environment (Fuchs et al., 2001). *Globigerina praebulloides*, *G. ciperensis*, *catapsydrax unicavus* and *Globorotalia opimana* date the Thomasl Formation into nannoplankton zone NP24 (Fuchs et al., 2001).

In the studied Thomasl 1 and Poysdorf 2 wells, the Thomasl Formation overlies discordantly Eocene and Upper Cretaceous sediments and is followed by Miocene (Eggenburgian) sediments, building up an intricate imbricated thrust system. The Thomasl Formation in well Thomasl 1 is 127 m thick. However, because of the basal tectonic contact, the true thickness may be higher.

### 3. SAMPLES AND METHODS

#### 3.1 Samples

74 samples from the “Waldweg section” representing the tectonic wedges IIa/b (Thomasl Fm.), IX (Ottenthal Mbr. and Galgenberg Mbr. “shale”), X (Galgenberg Mbr. “diatomite”), XI (Dynow Mbr.), and XII (Thomasl Fm.) were selected for this study. The samples were provided by NHM (Vienna) and have been previously studied by [Rögl et al. \(2001\)](#). Therefore, detailed paleontological data are available from all samples.

32 Cuttings and 18 core samples from boreholes Thomasl 1 and Poysdorf 2 have been taken in the core shed of OMV (Gänserndorf). Cuttings samples were taken every 10 (Thomasl 1: 1600-1800 m; Poysdorf 2: 2800-2910 m) and represent the Thomasl Formation as well as underlying Lower Eocene and overlying Eggenburgian sediments. Cuttings and cores have been (partly) described by [Fuchs et al. \(2001\)](#).

#### 3.2 Methods

Total carbon (TC), total sulphur (S) and total organic carbon (TOC) contents were analysed using an ELTRA Elemental Analyser for all samples. Samples for TOC measurements were decarbonized with concentrated phosphoric acid. Results are given in weight percent (wt.%). Total inorganic carbon (TIC) contents were determined ( $TIC=TC-TOC$ ) and used to calculate calcite equivalent percentages ( $TIC*8.333$ ).

Pyrolysis measurements were performed using a “Rock-Eval 6” instrument. The  $S_1$  and  $S_2$  peaks (mg HC/g rock) were used to calculate the petroleum potential ( $S_1+S_2$  [mg HC/g rock]), the production index ( $PI=S_1/(S_1+S_2)$ , [Lafargue et al., 1998](#)) and the hydrogen index ( $HI=S_2/TOC*100$  [mg HC/g TOC]).  $T_{max}$  was measured as a maturity indicator. The amount of hydrocarbons, which can be generated below 1 m<sup>2</sup> of surface area was calculated using the Source Potential Index ( $SPI=thickness*(S_1+S_2)*bulk\ density/1000$ ) of [Demaison and Huizinga \(1994\)](#).

Polished blocks were prepared for 50 samples. Semi quantitative maceral analysis using reflected white light and fluorescence light and vitrinite reflectance measurements were performed using an incident light Leitz microscope and following established procedures ([Taylor et al., 1998](#)).



48 samples were selected for biomarker analysis and extracted using dichloromethane in a Dionex ASE 200 accelerated solvent extractor at 75°C and 50 bar. Afterwards, asphaltenes were precipitated with a hexane-dichloromethane solution (ratio 80:1 according to volume) and separated by centrifugation. Medium-pressure liquid chromatography (MPLC) using a Köhnen-Willsch instrument was used to separate the hexane-soluble fractions into NSO compounds, saturated hydrocarbons and aromatic hydrocarbons (Radke et al., 1980).

The saturated and aromatic hydrocarbon fractions were analysed by a gas chromatograph equipped with a 30 m DB-5MS fused silica column (i.d. 0.25 mm; 0.25 mm film thickness), coupled to a ThermoFischer ISQ Dual-quadropole mass spectrometer. Using He as carrier gas, the oven temperature was programmed from 70°C to 300°C at 4°C/min increase, followed by an isothermal period of 15 min. With the injector temperature at 275°C, the samples were injected seamlessly. The spectrometer was operated in the EI (electron ionization) mode over a scan range from m/z 50 to 650 at 0.7 s total scan time. The procession of the data happened with an Xcalibur data system. Individual compounds were identified on the basis of retention time in the total ion current (TIC) chromatogram and the comparison of the mass spectra with published data. Percentages and absolute concentrations of various compound groups in the saturated and aromatic hydrocarbon fractions were calculated using peak areas in the gas chromatograms and their relations to the internal standards (deuterated n-tetracosane and 1,1'-binaphthyl, respectively). Concentrations were normalized to TOC.

Stable isotope ratios of carbon and oxygen were measured mainly on carbonate cements. The powdered samples were treated with 100% H<sub>3</sub>PO<sub>4</sub> at 70 °C in an online system (Gasbench II with carbonate option) and the released CO<sub>2</sub> analyzed by a ThermoFisher DELTA V isotope ratio mass spectrometer. The values are normalized to V-PDB (Vienna-Pee Dee Belemnite) for both  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ ; data have a standard deviation of 0.8‰ for  $\delta^{13}\text{C}$  and 0.1‰ for  $\delta^{18}\text{O}$ .

Atomic absorption spectroscopy (AAS) was performed on selected samples to determine biogenic silica contents using a modified method described by Zolitschka (1988). Approximately 100 mg sample material and 50 ml of 0.5 mol/l potassium-hydroxide solution were boiled for an hour to dissolve the opalitic diatom shells. Afterwards 5 ml of the solution were diluted with distilled water (1:1). Thermally attenuated metal atoms emit element-specific photons. The light source of the Perkin Elmer 3030 Atom-Absorption Spectrometer is a hollow-cathode lamp (reduced N<sub>2</sub>O-C<sub>2</sub>H<sub>2</sub>-flame) made from silicon and calibrated using Merck CertiPUR\* Silicon-Standard solution (#1.1231.0500). During the process Si<sup>4+</sup> is

reduced to Si and the reemitted amount of absorbed light is proportional to the concentration of Silicon in the sample.

For bulk mineralogy investigations, 80 X-ray diffractograms (XRD) were recorded using sideward-filled powder ( $\sim 10 \mu\text{m}$ ) mounts with nearly random particle-orientation. XRD analysis was also used to distinguish different types of opal: Opal-A produces a prominent single diffuse band centred at  $\sim 4 \text{ \AA}$ , whereas opal-CT is characterised by three reflections with decreasing intensity (4.11, 4.32, 2.50  $\text{ \AA}$ ; [Jones & Segnit, 1971](#)). Quantitative interpretation was done according to [Schultz \(1964\)](#). All mineral amounts are given as wt.%, with an relative estimated error at 5%.

The texture and chemical composition of rock samples were investigated on freshly broken surfaces and polished block sections with a Zeiss Evo Ma 15 scanning electron microscope (SEM). In addition an Inca Dry Cool EDX (energy dispersive) spectrometer, a high vacuum system at 10 mm working distance, acceleration voltages of 15 to 20 kV and 10 nA beam current were used. Pictures were obtained by secondary and backscattered electron detectors ([Gross et al., 2015](#)).

## 4. RESULTS

The results are presented separately for the “Waldweg section” near Ottenthal (Ottenthal Fm. and Thomasl Fm.) and the Thomasl Formation drilled in boreholes Thomasl 1 and Poysdorf 2.

### 4.1 “Waldweg section”

#### 4.1.1 Lithology and Stratigraphy

Based on age data provided by [Rögl et al. \(2001\)](#), the samples of the “Waldweg section” ([Fig. 3](#)) are arranged into a continuous pseudo-section in [Fig. 4](#). The studied rocks are about 32 m thick and include the Lower Oligocene Ottenthal Formation and the Upper Oligocene Thomasl Formation. The Ottenthal Formation comprises marly shales of the Ottenthal Member (31.51-27.97 m), shales (27.97-27.26 m) and diatomites (27.26-22.65 m) of the Galgenberg Member, and the calcareous Dynow Member (22.65-18.73 m). The base of the Thomasl Formation (18.73-18.05 m) is formed by shales with slumps and pebble layers (“Sitborice Event”; [Rögl et al., 2001](#)).

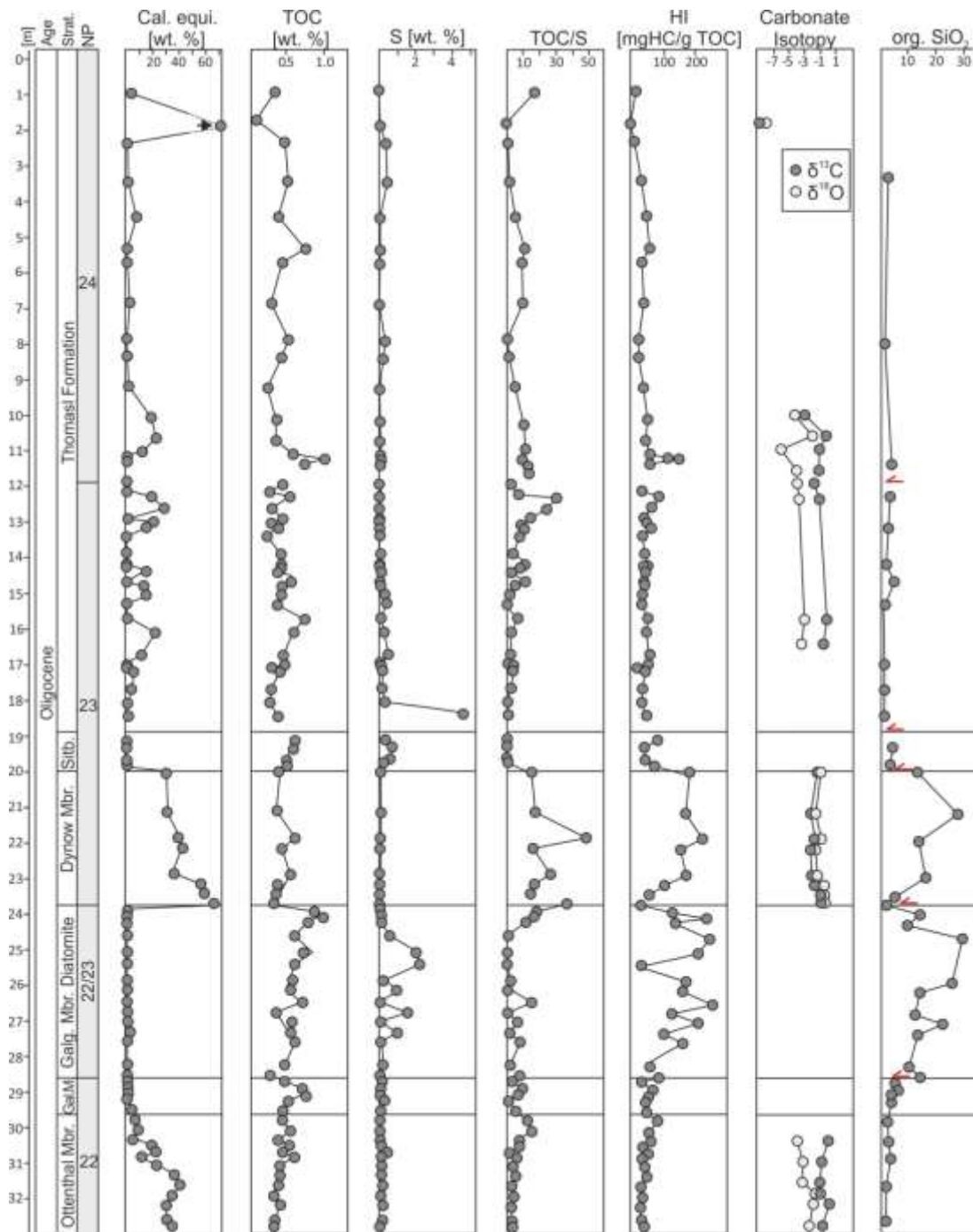
The lithological description follows [Rögl et al. \(2001\)](#). The Ottenthal Member consists from base to top of (i) alternating dark brown laminated and yellowish marls with silt layers; (ii) dark brown to greenish, partly laminated calcareous shales with pteropods and silt layers; (iii) light brown thin bedded and laminated marls with pteropods; and (iv) greenish brown, calcareous shales. Gypsum crusts are abundant. The average carbonate content is 21.4 wt.%.

The Galgenberg Member is largely carbonate-free (average: 0.3 wt.%) and consists of silty shale, overlain by light grey banded and laminated diatomaceous claystone and clayey diatomite. Percentages of biogenic SiO<sub>2</sub> increase upwards (max. 30 wt.%), but are low at the boundary between the Galgenberg Member and the Dynow Member ([Fig. 4](#)).

The Dynow Member includes whitish to yellowish marl (nannofossil-chalk) with thin dark laminae. Carbonate contents are high (average: 44.6 wt.%) and decrease upwards. Interestingly, SiO<sub>2</sub> contents in the Dynow Member are as high as in the underlying diatomaceous sediments.

The base of the Thomasl Formation is formed by variegated shales, sandy layers with clasts of glauconitic sand and clay pebbles (“Sitborice event”; [Krhovský & Djurasinovic, 1993](#)). These rocks are overlain by dark, mostly carbonate-free shales (carbonate content: 0.9 wt.%), interbedded by marly layers (carbonate content: 22.0 wt.%). A layer with whitish chalk

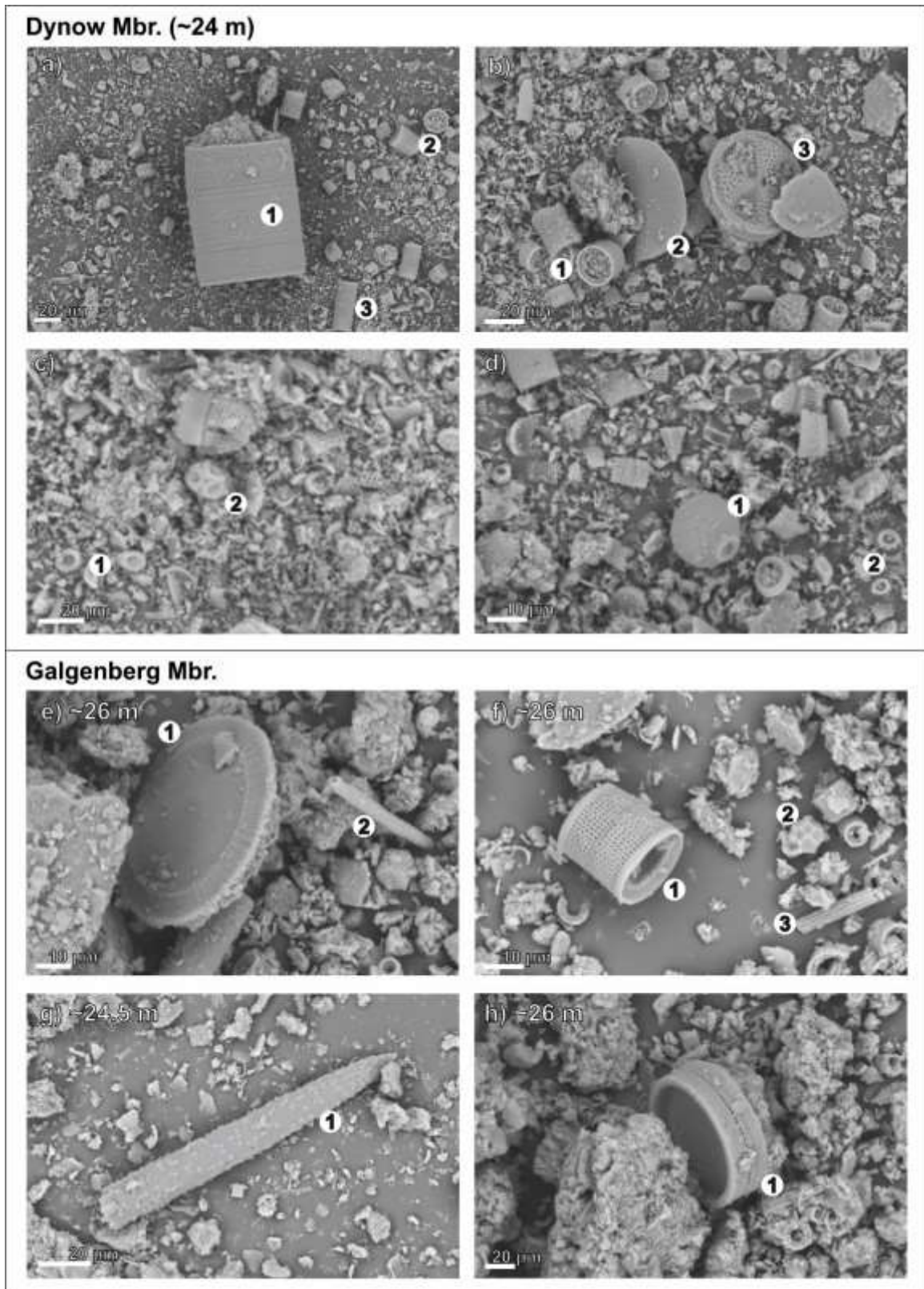
nodules occurs 2.13 m below the top of the profile (95 % calcite). The biogenic silica content is very low (<5% SiO<sub>2</sub>).



**Fig. 4:** Bulk geochemical parameters and isotopy of the Oligocene succession in the “Waldweg section” near Otenthal. NP-nannoplankton zones. Cal. equi. – calcite equivalents; TOC – total organic carbon; S – total sulphur; HI – Hydrogen Index. Red arrows mark boundaries between tectonic wedges.

Detailed micropaleontological investigations were performed by Rögl et al. (2001) and are beyond the scope of the present report. However, the following coccoliths and diatoms were recognized in samples from the Galgenberg and Dynow members (Fig. 5).

- Coccoliths:
  - Reticulofenestra sp. (Fig. 5, c)-2),
  - *Coccolithites cribellum* (Fig. 5, c)-1; Hekel, 1968),
  - *Braarudosphaera* (Fig. 5, f)-2; Burnett, 1998).
  
- Diatoms:
  - *Aulacoseira praeislandica* (e.g. Fig. 5, a)-2/3; cylindric shaped; even spaced rows of perivalvar areolae; brackish or freshwater; Rögl, 1997),
  - *Coscinodiscus* (Fig. 5,b)-2; disc-shaped, cylindrical or wedge-shaped; distinct rosettes of large areolae in the centre of the valve),
  - *Actinoptychus senarius* (Fig. 5, b)-3; disc-shaped with six chambers; marine; Hartley et al., 1996),
  - *Paralia* (Fig. 5, a)-1; barrel-shaped, marine; Cleve, 1873).



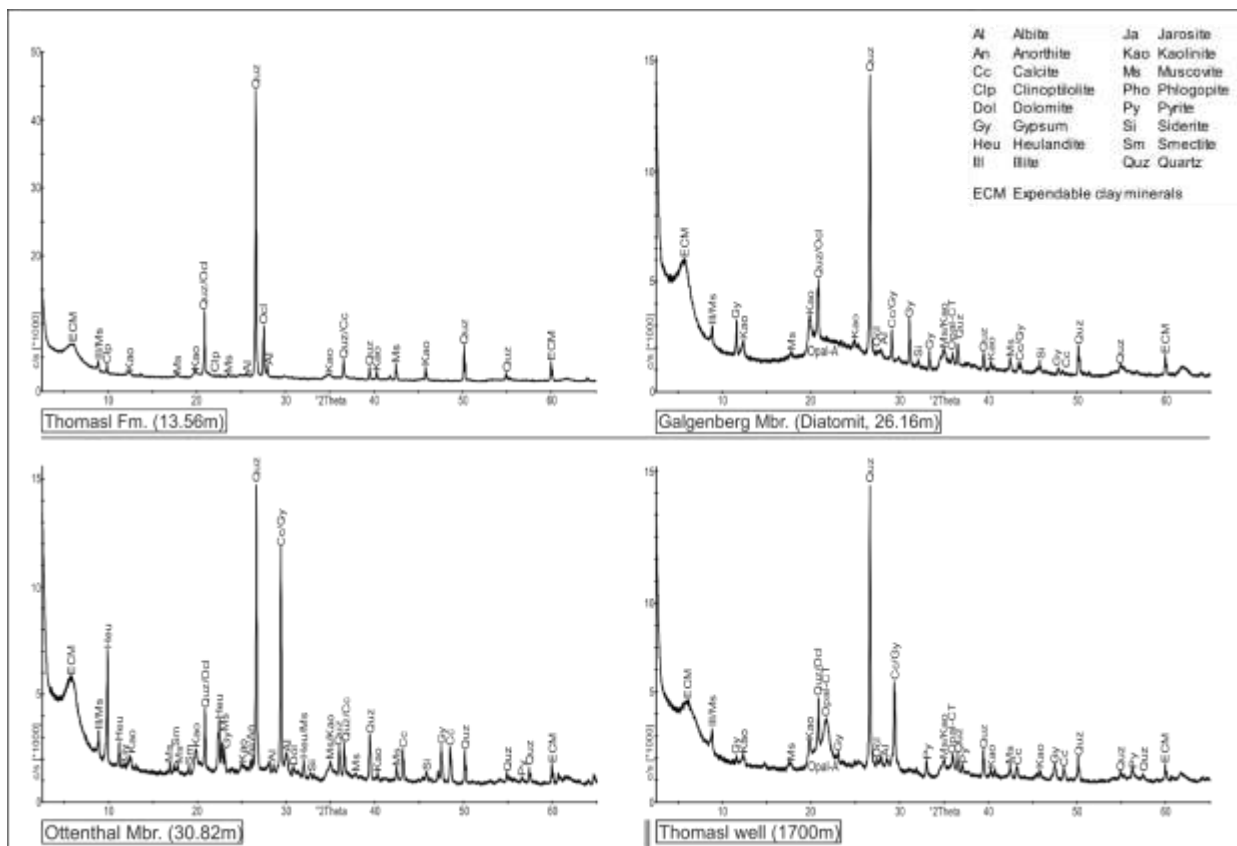
**Fig. 5:** Scanning electron microscopy (SEM) photographs of diatoms and coccoliths.

**a)** 1 *Paralia* (?), 2-3 *Aulacoseira*; **b)** 1 *Aulacoseira*, 2 *Coscinodiscus*, 3 *Actinopterychus senarius*; **c)** 1 *Coccolithites cribellum*, 2 *Reticulofenestra* sp.; **d)** 1 unknown siliceous particle, 2 *Coccolithites cribellum*; **e)** 1 *Coscinodiscus*, 2 sponge spiculae; **f)** 1 *Aulacoseira*, 2 Braarudosphaerales (?), 3 sponge spiculae; **g)** 1 sponge spiculae; **h)** 1 *Paralia* (?).

### 4.1.2 Mineralogy

X-ray diffractograms of 61 samples from the “Waldweg section” are compiled in [Appendix 1](#). Selected X-ray diffractograms are also shown in [Fig. 6](#). Mineral percentages have been estimated and are listed in [Appendix 2](#). However, these numbers are semi-quantitative at best.

The mineralogical composition of all samples is similar, but the relative amounts of carbonate minerals (calcite, dolomite, rare siderite), quartz, opal, feldspar, smectite and other expandable clay minerals (ECMs), illite, kaolinite, pyrite, muscovite and phlogopite vary along the section. Clinoptilolite and heulandite, interpreted as alteration products of volcanic ash layers, occur in significant amounts in the Ottenthal Member and the Thomasl Formation. Jarosite and gypsum, weathering products of sulphides, are present in most samples. Opal is present exclusively as opal A and its abundance correlates well with biogenic silica contents.



**Fig. 6:** XRD traces of three samples from the “Waldweg section” and one sample from the Thomasl well. Note the presence of opal-A in the outcrop section (26.16 m) and of opal-CT in the borehole sample (Thomasl, 1700 m). Heulandite is especially abundant in the “Waldweg section”.

Samples in the Galgenberg Member (23.81 m) and the Thomasl Formation (10.83 m) contain rhombohedral zoned dolomites with several carbonate phases that are distinguishable on the basis of their elemental composition measured with SEM. The phases are i) dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ) in the centre, surrounded by ii) kutnohorite ( $\text{CaMn}^{2+}(\text{CO}_3)_2$ ) in the middle zone, and iii) ankerite ( $\text{Ca}(\text{Mg, Fe, Mn})(\text{CO}_3)_2$ ) in the outermost zone. The outer zones are in optical continuity with the host dolomite, but are easily distinguishable based on their luminescence behaviour.

### 4.1.3 Characterization of organic matter

#### Bulk geochemical parameters and organic petrography

Bulk geochemical parameters are listed in [Appendix 3](#). TOC contents are relatively low in Oligocene sediments of the “Waldweg section” (0.08-1.13 wt.%; average: 0.47 wt.%), but increase upwards in the Ottenthal and Galgenberg members ([Fig. 4](#)). Hence the maximum TOC content (1.13 wt.%), is observed near the top of the Galgenberg Member. TOC contents of the Dynow Member and the Thomas Formation are typically in the range of 0.3-0.9 wt.%. However, a sample at profile meter 11.52 is characterized by a relatively high TOC content (1.13 wt.%; [Fig. 4](#)).

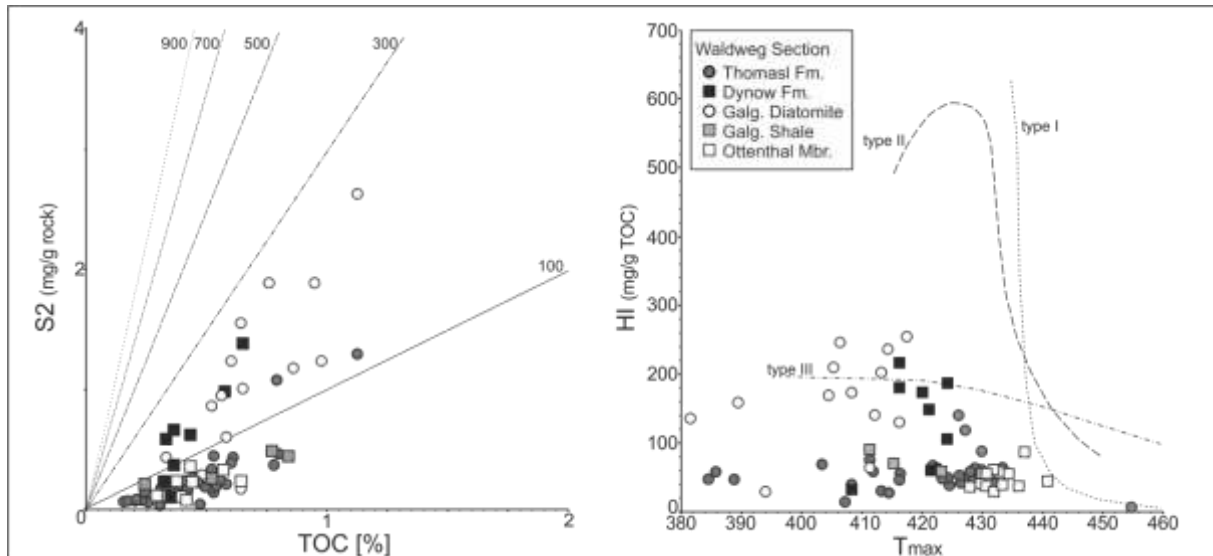
HI values vary from 7 to 252 mgHC/gTOC, indicating the dominance of type III kerogen ([Figs. 4 and 7](#)). Values above 150 mgHC/gTOC are restricted to the diatomaceous section of the Galgenberg Member and the Dynow Member.

Sulphur contents are generally low (av.: 0.3 wt.%), except in the lower part of the Thomasl Formation (~18 m, max.: 4.6 wt.%). TOC/S ratios range from 0.3-49.2. The highest values are observed in the Dynow Member. Another upward increase in TOC/S ratios is observed within the Thomasl Formation (~12 m).

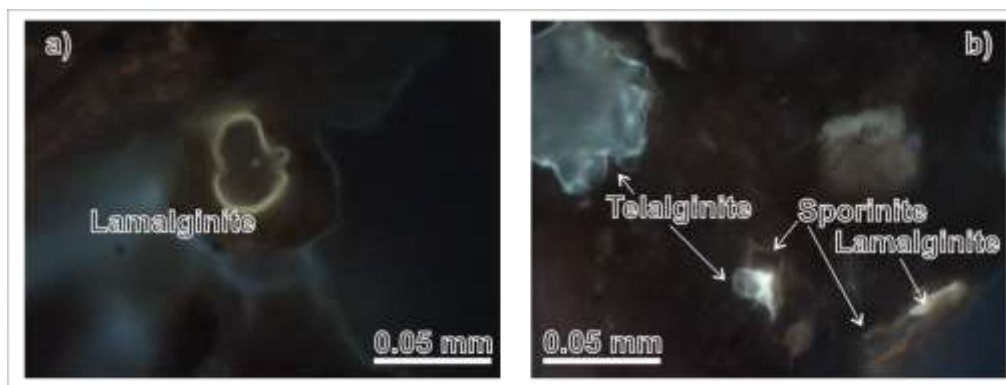
Based on TOC contents exceeding 1 wt.%, one sample from the Galgenberg Member and one sample from the Thomasl Formation were selected for maceral analysis ([Tab. 1](#)). The sample from the Galgenberg Member (23.81 m) comprises a high percentages of terrestrial macerals (vitrinite: 50 vol.%; inertinite: 8 vol.%; sporinite: 25 vol.%). In contrast, the sample from the Thomasl Formation (10.83 m) includes 72 vol.% alginite ([Fig. 8](#)) and a relative low amount of terrestrial macerals. This difference is not reflected by HI values, which are low in both samples ([Tab. 1](#)). Foraminifera (<1.2 wt.%), dinoflagellate cysts and glauconite can be observed in small percentages.



Vitrinite reflectance ( $\sim 0.30$  %Ro) and low  $T_{max}$  values (average:  $420^{\circ}\text{C}$ ) show that the organic matter is immature.



**Fig. 7:** Plots of  $S_2$  vs. TOC and Hydrogen Index (HI) vs.  $T_{max}$  (according to [Espitalie et al., 1984](#)) for the Waldweg section, **b)** Thomasl well and **c)** Poysdorf well. The Thomasl Formation in the Thomasl well contains type III/II kerogen, whereas the Waldweg section and Poysdorf well are only consisting of kerogen type III.



**Fig. 8:** Photomicrographs of samples from the “Waldweg section” in fluorescence mode. **a)** Thomasl Formation, **b)** Galgenberg Member.

**Table 1:** Maceral composition of selected samples of the Ottenthal Waldweg Section, Thomasl and Poysdorf wells.

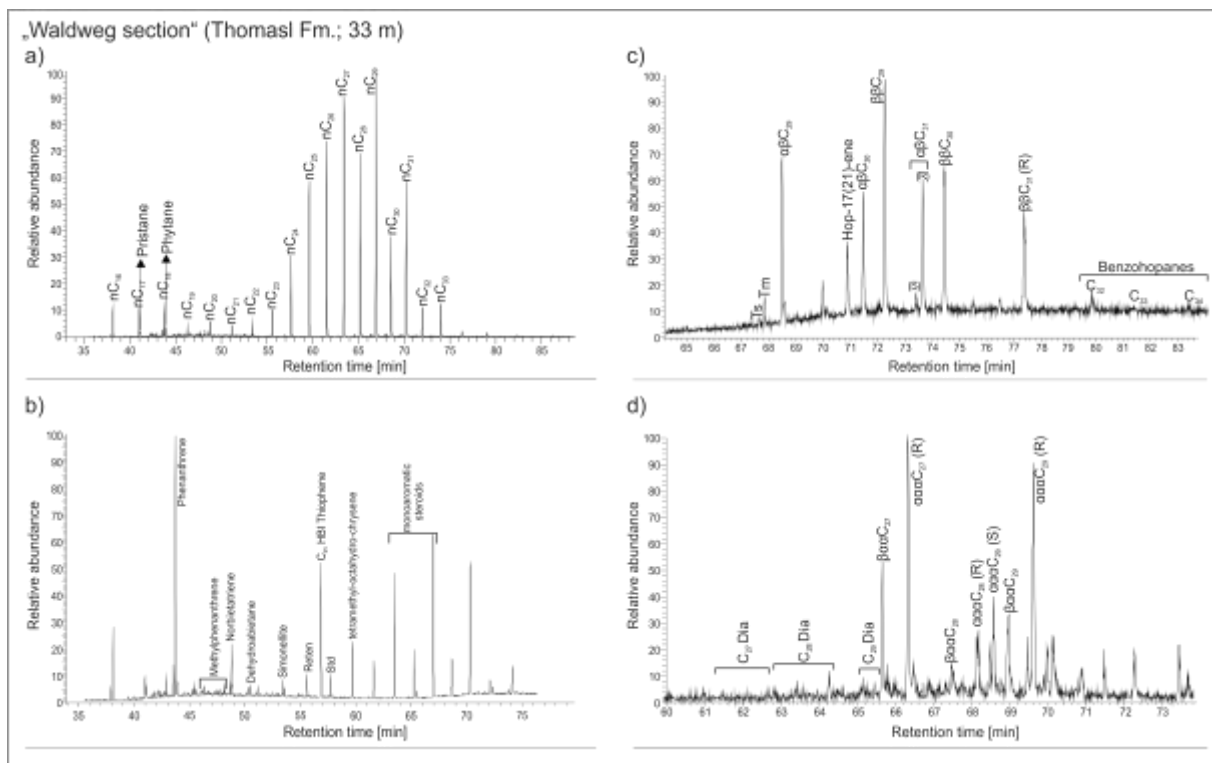
Depth [m]	TOC [wt.%]	HI [mg/gTOC]	VR [%Rr]	Vitrinite	Inertinite	Sporinite	Lamalginate	Telalginate	Σ macerals [vol.%]	Foraminifera [vol.%]	Glauconite yes/no
				[% OM normalized]							
<b>Ottenthal Waldweg Section</b>											
10.83	1.13	115	0.25	17	0	11	31	41	2.83	0	y
23.81	1.13	139	0.33	50	8	25	17	<1	2.11	1.239	n
<b>Thomasl Well Cuttings</b>											
1610	1.88	29		41	47	12	0	0	2.1	0.0	y
1620	0.98	14		71	0	29	0	0	1.9	0.0	n
1630	1.13	37	0.37	56	6	11	6	22	2.8	0.6	y
1640	1.05	123	0.37	62	0	27	8	4	2.3	0.0	n
1650	1.88	165		57	0	25	14	4	3.9	0.0	y
1660	1.63	140	0.38	55	3	21	14	7	3.4	0.2	y
1670	2.32	208		50	0	18	21	11	4.5	0.0	y
1680	1.97	191		53	3	27	7	10	4.4	0.4	y
1690	2.39	161									y
1700	3.67	416	0.35	69	9	11	4	7	7.7	0.0	y
1710	3.26	307		66	9	17	9	0	6.6	0.9	n
1720	2.66	223		48	4	28	8	12	4.4	0.9	y
1730	2.57	168		64	18	13	3	3	5.3	0.1	y
1740	2.46	183	0.35	56	6	22	12	4	5.2	0.0	y
1750	3.18	135		76	0	12	7	5	6.4	0.3	y
1760	3.33	116	0.37	68	4	14	4	11	5.1	0.2	y
1770	2.54	101		61	0	21	7	11	4.2	0.0	y
1780	1.28	38		54	17	11	0	18	2.3	0.2	y
<b>Thomasl Well Core</b>											
1760.4	2.43	44		50	0	8	25	17	3.7	0.0	y
<b>Poysdorf Well Core</b>											
2814.8	6.23	32	0.38	70	8	15	6	2	8.9	6.2	y
2815.1	1.17	139	0.39	60	10	24	0	7	3.3	5.4	y
2817.0	1.5	122	0.35	52	3	24	7	14	3.0	0.3	y

*Depth - measured depth, TOC - total organic carbon, HI – hydrogen index, VR – vitrinite reflectance*

## Molecular composition of hydrocarbons

The extractable organic matter (EOM) yields vary between 6.8 and 62.1 mg/g TOC and are dominated by polar compounds (NSO; 56-87% of EOM). Due to the low extract yields, a separation of the saturated and aromatic compounds was impossible.

Ion traces of saturated and aromatic hydrocarbons as well as steranes and hopanes patterns of a sample from the Thomasl Fm. (33 m) are shown in Fig. 9. Biomarker data of samples from the “Waldweg section” are listed in Tab. 2 and are plotted versus depth in Fig. 10.



**Fig. 9:** Ion traces of the saturated (a; m/z 85) and aromatic (b) hydrocarbon fractions and hopanes (c; m/z 191) and steranes (d; m/z 217+218) patterns of the “Waldweg section” (Thomasl Formation, 33 m). n-alkanes are labeled according to their carbon number.

**n-alkanes and isoprenoids** – n-alkane patterns are often characterized by a predominance of even- over uneven-numbered n-alkanes. This pattern is very rare, but may be attributed to i) specific “fire algae” (Grimalt et al., 1987), ii) a highly saline, carbonate environment (Tissot et al., 1977), or iii) a contribution of recent land plants (Bechtel et al., 2008). A highly saline environment can be excluded (Rögl et al., 2001). Therefore, a contamination with recent land plants seems most likely for the surface samples.

**Table 2:** Organic geochemical data of samples from the “Waldweg section”.

Waldweg section		Depth [m]	TOC [wt%]	HI [ $\mu\text{g/gTOC}$ ]	EOM [ $\mu\text{g/gTOC}$ ]	HC	NSO	Asph. [wt%]	n-C <sub>15-20</sub>	n-C <sub>21-25</sub>	n-C <sub>26-32</sub>	Pr/Ph	C <sub>25</sub> HBI [ $\mu\text{g/gTOC}$ ]	Steroids [ $\mu\text{g/gTOC}$ ]	C <sub>27</sub> Steranes/ Steranes	C <sub>28</sub> Steranes/ Steranes	C <sub>29</sub> Steranes/ Steranes
Thomast Formation		1.44	2.58	2	6.81	5	72	23	24	14	62	0.61	2.40	5.6	0.50	0.13	0.36
		3.03	0.52	33	35.02	5	71	24	5	16	79	0.86	0.02	2.9	0.39	0.22	0.40
		4.93	0.8	58	27.88	7	56	37	12	12	76	0.55	5.90	4.3	0.36	0.16	0.48
		7.48	0.53	27	17.07	2	75	23	3	10	88	0.47	0.89	4.1	0.40	0.16	0.44
		10.83	1.13	115	22.94	4	65	31	8	16	77	0.93	1.50	2.8	0.54	0.10	0.36
		10.97	0.79	138	40.14	2	74	25	7	18	77	0.80	13.53	3.9	0.56	0.10	0.34
		12.7	0.53	85	25.11	10	87	4	16	17	65	0.70	1.66	4.0	0.41	0.23	0.36
		13.32	0.42	39	31.41	13	74	13	29	17	55	0.98	2.91	2.4	0.49	0.14	0.38
		15.1	0.54	37	37.14	7	73	20	35	12	53	0.71	2.92	2.0	0.40	0.17	0.43
		16.13	0.78	47	30.46	8	66	27	28	12	60	1.27	0.83	1.1	0.48	0.14	0.38
17.43	0.46	49	38.94	4	73	23	7	13	81	0.04	1.78	4.7	0.45	0.17	0.38		
Silt.	18.88	0.58	36	33.58	12	69	19	33	17	50	1.08	2.09	12.9	0.44	0.26	0.30	
	19.56	0.52	65	53.26	5	66	29	15	17	70	0.89	0.43	2.7	0.48	0.23	0.30	
Dynow Mbr.	21.58	0.65	214	34.92	3	62	35	13	10	78	0.50	0.68	5.9	0.34	0.18	0.49	
	22.6	0.57	172	40.96	5	60	36	14	9	77	0.46	1.70	12.5	0.22	0.26	0.52	
Galgenberg Mbr.	Diatomite	23.81	1.13	236	62.06	3	53	44	10	12	78	0.82	0.68	3.2	0.29	0.27	0.44
		24.8	0.94	202	55.93	2	66	32	24	11	66	1.06	0.89	5.5	0.29	0.21	0.50
		26.2	0.75	252	59.76	6	51	43	57	12	28	1.54	3.56	1.2	0.35	0.18	0.47
		27.32	0.67	156	62.61	16	59	25	74	9	13	1.57	9.93	3.1	0.46	0.17	0.36
		28.63	0.77	64	41.92	6	64	30	35	12	53	0.63	1.62	8.1	0.36	0.17	0.47
Ottenthal Mbr.	shale	29.82	0.57	58	26.80	4	77	19	6	12	82	0.52	0.70	1.5	0.42	0.12	0.46
		30.59	0.64	34	45.76	3	57	40	16	14	70	0.68	1.66	2.2	0.36	0.16	0.49

Waldweg section		Depth [m]	Steroids/ hopanoids [ $\mu\text{g/gTOC}$ ]	MAS [ $\mu\text{g/gTOC}$ ]	Hopanes [ $\mu\text{g/gTOC}$ ]	22S(S+R) hopanes	Ts/Tm	$\beta\beta$ -Hopanes [ $\mu\text{g/gTOC}$ ]	Hop-17(21)-ene [ $\mu\text{g/gTOC}$ ]	Benzohop. [ $\mu\text{g/gTOC}$ ]	Phenanthren [ $\mu\text{g/gTOC}$ ]	MPI [ $\mu\text{g/gTOC}$ ]	Di/(Di+Tri) terpeno.	Di+Tri terpeno.
Thomast Formation		1.44	0.13	0.20	14.4	0.19	0.17	5.8	0.8	1.9	0.8	0.42	0.71	0.8
		3.03	0.05	0.13	24.2	0.21	0.19	8.1	1.9	5.3	1.8	0.48	0.63	0.8
		4.93	0.06	0.33	122.4	0.14	0.16	43.4	7.6	3.0	17.4	0.27	0.58	11.8
		7.48	0.05	0.06	59.3	0.22	0.16	22.1	3.3	1.0	1.3	0.31	0.20	1.3
		10.83	0.05	0.07	22.4	0.20	0.13	10.2	0.9	2.4	5.6	0.17	0.68	2.1
		10.97	0.06	1.41	69.4	0.21	0.13	27.3	3.0	20.5	8.2	0.45	0.72	5.9
		12.7	0.11	0.24	17.9	0.34	0.24	7.0	2.5	8.2	1.8	0.18	0.54	2.4
		13.32	0.12	0.86	87.1	0.25	0.20	26.3	8.7	11.2	5.6	0.23	0.44	8.5
		15.1	0.15	0.46	31.9	0.30	0.19	9.9	2.1	5.3	16.1	0.28	0.48	4.0
		16.13	0.08	0.25	25.6	0.30	0.11	8.0	1.5	4.6	6.4	0.38	0.51	2.2
17.43	0.11	0.61	96.7	0.18	1.00	38.0	7.9	8.2	2.8	0.34	0.15	5.9		
Silt.	18.88	0.27	0.32	16.0	0.21	0.28	4.8	1.3	0.1	2.5	0.35	0.15	3.4	
	19.56	0.21	0.08	4.5	0.27	0.23	1.4	0.3	0.5	0.6	0.27	0.25	0.5	
Dynow Mbr.	21.58	0.04	0.22	38.9	0.34	0.07	16.8	1.6	7.1	2.4	0.26	0.47	1.7	
	22.6	0.04	0.18	53.7	0.41	0.12	24.9	2.8	5.7	3.0	0.57	0.32	1.5	
Galgenberg Mbr.	Diatomite	23.81	0.03	0.50	121.7	0.33	0.09	56.7	5.9	5.0	7.1	0.32	0.45	2.8
		24.8	0.04	0.74	77.4	0.31	0.06	36.0	3.8	22.6	4.3	0.71	0.70	3.0
		26.2	0.08	0.30	28.2	0.31	0.15	12.0	1.9	2.6	16.0	0.27	0.80	2.5
		27.32	0.14	0.22	24.8	0.43	0.19	9.6	1.8	2.4	13.6	0.14	0.67	4.5
		28.63	0.13	0.27	29.3	0.26	0.24	8.9	2.6	1.3	6.1	0.30	0.56	2.3
Ottenthal Mbr.	shale	29.82	0.09	0.68	21.7	0.30	0.24	7.2	2.1	10.1	1.7	0.23	0.38	2.9
		30.59	0.09	0.91	49.9	0.19	0.18	15.8	3.6	11.6	15.3	1.66	0.53	5.9

TOC - total organic carbon, HI – hydrogen index, EOM – extracted organic matter, HC – hydrocarbons, NSO – polar compounds, Asph. – asphaltenes, n-C<sub>15-20</sub> – short-chain alkanes, n-C<sub>21-25</sub> – medium-chain alkanes, n-C<sub>26-32</sub> – long-chain alkanes; Pr/Ph – Pristane/Phytane ratio; MAS – monoaromatic steroids; MPI – Methylphenantrene Index; Di/(Di+Tri) terpeno. – Diterpenoids/triterpenoids ratio.

The “Waldweg section” is dominated by long chain n-alkanes (n-C<sub>26-32</sub>: av. 66%), which are characteristic for higher land plants (mainly plant waxes; [Eglinton and Hamilton, 1967](#)).

Middle chain n-alkanes (n-C<sub>21-25</sub>), typical for aquatic macrophytes (Ficken et al., 2000), occur in very low amounts (av. 13%). The short chain n-alkanes, in general related to algae and microorganisms are by far less frequent than the long chain but more dominant than the medium-chain n-alkanes (n-C<sub>15-20</sub>: av. 21%). However, because contamination by recent land plants cannot be excluded, the observed distributions must not be overinterpreted.

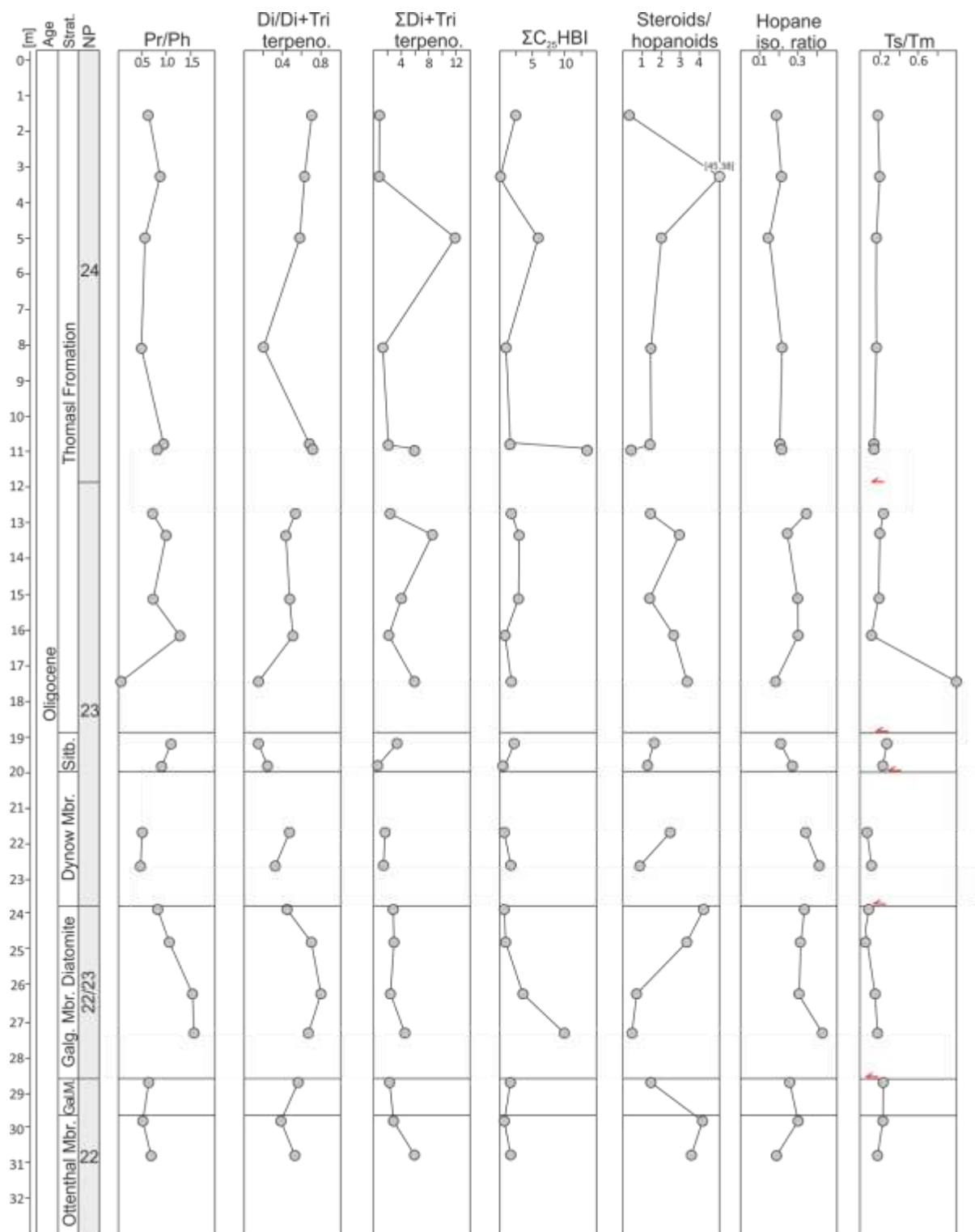
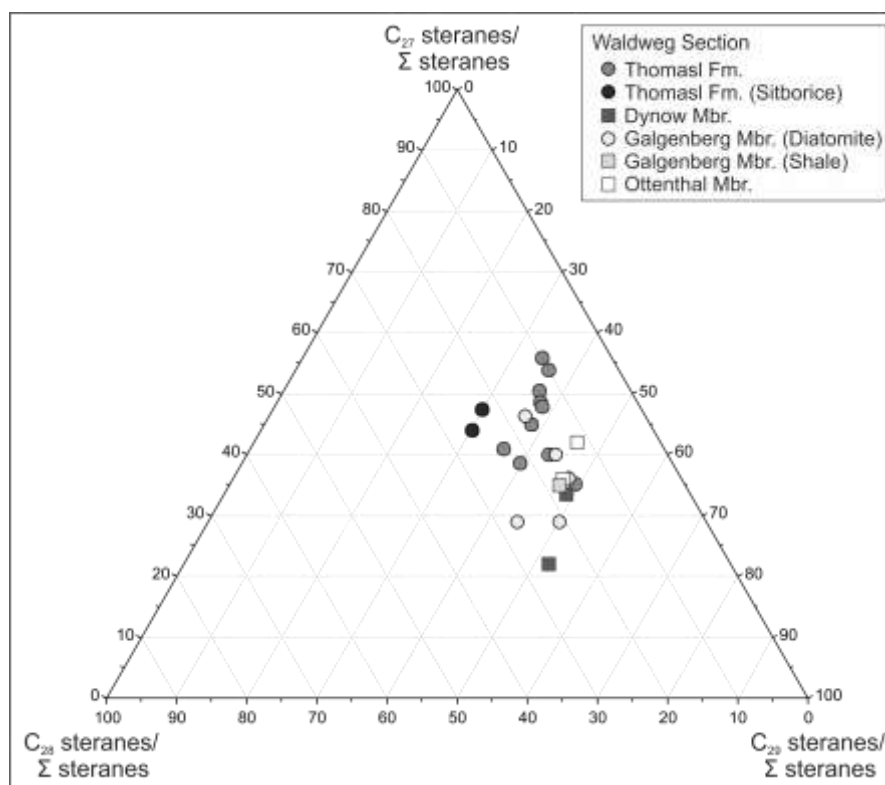


Fig. 10: Biomarker ratios and concentrations of Oligocene rocks from the “Waldweg section”.

The pristane/phytane (Pr/Ph) ratio is considered as a redox parameter by [Didyk et al. \(1978\)](#). The ratio varies between 0.46 and 1.27. It displays an upward decreasing trend in the interval comprising the diatomites of the Galgenberg Member and the Dynow Member. Pr/Ph ratios in the Thomasl Formation are typically below 1.0 and show a subtle upward decrease.

The C<sub>25</sub> HBI (highly branched isoprenoid) thiophenes are formed by the sulfurization of C<sub>25</sub> HBI alkanes and are indicative for diatoms. Their concentrations vary strongly along the profile. As expected, high concentrations of C<sub>25</sub> HBI thiophenes are observed in the diatomite section of the Galgenberg Member (up to 9.9 µg/g TOC). Surprisingly, the maximum concentration (13.5 µg/g TOC) is detected in the Thomasl Formation at c. 11 m depth.

**Steroids** – The steroid concentration decreases in the Ottenthal Formation, from 5.6 to 1.1 µg/g TOC. In the lower part of the Thomasl Formation they reach their peak values with 12.9 µg/g TOC, and decrease upwards. C<sub>27</sub> and C<sub>29</sub> steranes slightly dominate over C<sub>28</sub> steranes ([Fig. 11](#)).



**Fig. 11:** Distribution of C<sub>27</sub>, C<sub>28</sub> and C<sub>29</sub> steranes for samples from the “Waldweg section”.

Steroids/hopanoids ratios range from 0.03 to 0.27, which indicates organic matter input with major contribution of marine algae ([Moldowan et al., 1986](#)). The concentration of monoaromatic steroids (MAS) ranges from 0.08-1.42 µg/g TOC.

**Terpenoides** - Hopanes are non-aromatic cyclic triterpenoides that originate from precursors in bacterial membranes (Ourisson et al., 1979). Their concentration varies between 4.5 and 122.4 mg/g TOC in the “Waldweg section”. The 22S/(22S+22R) C<sub>31</sub> hopane isomerization ratio is a maturity parameter and reaches its equilibrium (~0.6) before oil expulsion (Peters et al., 2005). Within the “Waldweg section”, the 22S/(22S+22R) ratio varies between 0.19 and 0.41. Ts (C<sub>28</sub> 18 $\alpha$ -trisorhopane) and Tm (C<sub>27</sub> 17 $\alpha$ -trisorhopane) are often encountered in combination with each other. The Ts/Tm ratio is a parameter both dependent on source and maturity (Moldowan et al., 1986). In the “Waldweg section” the Ts/Tm ratio varies between 0.06 and 0.24 (exception: sample 17.43 m with a Ts/Tm ratio of 1.0). The  $\beta\beta$ -hopanes (1.4-43.38  $\mu$ g/g TOC) are highly specific for immature to early oil generation source rocks (Seifert and Moldowan, 1980). Hop-17(21)-ene is likely sourced from methanotrophic bacteria (Thiel et al., 1999) and often occurs in combination with carbonate rocks. It is present in relatively low concentrations (<0.43  $\mu$ g/g TOC). Benzohopanes (<22.59  $\mu$ g/g TOC) are derived from unknown precursors and occur at an early or late mature range.

**Phenantrenes, methylphenantrens** - Phenantrenes (Phen) and 3,2,9,1-methylphenantrens derive from a variety of non-specific precursors (e.g. steroids and triterpenoids) (Tissot and Welte, 1984). The phenantrene concentration varies between 0.6 and 16.1  $\mu$ g/g TOC. The MPI-1 (Radke and Welte, 1981) is typically below 0.5.

**Land plant related biomarkers** – Bi- and tricyclic diterpanes can be used to determine terrigenous and marine input (Simoneit, 1986). Norbietetatriene, simonellite, retene and dehydrobietetatriene are gymnosperm-derived biomarkers and occur in low concentrations (<6.8  $\mu$ g/g TOC), retene being the most abundant. Angiosperm derived biomarkers (triterpenoids) like variations of crysene and picene vary between 0.23-5.02  $\mu$ g/g TOC. The sum of di- and triterpenoids is often used as a proxy for landplant input, whereas the di-/(di- + triterpenoids) ratio is an established proxy for the ratio of gymnosperms to angiosperms (e.g. Bechtel et al., 2008). The sum of di- and triterpenoid is relative constant in the lower part of the succession (<5.92) and reaches two peaks within the Thomasl Formation (<11.83  $\mu$ g/g TOC). The di-/(di- + triterpenoids) ratio is low (<0.80) indicating a predominance of angiosperms.

**Carbon isotopic composition** –  $\delta^{13}\text{C}_{\text{carb}}$  values in the “Waldweg section” typically vary between +0.1 ‰ (Ottenthal Mbr.) and -3.0 ‰ (Thomasl Fm.), but reach a minimum of -8.7 ‰ in a layer with chalk nodules in the upper part of the Thomas Formation (~2 m; Fig. 4).

## 4.2 Borehole Thomasl 1

### 4.2.1 Lithology and Stratigraphy

The Thomasl Formation in borehole Thomasl 1 extends from 1763 to 1636 m depth. Its base is formed by a thrust plane separating the Thomasl Formation from Lower Eocene calcareous shale and clay. 12 core samples provide information on the lowermost 3 m of the Thomasl Formation (1763-1760 m) and indicate an upward increase in carbonate content in the dark brownish-grey sediments (Fig. 12).

Based on cuttings data, the Thomasl Formation consists mainly of marly shales with an average carbonate content of 17.1 wt.%. According to Fuchs et al. (2001), a prominent spike in the resistivity log at around 1695 m may indicate a layer with increased content of siliceous microfossils. Within this context, it is interesting to note that organic SiO<sub>2</sub> percentages are low, but reach 4.5 wt.% at 1700 m depth (Fig. 12). The Thomasl Formation is overlain by Lower Miocene (Eggenburgian) sediments (Fuchs et al., 2001).

Diagenetic carbonate phases with a distinct zonation (dolomite→kutnohorite→ankerite) occur in most samples (e.g. 1630, 1660, 1730, 1740, 1760, 1780 m).

### 4.2.2 Mineralogy

X-ray diffractograms were recorded from 19 samples from the Thomasl well (Appendix 1). The mineralogical composition (Appendix 2) is similar to that in the “Waldweg section”, however weathering products (jarosite, gypsum) are largely absent. Clinoptilolite and heulandite occur only in trace amounts. In the sample at 1700 m depth, opal C-T is present in significant amounts (Fig. 6). Samples from Eggenburgian horizons (and the uppermost Thomasl sample (which may include cavings from the Eggenburgian) are rich in quartz, feldspar and dolomite, but poor in clay minerals.



### 4.2.3 Characterization of organic matter

#### **Bulk geochemical parameters and organic petrography**

Cuttings from the Lower Eocene succession contain 1.3 to 2.5 %TOC. HI values (38-101 mgHC/gTOC) indicate the presence of type III kerogen.

TOC contents from the basal 3 m of the Thomasl Formation (core samples) are low (0.4-2.4 wt.%; av. 0.91 wt.%). HI values (<50 mgHC/gTOC) show the presence of type III kerogen. The main part of the Thomasl Formation, represented by cuttings samples, contains high TOC contents (av. 2.5 wt.%). The maximum TOC is observed at 1700 m depth (3.7 wt.%). The HI of cuttings samples varies between 116 and 416 mgHC/gTOC, representing type III kerogen and type II kerogen (Figs. 12 and 13).

TOC contents of Eggenburgian sediments are moderately high (0.43-1.88 wt.%), but their HI is low (<90 mgHC/gTOC; type III kerogen).

The sulphur content of cuttings samples from the Thomasl Formation varies between 1.9 and 3.8 wt.% and is slightly lower in Lower Eocene sediments (av.: 1.25 wt.%). Eggenburgian deposits are very low in sulphur (av. 0.3 wt.%). The average sulphur content of the core representing the lowermost 3 m of the Thomasl Formation is 0.5 wt.%.

TOC/S ratios <3.2 in Lower Eocene and Oligocene sediments agree with a marine depositional environment (Berner and Raiswell, 1984). Elevated values in the Eggenburgian section (2.5-7.8) may indicate a temporal brackish influence.

T<sub>max</sub> values (~412°C) in combination with vitrinite reflectance (<0.38%Ro) show that the organic matter is immature.

The maceral composition (Table 1, Fig. 14) is dominated by terrestrial macerals (vitrinite: 41-76 vol.%; sporinite: 11-29 vol.%). Inertinite is hardly present (0-18 vol.%), including one exception (47 vol.%, 1610 m). Lam- (0-25 vol.%) and telalginite (0-22 vol.%) are less abundant. Foraminifera are present in low concentrations (<0.9 wt.%). Glauconite occurs in most samples.

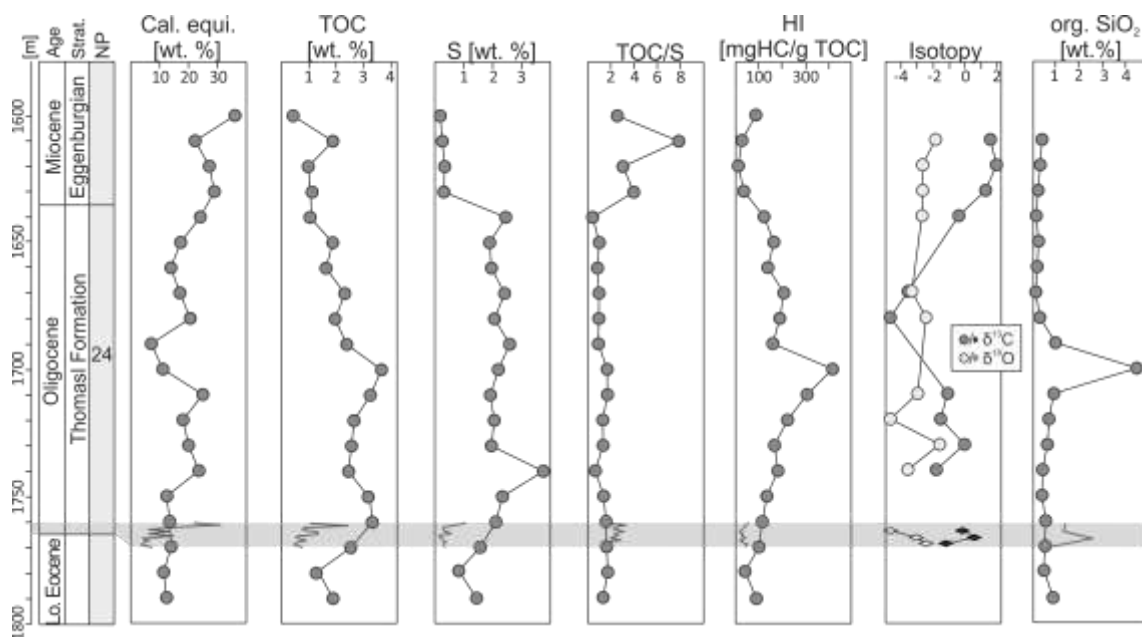


Fig. 12: Bulk geochemical parameters and isotopy of the Upper Oligocene Thomasl Formation in well Thomasl 1 with nannoplankton zones. Data from a core representing the lowermost 3 m of the Thomasl Formation are displayed (slightly enlarged; see grey bar) as lines.

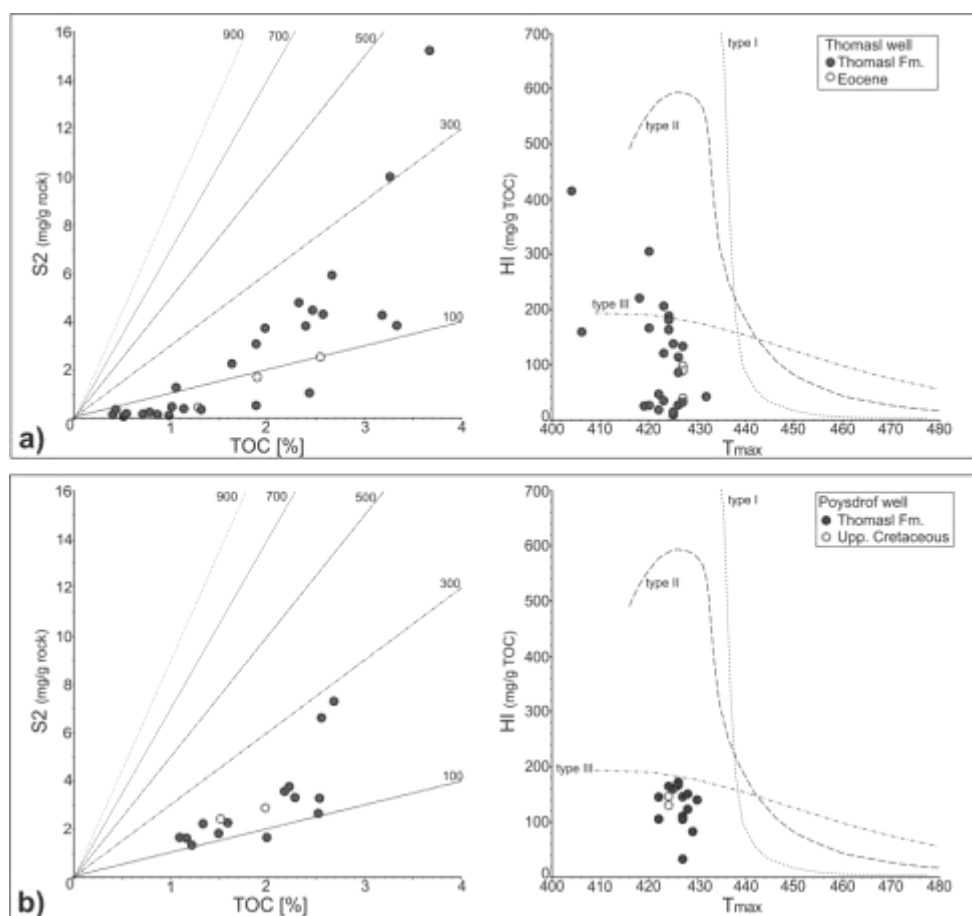
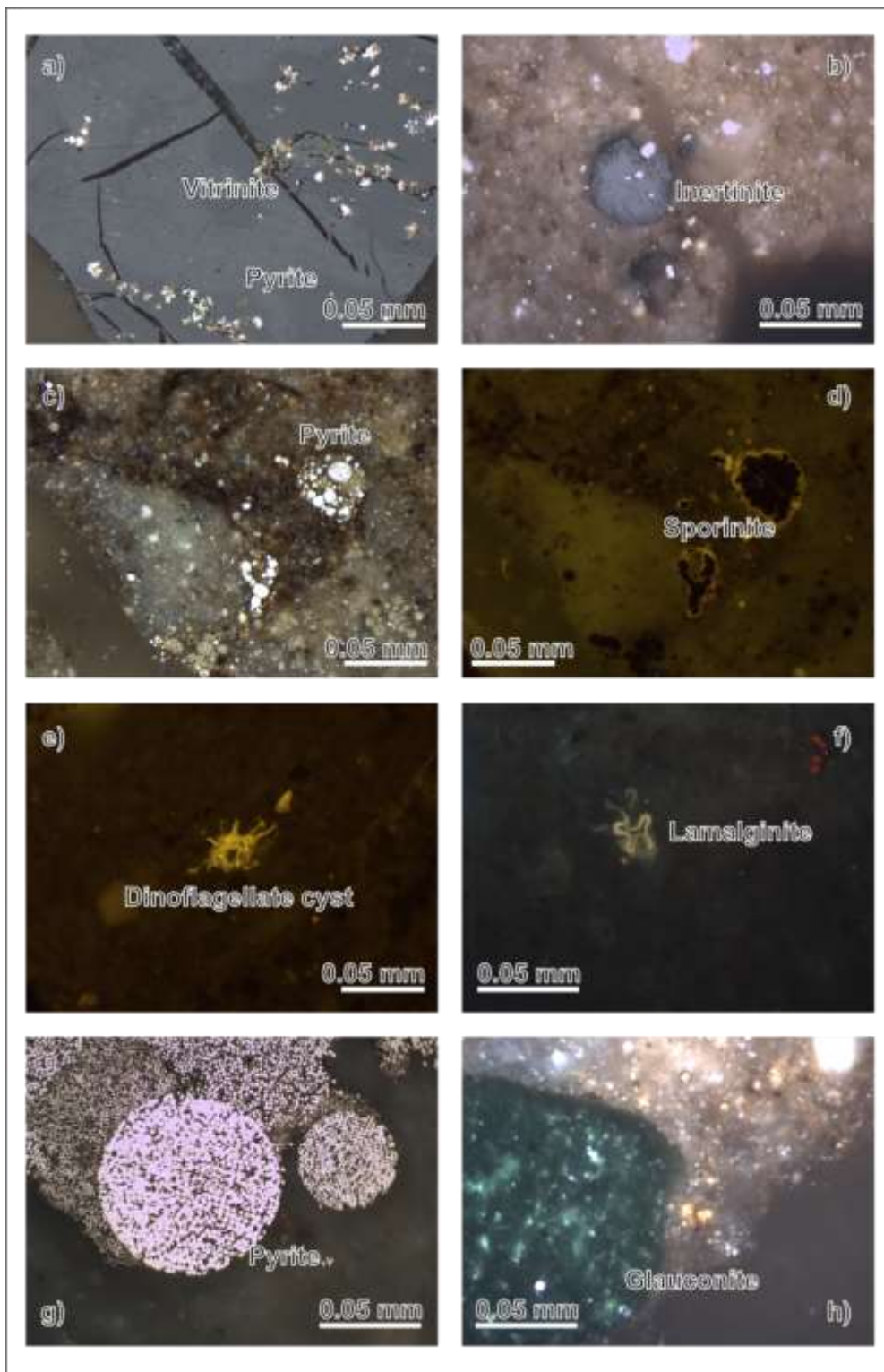


Fig. 13: Plots of  $S_2$  vs. TOC and Hydrogen Index (HI) vs.  $T_{max}$  (according to Espitalie et al., 1984) for the a) Thomasl well and the b) Poysdorf well.



**Fig. 14:** Photomicrographs of the Thomasl Formation (Thomasl well). a) large vitrinite particle (1640 m); b) inertinite (1760 m); c,d) pyrite and sporinite in normal and fluorescent light (1660 m); e) dinoflagellate cyst (1760 m); f) lamalginite (1770 m); g) framboidal pyrite (1780 m); h) glauconite (1660 m). d-f) fluorescent mode. f,g) are from 1770 m depth (uppermost Eocene sample). However, it is likely that this material represents cavings from the Thomasl Formation.



Pr/Ph ratios of the Thomasl Formation vary between 0.2 and 1.1 and show a cyclic variation (Fig. 17). A slightly higher ratio (1.25) is observed in the Lower Eocene succession. The concentrations of C<sub>25</sub> HBI thiophenes and alkanes are high in the upper part of the Thomasl Formation (17.3-48.3 µg/g TOC) and significantly lower in the rest of the studied succession (0.1-6.8 µg/g TOC).

**Steroids** -The average sterane concentration is 17.1 µg/g TOC within the Thomasl Formation and lower in the Eggenburgian (12.1 µg/g TOC) and the Lower Eocene (10.6 µg/g TOC). The core samples have an average sterane content of 14.5 µg/g TOC. In the upper part (1610-1660 m) of the section C<sub>27</sub> steranes dominate, in the lower part C<sub>28</sub> and C<sub>29</sub> steranes are most abundant. Algae are discussed as precursors for C<sub>27</sub>, whereas land plant waxes are the likely origin of C<sub>29</sub> steranes (Fig. 16; Volkman, 1986). The sterane/hopane ratio is low (<1.1) in the Lower Eocene succession, the lower part of the Thomasl Formation and in the overlying Eggenburgian sediments, but high (max. 2.6) in the upper part of the Thomasl Formation. The concentration of monoaromatic steroids (MAS) ranges from 1.5-52.3 µg/gTOC within the Thomasl well. At a depth of 1700 m the concentration is drastically elevated (445.3 µg/gTOC).

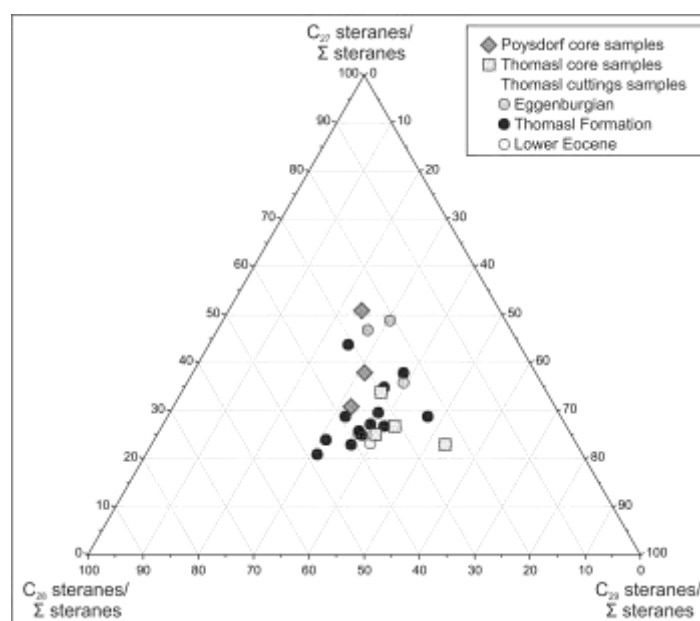


Fig. 16: Distribution of C<sub>27</sub>, C<sub>28</sub> and C<sub>29</sub> steranes for samples from the Thomasl and Poysdorf wells.

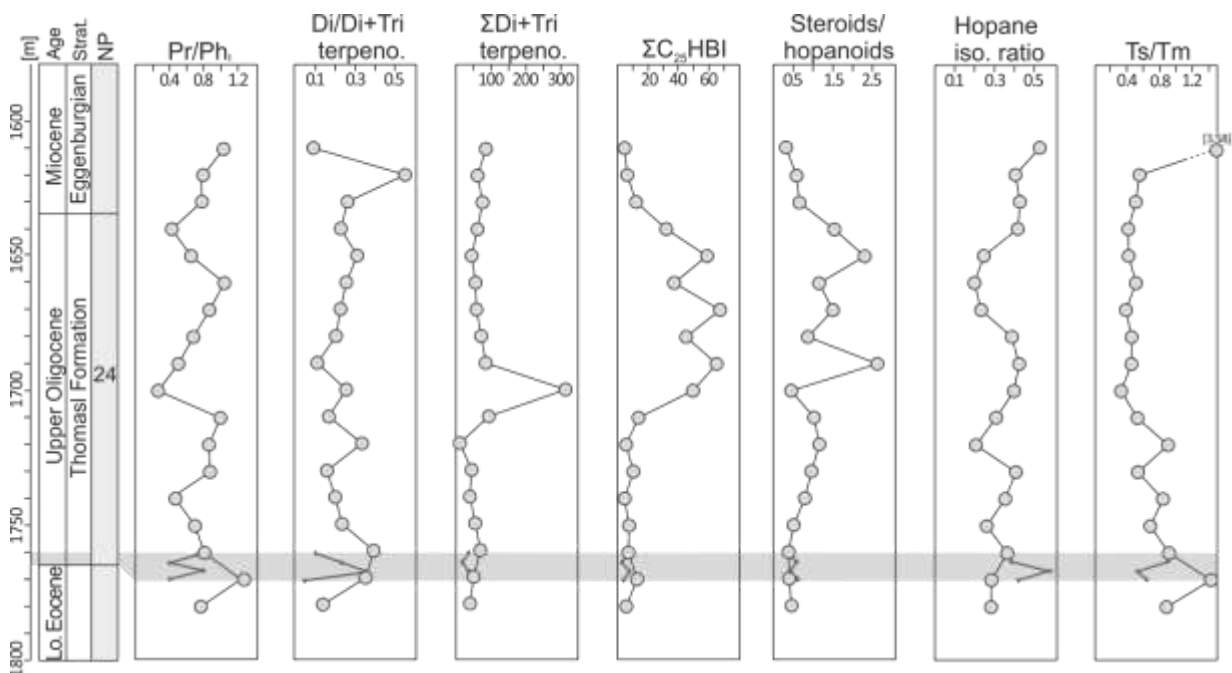
**Terpenoids** - The hopane concentrations vary between 3.4 and 68.2 µg/g TOC. The C<sub>31</sub> 22S/(22S+22R) hopane isomerization ratio ranges from 0.28 to 0.52. The Ts/Tm ratio ranges between 0.33 and 3.58; minimum values are encountered in the central part of the succession, whereas high values occur in Eggenburgian deposits. ββ-hopanes concentrations are about 8.6

$\mu\text{g/g}$  TOC, with the exception of the sample at 1770 m depth ( $33.5 \mu\text{g/g}$  TOC ). Hop-17(21)-ene is present in concentrations  $<3.72 \mu\text{g/g}$  TOC (1700 m). Benzohopanes concentrations range from 0.9 to  $25.9 \mu\text{g/g}$  TOC, but reach a maximum concentration of  $165.8 \mu\text{g/g}$  TOC at a depth of 1700 m.

**Phenantrenes, methylphenantrens** – The concentration of phenantrenes ( $29.3\text{-}289.6 \mu\text{g/g}$  TOC) is elevated in the lower part of the Thomasl Formation (1700-1760 m) and significantly lower in its upper part ( $3.1\text{-}39.3 \mu\text{g/g}$  TOC) and in Eggeburgian sediments ( $\sim 0.4 \mu\text{g/g}$  TOC). 3,2,9,1-methylphenantrens concentrations display the same pattern than the phenentrenes with concentrations below  $40.2 \mu\text{g/g}$  TOC.

**Land-plant related biomarkers** – Norbietetriene ( $<24.4 \mu\text{g/g}$  TOC), dehydrobietetriene ( $<27.5 \mu\text{g/g}$  TOC), simonellite ( $<17.2 \mu\text{g/g}$  TOC) and retene ( $<10.7 \mu\text{g/g}$  TOC) are most abundant at a depth of 1770 m. Crysene and picene vary from 0.3 to  $15.9 \mu\text{g/g}$  TOC, with a maximum at 1770 m ( $120.9 \mu\text{g/g}$  TOC). The sum of di- and triterpenoids is relative constant in the lower part of the succession ( $<70$ ) and reaches a peak at 1770 m depth ( $313.7 \mu\text{g/g}$  TOC). The di-/(di- + triterpenoids) ratio is low ( $<0.55$ ).

**Carbon isotopic composition** –  $\delta^{13}\text{C}_{\text{carb}}$  values in the lower part of the Thomasl Formation are around  $-1.5 \text{‰}$  and decrease upwards s to a minimum value of  $-4.7 \text{‰}$  at 1680 m depth. The upper part of the Thomasl Formation is characterized by an upward increase  $\delta^{13}\text{C}_{\text{carb}}$  values. Positive values (max.  $+1.9 \text{‰}$ ) prevail in rocks with an Eggenburgian age.



**Fig. 17:** Biomarker ratios and concentrations of Eocene/ Upper Oligocene source rocks of the Thomasl well.

**Table 3:** Organic geochemical data of the Thomasl and Poysdorf wells.

Depth [m]	TOC	HI	EOM	Sat. HC	Aro. HC	NSO	Asph.	n-C <sub>15-20</sub>	n-C <sub>21-25</sub>	n-C <sub>26-32</sub>	Pr/Ph	C <sub>25</sub> HBI	Steroids	C <sub>27</sub> Steranes/ Steranes	C <sub>29</sub> Steranes/ Steranes	C <sub>30</sub> Steranes/ Steranes	
	[wt%]	[µg/TOC]	[µg/TOC]				[wt.%]					[µg/TOC]	[µg/TOC]				
<b>Thomasl Well Cuttings</b>																	
Eggenb.	1610	1.88	29	34.78	27	4	62	7	15	55	28	1.0	0.56	23.4	0.36	0.25	0.39
	1620	0.98	14	23.19	21	1	78	0	8	71	23	0.8	1.3	8.9	0.49	0.21	0.30
	1630	1.13	37	40.86	20	1	71	8	6	66	28	0.8	1.1	23.0	0.29	0.24	0.47
	1640	1.05	123	73.78	17	4	71	8	36	64	14	0.4	6.8	25.9	0.47	0.26	0.27
	1650	1.88	165	41.53	9	1	76	14	45	51	12	0.6	41.6	25.4	0.44	0.31	0.25
	1660	1.63	140	38.86	5	2	84	9	68	23	12	1.0	25.7	25.1	0.38	0.24	0.38
	1670	2.32	208	35.41	5	0	82	12	46	31	20	0.9	48.3	33.1	0.35	0.29	0.36
	1680	1.97	191	24.99	9	1	76	14	34	40	26	0.7	31.9	30.8	0.27	0.33	0.40
	1690	2.39	161	47.80	8	1	74	18	32	44	20	0.5	17.3	89.5	0.29	0.39	0.32
	1700	3.67	416	52.96	8	2	74	16	19	47	28	0.3	43.6	106.4	0.25	0.38	0.36
Thomasl Formation	1710	3.26	307	42.79	5	1	75	19	56	46	15	1.0	4.5	43.5	0.25	0.35	0.39
	1720	2.66	223	44.80	1	4	79	15	51	24	0.8	1.0	6.4	0.27	0.35	0.37	
	1730	2.57	168	24.59	10	1	86	3	46	41	13	0.9	1.3	32.2	0.26	0.38	0.36
	1740	2.46	183	28.44	7	0	86	7	22	57	24	0.5	0.7	22.1	0.23	0.41	0.36
	1750	3.18	135	22.72	8	1	87	5	21	41	39	0.7	2.2	26.0	0.24	0.45	0.31
	1760	3.33	116	22.53	9	2	86	3	29	45	27	0.8	3.3	18.4	0.21	0.48	0.31
	1770	2.54	101	22.80	7	1	91	1	58	26	15	1.3	6.2	13.7	0.25	0.38	0.37
	1780	1.28	38	31.35	7	1	92	1	53	30	19	0.8	1.2	13.4	0.23	0.37	0.39
	<b>Thomasl Well Core</b>																
	Thom. Fm.	1760.0	1.01	49	47.02	9	2	86	4	44	49	21	0.9	0.1	28.9	0.27	0.31
1760.4		2.43	44	17.56	10	2	87	0	69	30	10	0.3	0.1	10.3	0.34	0.30	0.36
1761.0		1.31	30	36.81	13	0	84	3	41	45	24	0.9	0.4	12.5	0.23	0.24	0.53
1761.6		0.86	20	37.21	9	2	88	1	64	26	14	0.4	0.3	15.6	0.30	0.33	0.38
<b>Poysdorf Well Core</b>																	
Tho. Fm.	2814.8	6.23	32.47	8.76	12	3	83	2	50	46	12	0.6	31.5	7.4	0.38	0.31	0.31
	2815.1	1.17	139.09	11.87	9	4	83	3	28	56	23	0.4	33.8	19.9	0.31	0.37	0.32
	2817.0	1.5	122.30	23.24	22	0	77	1	61	22	17	1.3	0.2	64.5	0.51	0.25	0.24

Depth [m]	Steroids/ hopanoids	MAS	Hopan	22S(S+R)	Ts/Tm	β-Hopan	Hop-17(21)-ene	Benzohop.	Phenanthren	MPI	Di/(Di+Tri)	Di+Tri	
	[µg/gTOC]	[µg/gTOC]	[µg/gTOC]	hopanes		[µg/gTOC]	[µg/gTOC]	[µg/gTOC]	[µg/gTOC]		terpeno.	terpeno.	
<b>Thomasl Well Cuttings</b>													
Eggenb.	1610	0.4	7.2	50.0	0.52	3.58	9.7	1.2	14.2	0.3	0.50	0.09	84.7
	1620	0.6	6.8	8.8	0.40	0.88	2.5	0.4	6.2	0.4	0.84	0.55	61.2
	1630	0.7	8.9	31.1	0.42	1.43	7.3	1.1	3.1	0.5	0.35	0.26	75.3
	1640	1.5	9.5	14.9	0.41	0.91	3.1	1.2	0.9	16.0	0.29	0.23	60.7
	1650	2.2	25.9	8.7	0.24	0.69	3.4	0.1	2.4	39.9	0.13	0.31	43.7
	1660	1.1	21.5	18.9	0.19	0.84	8.7	0.5	2.8	7.0	0.25	0.25	55.2
	1670	1.5	31.7	19.1	0.23	0.53	9.3	0.5	2.9	3.1	0.27	0.22	57.6
	1680	0.9	30.8	26.7	0.38	0.90	9.2	0.7	8.6	3.6	0.33	0.20	71.3
	1690	2.6	30.8	27.7	0.41	0.53	8.9	1.6	5.7	28.8	0.10	0.11	84.4
	1700	0.4	445.3	68.2	0.39	0.33	33.5	3.7	165.8	78.4	0.34	0.25	313.7
Thomasl Formation	1710	1.0	52.4	29.5	0.30	0.45	12.5	1.2	13.7	151.3	0.10	0.17	93.1
	1720	1.1	9.0	3.4	0.20	0.46	1.5	0.1	2.1	29.3	0.09	0.33	10.1
	1730	0.9	10.2	28.8	0.40	0.39	11.5	2.0	3.2	43.7	0.14	0.15	43.9
	1740	0.8	10.0	23.7	0.35	0.51	10.1	0.8	3.7	41.2	0.11	0.20	38.9
	1750	0.5	20.6	28.0	0.25	0.42	11.4	0.6	25.9	84.0	0.11	0.23	54.2
	1760	0.4	31.7	25.9	0.36	0.42	10.1	1.2	20.4	92.8	0.24	0.39	68.8
	1770	0.4	26.6	20.8	0.28	0.51	8.8	0.9	12.7	54.2	0.33	0.35	49.9
	1780	0.5	5.6	26.2	0.28	0.55	11.4	0.6	2.6	2.1	0.46	0.14	39.5
	<b>Thomasl Well Core</b>												
	Thom. Fm.	1760.0	0.3	2.1	44.7	0.35	0.56	15.6	0.7	1.8	1.5	0.52	0.09
1760.4		0.6	4.1	20.5	0.38	0.55	6.1	1.2	2.7	65.8	0.52	0.23	17.4
1761.0		0.4	1.5	17.5	0.57	0.86	7.1	1.1	3.2	260.9	0.06	0.36	36.7
1761.6		0.6	1.8	42.3	0.42	1.02	17.9	1.1	9.5	289.6	0.14	0.04	55.5
<b>Poysdorf Well Core</b>													
Tho. Fm.	2814.8	0.3	38.8	7.5	0.47	0.60	2.2	0.3	16.6	476.7	0.30	0.78	57.6
	2815.1	0.6	43.9	18.9	0.42	0.56	5.4	0.9	13.5	234.9	0.29	0.48	78.5
	2817.0	0.5	0.7	108.8	0.27	0.62	35.1	8.2	0.7	17.9	0.11	0.28	53.0

TOC - total organic carbon, HI - hydrogen index, EOM - extracted organic matter, HC - hydrocarbons, NSO - polar compounds, Asph. - asphaltenes, n-C<sub>15-20</sub> - short-chain alkanes, n-C<sub>21-25</sub> - medium-chain alkanes, n-C<sub>26-32</sub> - long-chain alkanes; Pr/Ph - Pristane/Phytane ratio; MAS - monoaromatic steroids; MPI - Methylphenantrene Index; Di/(Di+Tri) terpeno. - Diterpenoids/triterpenoids ratio.

## 4.3 Borehole Poysdorf 2

### 4.3.1 Lithology and Stratigraphy

The Thomasl Formation in well Poysdorf 2 extends from 2801 to 2892 m depth (Fuchs et al., 2001). It overlies Upper Cretaceous sediments (Klement Fm.) with a tectonic contact and is overlain by Oligocene/Eggenburgian sediments. A core (core #21) was taken between 2813 and 2817.5 m depth, but only 2.6 m are left. The core is composed of mudstones with rare beds of thin silt- to sandstone. Fish remains are frequent. Fuchs et al. (2001) described prominent slump folds and the occurrence of frequent plant debris, including leaf fragments and partly large coalified wood fragments. Diagenetic carbonate phase with distinct zonation (dolomite → kutnohorite → ankerite) occur in all core samples.

### 4.3.2 Characterization of organic matter

#### Bulk geochemical parameters and organic petrography

The average TOC content of the Thomasl Formation in the Poysdorf well (2890-2800 m) is 2.2 wt.% and slightly lower than that in the Thomasl well (2.5 wt.%). Relatively low TOC contents (average: 1.3 wt.%) are observed in the core (2817-2813 m) and in cuttings from the same depth (Fig. 18). HI values in the lower part of the Thomasl Formation are low (~130 mgHC/gTOC) showing the presence of type III kerogen. HI values in the upper part (2840-2800 m) vary from 144 to 271 mgHC/gTOC) indicating the presence of type III/II kerogen (Figs. 13 and 18). Sulphur contents are in average 1.42 wt.%. TOC/S ratios <3.5 agree with the postulated marine depositional environment.  $T_{max}$  values (~425°C) show that the organic matter is immature.

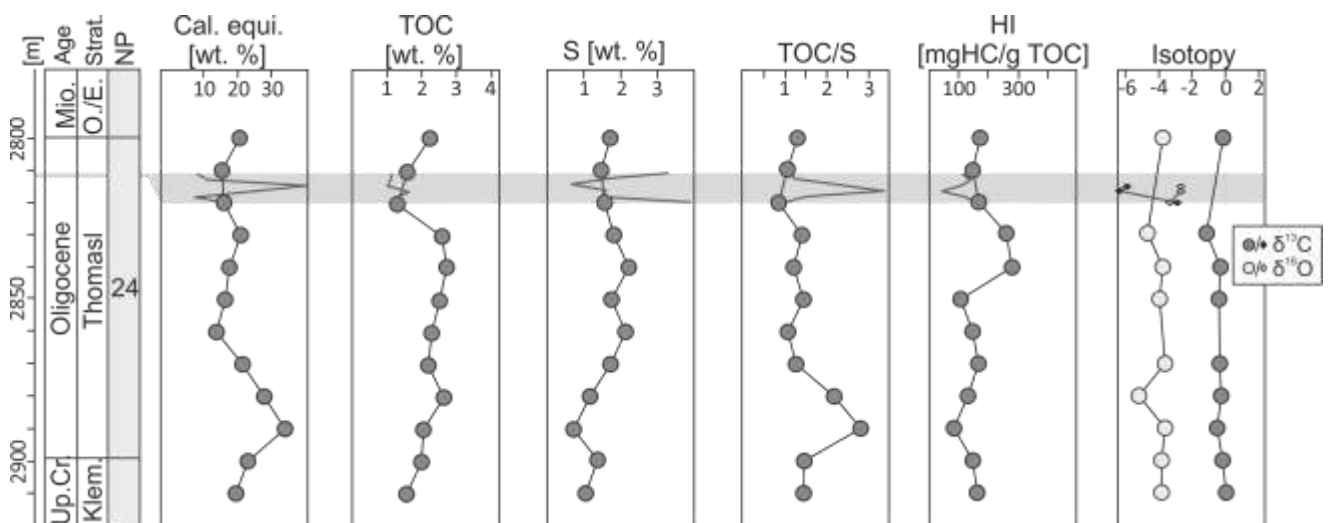
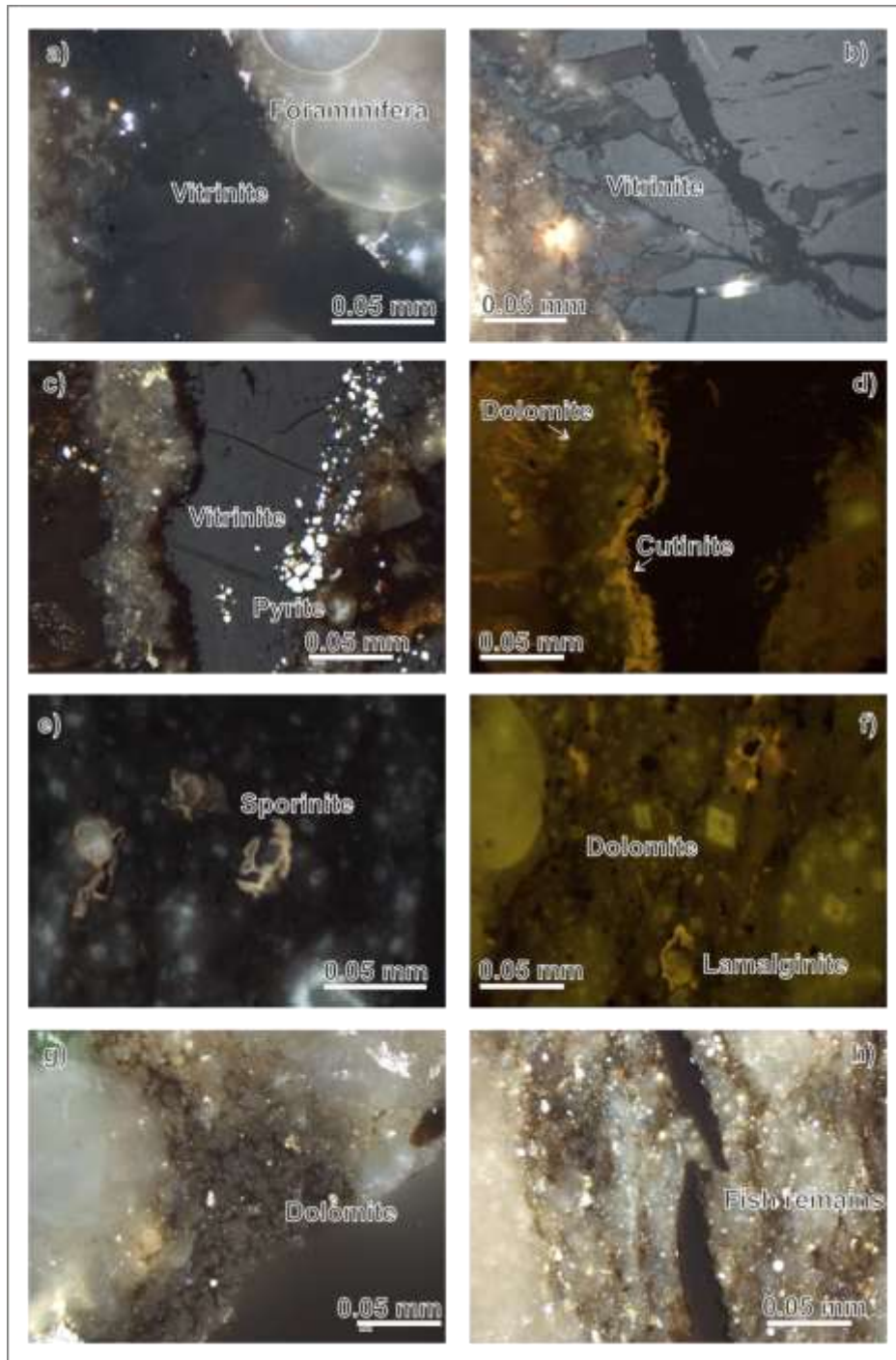


Fig. 18: Bulk geochemical parameters and isotopy with nannoplankton zones of the Upper Oligocene source rocks (Thomasl Formation) of the Poysdorf well. Core data are displayed (slightly enlarged; see grey bar) as lines.



The maceral composition of core samples (Table 3, Fig. 19) is dominated by terrestrial macerals vitrinite (52-70 vol.%) and sporinite (15-24 vol.%). Inertinite (3-10 vol.%), Lam- (0-7 vol.%) and Telalginite (2-14 vol.%) are less abundant. Foraminifera are present in moderate concentrations (<6.2 wt.%), glauconite has been found as well.



**Fig. 19:** Photomicrographs of the Thomasl Formation (Poysdorf well). a) vitrinite and foraminifera; b) vitrinite; c,d) vitrinite and cutinite in normal white light (c) and in fluorescent light (d); e) sporinite, f) lamalginite, g) dolomite; h) fish remains. d-f are in fluorescent mode. All samples are from 2815.3 m depth, with the exception of g) (2814.8 m).

## Molecular composition of hydrocarbons

Three core samples were selected for biomarker analysis. Their EOM yields vary between 8 and 24 mg/g TOC and are dominated by polar compounds (NSO; 77-83% of EOM). Saturated hydrocarbons (9-22 %) are more abundant than aromatic (0-4 %) hydrocarbons.

**n-alkanes and isoprenoids** – Short chain (28-61 %) and medium chain n-alkanes (22-56 %) are more or less equally abundant, whereas long chain n-alkanes occur in lower amounts (<23 %). Pr/Ph ratios vary between 0.36-1.32. The C<sub>25</sub> HBI thiophenes and alkanes concentration is high (<68.73 µg/g TOC), which is comparable to the upper part of the Thomasl Formation in the Thomasl well.

**Steroids** -The sterane concentration is high (<61.0 µg/g TOC). C<sub>27</sub>, C<sub>28</sub> and C<sub>29</sub> steranes are equally abundant (Fig. 16). The sterane/hopane ratio is low (<0.6 µg/g TOC). The concentration of monoaromatic steroids (MAS) ranges from 0.69 to 43.86 µg/g TOC.

**Terpenoids** - The hopane concentration varies between 7.5 and 108.8 µg/g TOC. The C<sub>31</sub> 22S/(22S+22R) hopane isomerization (<0.47) and the Ts/Tm ratios are low (<0.62). ββ-hopanes concentrations are <35.1 µg/g TOC. Hop-17(21)-ene is present in concentrations <8.2 µg/g TOC (2817 m). Benzohopanes concentrations decrease upwards from 35.1 µg/g TOC to 2.2 µg/g TOC.

**Phenantrenes, methylphenantrens** – The phenantrenes concentration is high (<476.7 µg/g TOC) and higher than in the Thomasl well. 3,2,9,1-methylphenantrens concentrations are below 210 µg/g TOC.

**Land-plant related biomarkers** –Norbietatriene (<22 µg/g TOC), dehydrobietatriene (<5.85 µg/g TOC), simonellit (<3.8 µg/g TOC) and retene (<13.4 µg/g TOC) are more abundant than caryophyllene and picene (<1.56 µg/g TOC). The sum of di- and triterpenoids is highest at a depth of 2815 m (78.52 µg/g TOC); the di-/(di- + triterpenoids) ratio is low (<0.78) indicating a predominance of angiosperms.

**Carbon isotopic composition** – δ<sup>13</sup>C<sub>carb</sub> values of cutting samples from the Poysdorf 2 well are rather uniform (+0.6 to -1.3 ‰). In contrast, core samples (~2815 m) have more negative values (-6.4 ‰).

## 5. DISCUSSION

### 5.1 Maturity

Average vitrinite reflectance of the “Waldweg section” (0.29 %Ro), as well as the samples from the Poysdorf (0.37 %Ro) and Thomasl wells (0.37 %Ro) indicate that the organic matter is immature. This is supported by average Tmax values (“Waldweg section”: 420°C; Thomasl: 422°C; Poysdorf: 425°C) and the presence of C<sub>29-31</sub> ββ-hopanes and C<sub>27-29</sub> βα-steranes.

Hopane isomeration varies between 0.19-0.43 (“Waldweg section”), 0.19-0.57 (Thomasl) and 0.27-0.47 (Poysdorf). In the light of the vitrinite reflectance and Tmax data, the higher values (>0.3) are very unlikely.

### 5.2 Diagenesis

During diagenesis siliceous deposits undergo mineralogical changes from amorphous silica (opal-A) to microcrystalline opal (opal-CT/-C) to microcrystalline quartz (Williams et al., 1985; Lynne & Campbell, 2004). Factors influencing the transformation are burial depth, temperature, time and host rock lithology (Jones & Segnit, 1971). Williams et al. (1985) stated that opal-CT forms when temperatures reach ~50°C. The higher thermal overprint of borehole samples, therefore, is reflected by the fact that opal-A is present in surface samples, but opal-CT in a sample from the Thomasl well (1700 m).

Diagenetic carbonate phases consisting of dolomite cores, surrounded by kutnohorite and ankerite rims, are commonly detected in calcareous sediments of the Thomasl Formations. (A single sample from the Galgenberg Member has been investigated. This sample also includes zoned dolomite phases). Although the exact mechanisms and rates of dolomite formation in marine environments are still discussed controversial, it may be assumed that the activity of aerobic microbes and denitrifying bacteria caused changes in alkalinity and pH values and favoured dolomite precipitation (Frölich et al., 1979). Mn-rich carbonate phases probably reflect strong Mn(IV) reduction in the sediment and Mn(II)-fixation at the chemocline (Algeo and Maynard, 2004; Cruse and Lyons, 2004). The formation of Fe-rich carbonate phases reflect Fe-reduction (and suppressed sulfate reduction) and postdates Mn-reduction. Omnipresent framboidal pyrite results from bacterial sulphate reduction (Canfield et al., 1993).

### 5.3 Depositional environment

Based on sedimentology and paleontological data, the depositional environment of the Oligocene successions in the Waschberg Zone has been described in detail by [Rögl et al. \(2001; “Waldweg section”\)](#) and [Fuchs et al. \(2001; Thomasl, Poysdorf wells\)](#). Some additional aspects are referred to in the following.

#### 5.3.1 “Waldweg section” near Ottenthal

The Pr/Ph ratio indicates changing dysoxic to anoxic conditions. Relative high ratios indicate dysoxic conditions during deposition of the Galgenberg diatomites and the lower part of the Thomasl Formation.

Upward decreasing carbonate contents in the Dynow Member reflect a general decrease in the productivity of calcareous nannoplankton. This fits well with observations in the Alpine Foreland Basin ([Schulz et al., 2004; 2005](#)).

The TOC/S ratio is controlled by the availability of sulphate and often used to distinguish marine and freshwater environments, as well as anoxic deposits ([Berner and Raiswell, 1984](#)). In the present case, because of low TOC and S contents, the significance of TOC/S ratios as salinity proxy (e.g. [Berner and Raiswell, 1984](#)) is reduced. Nevertheless, high TOC/S ratios in the Dynow Member match with the brackish depositional environment suggested by paleontological data (e.g. [Rögl et al., 2001](#)). The upward increase in the uppermost part of the Galgenberg Member indicates that brackish conditions commenced already before deposition of the Dynow Member. The presence of *Aulacoseira*, a brackish or freshwater diatom ([Rögl, 1997; Fig. 5](#)), both in the upper part of the Galgenberg Member and in the Dynow Member supports this statement. Another upward decrease in salinity is suggested by TOC/S ratios in the Thomasl Formation at about 12 m depth.

Vertical variations in biogenic silica contents reflect the productivity of siliceous organisms, mainly diatoms. A general upward increase in siliceous bioproductivity is observed in the Ottenthal and Galgenberg members. Surprisingly, siliceous productivity decreased during deposition of the uppermost part of the Galgenberg Member. Biogenic silica contents in the Dynow Member are as high as in the Galgenberg diatomites. Abundant diatoms from this member have been described by [Rögl et al. \(2001\)](#). Diatoms have also been observed in this study ([Fig. 5](#)). In contrast, siliceous organisms are largely absent in the Dynow Formation in the Alpine Foreland Basin ([Schulz et al., 2004](#)).

C<sub>25</sub>-HBI thiophenes and alkanes can indicate the contribution of diatoms to the biomass (Sinninghe Damste et al., 1989; Grossi et al., 2004). Maxima of the sum of C<sub>25</sub>-HBI thiophenes and alkanes are observed in the diatomites (Galgenberg Mb.) and the Thomasl Fm. (~11 m depth). However, concentrations are low in the Dynow Member, despite of high biogenic silica contents.

Steroids/hopanoids ratios reflect the input of eukaryotic (algae, higher landplants) versus prokaryotic (bacteria) organisms (Moldowan et al., 1986). Generally, the observed ratios (>1) indicate a minor input of bacterial biomass.

With the exception of the Galgenberg diatomites and the Dynow Member, HI values are very low in the entire Oligocene succession (<140 mgHC/gTOC) indicating a dominance of landplants. HI values in the Galgenberg diatomites and the Dynow Member (<252 mgHC/gTOC) reflect a higher contribution of aquatic organic matter. The sum of di- and triterpenoids may be used as a proxy for the relative contribution of landplants to the biomass.

In agreement with HI values, the trend of di- and triterpenoid concentrations (Fig. 4) shows relative low landplant input to the biomass in the Galgenberg and Dynow members and a significantly higher input in the Thomasl Formation.

Ratios of di-(di- + triterpenoids) show cyclic variations indicating that the relative amounts of gymnosperms and angiosperms varies significantly during deposition of the Oligocene succession. Gymnosperms dominated within the landplant fraction during deposition of the Galgenberg diatomites (e.g. 26 m) and during deposition of the lower (11 m) and upper part of the Thomasl Formation (1.5 m). In contrast, angiosperms are prominent near the top of the Ottenthal Member (~30 m), at the base (~18 m) and in the middle of the Thomasl Formation (8 m).

### **5.3.2 Thomasl Formation in the Thomasl and Poysdorf wells**

The Thomasl Formation in both wells was deposited during NP 24. Its organic matter content is significantly higher than in the Thomasl Formation in the “Waldweg section”. TOC/S ratios are typical for marine, oxygen-depleted conditions. In contrast, high TOC/S in the Eggenburgian interval may indicate sulphate-limitation due to freshwater influx. HI values are typically low (<200 mgHC/gTOC), but some samples have significantly higher values (max: 416 mgHC/gTOC). This indicates the dominance of landplant derived type III kerogen, but the additional presence of type II kerogen, typical for aquatic organisms.

Biomarker and maceral data are available only for the Thomasl well and for the Poysdorf core. The following discussion, therefore, concentrates on the Thomasl well.

The Pr/Ph ratio in the Thomasl well ranges between 0.3 and 1.2 indicating anoxic to dysoxic conditions.

Vitrinite and sporinite percentages are continuously high indicating a dominance of landplant derived macerals. Landplant related biomarkers (di- and triterpenoids) are also high and reach a maximum at 1700 m depth. The di-(di- + triterpenoids) ratios in the Thomasl Formation in the Thomasl well are typically low (av.: 0.24) compared to that in the Waldweg section" (av. 0.51) indicating a higher contribution of angiosperms in the Thomasl well.

C<sub>25</sub>-HBI thiophenes and alkanes, attributed to diatoms ([Sinninghe Damste et al., 1989](#); [Grossi et al., 2004](#)) occur in high concentrations in the upper part of the Thomasl Formation (1700-1640 m). However, only the sample at 1700 m depth is also rich in biogenic silica. This sample is also characterized by a very low Pr/Ph and steroids/hopanoids ratios and high TOC and HI values.

## 5.4 Source Rock potential conventional hydrocarbons

### 5.4.1 Conventional hydrocarbons

TOC contents and the petroleum potential ( $S_1+S_2$ ) are frequently used to classify the quality of potential source rocks (Tab. 4; Figs. 20, 21). The studied samples are characterized by varying, but often relative high TOC contents. In contrast, the petroleum potential is often low, which is therefore considered as the limiting factor.

Table 4. Parameters describing the petroleum potential (after Peters, 1986).

	TOC (wt.%)	S1+S2 (mg HC/g Rock)
Poor	<0.5	<3
Fair	0.5-1.0	3-6
Good	1.0-2.0	6-25
Very good	>2.0	>25

TOC contents (average: 0.5 wt.%) and HI values in the Oligocene succession exposed in the “Waldweg section” are surprisingly low. Therefore, the source rock potential of the outcrop section is negligible (Fig. 20). Within this respect, it has to be emphasized that weathering may decrease the source potential of source rocks. The studied samples show severe indications of weathering (e.g. presence of gypsum and jarosite). Hence, it cannot be ruled out completely, that the “true” potential is higher.

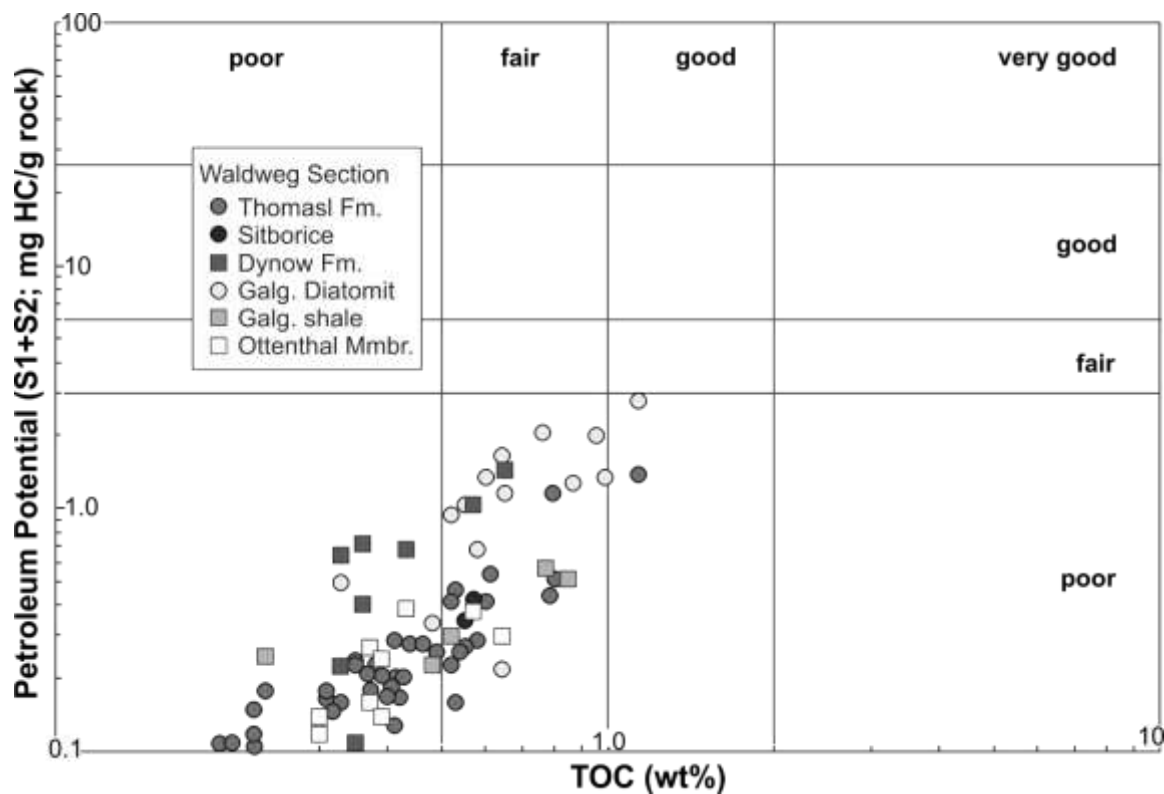


Fig. 20: Petroleum Potential versus total organic carbon (TOC) for the Ottenthal “Waldweg section”.

The core samples from the base of the Thomasl Formation in the Thomasl well do not hold any source rock potential. All other samples are characterized by a fair to good source rock potential (Fig. 21). The organic matter is dominantly of type III kerogen, but type II kerogen exists as well. Therefore it is likely that gas and minor oil would be generated in the oil window.

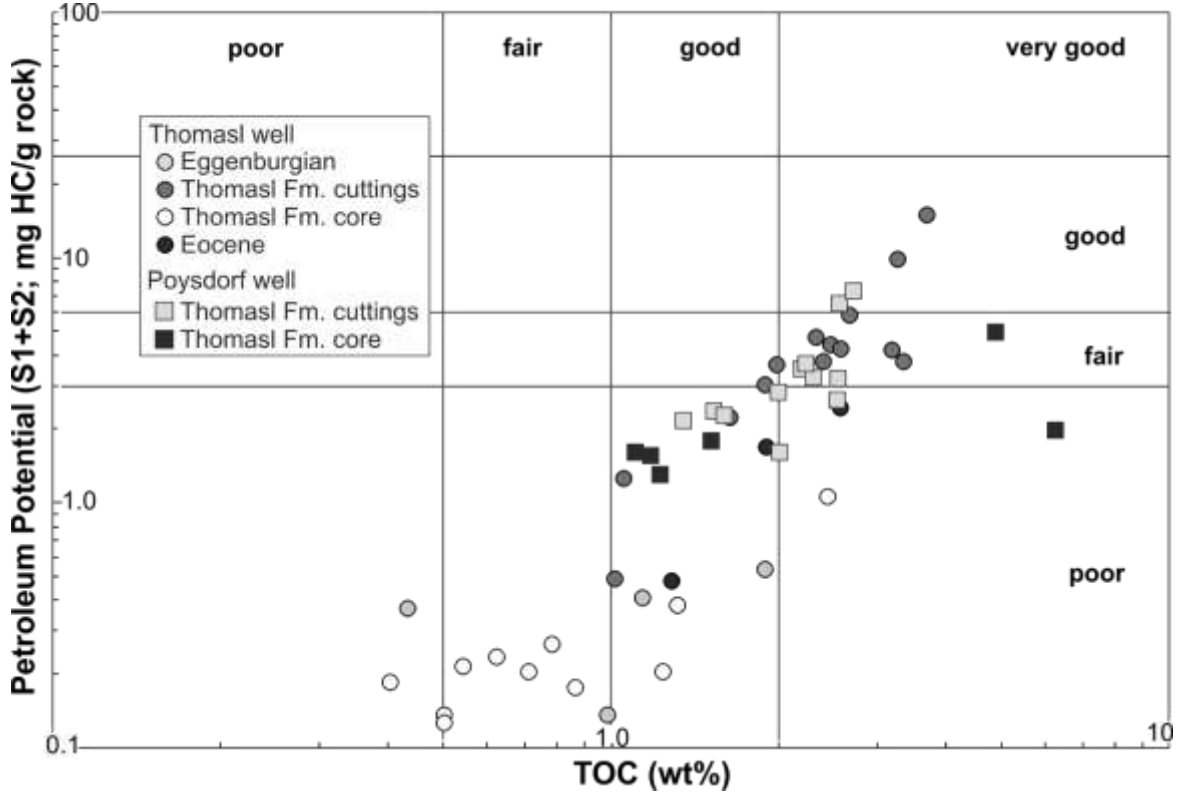


Fig. 21: Petroleum Potential versus total organic carbon (TOC) for the Thomasl Formation (Thomasl 1 and Poysdorf 2 well).

The SPI (Demaison and Huizinga, 1994) has been calculated using average S1+S2 values of cuttings samples, total thickness of the Thomasl Formation and estimated density. Based these data, it can be expected that the Thomasl Formation can generate between 0.9 and 1.6 tons of hydrocarbons/m<sup>2</sup> if it is mature.

Table 5: “Calculation of the Source Potential Index (SPI) for the Thomasl Formation in boreholes Thomasl and Poysdorf.

Unit	$\Delta(S1+S2)$ (mg HC/g rock)	Total thickness (m)	Estimated density (g/cm <sup>3</sup> )	SPI (tHC/m <sup>2</sup> )
Thomasl	5,33	127	2,3	1,55
Poysdorf	3,75	110	2,3	0,95



#### 5.4.2 Shale gas/oil potential of the Thomasl Formation

The following prerequisites for the presence of a successful unconventional shale gas/oil play are widely accepted (e.g. [Jarvie, 2012](#); [Charpentier and Cook, 2011](#); [Andrews, 2013](#) cum ref.): TOC content >2.0%, thickness >20 m, presence of kerogen type I, II or IIS. For shale gas, the maturity should be in the range of 1.2-3.5% %Ro, whereas lower maturity (>0.8 %Ro) is appropriate for shale oil. In order to enable hydraulic fracturing, a low percentage of ductile minerals is preferential (see also [Rupprecht et al., 2017](#)). Moreover, because of increasing drilling costs and increasing lithostatic pressure, the depth should not be greater than 5000 m. Similar parameters have been used by [Uffmann et al. \(2012\)](#) to delineate fields where commercial gas production can be achieved ([Fig. 22b](#)).

Based on low TOC contents, Oligocene rocks exposed at the “Waldweg section” obviously do not fulfil these requirements. Consequently the following discussion concentrates on the Thomasl Formation drilled in boreholes Thomasl 1 and Poysdorf 2.

**Organic matter richness:** With an average TOC content of 2.2 wt. (Poysdorf) and 2.5 wt.% (Thomasl), the Thomasl Formation exceeds the minimum requirements.

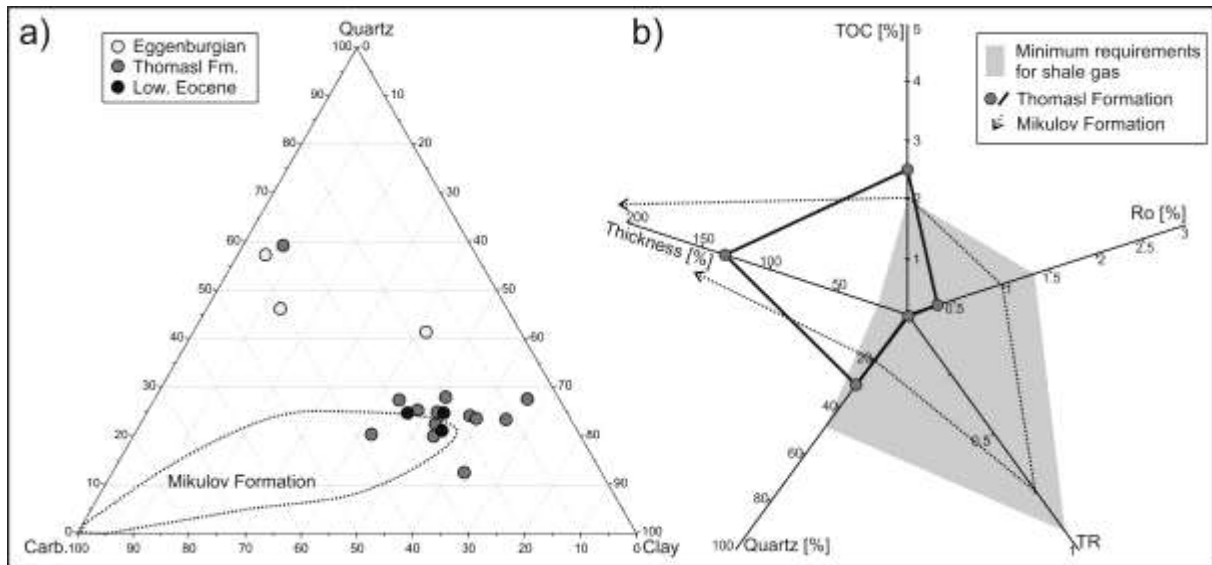
**Organic matter type:** The Thomasl Formation contains predominantly type III kerogen and subordinate type II kerogen. This suggests that only parts of the Thomasl Formation may be suitable for shale gas/oil production.

**Thickness:** The overall thickness of the Thomasl Formation is high. However, as mentioned above, probably only parts of the Thomasl Formation are suitable for shale gas/oil production.

**Thermal maturity:** The Thomasl Formation in the deep Poysdorf well (2800 m) is immature. This fits with the observation that the adjacent Vienna Basin area (see [Fig. 1](#)) is characterized by low maturity gradients. For example, 0.8 %Ro is reached only at 4000 m depth (according to vitrinite reflectance data of [Ladwein, 1988](#)) or even at greater depth ([Rupprecht et al., 2017](#)). A vitrinite reflectance of 1.2 %Ro is reached at ~5000 m depth, considered a cut-off value for economic shale gas production.

**Mineralogy:** The application of hydraulic stimulation techniques for the production of shale gas/shale oil depends on different factors including mineralogy ([Jarvie, 2012](#)). Expandable clay minerals are detrimental, whereas brittle minerals like quartz and calcite contents are critical. In the spider-diagram in [Fig. 22a](#) the Thomasl Formation plots into the non-productive field. This is mainly because quartz is considered the main phase controlling

brittleness. Hence, the geomechanical properties of the carbonate-rich samples should be investigated in the future.



**Fig. 22:** a) Mineralogical distribution of quartz, carbonates and clay. b) Spider-diagram displaying TOC content, vitrinite reflectance (%Ro), transformation ratio, quartz content and thickness of the Thomasl Formation. The area of non-productivity is highlighted by grey shading (modified from [Uffmann et al., 2012](#)). Data from the Malmian Mikulov Formation in the Vienna Basin area ([Rupprecht et al., 2017](#)) are shown for comparison in a) and b).

Summarizing, it is obvious that the Thomasl Formation is not mature enough for a shale oil/shale gas play where it is at shallow depth. Data from [Ladwein \(1988\)](#) and [Rupprecht et al. \(2017\)](#) indicate that maturity stages required for shale oil/shale gas production are reached in the Vienna Basin area only at uneconomic depth. Moreover, TOC contents only slightly exceed the accepted threshold value of 2.0 wt.%. Further investigations may show, if organic matter richness increases laterally. Perhaps also the kerogen type varies laterally towards a more preferable type II. In addition, economic shale gas/oil production needs a high number of production wells, which must be drilled with low costs. Therefore, a simple, easily predictable geology is regarded a key issue by most authors. Clearly, the Waschberg Zone does not fulfil this requirement either. Therefore, the chances of success for economic shale oil/shale gas production is considered low!

## 6 CONCLUSIONS AND OUTLOOK

The Oligocene succession in the Waschberg Zone has been studied using the “Waldweg section” near Ottenthal and two borehole profiles (Thomasl, Poysdorf). The main study results regarding the petroleum potential are summarized below:

- The Lower Oligocene Ottenthal Formation and the Upper Oligocene Thomasl Formation, exposed along the “Waldweg section”, hold a negligible petroleum potential and no potential for unconventional hydrocarbons. This result is surprising, because equivalent Lower Oligocene rocks in the Western Carpathians (Menilite Fm.) and the Alpine Foreland Basin (Schöneck Fm.; e.g. [Sachsenhofer et al., 2017](#)) are prolific source rocks.
- The Thomasl Formation in the boreholes (~2.2-2.5 %TOC; type III and type II kerogen) holds a fair to good hydrocarbon potential and may generate 1.0 to 1.6 tons of hydrocarbons per m<sup>2</sup>. Although geomechanical data of the Thomasl Formation are missing, the economic significance of the Thomasl Formation as a shale gas/shale oil play is considered low. This is mainly due to (i) the very deep position of the maturity cut-off values for shale oil (0.8 %Ro; ~4000 m) and shale gas (1.2 %Ro; ~5000 m), and (ii) the complex geological setting.

Apart from the petroleum potential, the study contributed to the understanding of the depositional environment:

- Siliceous organisms contributed significantly to the biomass in the Ottenthal Formation.
- The carbonate content of the Dynow Member decreases upwards, reflecting decreasing productivity of calcareous nannoplankton. A similar observation has been made in the Upper Austrian part of the Molasse Basin ([Schulz et al., 2004](#)). In contrast to the latter, siliceous organisms are present in high amounts in the Dynow Member.

As mentioned above, the low TOC contents of the Ottenthal Member in the “Waldweg section” are surprising. Because it cannot be excluded that weathering may cause a decrease in organic matter richness and hydrocarbon potential, it is suggested to drill a shallow borehole in order to prove the “true” hydrocarbon potential.

## References

- Algeo, T.J., Maynard, J.B., 2004. Trace-element behavior and redox facies in core shales of Upper Pennsylvanian Kansas-type cyclothems. *Chem. Geol.*, 206, 289–318.
- Andrews, I.J., 2013. The Carboniferous Bowland Shale Gas Study: Geology and Resource Estimation. British Geological Survey for Department of Energy and Climate Change, London, UK.
- Bechtel, A., Gratzner, R., Sachsenhofer, R.F., Gusterhuber, J., Lücke, A., Püttmann, W., 2008. Biomarker and carbon isotope variation in coal and fossil wood of Central Europe through the Cenozoic. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 262, 166–175.
- Berner, R.A., Raiswell, R., 1984. C/S method for distinguishing freshwater from marine sediments. *Geology*, 12, 365–368.
- Burnett, J.A., 1998. Upper Cretaceous. In: Bown, P.R. (Editor), *Calcareous Nannofossil Biostratigraphy*. British Micropalaeontological Society Publications Series. Chapman & Hall, London, 132–199.
- Canfield, D.E., Thamdrup, B., Hansen, J.W., 1993. The anaerobic degradation of organic matter in Danish coastal sediments: iron reduction, manganese reduction and sulfate reduction. *Geochim. Cosmochim. Acta*, 57, 3867–3883.
- Charpentier, R.R., Cook, T.A., 2011. USGS Methodology for Assessing Continuous Petroleum Resources. U.S. Geological Survey Open-File Report 2011-1167.
- Cleve, P.T., 1873. Examination of diatoms found on the surface of the Sea of Java. *Bihang till Kongliga Svenska Vetenskaps-Akademiens Handlingar* 1(11): 1–13, 3 pls.
- Cruse, A.M., Lyons, T.W., 2004. Trace metal records of regional paleoenvironmental variability in Pennsylvanian (Upper Carboniferous) black shales. *Chem. Geol.*, 206, 319–345.
- Demaison, G., Huizinga, B.J., 1994. Genetic classification of petroleum systems using three factors: charge, migration and entrapment. In: Magoon, L.B., Dow, W.G. (Eds.): *The Petroleum System, from Source to Trap*. AAPG Memoir, 60, 73–89.
- Didyk, B.M., Simoneit, B.R.T., Brassell, S.C., Eglinton, G., 1978. Organic geochemical indicators of palaeoenvironmental conditions of sedimentation. *Nature*, 272, 216–222.
- Eglinton, G., Hamilton, R.J., 1967. Leaf epicuticular waxes. *Science* 156, 1322–1335.
- Elzea, J. M., Odom, I. E. Miles, W. J., 1994. Distinguishing well-ordered opal-CT and opal-C from high temperature cristobalite by x-ray diffraction. *Analytica Chimica Acta.*, 286, 107–116.
- Espitalie, J., Marquis, F., Barsony, I., 1984. Geochemical logging. In: Voorhies, K.J. (Eds.): *Analytical Pyrolysis*. Butterworths, Boston, 53–79.
- Ficken, K.J., Li, B., Swain, D.L., Eglinton, G., 2000. An n-alkane proxy for the sedimentary input of submerged/floating freshwater aquatic macrophytes. *Org. Geochem.*, 31, 745–749.
- Frölich, P. N., Klinhammer, G. P., Bender, M. L., Lütke, N. A., Heath, G. R., Cullen, D., Dauphin, P., Hammond, D., Hartman, B., and Maynard V., 1979. Early oxidation of organic matter in pelagic sediments of the eastern equatorial Atlantic: Suboxic diagenesis. *Geochim. Cosmochim. Acta*, 43, 1075–1090.

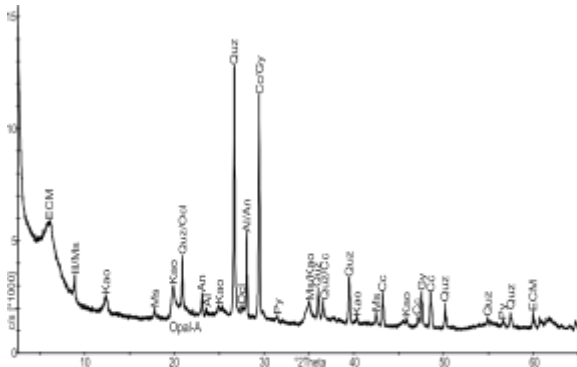
- Fuchs, R., Hamrsmid, B., Kuffner, T., Peschel, R., Rögl, F., Sauer, R., Schreiber, O., 2001. Mid-Oligocene Thomasl Formation (Waschberg Unit, Lower Austria) – micropaleontology and stratigraphic correlation. – In: Piller, W.E., Rasser, M.W. (Eds.) *Paleogene of the Eastern Alps*. Verlag der Österreichischen Akademie der Wissenschaften, Band 14, 255-288, Wien.
- Grimalt, J. Albaiges, J., 1987. Source and occurrence of C<sub>12</sub>-C<sub>22</sub> n-alkane distribution with even carbon-number preference in sedimentary environments. *Geochimica et Cosmochimica Acta*, 51, 1379-1384.
- Gross, D., Grundtner, M.L., Misch, D., Riedl, M., Sachsenhofer, R.F., Scheucher, L., 2015. Diagenetic Evolution and Reservoir Quality of Sandstones in the North Alpine Foreland Basin: A Microscale Approach. *Microscopy and Microanalysis*, 21, 1123-1137.
- Grossi, V., Beker, B., Geenevasen, J.A.J., Schouten, S., Raphel, D., Fontaine, M.-F., Sinninghe Damstè, J.S., 2004. C<sub>25</sub> highly branched isoprenoid alkenes from the marine benthic diatom *Pleurosigma strigosum*. *Phytochemistry*, 65, 3049-3055.
- Hartley, B., Barber, H.G., Carter, J.R. & Sims, P.A. [eds], 1996. *An atlas of British diatoms*. 601 pp., 290 pls. Biopress Ltd., Bristol.
- Hekel, H., 1968. Nannoplanktonhorizonte und tektonische Strukturen in der Flyschzone nördlich von Wien (Bisambergzug). *Jahrbuch Geol.-Bundesanstalt*, 111, 293-338.
- Hoefs, J., 2009. *Stable Isotope Geochemistry*. 6<sup>th</sup> Edition. Springer, Göttingen.
- Jarvie, D.M., Hill, R.J., Ruble, T.E., Pollastro, R.M., 2007. Unconventional shale gas systems: the Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale gas assessment. *AAPG Bulletin*, 91, 475-499.
- Jones, J. B., Segnit, E. R. (1971). The nature of opal I. nomenclature and constituent phases, *Journal of the Geological Society of Australia*, 18:1, 57-68.
- Krhovský, J. and Djurasinovic, M. 1993. The nannofossil chalk layers in the early Oligocene Sitborice Member in Velké Nemčice (the Menilitic formation, Zdánice Unit, South Moravia): Orbitally forced changes in paleoproductivity. In: Hamrsmid, B. (ed.) *Nové výsledky v teriiaru Zapadnich Karpat*. Sbornik referatu z 10. konference o mladším terciaru, Brno, 27.-28.4.1992, 15. Knihovnicka Zemni Plyn Nafta, Hodonin, 33–53.
- Ladwein, H.W., 1988. Organic geochemistry of Vienna Basin: model for hydrocarbon generation in overthrust belts. *AAPG Bull.*, 72, 586-599.
- Lafargue, E., Marquis, F., & Pillot, D., 1998. Rock-Eval 6 applications in hydrocarbon exploration, production, and soil contamination studies. *Revue de l'institut français du pétrole*, 53(4), 421-437.
- Lynne, B.Y., Cambell, K.A., 2004. Morphologic and mineralogic transitions from opal-A to opal-CT in low-temperature siliceous sinter diagenesis, Taupo volcanic zone, New Zealand. *Journal of Sedimentary Research*, 74, 4, 561 - 579.
- Mackenzie, A.S., McKenzie, D., 1983. Isomerization and aromatization of hydrocarbons in sedimentary basins formed by extension. *Geology Magazine*, 120, 417-470.
- Moldowan, J. M., Fago, F. J., 1986. Structure and significance of a novel rearranged monoaromatic steroid hydrocarbon in petroleum. *Geochimica et Cosmochimica Acta*, 50, 343–51.
- Ourisson, G., Albrecht, P., Rohmer, M., 1979. The hopanoids: palaeo-chemistry and biochemistry of a group of natural products. *Pure Appl. Chem.*, 51, 709-729.

- Peters, K.E., Walters, C.C., Moldowan, J.M. 2005. *The Biomarker Guide: Biomarkers and Isotopes in the Environment and Human History*, Volume 1 of the biomarker guide. Cambridge University Press.
- Radke, M., Welte, D.H., 1983. The methylphenanthrene index (MPI): a maturity parameter based on aromatic hydrocarbons. In: Bjoroy, M. (Ed.), *Advances in Organic Geochemistry*. Wiley, Chichester, 504-512.
- Radke, M. Willisch, H., Welte, D.H., 1980. Preparative hydrocarbon group type determination by automated medium liquid pressure chromatography. *Anal. Chem.*, 52, 406-411.
- Rögl, F., 1999. Mediterranean and paratethys: facts and hypotheses of an Oligocene to Miocene paleogeography (short overview). *Geologica Carpathica*, 50, 4, 339-349.
- Rögl, F., Krhovský, J., Hamrsmid, B., Braunstein, R., Sauer, R., Seifert, P., 2001. The Ottenthal Formation revised – sedimentology, micropaleontology and stratigraphic correlation of the Oligocene Ottenthal sections (Waschberg Unit, Lower Austria) – In: Piller, W.E., Rasser, M.W. (Eds.) *Paleogene of the Eastern Alps*. Verlag der Österreichischen Akademie der Wissenschaften, Band 14, 291-345, Wien.
- Rögl, F., Nagymarosy, A., 2012. Biostratigraphy and correlation of the Lower Miocene Michelstetten and Ernstbrunn sections in the Waschberg Unit, Austria (Upper Egerian to Eggenburgian, Central Paratethys). *Cour. Forsch.-Inst. Senckenberg*, 246 129–151.
- Rupprecht, B.J., Sachsenhofer, R.F., Gawlick, H.-J., Kallanxhi, M.-E., Kucher, F., 2017. Jurassic source rocks in the Vienna Basin (Austria): Assessment of conventional and unconventional petroleum potential, *Marine and Petroleum Geology*, 86, 1327-1356.
- Sachsenhofer, R.F., Popov, S.V., Bechtel, A., Coric, S., Francu, J., Gratzner, R., Kotarba, M., Mayer, J., Pupp, M., Rupprecht, B.J., Vincent, S.J., 2017. Oligocene and Lower Miocene source rocks in the Paratethys: palaeogeographical and stratigraphic controls. In: Simmons, M.D., Tari, G.C., Okay, A.I. (eds.) *Petroleum Geology of the Black Sea*. Geological Society, London, Special Publications, 464, <https://doi.org/10.1144/SP464.6>.
- Schultz, L. G. 1964. Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre shale. In *Analytical Methods in Geochemical Investigations of the Pierre Shale*. Geological Survey Professional Paper 391, C.
- Schulz H.-M., Bechtel A., Rainer T, Sachsenhofer R.F., Struck U., 2004. Paleogeography of the western Central Paratethys during nannoplankton zone NP 23: The Dynow Marlstone in the Austrian Molasse Basin. *Geologica Carpathica*, 55, 311-323.
- Schulz, H.-M., Bechtel, A., Sachsenhofer, R.F., 2005. The birth of the Paratethys during the early Oligocene: from Tethys to an ancient Black Sea analogue? *Global and Planetary Change*, 49, 163-176. <http://dx.doi.org/10.1016/j.gloplacha.2005.07.001>
- Seifert, P. 1982. Sedimentologie und Paleogeographie des Eozäns der Waschbergzone (Niederösterreich). *Mitt. Ges. Geol. Bergbaustud. Österreich*. 133-176.
- Seifert, W.K., Moldowan, J.M., 1980. The effect of thermal stress on source-rock quality as measured by hopane stereochemistry. *Physics and Chemistry of the Earth*, 12, 229-237.
- Simoneit, B.R.T., 1986. Cyclic terpenoids of the geosphere. In: Johns, R.B. (Ed.): *Biological Markers in the Sedimentary Record* Elsevier, New York, 43–99.
- Sinninghe Damstè, J.S., van Koert, E.R., Kock-van Dalen, A.C., de Leeuw, J.W., Schenck, P.A., 1989. Characterisation of highly branched isoprenoid thiophenes occurring in sediments and immature crude oils. *Org. Geochem.*, 14, 555-567.

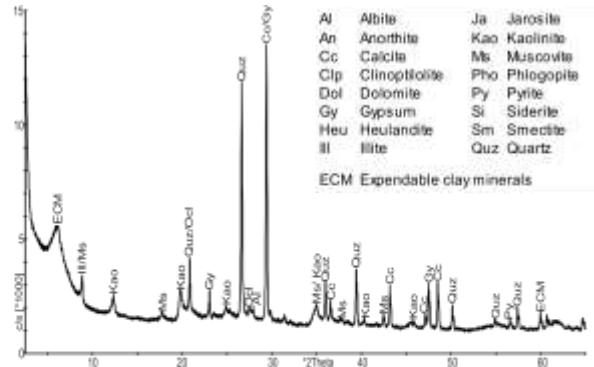
- Taylor, G.H., Teichmüller, M., Davis, A., Diessel, C.F.K., Littke, R., Robert, P., 1998. Organic Petrology. Gebrüder Bontaege, Berlin, 704.
- Thiel, V., Peckmann, J., Seifert, R., Wehrung, P., Reitner, J., Michaelis, W., 1999. Highly isotopically depleted isoprenoides: molecular markers for ancient methane venting. *Geochimica et Cosmochimica Acta*, 63, 3959–3966.
- Tissot, B.P., Welte, D.H. 1984. Petroleum formation and occurrence. 2<sup>nd</sup> Edition, Springer, Berlin, New York
- Tissot, B., Pelet, R., Roucache, J. Combaz, A., 1977. Alkanes as geochemical fossils indicators of geological environments. Campos, R., Goni, J. (Eds.) *Advances in Geochemistry*, Madrid, pp. 117-154.
- Uffmann, A.K., Littke, R., Rippen, D., 2012. Mineralogy and geochemistry of Mississippian and Lower Pennsylvanian Black Shales at the Northern Margin of the Variscan Mountain Belt (Germany and Belgium). *International Journal of Coal Geology*, 103, 92-108
- Volkman, J.K., Maxwell, J.R., 1986. Acyclic isoprenoids as biological markers. In: Johns, R.B. (Ed.) *Biological Markers in the Sedimentary Record*. Elsevier, Amsterdam, 42.
- Wessely, G., Peresson, H., Sauer, R., Draxler, I., Gangl, G., Gottschling, P., Heinrich, M., Hofmann, T., Lenhardt, W., Matura, A., Pavuza, R., 2006. *Geologie von Niederösterreich (Bundesländerserie)*. Verlag der Geologischen Bundesanstalt, Wien.
- Williams, L. A., Parks, G. A., Crerar, D. A. 1985. Silica diagenesis, I. Solubility controls. *Journal of Sedimentary Petrology*, 55, 3, 301-311.
- Zolitschka, B., 1998. Paläoklimatische Bedeutung laminiertes Sedimente. Holzmaar (Eifel, Deutschland), Lake C2 (Nordwest-Territorien, Kanada) und Lago Grande di Monticchio (Basilicata, Italien). *Bornträger*, Berlin, 176 S.



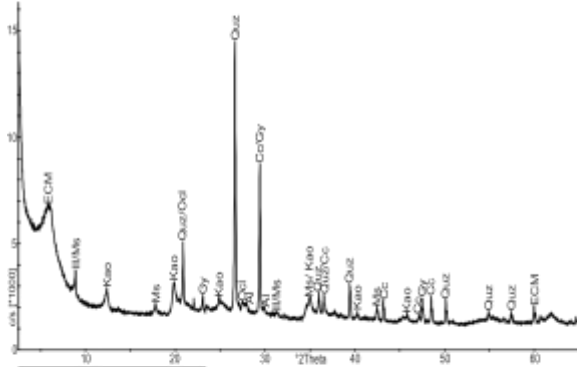




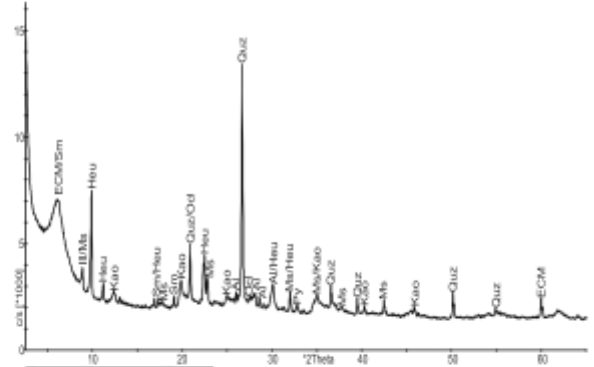
Thomasi Fm. (10.41 m)



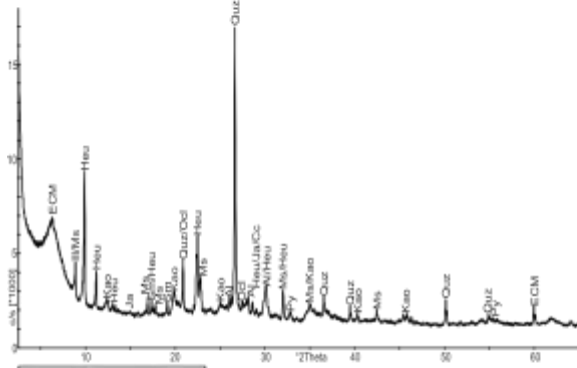
Thomasi Fm. (11.00 m)



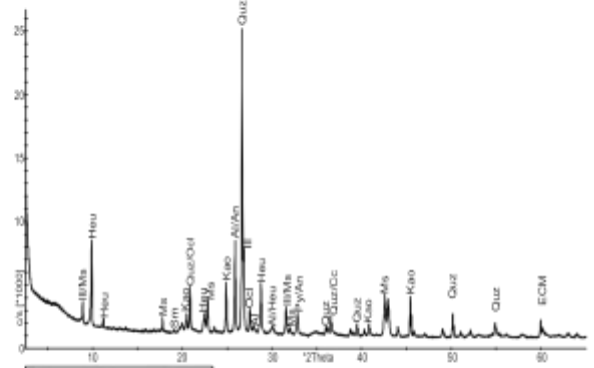
Thomasi Fm. (11.38 m)



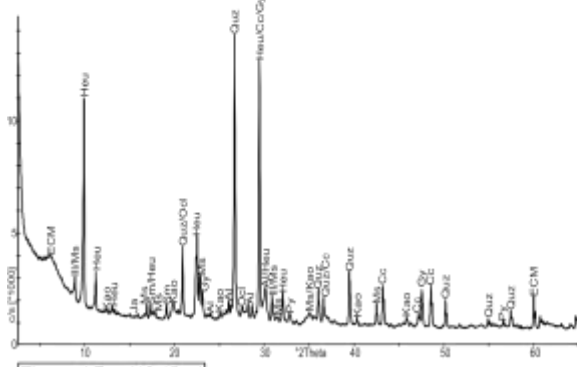
Thomasi Fm. (11.52 m)



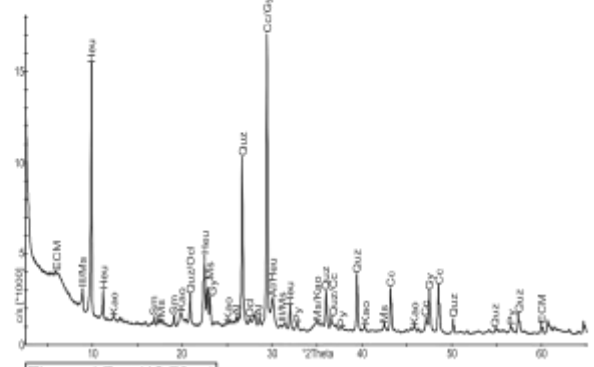
Thomasi Fm. (11.66 m)



Thomasi Fm. (12.31 m)



Thomasi Fm. (12.45 m)

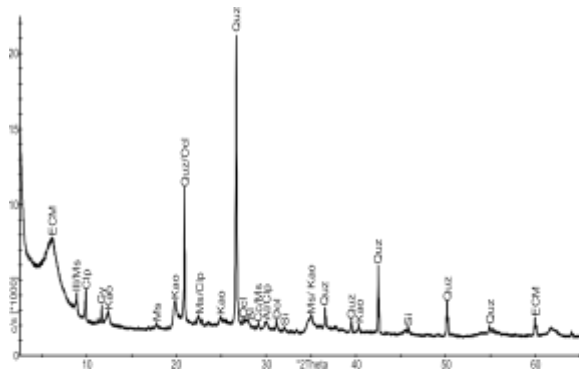


Thomasi Fm. (12.78 m)

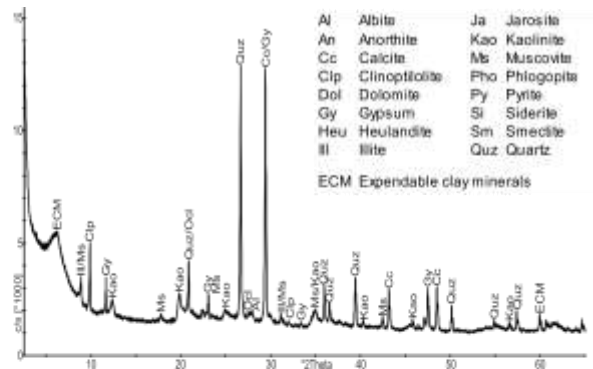
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An	Anorthite	Kao	Kaolinite
Cc	Calcite	Ms	Muscovite
Clp	Clinoptilolite	Pho	Phlogopite
Dol	Dolomite	Py	Pyrite
Gy	Gypsum	Si	Siderite
Heu	Heulandite	Sm	Smeectite
Ill	Illite	Quz	Quartz

ECM Expendable clay minerals





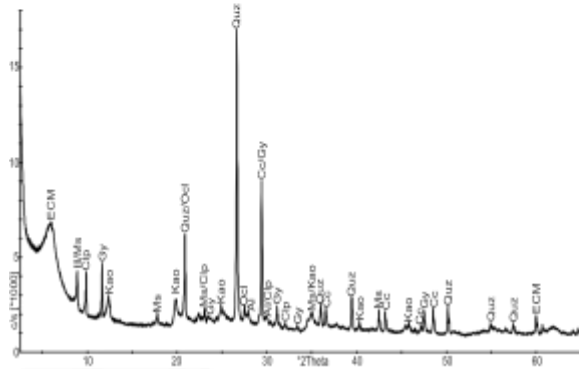
Thomasi Fm. (15.49 m)



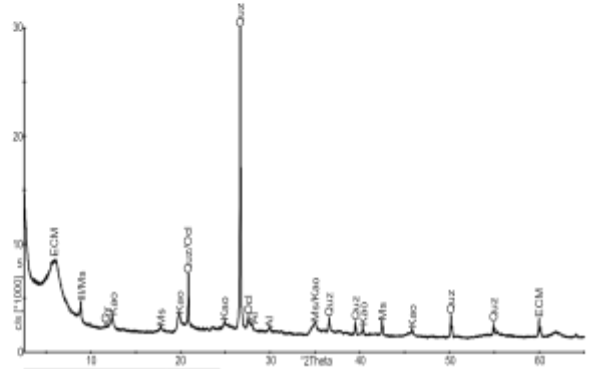
Thomasi Fm. (16.28 m)

Al	Albite	Ja	Jarosite
An	Anorthite	Kao	Kaolinite
Cc	Calcite	Ms	Muscovite
Clip	Clinoptilolite	Pho	Phlogopite
Dol	Dolomite	Py	Pyrite
Gy	Gypsum	Si	Siderite
Heu	Heulandite	Sm	Smectite
Ill	Illite	Quz	Quartz

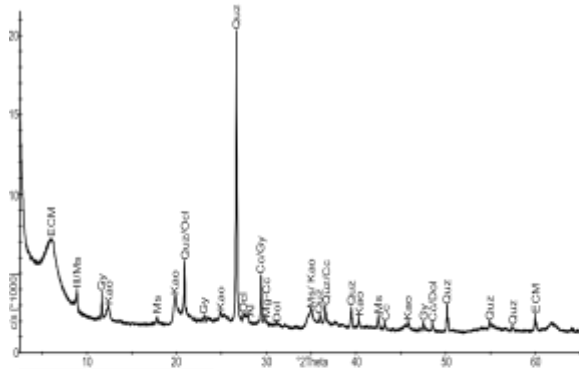
ECM Expendable clay minerals



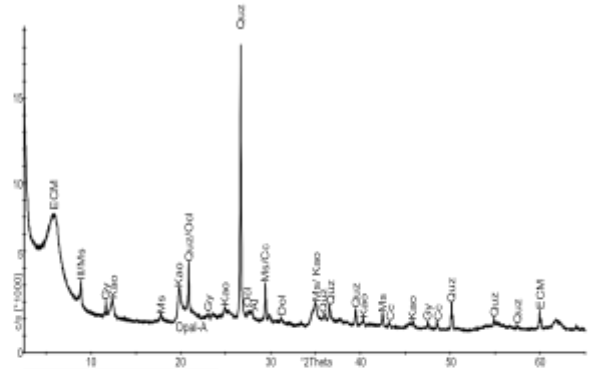
Thomasi Fm. (16.91 m)



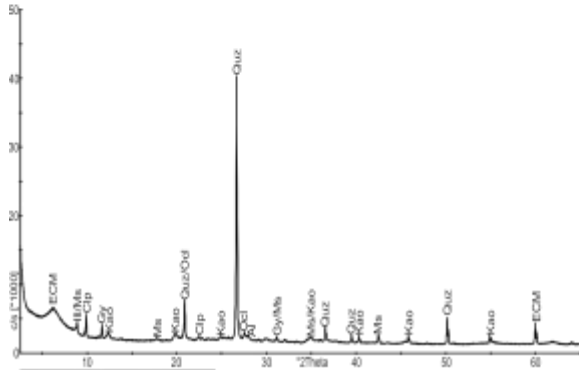
Thomasi Fm. (17.28 m)



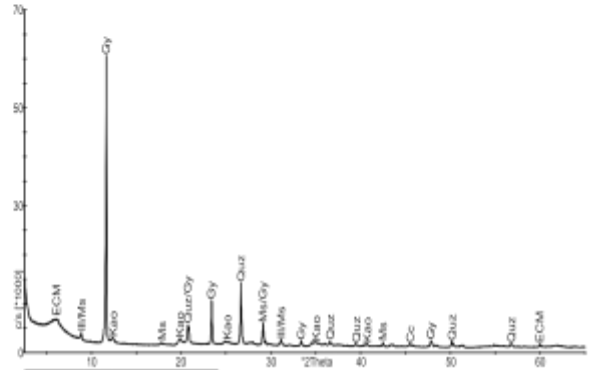
Thomasi Fm. (17.38 m)



Thomasi Fm. (17.87 m)

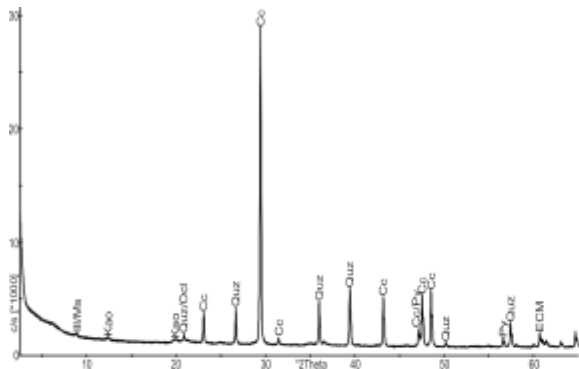


Thomasi Fm. (18.26 m)

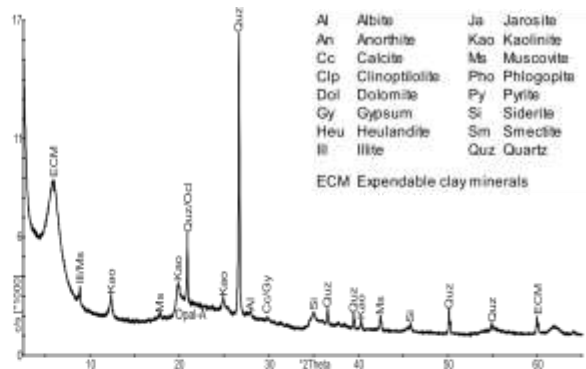


Thomasi Fm. (18.63 m)





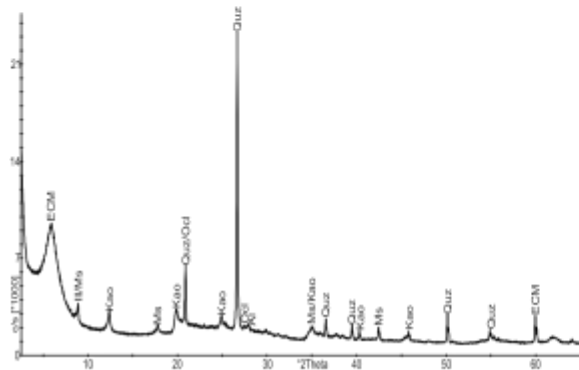
Dynow Mbr. (23.70 m)



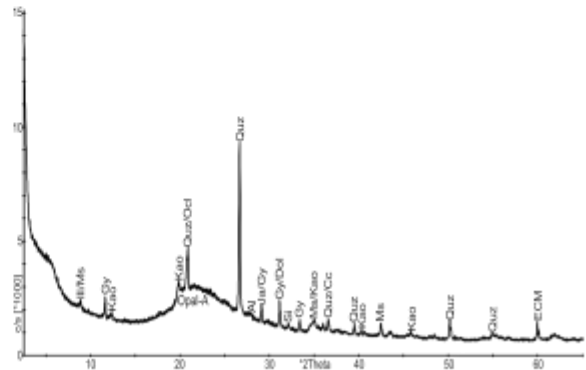
Galgenberg Mbr. (Diatomite, 23.95 m)

Al	Albite	Ja	Jarosite
An	Anorthite	Kao	Kaolinite
Cc	Calcite	Ms	Muscovite
Clp	Clinoptilolite	Pho	Phlogopite
Dol	Dolomite	Py	Pyrite
Gy	Gypsum	Si	Siderite
Heu	Heulandite	Sm	Smectite
Ill	Illite	Quz	Quartz

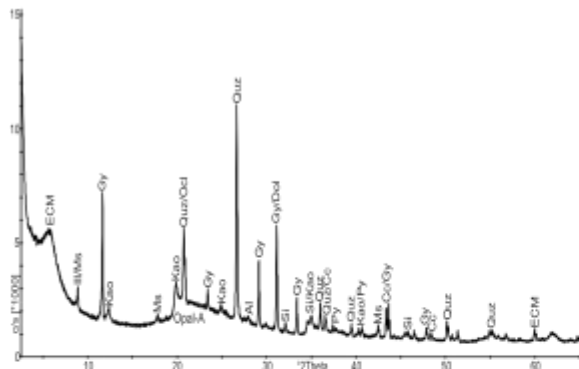
ECM Expendable clay minerals



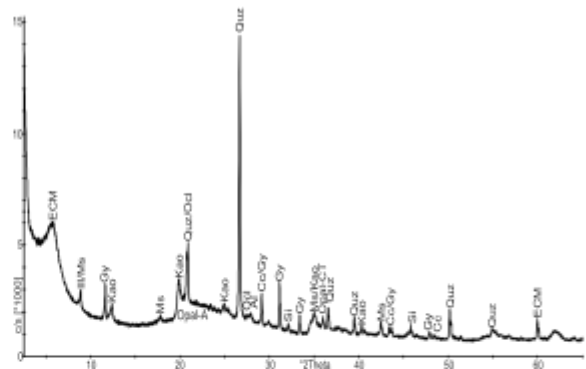
Galgenberg Mbr. (Diatomite, 24.25 m)



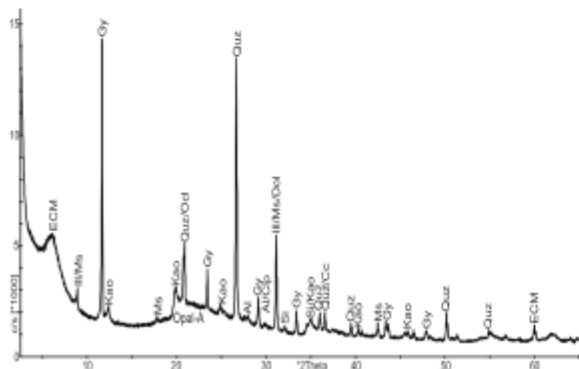
Galgenberg Mbr. (Diatomite, 24.63 m)



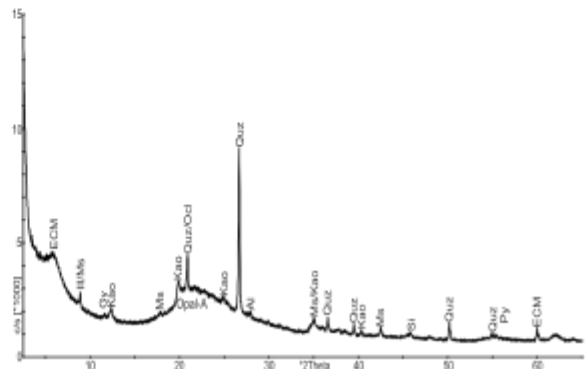
Galgenberg Mbr. (Diatomite, 25.43 m)



Galgenberg Mbr. (Diatomite, 26.16 m)

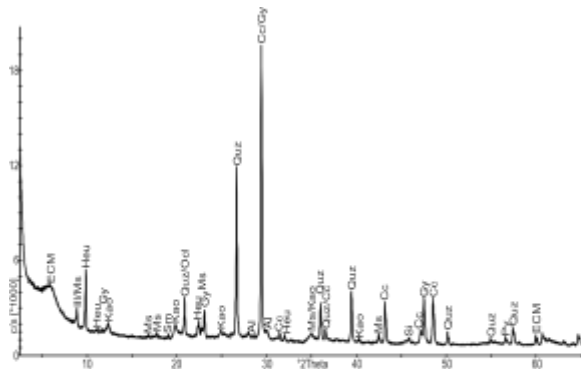


Galgenberg Mbr. (Diatomite, 26.79 m)

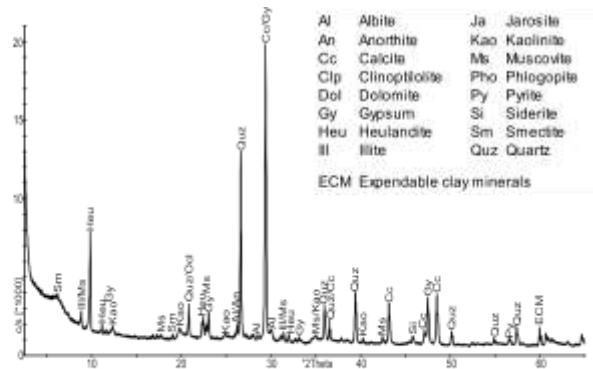


Galgenberg Mbr. (Diatomite, 27.05 m)





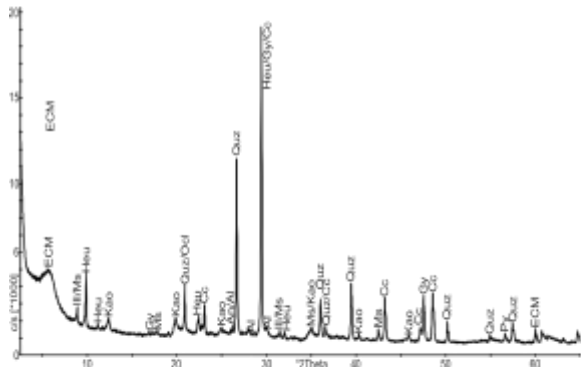
Ottenthal Mbr. (31.47 m)



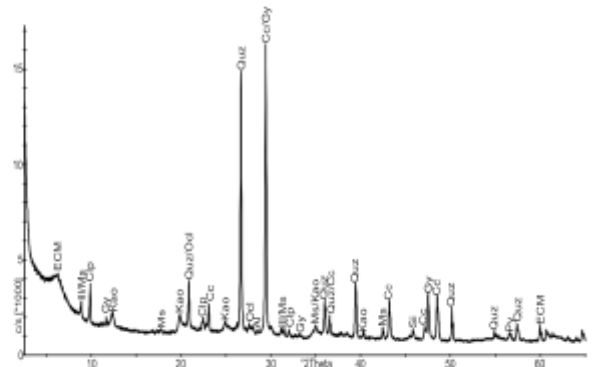
Ottenthal Mbr. (31.75 m)

Al	Albite	Ja	Jarosite
An	Anorthite	Kao	Kaolinite
Cc	Calcite	Ms	Muscovite
Clp	Clinoptilolite	Pho	Phlogopite
Dol	Dolomite	Py	Pyrite
Gy	Gypsum	Si	Siderite
Heu	Heulandite	Sm	Smerite
Ill	Illite	Quz	Quartz

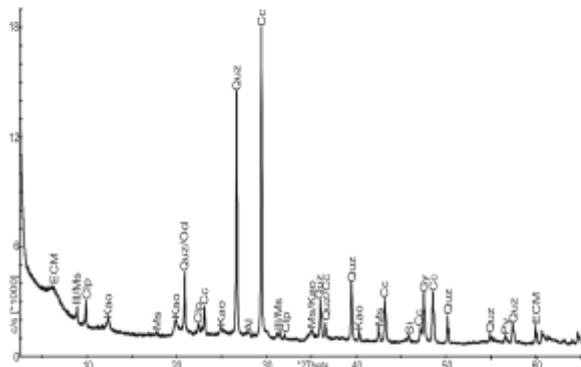
ECM Expendable clay minerals



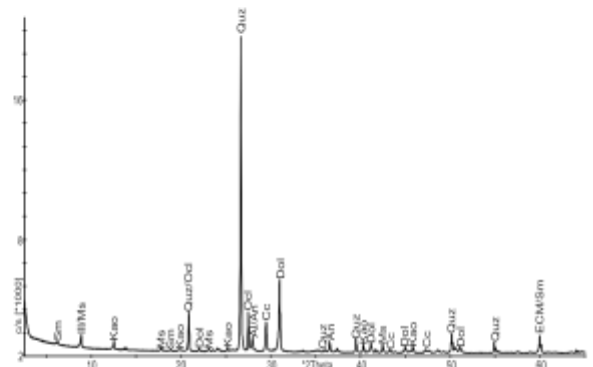
Ottenthal Mbr. (32.05 m)



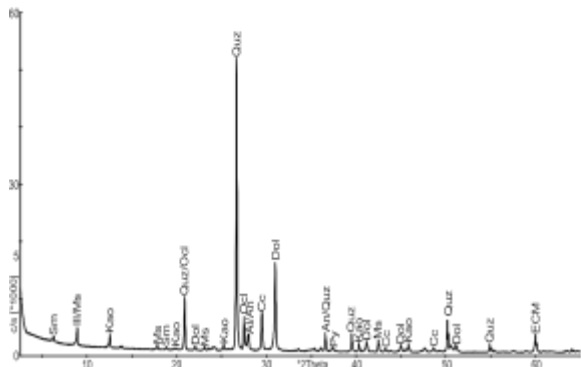
Ottenthal Mbr. (32.73 m)



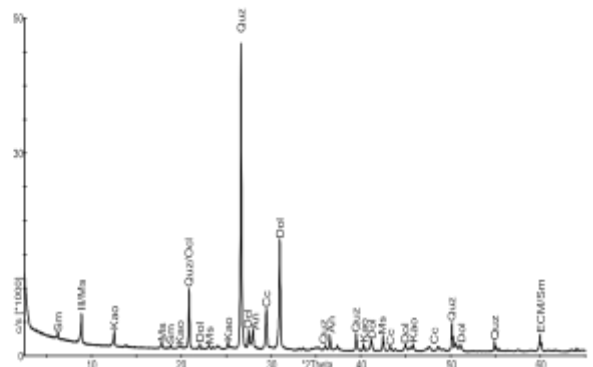
Ottenthal Mbr. (32.91 m)



Eggenburgian (1610 m)



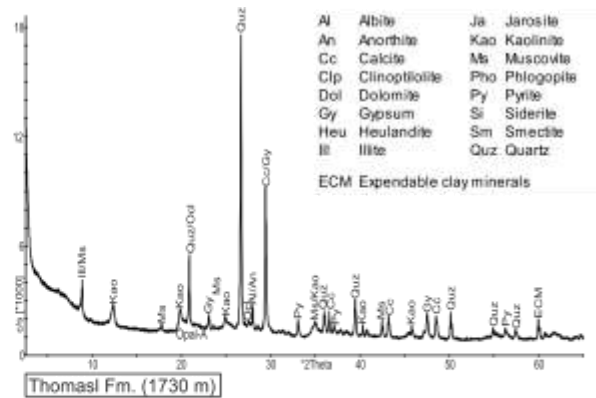
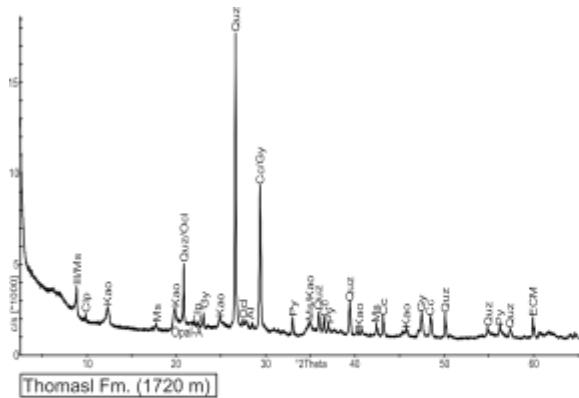
Eggenburgian (1620 m)



Eggenburgian (1630 m)

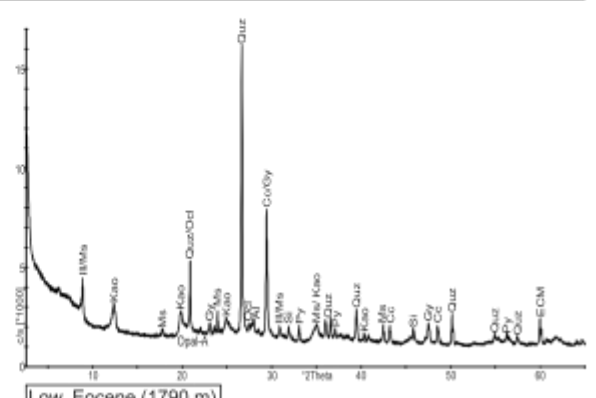
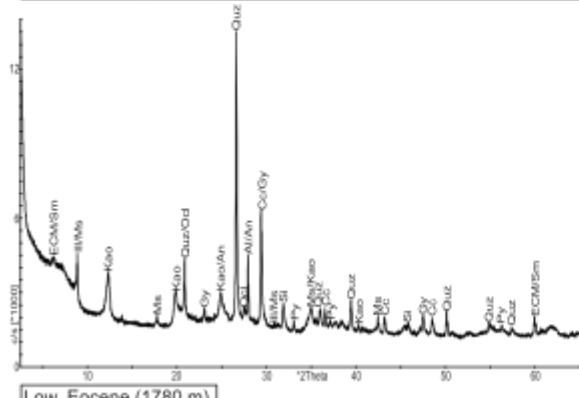
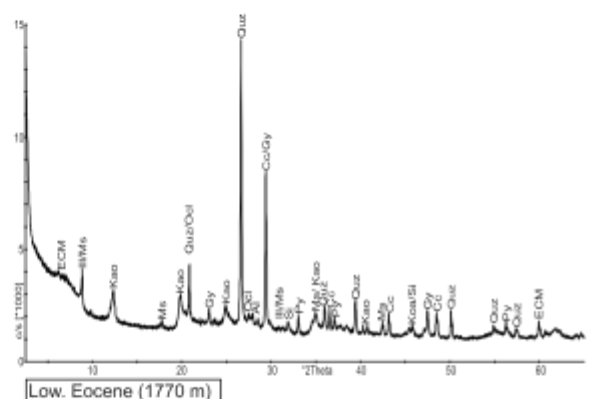
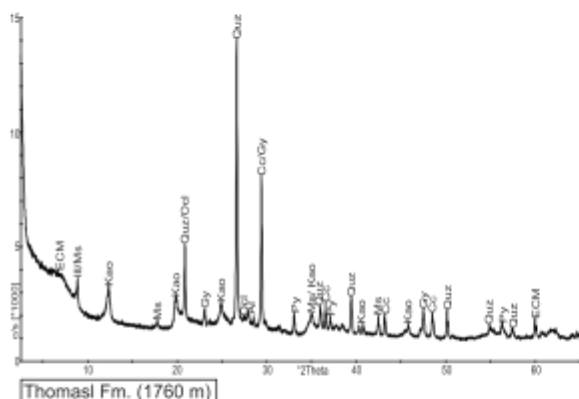
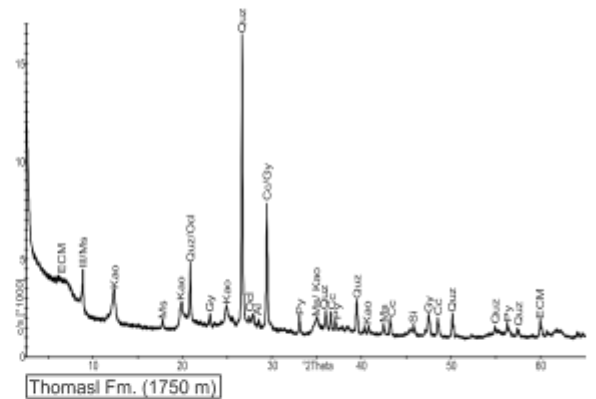
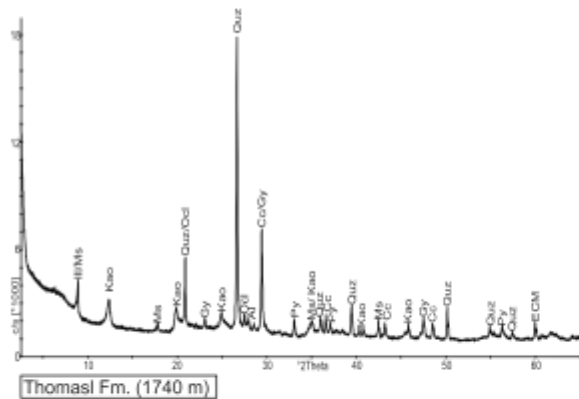






Al	Albite	Ja	Jarosite
An	Anorthite	Kao	Kaolinite
Cc	Calcite	Ms	Muscovite
Clp	Clinoptilolite	Pho	Phlogopite
Dol	Dolomite	Py	Pyrite
Gy	Gypsum	Si	Siderite
Heu	Heulandite	Sm	Smectite
Ill	Illite	Quz	Quartz

ECM Expendable clay minerals



## Appendix 2 – Mineral percentages (semi-quantitative)

XRD	Depth	Quartz	Opal	Plagio- class	K- feldspar	Calcite	Dolomite	Siderite	Pyrite	Jarosite	Heu- landite*	Gypsum	Σ Clay
	[m]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
<b>Waldweg Section</b>													
Thomasl Fm.		1.22	27	0	3	2	0	3	0	0	0	0	66
		2.13	74	0	7	14	5	0	0	0	0	0	0
		2.63	58	0	8	11	3	0	0	16	0	0	3
		3.72	52	0	0	6	5	0	0	14	0	0	23
		5.62	78	0	9	8	5	0	0	0	0	0	0
		6.01	25	0	3	3	1	0	0	0	0	0	67
		8.67	29	0	2	2	0	0	0	0	0	1	65
		9.52	71	0	6	6	0	0	0	0	0	4	12
		11.38	42	0	4	4	40	0	0	0	0	0	9
		11.52	39	0	4	3	0	0	0	0	43	0	10
		11.66	24	0	3	2	0	0	0	0	3	29	39
		12.45	15	0	2	1	27	0	0	0	0	27	29
		12.78	10	0	1	1	33	0	0	0	0	36	19
		13.07	57	0	5	4	0	0	0	0	2	32	0
		13.34	16	0	1	2	0	0	1	1	1	13	0
		13.56	44	0	0	16	0	0	0	0	0	4	0
		14.06	22	0	2	2	2	2	0	0	0	5	1
		14.45	29	0	2	2	0	0	0	0	0	9	0
		14.58	15	0	1	1	26	1	2	0	0	8	0
		14.97	14	0	2	1	26	0	0	0	4	7	0
	15.21	18	0	1	1	25	0	0	0	2	8	4	
	15.49	26	0	2	1	0	0	0	0	2	7	2	
	16.28	14	0	1	1	31	1	0	0	2	10	3	
	16.91	19	0	2	2	20	0	2	0	0	7	5	
	17.28	36	0	2	4	0	0	0	0	1	1	1	
	17.38	27	0	2	2	3	1	0	0	2	0	3	
	17.87	71	9	5	5	0	4	0	0	0	0	6	
	18.26	69	0	0	4	0	0	0	0	2	15	5	
	18.63	9	0	1	1	0	0	0	0	12	1	57	
	19.1	64	0	5	4	0	0	0	0	11	6	0	
	19.29	32	0	5	3	0	0	0	0	19	23	0	
	19.78	27	0	3	2	0	3	0	0	0	0	0	
Dynow Mbr.		20	23	2	0	0	54	0	0	0	0	0	
		21.13	11	3	0	0	85	0	0	0	0	0	
		22.15	12	0	0	0	73	0	0	0	0	0	
		22.87	9	2	0	1	51	0	0	1	0	0	
		23.42	5	1	0	1	93	0	0	0	0	0	
Galgenberg Mbr.	Diatomite	23.95	6	0	0	0	95	0	0	0	0	0	
		24.25	38	3	2	2	0	0	0	0	0	0	
		24.63	23	0	0	0	7	0	0	0	10	0	
		25.43	17	3	1	1	0	1	0	0	19	0	
		26.16	23	0	2	1	0	8	0	0	0	4	
		26.79	19	3	2	1	0	1	2	0	8	0	
		27.05	6	0	0	0	0	2	0	0	0	6	
		28.26	30	5	2	0	0	3	0	0	0	0	
Shale	28.83	42	17	7	5	0	6	8	0	0	15		
	29.22	45	0	4	2	7	2	11	0	0	24		
Ottenthal Mbr.		29.65	30	0	3	0	3	0	4	0	19		
		30.22	35	0	3	2	18	2	7	2	0		
		30.82	16	0	1	0	27	1	4	0	0		
		30.96	22	0	1	0	16	1	4	0	0		
		31.2	16	0	1	1	28	1	1	1	0		
		31.47	17	0	1	0	60	0	2	0	0		
		31.75	13	0	1	1	43	2	2	1	0		
		32.05	12	0	1	1	44	0	2	0	0		
		32.73	23	0	0	2	53	2	2	0	0		
		32.91	20	0	1	1	50	0	0	0	0		

\*includes clinoptilolite

<b>XRD</b>	Depth	Quartz	Opal	Plagio- clase	K- Felspar	Calcite	Dolomite	Siderite	Pyrite	Jarosite	Heu- land.*	Gypsum	Σ Clay		
	[m]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		
Thomasl Well	Egg.	1610	48	0	5	12	9	22	0	0	0	0	0	4	
		1620	40	0	4	9	11	24	0	0	0	0	0	11	
		1630	38	0	5	5	10	27	0	0	0	0	0	15	
	Thomasl Fm.	1640	46	0	12	10	17	9	0	0	0	0	0	6	
		1650	25	0	3	2	2	4	0	4	0	0	1	60	
		1660	23	0	1	2	15	2	0	3	0	0	0	54	
		1670	11	0	4	2	19	3	0	5	0	0	0	56	
		1680	19	0	2	2	23	2	0	4	0	0	0	50	
		1690	22	0	2	2	10	1	0	0	3	0	1	59	
		1700	20	10	2	1	13	1	0	1	0	0	0	50	
		1710	18	3	2	2	33	1	0	4	0	0	0	38	
		1720	25	3	1	1	25	1	0	4	0	2	0	39	
		1730	23	2	4	1	23	1	0	3	0	0	0	43	
		1740	25	3	1	3	18	0	0	4	0	0	0	46	
		1750	23	0	2	2	21	1	0	4	0	0	0	48	
		1760	20	4	2	1	22	0	0	0	0	0	0	47	
		L.Eoc.	1770	22	2	2	2	26	0	0	4	0	0	0	42
			1780	19	0	5	2	16	0	6	0	0	0	0	49
1790	22		2	3	2	19	0	3	3	0	0	0	47		

\*includes clinoptiolite

### Appendix 3 – Bulk parameters

Formation	NP	Section meter	Depth [m]	S <sub>1</sub> [mg HC/g]	S <sub>2</sub> [mg HC/g]	T <sub>max</sub> [°C]	C [%]	TOC [%]	S [%]	HI [mg HC/g TOC]	TOC/S Calc. [%]	Equiv. SiO <sub>2</sub> [%]	
<b>Ottenthal Section</b>													
Thomasl Fm.	NP24	54.11	1.22	0.01	0.03	407	0.53	0.30	0.02	10	17.55	1.92	
Thomasl Fm.	NP24	53.20	2.13	0.01	0.04	455	####	0.08	0.07	53	1.15	94.59	
Thomasl Fm.	NP24	52.70	2.63	0.01	0.04	364	0.53	0.47	0.39	7	1.20	0.55	
Thomasl Fm.	NP24	51.61	3.72	0.05	0.18	361	0.77	0.52	0.45	33	1.15	2.03	2.5
Thomasl Fm.	NP24	50.61	4.72	0.05	0.18	385	1.24	0.35	0.06	49	5.96	7.39	
Thomasl Fm.	NP24	49.70	5.62	0.05	0.47	428	0.86	0.80	0.07	58	10.87	0.45	
Thomasl Fm.	NP24	49.31	6.01	0.02	0.15	408	0.47	0.42	0.04	36	9.53	0.46	
Thomasl Fm.	NP24	48.17	7.15	0.02	0.10	384	0.52	0.23	0.02	44	9.59	2.38	
Thomasl Fm.	NP24	47.15	8.17	0.02	0.14	413	0.54	0.53	0.34	27	1.55	0.11	1.4
Thomasl Fm.	NP24	46.65	8.67	0.02	0.11	368	0.46	0.41	0.23	27	1.78	0.40	
Thomasl Fm.	NP24	45.80	9.52	0.01	0.07	388	0.35	0.17	0.03	38	5.25	1.54	
Thomasl Fm.	NP24	44.91	10.41	0.02	0.16	411	2.50	0.31	0.03	49	9.76	18.26	
Thomasl Fm.	NP24	44.32	11.00	0.02	0.15	416	2.96	0.31	0.03	48	11.19	22.07	
Thomasl Fm.	NP24	43.94	11.38	0.03	0.39	422	2.00	0.60	0.07	64	8.73	11.63	
Thomasl Fm.	NP24	43.80	11.52	0.08	1.31	427	1.18	1.13	0.10	115	11.93	0.42	3.8
Thomasl Fm.	NP24	43.66	11.66	0.08	1.09	426	0.84	0.79	0.06	138	13.33	0.39	
Thomasl Fm.	NP24	43.07	12.25	0.05	0.24	421	0.42	0.41	0.05	58	7.68	0.07	
Thomasl Fm.	NP23	11.87	12.31	0.03	0.08	432	0.24	0.21	2.27	37	0.09	0.26	
Thomasl Fm.	NP23	11.73	12.45	0.02	0.45	430	2.79	0.53	0.02	85	30.41	18.83	3.5
Thomasl Fm.	NP23	11.40	12.78	0.03	0.15	433	3.66	0.24	0.01	64	24.18	28.56	
Thomasl Fm.	NP23	11.11	13.07	0.03	0.17	428	0.56	0.42	0.03	39	13.74	1.10	
Thomasl Fm.	NP23	10.99	13.19	0.05	0.10	429	2.70	0.23	0.03	44	8.69	20.62	
Thomasl Fm.	NP23	10.84	13.34	0.04	0.20	430	2.19	0.35	0.03	56	10.47	15.36	2.8
Thomasl Fm.	NP23	10.62	13.56	0.02	0.06	431	0.22	0.16	0.02	35	7.59	0.50	
Thomasl Fm.	NP23	10.12	14.06	0.04	0.17	423	0.42	0.39	0.09	43	4.32	0.30	
Thomasl Fm.	NP23	9.82	14.36	0.04	0.17	424	0.41	0.40	0.04	41	10.89	0.10	2.0
Thomasl Fm.	NP23	9.73	14.45	0.05	0.18	430	0.41	0.38	0.05	46	7.90	0.23	
Thomasl Fm.	NP23	9.60	14.58	0.02	0.14	416	2.17	0.33	0.13	43	2.58	15.36	
Thomasl Fm.	NP23	9.33	14.85	0.06	0.20	426	0.58	0.54	0.05	37	11.36	0.27	5.1
Thomasl Fm.	NP23	9.21	14.97	0.03	0.16	428	2.07	0.41	0.09	39	4.86	13.78	
Thomasl Fm.	NP23	8.97	15.21	0.02	0.15	429	2.18	0.40	0.32	36	1.23	14.85	
Thomasl Fm.	NP23	8.69	15.49	0.03	0.12	429	0.36	0.32	0.34	37	0.96	0.29	1.6
Thomasl Fm.	NP23	8.30	15.88	0.07	0.37	426	0.87	0.78	0.11	47	7.27	0.69	
Thomasl Fm.	NP23	7.90	16.28	0.03	0.24	430	3.13	0.55	0.28	44	1.97	21.53	
Thomasl Fm.	NP23	7.27	16.91	0.04	0.24	428	1.78	0.44	0.51	55	0.86	11.16	
Thomasl Fm.	NP23	7.00	17.18	0.05	0.23	422	0.51	0.46	0.11	49	4.09	0.38	1.0
Thomasl Fm.	NP23	6.90	17.28	0.01	0.06	414	0.30	0.25	0.07	24	3.79	0.36	
Thomasl Fm.	NP23	6.80	17.38	0.02	0.17	426	1.00	0.37	0.19	47	1.93	5.23	
Thomasl Fm.	NP23	6.31	17.87	0.02	0.08	424	0.66	0.23	0.16	33	1.41	3.60	1.4
Thomasl Fm.	NP23	5.92	18.26	0.03	0.07	429	0.28	0.20	0.33	35	0.62	0.66	
Thomasl Fm.	NP23	5.55	18.63	0.04	0.17	426	0.54	0.37	4.61	46	0.08	1.37	1.3
Thomasl Fm. (Sitborice E.)	NP23	4.85	19.10	0.10	0.44	411	0.63	0.61	0.35	72	1.75	0.18	
Thomasl Fm. (Sitborice E.)	NP23	4.66	19.29	0.08	0.21	332	0.59	0.58	0.72	36	0.81	0.06	4.5
Thomasl Fm. (Sitborice E.)	NP23	4.31	19.64	0.07	0.19	365	0.50	0.49	0.58	39	0.84	0.07	
Thomasl Fm. (Sitborice E.)	NP23	4.17	19.78	0.08	0.34	403	0.56	0.52	0.26	65	2.02	0.32	3.3

Formation	NP	Section	Depth	S <sub>1</sub>	S <sub>2</sub>	T <sub>max</sub>	C	TOC	S	HI	TOC/S Calc.	Equiv. SiO <sub>2</sub>
		meter	[m]	[mg HC/g]	[mg HC/g]	[°C]	[%]	[%]	[%]	[mg HC/g TOC]	[%]	[%]
<b>Ottenthal Section</b>												
Dynow Mbr.	NP23	42.00	20	0.05	0.67	424	3.92	0.36	0.03	184	14.14	29.63 13.3
Dynow Mbr.	NP23	40.87	21.13	0.06	0.59	416	3.97	0.33	0.02	175	16.33	30.26 27.9
Dynow Mbr.	NP23	40.15	21.85	0.06	1.40	416	5.30	0.65	0.01	214	49.16	38.72 13.8
Dynow Mbr.	NP23	39.85	22.15	0.05	0.63	421	5.48	0.43	0.03	147	15.07	42.12
Dynow Mbr.	NP23	39.13	22.87	0.06	0.98	420	4.84	0.57	0.02	172	27.11	35.58 16.3
Dynow Mbr.	NP23	38.85	23.15	0.04	0.37	424	7.09	0.36	0.02	102	16.11	56.07
Dynow Mbr.	NP23	38.58	23.42	0.03	0.20	422	7.36	0.33	0.02	60	14.10	58.59 5.2
Dynow Mbr.	NP23	38.30	23.70	0.01	0.10	408	8.27	0.35	0.01	28	35.79	65.96 2.7
Galgenberg Mbr. Diatomite	NP22/23	38.08	28.26	0.11	1.25	416	1.02	0.98	0.05	128	18.49	0.30 14.2
Galgenberg Mbr. Diatomite	NP22/23	37.92	27.62	0.13	2.66	414	1.13	1.13	0.07	236	15.88	0.03
Galgenberg Mbr. Diatomite	NP22/23	37.78	27.36	0.09	1.19	412	0.89	0.86	0.07	139	11.91	0.30 9.7
Galgenberg Mbr. Diatomite	NP22/23	37.40	27.05	0.09	1.57	406	0.66	0.64	0.57	243	1.12	0.12 29.5
Galgenberg Mbr. Diatomite	NP22/23	36.93	26.79	0.09	1.91	413	0.94	0.95	2.02	202	0.47	0.00
Galgenberg Mbr. Diatomite	NP22/23	36.60	26.50	0.05	0.17	393	0.65	0.64	2.21	26	0.29	0.05
Galgenberg Mbr. Diatomite	NP22/23	36.14	26.16	0.08	0.96	408	0.55	0.56	0.22	171	2.57	0.00 25.8
Galgenberg Mbr. Diatomite	NP22/23	35.87	25.89	0.08	0.87	404	0.54	0.52	0.95	165	0.55	0.16 14.2
Galgenberg Mbr. Diatomite	NP22/23	35.53	25.43	0.17	1.91	417	0.75	0.76	0.05	252	15.23	0.00
Galgenberg Mbr. Diatomite	NP22/23	35.24	25.10	0.06	0.44	381	0.36	0.33	1.55	132	0.21	0.25 12.4
Galgenberg Mbr. Diatomite	NP22/23	34.98	24.63	0.10	1.25	405	0.61	0.60	0.08	207	7.18	0.10 22.4
Galgenberg Mbr. Diatomite	NP22/23	34.67	24.25	0.07	0.61	374	0.84	0.58	0.98	105	0.59	2.19 13.4
Galgenberg Mbr. Diatomite	NP22/23	34.41	24.11	0.14	1.02	389	0.67	0.65	0.08	156	8.09	0.12
Galgenberg Mbr. Diatomite	NP22/23	33.77	24	0.05	0.29	411	0.50	0.48	0.20	60	2.45	0.16 10.2
Galgenberg Mbr. Shale	NP22	33.47	28.7	0.04	0.21	411	0.23	0.24	0.03	86	7.73	0.00
Galgenberg Mbr. Shale	NP22	33.30	28.83	0.03	0.20	424	0.51	0.48	0.16	41	3.01	0.23 5.2
Galgenberg Mbr. Shale	NP22	33.10	29.03	0.08	0.49	415	0.80	0.77	0.08	64	9.99	0.21 5.7
Galgenberg Mbr. Shale	NP22	32.91	29.22	0.07	0.45	421	0.94	0.84	0.14	53	6.22	0.84 4.2
Galgenberg Mbr. Shale	NP22	32.76	29.37	0.04	0.26	430	0.56	0.52	0.31	50	1.71	0.32 3.9
Ottenthal Mbr.	NP22	32.48	29.65	0.04	0.24	431	0.85	0.44	0.07	53	6.04	3.36
Ottenthal Mbr.	NP22	32.21	29.92	0.03	0.36	437	1.14	0.43	0.03	84	12.80	5.90 2.5
Ottenthal Mbr.	NP22	31.91	30.22	0.05	0.33	432	1.60	0.57	0.04	58	15.31	8.57
Ottenthal Mbr.	NP22	31.65	30.48	0.06	0.21	423	0.86	0.37	0.05	57	7.62	4.12 2.9
Ottenthal Mbr.	NP22	31.49	30.64	0.05	0.22	427	2.77	0.54	0.08	40	6.74	18.57
Ottenthal Mbr.	NP22	31.31	30.82	0.05	0.23	433	3.04	0.44	0.45	52	0.98	21.66
Ottenthal Mbr.	NP22	31.17	30.96	0.08	0.22	430	1.94	0.64	0.12	34	5.29	10.85 3.6
Ottenthal Mbr.	NP22	30.93	31.20	0.04	0.16	441	3.06	0.39	0.13	40	2.97	22.30
Ottenthal Mbr.	NP22	30.66	31.47	0.04	0.19	434	4.68	0.39	0.09	49	4.25	35.73
Ottenthal Mbr.	NP22	30.38	31.75	0.03	0.13	433	5.17	0.37	0.19	34	1.91	40.02 2.0
Ottenthal Mbr.	NP22	30.08	32.05	0.03	0.11	436	4.38	0.30	0.08	37	3.70	34.08
Ottenthal Mbr.	NP22	29.80	32.33	0.03	0.11	432	3.95	0.39	0.17	28	2.30	29.63
Ottenthal Mbr.	NP22	29.40	32.73	0.02	0.10	428	3.90	0.30	0.18	33	1.71	29.99 1.9
Ottenthal Mbr.	NP22	29.22	32.91	0.02	0.12	430	4.39	0.30	0.10	38	2.89	34.05

Formation	NP	Depth [m]	S <sub>1</sub> [mg HC/g]	S <sub>2</sub> [mg HC/g]	T <sub>max</sub> [°C]	C [%]	TOC [%]	S [%]	HI [mg HC/g TOC]	TOC/S Calc. Equiv.	SiO <sub>2</sub> [%]
<b>Thomasl well</b>											
<b>cuttings samples</b>											
Eggenburgian		1600	0.09	0.38	426	4.75	0.43	0.17	88	2.54	35.99
Eggenburgian		1610	0.11	0.55	420	4.55	1.88	0.24	29	7.82	22.18 0.4
Eggenburgian		1620	0.03	0.14	425	4.24	0.98	0.33	14	3.03	27.15 0.3
Eggenburgian		1630	0.06	0.42	423	4.59	1.13	0.29	37	3.84	28.82 0.2
Thomasl Fm.	NP24	1640	0.09	1.29	423	3.93	1.05	2.46	123	0.43	23.99 0.1
Thomasl Fm.	NP24	1650	0.09	3.10	424	3.94	1.88	1.90	165	0.99	17.17 0.2
Thomasl Fm.	NP24	1660	0.07	2.28	425	3.29	1.63	1.96	140	0.83	13.81 0.2
Thomasl Fm.	NP24	1670	0.11	4.82	423	4.36	2.32	2.42	208	0.96	16.94 0.1
Thomasl Fm.	NP24	1680	0.11	3.75	424	4.43	1.97	2.07	191	0.95	20.50 0.3
Thomasl Fm.	NP24	1690	0.15	3.85	406	3.23	2.39	2.60	161	0.92	7.00 1.0
Thomasl Fm.	NP24	1700	0.42	15.24	404	4.99	3.67	2.20	416	1.67	11.03 4.5
Thomasl Fm.	NP24	1710	0.31	10.01	420	6.24	3.26	1.92	307	1.70	24.86 0.9
Thomasl Fm.	NP24	1720	0.19	5.94	418	4.82	2.66	2.05	223	1.29	18.00 0.7
Thomasl Fm.	NP24	1730	0.16	4.32	420	4.96	2.57	1.95	168	1.32	19.95 0.6
Thomasl Fm.	NP24	1740	0.12	4.50	424	5.28	2.46	3.77	183	0.65	23.50 0.4
Thomasl Fm.	NP24	1750	0.13	4.30	427	4.67	3.18	2.34	135	1.36	12.43 0.4
Thomasl Fm.	NP24	1760	0.12	3.86	426	4.94	3.33	2.12	116	1.57	13.39 0.5
Low. Eocene		1770	0.09	2.57	427	4.20	2.54	1.57	101	1.62	13.86 0.5
Low. Eocene		1780	0.04	0.49	427	2.63	1.28	0.75	38	1.71	11.31 0.5
Low. Eocene		1790	0.08	1.73	427	3.37	1.89	1.44	91	1.31	12.34 0.8
<b>core samples</b>											
Thomasl Fm.	NP24	1765-1765	0.06	0.24	308	1.59	0.62	0.39	38	1.59	8.01
Thomasl Fm.	NP24	3/1/2	0.05	0.19	307	0.94	0.40	0.36	47	1.13	4.44
Thomasl Fm.	NP24	3/1/3	0.03	0.14	419	1.16	0.50	0.43	27	1.17	5.50
Thomasl Fm.	NP24	3/1/4	0.04	0.18	422	1.69	0.86	0.31	20	2.73	6.96 1.4
Thomasl Fm.	NP24	3/1/5	0.04	0.22	317	1.10	0.54	0.29	40	1.87	4.65
Thomasl Fm.	NP24	3/1/6	0.03	0.13	425	2.28	0.50	0.21	26	2.44	14.79
Thomasl Fm.	NP24	3/2/1	0.05	0.39	426	2.15	1.31	0.59	30	2.19	7.00 1.2
Thomasl Fm.	NP24	3/2/2	0.03	0.21	425	2.83	1.23	0.41	17	3.00	13.34
Thomasl Fm.	NP24	3/2/3	0.02	0.21	428	1.55	0.71	0.34	29	2.13	6.94
Thomasl Fm.	NP24	3/2/4	0.03	0.27	427	2.70	0.78	0.36	34	2.17	16.03
Thomasl Fm.	NP24	3/2/5	0.06	1.08	432	6.11	2.43	0.76	44	3.19	30.67 2.5
Thomasl Fm.	NP24	3/2/6	0.06	0.50	422	3.66	1.01	1.05	49	0.96	22.08 0.8
<b>Poysdorf well</b>											
<b>cuttings samples</b>											
Thomasl Fm.	NP24	2800	0.16	3.77	426	4.67	2.23	1.71	169	1.30	20.29
Thomasl Fm.	NP24	2810	0.09	2.31	427	3.41	1.59	1.47	145	1.09	15.11
Thomasl Fm.	NP24	2820	0.11	2.22	426	3.22	1.34	1.56	166	0.85	15.68
Thomasl Fm.	NP24	2830	0.27	6.62	420	5.03	2.56	1.81	259	1.41	20.61
Thomasl Fm.	NP24	2840	0.52	7.30	420	4.76	2.69	2.22	271	1.21	17.29
Thomasl Fm.	NP24	2850	0.24	2.64	422	4.45	2.53	1.75	105	1.45	16.04
Thomasl Fm.	NP24	2860	0.28	3.31	422	3.91	2.29	2.13	145	1.07	13.49
Thomasl Fm.	NP24	2870	0.17	3.57	424	4.72	2.18	1.72	164	1.27	21.15
Thomasl Fm.	NP24	2880	0.10	3.29	424	5.85	2.54	1.17	129	2.18	27.54
Thomasl Fm.	NP24	2890	0.09	1.64	429	6.04	2.00	0.71	82	2.81	33.71
Upper. Cretaceous		2900	0.40	2.88	424	4.71	1.98	1.35	145	1.46	22.73
Upper. Cretaceous		2910	0.53	2.42	425	3.82	1.52	1.05	160	1.45	19.21
<b>core samples</b>											
Thomasl Fm.	NP24	2817	0.06	1.83	428	2.27	1.50	1.41	122	1.06	6.39 0.4
Thomasl Fm.	NP24	2816	0.08	1.65	428	3.25	1.10	3.89	149	0.28	17.90
Thomasl Fm.	NP24	2814.8	0.15	2.02	427	9.14	1.02	1.55	199	0.66	67.66 0.1
Thomasl Fm.	NP24	2815.1	0.10	5.06	427	9.83	2.04	0.59	248	3.48	64.90
Thomasl Fm.	NP24	2815.3	0.05	1.63	430	2.53	1.17	1.79	139	0.66	11.31 0.3
Thomasl Fm.	NP24	2813.5	0.07	1.34	427	2.19	1.22	3.27	110	0.37	8.12