

## ORGANIC FACIES DISTRIBUTION AT THE PLATFORMWARD MARGIN OF THE KÖSSEN BASIN

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### ABSTRACT

Assessment of the organic facies and that of organic precursors were performed on an 83 m thick core section of the Upper Norian Kössen Formation (Hungary), exposed in Sümeg by Süt-17 borehole. Carbon-dioxide, mineral carbon and organic carbon contents, determined on a large number (70) of samples, exhibit a carbonate-rich, organic-poor sequence. Cyclic variations observed in both forms of carbon, throughout the sequence, reveal cyclic alternations of the platform-derived input and the terrestrial-derived one. Owing to the especially low organic carbon content ( $C_{org} < 0.2\%$ ), half of the investigated rocks, composed mainly of carbonate particles, can not be considered as source rocks either for oil and gas. Most of them were formed under shallow subtidal conditions in a highly oxic environment. Rock Eval pyrolyses performed on selected argillaceous samples ( $C_{org} > 0.2\%$ ) together with organic petrographical data from a small sample set, show that the immature organic matter is of predominantly terrestrial origin and composed of mainly inertinite and vitrinite deposited in oxic environment. The predominance of the highly degraded land plant remnants resulted in organic facies D and CD with very low source potential in rocks containing less than 6 % of  $C_{carb}$ . Organic facies CD is also common in rocks containing more than 6 % of  $C_{carb}$ . Owing to the negligible amount of oil and minor amount of gas generated by all of these samples, they are rated as non-source rocks in any commercial sense. Gas-prone C facies and B facies with marginal potential for oil generation, observed in some carbonate-rich samples, formed from a mixture of different types of precursors and accumulated also in an oxic environment. The very minor amount of algal-derived liptinite was probably preserved by inclusion in carbonate skeleton.

**Key words:** carbonate platform, petroleum source potential, organic facies, organic precursors, depositional environment

### INTRODUCTION

The Upper Norian–Lower Rhaetian Kössen Formation is regarded as the source rock of heavy sulfur-rich oil of the adjacent oil field in the Transdanubian Range Unit (Hungary) (Clayton and Koncz, 1994). It was deposited in a backplatform basin in the background of the Dachstein platform. Organic petrographical and geochemical data (Brukner-Wein and Vető, 1986; Hetényi, 1989; Hetényi et al., 2002; Vető et al., 2000), as well as geochemical assessment of production and preservation of organic matter (OM) (Vető et al., 2000) have recently been reported. These examinations were performed on thermally immature OM accumulated on the gentle slope located between the basin and a late Triassic carbonate platform of the South-Alpine domain. Parallel variations were observed in the mineral composition and in the organic geochemical features of the Kössen Formation for the two studied boreholes as a function of their paleo-position on the slope. The immature OM is of predominantly marine origin and composed of mainly liptinites in both boreholes. Precursor biomass accumulated at the toe of the slope is mainly of algal origin with a minor bacterial and terrestrial contribution. A significantly higher proportion of bacterial biomass and a very small amount of higher plant remnants were found in the OM of the borehole located on the slope. The source potential of the Kössen Formation is nearly three times higher for the rocks deposited at the toe of the slope than for rocks deposited on the slope. This ratio fairly correlates with the average  $C_{org}$  content of the two sequences. Furthermore, rocks accumulated at the toe of the slope contain lower amount of

carbonate minerals than those accumulated on the relatively upper part of the slope.

This paper presents the bulk organic geochemical data measured on core samples taken from an immature section of the Kössen Formation deposited on the belt of the slope. Core samples were collected from Süt-17 well (Sümeg). On the basis of these data the petroleum source potential of the rocks were evaluated. Assessment of the organic facies and organic precursors for samples with different carbonate content, as well as that of the geochemical characteristics for depositional environment were attempted.

### GEOLOGICAL SETTING

Upper Triassic of the Transdanubian Range (Hungary) is made up from platform carbonates and intraplatform basin deposits (Haas, 2002). This segment of the large (200 km wide) Late Triassic carbonate platform belonging to the passive margin of the Tethys ocean, may have been situated between the North and South Alpine realms in the Triassic (Klimetz, 1983; Ziegler et al., 1983; Parrish, 1993). In the Paleogene the TR block moved eastward reaching its present position in the Early Miocene (Kázmér and Kovács, 1985; Balla, 1988; Haas et al., 1990). The lower unit of the platform, the Upper Carnian–Middle Norian Main Dolomite (Hauptdolomite) Fm. of about 1,000 m thickness is overlain by the Upper Norian–Rhaetian Dachstein Limestone of about 800 m thickness. Development and subsequent dolomitization of the platform was strongly affected by the climate (Balog et al., 1999). Formation of the Kössen Basin started at the very end of the Middle Norian as a result of the

extensional tectonics, which led to the disintegration of the previously existing carbonate platform and to a sea-level rise resulting in drowning of the platform. The basin was filled in by fine terrigenous siliciclastics and platform-derived carbonate particles during the Late Norian-Rhaetian (Haas and Budai, 1995; Haas, 2002). Cyclic alternation of carbonate sedimentation and argillaceous one, reflecting short-term (100-400 ka) sea-level fluctuations, is characteristic of the inner marginal belt of the platform. The carbonate-poor rocks deposited in relatively deeper water when the input of carbonate particles from the back stepping platform decreased (Haas, 1993).

Based on foraminifera and ostracodes the studied sequence, penetrated by Süt-17 well, represents the latest Norian interval (Oravecz-Scheffer, 1987). The carbonate-rich layers are composed mainly of limestone, argillaceous limestone and dolomitic limestone. The marly layers contain calcite, ankerite, and clay minerals (Haas, 1993).

## METHODS

70 samples were collected from the 83 m thick section of the Süt-17 well. Inorganic carbon ( $C_{carb}$ ) was determined by

measuring the  $CO_2$  released by HCl-acid treatment.  $C_{org}$  content, source potential (S1 + S2), hydrogen index (HI) and  $T_{max}$  considered as a maturity parameter were measured by standard Rock Eval method using an Oil Show Analyzer. Measurement of oxygen index (OI) was carried out in a Rock Eval II Pyrolyzer. Both types of the Rock Eval pyrolysis were performed on 100 mg powdered samples at 300°C for 4 min, followed by programmed pyrolysis at 25°C/min to 550°C in a helium atmosphere. The organic carbon remaining after pyrolysis was measured by oxidation under air atmosphere at 600°C. (Espitalié et al., 1977; Bordenave et al., 1993).

Organic petrographic observations were performed on a six sample set of different carbonate content with reflected light microscopy in oil immersion.

## RESULTS AND DISCUSSION

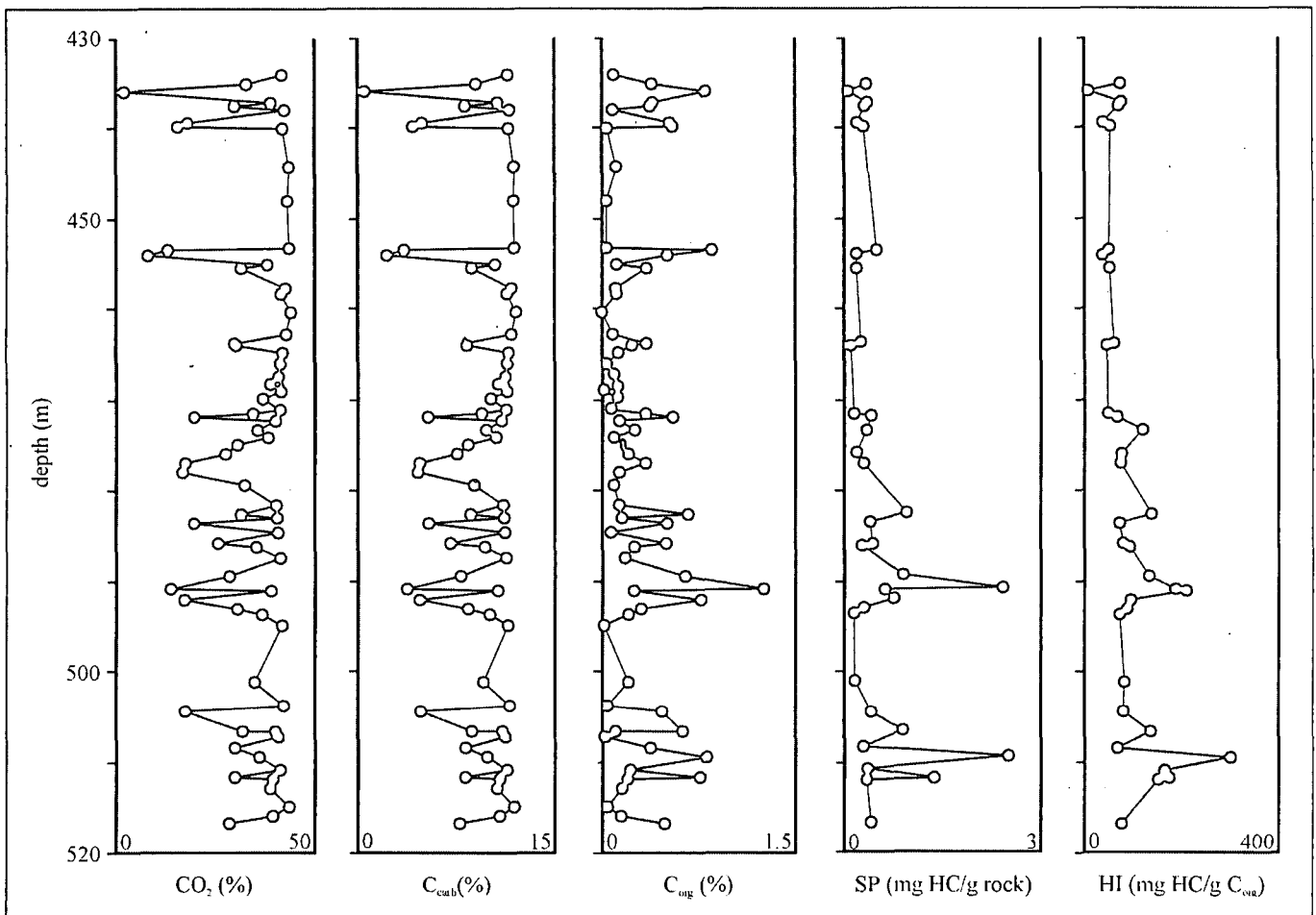
### Organic and mineral carbon

Carbon-dioxide ( $CO_2$ ),  $C_{carb}$  and  $C_{org}$  contents of the studied samples are listed in Table 1.  $CO_2$  and  $C_{org}$  contents are plotted along the depth in Fig. 1.

The studied succession is rich in carbonate minerals;  $CO_2$

**Table 1:** Carbon-dioxide content ( $CO_2$ ), mineral carbon content ( $C_{carb}$ ) and organic carbon content ( $C_{org}$ ) of the samples taken from Süt-17 well

Depth	$CO_2$	$C_{carb}$	$C_{org}$	Depth	$CO_2$	$C_{carb}$	$C_{org}$
434.0	41.5	11.32	0.10	474.8	30.3	8.27	0.17
435.0	32.6	8.89	0.39	475.9	27.3	7.45	0.21
435.8	1.6	0.43	0.80	477.0	16.9	4.61	0.34
437.0	38.8	10.59	0.40	478.0	16.2	4.42	0.14
437.5	29.6	8.08	0.38	479.3	32.0	8.73	0.10
437.9	42.1	11.49	0.09	481.6	40.2	10.97	0.14
439.3	17.6	4.80	0.53	482.5	31.1	8.49	0.67
439.8	15.1	4.12	0.55	483.5	19.3	5.26	0.51
440.0	41.7	11.38	0.05	484.7	40.7	11.11	0.08
444.1	43.3	11.82	0.12	485.9	25.5	6.96	0.50
448.0	43.0	11.73	0.04	486.2	35.0	9.55	0.26
453.2	43.3	11.82	0.04	487.5	41.0	11.19	0.18
453.5	12.6	3.43	0.85	489.4	28.3	7.72	0.64
454.0	7.6	2.07	0.51	490.8	13.3	3.63	1.25
455.0	37.9	10.34	0.12	491.1	38.7	10.56	0.25
455.5	31.2	8.51	0.35	492.0	16.7	4.55	0.77
457.7	42.5	11.60	0.11	493.0	30.2	8.24	0.31
458.4	41.2	11.24	0.12	493.7	36.5	9.96	0.21
460.3	43.7	11.93	0.01	495.0	41.5	11.32	0.02
462.8	42.6	11.62	0.09	501.2	34.7	9.47	0.21
463.7	29.5	8.05	0.35	503.9	42.0	11.46	0.05
464.0	30.0	8.19	0.24	504.5	17.0	4.64	0.47
464.8	41.7	11.38	0.13	506.6	31.6	8.62	0.63
466.0	41.1	11.22	0.05	506.7	40.0	10.92	0.11
467.5	40.7	11.11	0.10	507.2	40.7	11.11	0.03
468.2	38.6	10.53	0.09	508.4	29.5	8.05	0.38
468.6	41.3	11.27	0.12	509.5	35.7	9.74	0.81
469.0	41.3	11.27	0.02	510.8	41.1	11.22	0.22
469.8	36.6	10.00	0.14	511.8	29.6	8.08	0.76
471.0	41.0	11.19	0.06	512.0	39.2	10.70	0.20
471.5	34.2	9.33	0.34	513.0	38.5	10.51	0.16
471.8	19.2	5.24	0.55	515.0	43.4	11.84	0.05
472.2	39.8	10.86	0.14	516.0	39.3	10.72	0.15
473.3	35.4	9.66	0.26	516.7	28.1	7.67	0.49
474.1	38.1	10.40	0.10				



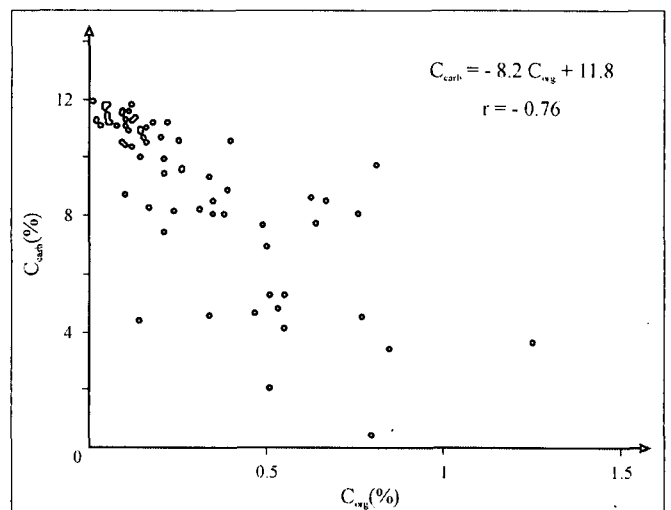
**Fig. 1:** Depth profile of mineral carbon content ( $C_{carb}$ ), organic carbon content ( $C_{org}$ ), source potential (SP) and hydrogen index (HI) in Süt-17 well

content exceeds 10 % for all but two samples and ranges between 27.3 and 43.3 % for most of the samples. 84% of the rocks contain more than 6% of  $C_{carb}$ , which value corresponds to 50 % of  $CaCO_3$ . (In this paper carbonate rocks refer to those of the studied rocks which contain 50 % or more carbonate minerals. Those rocks containing less than 50 % of carbonate are referred to as carbonate-poor ones.) The organic carbon content is low throughout the entire borehole, less than 1.0 % for all but one (490.8 m) sample.

Both the  $C_{org}$  and  $C_{carb}$  contents exhibit cyclic variations throughout the succession. The depth profile of  $CO_2$  content and that of  $C_{org}$  content appear to be inverse of each other (Fig. 1). A fair, but not close, correlation existing between the two carbon forms is shown in Fig. 2. The very high  $C_{carb}$  values (> 10 %) determined for half of the samples suggest strong predominance of platform-derived input. Most of these carbonate-rich ( $CaCO_3 > 83$  %) samples are especially lean in OM ( $C_{org} < 0.2$  %) (Table 1).

On the basis of the results of several previous studies, 0.2 % is considered as the lowest limit of  $C_{org}$  content for bulk organic geochemical characterization of rocks. Comprehensive studies of numerous samples of different ages and environment, from all over the world, have led to the conclusion that the minimum values of  $C_{org}$  content are 0.5 % for immature detrital source rocks and 0.3 % for carbonate-type source rocks (Hunt, 1972; Tissot and Welte, 1984). The standard pyrolysis method (Rock Eval),

developed by Espitalié et al. (1977), is a good tool also for source rock characterization and evaluation of samples containing more than 0.3 % of  $C_{org}$ . However, our experiences based on thousands of Rock Eval pyrolyses, show that this method gives fair information about the organic features of the rocks containing at least 0.2 % of  $C_{org}$ . Considering this observation, half of the samples ( $C_{org} > 0.2$  %) could be selected for more detailed organic geochemical characterization (Table 2).



**Fig. 2:** Correlation between the two carbon forms in Süt-17 well

On the basis of carbonate contents, two groups of the selected samples can be differentiated. More than two thirds of these samples are also relatively rich in carbonate minerals ( $C_{carb} > 6\%$ ). The average value of the  $C_{org}$  content is 1.6 times lower for these rocks than for those containing less than 6 % of  $C_{carb}$  (Table 3). Cyclic variations of  $C_{carb}$  and  $C_{org}$  content can be interpreted to mean that water depth repeatedly changed during the deposition of the studied succession. According to Haas (1993) the shallow subtidal carbonate beds (e.g. 456-462.5, 500-504.5 m depth) in the cyclic Kössen Formation are similar to those of the subtidal C members of the Lofer cycles in the Dachstein Formation suggesting similar depositional conditions. With the sea-level rise the carbonate sedimentation was gradually replaced by deposition of argillaceous sediments (e.g. 462.5-475, 490-500, 504.5-512 m depth). The increasing terrestrial contribution can be recognized not only in the decreasing carbonate content but in the increasing organic carbon content of the samples, too. This observation indicates that OM probably originated mainly from terrestrial-derived precursors.

#### Petroleum source potential

Petroleum source potential (referred as SP in this paper) represents the amount of hydrocarbon compounds (oil and gas) which can be generated by a rock during thermal evolution.

In contrast with the previously studied sequences of the Upper Norian Kössen Formation, which were classified as good oil-source rocks (Zl-1 well) and as excellent ones (Rzt-1 well), Süt-17 well penetrated a non oil-source succession of the Kössen Formation. SP of the selected samples ranges from 0.08 to 2.41 mg HC/g rock (Table 2), with an average of 0.53 mg HC/g rock (Table 3). According to classification suggested by Tissot and Welte (1984), rocks having SP of less than 2 mg HC/g rock correspond to gas-prone rocks or non-generative ones. Owing to the negligible amount of oil and minor amount of gas generated by these rocks, they are rated as non-source ones in any commercial sense (Espitalié and Bordenave, 1993).

Independently both of their  $C_{carb}$  and  $C_{org}$  content, selected samples have similar source potential. The average SP

**Table 2:** Rock Eval data, type of kerogen and organic facies for selected samples

Depth (m)	S1	S2	SP	$T_{max}$	HI	OI	Type of kerogen	Organic facies	$C_{org}$
435.0	0.06	0.29	0.35	406	74	87	III	CD	0.39
435.8	0.02	0.06	0.08	367	7	51	IV	D	0.80
437.0	0.07	0.30	0.37	376	75	57	III	CD	0.40
437.5	0.06	0.27	0.33	396	69	71	III	CD	0.38
439.3	0.02	0.20	0.22	411	37	43	IV	D	0.53
439.8	0.02	0.29	0.31	413	52	49	III	CD	0.55
453.5	0.09	0.41	0.50	396	48	27	IV	D	0.85
454.0	0.02	0.18	0.20	406	35	33	IV	D	0.51
455.5	0.03	0.18	0.21	399	51	60	III	CD	0.35
463.7	0.06	0.21	0.27	394	60	80	III	CD	0.35
464.0	0.01	0.11	0.12	398	45	125	IV	D	0.24
471.5	0.01	0.16	0.17	401	47	45	IV	D	0.34
471.8	0.06	0.36	0.42	401	65	40	III	CD	0.55
473.3	0.05	0.31	0.36	402	119	100	III	CD	0.26
475.9	0.04	0.16	0.20	390	76	119	III	CD	0.21
477.0	0.06	0.25	0.31	396	73	44	III	CD	0.34
482.5	0.04	0.92	0.96	421	137	47	II	C	0.67
483.5	0.04	0.37	0.41	405	72	54	III	CD	0.51
485.9	0.06	0.39	0.45	407	78	66	III	CD	0.50
486.2	0.05	0.24	0.29	400	92	103	III	CD	0.26
489.4	0.07	0.84	0.91	409	131	50	III	C	0.64
490.8	0.10	2.31	2.41	416	185	44	II-III	C	1.25
491.1	0.11	0.52	0.63	399	208	80	II	C	0.25
492.0	0.05	0.72	0.77	409	93	32	III	CD	0.77
493.0	0.05	0.27	0.32	408	87	67	III	CD	0.31
493.7	0.02	0.15	0.17	408	71	114	III	CD	0.21
501.2	0.01	0.17	0.18	408	80	100	III	CD	0.21
504.5	0.06	0.37	0.43	406	78	61	III	CD	0.47
506.7	0.02	0.89	0.91	416	136	49	III	C	0.63
508.4	0.05	0.25	0.30	402	65	44	III	CD	0.38
509.5	0.07	2.42	2.49	411	298	54	II	BC	0.81
510.8	0.01	0.36	0.37	412	163	86	II-III	C	0.22
511.8	0.05	1.32	1.37	406	173	36	II-III	C	0.76
512.0	0.06	0.30	0.36	396	150	95	III	C	0.20
516.7	0.05	0.37	0.42	402	75	100	III	CD	0.49

S1 (free hydrocarbons), S2 (pyrolysable hydrocarbons) and SP (source potential=S1+S2) given in mg hydrocarbons/g rock; HI (hydrogen index) given in mg hydrocarbons/g  $C_{org}$ ; OI (oxygen index) given in mg  $CO_2/g C_{org}$ ,  $T_{max}$  (maximum temperature of S2) given in °C, Corg (organic carbon) given in %.

**Table 3:** Average values of Rock Eval data calculated for selected samples of different carbonate content

$C_{carb}$ %	No. of samples	$C_{org}$ %	S1	S2	SP	$T_{max}$	HI	OI
<6	11	0.65	0.05	0.50	0.55	402	68	43
>6	24	0.39	0.05	0.48	0.52	403	107	76
0.4-11.2	35	0.47	0.05	0.49	0.53	403	94	66

S1 (free hydrocarbons), S2 (pyrolysable hydrocarbons) and SP (source potential=S1+S2) given in mg hydrocarbons/g rock; HI (hydrogen index) given in mg hydrocarbons/g  $C_{org}$ ; OI (oxygen index) given in mg  $CO_2/g C_{org}$ ,  $T_{max}$  (maximum temperature of S2) given in °C.

values are 0.55 mg HC/g rock for the samples with  $C_{carb} < 6\%$  and average  $C_{org}$  0.65 % and 0.52 mg HC/g rock for samples with  $C_{carb} > 6\%$  and average  $C_{org}$  0.39 %. These observations together with the average HI and OI values exhibit that not only the

abundance but the quality of the OM is also different in the two groups (Table 3).

#### Organic facies

Nowdays it is widely accepted that the source potential of any sedimentary rock depends primarily on its organic

facies (Jones and Demaison, 1982). Organic facies is defined similarly to other facies, such as biofacies. As proposed by Rogers (1980) it refers to a rock body characterized by a specific amount, type and source of OM and type of depositional environment. Organic facies is primarily determined by the amount and the type of the original OM, by the time the OM spends in an oxygenated water column and by the oxygen content of the water near the sediment-water interface during and shortly after deposition (Jones, 1984).

Hydrogen index (HI) and oxygen index (OI) derived from Rock Eval pyrolysis are used as a primary technique for evaluating the source potential of rocks and for identifying the organic facies. In terms of Rock Eval data measured on immature (vitrinite reflectance is 0.5 %  $R_o$  or less) OM, four types of kerogens (Tissot et al., 1974; Espitalié et al., 1986) and seven different organic facies (Jones, 1987) are classified. The same organic facies can contain a variety of kerogen types in different mixtures. For example, the gas-prone organic facies C could be composed of dominantly vitrinite or a mixture of algal debris and inertinite deposited under anoxic water or algal debris that was partially oxidized (Jones, 1984).

According to maturity parameter from Rock Eval pyrolysis ( $T_{max} < 418^\circ\text{C}$ ), all of the selected samples contain immature OM, hence they are suitable for evaluating the organic facies. The low maturity of the OM is also supported by vitrinite reflectance ( $R_o$ : 0.35 %) measured on six samples of different carbonate contents.

HI values ranging between 7 and 93 mgHC/g TOC for all but one sample and OI values lower than 62 mg  $\text{CO}_2$ /g TOC indicate type III and type IV kerogen in carbonate-lean samples. HI and OI values, varying between wider intervals, (between 45 and 298 mg HC/g TOC and between 36 and 125 mg  $\text{CO}_2$ /g TOC, respectively) reveal that not only type III and IV kerogens but type II kerogens also occur in carbonates.

Four types of the organic facies (BC, C, CD and D), defined in terms of HI and OI (Jones, 1987), were observed in the series of the selected samples.

More than half of the selected samples (57 %) contain organic facies CD. The proportion of organic facies C and D is 23 % and 17 %, respectively. Only one sample represents the BC facies.

The practically non-generative organic facies D (HI < 50 mg HC/g TOC, OI: 20-200 mg  $\text{CO}_2$ /g TOC) is strongly redominated by OM of the inertinite maceral group. Nevertheless, half of the samples containing organic facies D are located at the boundary of organic facies D and CD in Fig. 3. With regard to the continuous transition which can be supposed between the two adjacent organic facies, the samples having HI values above 45 mg HC/g  $C_{org}$  can also be assigned to facies CD. Thus, only three samples from the uppermost part of the succession (435.8, 439.3 and 454.0 m) represent typical organic facies D. All of them occur in the carbonate-poor layers containing  $C_{carb} < 6\%$ . Their very low P (from 0.08 to 0.22 mg HC/g rock) in spite of relatively high  $C_{org}$  content (between 0.51 and 0.80 %) suggests a highly oxic depositional environment and highly reworked terrestrial precursor material.

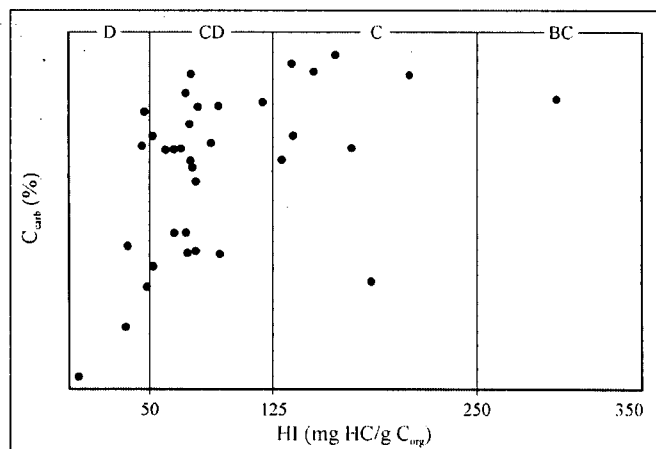


Fig. 3: Plot of carbonate-richness of samples versus hydrogen index for different organic facies determined in Süt-17 well

The carbonate-poor rocks ( $C_{carb} < 6\%$ ), deposited in relatively deeper water when the input of carbonate particles from the back stepping platform decreased (Haas, 1993), preferentially have organic facies CD (Fig. 3). Both HI and OI values of these samples vary in a relatively narrow range, from 48 to 93 mg HC/g TOC and from 32 to 61 mg  $\text{CO}_2$ /g TOC, respectively. More than half of the carbonate rocks also contain organic facies CD covering the same narrow range of HI values for all but one sample (Table 2 and Fig. 3). OI values ranging between 44 and 125 mg  $\text{CO}_2$ /g TOC, can show variable oxygenation of the depositional environment. However, it is more likely that the high OI values are due to the inaccuracy of OI determination, which is common for organically lean carbonates. A great variation of organic input can lead to organic facies CD. Terrestrial plant remnants in various stages of degradation and reworked OM are considered the main precursors of this facies. In carbonate sequences highly oxidized algal material can also contribute to the OM (Jones, 1987). Organic petrographical analysis performed on three samples indicates the predominance of degraded inertinite. However, a relatively significant amount of vitrinite and some trace of algal-derived liptinite were also observed in both of the two carbonate-poor samples (492.0, 504.5 m) and in the sample representing the carbonate rocks (485.9 m). The higher SP determined for carbonate-poor rocks are consistent with their higher organic contents (Table 2, 4). This observation together with the same narrow range of HI values and maceral composition of the OM reveal very similar quality of the OM for samples containing organic facies CD.

Organic facies C (HI: 125-250 mg HC/g TOC, OI: 50-150 mg  $\text{CO}_2$ /g TOC) is considered to be the typical gas-prone facies. It is composed mainly of partially oxidized terrestrial OM and generally occurs in carbonate rocks only in limited amount. Nevertheless, several processes can be

Table 4: Average values of source potential (mg HC/g rock) calculated for samples containing different organic facies

$C_{carb}$ %	Organic facies			
	D	CD	C	BC
<6	0.25	0.44	2.41	—
>6	0.15	0.30	0.79	2.49
average	0.22	0.34	0.99	2.49

involved in the formation of organic facies C in carbonate rocks. A limited amount of higher plant debris is common source of OM composed of mainly vitrinite. However, degradation of algal debris, which is the main precursor of the oil-prone organic facies AB or B, can also lead to the formation of gas-prone C facies. The variation in the oxygen content at the water sediment interface can stabilize the degrading algal-derived OM in the geochemical characteristics of organic facies C (Dean et al., 1981). In anoxic environment this facies can also be formed from a mixture of algal debris and inertinite. On the basis of our results the probable scenario for development of organic facies C in carbonate rocks, studied here, is the existence of a mixture of different organic precursors deposited in an oxic environment. Results of organic petrographical analysis performed on two samples (490.8 and 511.8 m) with different carbonate content ( $C_{carb}$  are 3.63 and 8.08 %, respectively) exhibit a small amount of algal-derived OM beside a significant amount of highly degraded inertinite and vitrinite. The algal-derived OM was probably protected from degradation by inclusion in carbonate skeleton. A similar protection effect of carbonate skeleton could play an important role in the preservation of marine OM in the Triassic-Jurassic boundary section of the Csövár Limestone Fm., too. These sediments contain an extremely low amount of hydrogen-rich oil prone kerogen (Pálffy et al., 2001). The remarkably higher SP of samples, having organic facies C compared with samples having organic facies CD (Table 4), can be attributed to the minor input of the oil-prone algal-derived OM. This assumption is confirmed by the different ratios of the average values of  $C_{org}$  content (1.5) and that of SP (2.9) calculated for samples containing C and CD facies. Despite the minor well preserved oil-prone algal-derived input, the OM has gas-prone character. No matter what type of kerogen they have, gas-prone rocks produce only a negligible amount of oil. It can be due to the adsorption of hydrocarbons generated by liptinite macerals on inertinite and vitrinite. The adsorbed hydrocarbons are gradually cracked within these macerals and not released until the dry gas stage of maturation is reached. (Albrecht et al., 1976; Behar and Vandenbroucke, 1988). Probably a slightly higher proportion of the relatively well-preserved liptinite resulted in organic facies BC at the top (509.5 m depth) of the lower section containing organic facies C.

Results presented here indicate interlayerings of organic facies C, CD and D. An upward decreasing trend in the H-richness and in the SP of the studied sequence is manifested well by variations of different organic facies. Alternations of C-CD and those of CD-D facies are characteristic below and above 471.5 m, respectively.

## CONCLUSIONS

The studied succession is rich in carbonates and contains a low amount of organic matter,  $C_{org}$  content is less than 1 % for all but one sample. Cyclic variations observed in both of the  $C_{carb}$  and  $C_{org}$  content can be interpreted by cyclic alternation of carbonate sedimentation and argillaceous one controlled by short-term (100-400 ka) sea-level fluctuation.

The OM is of predominantly terrestrial origin and probably accumulated in an oxic environment.

On the basis of the  $C_{carb}$  and  $C_{org}$  content three groups of the samples can be differentiated.

1) Half of the samples is composed of mainly carbonate minerals ( $C_{carb} > 10$  %) with very low  $C_{org}$  content ( $< 0.2$  %). These rocks can not be considered as source rocks, either for oil or gas and they are not available for assessment of organic facies. Most of them were formed during shallow subtidal carbonate sedimentation. Due to the highly oxic environment only a negligible part of the OM was preserved.

2) During sea-level rise due to backstepping of the carbonate producing platform the predominantly carbonate sedimentation was progressively replaced by an argillaceous one (Haas, 1993). Decreasing carbonate content is associated with slightly increasing abundance of organic carbon. About 35 % of the samples (average  $C_{carb}$  content is 9 %) deposited in relatively deeper water during sea-level rise, when a slightly higher proportion of the OM was preserved resulting in a continuous suite of organic facies D-CD-C-BC in the rocks with 0.39 % of average  $C_{org}$  content. More than half of these samples contains organic facies CD with low SP (0.34 mg HC/g rock). OM is predominated by degraded inertinite and vitrinite. The significantly higher SP (0.99 mg HC/g rock) of C facies, and that of the only sample containing BC facies (2.49 mg HC/g rock), can be attributed to a minor amount of algal-derived liptinite which was probably preserved by inclusion in carbonate skeleton.

3) The further sea-level rise associated with increasing land-derived contribution resulted in lower abundance of carbonate minerals ( $C_{carb} < 6$  %) and higher amount of OM (average  $C_{org}$  is 0.65 %) for the 15 % of the samples. The OM originated practically only from terrestrial-derived precursors. These rocks contain organic facies D (SP: 0.25 mg HC/g rock), composed of inertinite, and preferentially organic facies CD (SP: 0.44 mg HC/g rock), composed of inertinite and vitrinite.

The different SP of the rocks, containing the same organic facies and different carbonate content, is consistent with their  $C_{org}$  content.

SP displays much scatter and upward decreasing trend. Cyclic alternations of CD facies and the gas-prone C facies are characteristic of the lower section of the studied succession. Variations of CD facies and non-generative D facies were observed for the upper section.

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