Report of Investigations 2015-3

ROCK-EVAL PYROLYSIS, VITRINITE REFLECTANCE, AND KEROGEN MICROSCOPY RESULTS FROM MIOCENE CARBONACEOUS MUDSTONES AND COALS IN OUTCROP, McGRATH QUADRANGLE, SOUTHWESTERN ALASKA

David L. LePain and Russell A. Kirkham

Exposure of early Miocene carbonaceous mudstone and coal along Windy Fork (of Middle Fork of Kuskokwim River), McGrath Quadrangle. These rocks belong to Dickey's (1982) map unit Tqa, which corresponds to a fault-bounded package of Tertiary sedimentary rocks along the Denali–Farewell fault zone. The photograph shows the 40–56 m interval in measured section 02DL053 (see figure 3 in this report). The white objects visible in the photograph near the base of the exposure are Rock-Eval samples. Geologist is sitting at the 52 m level in the section. Photo by D.L. LePain.

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David L. LePain[1] and Russell A. Kirkham[2]

INTRODUCTION

The Cenozoic Holitna basin is a gravity-defined feature that sits astride the Denali–Farewell fault zone in southwestern Alaska (fig. 1). The basin corresponds to a gravity low in excess of -40 milligals (mGals) (Kirschner, 1994; Meyer and Krouskop, 1984). No outcrops exist within the footprint of the gravity low and no subsurface data are available; consequently, the stratigraphy and age of its fill are unknown. The Alaska Division of Geological & Geophysical Surveys (DGGS) investigated the shallow gas potential of the basin during the summer of 2000 by studying Tertiary coal-bearing rocks exposed along the Denali–Farewell fault zone to the northeast of the basin in the southern McGrath Quadrangle as an outcrop analog to the subsurface stratigraphy of the basin (LePain and others, 2003). This initial work included a limited suite of samples collected from carbonaceous mudstones and high-ash coals for Rock-Eval pyrolysis and, not surprisingly, the results suggest they were potential source rocks for gas. Results for two samples in this suite, collected along the Middle Fork of the Kuskokwim River, indicate the potential to generate liquid hydrocarbons. Three samples were collected for the same purpose from carbonaceous claystones near the top of a long exposure along the west bank of the Windy Fork of the Middle Fork (Kuskokwim River), and are thought to be correlative to the section sampled along the Middle Fork. Results for two of the samples indicate moderate potential as gas source rocks. The third sample contained very little organic material and results indicate poor gas source-rock potential.

Results for samples collected during the 2000 field season raise two fundamental questions. (1) Are carbonaceous

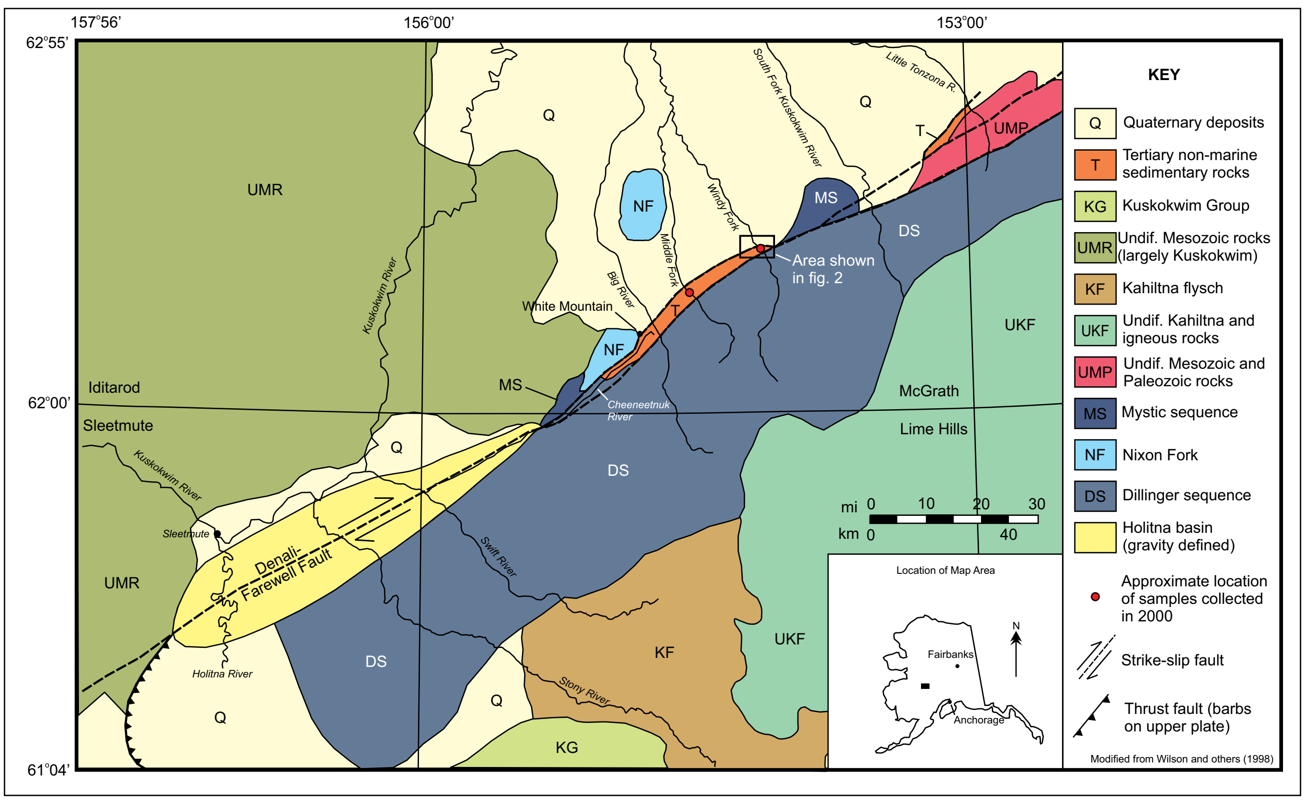

Figure 1. Simplified geologic map of the Holitna region in southwestern Alaska. The gravity-defined Holitna basin is the yellow tear-drop-shaped feature straddling the Denali-Farewell fault. Modified from Wilson and others (1998).

[1]Alaska Division of Geological & Geophysical Surveys, 3354 College Road, Fairbanks, AK 99709-3707, david.lepain@alaska.gov
[2]Alaska Division of Mining, Land, and Water, 550 W 7th Ave., Suite 900, Anchorage, AK 99501, russell.kirkham@alaska.gov

mudstones and coals capable of generating liquid hydrocarbons common in the Middle Fork and Windy Fork exposures? (2) What is the hydrocarbon potential of coals from these outcrops? Only a few high-ash coals were sampled in 2000 for Rock-Eval pyrolysis, so the hydrocarbon source-rock characteristics of low-ash coals in these exposures were unknown. To help answer these questions, in 2002 we revisited the same exposures along Middle Fork and Windy Fork to collect additional samples for source-rock characterization, including Rock-Eval pyrolysis, vitrinite reflectance measurements, and visual kerogen analysis (figs. 1 and 2). During the 2002 field season the Middle Fork exposure was inaccessible due to changes in the location of the active stream channel, while the north end of the Windy Fork exposure was relatively well exposed and easily accessible (locality 02DL53 on fig. 2). For these reasons a stratigraphic section was measured at locality 02DL53 and an extensive suite of samples suitable for Rock-Eval pyrolysis were collected from mudstones, carbonaceous mudstones, and coals (fig. 3, on sheet). Grab samples for Rock-Eval were collected south of locality 02DL53, a short distance north of the mapped trace of the Farewell fault, at locality 02DL54 (fig. 2). This report summarizes the results of the 2002 dataset.

GEOLOGIC SETTING

Discontinuous exposures of Tertiary nonmarine sedimentary rocks are present northeast of the gravity-defined Holitna basin in fault-bounded slivers associated with the Denali–Farewell fault zone (fig. 1; Bundtzen and others, 1997; Dickey, 1982; Gilbert and others, 1982). Exposures extend from the White Mountains area northeastward to the Little Tonzona River (fig. 1) and consist of thick packages of conglomerate, sandstone, and mudstone (Dickey, 1982, 1984; LePain and others, 2003; Ridgway and others, 2000).

Dickey (1982) recognized three Tertiary map units, of which only unit Tqa includes appreciable fine-grained rocks and coal. Dickey (1982) measured a thickness of 1,700 m and 650 m along Windy Fork and Middle Fork, respectively, in his map unit Tqa, and noted it included conglomerate, sandstone, siltstone, shale, carbonaceous shale, and coal. He was unable to measure a complete section through this unit due to structural complications, but noted the exposures had an overall fining-upward trend and were capped by a thick succession of coal-bearing siltstones and shales. DGGS's work in 2000 and 2002 focused on Dickey's (1982) map unit Tqa. Solie and Dickey (1982) classified the coals in the Windy Fork section as subbituminous A to high volatile C bituminous using vitrinite reflectance data. Coal-bearing strata are absent in outcrop between the Big River and White Mountain, and coal was seen only in float along the Cheeneetnuk River (LePain and others, 2003). The age of unit Tqa is early to middle Miocene on the basis of plant fossils, including megafossils and palynomorphs (LePain and others, 2003). These rocks were deposited in a basin, or basins, associated with the Denali–Farewell fault system (Ridgway and others, 2000).

METHODS

Forty-two samples were collected from exposures along Windy Fork. A northeast-trending syncline was mapped by Dickey (1982) along Windy Fork in his map unit Tqa. A thick succession of mudstone, carbonaceous mudstone, coal, and

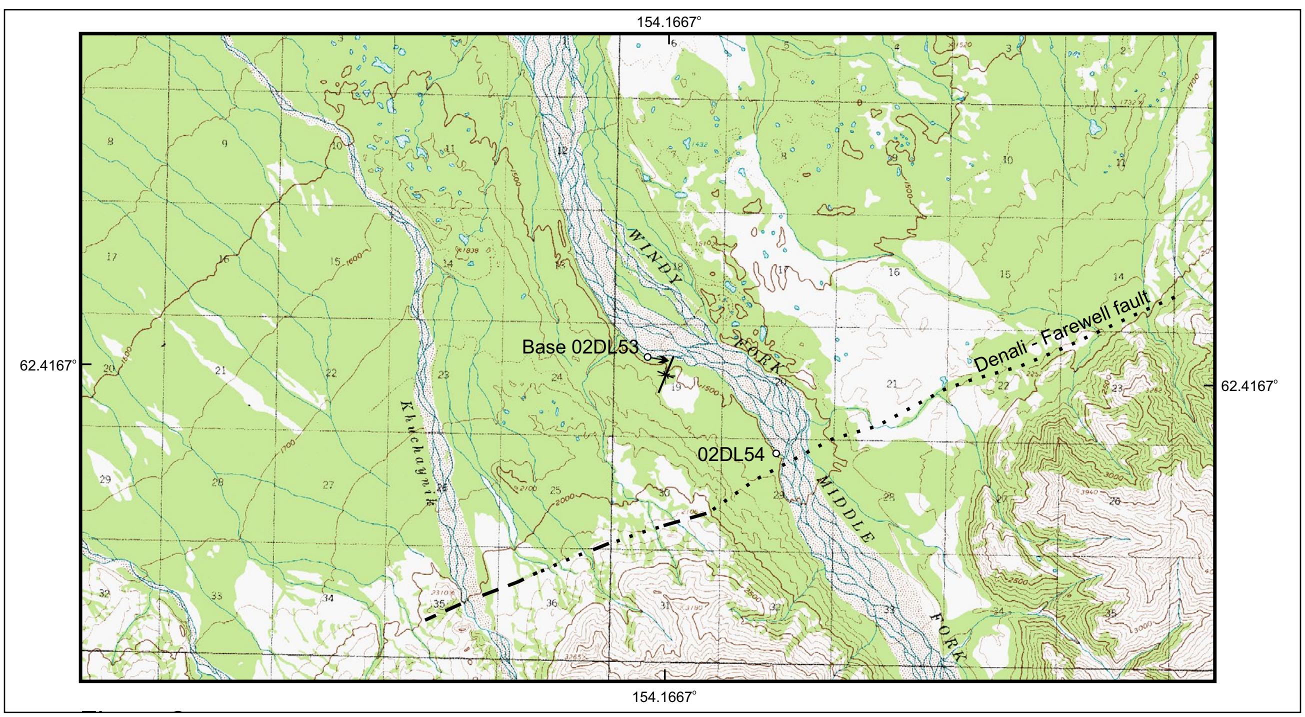

Figure 2. Portion of the McGrath B-3 Quadrangle, showing the location of the base of the measured stratigraphic section (Base 02DL53) and the location of grab samples (02DL54) discussed in this report. The trace of the Farewell fault and synclinal axis shown on this map are from Gilbert and others (1982).

minor sandstone was well exposed in 2002 on the northwest limb of this structure. The succession on the southeast limb of the syncline was poorly exposed. Thirty-seven samples for organic geochemical analysis were collected from a 92-m-thick measured section (locality 02DL53) on the northwest limb of the syncline, near the stratigraphic top of the Windy Fork exposure of map unit Tqa (figs. 2 and 3). A Garmin handheld GPS unit (datum NAD27 Alaska) was used to determine the latitude and longitude of the base of the section and the section was measured using a Jacob staff. All sample locations associated with our measured section are relative to the coordinates of the base of the section and the position in the section measured in meters above the base in the dip direction. Southeast of the syncline, a short distance north of the mapped trace of the Farewell fault (Gilbert, 1982), five grab samples for organic geochemical analyses were collected from a recessive weathering succession between two thick sandstone bodies (locality 02DL54), including three from carbonaceous mudstone and one each from mudstone and coal (fig. 2). This locality is also in Dickey's unit Tqa, but in a succession with abundant interbedded sandstone and conglomerate. All samples were submitted to Baseline-DGSI in The Woodlands, TX, for Rock-Eval pyrolysis and measurement of total organic carbon (TOC). The same laboratory analyzed splits of 19 samples for visual kerogen and vitrinite reflectance (percent R_o). Solvent extract and whole extract chromatography was done on splits from eight of the samples. A report submitted to DGGS from the laboratory includes a brief summary of the analytical methods used and an interpretive summary of the sample results by Dr. Wallace G. Dow. This report is included in the appendix.

Rock-Eval data are used to assess the generative potential and thermal maturity of rocks (Peters, 1986). The following description of the method is taken from Peters (1986), Peters and Cassa (1994), and Dow (appendix of this report). The technique requires approximately 100 mg of sample material, which is heated in a pyrolysis crucible attached to a flame ionization detector. The method provides several measurements, including S1, S2, S3, and T_{max}. S1, reported in mg/g rock, measures the amount of hydrocarbons volatilized from the sample by heating to 300°C and represents the hydrocarbons in the sample at the start of the procedure—that is, hydrocarbons that have already been generated. S2, reported in mg/g rock, measures the hydrocarbons generated by pyrolytic degradation of kerogen (cracking) by heating from 300°C to 550°C in 25°C per minute increments. S2 represents the generative potential remaining in the sample. S3 measures the carbon dioxide generated during S2 heating up to 390°C and is reported in mg CO_2/g rock. T_{max} is an indicator of thermal maturity and corresponds to the temperature of maximum S2 generation. When combined with TOC measurements, S2 and S3 are used to calculate the hydrogen and oxygen indices, respectively (HI = S2/TOC and OI = S3/TOC). The HI and OI are typically plotted on a modified van Krevelen diagram and used to indicate the type of kerogen present in a sample (Type 1 – highly oil-prone, Type 2 – oil-prone, and Type 3 – gas-prone; Peters, 1986). TOC, mean vitrinite reflectance, and Rock-Eval results are summarized in table 1.

We use Potter and others' (2005) terminology for fine-grained sedimentary rocks and in this report we use TOC in weight percent to help classify sample lithology. Samples with TOC values 50 weight percent or greater are classified as coal; samples with TOC values greater than or equal to 2 weight percent and less than 50 weight percent are classified as carbonaceous mudstones; and samples with less than 2 weight percent organic carbon are classified as mudstones. The high TOC content in many of our carbonaceous mudstone samples is likely due to the fact that most sample locations included thinly interbedded organic-rich mudstone and stringers of coal.

RESULTS

MEASURED SECTION

The stratigraphic section measured along the west side of Windy Fork at locality 02DL53 (figs. 2 and 3) consists of a 92-m-thick succession of interbedded carbonaceous claystone, carbonaceous siltstone, siltstone, coal, and minor fine-grained sandstone. This section is located at the top of a thick succession of dominantly sandstone and conglomerate (Dickey, 1982). Most claystone and carbonaceous siltstone is dark gray to nearly black weathering. Coal is present as seams up to 4 m thick and as thin, discontinuous stringers ranging from 0.1 cm to several centimeters thick, and includes alternating dull and bright bands, each a few millimeters thick. Megascopic plant material is very abundant throughout the section and includes variably preserved broad-leaf fossils and coalified woody branch material and logs. Brown, orange-brown and orange mottling are present locally and rhizoliths are abundant in siltstones and sandstones. Carbonaceous lithologies display thin parting character (few millimeters to centimeters thick), which may correspond to bedding. Bedding in siltstones and sandstones ranges from a few centimeters to a few decimeters thick and bounding surfaces are typically wavy and non-parallel. Small-scale trough cross-bedding is present locally but most sandstones and siltstones appear structureless.

The features described in the previous paragraph are consistent with deposition in a poorly drained overbank setting located away from active fluvial channel tracts. Thinly interbedded carbonaceous claystone and coal stringers appear undisturbed and are interpreted as lacustrine deposits. The thinner sandstone beds are interpreted as splay sheet sands (sand at 71.4 m), whereas the thicker bed sets could represent channel levees or crevasse splay sand bodies (sand body from 2.8 m to 5.6 m and at top of measured section). Brown, orange-brown and orange mottling and rhizoliths indicate the depositional surface was locally elevated above standing water level and was modified by vegetation and soil development.

Table 1. Summary of mean vitrinite reflectance, total organic carbon (TOC), and Rock-Eval pyrolysis data from outcrop samples collected from Miocene coal-bearing strata along the Middle and Windy Forks of the Kuskokwim River, McGrath B-3 Quadrangle, Alaska. Station 02DL53 is located on Windy Fork and 02DL54 is on Middle Fork. Supporting laboratory data are included in appendix A. The column labeled Client ID includes sample numbers assigned in the field. The digits to the right of hyphen in the sample number indicate sample position, in meters measured perpendicular to bedding, above the base of the measured section.

Client ID	Sample Type	Field Lithology	TOC-Based Lithology	Mean VR	TOC Wt.%	S1 mg/g	S2 mg/g	S3 mg/g	Tmax	HI	OI	S1/TOC	PI	S2/S3	Notes
02DL53-0.5	Outcrop	Carbonaceous claystone	Carbonaceous claystone	0.44	42.04	1.26	99.26	4.84	407	236	12	3	0.01	20.5	Many coal stringers - coaly claystone
02DL53-2	Outcrop	Coal	Coal		55.95	0.98	79.9	10.68	421	143	19	2	0.01	7.5	Sheared
02DL53-2.6	Outcrop	Carbonaceous claystone or high-ash coal	Coal	0.49	60.82	2.18	120.68	8.54	410	198	14	4	0.02	14.1	
02DL53-6.3	Outcrop	Siltstone	Carbonaceous siltstone		8.98	0.14	8.22	3.31	432	92	37	2	0.02	2.5	
02DL53-6.45	Outcrop	Carbonaceous claystone	Carbonaceous claystone		6.63	0.03	11.37	1.07	418	171	16	0	0.00	10.6	
02DL53-11.8	Outcrop	Carbonaceous claystone	Carbonaceous claystone	0.46	33.19	1.22	103.39	2.85	413	312	9	4	0.01	36.3	Many coal stringers - coaly claystone
02DL53-14	Outcrop	Carbonaceous claystone	Carbonaceous claystone		22.98	0.75	54.97	4.47	420	239	19	3	0.01	12.3	Many coal stringers - coaly claystone
02DL53-27.0	Outcrop	Coal	Coal		51.78	1.67	131.36	6.58	416	254	13	3	0.01	20.0	Highly fractured, locally sheared
02DL53-28.05	Outcrop	Carbonaceous claystone	Carbonaceous claystone	0.46	37	1.39	103.3	5.27	419	279	14	4	0.01	19.6	
02DL53-30	Outcrop	Siltstone	Carbonaceous siltstone		12.58	0.65	29.74	1.69	418	236	13	5	0.02	17.6	
02DL53-31.5	Outcrop	Siltstone	Carbonaceous siltstone		5.09	0.22	9.85	0.92	426	194	18	4	0.02	10.7	Chippy weathering, immature paleosol?
02DL53-34	Outcrop	Heterolithic - siltstone, carbonaceous claystone, coal stringers	Carbonaceous siltstone/claystone	0.44	48.73	0.96	107.04	5.4	411	220	11	2	0.01	19.8	Thinly interbedded lithologies
02DL53-36	Outcrop	Coal with carbonaceous claystone partings	Carbonaceous claystone		19.35	0.73	46.65	2.42	416	241	13	4	0.02	19.3	
02DL53-36.75	Outcrop	Carbonaceous claystone	Coal		50.83	2.57	137.56	5.35	413	271	11	5	0.02	25.7	
02DL53-38	Outcrop	Coal with carbonaceous claystone partings	Carbonaceous mudstone	0.48	31.91	1.26	82.41	4.09	414	258	13	4	0.02	20.1	
02DL53-40	Outcrop	Coal with interbedded carbonaceous claystone splits	Carbonaceous mudstone		34.83	1.4	94.91	4.72	412	272	14	4	0.01	20.1	Coal has dull luster on fresh surfaces. Claystone splits up to 5 cm thick
02DL53-42	Outcrop	Coal	Coal	0.44	55.84	2.27	144.42	6.05	406	259	11	4	0.02	23.9	Thin carbonaceous claystone partings
02DL53-44	Outcrop	Coal	Coal	0.51	74.35	1.54	128.65	8.41	409	173	11	2	0.01	15.3	Coal has bright luster on fresh surfaces
02DL53-46	Outcrop	Heterolithic - siltstone and carbonaceous claystone	Carbonaceous mudstone		4.5	0.41	7.17	1.01	426	159	22	9	0.05	7.1	
02DL53-48	Outcrop	No field assigned lithology	Carbonaceous mudstone	0.49	44.85	1.44	107.44	4.4	410	240	10	3	0.01	24.4	
02DL53-50	Outcrop	Coal with carbonaceous claystone partings	Carbonaceous claystone		41.97	1.58	99	7.99	416	236	19	4	0.02	12.4	Coal has dull luster on fresh surfaces
02DL53-52	Outcrop	Carbonaceous claystone and siltstone	Carbonaceous mudstone		33.5	0.75	61.53	6.53	418	184	19	2	0.01	9.4	Thinly interbedded lithologies
02DL53-54	Outcrop	Heterolithic - siltstone, carbonaceous claystone, and coal	Carbonaceous mudstone	0.47	26.88	0.91	67.93	5.43	419	253	20	3	0.01	12.5	Coals are thin
02DL53-56	Outcrop	Heterolithic - clayey siltstone and carbonaceous claystone	Carbonaceous mudstone		8.99	0.39	19.09	1.68	420	212	19	4	0.02	11.4	
02DL53-58	Outcrop	Siltstone	Carbonaceous mudstone	0.42	7.45	0.3	15.72	1.37	423	211	18	4	0.02	11.5	Nodular siltstone immediately above sample position
02DL53-60	Outcrop	Nodular siltstone	Mudstone		1.71	0.06	0.85	1.21	439	50	71	4	0.07	0.7	Sparsely rooted, paleosol
02DL53-62	Outcrop	Siltstone	Carbonaceous mudstone	0.45	3.18	0.12	3.47	0.62	427	109	19	4	0.03	5.6	Gray, chippy weathering
02DL53-67	Outcrop	Heterolithic - siltstone, carbonaceous claystone, coal stringers	Carbonaceous mudstone		36.75	0.92	90.57	7.41	422	246	20	3	0.01	12.2	
02DL53-71	Outcrop	Heterolithic - siltstone and carbonaceous claystone	Coal	0.43	70.24	1.75	152.22	12.81	420	217	18	2	0.01	11.9	
02DL53-74	Outcrop	Siltstone	Carbonaceous mudstone		18.93	0.56	36.65	3.79	422	194	20	3	0.02	9.7	Locally nodular. Steady, hard rain made it difficult to write in field notebook
02DL53-76	Outcrop	Siltstone	Carbonaceous mudstone	0.47	42.88	0.99	109.58	5.98	418	256	14	2	0.01	18.3	Carbonaceous claystone partings
02DL53-78	Outcrop	Siltstone with coal stringers	Carbonaceous mudstone		16.14	0.54	36.35	4.01	424	225	25	3	0.01	9.1	Hard rain
02DL53-80	Outcrop	Coal	Carbonaceous mudstone	0.46	33.87	1.65	93.9	5.21	417	277	15	5	0.02	18.0	Hard rain
02DL53-82	Outcrop	Coal	Coal		56.43	0.89	88.45	9.2	418	157	16	2	0.01	9.6	Siltstone interbeds up to 7 cm thick; hard rain
02DL53-84	Outcrop	Carbonaceous claystone	Carbonaceous mudstone		8.29	0.35	13.97	1.28	424	169	15	4	0.02	10.9	Hard rain
02DL53-85.5	Outcrop	Heterolithic - siltstone, carbonaceous claystone, coal	Carbonaceous mudstone	0.47	12.78	0.3	24.82	2.72	424	194	21	2	0.01	9.1	Hard rain
02DL53-90.1	Outcrop	Siltstone	Mudstone		1.86	0.06	1.47	0.51	431	79	27	3	0.04	2.9	Thin carbonaceous claystone interbeds; hard rain
02DL54A	Outcrop	Carbonaceous claystone	Carbonaceous mudstone	0.53	4.84	0.16	7.4	0.82	429	153	17	3	0.02	9.0	
02DL54B	Outcrop	Siltstone	Mudstone		1.11	0.06	0.49	0.91	434	44	82	5	0.11	0.5	
02DL54D	Outcrop	Siltstone	Carbonaceous mudstone	0.51	2.52	0.15	4.79	0.55	425	190	22	6	0.03	8.7	
02DL54E	Outcrop	Siltstone and carbonaceous claystone	Carbonaceous mudstone		3.47	0.09	2.39	1.27	432	69	37	3	0.04	1.9	
02DL54F	Outcrop	Carbonaceous claystone	Coal	0.59	60.94	3.05	156.89	4.43	418	257	7	5	0.02	35.4	

Location of base of measured section - Latitude 62.4190 Longitude -154.1718 (datum - NAD27 Alaska)
Location of grab samples at station 02DL054 - Latitude 62.40706 Longitude -154.13548 (datum - NAD27 Alaska)

ANALYTICAL RESULTS

Total organic carbon (TOC) and hydrogen index (HI) are measures of the amount of organic carbon in a rock and the fraction of that carbon that is convertible to hydrocarbons by pyrolysis (Peters, 1986). This information provides a general indication of a rock's hydrocarbon-generating potential under favorable subsurface conditions. The TOC values for the samples collected from the Windy Fork measured section range from 1.71 to 74.3 percent and the TOC values in grab samples from the southeast end of the Windy Fork exposure range from 1.11 to 60.94 weight percent. As noted previously, coal typically has a TOC value equal to or greater than 50 weight percent. For most samples, the TOC results are consistent with the lithology assigned to the sample when it was collected in the field.

The vitrinite reflectance and T_{max} values indicate that samples from both locations are immature with respect to the onset of hydrocarbon generation, with the exception of sample 02DL53-60 which has a T_{max} of 439. Vitrinite reflectance and T_{max} values of 0.6 percent R_o and greater than 435, respectively, mark the onset of oil generation. Mean vitrinite reflectance of the samples from our Windy Fork measured section range from 0.42 to 0.51 percent R_o, with a mean value (mean of the mean) of 0.46 percent R_o. The mean vitrinite reflectance of grab samples from the Windy Fork exposure ranges from 0.51 to 0.59 percent R_o, with a mean value of 0.54 percent R_o. T_{max} ranges from 406 to 439 for the Windy Fork measured section samples and 418 to 434 for the Windy Fork grab samples. Kerogen microscopy on splits of 19 samples indicate that most contain very high percentages of lipid-rich (fluorescent) vitrinite and only minor amounts of structured and unstructured lipid material (see laboratory report in appendix). Dow states that our samples are in the late pre-oil generation stage (see appendix a).

S1 and S2 results are consistent with the thermal maturity of the samples. Low S1 values indicate that few to no hydrocarbons were present in the samples at the start of the Rock-Eval analysis, which is to be expected for thermally immature rocks. S2 results indicate that significant volumes of organic carbon were converted to hydrocarbons by pyrolysis. The S2 yield ranges from about 55 mg/g to 157 mg/g for coals (mean S2 = 105 mg/g), from about 2 mg/g to 47 mg/g for carbonaceous mudstones (mean S2 = 17 mg/g), and 0.5 mg/g to 1.5 mg/g for siltstones (mean S2 = 1 mg/g). Based on criteria outlined in Peters and Cassa (1994, table 5.1), the S2 yields suggest that our coal samples and most of our carbonaceous mudstone samples have excellent hydrocarbon potential, and that our siltstone samples have poor petroleum potential. Figure 4 is a plot of hydrogen index (HI) versus S2/S3. Samples with HI values between 50 and 200 correspond to Type III kerogen that would be expected to expel mainly gas at peak maturity and those with HI values between 200 and 300 correspond to a mixture of Type II and III kerogen and would be expected to expel a mix of oil and gas at peak maturity (Peters and Cassa, 1994). Most of the coals and some carbonaceous mudstones in our sample suite plot in the "mixed oil and gas" field and some coals and most carbonaceous mudstones plot in the "gas" field on figure 4. One sample from the Windy Fork measured section (collected at 11.8 m above the base) has an HI greater than 300 and S2/S3

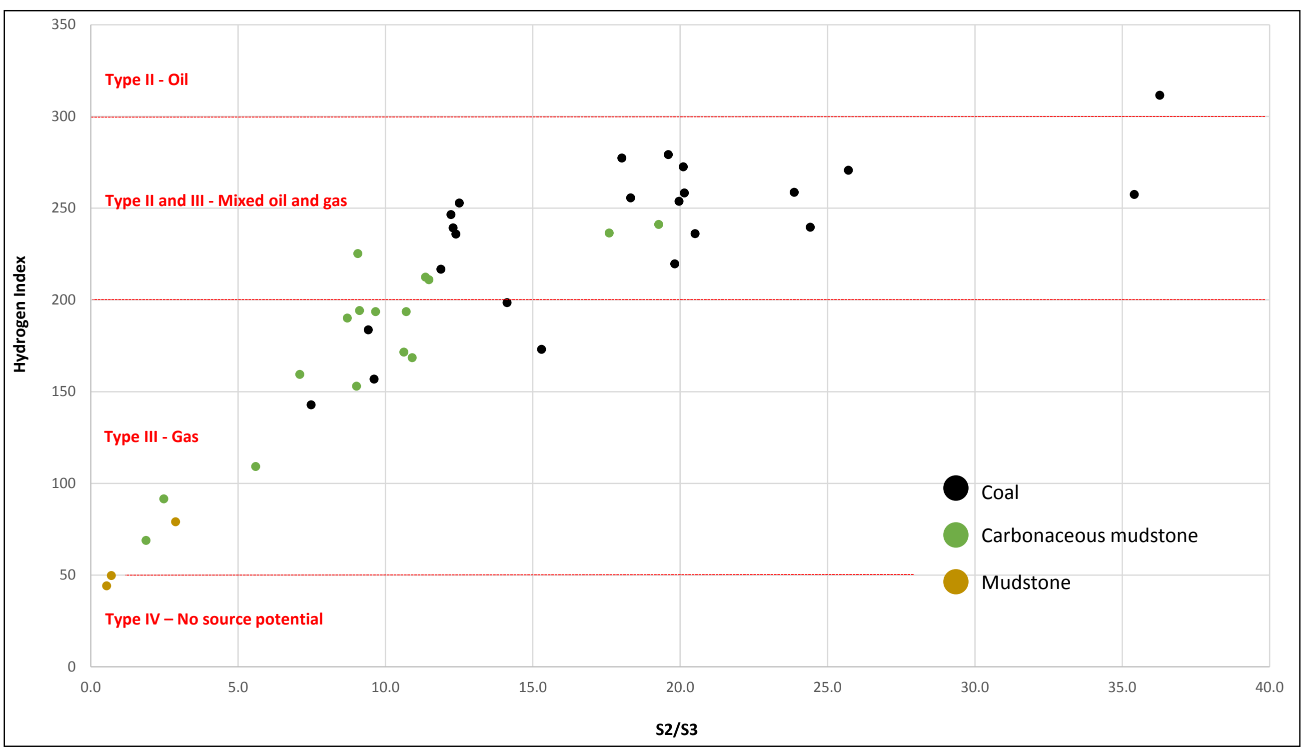

Figure 4. Plot of hydrogen index (HI) versus S2/S3. Rock-Eval pyrolysis data are summarized in table 1. Supporting laboratory data are included in appendix A.

value greater than 35, suggesting it is oil-prone. Low production index (PI) values, the ratio of generated hydrocarbons to potential hydrocarbons, (PI = S2/(S1+S2); table 1) are consistent with immature coals.

Assessing the liquid hydrocarbon generative potential of coals presents some challenges. Peters (1986) cautions that pyrolysis, for reasons not fully understood, tends to overestimate the liquid hydrocarbon potential of coaly rocks. Most of the samples in our suite are coaly, including many of the carbonaceous mudstones that commonly include thin, coaly stringers, so the liquid hydrocarbon potential may be less than suggested by the Rock-Eval results (table 1 and fig. 4). Stanley and others (2014) evaluated the petroleum potential of coals and carbonaceous mudstones in the Sheep Creek 1 well in the Susitna basin in south-central Alaska. Their results suggest that most of the coals in their suite contain mixed oil- and gas-prone kerogen. Sykes and Snowdon (2002) and Petersen (2006) demonstrate that coals have a unique characteristic in that the HI increases with increasing thermal maturity up to the threshold of oil expulsion and that proper evaluation of the petroleum potential of coals should account for this increase. Petersen (2006) states that the HI of immature humic coals should be adjusted upward by up to 90 mg hydrocarbons/g rock. Shifting our coal samples by this amount would result in all of them plotting in the oil-prone field on figure 4.

Another aspect of coals as source rocks is that they tend to act as a “sponge” for liquid hydrocarbons in that oil generated from them is stored initially in the coal matrix. Petersen (2006) states that the effective oil window for Cenozoic coals ranges from 0.85 to 2.0 percent R_o. At 0.85 percent R_o the coal matrix is thought to be saturated with hydrocarbons, and continued oil generation results in oil expulsion.

Given that our samples were collected from outcrops, the organic material they contain has been altered by surface-weathering processes. Stanley (1987) found that S2 values in weathered coals are lower than in fresh coals. Due to effects of weathering, the results presented in this report may underestimate the hydrocarbon generative potential of the sampled rocks. Despite Peters’ (1986) cautionary statement regarding the tendency of Rock-Eval data to overestimate the liquid hydrocarbon potential of coaly rocks, in light of Petersen’s (2006) work our sample results suggest that if a comparable carbonaceous mudstone- and coal-bearing succession is present in the subsurface of the Holitna basin at depths within the oil window, its liquid hydrocarbon potential may be greater than indicated by our data.

The depth to the top of the oil window in the Holitna basin can be calculated using an estimate of the temperature for the onset of effective oil generation in coaly rocks and the geothermal gradient. Petersen (2006) states that generation of liquid petroleum in humic coals is a complex, three-phase process that includes the onset of petroleum generation, petroleum build-up in the coal, and initial petroleum expulsion followed by efficient expulsion. He defines the effective oil window as the onset of liquid petroleum expulsion from coaly source materials and states that this corresponds to a vitrinite reflectance range of 0.85 to 1.05 percent R_o and the termination of liquid petroleum generation corresponds to a vitrinite reflectance range of 1.5 to 2.0 percent R_o. For our calculation we assume the onset of liquid petroleum expulsion occurs at 0.85 percent R_o. Using the linear regression equation in Barker and Pawlewicz (1986) that relates mean vitrinite reflectance and maximum temperature (ln [R_o mean] = 0.0096 – 1.4) and using a mean vitrinite reflectance value to 0.85 percent R_o yields a maximum temperature for the start of the effective oil window of 129^{o}C. Assuming a geothermal gradient of 25^{o}C/km in the gravity-defined Holitna basin and mean annual temperature at the surface of 0.0^{o}C, the depth to the top of the effective oil window is estimated to be 5.2 km (17,056 ft). Assuming a geothermal gradient of 30^{o}C/km, the depth to the top of the effective window is estimated to be 4.3 km (14,104 ft). The coal-bearing succession summarized in this report has experienced maximum temperatures ranging from 56^{o}C to 91^{o}C. These temperatures indicate a maximum burial depth ranging from 1.9 to 3.6 km (6,100–11,808 ft). This calculation applies to a conventional liquid petroleum system in which hydrocarbons generated from coaly source rocks are expelled from the source material and migrate to a porous and permeable reservoir. As noted earlier, the Holitna basin is defined by a gravity low of -40 mGals, which Smith and others (1985) interpreted to represent a sedimentary succession up to 4.5 km (14,800 ft) thick. If their estimate is close to the true thickness of Cenozoic strata in the basin, it is possible that coal-bearing strata are present in the basin at depths in the oil window.

The onset of petroleum generation in most source rocks is generally agreed to occur at a vitrinite reflectance of 0.6 percent R_o. This correspond to a temperature of approximately 93^{o}C. Using the same range of geothermal gradients (25^{o}C and 30^{o}C), the onset of liquid hydrocarbon generation would occur at depths of approximately 3.7 km (12,200 ft) and 3.1 km (10,200 ft), respectively. The depth range between the onset of liquid hydrocarbon generation and the onset of efficient expulsion (top of the effective oil window) can be regarded as the depth range where the coal and coaly mudstone function as both source and reservoir for generated hydrocarbons. Coals are mechanically weak and it is unclear if they have the requisite mechanical properties to serve as reservoir rocks at these depths.

CONCLUSIONS

Rock-Eval pyrolysis results from carbonaceous mudstone and coal samples along Windy Fork indicate the presence of Type II and Type III kerogen, which are expected to be excellent sources of oil and gas under favorable subsurface conditions. Available thermal maturity data for the samples indicate they are immature for oil and gas, but are in the late pre-oil phase of maturity.

If a coal- and carbonaceous-mudstone-bearing succession similar to the rocks discussed in this report from the McGrath Quadrangle are present in the subsurface of the gravity-defined Holitna basin at favorable depths, they can be expected to have significant thermogenic oil and gas generative potential. The depth in the basin to the top of the oil (and gas) window will depend on the geothermal gradient. In addition, if coal and carbonaceous mudstone are present in the subsurface they might serve as substrates for microbial generation of methane, as in Cook Inlet.

ACKNOWLEDGMENTS

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APPENDIX

Geochemical Analysis of Holitna Outcrop Samples Series "WF" North Slope, Alaska

Prepared for:

State of Alaska
Department of Natural Resources
Division of Geological & Geophysical Surveys

Prepared by:

Wallace G. Dow

Project: 02/011
June 24, 20003

GEOCHEMICAL ANALYSIS OF WF SERIES HOLITNA OUTCROPS NORTH SLOPE OF ALASKA

Forty-two "WF" Holitna outcrop samples vary considerably in total organic carbon (1.11 – 70.24 wt. % TOC) and many contain significant percentages of low rank, bituminous coal. Rock-Eval response also is variable and many samples appear to have moderate hydrocarbon generating capabilities based on their hydrogen indices. Pyrolysis Tmax values are very low and all of the samples are in the pre-oil generation maturity zone (less than 435° F.). Some variation in Tmax data may be due to traces of solid bitumen in some of the samples. Pyrolysis S1/TOC ratios and production indices (PI) are consistently low and indicate lack of significant liquid hydrocarbons in the samples.

Kerogen microscopy on nineteen of the samples reveal that they all contain very high percentages of lipid-rich (fluorescent) vitrinite and only minor amounts of structured and unstructured lipid material. Vitrinite reflectance maturities range from 0.42 to 0.59 % Ro and average about 0.47 % Ro and some of the reflectance measurements may be very slightly suppressed by fluorescent bitumen. These samples are classified as sub-bituminous to high volatile "C" bituminous humic coals and are in the late pre-oil generation maturity zone. Because they occur at the present surface, a considerable amount of overburden has been removed since maximum burial took place.

Solvent extraction and whole extract gas chromatography was done on eight of the samples to define the nature of the fluorescent bitumen material they contain and to verify their organic facies and thermal maturity. Total organic extract contents are quite high, but the extract/TOC ratios are low, indicating a lack of indigenous or migrated oil in the samples. This is characteristic of immature humic coals. Pristane/phytane ratios between 1.8 and 6.1 and the position of the samples on the Pr/nC17 vs. ph/nC18 plot are both consistent with immature, terrigenous organic matter and peat-coal depositional environments. Whole extract gas chromatograms exhibit very little oil-like material and also show distinct odd-carbon predominance in the nC20 to nC35 normal alkanes (also expressed by high OEP indices). This is especially evident in the sample 80 WF gas chromatogram, but the different appearance is due primarily to instrument attenuation variations (note the relative heights of the pristine (Pr) peaks between sample 80 WF and the others). This odd-carbon predominance in the heavy alkanes is typically found in samples containing terrigenous structured lipids such as cutinite with pre-oil generation maturities.

ORGANIC CARBON AND PYROLYSIS DATA

Total Organic Carbon (TOC) and Rock-Eval pyrolysis data provide basic geochemical information and are frequently used to select samples for more detailed studies, particularly kerogen microscopy, extract chromatography and biomarker analyses. Well data can be plotted to make geochemical logs. Unless otherwise specified by a client, DGSI uses LECO TOC then Rock-Eval II pyrolysis as the standard analytical sequence and Rock-Eval is recommended for samples with greater than 0.4% TOC. Samples for LECO TOC and Rock-Eval pyrolysis are ground to pass through a 60 mesh sieve to assure homogeneity.

LECO Organic Carbon and Total Sulfur

Total Organic Carbon is best determined by direct combustion. Approximately 0.15 grams of sample are carefully weighed, treated with concentrated HCl to remove carbonates, and vacuum filtered on glass fiber paper. The residue and paper are placed in a ceramic crucible, dried, and combusted with pure oxygen in a LECO EC-12 or LECO CS-444 carbon analyzer at about 1,000°C. A laboratory standard is run every five samples. Total, insoluble, mineral plus organic sulfur can be determined by the CS-444 analyzer during the carbon analysis. Total carbonate can be determined from sample and acid residue weight differences or by LECO combustion TOC differences before and after acid digestion.

Rock-Eval II Pyrolysis

Rock-Eval II pyrolysis is used to determine kerogen type, kerogen maturity and the amount of free hydrocarbons. About 0.1 grams of the same ground sample used for LECO TOC are carefully weighed in a pyrolysis crucible and then heated to 300°C to determine the amount of free hydrocarbons, S_1, that is thermally distilled. Next, the amount of pyrolyzable hydrocarbons, S_2, is measured when the sample is heated in an inert environment which rises from 300° to 550°C at a heating rate of 25°C/minute. S_1 and S_2 are reported in mg HC/g sample. T_{max}, a maturity indicator, is the temperature of maximum S_2 generation. When S_2 values are less than 0.2 mg HC/g sample, the S_2 maximum typically has poor definition and thus, Tmax cannot be reliably determined (Peters, 1986). T_{max} values are reported as N.A. on samples with 0.00 S_2. Carbon dioxide generated during the S_2 pyrolysis, an indicator of kerogen oxidation, is collected up to a temperature of 390°C and reported as S_3 in units of mg CO_2/g sample. A laboratory standard is run every 10 samples. Hydrogen Index ($HI = S_2 *100/TOC$) and Oxygen Index ($OI = S_3*100/TOC$) are used as kerogen type indicators when plotted on a van Krevelen type diagram.

Rock-Eval II Pyrolysis with TOC

Rock-Eval II Plus TOC is used to determine both Rock-Eval data (S_1, S_2, S_3, T_{max}) and TOC of a 0.1 gram ground sample. With this instrument, the pyrolysis stage (S_2) ramps to 600°C at which point the sample is switched to an oxidation oven where the sample is oxidized at 600°C for 5 minutes in air to measure the residual organic matter (S_4). A laboratory standard is run every 10 samples. S_1, S_2, S_3, and S_4 are summed appropriately to calculate TOC. True TOC will be greater than this calculated sum for samples with maturity greater than about 1.0% R_o because the Rock-Eval final temperature is inadequate for complete combustion (Peters, 1986). This instrument is preferred when there is insufficient sample to run TOC and pyrolysis separately, or when all samples in a study are to be analyzed for both TOC and Rock-Eval data without prior TOC screening.

BASELINE DGSI
ANALYTICAL LABORATORIES

Total Organic Carbon, Pyrolysis

WINDY FORK SAMPLES — Project #: 03-211-A

Client ID	Lab ID	Sample Type	Depth	Prep	TOC Wt. %	S1 mg/g	S2 mg/g	S3 mg/g	Tmax	HI	OI	S1/ TOC	PI	Check
02DL53 0.5 WF	WD000146	OTCP	-	NOPR	42.04	1.26	99.26	4.84	407	236	12	3	0.01	Verified
02DL53 2 WF	WD000147	OTCP	-	NOPR	55.95	0.98	79.90	10.68	421	143	19	2	0.01	Verified
02DL53 2.6 WF	WD000148	OTCP	-	NOPR	60.82	2.18	120.68	8.54	410	198	14	4	0.02	
02DL53 6.3 WF	WD000149	OTCP	-	NOPR	8.98	0.14	8.22	3.31	432	92	37	2	0.02	Verified
02DL53 6.45 WF	WD000150	OTCP	-	NOPR	6.63	0.03	11.37	1.07	418	171	16	0	0.00	
02DL53 11.8 WF	WD000151	OTCP	-	NOPR	33.19	1.22	103.39	2.85	413	312	9	4	0.01	Verified
02DL53 14 WF	WD000152	OTCP	-	NOPR	22.98	0.75	54.97	4.47	420	239	19	3	0.01	Verified
02DL53 27.0 WF	WD000153	OTCP	-	NOPR	51.78	1.67	131.36	6.58	416	254	13	3	0.01	Verified
02DL53 28.05 WF	WD000154	OTCP	-	NOPR	37.00	1.39	103.30	5.27	419	279	14	4	0.01	Verified
02DL53 30 WF	WD000155	OTCP	-	NOPR	12.58	0.65	29.74	1.69	418	236	13	5	0.02	
02DL53 31.5 WF	WD000156	OTCP	-	NOPR	5.09	0.22	9.85	0.92	426	194	18	4	0.02	
02DL53 34 WF	WD000157	OTCP	-	NOPR	48.73	0.96	107.04	5.40	411	220	11	2	0.01	Verified
02DL53 36 WF	WD000158	OTCP	-	NOPR	19.35	0.73	46.65	2.42	416	241	13	4	0.02	Verified
02DL53 36.75 WF	WD000159	OTCP	-	NOPR	50.83	2.57	137.56	5.35	413	271	11	5	0.02	Verified
02DL53 38 WF	WD000160	OTCP	-	NOPR	31.91	1.26	82.41	4.09	414	258	13	4	0.02	Verified
02DL53 40 WF	WD000161	OTCP	-	NOPR	34.83	1.40	94.91	4.72	412	272	14	4	0.01	Verified
02DL53 42 WF	WD000162	OTCP	-	NOPR	55.84	2.27	144.42	6.05	406	259	11	4	0.02	Verified
02DL53 44 WF	WD000163	OTCP	-	NOPR	74.35	1.54	128.65	8.41	409	173	11	2	0.01	Verified
02DL53 46 WF	WD000164	OTCP	-	NOPR	4.50	0.41	7.17	1.01	426	159	22	9	0.05	
02DL53 48 WF	WD000165	OTCP	-	NOPR	44.85	1.44	107.44	4.40	410	240	10	3	0.01	Verified
02DL53 50 WF	WD000166	OTCP	-	NOPR	41.97	1.58	99.00	7.99	416	236	19	4	0.02	Verified
02DL53 52 WF	WD000167	OTCP	-	NOPR	33.50	0.75	61.53	6.53	418	184	19	2	0.01	Verified
02DL53 54 WF	WD000168	OTCP	-	NOPR	26.88	0.91	67.93	5.43	419	253	20	3	0.01	Verified
02DL53 56 WF	WD000169	OTCP	-	NOPR	8.99	0.39	19.09	1.68	420	212	19	4	0.02	
02DL53 58 WF	WD000170	OTCP	-	NOPR	7.45	0.30	15.72	1.37	423	211	18	4	0.02	
02DL53 60 WF	WD000171	OTCP	-	NOPR	1.71	0.06	0.85	1.21	439	50	71	3	0.07	

Baseline DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

Baseline DGSI - Brazil
Rua Jardim Botânico 674 / 413
Jardim Botânico
22460-030 Rio de Janeiro (RJ) - Brazil
Telefone / fax: + 55.21 / 2259.5992
e-mail: office@reslabsolintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

Total Organic Carbon, Pyrolysis

WINDY FORK SAMPLES **Project #: 03-211-A**

Client ID	Lab ID	Sample Type	Depth	Prep	TOC Wt. %	S1 mg/g	S2 mg/g	S3 mg/g	Tmax	HI	OI	S1/ TOC	PI	Check
02DL53 62 WF	WD000172	OTCP	-	NOPR	3.18	0.12	3.47	0.62	427	109	19	4	0.03	
02DL53 67 WF	WD000173	OTCP	-	NOPR	36.75	0.92	90.57	7.41	422	246	20	3	0.01	Verified
02DL53 71 WF	WD000174	OTCP	-	NOPR	70.24	1.75	152.22	12.81	420	217	18	2	0.01	Verified
02DL53 74 WF	WD000175	OTCP	-	NOPR	18.93	0.56	36.65	3.79	422	194	20	3	0.01	Verified
02DL53 76 WF	WD000176	OTCP	-	NOPR	42.88	0.99	109.58	5.98	418	256	14	2	0.01	Verified
02DL53 78 WF	WD000177	OTCP	-	NOPR	16.14	0.54	36.35	4.01	424	225	25	3	0.01	Verified
02DL53 80 WF	WD000178	OTCP	-	NOPR	33.87	1.65	93.90	5.21	417	277	15	5	0.02	Verified
02DL53 82 WF	WD000179	OTCP	-	NOPR	56.43	0.89	88.45	9.20	418	157	16	2	0.01	Verified
02DL53 84 WF	WD000180	OTCP	-	NOPR	8.29	0.35	13.97	1.28	424	169	15	4	0.02	
02DL53 85.5 WF	WD000181	OTCP	-	NOPR	12.78	0.30	24.82	2.72	424	194	21	2	0.01	
02DL53 90.1 WF	WD000182	OTCP	-	NOPR	1.86	0.06	1.47	0.51	431	79	27	3	0.04	
02DL54 A WF	WD000183	OTCP	-	NOPR	4.84	0.16	7.40	0.82	429	153	17	3	0.02	
02DL54 B WF	WD000184	OTCP	-	NOPR	1.11	0.06	0.49	0.91	434	44	82	5	0.11	
02DL54 D WF	WD000185	OTCP	-	NOPR	2.52	0.15	4.79	0.55	425	190	22	6	0.03	
02DL54 E WF	WD000186	OTCP	-	NOPR	3.47	0.09	2.39	1.27	432	69	37	3	0.04	
02DL54 F WF	WD000187	OTCP	-	NOPR	60.94	3.05	156.89	4.43	418	257	7	5	0.02	Verified

Baseline DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

Baseline DGSI - Brazil
Rua Jardim Botânico 674 / 413
Jardim Botânico
22460-030 Rio de Janeiro (RJ) - Brazil
Telefone / fax: + 55.21 / 2259.5992
e-mail: office@reslabsolintec.com.br

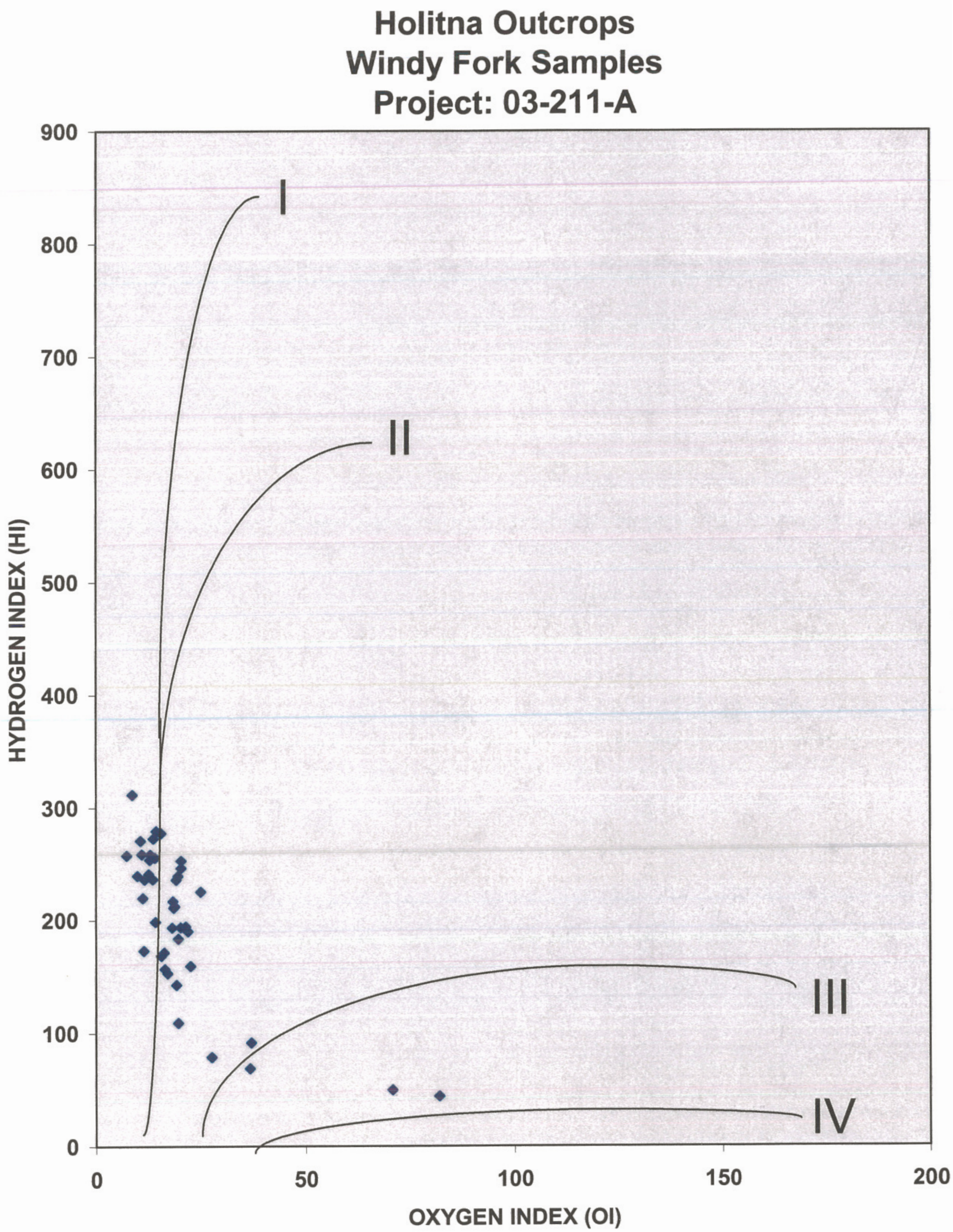


FIGURE - 2 Kerogen type determination from TOC and Rock-Eval pyrolysis data. Types I and II will generate oil, type III gas, and type IV little or no hydrocarbons.

KEROGEN MICROSCOPY

A Zeiss Universal microscope system equipped with halogen, xenon, and tungsten light sources is used for visual kerogen analysis. The halogen light source is used for vitrinite reflectance with a digital indicator calibrated on a glass standard with a reflectance of 1.02% in oil. The xenon light source is used for blue light fluorescence with an excitation filter at 495 nm. and a barrier filter at 520 nm. The tungsten light source is used for TAI analysis.

Vitrinite reflectance measurements are performed on a polished plug in reflected light, TAI is performed on a strewn slide in transmitted light, and kerogen typing and percent of organic matter is estimated from both preparations using a combination of reflected, transmitted, and fluorescent light techniques. Fluorescence is used to enhance the identification of structured and unstructured lipid material, solid bitumen, and drilling mud contaminants. Fluorescence also correlates with the maturity and state of preservation of the organic matter. Kerogen typing indicates, as closely as possible, the original organic constituent and is not reclassified with increasing maturity or changing chemistry.

Vitrinite Reflectance

Reflectance values are normally recorded only on the best quality vitrinite, including obvious contamination and recycled material. When good quality vitrinite is absent, notations are made that indicate how reflectance values may be affected by rough texture, lipid content, oxidation, or coking. When vitrinite is absent or sparse, other macerals such as solid bitumen or graptolites may be substituted with reflectance correlations indicated on the histogram.

Maturity calculations are made from the vitrinite reflectance histograms. Decisions as to which reflectance measurements indicate the maturity of the sample are based on the histogram and on data from the Visual Kerogen Analysis (VKA) Table. Geochemical and geological information is also used if available. All recorded reflectance values are reported on the histogram and alternate maturity calculations can be made if additional information dictates.

Histograms

Vitrinite reflectance histograms contain useful information in addition to reflectance values. Sample type, TOC, T_{max}, HI, reflectance means, Visual Kerogen Summary, and Comments are also listed.

All reflectance measurements are graphically displayed and the individual readings are listed below the histogram in numerical order with a letter code. The code indicates the type of material on which the measurement was made. Capital letters designate reflectance values used in calculating the mean reflectance for maturity. Lower case letters indicate values that are outside the selected maturity range. Reflectance values used for maturity calculations are shaded on the histogram and values outside the selected range are left open.

Reflectance codes are:

Vitrinite – V	**Solid bitumen – B**	**Graptolites – G**
Lipid-rich vitrinite – L	**Coked solid bitumen – Y**	**Inertinite – I**
Coked vitrinite – Z	**Granular solid bitumen – X**	**Other1 – O**
		Other2 – W

The two 'other' categories allow the flexibility of measuring unusual materials or contamination from mud additives or caving. Specific information regarding 'other' material is shown in the Comments section at the lower right corner of the Histogram Figure and in the Comments section of the VKA Table.

Statistics for selected constituents are listed adjacent to the histogram and the mean reflectance values are also listed below the TOC and Rock-Eval data at the upper right corner of the Figure. The measured values for solid bitumen and graptolites may be recalculated using appropriate formulas to obtain a **vitrinite reflectance equivalent (VRE)**. Therefore, for these two macerals we show both the measured reflectance and the VRE. For example, VRE-B is the vitrinite reflectance equivalent for solid bitumen and VRE-G is the vitrinite reflectance equivalent for graptolites – see list under Vit. Reflect. Equivalence at bottom of Visual Kerogen Analysis Table.

Visual Kerogen Analysis Table
(Brief Explanation)

The VKA Table is a list of the data for each sample. Samples can easily be compared and maturity trends established.

Lab Number – Lab number assigned to client's sample.
Sample ID or Depth – Client's ID or depth of sample.
Preparation/Sample – See list under Sample Type/Prep at bottom of Table.

- Organic Matter (%) Lipids - Unstructured

Undifferentiated – Unstructured lipids that do not fit in the other groups – oxidized, small amount, etc.
Amorphous – Immature unstructured lipids, less than R_o 0.50%, possibly with remnant algal structures.
Massive – Unstructured lipids that have a cohesive texture as the result of polymerization.
Micrinized – Unstructured lipids with granular or fine-grained texture and maturity above R_o 1.30%.

- Organic Matter (%) Lipids – Structured

Type – See list under Structured Lipids at bottom of VKA Table.
Type – "
Type – "
Type – "
Solid Bitumen – Expelled hydrocarbon from the maturation of lipid material.

- Organic Matter (%) Humic

Inertinite – Non-reactive (inert) constituents formed from woody material, fungal structures, etc.
Vitrinite – Derived from woody material.

- Organic Matter (%) Other

Type – See list under Other Organic Matter at bottom of Table.
Type – "

- Relative Abundance – see list under Abund. at bottom of Table.

Pyrite Type – See list under Pyrite at bottom of Table.
Pyrite – Amount of pyrite observed in the reflected light plug.
Organic Concentration – Amount of organic matter in the reflected light plug – Not TOC.

- Relative Abundance Vitrinite

Normal – Unaltered vitrinite.
Rough – Texture that may be caused by oxidation, dissolving of lipid materials, or coking.
Lipid-Rich – Vitrinite that has a higher than normal lipid content resulting in lower R_o values.
Oxidized – Vitrinite that has lower or higher R_o caused by weathering, microbial activity, or heating.
Coked – Texture caused from rapid heating as from intrusions.

- Fluorescence/TAI Reflected Lipids Unstructured

Color – See list under Fluor. Color at bottom of Table. Letters may be combined to indicate color.
Intensity – See list under Fluor. Intens. at bottom of Table.

- Fluorescence/TAI Reflected Lipids Structured

Color – See list under Fluor. Color at bottom of Table.
Intensity – See list under Fluor. Intens. at bottom of Table.

- Fluorescence/TAI Reflected

Background Intensity – Fluorescence of the epoxy mounting medium around the organic matter.

- Fluorescence/TAI Transmitted Lipids Unstructured – TAI and Fluorescence

Value (TAI) – Color of unstructured lipids in transmitted light – see list under TAI Color Values.
Color – See list under Fluor. Color at bottom of Table. Letters may be combined to indicate color.
Intensity – See list under Fluor. Intens. at bottom of Table.

- Fluorescence/TAI Transmitted Lipids Structured – TAI and Fluorescence

Value (TAI) – Color of sporinite of terrestrial origin in transmitted light – see list under TAI Color Values.
Color – See list under Fluor. Color at bottom of Table.
Intensity – See list under Fluor. Intens. at bottom of Table.

- R_o Vitrinite Reflectance or Equivalent – **interpreted value.**

Visual Kerogen Analysis Table (Detailed Explanation)

The VKA Table is a list of the data for each sample. Samples can easily be compared and maturity trends established

- **Lab Number** – Lab number assigned to client's sample.
- **Sample ID or Depth** – Client's identification or depth of sample.
- **Preparation/Sample Type** – See list under Sample Type/Prep at bottom of Table. Unfloated kerogen concentrates are used to prevent biasing of the organic matter.

ORGANIC MATTER (%) – Organic material in sedimentary rocks consists of different constituents called macerals. On the VKA Table, these constituents are divided into two groups generally characterized by their chemical composition – **Lipids** and **Humic**. A group for **Other** is included to separate special interest components.

Lipids are divided into two groups – **Unstructured** and **Structured**:

Unstructured lipids represent the material resulting from bacterial or thermal breakdown of lipid organic matter. Most unstructured material results from algae, but also may include fecal pellets, organic gels, humic components, and other debris. Unstructured lipid material changes character and texture with increasing maturity or chemical alteration and is divided into four groups:

- **Undifferentiated** – Unstructured lipids that do not fit in the other groups because of oxidation, mixing with other organic material or mineral that makes identification difficult, or small amounts of organic matter.
- **Amorphous** – Immature unstructured lipids with generally fluffy texture, light brown or amber color, and possibly remnant algal structure. Maturity is usually less than R_o 0.50%.
- **Massive** – Unstructured lipids that have a cohesive texture as the result of polymerization during the process of oil generation and may contain solid bitumen. Color generally ranges from brown to dark gray and maturity from R_o 0.50 to R_o 1.30%.
- **Micrinized** – Unstructured lipids with maturity generally above R_o 1.30% and consisting of granular to fine-grained texture. Color is dark gray, light gray, or black.

Structured lipids consist of a group of macerals which have a recognized structure and can be related to the original living tissue from which they were derived – see list under Structured Lipids at bottom of VKA Table.

- **Alginite** – Derived from algae. It is sometimes very useful to distinguish the different algal types, for example, botryococcus and pediastrum are associated with lacustrine and non-marine source rocks, while algae such as tasmanites, gloecapsomorpha, and nostrocopsis are typically marine. Acritarchs and dinoflagellates are marine organisms that are also included in the algal category.
- **Suberinite** – Derived from the corky tissue of land plants.
- **Cutinite** – Derived from plant cuticles, the remains of leaves.
- **Liptodetrinite** – Structured lipid material with fluorescence that is too small to be specifically identified. Usually, it is derived from alginite or sporinite with maturity less than R_o 1.40%.
- **Undifferentiated** – Structured lipid material that does not fluoresce and is too small to be specifically identified. Maturity is usually higher than R_o 1.40% and sometimes fragments are difficult to distinguish from vitrinite or inertinite.
- **Sporinite** – Derived from spores and pollen from a wide variety of land plants.
- **Resinite** – Derived from plant resins, balsams, latexes, and waxes, also includes fluorinite.
- **Other** – Category for varieties listed above or from contaminants such as nutshell.
- **Solid Bitumen** – Also called migrabitumen or solid hydrocarbon, it is a secondary product formed from the maturation of lipid components. Solid bitumen is an expelled hydrocarbon that has characteristic shape, texture, and fluorescence and is listed with structured lipids. It represents two classes of substances: one which is present at or near the place where it was generated, and the other which is present in reservoir rock and may have migrated a great distance from its point of origin. It is sometimes possible to use the reflectance of solid bitumen for maturation determinations when vitrinite is not present.

<u>**Humic**</u> material is derived from the woody components of land plants and is divided into two groups:

- **Inertinite** – Derived from woody material that has been matured by a different pathway from that of normal vitrinite. Early intense oxidation, usually involving charring, fungal attack, or biochemical gelification creates the higher reflecting fusinite and semi-fusinite. Sometimes the division between vitrinite and fusinite is transitional. Sclerotinite, fungal remains having a distinct morphology, is considered to be inert. Inertinite, as the name implies, is largely non-reactive "dead carbon" and has an extremely low hydrogen index.
- **Vitrinite** – Derived from woody material that has been subjected to a minimum amount of oxidation. The rate of change of vitrinite reflectance with increasing temperature is more consistent than for other macerals, and offers the best means of obtaining thermal maturity data in coals and other types of sedimentary rocks.

<u>**Other Organic Matter**</u> – See list at bottom of Table.

- **Exsudatinite** – Oil and oily exudates are included in this group. Exsudatinite differs from solid bitumen on the basis of mobility and solubility. We prefer to maintain this distinction although the International Committee for Coal Petrology (I.C.C.P.) has now included solid bitumen with the exsudatinite group.
- **Graptolites** – Marine organisms that range from the Cambrian to the lower Mississippian. They have a reflectance similar to that of vitrinite and can be used for maturity measurements in the early Paleozoic rocks that do not contain vitrinite.
- **Lipid-rich vitrinite, Vitrinite contamination, and Recycled Vitrinite** – These groups are often separated from the vitrinite maceral to help in the interpretation of the reflectance data.

RELATIVE ABUNDANCE – The relative amounts of items listed below. See list under Abund. at bottom of Table.

- **Pyrite Type** – See list under Pyrite at bottom of Table.
- **Pyrite** – Amount of pyrite observed in the reflected light plug.
- **Organic Concentration** – Amount of organic matter observed in the reflected light plug. (<u>Not to be confused with Total Organic Carbon</u>). Concentration is a function of the amount of organic matter recovered after acid treatment as well as the amount of epoxy mounting medium that it is mixed with to form the plug. Kerogen typing and percentages are more accurate with larger amounts of organic material.

<u>**Vitrinite**</u> – Amount of vitrinite with the following characteristics:

- **Normal** – Unaltered vitrinite. Reflectance measurements of vitrinite are important and care is taken to distinguish normal from other kinds of vitrinite for accurate reflectance measurements.
- **Rough** – Texture that may be caused by oxidation, dissolving of lipid materials, or coking. Rough texture lowers reflectance values.
- **Lipid–Rich** – Vitrinite that has a higher than normal lipid content caused by type of original plant material, depositional environment, or bitumen saturation. Lipid-rich vitrinite has a lower reflectance than normal vitrinite, depending upon the amount of lipid content, and may produce an abnormally low maturity value. It is identified by visual characteristics and fluorescence.
- **Oxidized** – Oxidized vitrinite may have a reflectance lower or higher than normal vitrinite, depending on the method of oxidation and when it took place during the maturation process. Weathering and microbial degradation generally cause a darker surface resulting in lowered reflectance values. Heating generally causes a lighter surface resulting in higher reflectance values. Vitrinite fragments may exhibit dark or light oxidation rims or crusts, or be completely oxidized. Various depths of polishing of oxidized vitrinite fragments in the reflected light plug make differentiation of normal and oxidized fragments difficult. As a result, a sample with oxidized vitrinite may exhibit a wide range of reflectance values.
- **Coked** – Naturally coked vitrinite is the product of very rapid heating, such as that found adjacent to intrusions. During the coking process, vitrinite goes through a softening stage that affects texture and color and lowers reflectance values. With continued heating, the vitrinite becomes anisotropic and reflectance rises. With both high temperature and pressure, graphite is produced.

FLUORESCENCE/TAI – Blue light fluorescence is performed on the reflected light plug and on the strewn slide to help identify the lipid components not visible in the other types of light. Fluorescence is also used to estimate maturity. Fluorescence color in the range we analyze changes from yellow to black with increasing maturity. However, oxidation and other factors may affect the color and intensity of fluorescence. TAI is performed on the strewn slide using transmitted light from the tungsten light source. On the VKA Table, the two sample preparations are divided into **Reflected Light** and **Transmitted Light** categories.

Reflected Light Lipids are divided into two groups – **Unstructured** and **Structured**:

Unstructured – See previous definition under Organic Matter %.

- **Color** – See list under Fluor. Color at bottom of Table. Letter abbreviations may be combined to indicate color, such as OB for orange-brown, LY for light-yellow, etc. Two sets of letters may be used to indicate a range of colors. The most abundant color is reported at the top.
- **Intensity** – See list under Fluor. Intens. at bottom of Table. Two numbers may be listed to indicate a range of intensity. The most abundant intensity is reported at the top.

Structured – See previous definition under Organic Matter %.

- **Color** – See list under Fluor. Color at bottom of Table.
- **Intensity** – See list under Fluor. Intens. at bottom of Table.
- **Background Intensity** – The intensity of fluorescence of the epoxy mounting medium used to bind the organic material together for the reflected light plug. The intensity of fluorescence correlates well with the onset of oil generation and destruction. It is also used to detect contamination.

Transmitted Light Lipids are also divided into two groups – **Unstructured** and **Structured**. The fluorescence of lipids in the strewn slide is not masked by background fluorescence as in the reflected light plug.

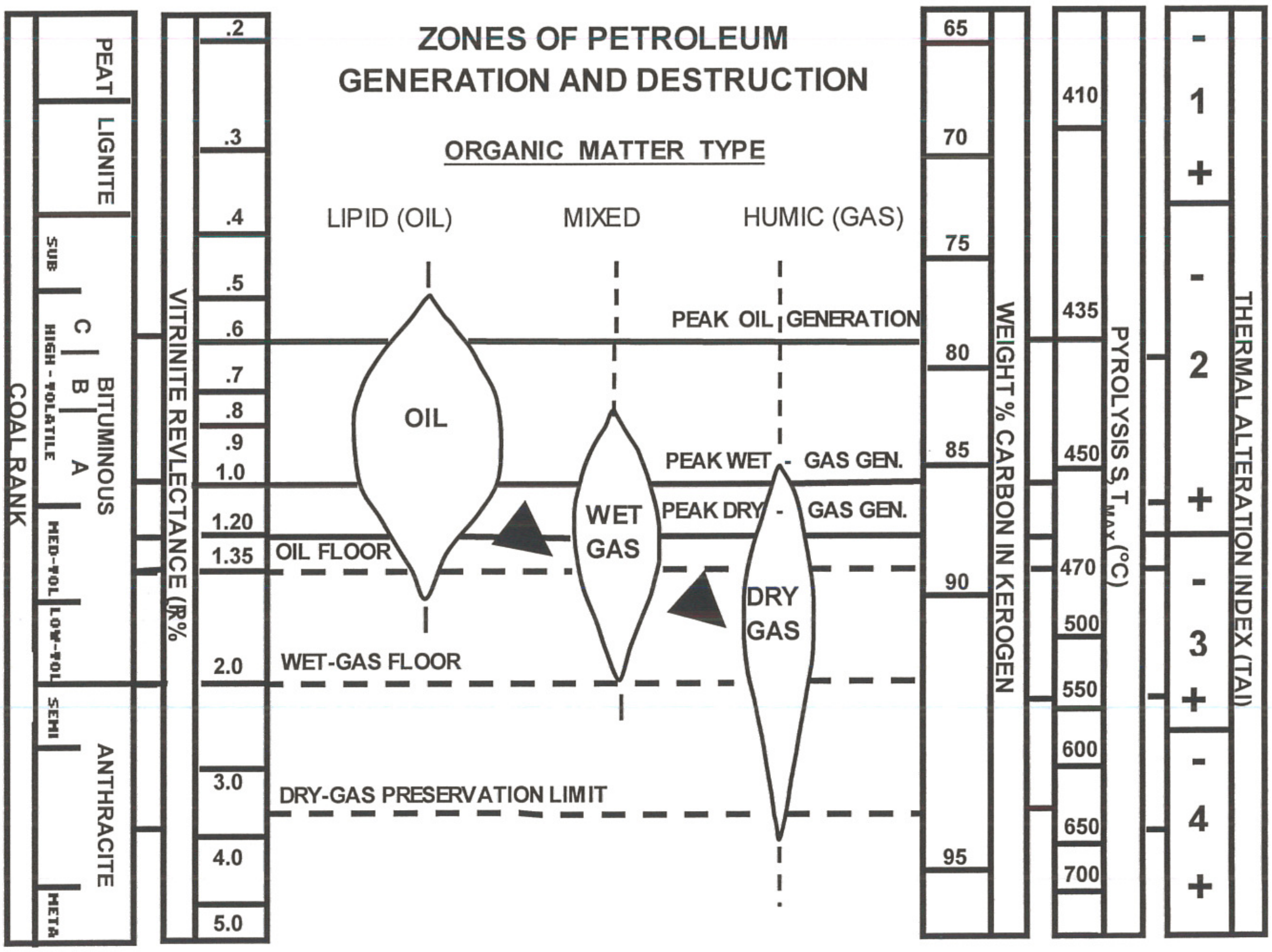
Unstructured – See previous definition under Organic Matter %.

- **Value (TAI)** – Color of unstructured lipids in transmitted light represented by a number – see list under TAI Color Values at bottom of Table. Weathering (oxidation), presence of solid bitumen, and micrinization can darken the kerogen and raise the TAI value. Two sets of values may be used to indicate a range of color. The most abundant color is reported at the top.
- **Color** – See list under Fluor. Color at bottom of Table.
- **Intensity** – See list under Fluor. Intens. at bottom of Table.

Structured – See previous definition under Organic Matter %.

- **Value (TAI)** - Color of sporinite of terrestrial origin in transmitted light represented by a number – see list under TAI Color Values at bottom of Table.
- **Color** – See list under Fluor. Color at bottom of Table.
- **Intensity** – See list under Fluor. Intens. at bottom of Table.

R_o – The vitrinite reflectance or equivalent mean obtained from the histogram.



CORRELATION OF VARIOUS MATURATION INDICES AND ZONES OF PETROLEUM GENERATION AND DESTRUCTION

Holitna Outcrop
Windy Fork Samples
BaselineDGSI Project: 03-211-A

Summary of Visual Kerogen Analysis

Nineteen outcrop samples were analyzed for vitrinite reflectance maturity, TAI maturity, and kerogen type. Some reflectance values may be lowered by suppression or slightly rough texture. Pyrolysis T_{max} values may be slightly lowered by lipid content. Maturity interpretations are based on visual analysis and pyrolysis data, but may change with additional geological and geochemical information.

WD000146: 02DL53 0.5 WF
Organic matter consists of lipid-rich vitrinite with some unstructured material that may be degraded humic debris. Organic matter is slightly immature for oil generation.

WD000148: 02DL53 2.6 WF
Organic matter is similar to that in sample 02DL53 0.5 WF. Organic matter is slightly immature for oil generation.

WD000151: 02DL53 11.8 WF
Organic matter consists primarily of lipid-rich vitrinite. Unstructured material is laminated with the vitrinite and may be unstructured lipids. Unstructured lipid material is difficult to identify as lipid or humic when mixed with low-rank, lipid-rich vitrinite, especially in the transmitted light slide. Organic matter is slightly immature for oil generation.

WD000154: 02DL53 28.05 WF
Organic matter is similar to that in sample 02DL53 11.8 WF. The unstructured material is difficult to identify as humic debris or lipids. Organic matter is slightly immature for oil generation.

WD000157: 02DL53 34 WF
Organic matter consists of lipid-rich vitrinite and unstructured material that appears to be lipid. The unstructured material does not fluoresce and may be oxidized. Organic matter is slightly immature for oil generation.

WD000160: 02DL53 38 WF
Organic matter consists of lipid-rich vitrinite with a small amount of unstructured material. Organic matter is slightly immature for oil generation.

WD000162: 02DL53 42 WF
Organic matter consists of lipid-rich vitrinite and unstructured material that is difficult to identify as humic debris or lipids. Organic matter is slightly immature for oil generation.

WD000163: 02DL53 44 WF

Organic matter consists of slightly lipid-rich vitrinite with a trace of unstructured lipids. Maturity is at the top of the oil generation zone.

WD000165: 02DL53 48 WF

Organic matter consists of lipid-rich vitrinite and unstructured material that is probably lipid. Organic matter is slightly immature for oil generation.

WD000168: 02DL53 54 WF

Organic matter consists of lipid-rich vitrinite and unstructured material. Some fragments of lipid-rich vitrinite have inclusions of structured lipids that do not fluoresce. The unstructured material is difficult to identify, but some appears to be lipid. Most reflectance values may be suppressed. Maturity is estimated to be at the top of the oil generation zone.

WD000170: 02DL53 58 WF

Organic matter consists of lipid-rich vitrinite and unstructured material. The unstructured material is difficult to identify as humic debris or lipids. Moderately rough texture or suppression may lower all reflectance values. Maturity is estimated to be slightly immature for oil generation.

WD000172: 02DL53 62 WF

Organic matter consists of lipid-rich vitrinite with slight to moderate rough texture. Some reflectance values may be lowered by suppression or rough texture. Most lipid-rich vitrinite has orange fluorescence in the transmitted light slide. The unstructured material is difficult to identify. Organic matter is slightly immature for oil generation.

WD000174: 02DL53 71 WF

Organic matter consists of lipid-rich vitrinite and some unstructured material. Most vitrinite has a high lipid content with some resinite, sporinite, and liptodetrinite structure still visible. Reflectance values may be suppressed. Some unstructured material appears to be lipid. Organic matter is slightly immature for oil generation.

WD000176: 02DL53 76 WF

Organic matter consists of lipid-rich vitrinite and some unstructured material. Some vitrinite fragments have a high lipid content with some resinite, sporinite, and liptodetrinite structure still visible. Some reflectance values may be slightly suppressed. Some unstructured material appears to be lipid. Organic matter is slightly immature for oil generation.

WD000178: 02DL53 80 WF

Organic matter consists of lipid-rich vitrinite. Some fragments are laminated with unstructured material that is difficult to identify. Reflectance values may be suppressed. Organic matter is slightly immature for oil generation.

WD000181: 02DL53 85.5 WF

Organic matter consists of lipid-rich vitrinite and unstructured lipids with grainy-massive texture. Lipid-rich vitrinite has moderately rough texture and reflectance values may be slightly lowered. Organic matter is slightly immature for oil generation.

WD000183: 02DL54 A WF

Organic matter consists of lipid-rich vitrinite and unstructured lipids. Lipid-rich vitrinite has moderately rough texture that may slightly lower some reflectance values. Maturity is at the top of the oil generation zone.

WD000185: 02DL54 D WF

Organic matter consists of lipid-rich vitrinite and unstructured material that is difficult to identify. Maturity is at the top of the oil generation zone.

WD000187: 02DL54 F WF

Organic matter consists of normal vitrinite laminated with liptodetrinite and some lipid-rich vitrinite. Most lipid-rich vitrinite is too rough textured for valid reflectance measurements. Maturity is in the upper oil generation zone.

HOLITNA OUTCROP
WINDY FORK
Baseline DGSI Project: 03-211-A

BaselineDGSI

BaselineDGSI Number / Sample Id or Depth	Preparation/Sample Type	ORGANIC MATTER (%) – LIPIDS – UNSTRUCTURED: Undifferentiated	Amorphous	Massive	Micrinized	LIPIDS – STRUCTURED: Type	Type	Type	Type	Solid Bitumen	HUMIC: Inertinite	Vitrinite	OTHER: Type	Type	RELATIVE ABUNDANCE: Pyrite Type	Pyrite	Organic Concentration	VITRINITE: Normal	Rough	Lipid-Rich	Oxidized	Coked	FLUORESCENCE / TAI – REFLECTED – LIPIDS – UNSTR.: Color	Intensity	STRU.: Color	Intensity	Background Intensity	TRANSMITTED – LIPIDS – UNSTR.: TAI Value	FLUOR. Color	Intensity	STRU.: TAI Value	FLUOR. Color	Intensity	Ro: Vit. Reflectance or Equiv.
NOPR WD000146 02DL53 0.5 WF	K/OC	10				LD T	C T						VL 90		MA	T	+	N	-	+			B	1	Y O	1 2	3	n.d.				Y O	1 2	V 0.44
COMMENTS: Lipid-rich vitrinite. Unstructured material may be humic debris.																																		
NOPR WD000148 02DL53 2.6 WF	K/OC	5				LD T							VL 95		MA	T	+	N	-	+			B DB	1	Y OB	1 2	2 3	n.d.				Y O	1	V 0.49
COMMENTS: Similar to 02DL53 0.5 WF.																																		
NOPR WD000151 02DL53 11.8 WF	K/OC	10				LD 5							VL 85		MA	T	+	N	-	+			B	1	Y O	1 2	3	n.d.				O Y	2 1	V 0.46
COMMENTS: Lipid-rich vitrinite. Unstructured material is laminated with vitrinite and may be unstructured lipids.																																		
NOPR WD000154 02DL53 28.05 WF	K/OC	20				LD 5					T	? T	VL 75		MA	T	+	?	-	+			B	1	O	1	3	n.d.				O	2	V 0.45
COMMENTS: Lipid-rich vitrinite. Difficult to identify unstructured material.																																		
NOPR WD000157 02DL53 34 WF	K/OC	30				LD T					T		VL 70		MA	T	+	N	-	+			DB	1	Y O	1 2	2	2+	BL	0		Y O	1	V 0.44
COMMENTS: Lipid-rich vitrinite. Unstructured material appears to be lipid, but has no fluorescence.																																		

ANALYST

X O'Connor

MICROSCOPE

X Zeiss
___ Jena
___ Leitz

SAMPLE TYPE/PREP

CTG	Cuttings
CC	Conv. Core
SWC	SideWallCore
OC	Outcrop
NI	No Inform.
C	Coal
K	Kerogen
WR	Whole Rock
n.d.	Not Determined

STRUCTURED LIPIDS

AL	Alginite
SB	Suberinite
C	Cutinite
LD	Liptodetrinite
U	Undiffer.
S	Sporinite
R	Resinite
O	Other

OTHER ORGANIC MATTER

E	Exsudatinite
G	Graptolites
V	Vitrnite
VL	Lipid-Rich Vitrinite
VC	VitriniteContamination
VR	Recycled Vitrinite

PYRITE

E	Euhedral
F	Framboid
MA	Massive
RI	Replace-infill

ABUND.

N	None
T	Trace
-	Small Amt.
M	Mod. Amt.
+	Large Amt.
++	Abundant

FLUOR. INTENS.

0	None
1	Weak
2	Moderate
3	Strong
4	Intense

VIT. REFLECT. EQUIVALENCE

B	Bitumen
G	Graptolites
VL	Lipid-Rich Vitrinite
VC	Vitrinite Contam.
VR	Recycled Vitrinite

FLUOR. COLOR

W	White
G	Green
Y	Yellow
O	Orange
R	Red
B	Brown
BL	Black
L	Light
D	Dark

TAI COLOR VALUES

1-	Straw Yellow
1	Pale Yellow
1+	Yellow
2-	Yellow-Orange
2	Golden
2+	Amber
3-	Reddish Brown
3	Medium Brown
3+	Dark Brown
4-	Brown-Black
4	Black
4+	Black-Opaque

VISUAL KEROGEN ANALYSIS

BaselineDGSI

HOLITNA OUTCROP
WINDY FORK
Baseline DGSI Project: 03-211-A

BaselineDGSI Number	Sample Id or Depth	Preparation/Sample Type	ORGANIC MATTER (%) LIPIDS UNSTRUCTURED Undifferentiated	Amorphous	Massive	Micrinized	LIPIDS STRUCTURED Type	Type	Type	Type	Solid Bitumen	HUMIC Inertinite	Vitrinite	OTHER Type	Type	RELATIVE ABUNDANCE Pyrite Type	Pyrite	Organic Concentration	VITRINITE Normal	Rough	Lipid-Rich	Oxidized	Coked	FLUORESCENCE / TAI REFLECTED LIPIDS UNSTR. Color	Intensity	STRU. Color	Intensity	Background Intensity	TRANSMITTED LIPIDS UNSTR. TAI Value	FLUOR. Color	Intensity	STRU. TAI Value	FLUOR. Color	Intensity	Ro Vit. Reflectance or Equiv.
NOPR WD000160	02DL53 38 WF	K/OC	5				LD T							VL 95		MA	T	+	N	-	+			B	1			3	n.d.				O Y	2	V 0.48
COMMENTS: *Lipid-rich vitrinite.*																																			
NOPR WD000162	02DL53 42 WF	K/OC	20				LD T							VL 80		MA	T	+	N	-	+			B	1			3 4	n.d.				Y O	2	V 0.44
COMMENTS: *Lipid-rich vitrinite. Unstructured material is difficult to identify as humic debris or lipid.*																																			
NOPR WD000163	02DL53 44 WF	K/OC	T				LD T							VL 100		MA	T	+	N	T	+			B	1	Y	2	1 2	n.d.				Y O	2	V 0.51
COMMENTS: *Slightly lipid-rich vitrinite with a trace of unstructured lipids.*																																			
NOPR WD000165	02DL53 48 WF	K/OC	20				LD T					T		VL 80		MA	T	+	N	-	+			DB	1			3	n.d.				O Y	2 1	V 0.49
COMMENTS: *Lipid-rich vitrinite. Unstructured material is probably lipid.*																																			
NOPR WD000168	02DL53 54 WF	K/OC	20				LD 5							VL 75		MA	-	+	N	M	+			B	1	BL Y	0 2	3 4	n.d.				O Y	2 1	V 0.47
COMMENTS: *Lipid-rich vitrinite, most Ro values may be suppressed. Some unstructured material appears to be lipid.*																																			

ANALYST

X O'Connor

MICROSCOPE

X Zeiss
___ Jena
___ Leitz

SAMPLE TYPE/PREP
CTG Cuttings
CC Conv. Core
SWC SideWallCore
OC Outcrop
NI No Inform.
C Coal
K Kerogen
WR Whole Rock
n.d. Not Determined

STRUCTURED LIPIDS
AL Alginite
SB Suberinite
C Cutinite
LD Liptodetrinite
U Undiffer.
S Sporinite
R Resinite
O Other

OTHER ORGANIC MATTER
E Exsudatinite
G Graptolites
V Vitrinite
VL Lipid-Rich Vitrinite
VC VitriniteContamination
VR Recycled Vitrinite

PYRITE
E Euhedral
F Framboid
MA Massive
RI Replace-infill

ABUND.
N None
T Trace
- Small Amt.
M Mod. Amt.
+ Large Amt.
++ Abundant

FLUOR. INTENS.
0 None
1 Weak
2 Moderate
3 Strong
4 Intense

VIT. REFLECT. EQUIVALENCE
B Bitumen
G Graptolites
VL Lipid-Rich Vitrinite
VC Vitrinite Contam.
VR Recycled Vitrinite

FLUOR. COLOR
W White
G Green
Y Yellow
O Orange
R Red
B Brown
BL Black
L Light
D Dark

TAI COLOR VALUES
1- Straw Yellow
1 Pale Yellow
1+ Yellow
2- Yellow-Orange
2 Golden
2+ Amber
3- Reddish Brown
3 Medium Brown
3+ Dark Brown
4- Brown-Black
4 Black
4+ Black-Opaque

VISUAL KEROGEN ANALYSIS

BaselineDGSI

HOLITNA OUTCROP
WINDY FORK
Baseline DGSI Project: 03-211-A

BaselineDGSI Number / Sample Id or Depth	Preparation/Sample Type	ORGANIC MATTER (%) LIPIDS UNSTRUCTURED: Undifferentiated	Amorphous	Massive	Micrinized	LIPIDS STRUCTURED: Type	Type	Type	Type	Solid Bitumen	HUMIC: Inertinite	Vitrinite	OTHER: Type	Type	RELATIVE ABUNDANCE: Pyrite Type	Pyrite	Organic Concentration	VITRINITE: Normal	Rough	Lipid-Rich	Oxidized	Coked	FLUORESCENCE / TAI REFLECTED LIPIDS UNSTR.: Color	Intensity	STRU.: Color	Intensity	Background Intensity	TRANSMITTED LIPIDS UNSTR. TAI: Value	FLUOR.: Color	Intensity	STRU. TAI: Value	FLUOR.: Color	Intensity	Ro: Vit. Reflectance or Equiv.
NOPR WD000170 02DL53 58 WF	K/OC	30				LD T							VL 70		MA	-	+	N	M	+			DB	1			2 3	? 2+	BL	0		O Y	1 2	V 0.42
COMMENTS: *Lipid-rich vitrinite with moderately rough texture. Ro may be lowered by suppression or rough texture. Unstructured material is difficult to identify.*																																		
NOPR WD000172 02DL53 62 WF	K/OC	10				LD 5					T		VL 85		MA	-	+	N	M	+			DB	1	Y	2 3	2	n.d.				O	2	V 0.45
COMMENTS: *Lipid-rich vitrinite with slight to moderately rough texture. Some Ro values may be suppressed. Most vitrinite has orange fluorescence in slide.*																																		
NOPR WD000174 02DL53 71 WF	K/OC	10				LD 10	S T	R 5			T		VL 75		MA	-	+	N	-	+			DB	1	O Y	1	2 3	2+	BL	0		YO Y	2	V 0.43
COMMENTS: *Most lipid-rich vitrinite has high lipid content and Ro may be suppressed. Some unstructured material appears to be lipid.*																																		
NOPR WD000176 02DL53 76 WF	K/OC	15				LD 5	S T	R T			T		VL 80		MA	-	+	N	-	+			DB	1	Y O	1	3 2	2+	BL	0		O Y	1 2	V 0.47
COMMENTS: *Some lipid-rich vitrinite has high lipid content and some Ro values may be suppressed.*																																		
NOPR WD000178 02DL53 80 WF	K/OC	10				LD 5	S T				5		VL 80		MA	-	+	N	M	+			B	1	O Y	1 2	3 4	n.d.				O Y	2 3	V 0.46
COMMENTS: *Lipid-rich vitrinite, some laminated with unstructured material that is difficult to identify. Some fragments fluoresce in slide. Some Ro values may be suppressed.*																																		

ANALYST

X O'Connor

MICROSCOPE

X Zeiss
__ Jena
__ Leitz

SAMPLE TYPE/PREP
- CTG Cuttings
- CC Conv. Core
- SWC SideWallCore
- OC Outcrop
- NI No Inform.
- C Coal
- K Kerogen
- WR Whole Rock
- n.d. Not Determined

STRUCTURED LIPIDS
- AL Alginite
- SB Suberinite
- C Cutinite
- LD Liptodetrinite
- U Undiffer.
- S Sporinite
- R Resinite
- O Other

OTHER ORGANIC MATTER
- E Exsudatinite
- G Graptolites
- V Vitrinite
- VL Lipid-Rich Vitrinite
- VC VitriniteContamination
- VR Recycled Vitrinite

PYRITE
- E Euhedral
- F Framboid
- MA Massive
- RI Replace-infill

ABUND.
- N None
- T Trace
- - Small Amt.
- M Mod. Amt.
- + Large Amt.
- ++ Abundant

FLUOR. INTENS.
- 0 None
- 1 Weak
- 2 Moderate
- 3 Strong
- 4 Intense

VIT. REFLECT. EQUIVALENCE
- B Bitumen
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC Vitrinite Contam.
- VR Recycled Vitrinite

FLUOR. COLOR
- W White
- G Green
- Y Yellow
- O Orange
- R Red
- B Brown
- BL Black
- L Light
- D Dark

TAI COLOR VALUES
- 1- Straw Yellow
- 1 Pale Yellow
- 1+ Yellow
- 2- Yellow-Orange
- 2 Golden
- 2+ Amber
- 3- Reddish Brown
- 3 Medium Brown
- 3+ Dark Brown
- 4- Brown-Black
- 4 Black
- 4+ Black-Opaque

VISUAL KEROGEN ANALYSIS

BaselineDGSI

HOLITNA OUTCROP
WINDY FORK
Baseline DGSI Project: 03-211-A

BaselineDGSI Number / Sample Id or Depth	Preparation/Sample Type	Organic Matter (%): Lipids, Unstructured: Undifferentiated	Amorphous	Massive	Micrinized	Lipids, Structured: Type	Type	Type	Type	Solid Bitumen	Humic: Inertinite	Vitrinite	Other: Type	Type	Relative Abundance: Pyrite Type	Pyrite	Organic Concentration	Vitrinite: Normal	Rough	Lipid-Rich	Oxidized	Coked	Fluorescence/TAI Reflected, Lipids Unstr.: Color	Intensity	Stru.: Color	Intensity	Background Intensity	Transmitted, Lipids Unstr.: TAI Value	Fluor. Color	Intensity	Stru.: TAI Value	Fluor. Color	Intensity	Ro: Vit. Reflectance or Equiv.
NOPR WD000181 02DL53 85.5 WF	K/OC			? 20		LD T					T		VL 80		MA	-	+	N	M	+			DB	1			3	2 2+	BL	0		O Y	1 4	V 0.47
COMMENTS: Unstructured lipids have grainy-massive texture. Lipid-rich vitrinite has moderately rough texture. Ro may be slightly lowered.																																		
NOPR WD000183 02DL54 AWF	K/OC	30				LD 5					T		VL 65		MA	-	+	N	M	+			DB	1			3	? 2+	BL	0		O	1 2	V 0.53
COMMENTS: Lipid-rich vitrinite has moderately rough texture and is mixed with unstructured lipids. Some Ro values may be slightly lowered.																																		
NOPR WD000185 02DL54 D WF	K/OC	25				LD 5					T	T	VL 70		MA	-	+	T	-	+			DB	1	O	2	3 2	n.d.				Y O	2	V 0.51
COMMENTS: Lipid-rich vitrinite is mixed with unstructured material that is difficult to identify.																																		
NOPR WD000187 02DL54 F WF	K/OC					LD 20					5	55	VL 20		MA	T	+	+	-	-					O Y	1 3	3 2					O Y	1 3	V 0.59
COMMENTS: Most vitrinite is normal, but laminated with liptodetrinite.																																		

ANALYST

X O'Connor

MICROSCOPE

X Zeiss
___ Jena
___ Leitz

SAMPLE TYPE/PREP
- CTG Cuttings
- CC Conv. Core
- SWC SideWallCore
- OC Outcrop
- NI No Inform.
- C Coal
- K Kerogen
- WR Whole Rock
- n.d. Not Determined

STRUCTURED LIPIDS
- AL Alginite
- SB Suberinite
- C Cutinite
- LD Liptodetrinite
- U Undiffer.
- S Sporinite
- R Resinite
- O Other

OTHER ORGANIC MATTER
- E Exsudatinite
- G Graptolites
- V Vitrnite
- VL Lipid-Rich Vitrinite
- VC VitriniteContamination
- VR Recycled Vitrinite

PYRITE
- E Euhedral
- F Framboid
- MA Massive
- RI Replace- infill

ABUND.
- N None
- T Trace
- \- Small Amt.
- M Mod. Amt.
- \+ Large Amt.
- ++ Abundant

FLUOR. INTENS.
- 0 None
- 1 Weak
- 2 Moderate
- 3 Strong
- 4 Intense

VIT. REFLECT. EQUIVALENCE
- B Bitumen
- G Graptolites
- VL Lipid-Rich Vitrinite
- VC Vitrinite Contam.
- VR Recycled Vitrinite

FLUOR. COLOR
- W White
- G Green
- Y Yellow
- O Orange
- R Red
- B Brown
- BL Black
- L Light
- D Dark

TAI COLOR VALUES
- 1- Straw Yellow
- 1 Pale Yellow
- 1+ Yellow
- 2- Yellow-Orange
- 2 Golden
- 2+ Amber
- 3- Reddish Brown
- 3 Medium Brown
- 3+ Dark Brown
- 4- Brown-Black
- 4 Black
- 4+ Black-Opaque

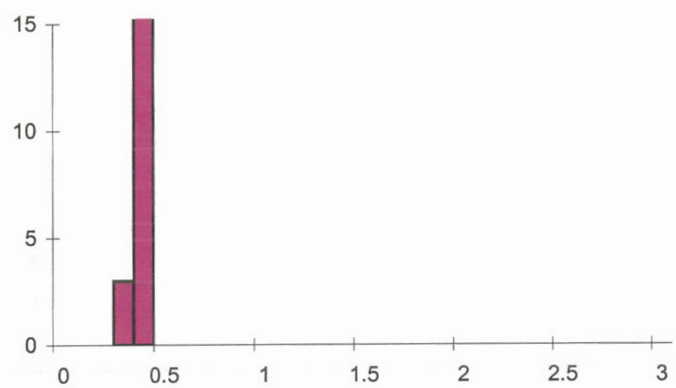
VISUAL KEROGEN ANALYSIS

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	**02DL53 0.5 WF**
Country:		**Project #:**	**03-211-A**
Basin:		**Lab ID:**	**WD000146**
Lease:		**Sample Type:**	**OTCP**
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	**WINDY FORK SAMPLES HOLITNA OUTCROP**	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Vitrinite Data:

L0.38	L0.48
L0.38	L0.48
L0.39	L0.49
L0.401	L0.49
L0.401	
L0.401	
L0.401	
L0.41	
L0.41	
L0.43	
L0.43	
L0.44	
L0.44	
L0.45	
L0.45	
L0.47	
L0.47	
L0.48	
L0.48	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.44				
STDEV:	0.04				
Variance:	0				
Min:	0.38				
Max:	0.49				
Number:	23				

TOC

TYPE	K/OC
TOC	42.035
TMAX	407
HI	236
V Ro	0.44

Visual Kerogen Summary

	%
Unstructured Lipids	10
Structured Lipids	0
Solid Bitumen	
Inertinite	
Vitrinite	
Other	90
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3
TAI Unstructured	n.d.
TAI Structured	

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

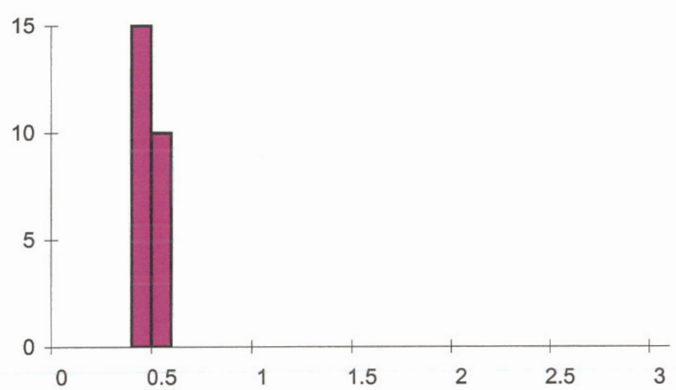
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 2.6 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000148
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.44	L0.51
L0.44	L0.52
L0.45	L0.52
L0.45	L0.53
L0.46	L0.54
L0.47	L0.54
L0.47	
L0.48	
L0.48	
L0.48	
L0.49	
L0.49	
L0.49	
L0.49	
L0.49	
L0.501	
L0.51	
L0.51	
L0.51	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.49				
STDEV:	0.03				
Variance:	0				
Min:	0.44				
Max:	0.54				
Number:	25				

TOC

TYPE	K/OC
TOC	60.815
TMAX	410
HI	198
V Ro	0.49

Visual Kerogen Summary

	%
Unstructured Lipids	5
Structured Lipids	0
Solid Bitumen	
Inertinite	
Vitrinite	
Other	95
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	2	3
TAI Unstructured		n.d.
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

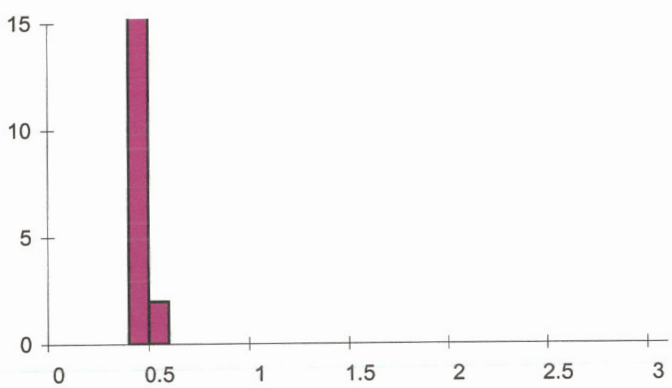
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	02DL53 11.8 WF
Country:		**Project #:**	03-211-A
Basin:		**Lab ID:**	WD000151
Lease:		**Sample Type:**	OTCP
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Vitrinite Data:

L0.42	L0.47
L0.43	L0.48
L0.43	L0.49
L0.44	L0.49
L0.44	L0.501
L0.44	L0.51
L0.45	
L0.45	
L0.45	
L0.45	
L0.46	
L0.46	
L0.46	
L0.46	
L0.46	
L0.46	
L0.47	
L0.47	
L0.47	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.46				
STDEV:	0.02				
Variance:	0				
Min:	0.42				
Max:	0.51				
Number:	25				

TOC

TYPE	K/OC
TOC	33.185
TMAX	413
HI	312
V Ro	0.46

Visual Kerogen Summary

	%
Unstructured Lipids	10
Structured Lipids	5
Solid Bitumen	
Inertinite	
Vitrinite	
Other	85
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3
TAI Unstructured	n.d.
TAI Structured	

COMMENTS:

Baseline/DGSI - USA
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E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

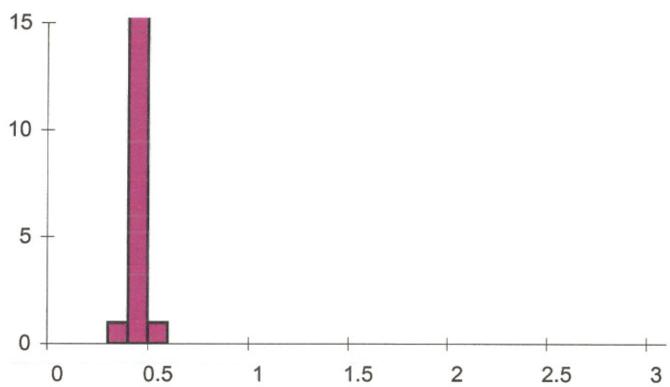
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 28.05 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000154
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.39	L0.47
L0.41	L0.48
V0.41	L0.48
L0.42	L0.48
L0.42	L0.49
L0.42	L0.52
L0.42	
L0.42	
L0.42	
L0.43	
L0.43	
L0.43	
L0.44	
L0.46	
L0.46	
L0.46	
L0.46	
L0.46	
L0.47	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.45				
STDEV:	0.03				
Variance:	0				
Min:	0.39				
Max:	0.52				
Number:	25				

TOC

TYPE	K/OC
TOC	36.995
TMAX	419
HI	279
V Ro	0.45

Visual Kerogen Summary

	%
Unstructured Lipids	20
Structured Lipids	5
Solid Bitumen	
Inertinite	T
Vitrinite	T
Other	75
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3
TAI Unstructured	n.d.
TAI Structured	

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
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E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

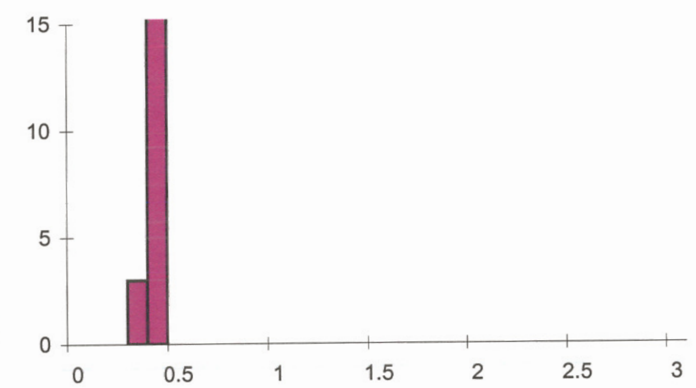
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI — ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 34 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000157
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.34	L0.46
L0.38	L0.47
L0.38	L0.47
L0.401	L0.47
L0.41	L0.48
L0.41	L0.49
L0.41	
L0.44	
L0.44	
L0.44	
L0.44	
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	
L0.46	
L0.46	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.44				
STDEV:	0.04				
Variance:	0				
Min:	0.34				
Max:	0.49				
Number:	25				

TOC

TYPE	K/OC
TOC	48.725
TMAX	411
HI	220
V Ro	0.44

Visual Kerogen Summary

	%
Unstructured Lipids	30
Structured Lipids	0
Solid Bitumen	
Inertinite	T
Vitrinite	
Other	70
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	2
TAI Unstructured	2+
TAI Structured	

COMMENTS:

Baseline/DGSI - USA
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Web Site: http://www.baselinedgsi.com

Baseline DGSI - Brazil
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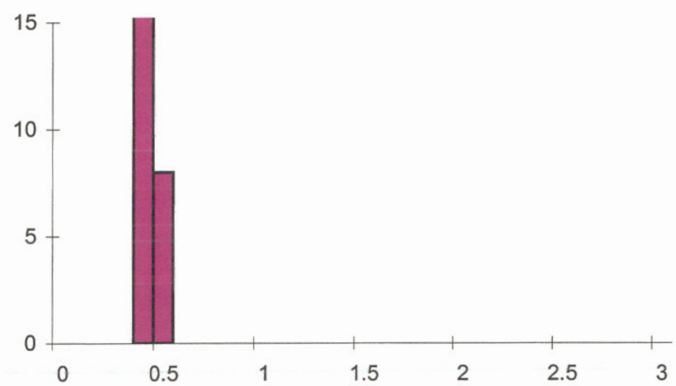
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 38 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000160
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.48				
STDEV:	0.03				
Variance:	0				
Min:	0.42				
Max:	0.55				
Number:	25				

TOC

TYPE	K/OC
TOC	31.91
TMAX	414
HI	258
V Ro	0.48

Visual Kerogen Summary

	%
Unstructured Lipids	5
Structured Lipids	0
Solid Bitumen	
Inertinite	
Vitrinite	
Other	95
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3
TAI Unstructured	n.d.
TAI Structured	

COMMENTS:

Vitrinite Data:

L0.42	L0.51
L0.42	L0.51
L0.44	L0.52
L0.44	L0.52
L0.45	L0.53
L0.45	L0.55
L0.45	
L0.46	
L0.47	
L0.47	
L0.47	
L0.48	
L0.48	
L0.48	
L0.49	
L0.49	
L0.49	
L0.501	
L0.501	

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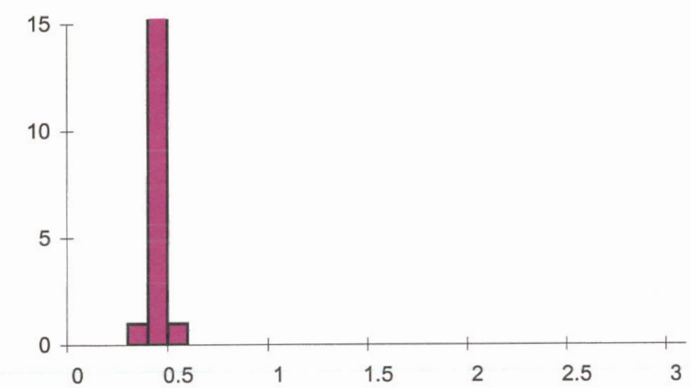
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	**02DL53 42 WF**
Country:		**Project #:**	**03-211-A**
Basin:		**Lab ID:**	**WD000162**
Lease:		**Sample Type:**	**OTCP**
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	**WINDY FORK SAMPLES HOLITNA OUTCROP**	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Vitrinite Data:

L0.39	L0.46
L0.41	L0.46
L0.41	L0.46
L0.42	L0.46
L0.42	L0.47
L0.42	L0.501
L0.42	
L0.42	
L0.42	
L0.42	
L0.43	
L0.44	
L0.44	
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.44				
STDEV:	0.02				
Variance:	0				
Min:	0.39				
Max:	0.5				
Number:	25				

TOC

TYPE	K/OC
TOC	55.835
TMAX	406
HI	259
V Ro	0.44

Visual Kerogen Summary

	%
Unstructured Lipids	20
Structured Lipids	0
Solid Bitumen	
Inertinite	
Vitrinite	
Other	80
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3	4
TAI Unstructured		n.d.
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

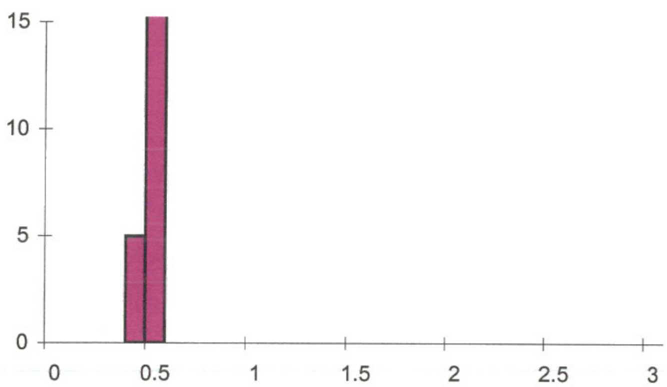
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 44 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000163
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.51				
STDEV:	0.02				
Variance:	0				
Min:	0.48				
Max:	0.54				
Number:	27				

TOC

TYPE	K/OC
TOC	74.345
TMAX	409
HI	173
V Ro	0.51

Vitrinite Data:

L0.48	L0.52
L0.49	L0.52
L0.49	L0.52
L0.49	L0.53
L0.49	L0.53
L0.501	L0.54
L0.501	L0.54
L0.501	L0.54
L0.501	
L0.501	
L0.501	
L0.501	
L0.501	
L0.51	
L0.51	
L0.51	
L0.51	
L0.52	
L0.52	

Visual Kerogen Summary

	%
Unstructured Lipids	0
Structured Lipids	0
Solid Bitumen	
Inertinite	
Vitrinite	
Other	100
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	1	2
TAI Unstructured		n.d.
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

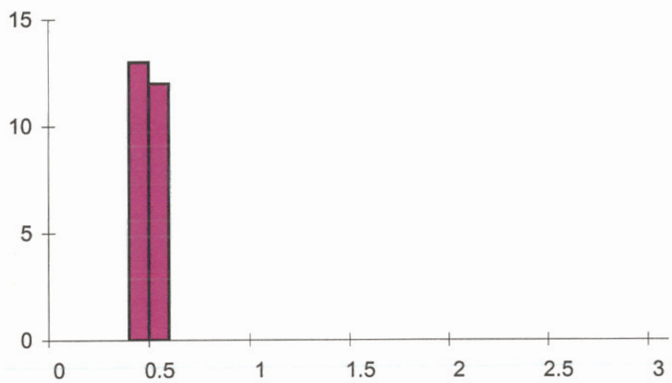
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	02DL53 48 WF
Country:		**Project #:**	03-211-A
Basin:		**Lab ID:**	WD000165
Lease:		**Sample Type:**	OTCP
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.49				
STDEV:	0.03				
Variance:	0				
Min:	0.43				
Max:	0.54				
Number:	25				

TOC

TYPE	K/OC
TOC	44.85
TMAX	410
HI	240
V Ro	0.49

Vitrinite Data:

L0.43	L0.51
L0.44	L0.52
L0.44	L0.52
L0.45	L0.52
L0.46	L0.53
L0.46	L0.54
L0.47	
L0.47	
L0.47	
L0.47	
L0.47	
L0.49	
L0.49	
L0.501	
L0.501	
L0.501	
L0.51	
L0.51	
L0.51	

Visual Kerogen Summary

	%
Unstructured Lipids	20
Structured Lipids	0
Solid Bitumen	
Inertinite	T
Vitrinite	
Other	80
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3
TAI Unstructured	n.d.
TAI Structured	

COMMENTS:

Baseline/DGSI - USA
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Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

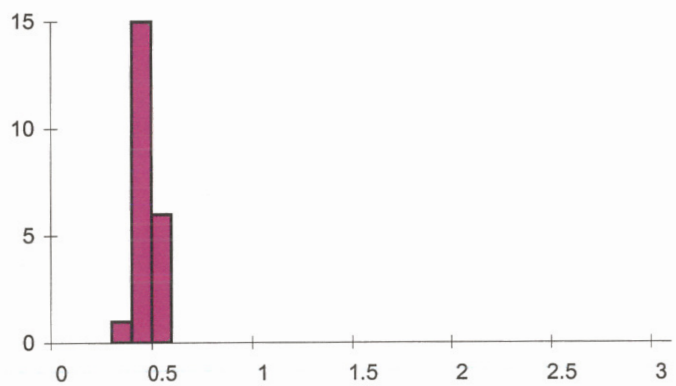
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	**02DL53 54 WF**
Country:		**Project #:**	**03-211-A**
Basin:		**Lab ID:**	**WD000168**
Lease:		**Sample Type:**	**OTCP**
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	**WINDY FORK SAMPLES HOLITNA OUTCROP**	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Vitrinite Data:

L0.39	L0.53
L0.42	L0.53
L0.42	L0.53
L0.42	
L0.43	
L0.43	
L0.43	
L0.44	
L0.44	
L0.45	
L0.45	
L0.46	
L0.47	
L0.48	
L0.49	
L0.49	
L0.501	
L0.52	
L0.53	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.47				
STDEV:	0.04				
Variance:	0				
Min:	0.39				
Max:	0.53				
Number:	22				

TOC

TYPE	K/OC
TOC	26.875
TMAX	419
HI	253
V Ro	0.47

Visual Kerogen Summary

	%
Unstructured Lipids	20
Structured Lipids	5
Solid Bitumen	
Inertinite	
Vitrinite	
Other	75
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3	4
TAI Unstructured		n.d.
TAI Structured		

COMMENTS:

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Telephone: 281-681-2200
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E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

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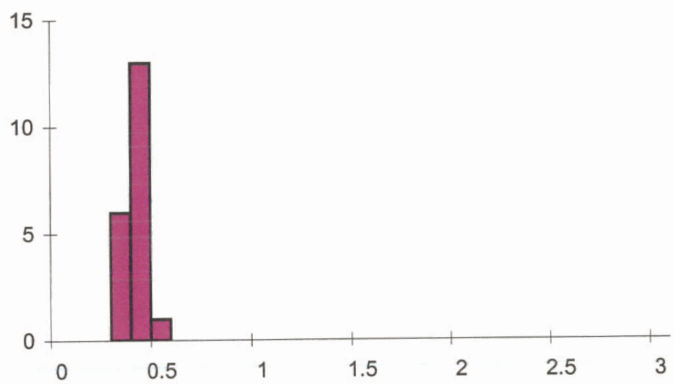
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 58 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000170
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.32 L0.51
L0.36
L0.37
L0.38
L0.38
L0.39
L0.401
L0.41
L0.42
L0.42
L0.43
L0.43
L0.43
L0.44
L0.45
L0.45
L0.45
L0.46
L0.47

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.42				
STDEV:	0.04				
Variance:	0				
Min:	0.32				
Max:	0.51				
Number:	20				

TOC

TYPE	K/OC
TOC	7.45
TMAX	423
HI	211
V Ro	0.42

Visual Kerogen Summary

	%
Unstructured Lipids	30
Structured Lipids	0
Solid Bitumen	
Inertinite	
Vitrinite	
Other	70
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	2	3
TAI Unstructured	?	2+
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
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Web Site: http://www.baselinedgsi.com

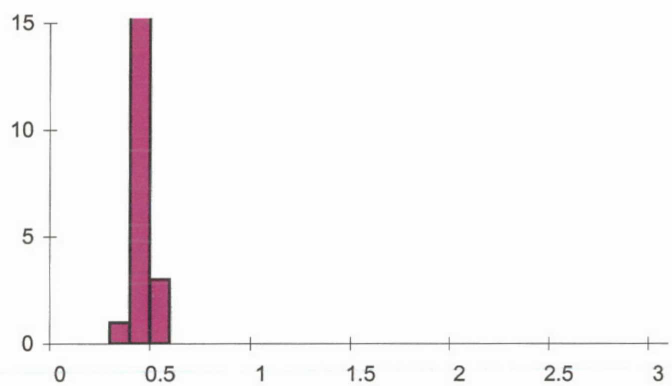
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 62 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000172
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.39	L0.47
L0.401	L0.47
L0.401	L0.48
L0.41	L0.501
L0.41	L0.501
L0.41	L0.501
L0.42	
L0.43	
L0.43	
L0.43	
L0.44	
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	
L0.46	
L0.47	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.45				
STDEV:	0.03				
Variance:	0				
Min:	0.39				
Max:	0.5				
Number:	25				

TOC

TYPE	K/OC
TOC	3.18
TMAX	427
HI	109
V Ro	0.45

Visual Kerogen Summary

	%
Unstructured Lipids	10
Structured Lipids	5
Solid Bitumen	
Inertinite	T
Vitrinite	
Other	85
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	2
TAI Unstructured	n.d.
TAI Structured	

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

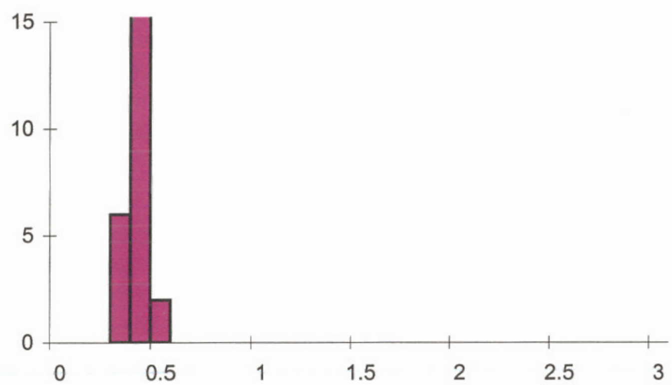
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	**02DL53 71 WF**
Country:		**Project #:**	**03-211-A**
Basin:		**Lab ID:**	**WD000174**
Lease:		**Sample Type:**	**OTCP**
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	**WINDY FORK SAMPLES HOLITNA OUTCROP**	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.43				
STDEV:	0.05				
Variance:	0				
Min:	0.34				
Max:	0.51				
Number:	25				

Vitrinite Data:

L0.34	L0.48
L0.34	L0.48
L0.35	L0.49
L0.35	L0.49
L0.36	L0.501
L0.39	L0.51
L0.401	
L0.41	
L0.41	
L0.42	
L0.42	
L0.42	
L0.43	
L0.43	
L0.45	
L0.45	
L0.45	
L0.47	
L0.47	

TOC

TYPE	K/OC
TOC	70.24
TMAX	420
HI	217
V Ro	0.43

Visual Kerogen Summary

	%
Unstructured Lipids	10
Structured Lipids	15
Solid Bitumen	
Inertinite	T
Vitrinite	
Other	75
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	2	3
TAI Unstructured		2+
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

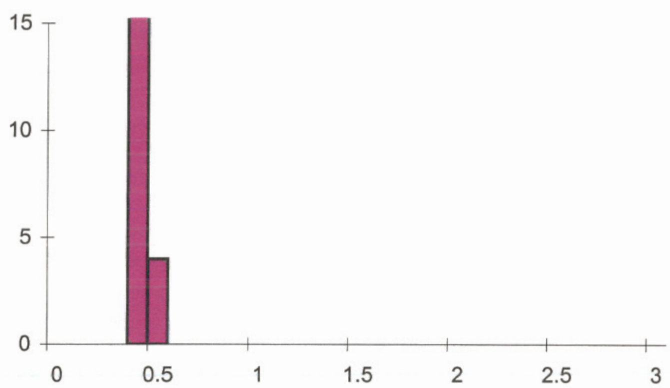
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 76 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000176
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.401	L0.49
L0.42	L0.49
L0.43	L0.501
L0.44	L0.501
L0.45	L0.51
L0.45	L0.53
L0.45	
L0.46	
L0.46	
L0.46	
L0.46	
L0.46	
L0.46	
L0.47	
L0.47	
L0.48	
L0.48	
L0.48	
L0.49	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.47				
STDEV:	0.03				
Variance:	0				
Min:	0.4				
Max:	0.53				
Number:	25				

TOC

TYPE	K/OC
TOC	42.88
TMAX	418
HI	256
V Ro	0.47

Visual Kerogen Summary

	%
Unstructured Lipids	15
Structured Lipids	5
Solid Bitumen	
Inertinite	T
Vitrinite	
Other	80
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3	2
TAI Unstructured		2+
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

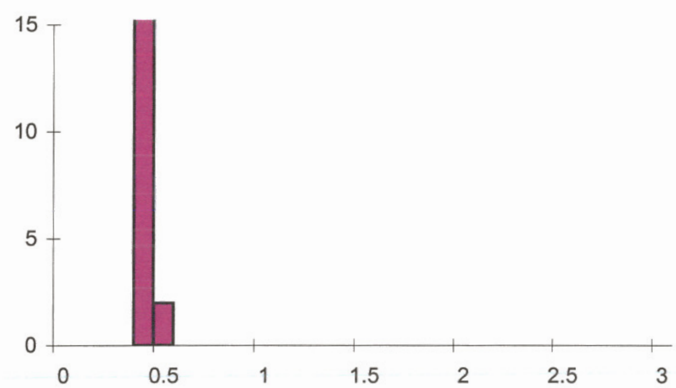
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 80 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000178
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.46				
STDEV:	0.03				
Variance:	0				
Min:	0.4				
Max:	0.54				
Number:	27				

TOC

TYPE	K/OC
TOC	33.865
TMAX	417
HI	277
V Ro	0.46

Vitrinite Data:

L0.401	L0.47
L0.41	L0.47
L0.42	L0.48
L0.43	L0.48
L0.44	L0.48
L0.44	L0.49
L0.44	L0.501
L0.44	L0.54
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	
L0.45	
L0.46	
L0.46	
L0.46	
L0.46	
L0.46	

Visual Kerogen Summary

	%
Unstructured Lipids	10
Structured Lipids	5
Solid Bitumen	
Inertinite	5
Vitrinite	
Other	80
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3	4
TAI Unstructured		n.d.
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
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E-mail: info@baselinedgsi.com
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Baseline DGSI - Brazil
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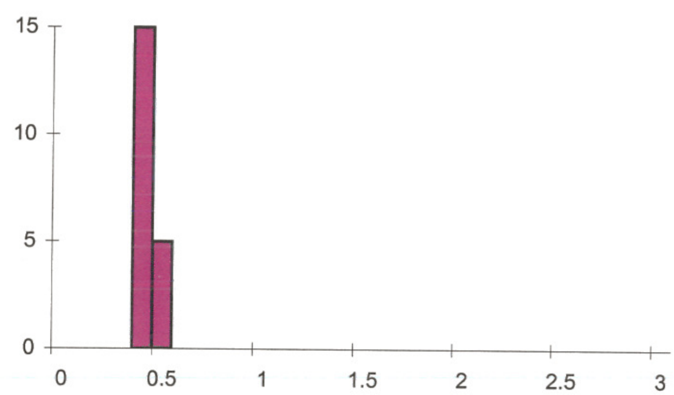
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL53 85.5 WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000181
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.42	L0.52
L0.42	
L0.43	
L0.43	
L0.43	
L0.46	
L0.46	
L0.47	
L0.47	
L0.47	
L0.48	
L0.48	
L0.48	
L0.49	
L0.49	
L0.501	
L0.501	
L0.51	
L0.51	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.47				
STDEV:	0.03				
Variance:	0				
Min:	0.42				
Max:	0.52				
Number:	20				

TOC

TYPE	K/OC
TOC	12.78
TMAX	424
HI	194
V Ro	0.47

Visual Kerogen Summary

	%
Unstructured Lipids	20
Structured Lipids	0
Solid Bitumen	
Inertinite	T
Vitrinite	
Other	80
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence		3
TAI Unstructured	2	2+
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
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E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

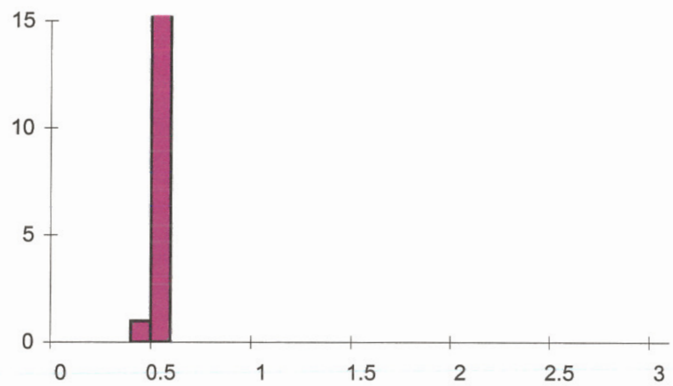
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI
ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		Client ID:	02DL54 A WF
Country:		Project #:	03-211-A
Basin:		Lab ID:	WD000183
Lease:		Sample Type:	OTCP
Block:		Sampling Point:	
Field:		Formation:	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	Geologic Age:	
Latitude:		Top Depth:	
Longitude:		Bottom Depth:	

Histogram Vitrinite Data



Vitrinite Data:

L0.47	L0.55
L0.501	L0.55
L0.51	L0.57
L0.51	L0.57
L0.51	
L0.51	
L0.51	
L0.52	
L0.52	
L0.52	
L0.53	
L0.53	
L0.53	
L0.53	
L0.54	
L0.54	
L0.54	
L0.54	
L0.55	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.53				
STDEV:	0.02				
Variance:	0				
Min:	0.47				
Max:	0.57				
Number:	23				

TOC

TYPE	K/OC
TOC	4.84
TMAX	429
HI	153
V Ro	0.53

Visual Kerogen Summary

	%
Unstructured Lipids	30
Structured Lipids	5
Solid Bitumen	
Inertinite	T
Vitrinite	
Other	65
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence		3
TAI Unstructured	?	2+
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

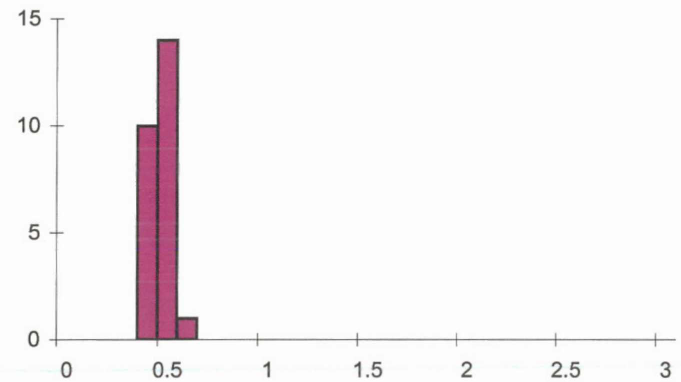
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	**02DL54 D WF**
Country:		**Project #:**	**03-211-A**
Basin:		**Lab ID:**	**WD000185**
Lease:		**Sample Type:**	**OTCP**
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	**WINDY FORK SAMPLES HOLITNA OUTCROP**	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Vitrinite Data:

L0.43	L0.53
L0.47	L0.54
L0.47	L0.55
L0.47	L0.55
L0.48	V0.55
L0.48	L0.61
L0.48	
L0.49	
L0.49	
V0.49	
L0.501	
L0.501	
L0.51	
L0.51	
L0.51	
L0.52	
L0.52	
L0.52	
L0.53	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.51				
STDEV:	0.04				
Variance:	0				
Min:	0.43				
Max:	0.61				
Number:	25				

TOC

TYPE	K/OC
TOC	2.52
TMAX	425
HI	190
V Ro	0.51

Visual Kerogen Summary

	%
Unstructured Lipids	25
Structured Lipids	5
Solid Bitumen	
Inertinite	T
Vitrinite	T
Other	70
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3	2
TAI Unstructured		n.d.
TAI Structured		

COMMENTS:

Baseline/DGSI - USA
8701 New Trails Drive, The Woodlands, TX 77381-4241
Telephone: 281-681-2200
Facsimile: 281-681-0326
E-mail: info@baselinedgsi.com
Web Site: http://www.baselinedgsi.com

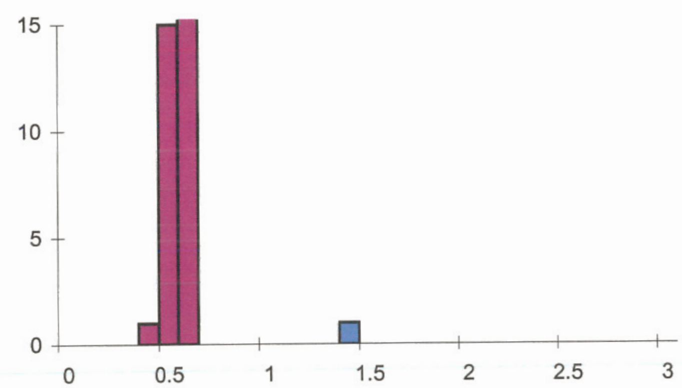
Baseline DGSI - Brazil
Rua Benjamin Batista 55 / 301 Jardim Botânico,
22461-120 Rio de Janeiro (RJ) – Brazil
Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

BASELINE DGSI ANALYTICAL LABORATORIES

VITRINITE REFLECTANCE

Company:		**Client ID:**	02DL54 F WF
Country:		**Project #:**	03-211-A
Basin:		**Lab ID:**	WD000187
Lease:		**Sample Type:**	OTCP
Block:		**Sampling Point:**	
Field:		**Formation:**	
Well Name:	WINDY FORK SAMPLES HOLITNA OUTCROP	**Geologic Age:**	
Latitude:		**Top Depth:**	
Longitude:		**Bottom Depth:**	

Histogram Vitrinite Data



Vitrinite Data:

V0.49	V0.62
L0.501	V0.62
V0.52	V0.62
L0.53	V0.63
L0.54	V0.63
L0.54	V0.63
V0.54	V0.63
V0.54	V0.63
V0.55	V0.64
L0.56	V0.64
L0.56	V0.65
L0.57	V0.65
L0.57	V0.65
V0.57	V0.66
V0.57	V0.67
L0.59	v1.48
V0.601	
V0.62	
V0.62	

Sample Info

Vitrinite	Vit	Bit	Oth	LRV	Grap
Mean:	0.59				
STDEV:	0.05				
Variance:	0				
Min:	0.49				
Max:	0.67				
Number:	34				

TOC

TYPE	K/OC
TOC	60.935
TMAX	418
HI	257
V Ro	0.59

Visual Kerogen Summary

	%
Unstructured Lipids	0
Structured Lipids	20
Solid Bitumen	
Inertinite	5
Vitrinite	55
Other	20
TOTAL	100

Visual Kerogen Fluorescence

Background Fluorescence	3	2
TAI Unstructured		
TAI Structured		

COMMENTS:

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Tel/Fax: + 55.21 / 537 7893
E-mail: ssp@solintec.com.br

GAS CHROMATOGRAPHY
High Resolution Capillary GC (HRCGC)

Techniques and Parameters

High Resolution Capillary Gas Chromatography (HRCGC) is an analytical technique which is used to separate and identify a multitude of hydrocarbon compounds in a crude oil or a rock extract. A single analysis on an oil can resolve compounds in great detail between C_2 and C_{40} which previously took three separate runs to achieve. For a rock extract only the fraction C_{15+} is preserved. Compounds less than C_{15} are partially lost during extraction. Key compounds are identified and ratios calculated which are then used to interpret the kerogen type, organic facies, depositional environment and thermal history in the source rocks; the origin, type, thermal maturity and other alteration effects including water washing, biodegradation and evaporative fractionation in crude oils; and to help make oil-oil and oil-source rock correlations.

Whole Extract Gas Chromatography

About 50 grams of sample are crushed, passed through a 20 micron sieve, accurately weighed, and soxhlet extracted for 16 hours with dichloromethane. Other solvents can be substituted if desired. The solvent is evaporated and the residue weighed to obtain the weight percent of total organic extract. The advantage to doing whole extract chromatography is that more of the lighter fraction (C_{10} – C_{15}) is preserved than if the saturated fraction were separated by column chromatography. A disadvantage is that nonsaturate compounds are retained which may complicate the chromatogram. Fortunately, this is a problem only in some relatively immature extracts. A sample of whole extract is injected directly into a gas chromatograph fitted with the same GC column and using the same temperature programming and computer software described in the section on whole oil analysis. A gas chromatogram as shown in Figure 1A is provided.

Whole extract gas chromatography provides information on the organic facies and thermal maturity of source rocks, on migrated petroleum, and serves as a basis for oil-rock correlations. It is recommended primarily to evaluate known or suspected source beds, oil shows, samples with anomalous pyrolysis S_1 values and to identify possible contamination products.

Aromatic GC

High Pressure Liquid Chromatography is used to prepare an aromatic fraction, which is then injected into a Varian model 3400 gas chromatograph, fitted with a Quadrex 50 meter fused silica capillary column. The GC is programmed from 40°C to 350°C at 10°C/minute with a two minute hold at 40°C and a 20 minute hold at 350°C. Analytical data are processed with Genie Software System® and HP ChemStation data acquisition software. This software system facilitates data processing and graphic display as well as electronic data transmission. Thirty-three aromatic hydrocarbons are separated and detected and these are broken down into six aromatic hydrocarbon types.

Whole Oil GC

A sample of whole oil is injected directly into a Varian model 3400 gas chromatograph fitted with a Quadrex 50 meter fused silica capillary column. The GC is programmed from 40 to 350° C at 10° C/minute with a 2 minute hold at 40° and a 20 minute hold at 350° C. Analytical data are processed with Genie Software System and HP ChemStation data acquisition software. This software system facilitates data processing and graphic display as well as electronic data transmittal. All standard calculations are made including pristane/phytane ratio, carbon preference index, and other key parameters (Tables 1 and 2). Two gas chromatograms are provided, one showing all compounds between nC_2 and nC_{40} (Figure 1A) and the other a computer enhanced version of the chromatogram between nC_2 and nC_{10} (Figure 1 B). Compounds as low as ethane can be detected if present. In addition, the concentration of C_{13} to C_{20} isoprenoids are determined and plotted (see example of standard report).

BASELINE DGSI
ANALYTICAL LABORATORIES

SOXHLET

WINDY FORK SAMPLES HOLITNA OUTCROPS — Project #: 03-211-A

Client ID	Lab ID	Rock Weight (g)	Net Extract Weight (g)	% Extract	EOM (ppm)
02DL53 0.5 WF	WD000146	53.8083	0.1961	0.36	3644
02DL53 11.8 WF	WD000151	21.3310	0.0944	0.44	4425
02DL53 38 WF	WD000160	36.8598	0.1817	0.49	4929
02DL53 42 WF	WD000162	37.9337	0.1005	0.26	2649
02DL53 54 WF	WD000168	46.6886	0.0968	0.21	2073
02DL53 71 WF	WD000174	46.5771	0.0514	0.11	1104
02DL53 80 WF	WD000178	30.7105	0.1614	0.53	5256
02DL54 F WF	WD000187	42.5603	0.3282	0.77	7711

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22461-120 Rio de Janeiro (RJ) – Brazil
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WHOLE EXTRACT GAS CHROMATOGRAPHY

Holitna Outcrop
WINDY FORK SAMPLES
BaselineDGSI Project: 03/211A

Sample Identification ID		TOC Wt%	PPM	Ext./TOC	GAS CHROMATOGRAPHY RATIOS Pr/Ph	Pr/C17	Ph/C18	OEP
WD000146 :	02DL53 0.5 WF	42.04	3644	0.009	4.5	3.88	0.68	3.00
WD000151 :	02DL53 11.8 WF	33.19	4425	0.013	2.9	2.29	0.60	3.19
WD000154 :	02DL53 28.05 WF	37.00	10045	0.027	3.3	3.03	0.79	2.98
WD000160 :	02DL53 38 WF	31.91	4929	0.015	2.9	2.99	0.79	3.33
WD000162 :	02DL53 42 WF	55.84	2649	0.005	3.1	2.42	0.68	3.40
WD000168 :	02DL53 54 WF	26.88	2073	0.008	2.3	3.29	1.20	3.42
WD000174 :	02DL53 71 WF	70.24	1104	0.002	1.8	1.87	0.66	2.78
WD000178 :	02DL53 80 WF	33.87	5256	0.016	3.9	4.35	0.88	3.06
WD000187 :	02DL54 F WF	60.94	7711	0.013	6.1	3.26	0.40	3.03

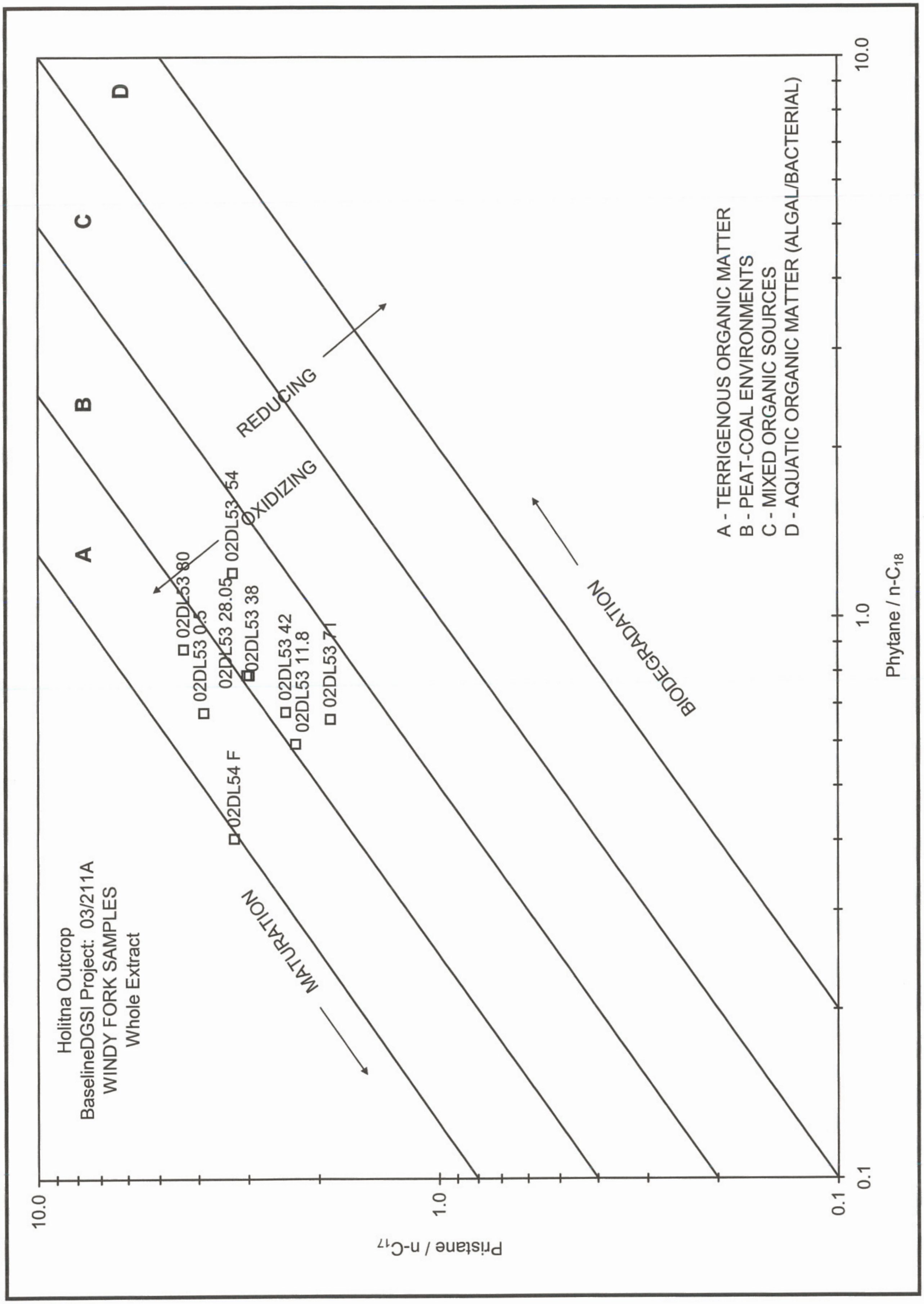
ID	Sample Weight	Extract Weight	C17	Pr	AREA DATA C18	Ph	C28	C29	C30
WD000146 :	53.8083	0.1961	32585	126489	41306	27980	25157	62413	16434
WD000151 :	21.3309994	0.0944	45083	103095	59888	35692	32029	81054	18800
WD000154 :	36.1777992	0.36340001	24453	74014	28403	22453	19281	47745	12720
WD000160 :	36.8597984	0.18170001	37019	110622	48431	38252	45063	119428	26763
WD000162 :	37.9337006	0.1005	61872	149914	71131	48336	55433	160017	38807
WD000168 :	46.6885986	0.0968	47793	157077	57352	68941	73743	209973	49116
WD000174 :	46.5770988	0.0514	52913	99062	82492	54439	33680	78131	22526
WD000178 :	30.7105007	0.16140001	28275	123038	36000	31653	51004	130598	34356
WD000187 :	42.5602989	0.32820001	28705	93493	38159	15412	19207	45068	10560

WHOLE EXTRACT GAS CHROMATOGRAPHY

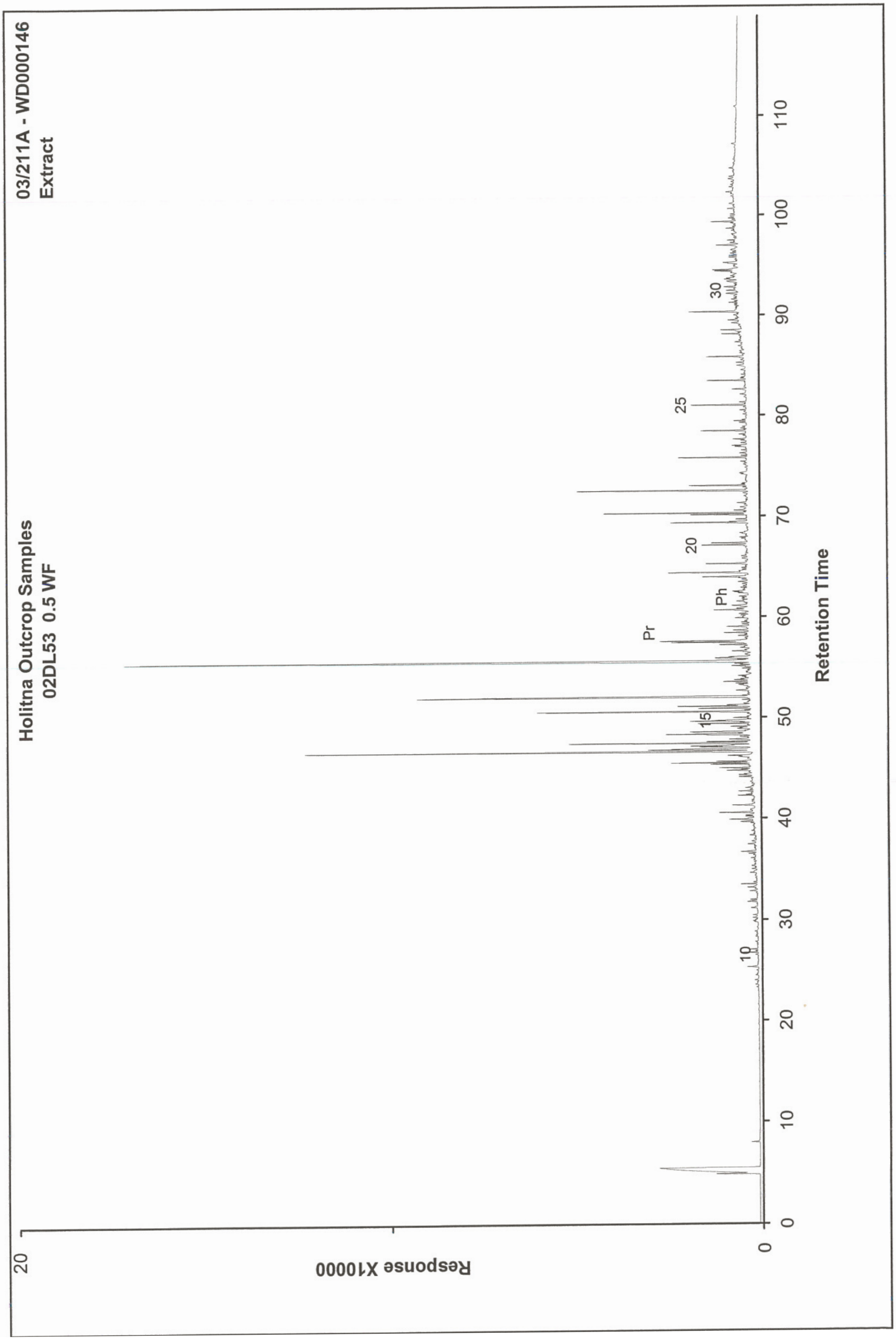
Holitna Outcrop
WINDY FORK SAMPLES
BaselineDGSI Project: 03/211A

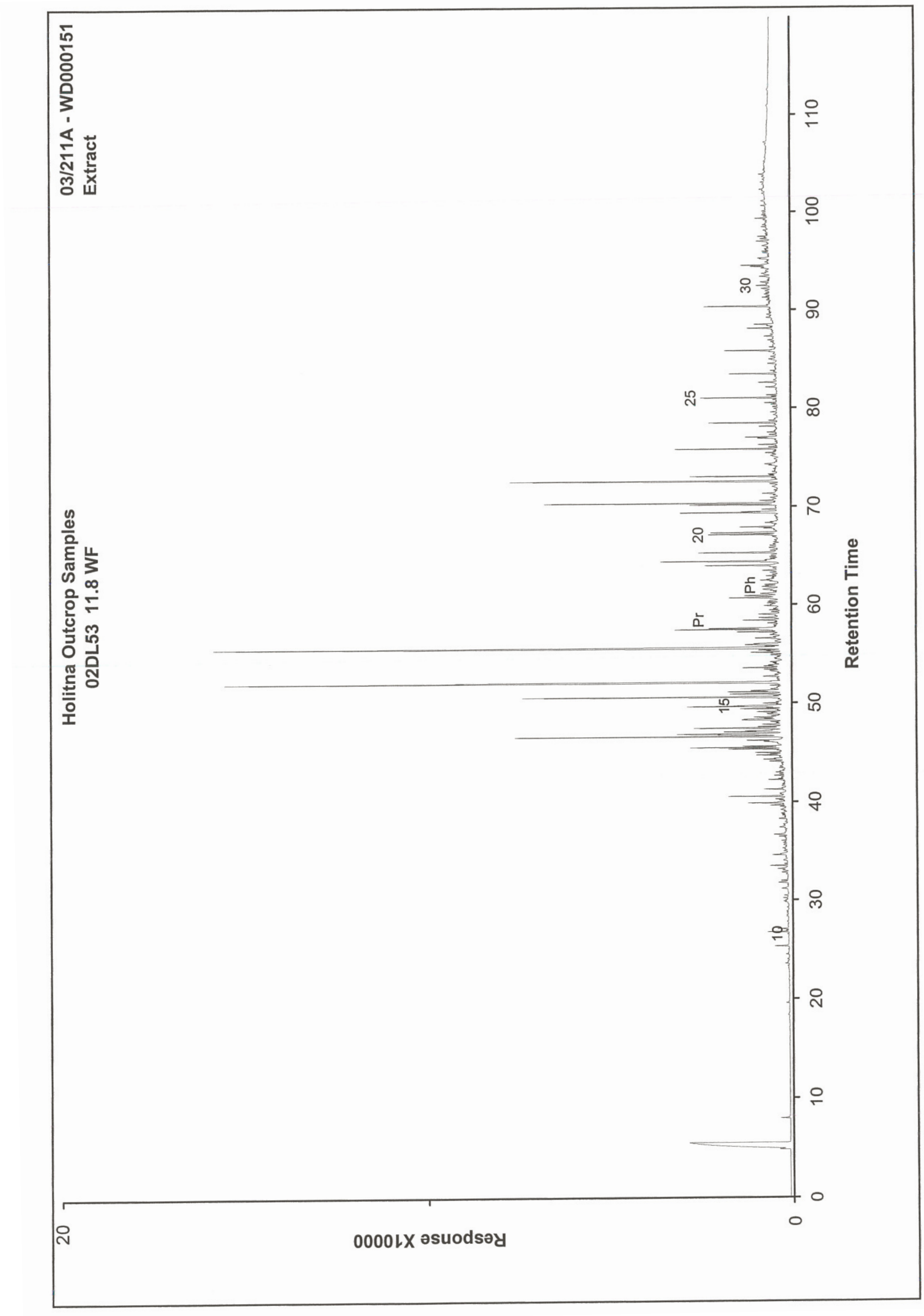
Sample Identification ID	NORMALIZED ISOPRENOID PERCENT iC13	iC14	iC15	iC16	iC18	iC19	iC20
WD000146 : 02DL53 0.5 WF	4.0	3.5	12.4	17.3	N.A.	51.4	11.4
WD000151 : 02DL53 11.8 WF	4.0	2.8	14.1	19.1	N.A.	44.7	15.5
WD000154 : 02DL53 28.05 WF	7.5	3.3	12.7	15.1	N.A.	47.1	14.3
WD000160 : 02DL53 38 WF	2.8	1.6	8.3	11.0	N.A.	56.7	19.6
WD000162 : 02DL53 42 WF	2.5	1.6	7.4	12.8	N.A.	57.2	18.4
WD000168 : 02DL53 54 WF	1.4	0.9	4.1	28.7	N.A.	45.1	19.8
WD000174 : 02DL53 71 WF	0.1	0.4	3.0	6.8	N.A.	57.8	31.8
WD000178 : 02DL53 80 WF	0.6	1.3	5.4	10.5	N.A.	65.3	16.8
WD000187 : 02DL54 F WF	4.0	5.6	6.5	19.6	N.A.	55.1	9.1

Sample Identification ID	AREA DATA iC13	iC14	iC15	iC16	iC18	iC19	iC20
WD000146 : 02DL53 0.5 WF	9735	8705	30621	42449	n.d.	126489	27980
WD000151 : 02DL53 11.8 WF	9123	6432	32431	44034	n.d.	103095	35692
WD000154 : 02DL53 28.05 WF	11794	5233	19997	23671	n.d.	74014	22453
WD000160 : 02DL53 38 WF	5494	3104	16124	21478	n.d.	110622	38252
WD000162 : 02DL53 42 WF	6627	4239	19526	33536	n.d.	149914	48336
WD000168 : 02DL53 54 WF	5012	3109	14256	100102	n.d.	157077	68941
WD000174 : 02DL53 71 WF	232	721	5190	11633	n.d.	99062	54439
WD000178 : 02DL53 80 WF	1163	2515	10151	19766	n.d.	123038	31653
WD000187 : 02DL54 F WF	6840	9574	11067	33289	n.d.	93493	15412



Plot from chromatography data showing organic matter type, source rock depositional environment, and thermal maturity.


Holitna Outcrop Samples
02DL53 0.5 WF
03/211A - WD000146
Extract
Response X10000
Retention Time
20
0
0
10
20
30
40
50
60
70
80
90
100
110
10
15
Pr
Ph
20
25
30


Holitna Outcrop Samples
02DL53 11.8 WF
03/211A - WD000151
Extract
Response X10000
20
0
Retention Time
0
10
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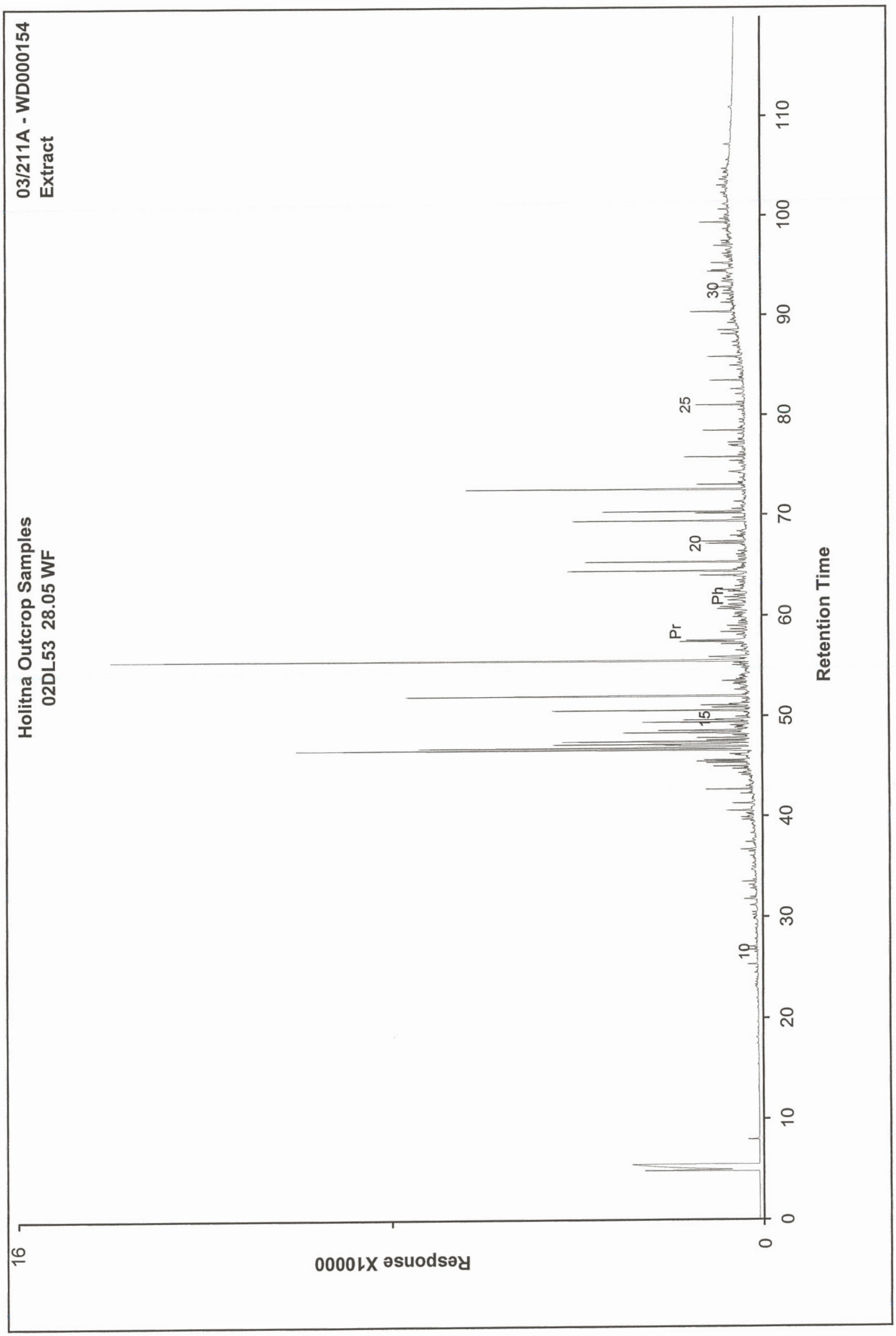
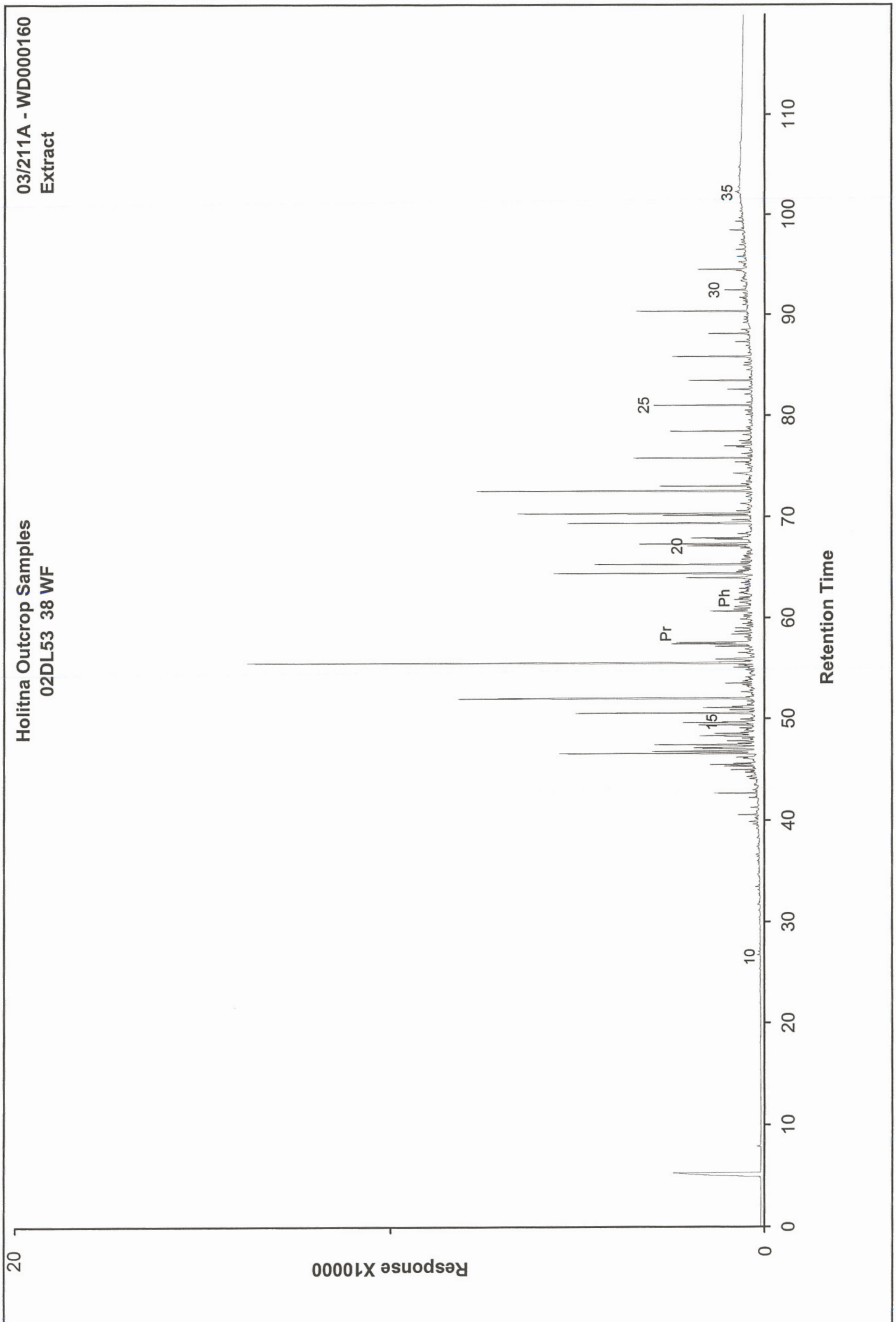
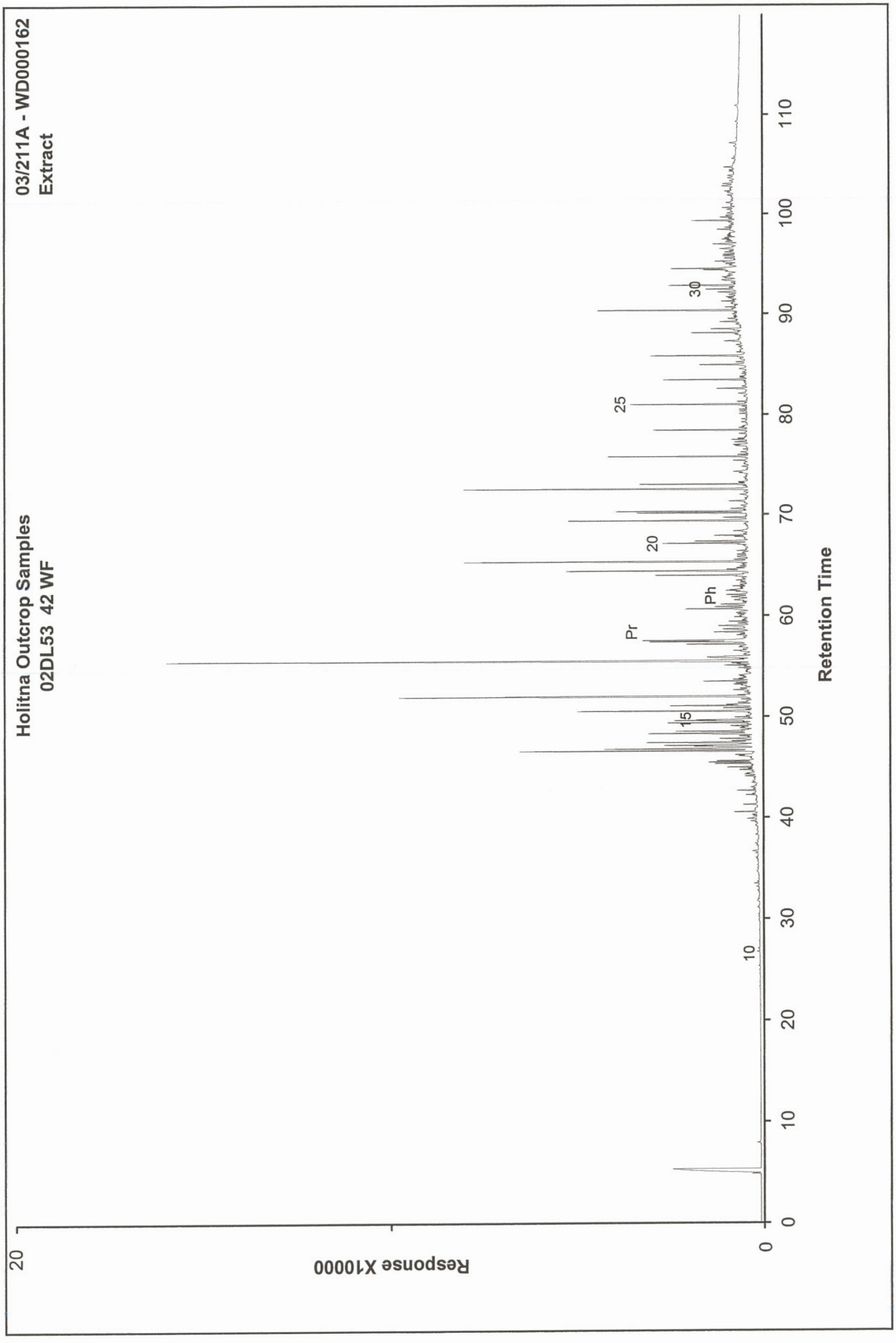
30
40
50
60
70
80
90
100
110
10
15
Pr
Ph
20
25
30


Holitna Outcrop Samples
02DL53 28.05 WF
03/211A - WD000154
Extract
Response X10000
Retention Time
Pr
Ph
10
15
20
25
30


Holitna Outcrop Samples
02DL53 38 WF
03/211A - WD000160
Extract
Response X10000
Retention Time
Pr
Ph
10
15
20
25
30
35


Holitna Outcrop Samples
02DL53 42 WF
03/211A - WD000162
Extract
Response X10000
20
0
Retention Time
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10
20
30
40
50
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70
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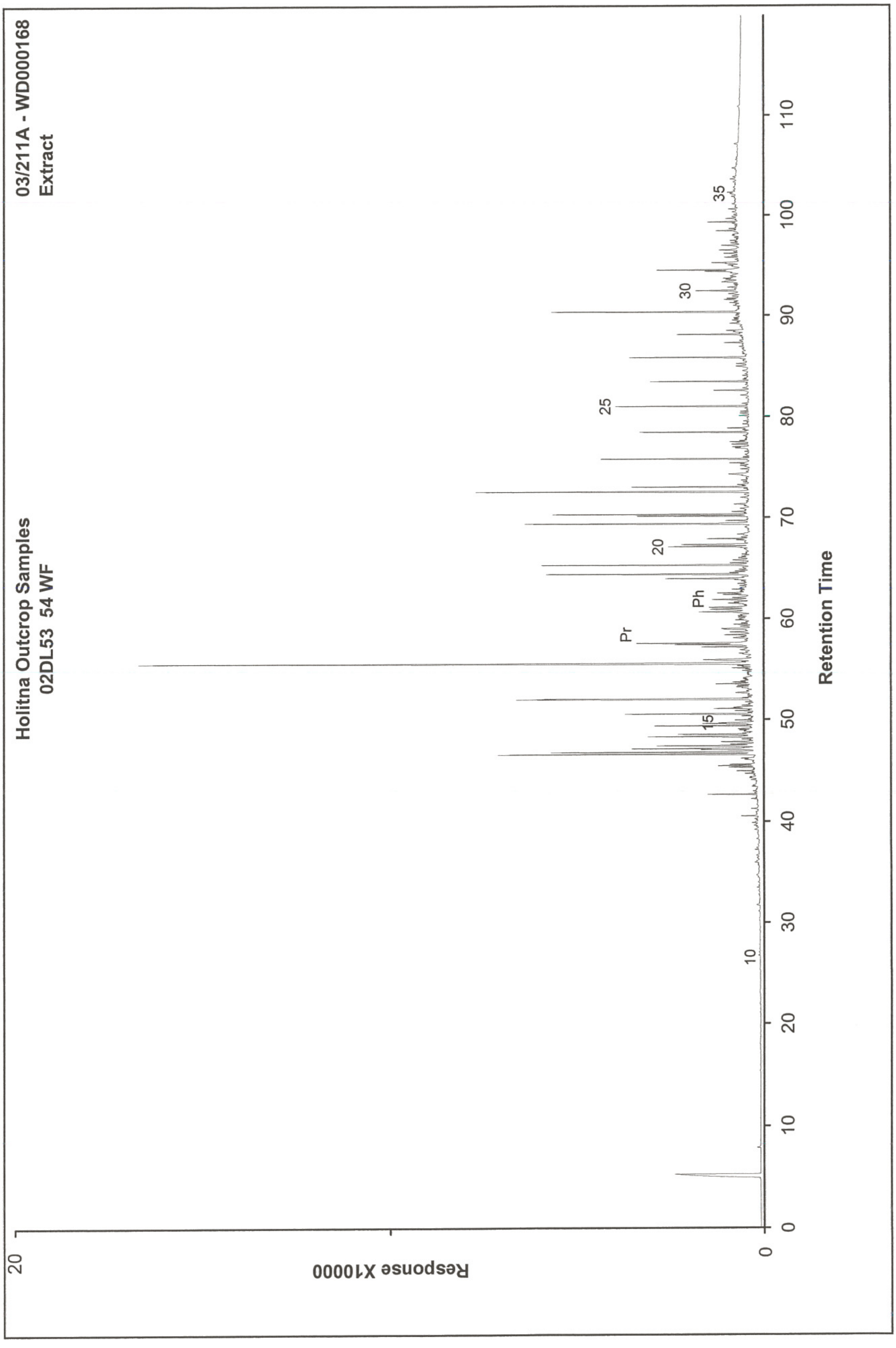
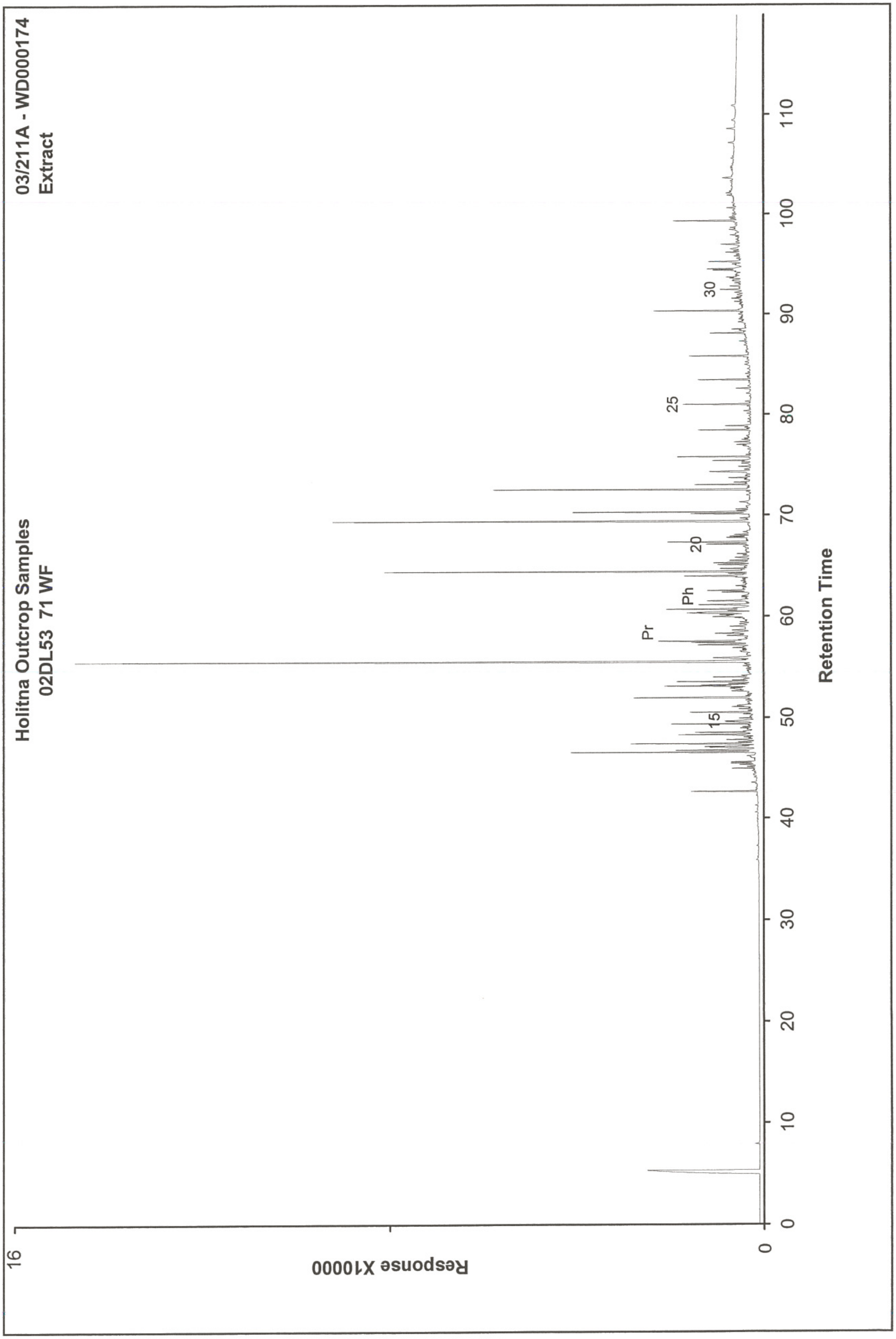
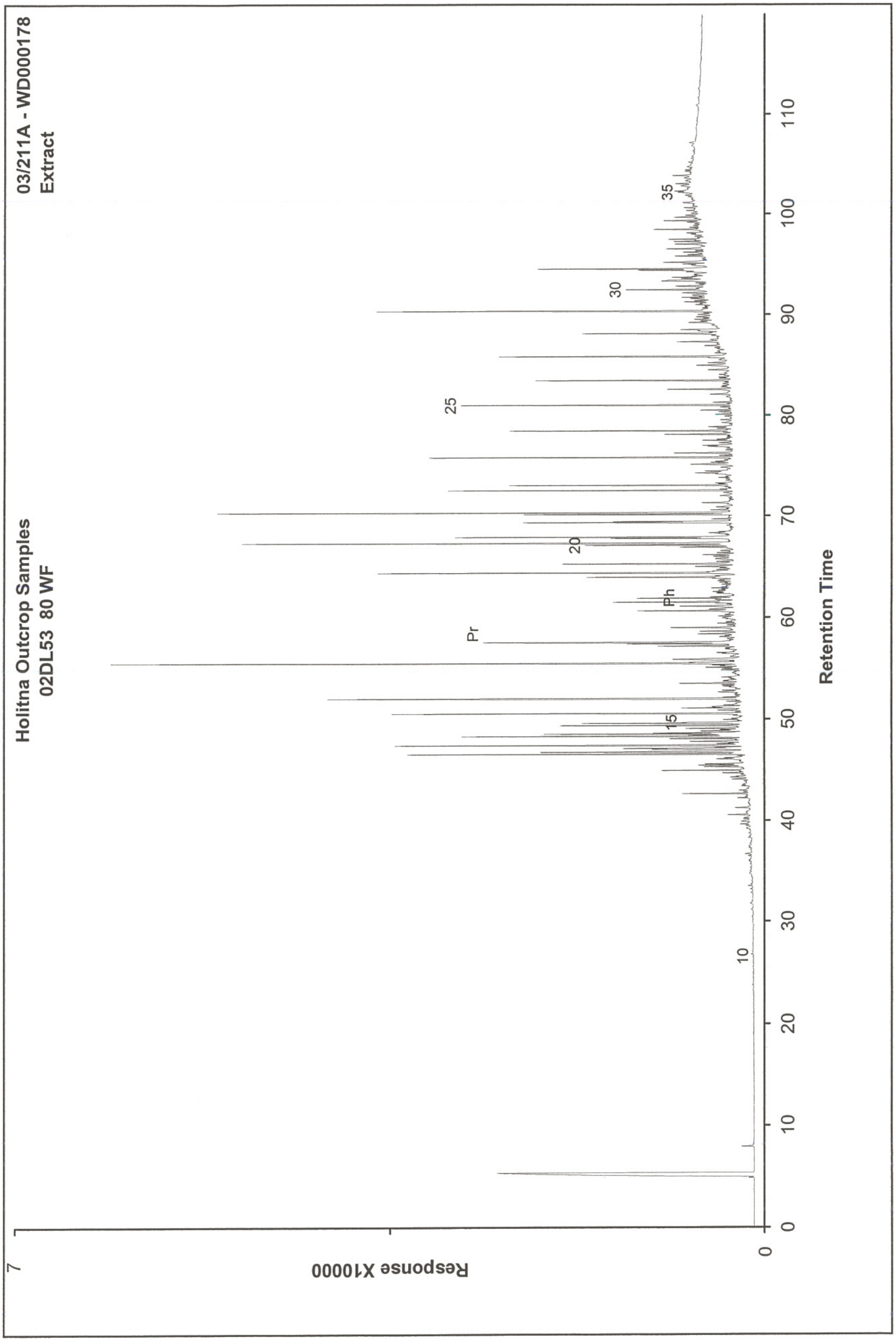
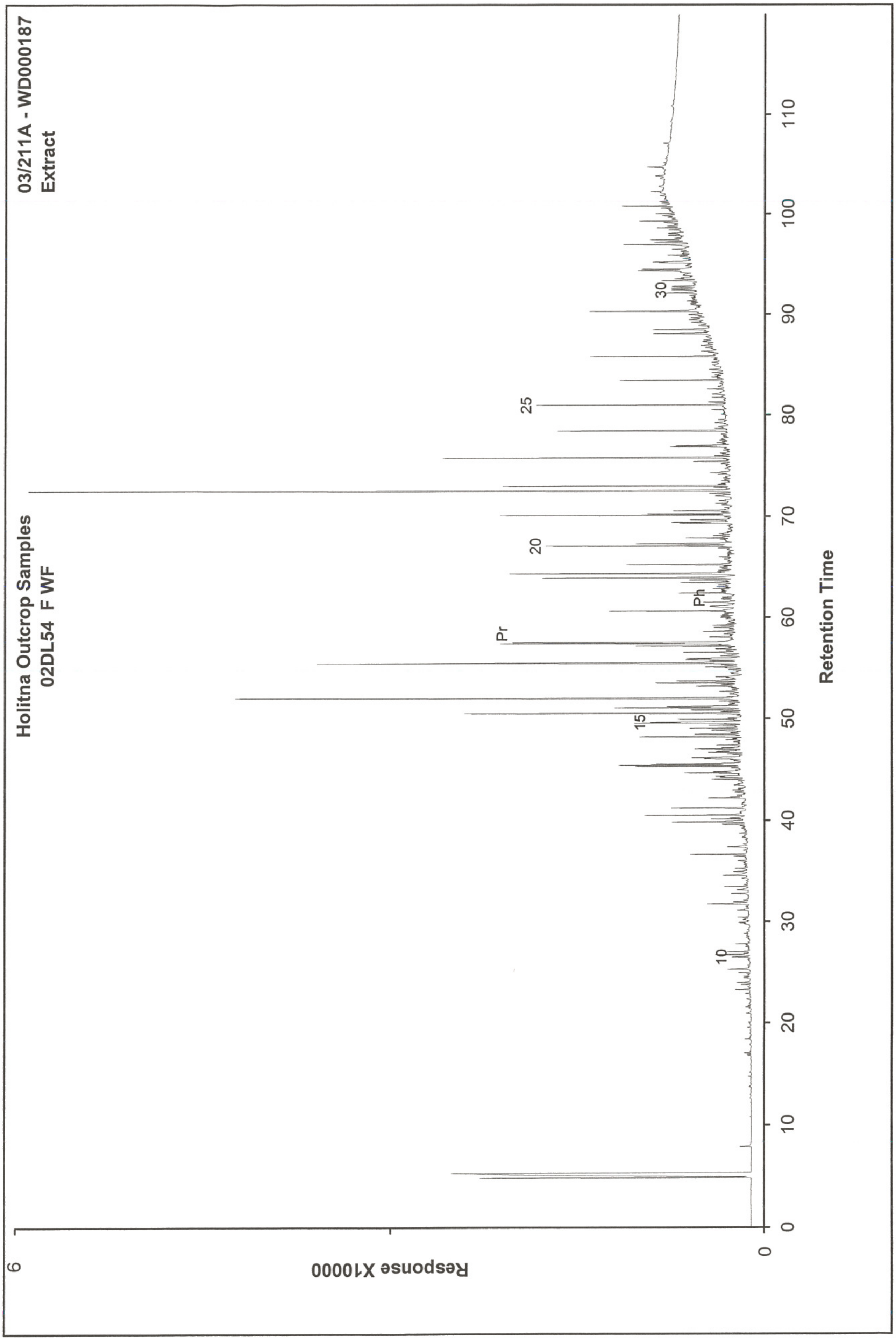
90
100
110
10
15
Pr
Ph
20
25
30


Holitna Outcrop Samples
02DL53 54 WF
03/211A - WD000168
Extract
Pr
Ph
Retention Time
Response X10000


Holitna Outcrop Samples
02DL53 71 WF
03/211A - WD000174
Extract
Pr
Ph
15
20
25
30
Response X10000
16
0
Retention Time
0
10
20
30
40
50
60
70
80
90
100
110



Holitna Outcrop Samples
02DL53 80 WF
03/211A - WD000178
Extract
Response X10000
Retention Time
10
15
Pr
Ph
20
25
30
35
0
7
0
10
20
30
40
50
60
70
80
90
100
110



Holitna Outcrop Samples
02DL54 F WF
03/211A - WD000187
Extract
Pr
Ph
10
15
20
25
30
Response X10000
0
6
0
10
20
30
40
50
60
70
80
90
100
110
Retention Time