DEPARTMENT OF THE INTERIOR

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Amount and type of organic matter in the Cretaceous Mowry Shale of Wyoming

by

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INTRODUCTION

This report contains information on the amount and type of organic matter in the Lower Cretaceous Mowry Shale of Wyoming. The Mowry Shale has been cited as an important petroleum source rock in Wyoming, especially in the Powder River Basin (Nixon, 1973; Seifert and Moldowan, 1981; Burtner and Warner, 1984; Momper and Williams, 1984). Data included here were collected from five localities which span 200 kms. The scale of the study area allows for comparison of organic matter from several geologic settings in the Mowry seaway.

GEOLOGIC SETTING

During the Cretaceous, worldwide fluctuations in sea level caused flooding of a major elongate basin in the Western Interior of the United States, Mexico and Canada. This basin was initially flooded from the north during the Aptian stage, when an extensive south-extending arm of the seaway formed. This arm and a smaller north-extending arm met in middle late Albian time in central and southern Colorado (Kauffman, 1969, 1977; Williams and Stelck, 1976). By late Albian time, this continuous seaway across North America retreated partially to form the Mowry Sea (Figure 1), which was open to the Arctic Ocean and terminated in southern Colorado. The Mowry Shale was deposited in this body of water. The Mowry sea probably existed until early Cenomanian time (Williams and Stelck, 1976), when the two arms of the seaway joined once again, this time for over 40 million years (Kauffman, 1983). During most of the Cretaceous, coarse sediments from the Cordilleran highlands were shed into the western side of the linear seaway, while fine-grained clastic sediments, characteristically rich in organic matter, were deposited in the center. Rivers along the eastern shoreline drained a nonorogenic midcontinent region and were only a minor source of siliclastic sediments.

The Mowry Shale is chiefly composed of fine-grained siliceous sediments, that contain abundant fish scales and radiolarians. The present-day outcrop distribution of the Mowry is primarily along the margins of Laramide basins over nearly all of Wyoming and adjacent parts of Montana, South Dakota, Colorado, and northeastern Utah. The name Aspen Shale (Veatch, 1907) is applied to strata of equivalent age to the Mowry in the western Wyoming Thrust Belt and north-central Utah.

In central and eastern Wyoming, the Mowry Shale is underlain and overlain by soft dark shale of the Shell Creek Shale and Frontier Formation, respectively. The name "Nefsy" is informally applied to shale underlying the Mowry in the Black Hills region. At most localities, the contact between the Mowry Shale and the underlying shale can be recognized by the greater silicification and greater reistance of the Mowry Shale outcrop to weathering. The upper contact of the Mowry over much of Wyoming coincides with the base of the "Clay Spur Bentonite", a widely recognized marker bed which corresponds closely to the top of the siliceous mudstone sequence. In western Wyoming, the Clay Spur is not always present, and the upper Mowry Shale contact is generally taken as the first Frontier sandstone.

ACKNOWLEDGMENTS

The work presented here, performed during the 1985 field season, is part of the author's Ph.D. dissertation at the University of Wisconsin-Madison. The field work and laboratory analyses were supported in part by the USGS Branch of Oil and Gas, Denver, Colorado. I am grateful to several members of the Branch of Oil and Gas who assisted me in this work, including D. Malone, D. McManamen, J. Novosel, J. Palacas, D. Smith, C. Threlkeld and T. Daws. Special thanks go to L. Pratt who strongly encouraged this project and introduced me to the potentials of organic geochemistry.

METHODS

Five localities that extend across central Wyoming and the Powder River Basin were chosen for detailed study (Figure 2). The geographic spread of these locations allows for comparison of organic matter from different basinal settings in the Mowry Sea. At each of the five localities, excepting Goose Egg, the Mowry Shale and parts of adjacent stratigraphic units, if exposed, were described and measured with a Jacob's staff by the author. The Goose Egg locality was similarly described and measured in 1984 by F. Zelt and L. Pratt of the USGS, Denver. Trenching was employed where intervals were covered with a thin layer of alluvium or if the outcrop was deeply weathered. Outcrop samples were taken at regular intervals that ranged from one to two meters at different localities. Larger sampling intervals were chosen at thicker sections in order to adequately represent the section, yet not overtax laboratory capabilities. Samples were obtained by digging with a mattock until fresh rock was exposed. Each sample was wrapped in aluminum foil that was pretreated by overnight heating at 300 degrees centigrade to remove any organic residues.

Total organic carbon was measured using a LECO induction furnace and volumetric CO_2 analyzer located at the USGS, Denver, Colorado. A subsample weighing several grams was cut from the inside of each rock specimen with a rock saw. Samples were then crushed, powdered in a ball mill and oven dried at 50 degree centigrade. To remove mineral carbon, 0.1 to 0.5g of rock powder was treated with 2.0 N HCl for twenty-four hours. Insoluble residues were collected on a glass fiber filter by washing with distilled water. Filters and residue were oven dried at 50 degrees centigrade for 4 hours. Samples were then combusted in the induction furnace and values were obtained for total organic carbon.

Pyrolysis of organic matter was performed with a Rock-Eval instrument that was calibrated by analysis of a synthetic standard ($n\text{-}C_{20}H_{42}$) and dry ice. Samples cut from inside each rock specimen were crushed, powdered and oven dried. Approximately 50 mg of each subsample was pyrolyzed in flowing helium. S_1, S_2, and S_3 peaks were calculated from the following heating program: S_1 is taken as the integral of the first hydrocarbon peak detected after heating the sample at 250 degrees centigrade for five minutes, S_2 is the integral of the second hydrocarbon peak produced when the sample is heated from 250-550 degrees centigrade at the rate of 25 degrees per minute, S_3 is the integral of the carbon dioxide peak measured on a split of the gas trapped during the 250-390 degree centrigrade heating interval.

Thermal maturity is indicated by T_{max}, the temperature of maximum hydrocarbon yield during generation of the S_2 peak. Hydrogen index (HI) is defined as the integral of the S_2 peak divided by total organic carbon. Oxygen index (OI) is defined as the integral of the S_3 peak divided by total organic carbon. OI and HI values are given in mg of CO_2 and hydrocarbons, respectively, per gram of organic carbon.

RESULTS

Total organic carbon (TOC) and pyrolysis data for the Mowry Shale and parts of adjacent formations are given for the five sections in tables 1-5, and as HI and OI cross-plots in Figure 4. Vertical plots are given adjacent to stratigraphic columns for 4 of the 5 sections in Figures 3-6.

CONCLUSIONS

In the five Mowry Shale sections studied, TOC ranges from less than 0.1 wt. % to 5 wt. % and is highly variable through each section. Average total organic carbon is lowest at the two westernmost localities (Cody and Tensleep) and highest at the two central localities (Mayoworth and Goose Egg). The Mowry Basin was deeper in central Wyoming and contained poorly oxygenated bottom waters (Byers and Larson, 1979; Davis, 1970) that were amenable for preservation of organic matter.

Organic matter in the Mowry is of Type II and III as defined on a modified Van Krevelen diagram with OI and HI axes (Espitalie et al, 1977). In marine settings, Type II kerogen can be the product of marine pelagic detritus and microbial materials, as well as of cutins, resins and spores introduced from land (Tissot et al, 1974). Type III kerogen is generally considered to be the product of terrestrial organic matter. Biological degradation, outcrop weathering, or recycling of organic matter tends to lower its hydrogen content and increase its oxygen content, thereby making direct provenance interpretations difficult (Pratt, 1984; Peters, 1986). Trenches up to a meter deep were dug to obtain fresh samples with a minimum of kerogen breakdown from weathering. Bioturbation in the Mowry rocks studied was minimal, as well preserved sedimentary laminae. The quantity of recycled organic matter, if any, is not known in the Mowry.

Average hydrogen content is lowest in the westernmost section, Cody, and highest in the Goose Egg and Mayoworth sections. These latter two localities are farthest removed from the terrestrial influence of the major sediment area in western Wyoming. Hydrogen values of organic matter from Thornton Dome are less than those at Goose Egg and Mayoworth. Coarse sediment layers in the Mowry Shale in the Black Hills region, where Thornton Dome is located, suggest that a sediment source from the east affected that region. In poorly oxygenated settings, increase in marine conditions away from shorelines should be reflected in a proportionate increase in marine organic matter in the sediments.

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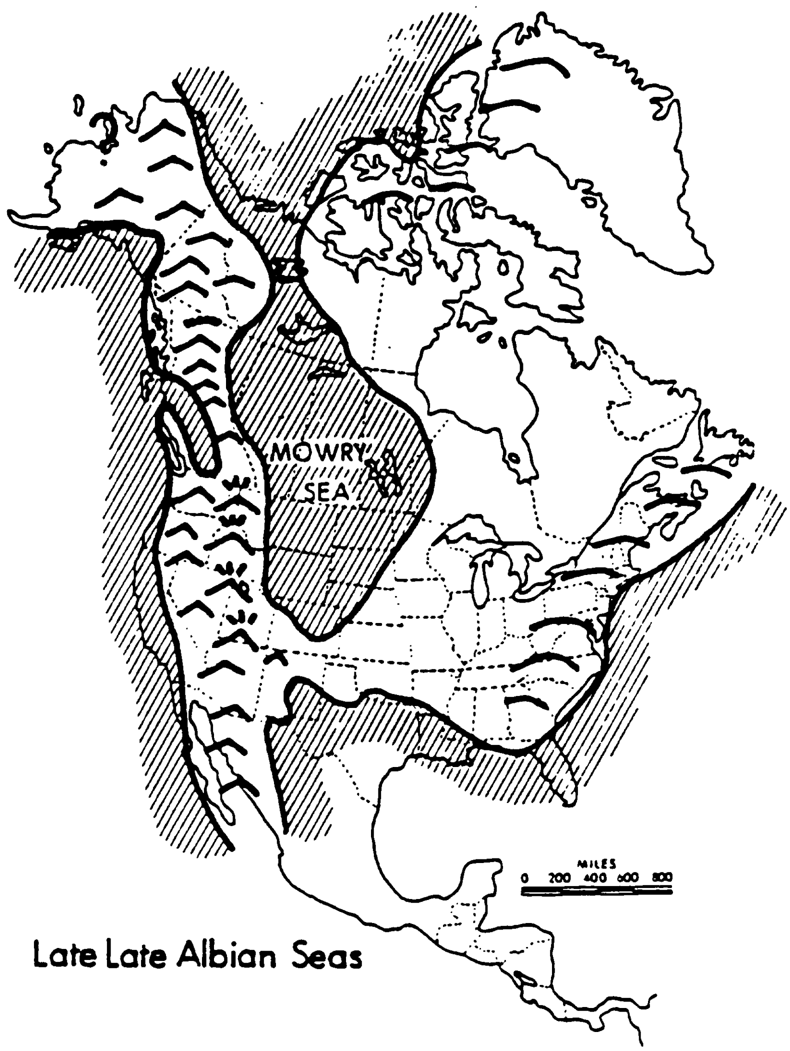
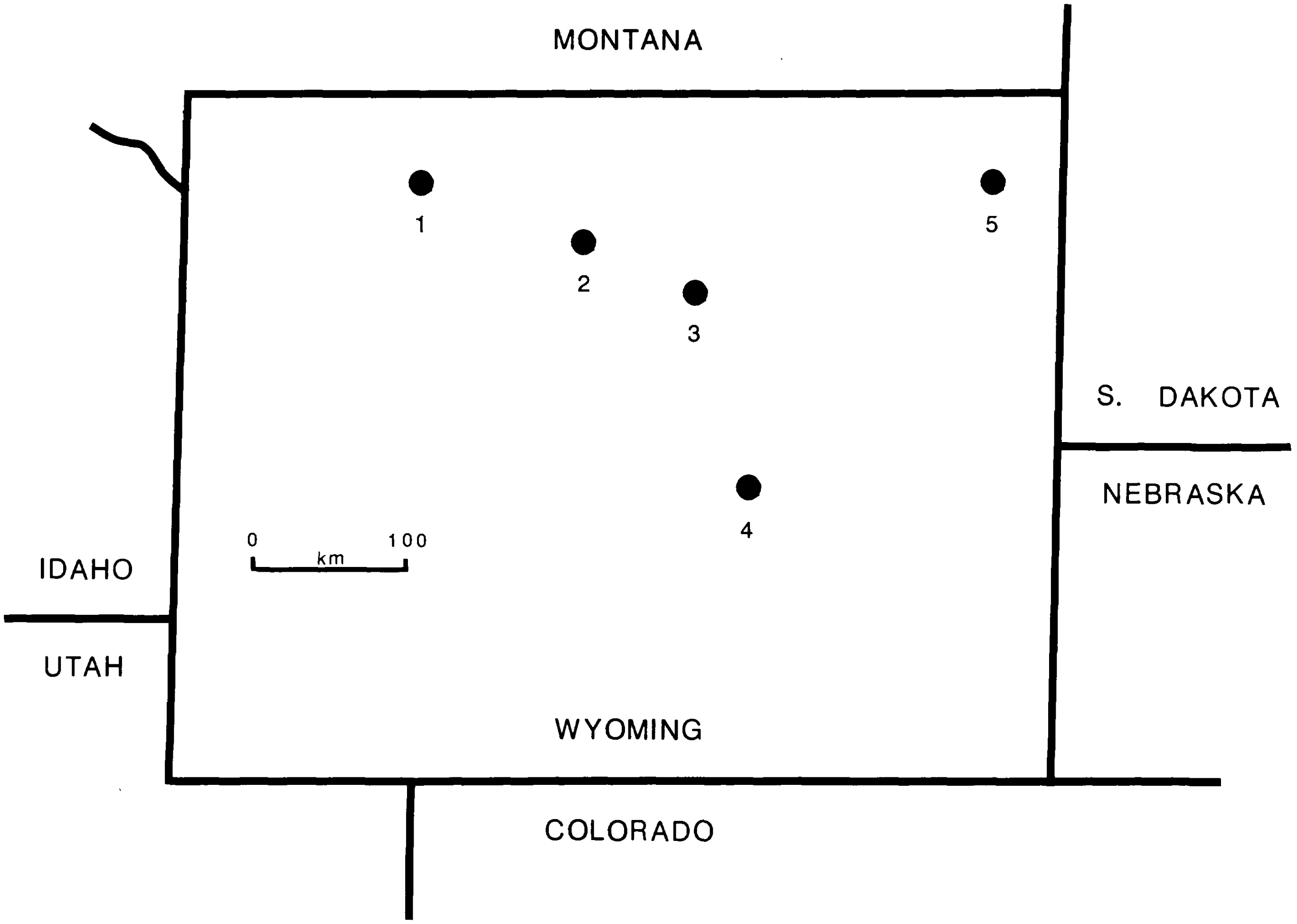


Figure 1. Extent of Cretaceous Seas during deposition of the Mowry Shale (Late Cretaceous). After Williams and Stelck (1975).



1. CODY NW1/4 SW1/4 Sec. 21, T51N, R102W

2. TENSLEEP E1/2 Sec. 21, W1/2 Sec. 22, T47N, R89W

3. MAYOWORTH NW1/4 Sec. 35, T45N, R83W

4. GOOSE EGG NW1/4 Sec. 6, T32N, R80W

5. THORNTON DOME N1/2 Sec. 17, T48N, R65W

Figure 2. Outcrop localities of the Mowry Shale.

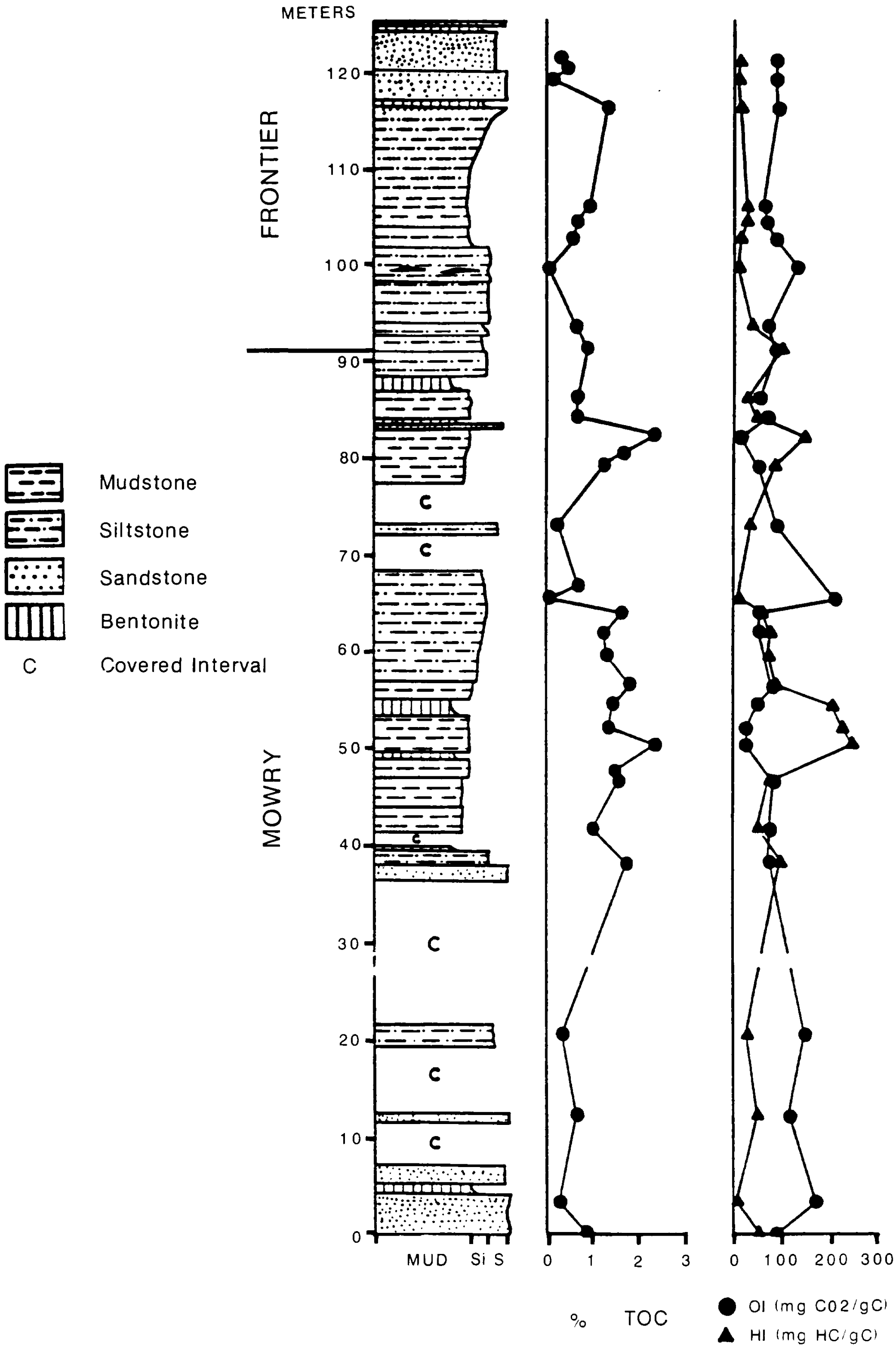


Figure 3. Stratigraphic column, total organic carbon content, and hydrogen and oxygen indices of organic matter for the Mowry Shale and Frontier Formation at Cody, Wyoming.

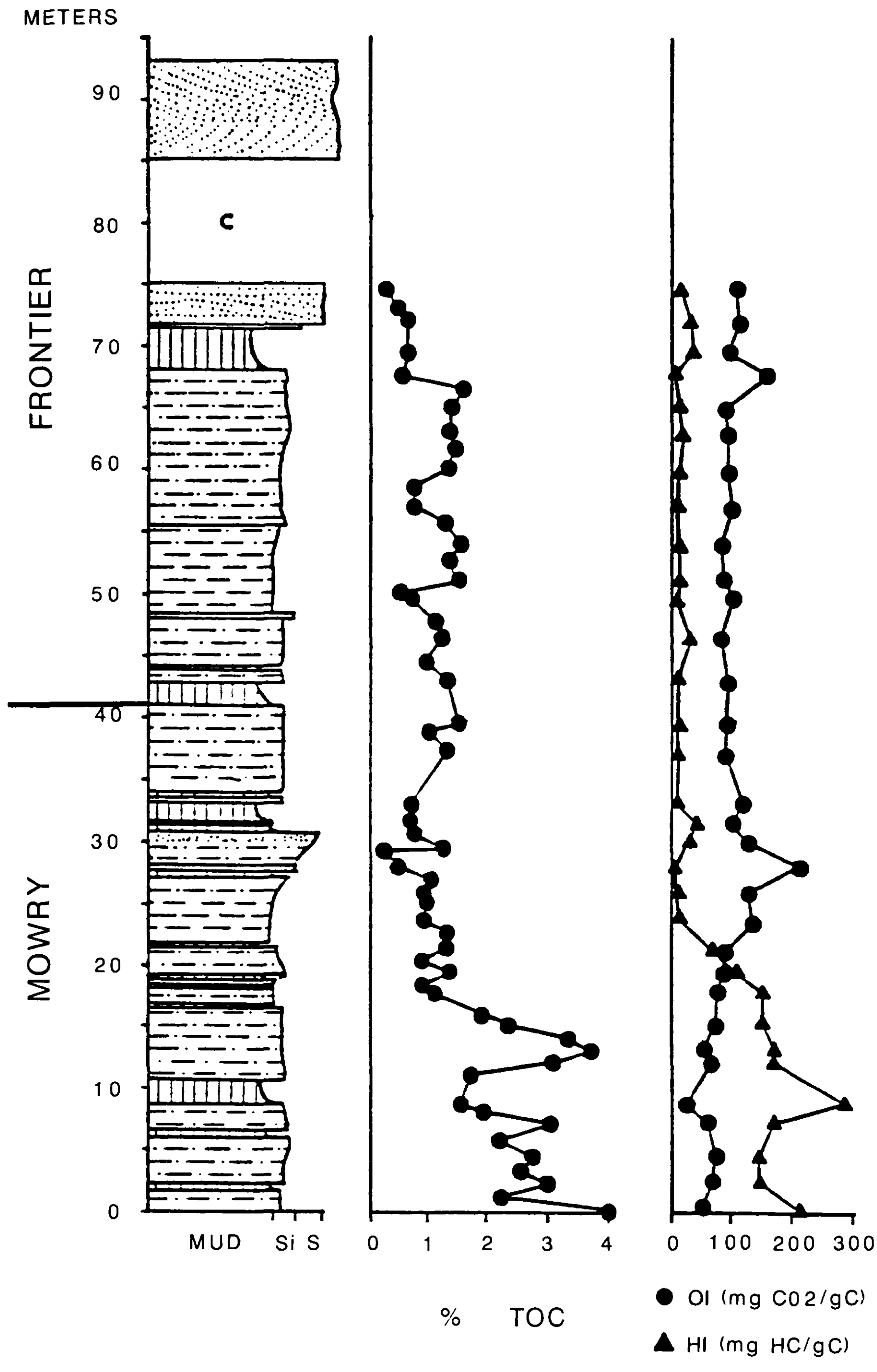


Figure 4. Stratigraphic column, total organic carbon content, and hydrogen and oxygen indices of organic matter for the Mowry Shale and Frontier Formation at Tensleep, Wyoming.

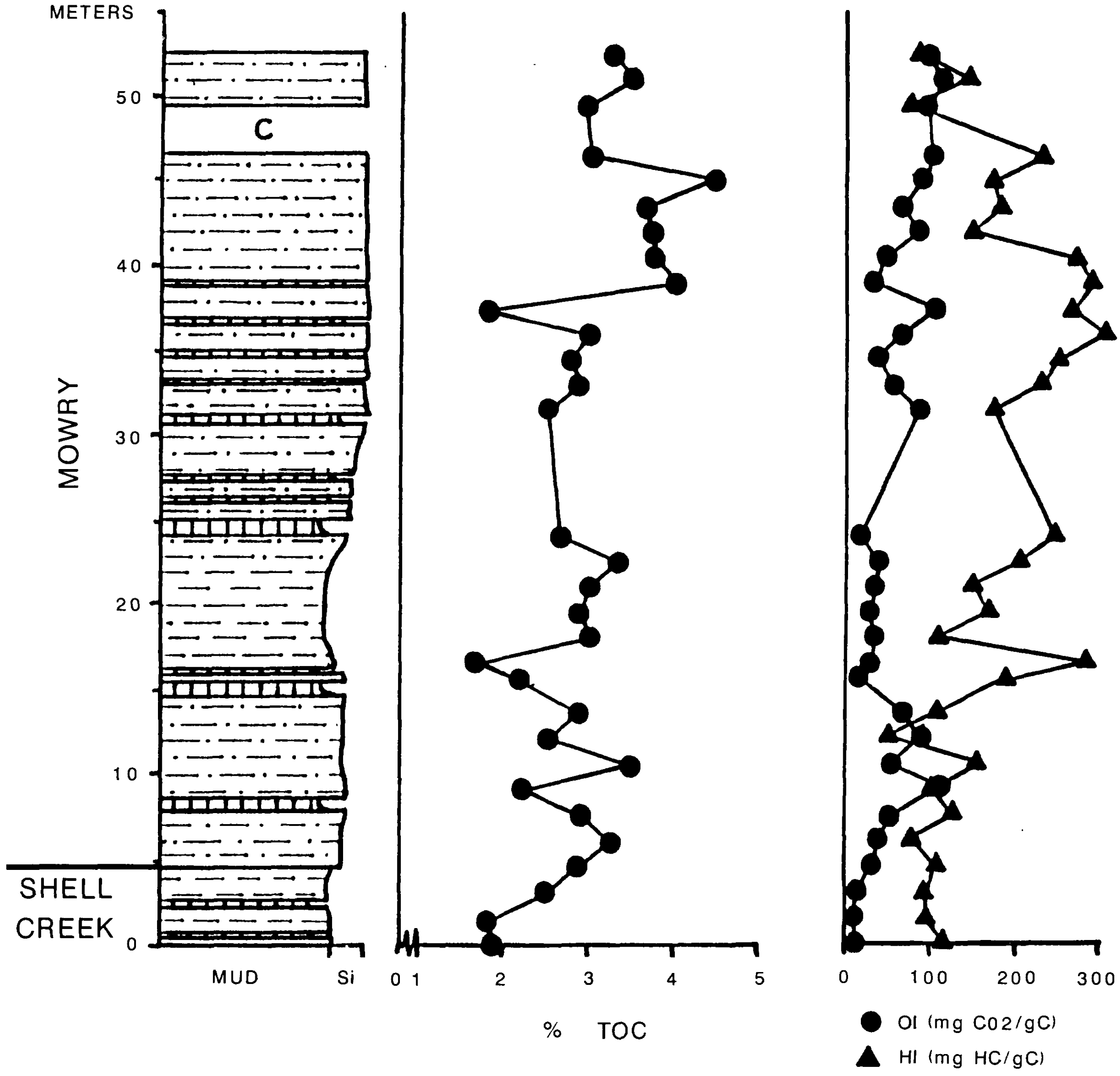


Figure 5. Stratigraphic column, total organic carbon content, and hydrogen and oxygen indices of organic matter for the Shell Creek Shale and Mowry Shale at Mayoworth, Wyoming.

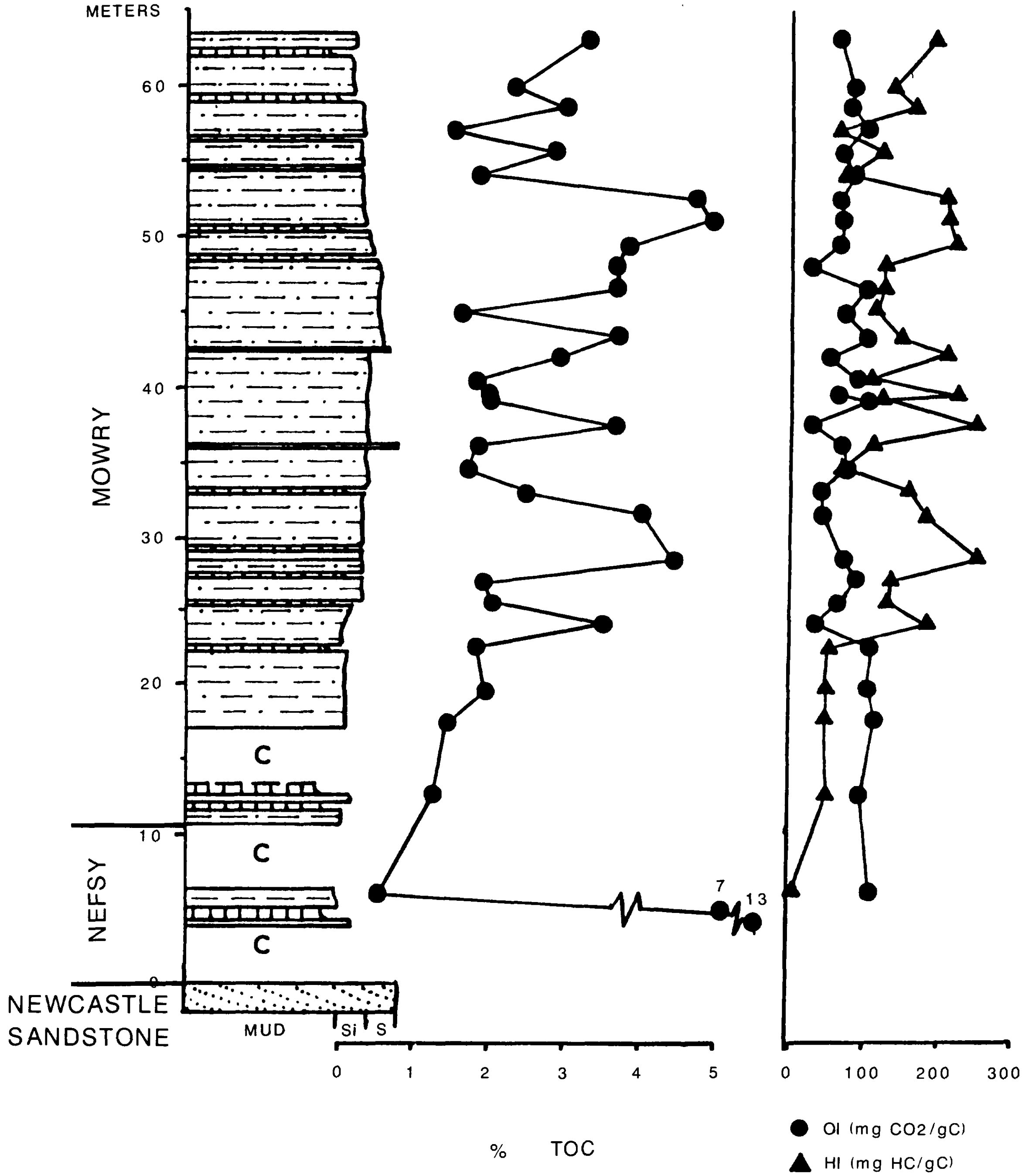


Figure 6. Stratigraphic column, total organic carbon content, and hydrogen and oxygen indices of organic matter for the Newcastle Sandstone, Nefsy Shale and Mowry Shale at Thornton Dome, Wyoming.

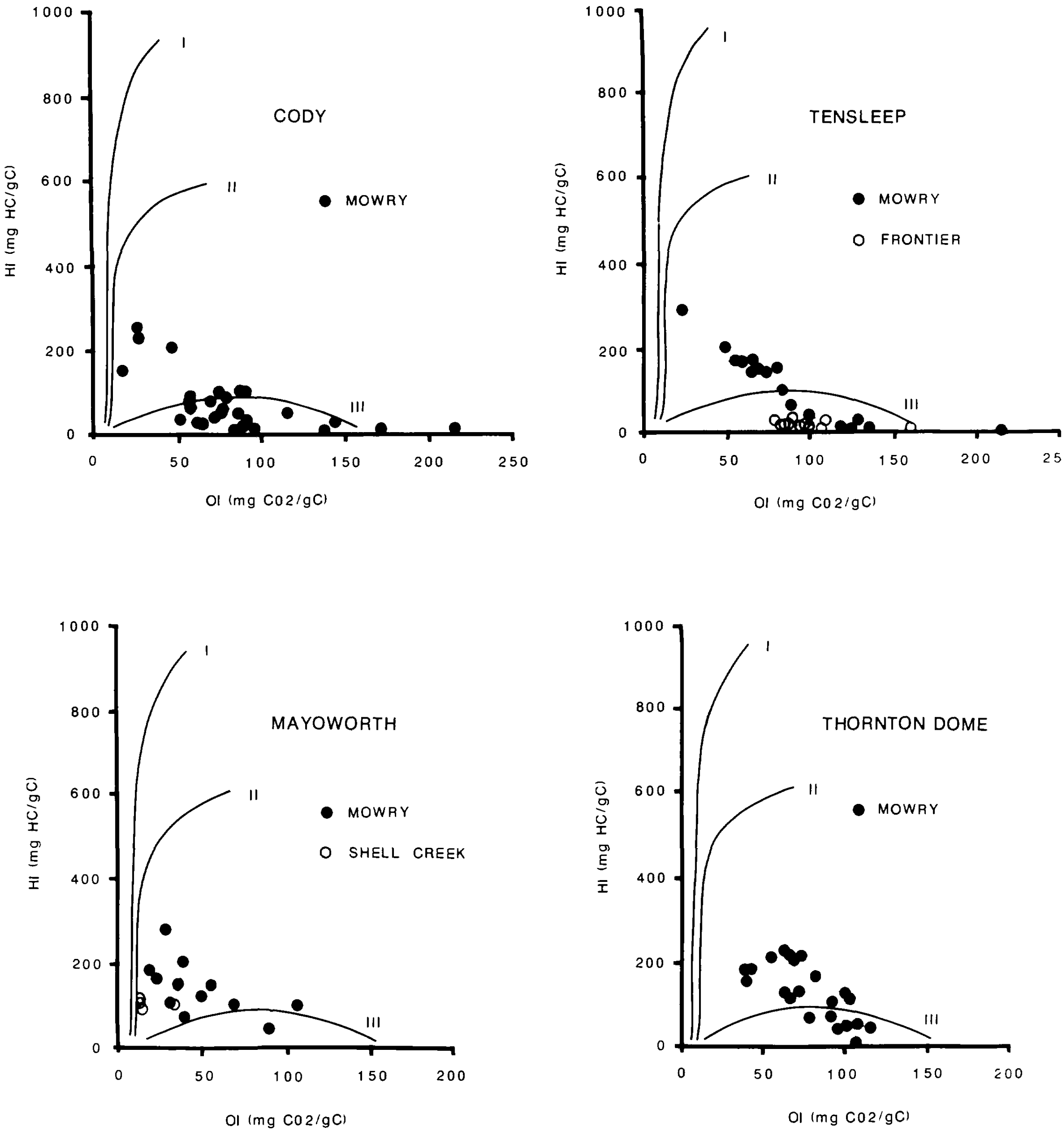


Figure 7. Crossplots of hydrogen and oxygen indices of organic matter in Mowry Shale from Cody, Tensleep, Mayoworth, and Thornton Dome, Wyoming.

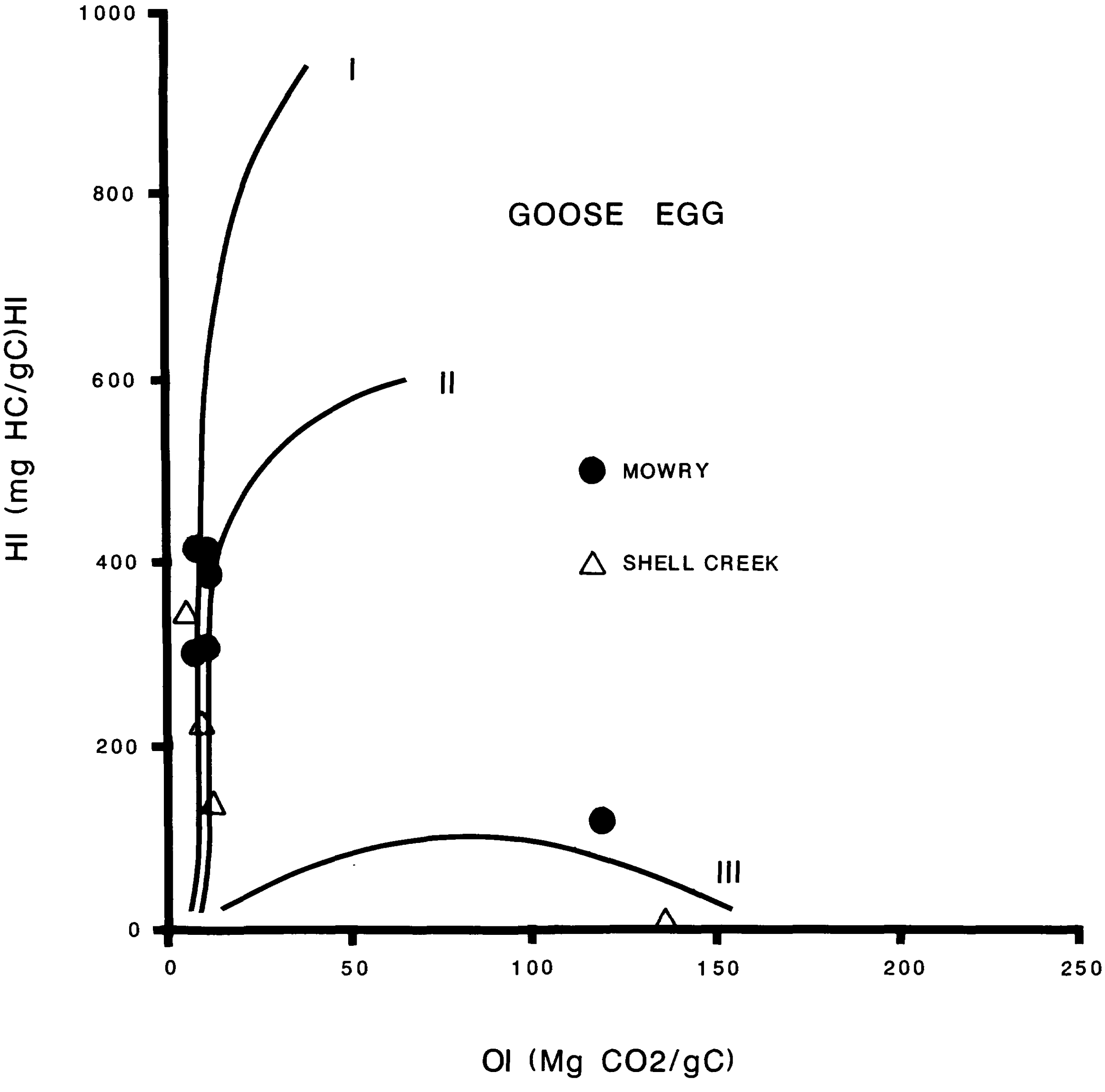


Figure 8. Crossplot of hydrogen and oxygen indices of organic matter in Mowry Shale and Shell Creek Formation from Goose Egg, Wyoming.

Table 1. Pyrolysis data from Cody, Wyoming. Samples 1-51 are from the Mowry Shale; samples 55-67 are from the Frontier Formation. Total organic carbon values were computed on a LECO carbon induction furnace.

Sample	TOC	T_{max}	HI	OI
C851	0.75	432	60	90
C854	0.57	427	60	130
C855	0.34	438	30	160
C856	1.6	428	110	80
C857	1.1	428	50	70
C8512	1.6	424	80	90
C8516	2.4	407	250	30
C8519	1.7	410	330	40
C8522	1.6	420	190	40
C8525	1.7	427	100	90
C8528	1.2	426	80	70
C8531	1.2	431	90	60
C8534	1.5	423	70	60
C8536	0.08	429		200
C8538	0.24	422	30	80
C8539	1.2	421	90	60
C8542	2.4	414	150	20
C8544	0.68	420	50	70
C8546	0.73	420	30	50
C8551	0.86	423	100	90
C8555	0.64	422	40	170
C8558	0.11	432		110
C8560	0.61	418	20	80
C8561	0.63	421	30	70
C8563	0.99	420	30	60
C8564	0.96	428	30	130
C8567	0.16	430		90

Average values for the Mowry Shale, samples 1-51:

C851-51	1.2		100	80

Average values for the Frontier Formation, samples 55-67:

C855-67	0.59		30	100

Table 2. Pyrolysis data from Tensleep, Wyoming. Samples 1-41 are from the Mowry Shales; samples 43-63 are from the Frontier Formation. Total organic carbon values were computed on a LECO carbon induction furnace.

Sample	TOC	T_{max}	HI	OI
T851	3.6	411	220	50
T853	2.9	416	150	70
T855	2.7	409	140	80
T857	3.0	411	180	60
T8510	1.6*	412	290	20
T8512	3.0	410	180	70
T8513	3.6	411	180	60
T8515	2.3	414	160	70
T8517	1.1	417	210	100
T8519	1.3	422	100	80
T8521	1.3	423	70	90
T8523	0.91	427	20	150
T8525	0.91	425	10	130
T8533	1.2	414	30	130
T8535	0.66	425	50	110
T8536	1.2	423	10	70
T8539	1.3	422	20	90
T8541	1.4	423	20	100
T8543	1.2	423	20	100
T8545	1.1	422	40	90
T8547	0.72	425	10	110
T8549	1.4	424	20	100
T8551	1.4	424	20	90
T8553	0.74	424	10	110
T8555	1.2	424	20	110
T8557	1.3	424	20	100
T8558	1.4	419	20	90
T8561	0.58	426	40	100
T8463	0.56	425	40	130

*TOC computed on Rock-Eval

Average values for the Mowry Formation, samples 1-41:

T851-41	1.8		100	90

Average values for the Frontier Formation, samples 43-63:

T8543-63	1.1		20	100

Table 3. Pyrolysis data from Mayoworth, Wyoming. Samples 1-5 are from the Shell Creek Shale; samples 6-39 are from the Mowry Shale. Total organic carbon values were computed by Rock-Eval apparatus.

Sample	TOC	T_{max}	HI	OI
MY851	1.9	415	120	10
MY852	1.8	415	100	10
MY853	2.5	410	90	20
MY855	2.9	410	110	30
MY856	3.3	414	80	40
MY857	2.9	414	130	50
MY858	2.2	418	100	110
MY859	3.5	413	160	60
MY8510	2.5	423	50	90
MY8513	2.9	418	110	70
MY8514	2.2	406	190	20
MY8515	1.7	405	280	30
MY8516	3.1	407	110	30
MY8517	2.9	408	170	20
MY8518	3.1	409	150	40
MY8519	3.4	412	210	40
MY8520	2.7	406	250	20
MY8525	2.6	414	180	80
MY8526	2.9	410	230	60
MY8527	2.8	404	250	40
MY8528	3.0	410	310	60
MY8529	1.8	411	270	110
MY8530	4.0	413	290	40
MY8531	3.8	414	270	40
MY8532	3.8	414	150	80
MY8533	3.7	411	180	70
MY8534	4.5	414	180	90
MY8535	3.1	415	230	100
MY8537	3.0	409	80	100
MY8538	3.5	421	140	110
MY8539	3.3	412	80	100
Average values for the Shell Creek Shale, samples 1-5:				
MY851-5	2.3		100	19
Average values for the Mowry Shale, samples 6-39:				
MY856-39	3.00		180	60

Table 4. Pyrolysis data from Goose Egg, Wyoming. Samples 3-6 are from the Shell Creek Shale; samples 7-9 are from the Mowry Shale. Total organic carbon values were computed on a LECO induction furnace.

Sample	TOC	T_{max}	HI	OI
GEW9843	0.6	430	10	140
GEW9844	2.6	418	340	10
GEW9845	2.4	417	220	10
GEW8546	3.1	417	170	10
GEW8547	3.2	422	310	10
GEW8548	3.2	415	310	10
GEW8549	3.2	421	410	10
GEW85411	4.0	419	410	10
GEW85312	3.1	418	390	10
GEW85413	1.4	429	70	120
Average values for the Shell Creek Formation, samples 3-6:				
GEW8543-6	2.2		190	40
Average values for the Mowry Shale, samples 7-13:				
GEW8547-13	3.0		320	30

Table 5. Pyrolysis data from Thornton Dome, Wyoming. Samples 1-3 are from the Nefsy Shale; samples 4-42 are from the Mowry Shale. Total organic carbon values were computed by a Rock-Eval apparatus.

Sample	TOC	T_{max}	HI	OI
TD851	12.8	440	70	50
TD852	7.3	438	40	110
TD853	0.6	417	10	110
TD854	1.3	424	50	100
TD855	1.5	426	40	120
TD856	2.0	426	50	100
TD858	1.8	426	60	110
TD859	3.6	415	180	40
TD8510	2.3	419	130	60
TD8511	2.0	423	130	90
TD8512	4.4	417	260	70
TD8514	4.1	412	180	40
TD8515	2.5	412	160	40
TD8516	1.7	411	70	80
TD8517	1.9	415	120	70
TD8521	2.1	424	120	100
TD8522	2.2	416	230	60
TD8523	1.8	424	110	90
TD8524	2.9	417	210	60
TD8527	3.7	422	150	100
TD8528	1.6	427	120	80
TD8530	3.7	418	130	100
TD8531	3.8	417	230	70
TD8532	5.0	421	220	70
TD8533	4.8	419	210	70
TD8534	1.9	423	80	90
TD8535	2.9	417	130	70
TD8537	1.6	425	70	110
TD8538	3.2	419	170	80
TD8539	2.4	424	140	90
TD8542	3.4	422	200	70

Average values for the Nefsy Shale, samples 1-3:

TD851-3	6.9*		40	90

Average values for the Mowry Shale, samples 4-42:

TD854-42	2.8		140	80

*Samples TD851 and TD852 are lignitic.