Final Report

DE-FC26-01NT41248

Rural Alaska Coal bed Methane: Application of New Technologies to Explore and Produce Energy

Work Performed During Period: June 1, 2003 – June 30, 2005

For

National Energy Technology Laboratory
Arctic Energy Office
US Department of Energy

Through

Arctic Energy Technology Development Laboratory
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December 2006

DISCLAIMER

ACKNOWLEDGEMENTS

The Petroleum Development Laboratory, University of Alaska Fairbanks prepared this report. The US Department of Energy NETL sponsored this project through the Arctic Energy Technology Development Laboratory (AETDL) of the University of Alaska Fairbanks. The financial support of the AETDL is gratefully acknowledged. We also acknowledge the co-operation from the other investigators, including James G. Clough of the State of Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys; Art Clark, Charles Barker and Ed Weeks of the USGS; Beth Mclean and Robert Fisk of the Bureau of Land Management. James Ferguson and David Ogbe carried out the pre-drilling economic analysis, and Doug Reynolds conducted post drilling economic analysis. We also acknowledge the support received from Eric Opstad of Elko International, LLC; Anchorage, Alaska who provided a comprehensive AFE (Authorization for Expenditure) for pilot well drilling and completion at Fort Yukon. This report was prepared by David Ogbe, Shirish Patil, Doug Reynolds, and Santanu Khataniar of the University of Alaska Fairbanks, and James Clough of the Alaska Division of Geological and Geophysical Survey. The following research assistants, Kanhaiyalal Patel, Amy Rodman, and Michael Olaniran worked on this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Rural Alaska Coal Bed Methane: Application of New Technologies to Explore and Produce Energy

EXECUTIVE SUMMARY

The conventional method of power generation in the remote and rural areas of Alaska involves use of diesel powered electric generators. Use of diesel for power generation in remote areas is very expensive because of high diesel price and additional transportation costs to remote locations. A possible alternative for power generation in the remote areas of Alaska is use of natural gas associated with coal deposits, known as coal bed methane (CBM). Alaska has the largest coal deposit in the entire US. The CBM potential in Alaska has been estimated to be 1000 trillion cubic feet (TCF) methane in place. The Alaska Division of Geological and Geophysical Survey has determined that over 37 remote villages are situated on or are immediately adjacent to coal deposits. Therefore, Alaska's vast coal reserve could potentially provide clean and low cost power to the rural areas if the CBM could be harnessed.

The objective of this project was to investigate the feasibility of CBM production in rural Alaska for the purpose of power generation for local use. The project would evaluate producibility of methane from low rank coals using slim hole drilling techniques that are essential to greatly reducing mobilization and drilling costs in remote areas. During the first year of the project, an initial core hole would be drilled to collect reservoir and geologic data, to determine well spacing, and to identify potential water injection zones in the largest identified rural village, Fort Yukon. In the later part of the project,

methodology of small scale production would be tested by drilling a five spot pattern at a more accessible and affordable location in the Matanuska-Susitna valley. Reservoir modeling to forecast production rate and economic analysis would be performed to determine feasibility of overall CBM production scheme for power generation.

The project was initiated by re-entering a core hole drilled in 1994 by USGS at Fort Yukon. The well was deepened to 2287 ft and coal samples were retrieved from two different zones. The coal samples were analyzed for gas (CBM) content by desorption experiments. Petrophysical analysis of coal samples was also carried out to generate input data for reservoir modeling. An economic analysis of a typical CBM power generation project for a remote Alaskan village like Fort Yukon was conducted using technical and economic data obtained from the Fort Yukon well.

The results from coal desorption study showed that the Fort Yukon CBM content was 3.5 and 19 SCF/ton for the upper and the lower coal zones, respectively. This level of gas content is extremely low compared to gas content of the coal deposits in the Lower 48 states. The permeability of the coal samples was also determined to be very low, of the order of 1 to 2 millidarcy (md). Reservoir modeling studies to predict gas production rate showed the maximum possible production rates to be less than 10 MSCF/D, even with well spacing as close as 20 acres. The economic analysis including the costs of drilling, maintenance and dewatering indicated that the cost of electricity generated at Fort Yukon from CBM would be in the range of 35 to 50 cents per kWH. However, in order to fulfill the energy needs of Fort Yukon, the gas requirements were estimated at 220 MSCF/D, which was far in excess of the gas production rate possible from Fort Yukon coal beds.

Conclusions

From the results summarized above, it was concluded that Fort Yukon coal deposit has neither an adequate gas content, nor sufficient permeability to supply the amount of gas required to meet the energy needs of Fort Yukon village. Even if the required amount of methane could be produced, the cost of electricity may not be competitive with the current method of power generation using diesel. However, the project did show that slim hole drilling with lightweight, portable rigs is a technically feasible method for CBM gas production in remote areas.

An initially unanticipated outcome of the project was that drilling waste generated in the project could be successfully used as a sealant in landfill areas without any significant environmental risk. This provides for a method to dispose of drilling waste in remote areas at reduced cost.

NOMENCLATURE

ATROR = After-tax rate of return

BTROR = Before-tax rate of return

BTU = British thermal unit, an English standard unit of energy. It is the amount of thermal energy required to raise the temperature of one pound of water by one degree Fahrenheit. One BTU is equivalent to approximately 1055 joule (or 1055 watt-seconds)

CBM = Coal bed methane

ID = Inner diameter of pipe

MAOP = Maximum allowable operating pressure

MMBTU = Million BTU

MSCF = Thousands standard cubic foot of gas at 14.7 psia and 60°F

MSCFD = Gas flow rate in thousands standard cubic foot of gas per day

MMSCF = Million standard cubic foot of gas at 14.7 psia and 60°F

OD = Outer diameter of pipe

O&M = Operations and maintenance

ROR = Rate of return

TD = Total depth

USAF = United States Air Force

CHAPTER 1

INTRODUCTION

At a high cost to the state and to the people of Alaska, diesel is used for power generation in the remote and rural areas of the state. Alaska has the largest coal deposits in US. Natural gas is often associated with coal deposits. This associated gas, known as coal bed methane (CBM), can potentially be produced to replace diesel as energy source in remote areas. The Alaska Division of Geological & Geophysical Surveys (DGGS) investigated CBM potential in rural Alaska and reported over 37 rural villages are situated on or are immediately adjacent to coals. This vast potential resource, that has been estimated to be 1,000 trillion cubic feet of methane in-place, could provide low cost and relatively clean energy to rural Alaska for generations to come. However, compared to the lower 48 states, coal bed methane production in Alaska poses some unique challenges as listed below.

1. Alaska's coals are young and low-rank. Production of natural gas from these coals can be difficult, depending on gas content and permeability of the coal.
2. Exploration drilling costs are 10 times higher than equivalent wells in the continental US.
3. Produced water management in rural arctic to sub-arctic environments poses a problem.
4. Ability to produce gas, saturated with water, at low temperatures well below freezing.

1.1 OBJECTIVES

The objective of this study is to investigate the technical and economic feasibility of producing natural gas from Alaska's low rank coals for the purpose of power generation in remote areas of the state. The project will involve drilling test wells in Fort Yukon and in the Matanuska-Susitna valley for producing coal bed methane. These wells will test the producibility of low-rank coals using slim-hole drilling techniques that are essential to greatly reduce mobilization and drilling costs, especially in remote locations. During year one of the program, an initial core hole will be drilled to collect reservoir and geologic data, to determine well spacing, and to identify potential water injection zones in the largest identified rural village, Ft. Yukon. If this study demonstrates success of closely spaced slim hole drilling plan for producing coal bed methane from Alaska's low rank coals, then clean and low cost energy can be made available in remote areas of Alaska on a sustained, long term basis.

1.2 TASKS

The proposed research program is to design, drill, and test six pilot slim-holes to collect reservoir and geologic data, evaluate producibility of low-rank coals, and utilize slim-hole drilling techniques in CBM well production and dewatering. Of all the places in Alaska to conduct our research, Fort Yukon is the best logical location to base this pilot study because it is the largest remote village near a coal bed identified in the DGGS study. Fort Yukon is a community of about 600 people without any road access, located along the Yukon River. Based on village demographics, geological setting and presence of potentially gassy coal beneath the community (Tyler et al., 2000), Fort Yukon was determined as a priority site for testing CBM gas production potential. Currently, diesel fuel is barged into the village during summer months when the river is ice-free. The diesel is used in power generators which provide residential and commercial electricity. The cost of diesel at Fort Yukon can be as much as $4 per gallon (as of 2003), which translates to the cost of electricity being about 45 cents per kWH. Because of such high energy costs, it is necessary to evaluate the potential of producing CBM from local coal deposits for the purpose of power generation at lower cost. From past research, the following are known:

(1) There is gas in the coals (indicated by well drilled in 1994), and

(2) Coals are laterally continuous over a large area (seismic survey in 2001).

The proposed work encompasses three consecutive years, with each year gathering additional data needed for the next step. During year one, the well drilled by the USGS at Fort Yukon in 1994 will be re-entered to collect coal gas content, continuous stratigraphic, water quality and geophysical data. While continuing the project at Fort Yukon would be optimal, logistical costs associated with a production test are prohibitive. Therefore, during years two and three, the project will relocate to the Matanuska-Susitna Valley, close to Evergreen Resources Alaska's operations. Here, a closely spaced five-spot well consisting of four dewatering holes surrounding a central gas producer will be drilled, completed and production tested. Results from this production test will then be combined with geologic and hydrologic data from the Fort Yukon well to develop a comprehensive CBM exploration-to-production model. The following specific tasks are envisioned in this project.

1.2.1 First Year: June 1, 2003 to June 1, 2004

Task 1: Pre-Field Evaluation

This task is designed to resolve the challenging logistics of working in rural Alaska. Major sub-tasks are: Define overall project work plan for Fort Yukon pilot hole designed to gather baseline geologic and hydrologic data; Identify geophysical logging methods and site preparation requirements; Acquire necessary permits and hold public meetings to educate local groups; and Contract drilling equipment and services or outright purchase necessary drilling equipment and transport materials and project personnel to Fort Yukon. Conduct an economic analysis to define the fuel gas requirements and the surface facility conceptual design to meet energy needs in a medium-sized village based on Fort Yukon example (approximately 650 people). This information is needed to plan well spacing, identify number of wells to be drilled and forecast production rates necessary to meet village energy needs.

Task 2: Drilling and development of first test well at Fort Yukon

Following the pre-field tasks, we propose to locate and re-enter the existing test-hole drilled by the US Geological Survey (USGS) in 1994. We will utilize a helicopter-portable coring rig to drill and core a slim-hole to approximately 2500 ft, collect open-hole geophysical logs, analyze core data, determine hydraulic properties, collect reservoir and water quality data in targeted coal beds, and identify possible zones for re-injection of produced water. Data from the test hole will be analyzed to support future CBM exploration programs in Fort Yukon and other areas in rural Alaska.

1.2.2 Second Year: June 1, 2004 to June 1, 2005

Task 3: Drill and complete the first three-well set in Matanuska-Susitna

In the second year, the project will focus on testing and proving methodology of small-scale production techniques in a more accessible and affordable location near Houston, Alaska. The pilot slim-holes will be drilled near Evergreen Resource's Houston leases to share water disposal facilities and to considerably reduce costs. This task will include the following:

- Design the work plan for the first three-well set. Secure permits to drill, test and produce pilot holes in the northern Cook Inlet.
- Drill, case and cement three wells – one producer and two dewatering wells to a depth of about 900 feet. Obtain suites of well logs.
- Complete both dewatering wells by perforating, & slightly stimulating with a water fracture treatment.

Task 4: Pilot production, system monitoring and coal seam evaluations

We plan to pump and produce gas and water from the pilot holes. Water production requirements versus gas recovery from the coal beds will be used to specify hole size, casing design, details of cementing and production, testing, perforating and other operations necessary to put the well on production. Well design will include facilities to execute post-drilling remedial services inside the wellbore, stimulation and water production operations. The wells will be instrumented to monitor water and gas production until completion of the project. The production data will be evaluated and related to coal seam properties, and used to develop gas well deliverability models (predictive tools) for future applications of this technology.

Water production is an essential companion to coal bed gas production. The technological challenge is to produce gas from a central slim-hole with well drawdown interference from surrounding dewatering wells rather than co-production in single wells. Surface and underground water disposal systems will be evaluated. Will evaluate downhole produced water injection systems and gas stream dehydration systems as this is likely what permafrost production will require. Produced water will be reinjected in the Evergreen water disposal well.

1.2.3 Third Year: June 1, 2005 to June 1, 2006

Task 5: Drill and complete the final two dewatering well set in Matanuska-Susitna Valley

Design work plan for two additional dewatering wells. Obtain permits for drilling, production and testing. Drill, case, cement and complete two dewatering wells in the same manner as the year two wells.

Task 6-Pilot production, system monitoring, analyses and model northern Cook Inlet exploration-to-production data

Assemble a database of information on gas and water flow rates, gas content, coal seam properties, well drilling, completion and stimulation techniques, pumping and injection systems for dewatering and water management. The data will be analyzed to model the economics of coal bed methane production in rural Alaska.

Reference

Tyler, R., Scott, A.R., and Clough, J.G., 2000, "Coalbed methane potential and exploration targets for rural Alaska communities", Alaska Division of Geological & Geophysical Surveys, Preliminary Interpretative Report 2000-2, 169 p., 1 sheet.

CHAPTER 2

GAS CONTENT DETERMINATION

The gas content study for Fort Yukon coal was done by reentering a 1994 USGS core hole to sample lignite coal found in Tertiary strata of the Yukon Flats Basin (Ager, 1994). The 1994 well cut a coal bed at 1253 ft and drilled into it for 28 ft when coring stopped at 1281 ft, still in coal. In 1994, it was noted that gas was bubbling from the core but desorption testing of the coal was not possible at that time. Consequently, the reentry of the 1994 well, now officially named DOI-04-1A, was designed to test the methane content of the Miocene age coal (Ager, 1994). The DOI-04-1A well (API No. 50-091-20001) is located at latitude 66.55949^{o}N and longitude 145.20616^{o}W, on the southeast end of the community site. A topographic map and areal view of Fort Yukon area indicating drill site location is shown in Figure 2.1. In 2001, high resolution shallow seismic reflection data was acquired to estimate the thickness and lateral extent of the coal seam encountered in 1994 coring operation (Miller et al., 2002). After reentry in 2004, the well was drilled to total depth (TD) of 2287 feet. Figure 2.2 shows construction and completion scheme of the well. The strata encountered was about 100 ft of River Gravel, followed by Pliocene to Miocene lake beds some 1.5 to 15 million years old (Ager, 1994). Permafrost was encountered in the well from just below the surface to about 300 ft depth. The well cut three major coal beds in two coal zones: the shallowest coal zone has two major coal beds from 1257 to 1315 ft (from gamma log picks) and at 1340 to 1345 ft. The second coal zone was at 1875 to 1920 ft with a major coal bed at 1900 to 1920 ft. The net coal thickness for the major coal beds in the two coal zones was

83 ft. Thin or muddy coals at 1875-1880 ft, 2030 ft, 2039 ft, 2057 ft. and 2067 ft were not sampled for desorption. The following sections describe the coring operations at the reentry well and the desorption method used to determine gas content of the coal from core samples.

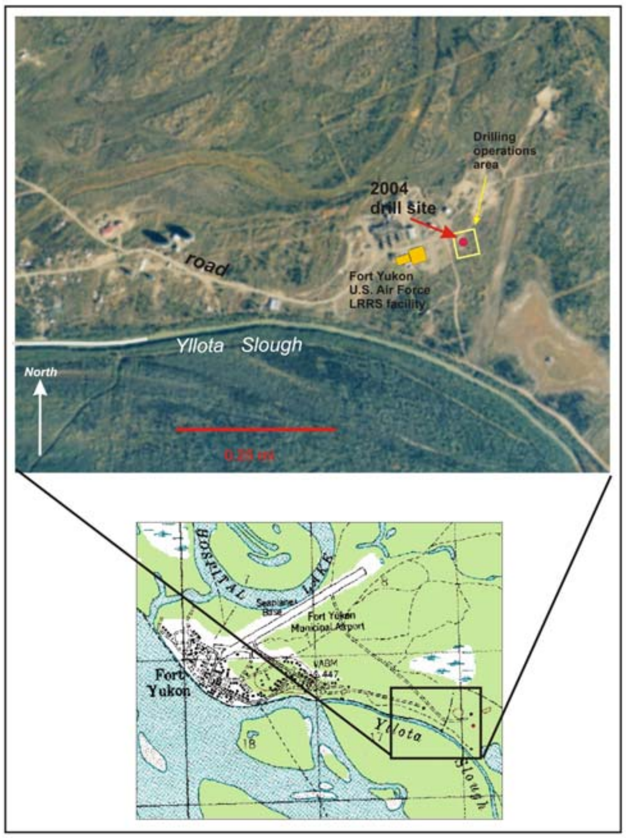

Figure 2.1 Location of 2004 slim hole drilling operations area (yellow box) and drill hole location (shown as red circle) to the southeast of the community of Fort Yukon

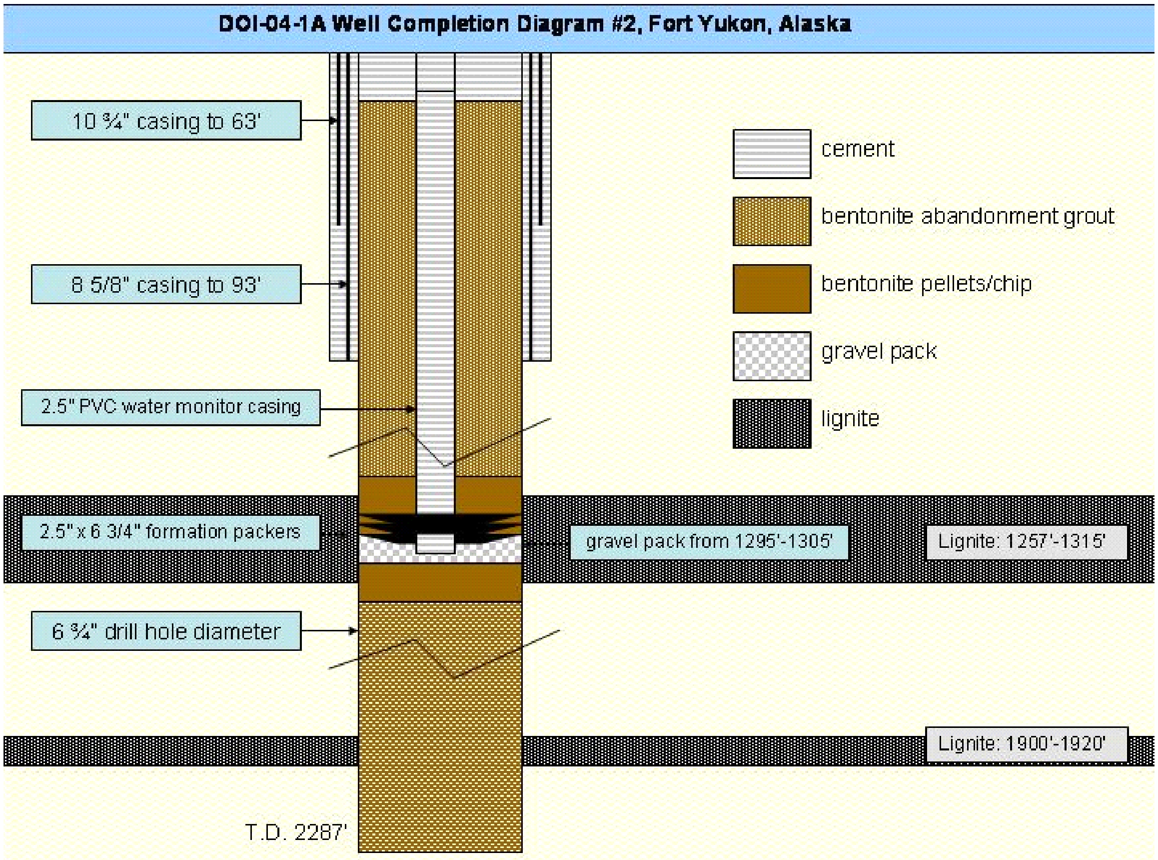

Figure 2.2 Well completion scheme at Fort Yukon, Alaska

2.1 CORING OPERATIONS

The 2004 reentry well, DOI-04-1A was spudded on August 21, 2004 by drilling out a cement and completion bentonite plug in an existing 120 ft of casing left from the 1994 USGS well. The drillers expected that the new well would soon divert away from the strata disturbed by the 1994 well and enable us to core the entire coal rather than missing the first 28 feet that had been cored in 1994. Open-hole drilling was used to reach the core point at 1200 ft. A Christensen CS 1000 P6L portable rig was used in drilling (re-entering) the well. The drilling rig specifications are listed below.

Christensen CS 1000 P6L specifications

Lightweight, helicopter portable

Fly-in Total Wt: 8,605 LB (3,904 kg)

Power Unit: Cummins Model: 6BTA 5.9 LITER 6 CYLINDER

Power: 175 HP (131 KW), RPM: 2,500

Engine Type: DIESEL TURBOCHARGED/AFTER COOLED

Cooling: Water

Capable of drilling/coring 2.5 inch diameter core to depths up to 3000 ft.

Capable of making single-stroke 10 ft. core runs

Capable of drilling (advancing) 4 5/8 inch OD casing through surficial (glacial, alluvial, colluvial) deposits

Using lightweight HCT composite drill rod (57 lbs/10' section)
depth capacity of the CS 1000 P6L rig is increased to 3000' taking a 2.5" core

2.1.1 Upper Coal Zone

The core point at 1200 ft is some 53 ft above the upper coal zone, the open-hole drill string was tripped out of the well to put in the slim-hole diamond wireline coring system. Tripping in the core string proceeded normally until the core string was dropped early in the morning of August 25. Drill string recovery operations ("fishing") ensued and the string was recovered to the surface during the evening of August 25. Given the depth of top of the lost core string and its known length, it appears that the core string had accessed the existing 1994 hole and the core bit had settled to within 4 feet of the original 1994 core well TD (total depth) at 1281 ft.

When the core string was recovered, the base of the core string was plugged with about 12-15 inches of what appeared to be solid coal rather than coal cuttings. This coal plug was interpreted as further evidence that the base of the drill string had penetrated the coal at the base of the existing 1994 hole. Given the evidence, the decision was made to ream out the hole to within a few feet of the original 1994 TD and start coring from there. Monitoring of drill cuttings during reaming confirmed that a thick section of coal was now found above the base of the well. Addition of the 12 to 15 inches of coal found in the base of the recovered drill string to the original 28 feet cored in 1994 means that approximately first 30 feet of the coal seam were not cored in DOI-04-1A. However, as the coal bed was reamed in preparation for coring, we recovered three drill cuttings samples from the interval 1251 – 1281 ft and placed them in canisters for desorption (canister sample cuttings 104-1, -2, -3 in Table 2.1).

The first core run, intentionally cut short to test the coring system and recovery, was retrieved at about 19:30 on August 26, 2004 and consisted of 18 inches of brown coal (lignite) that were placed in canisters 104-1 and 104-2. To ensure that we had enough desorption data, we placed all coal core in canisters for the first ten feet of recovered coal. After we had about 10 canisters filled with coal, we started desorbing every other foot of coal. Some coal core was lost during coring and core retrieval as well. Among the other vagaries of coring in general, the recovery problems are thought to be caused by sticky clay partings in the coal zone that clogged the carbide core catcher leading to some core slipping out of the core barrel during retrieval. In some cases, the lost coal cores were recovered on the next core run and placed in canisters (see can 104-9 spreadsheet notes) since they should have retained their gas by staying at the hydrostatic pressure at the bottom of the well. Coring in mostly coal continued to about 1345 ft when the last approximately 4 ft thick coal was recovered from the coal zone. Thus, the major Fort Yukon coal zone lies from about 1257 to 1345 ft (drillers depths corrected using gamma log picks).

2.1.2 Lower Coal Zone

A lower coal zone was intersected at about 1900 ft (driller depths are herein corrected to gamma log depths) and was inadvertently drilled into for about 10 ft before the open hole drilling was stopped. Coal cuttings were recovered from 1905 – 1910 ft in placed in canisters 104-31 and 104-32. Coring commenced at 1909 ft and continued to 1919 ft. A total of 10 ft of coal core was recovered and all of this core was placed in canisters 104-33 to 104-42. Figure 2.3 shows the photograph of a core sample retrieved from the lower coal zone. Core samples from the upper and the lower coal zones were studied for methane content using a canister desorption method, as well as for lithology, depositional settings and fluid flow properties.

Figure 2.3 Photograph of lower Fort Yukon core removed from core barrel

2.2 CORE ANALYSIS

2.2.1 Desorption Method

Coal desorption followed a modified US Bureau of Mines (USBM) canister desorption method as described by Diamond and Levine (1981), Close and Erwin (1989), Ryan and Dawson (1993), McLennan et al. (1994), Mavor and Nelson (1997) and Diamond and Schatzel (1998) as adapted and modified by Barker et al. (1991, 2002) for the use of PVC canisters.

A major modification of the USBM technique in this study was the use of zero-headspace canisters (Barker and Dallegge, 2005). Canisters were filled with distilled water instead of helium gas as described in Barker et al. (2002). Distilled water was pre-chilled to about 45 to 50 ^{o}F in the chilled water tanks to speed up equilibration of the can and the coal core to the lost gas temperature.

Also we used a different desorption log form in the Barker et al. (2002) modified for zero headspace canisters. In zero headspace canisters, it is not necessary to measure internal can temperature for a subsequent headspace correction (Barker and Dallegge, 2005). All canisters were pressure tested for leaks at 6 psi over a period of at least 24 hours before use.

2.2.2 Desorption Temperature during Lost Gas Estimate

Lost gas is the unmeasured gas desorbed from coal core from the time it is cut by the drill bit to the time the sample is sealed within the canister. Lost gas is controlled by the coal diffusivity and the length of time required to retrieve a sample. Lost gas is estimated by measuring the apparent rate of gas desorption from the sample sealed in the canister. This rate is used to extrapolate back to time zero, the time of the onset of sample desorption during retrieval.

During the lost gas period, we desorb at ambient mud temperature as discussed further in Barker et al. (2002). This is because mud temperature has been found at DOI-04-1a and wells in several other basins, such as the Maverick basin in Texas; the Nenana and Cook Inlet basins in Alaska to be close to the temperature measured at the center of a freshly opened core face (unpublished USGS data). We imply that because the gas is lost during core retrieval, as pressure decreases, that the mud temperature that the core is bathed in and has equilibrated to, rather than the in-situ coalbed temperature, is the relevant temperature to estimating diffusion of gas out of the coal matrix and therefore, lost gas.

We calculated a formation temperature in the coal zone by using a subsurface temperature of 32 ^{o}F at the base of the permafrost at about 300 ft and a geothermal gradient range of 1 to 2 ^{o}F/100 ft. Thus, 950 ft below the base of the permafrost at about 1250 ft, a temperature of 41.5 to 51 ^{o}F is estimated for the undisturbed equilibrium rock temperature. The drilling operations may warm the mud in the well somewhat above this temperature range. Infrared thermometers were used to check drilling mud, tank and core-face temperature.

Actual mud temperature measurements varied on a roughly diurnal cycle with highs of about 48 to 52 ^{o}F reached during the day and lows of about 42-45 ^{o}F reached at night. Depending on the time of the core run, the tank temperatures were adjusted to the mud temperature. Confirmation of the use of mud temperature is made by measuring the temperature at the center of core faces freshly broken open immediately after the core is extruded from the core barrel into the tray. These measurements are typically very close to mud temperature if mud circulation through the well has been maintained for enough time for a thermal stability to be established.

After desorption during the lost gas period was nearly completed, tank temperature was allowed to rise to room temperature to prepare the canisters for transport from the drill site to the laboratory.

2.2.3 Analysis of Desorption Data

The method used for correction of the data to standard pressure and preparation of a lost gas estimate uses a spreadsheet described in Barker et al (2002). The data from this analysis are presented in Table 2.1 (for the upper coal bed) and Table 2.2 (for the lower coal bed)

2.3 RESULTS

2.3.1 Desorption

The upper coal zone cores gas contents average 13.1 scf/ton with a standard deviation of 3.5 scf/ton for 21 samples. The lower coal zone cores gas contents average 19.1 scf/ton with a standard deviation of 4.0 scf/ton for 10 samples.

2.3.2 Coalbed Saturation from Isotherms.

Methane adsorption isotherms are measured by reintroducing methane to a coal and measuring the equilibrium gas content at a given pressure and at a constant temperature. The resulting curves (Figures 2.4 and 2.5) can be used with measured gas content from canister desorption (Tables 2.1 and 2.2) to estimate several parameters. Two of these parameters, degree of saturation and the reduction in reservoir pressure needed to saturate the coal, are significant in resource assessment.

The degree of saturation for the upper coal zone is calculated to be 31%. The reduction of reservoir pressure to saturate the coal bed with methane is 435 psi. The degree of saturation for the lower coal zone is calculated to be 41%. The reduction of reservoir pressure to saturate the coal bed with methane is 600 psi. This is a relatively low degree of saturation in both coal zones. The low saturation is reflected in the relatively high reduction in reservoir pressure required to saturate the coals in either coal zone. Because a coal bed must reach saturation for desorption to occur, the large indicated pressure reduction required to reach saturation suggests that a large volume of water would have to be pumped out of the coal beds before gas production by desorption would occur. Based on this analysis, the cost for pumping out the coal bed water and disposing of the produced water would appear to be a major factor in determining if gas production is cost effective at Fort Yukon.

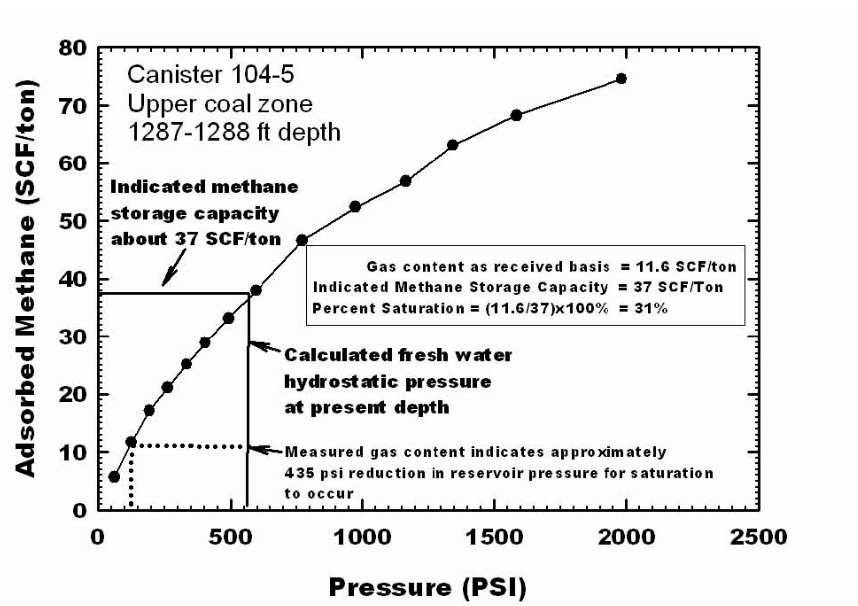

Figure 2.4 Methane adsorption isotherm for Canister 104-5 at 1287 to 1288 ft depth in the upper coal zone, DOI-04-1A well, Fort Yukon, AK. Isotherm conditions were: 15 ^{o}C, coal at equilibrium moisture. Absorbed methane values reported on an as received basis. Coal zone pressures calculated using a fresh water hydrostatic gradient projected to the sample depth.

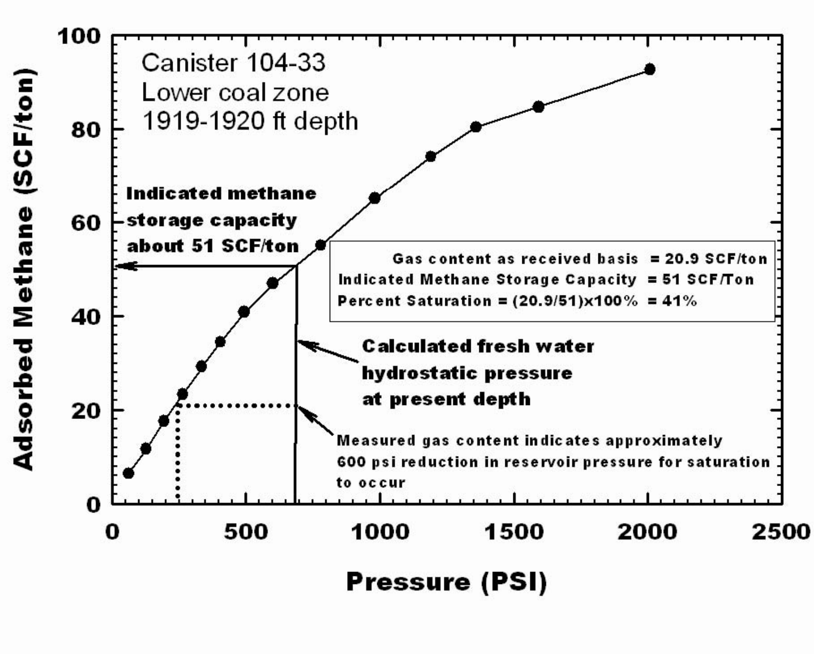

Figure 2.5 Methane adsorption isotherm for Canister 104-33 at 1919 to 1920 ft depth in the lower coal zone, DOI-04-1A well, Fort Yukon, AK. Isotherm conditions were: 15 ^{o}C, coal at equilibrium moisture. Absorbed methane values reported on an as received basis. Coal zone pressures calculated using a fresh water hydrostatic gradient projected to the sample depth.

Conclusion

From the canister desorption study and methane adsorption isotherms, gas content of the tertiary age Fort Yukon coal was found to be very low.

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Table 2.1 Summary of Canister Desorption Results, Upper Coal Zone

Canister Number	Depth Interval From gamma ray log (drillers depth)		Canister Sample Lithology	Raw coal mass	Lost Gas Estimate	Total Raw Gas Content
Upper Coal Zone	Top	Bottom				(as-received basis)
	(feet)	(feet)	% coal	(g)		(scf/ton)
CORE						
104-1	(1283)	(1284)	100	1056	60	14.1
104-2	(1284)	(1284.5)	50	490	40	13.5
104-3	(1285)	(1286)	100	907	85	10.8
104-4	(1286)	(1287)	100	905	80	9.8
104-5	(1287)	(1288)	100	951	80	11.6
104-6	(1288)	(1289)	100	1009	115	21.1
104-7	(1289)	(1290)	100	1149	85	7.0
104-8	(1290)	(1290.7)	70	471	85	14.5
104-9	(1295)	(1296)	100	961	85	13.4
104-10	(1304.5)	(1305.5)	100	1087	110	13.8
104-11	(1306.5)	(1307.5)	100	1193	95	12.1
104-12	(1308.5)	(1309.5)	100	1115	130	13.6
104-13	(1310.5)	(1311.5)	100	1132	130	13.9
104-14	(1312.5)	(1313.5)	100	842	80	11.0
104-15	(1315)	(1316)	100	1038	80	12.9
104-16	(1319)	(1320)	100	1171	85	8.6
104-17	(1324)	(1325)	100	1518	100	9.0
104-18	(1339.7)	(1340.7)	100	1082	100	18.7

104-19	1342 (1343)	1343 (1344)	100	749	100	19.5
104-20	1343 (1346)	1344 (1347)	100	1028	110	15.2
104-21	1344 (1349.25)	1345 (1350.25)	100	1098	100	10.9
Statistics:				Sample	Mean	13.1
				Standard	Deviation	3.5
CUTTINGS						
Cuttings-1	1265*	1270*	80	575	45	7.7
Cuttings-2	1270*	1275*	80	609	20	4.6
Cuttings-3	1275*	1280*	80	886	20	2.0
Statistics:				Sample	Mean	4.8
				Standard	Deviation	2.9

* = depth interval estimated from lag time. These cuttings were not screened and the coal fines lose their gas quickly thought to lead to the spuriously low raw gas content.

Table 2.2 Summary of Canister Desorption Results, Lower Coal Zone

Canister Number	Depth Interval From gamma ray log (drillers depth)		Canister Sample Lithology*	Raw coal mass	Lost Gas Estimate	Total Raw Gas
Lower Coal Zone	Top	Bottom				Content (as-received basis)
	(feet)	(feet)	% coal	(g)		(cc/g)
CORE						
104-33	1909 (1919)	1910 (1920)	n.r. 100?	1006	120	20.9
104-34	1910 (1920)	1911 (1921)	n.r. 100?	1037	100	22.5
104-35	1911 (1921)	1912 (1922.1)	n.r. 100?	1105	100	19.4
104-36	1912 (1922.1)	1913 (1923.1)	n.r. 100?	994	120	20.4
104-37	1913 (1923.1)	1914 (1924.1)	n.r. 100?	996	120	20.9
104-38	1914 (1924.1)	1915 (1925.0)	n.r. 100?	1239	120	12.8
104-39	1915 (1925.0)	1916 (1926.0)	n.r. 100?	1118	120	17.8
104-40	1916 (1926.0)	1917 (1927.0)	n.r. 100?	1115	125	21.7
104-41	1917 (1927.0)	1918 (1928.0)	n.r. 100?	993	85	23.1

104-42	1918 (1928.0)	1919 (1929.0)	n.r. 100?	1233	85	11.2
					Mean	19.1
					Standard Deviation	4.0

Abbrevations: n.r. = not reported.

*Lithology about 100% coal from gamma log interpretation

CHAPTER 3

COAL BED PROPERTIES

This chapter describes the geological and reservoir properties measured from the Fort Yukon Pilot hole. The drill cores collected during the 2004 operations at Fort Yukon were studied for general lithology, characteristics, depositional settings and flow properties. The results in this chapter include data obtained from core analysis and well log analysis.

3.1 LABORATORY MEASUREMENT OF PERMEABILITY

The results of the permeability measurements are presented in this section. It is noted that the results may not be quite representative as it was not possible to replicate the reservoir conditions in the laboratory.

3.1.1 Experimental Set Up

The experimental set up used in the permeability measurements is shown in the schematic diagram (Figure 3.1). The set up consists essentially of a pump to circulate fluid (water) through a series of flow lines and across the face of core plug and to a flow meter. The flow rate is controlled from a digital controller attached to the pump. The core holder is a standard Hassler-sleeve core holder. It can hold cores of 1 inch to 2 inch diameter, with a length of 2 to 10 inches. The core holder has ports for applying confining pressure of up to 2000 psi. The pressure measurements and flow rates are recorded automatically using a data acquisition system with interface from the digital pump controller.

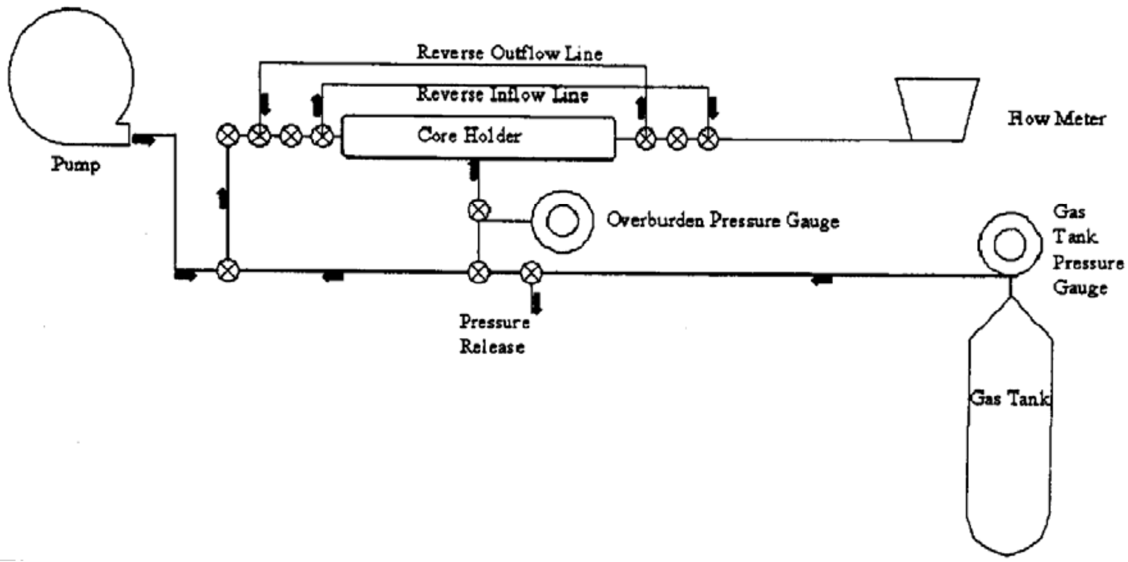

Figure 3.1 Schematic diagram of experimental set up

3.1.2 Core Plug and Sample Preparation

The core plug samples used were obtained from Fort Yukon. Two core plug samples, one extracted from depth intervals ranging from 1307.5 to 1308.5 ft and other from 1810.3 to 1820.7 ft, were used. The core plug samples were kept under freezing conditions to preserves the initial characteristics prior to the tests. The permeability was measured at an average room temperature of 71^{o}F. The nitrogen gas was used to provide the overburden pressure. Overburden pressure of 300 psi was applied for both samples.

The core plug samples were very unconsolidated. The cross-sectional area of the core plugs was reduced using core-cutting tool to fit into the core sleeve of the equipment used. The lengths of the samples were also trimmed to obtain even cross-sectional area at both ends. Water was used as injection fluid in a single-phase flow determination of the initial permeability. The average viscosity of water used was 1 centipoise.

3.1.3 Experimental Procedure

The procedure for performing the permeability measurements is detailed as follows. There were two core plug samples. Each one was removed from the preserved condition in a freezer. Detailed information about the core plug (mainly depth interval, and physical dimensions) was recorded. The laboratory temperature condition was also recorded. In all cases, the original diameter of the core plug was wider than the core sleeve used. The core plug was then trimmed to obtain an average diameter of 1.5 inches using a 1.5 inch diameter diamond core bit in a water-lubricated drill press. Significant portions of the core samples were lost to the trimming process due to brittle nature of the core samples. The core plug was also trimmed at both ends to obtain even cross-sectional areas. The core length and the diameter were then recorded. The flow lines between the various units of the equipment setup were pressure-checked to circumvent leakages. The core was inserted into the core sleeve and loaded into the core holder. An overburden pressure of 300 psi was applied to the rubber sleeve of the core holder by injecting the nitrogen gas. The water was then allowed to flow through the core samples at a constant flow rate. The pressure drop was recorded for that particular flow rate. The water flow rate was then changed and again the pressure drop was recorded. The experiment was repeated a number of times by varying the flow rate.

3.1.4 Results

The results obtained from the experiments are summarized in this section. Table 3.1 lists the permeabilities measured from the core samples obtained from the upper coal seam.

Measurement of Horizontal Permeability:
Sample: Coal Seam
Depth Interval Sampled: 1307.5 – 1308.5 ft
Length of core sample, L: 1.46 cm
Diameter of core sample, D: 3.6 cm
Cross section area of core, A: 10.18 cm^2
Viscosity of water, μ: 1 cp

Table 3.1 Measurement of Horizontal Permeability

Flow rate	Pressure drop (Δp)	k
(ml/min)	(psia)	(md)
5	196	0.896058
10	225	1.561133
15	235	2.242052
20	248	2.8327

The results show permeability values between 0.9 and 2.8 md. These permeabilities are relatively high compared to those obtained from the hydrologic test. It is observed that the core samples were quite unconsolidated and the experimental conditions (in-situ stresses, gas saturations) do not represent the in-situ reservoir conditions. Coal permeability at reservoir conditions is expected to be lower than the laboratory measured premeabilities.

3.2 WELL LOG ANALYSIS

The major objectives of well log analysis of Fort Yukon well (DOI-04-1A) were to identify the hydrocarbon bearing zones and to determine the petrophysical properties of these zones, such as porosity, water saturation, and clay contents. Well log analysis is the process by which the reservoir rock and fluid properties are obtained from the interpretation of the responses of various logging tools. Analysis was performed using a computer software package Interactive Petrophysics (IP*)* developed by PGL (Production Geoscience Ltd.) in Banchory, Scotland. The technical support for Interactive Petrophysics (IP) is provided by Schlumberger GeoQuest. The original well log data used were obtained from U. S. Geological Survey (USGS). The first step was to generate a trace plot which displayed the various log responses versus depth (see Figure 3.2). From the trace plot, the zones of interest were identified. These zones include: hydrocarbon bearing zones, the 100% water saturation zone, clean sands and shale zone. From the trace plot it can be observed that for the intervals 1258 ft-1317 ft (zone 2); 1340 ft-1348 ft (zone 4) and 1900 ft- 1920 ft (zone 6), the gamma ray response is very low and the resistivity response is high, indicating the presence of hydrocarbon bearing zones. Also for these zones the density response is very low (see Figure 3.3).

The basic log analysis module is useful for making a quick basic log interpretation. Clay volume is calculated using the gamma ray (GR), SP, Neutron, and Resistivity responses, which allow us to compare the results obtained from different indicators. But for Fort Yukon well we had only GR and resistivity responses for calculation of clay volume (see Figure 3.4). Porosity is calculated either from the density or sonic tool. Water saturations are calculated from the electrical resistivity curves using the basic Archie equation.

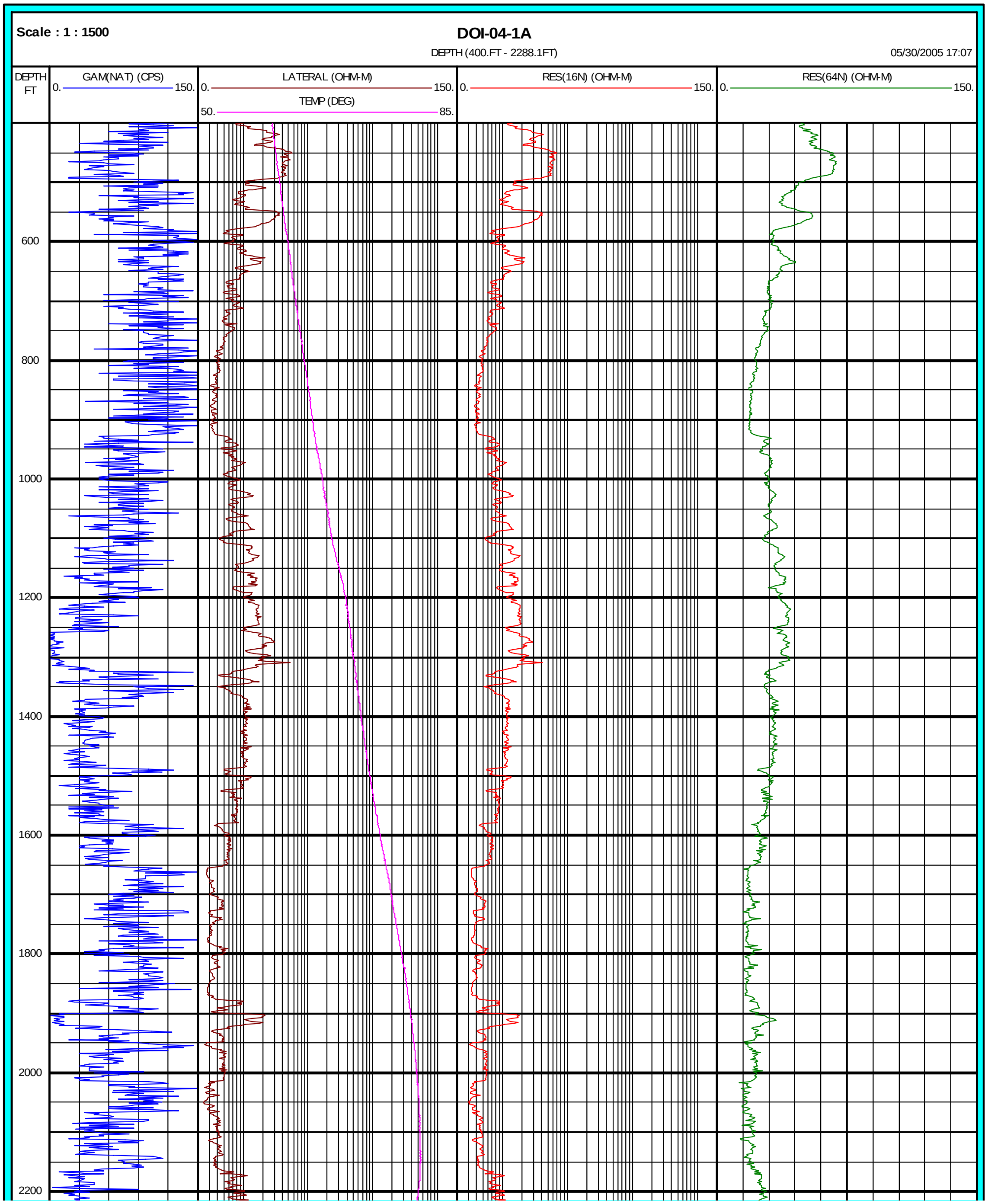

Figure 3.2 Trace plot for Fort Yukon well (DOI-04-1A)

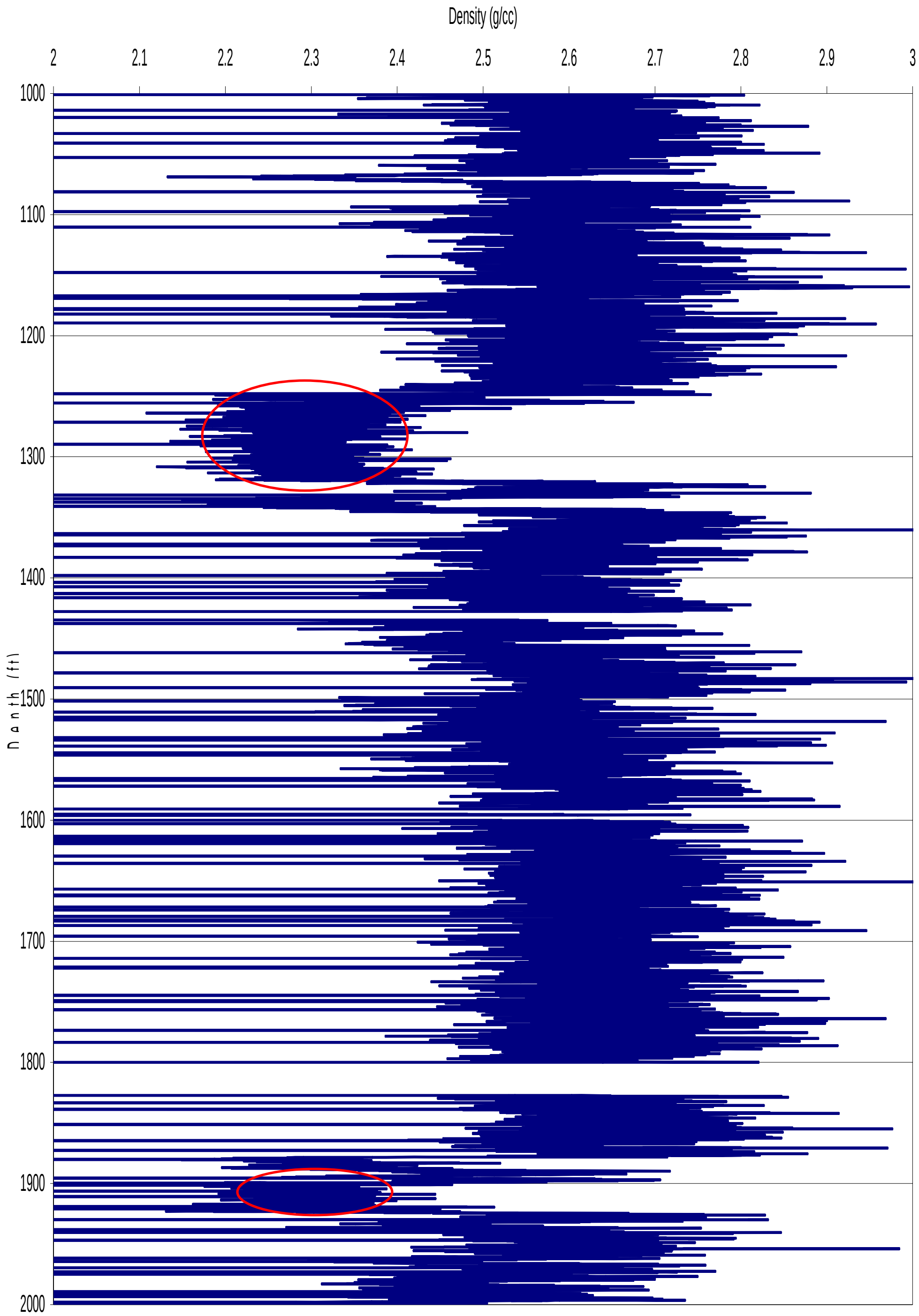

Figure 3.3 Density response for Fort Yukon well (DOI-04-1A)

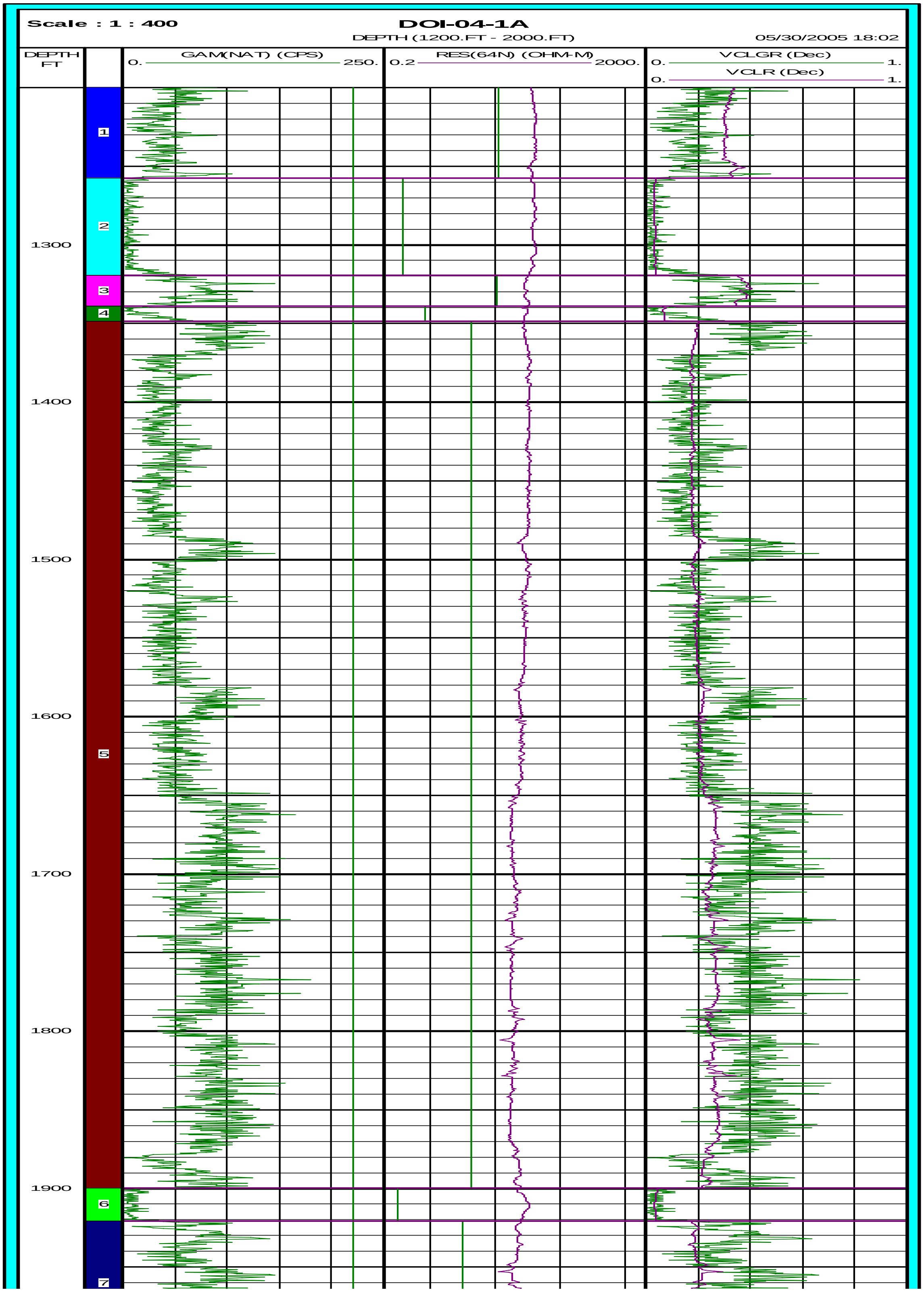

Figure 3.4 Clay volume interactive plot for Fort Yukon well (DOI-04-1A)

3.2.1 Log-Derived Properties

The average petrophysical properties (porosity, water saturation, and clay volume) obtained from well logs of the Fort Yukon well (DOI-04-1A) are summarized in Table 3.2 as shown below.

Table 3.2 Petrophysical Properties of Fort Yukon well (DOI-04-1A)

Productive zone	Depth Interval (ft)	Porosity (%)	Water Saturation (%)	Clay Volume (%)
2	1258-1317	16.41	36.87	3.37
4	1340-1348	15.3	43.66	9.55
6	1900-1920	17.4	39.23	4.576

The relatively high water saturations indicate presence of mobile water in the coal beds. Mobile water contributes to water production.

Conclusions

Low coal permeability observed in the laboratory experiments indicates that permeability of Fort Yukon coal in-situ will be even lower. The well logs indicate that these coals also have significant water saturation, which may prolong the dewatering process.

References

Production Geoscience Ltd.: “Interactive Petrophysics (IP) Help Manual, Version 3.0.0.13”, Banchory, Scotland, 2003.

Schlumberger Ltd.: “Log Interpretation Principles/Applications,” Schlumberger Educational Service, Houston, Texas, 1987

CHAPTER 4

RESERVOIR MODELING

A numerical reservoir simulation study was conducted to forecast CBM production rates in the Fort Yukon area. Gas production rate and cumulative recovery depend on gas content of the coal, coal bed permeability and well spacing. A previous study by Olsen et al. (2004) showed that gas recovery may decrease significantly in coal beds with permeability less than 10 md (Figure 4.1). In this study, Fort Yukon reservoir data were used to forecast gas production rates and gas recovery from coal beds using five-spot injection pattern.

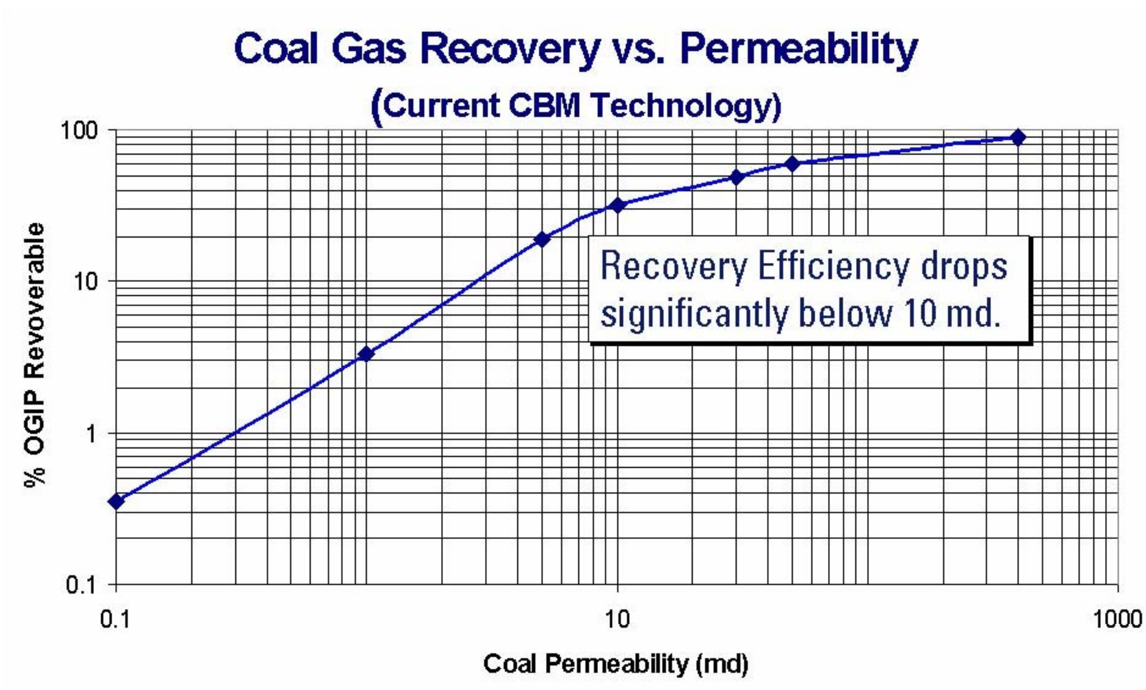

Figure 4.1 Impact of Permeability on Coal Gas Recovery (Source: Olsen et al., 2004)

4.1 Reservoir Modeling Results

The results from this simulation study are shown in Figures 4.2 through 4.7. Figure 4.2 shows gas in place as a function of time with three different production scenarios, where well spacing is varied from 80 acres to 20 acres. With 80 acre spacing, no significant decline in gas in place is seen even after 30 years of production. This shows that large well spacing may not be suitable for recovering CBM from Alaska's low rank coals. With 20 and 40 acre well spacings, significant decline in gas in place is seen after 10 to 15 years of production.

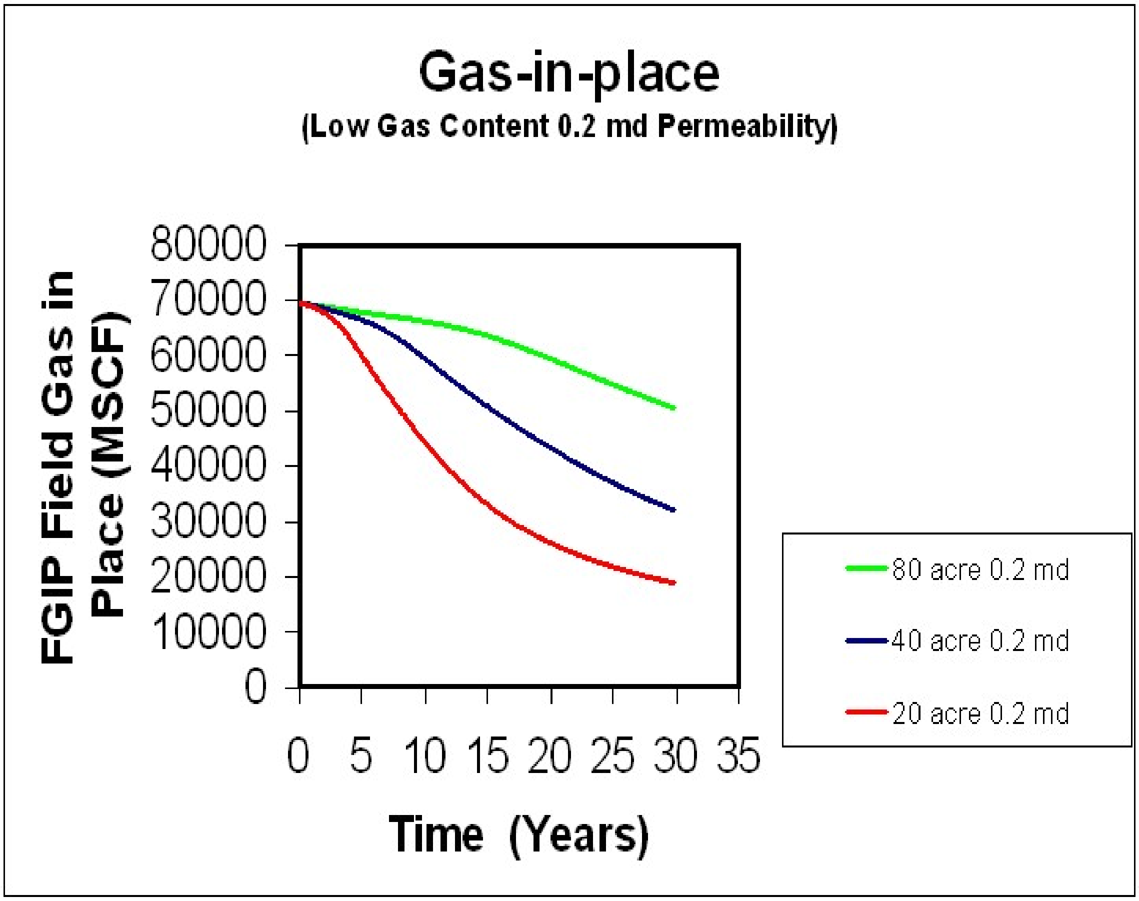

Figure 4.2 Gas in place (FGIP Field Gas in Place) vs. Time

The gas content of Fort Yukon coal, as determined from the canister desorption experiments, is shown in Figure 4.3. For comparison, the average gas content of coal from the lower 48 states is also plotted on the same graph. It is clear that Fort Yukon coal is very low in gas content. At 1000 psi, Fort Yukon coal's gas content is less than one sixth that of the lower 48 coal. The low gas content makes it difficult to produce CBM from Fort Yukon coal at significant rates. Figure 4.4 shows that even with well spacing as close as 20 acres, the maximum daily gas production rate is less than 10

MSCF/D. Such a low production rate is not adequate to provide enough gas for power generation. Cumulative gas recovery as a function of time is shown in Figure 4.5. The cumulative recovery declines sharply with increasing well spacing.

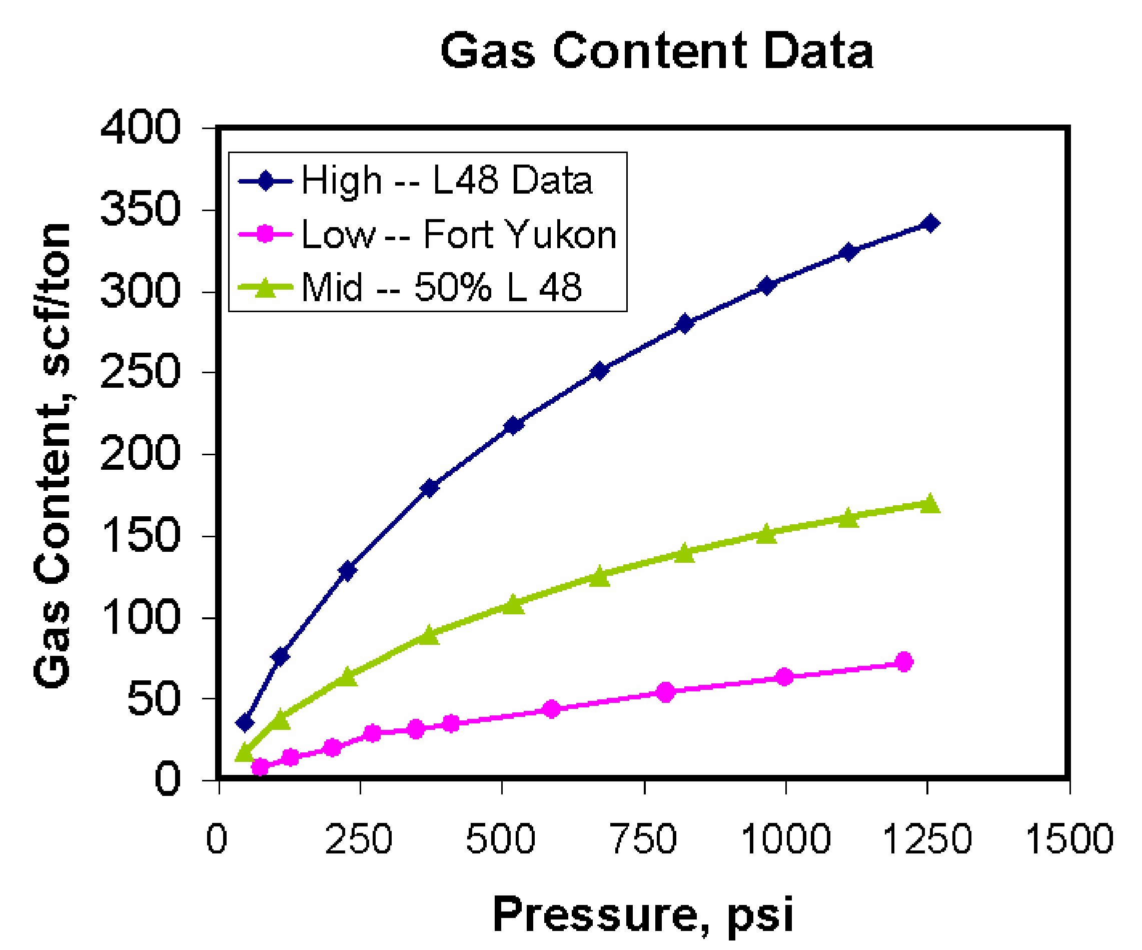

Figure 4.3 Coalbed Gas Content from Fort Yukon and Continental US

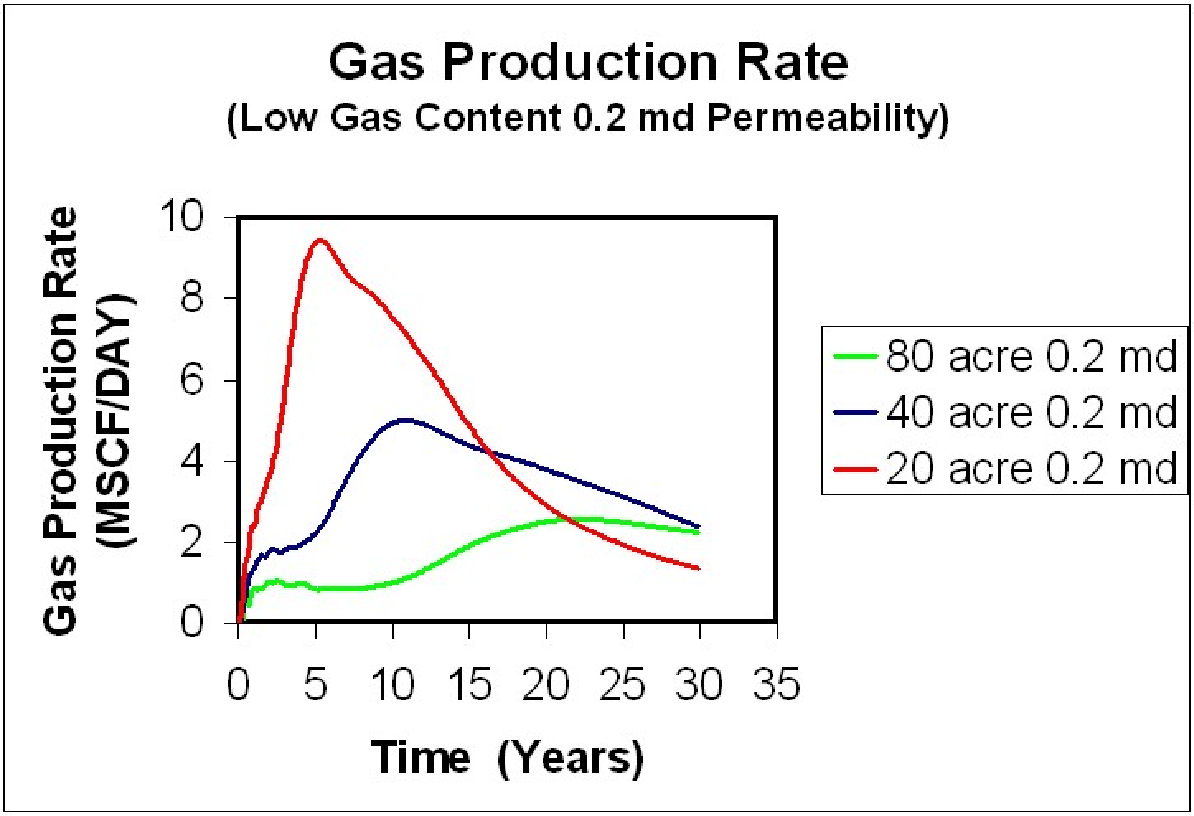

Figure 4.4 Gas Production Rate (MSCF/D) vs. Time (Years)

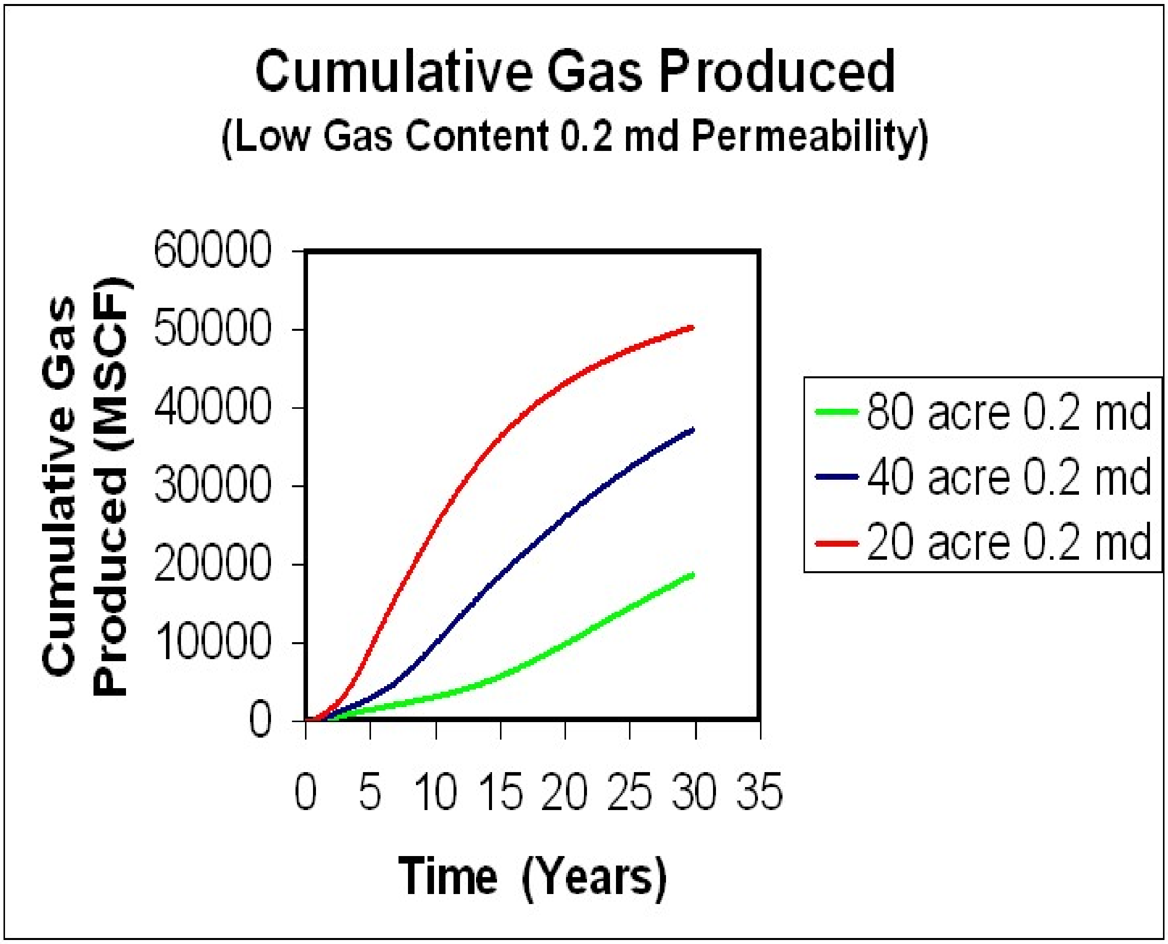

Figure 4.5 Cumulative Gas Produced (MSCF) vs. Time (Years)

Another issue associated with CBM production is disposal of produced water. The 20 acre well spacing results in the highest amount of produced water as shown in Figure 4.6. Disposal of produced water adds to the overall cost of CBM production. A sensitivity study of the effect of coal bed permeability on gas production rate is shown in Figure 4.7. The gas production rate increased from 10 to 25 MSCF/D when coal permeability was increased from 0.2 to 2 md, however, further increase in coal permeability did not increase the gas production rate. Clearly, at permeabilities above 2 md, gas production rate becomes constrained by low gas content of the coal.

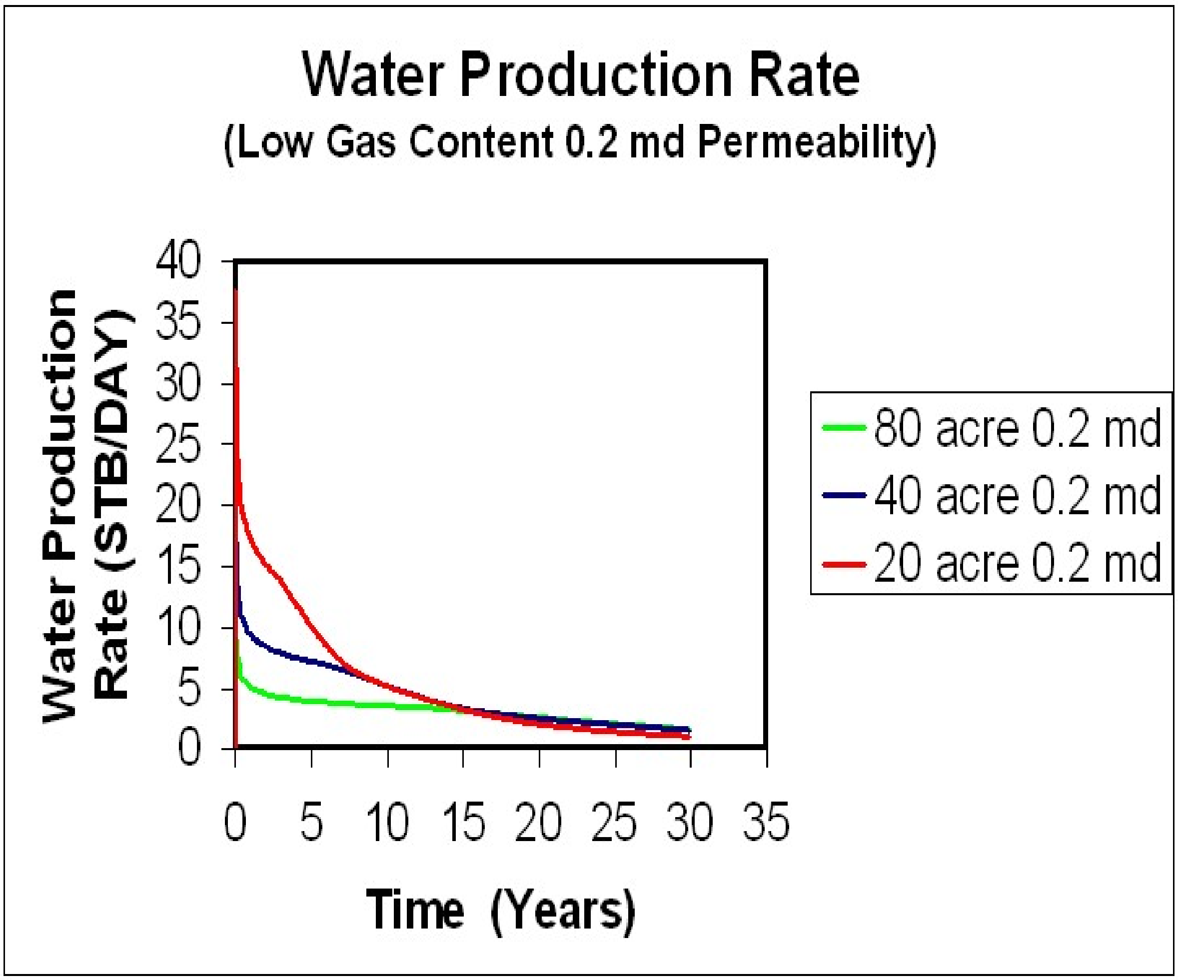

Figure 4.6 Water Production Rate (STB/D) vs. Time (Years)

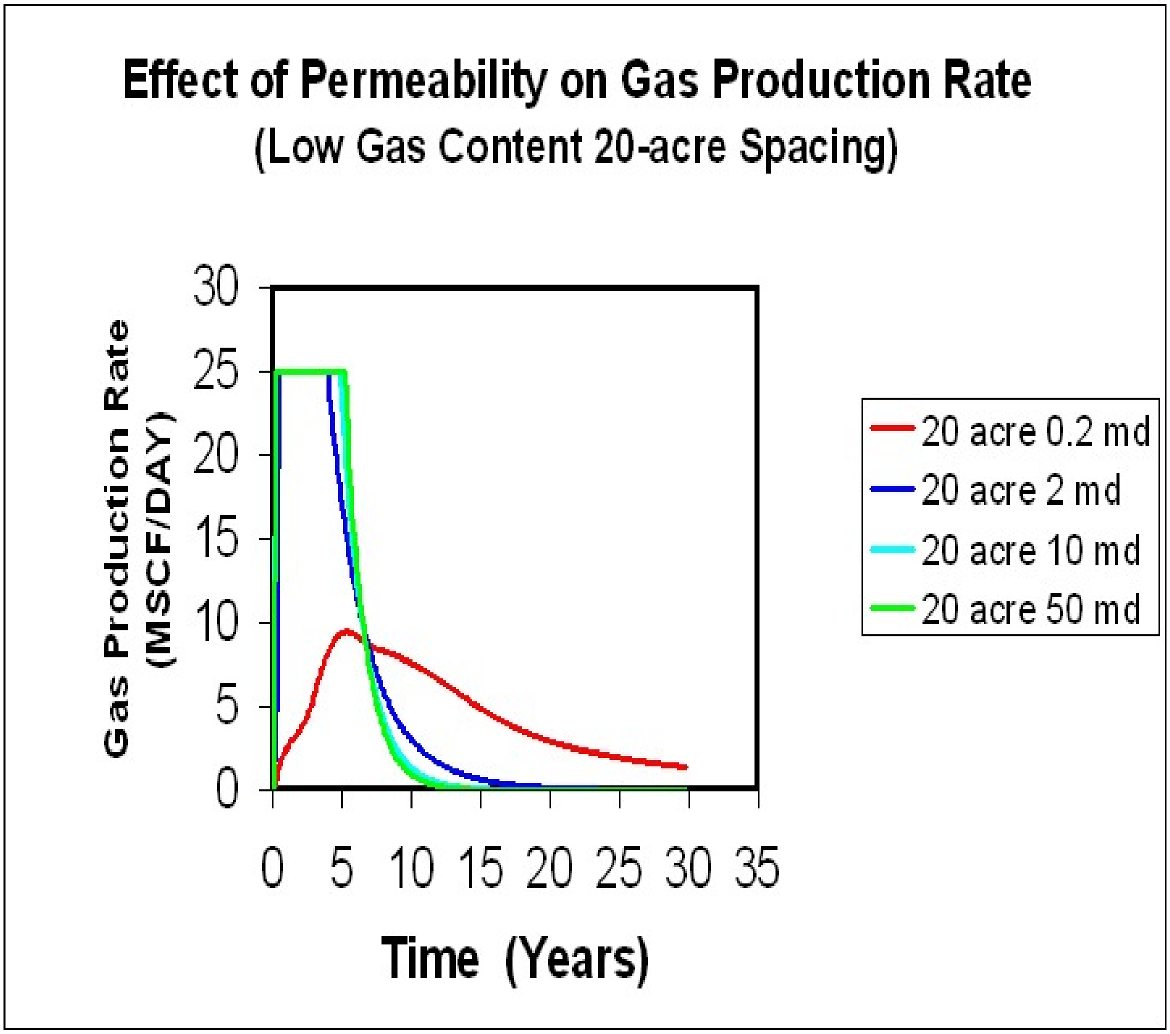

Figure 4.7 Effect of Coal Permeability on Gas Production Rate

Conclusions

In conclusion, the simulation study indicated that CBM gas production from the Fort Yukon coal beds would not result in significant gas production, even if close well spacing were used, because of low gas content and low permeability of the Fort Yukon coal beds.

The simulation study also showed that low gas content, rather than low permeability, is the primary cause of the lack of significant gas production from these coal beds.

Reference

T. Olsen, G.Brenize and T. Frenzel: “Improvement Processes for Coalbed Natural Gas Completion and Stimulation,” ICMS 2004

CHAPTER 5

ECONOMIC ANALYSIS

The first step in evaluating the viability of coal bed gas as an alternative source of energy is to correctly define the equivalent fuel gas usage rates, surface facility specifications and design requirements for this community. In an earlier study (Ferguson and Ogbe, 2003), the surface facility design requirements, approximate costs for using treated coal bed gas as the primary energy source were estimated and used to establish "rough order of magnitude" costs for developing total system for production of CBM. The study gathered data on the volumes of fuel consumed in Fort Yukon area and performed a preliminary economic analysis of CBM production using a conceptual surface production and distribution facility. Table 5.1 summarizes the fuel gas utilization data for Fort Yukon area. Equivalent CBM fuel gas rate requirements were determined based on the current liquid fuel heating values and expected heating values of future coal bed gas. The conceptual production facility design was based on peak anticipated fuel gas needs through the year 2015. The cost estimate utilized typical factors for similar equipment installed in remote arctic environments such as the Alaskan North Slope oil fields.

The key findings of this pre-drilling economic study are as follows:

1. The total equivalent fuel gas usage needs for the Ft. Yukon area were determined to be 250 MSCFD based on current electric and heating needs (as of 2003). This includes both the local community and the adjacent USAF military facility.

Table 5.1 Summary of Current Fort Yukon Area Fuel Usage

(Source: Ferguson and Ogbe, 2003)

Consumer	**Current Fuel Usage (Gallons/ Year)**	**Project Fuel Gas Needs (MSCF / Day)**
GZ Power Utility	186,000	74
USAF Power Utility	109,000	43
Local Grocery Store	35,000	14
Other/Contingency (10%)	32,000	13
Total Electric	**362,000**	**143**
Yukon Flats School District	27,000	11
Water Treatment and Supply	31,000	12
Municipal/Tribal Gov't	30,000	12
Residential housing	150,000	59
Other/Contingency (10%)	23,000	9
Total Heating	**261,000**	**103**
Grand Total	**623,000**	**247**

2. Including the effects of peak winter month consumption swings and the projected future needs through the year 2015, a peak fuel gas need of 460 MSCFD was projected.
3. The total capital costs for the subsurface and surface equipment to supply coalbed gas for Fort Yukon's energy needs were estimated at $5.06 to $7.06 million for a range of potential well development costs to provide the necessary gas rate. This assumes the current plan to relocate the GZ Power Utility proceeds. We also estimated the incremental cost to convert from diesel to gas fired generators.
4. The current total electric and heating fuel cost to the Fort Yukon community is approximately $1.2 million per year. The energy cost for the average commercial and residential consumer in the Fort Yukon area is approximately $14.40/ MMBTU. Assuming a fuel gas value of $8/MSCF ($8.89/MMBTU), the total energy cost to all commercial and residential consumers in the community would be reduced to approximately $700,000 per year resulting in a savings of approximately $500,000 per year. The average residential household savings were estimated to be $700 to $1,500 per year depending on the Power Cost Equalization (PCE) subsidy assumed in the calculations.

The Fort Yukon well drilled in 2004 as a part of this project determined that the coal beds in this area cannot produce adequate amount of CBM to meet the energy needs of the village. However, the cost data from the trial can be used to perform a realistic economic analysis of a Fort Yukon project for developing and producing CBM, and the data may also be useful for studying similar developments in other remote Alaskan villages. In this chapter, the Fort Yukon drilling costs and fuel usage rates are entered into an economic model to determine the final CBM based energy prices for the area. The cost of delivery of CBM gas determined from this study can be compared to the current energy costs as well as other alternative sources of energy. The following sections describe the specific objectives, methodology, and results from the economic analysis.

5.1 OBJECTIVES OF ECONOMIC ANALYSIS

The Fort Yukon CBM project conducted a trial drilling in a Fort Yukon coal bed in order to determine the costs and physical potential of fully developing a reservoir. Data on costs for building and constructing surface facilities to handle gas processing and gas distribution to end users in the community was also gathered. The cost data is evaluated using an economic model to determine the feasibility of CBM for rural Alaskan communities. While the trial drill hole in Fort Yukon came up dry, the cost data from the trial was sufficient to determine the feasibility of a CBM project in other locations.

Specific goals of the economic analysis are as follows.

1. To assemble a database of information. The data base will include the estimated fuel gas required to meet current energy usage/consumption in Fort Yukon, the reservoir characteristics, the number of wells required to deliver gas, and the water production rates. The previous trial drill established the costs of drilling, completing, and maintaining the wells down to a depth of 3,000 ft. sub-sea.

2. To develop an economic model to show the feasibility of developing a CBM project for Fort Yukon. The model is general enough to use for other rural Alaska areas.
3. To give results from the model to show how feasible a CBM project is in Fort Yukon or in a comparable rural Alaskan village.
4. To prepare the data and results in a format that can be used as a model for implementing the use of CBM gas in other rural Alaska communities.

5.2 METHODOLOGY

Oil and gas companies use economic models of projects to determine whether a project is economically feasible and to compare the economics of various projects. They also use the models to conduct "sensitivity analyses," that is to answer questions like how will the project's economics change if the price of oil increases by ten percent or there are cost overruns of twenty percent. Governments use economic models to determine the appropriateness of fiscal systems and the effect of various incentives on private investment and government revenues.

All models are evaluated using the project return on investment (ROI). The ROI indicates which project may prove the better investment. The ROI is used to compare project scenarios that have different patterns of costs and expenditures and evaluate them all on a common basis. Generally, better projects have higher returns on investments. The ROI, however, must be high enough to make the project feasible. The point at which a project becomes feasible is called the hurdle rate.

In this analysis, a specific hurdle rate is fixed and the economic model is used to determine a price for heat and electricity for the village based on that specific hurdle rate. Cost data obtained from the trial drilling and other sources are included in the model. In addition, a sensitivity analysis is carried out. Since costs to run a CBM project in a rural Alaskan village are expected to be higher than some of the cost estimates included, the economic model was run over different cost scenarios. Specifically a cost overrun multiplier was created at 50%, 100%, 150%, and 200% above the base case data to determine how such a cost overrun will affect the final price of heat. The model runs given in the appendixes show the relationships between the final price of energy and the cost overrun multiplier.

5.3 ASSUMPTIONS

5.3.1. CBM Field Modeled

The model assumes that the project occurs in Fort Yukon. The field is in the vicinity of the site where an exploratory well was drilled in 2004.

5.3.2. Scale and Duration

The economic model is constructed at the pod level, where a series of CBM wells from a contiguous field tie into a single pod. The node feeds its gas into higher-pressured pipelines. The produced gas is transported to Gwichyaa Zhee (GZ) Corporation power utility plant for electrical power generation and also distributed to end users (homes) for heating. The FY-CBM (Fort Yukon CBM) model assumes that the entire system operates for 15 years. Costs, revenues, and profits are calculated as if the entire system from wellhead to burner tip and electrical appliance were one system.

5.3.3. Ramp Up

The model includes three scenarios for the ramp up of the system. Usually coal-bed methane fields take one to three years to dewater before the methane becomes available for sale. Since dewatering represents a significant cost and since it causes revenues to be delayed, it will have a significant impact on the economics of such a project. In this study, a one year, two year, and three year ramp up are considered.

5.3.4. Energy Demand

Energy demand includes the demand for CBM gas delivered to the GZ power utility plant in Fort Yukon as well as gas delivered to the town for heating. Another energy user is the U.S. Air Force's Power House that is on location near Fort Yukon. The consumption quantities were estimated from earlier studies for Fort Yukon. The demand also includes fuel use for powering the compressors that transport the gas through the pipeline. The demand is adjusted for differences in the BTU content and the impurities of the FY-CBM gas, as measured against natural gas standards. The demand for Fort Yukon is shown in the Appendix A.

5.3.5. Costs

Costs are broken down as follows. Tables 5.2 to 5.7 give specific estimates. These include the costs of CBM production and dewatering well construction, water disposal well, fuel gas distribution system, utility conversion costs, operating costs, taxes and other costs.

A.) CBM production and dewatering wells

Based on project specifications, five wells will be used to create a single pod. This one pod will normally be enough to produce the required methane consumption. Slim hole wells were used in the analysis. The tangible and intangible costs for each well drilled are $853,000. These capital costs of constructing the pod include drilling and completing the five wells. Each well will be used to dewater and to produce CBM gas. Detailed cost estimates of CBM production and dewatering wells at Fort Yukon are shown in Table 5.2.

Table 5.2 Coal Bed Methane Well Costs for Site #1: Fort Yukon
(Cost of Constructing Five Wells for Producing CBM gas and Dewatering)

Itemized Project Expenses	**Drill, Test & Completion Summary Costs**	***Sources and Comments***
Tangible Costs:		
Tubular Equipment	---	
Wellhead Equipment	---	
Completion Equipment	---	
Dewatering Equipment	---	
Total Tangible Costs:	**$150,000**	Based on Petroleum News Article

Intangible Costs:		
Project preparation including equipment repair, parts, and supplies	$112,000	Based on 2004 Drilling Costs
USGS Headquarters Assessment	$96,000	"
Drilling charges	$175,000	"
Expendable items (bits, mud, casing, grout, cement etc)	$81,000	"
Other USGS personnel charges (logging, GW, QW) and data analysis	$13,000	"
Shipping and transportation related expenses	$143,000	"
Pack equipment and prepare for barge	$15,000	"
Transportation of equipment from Denver to Nenana	$30,000	"
Transportation of equipment from Nenana to Fort Yukon	$35,000	"
Total Intangible Expenses	**$702,000**	
Tangible and Intangible	**$853,000**	
Open Hole Costs	**$853,000**	Per well
Total Site Costs	**$4,264,000**	5 wells for dewatering and producing CBM gas

B.) Water disposal well

There are two options for water disposal. One option is shallow re-injection, and the other is deep re-injection. The options are governed by finding a competent formation to contain the produced water. An important consideration is to avoid contaminating water tables in the vicinity of the formation. Such formations could be 3000 feet (shallow well) or deeper (deep well). Since a deep well is not going to cost much more than a shallow well, we assume a typical well cost similar to the CBM wells as listed in Table 5.2 above. This would include the costs of constructing the surface water re-injection facilities.

C.) Well peripherals

Capital costs of constructing surface facilities for gas processing include water removal, gas treatment, and a pipeline to the relocated power utility. The following items are expected as part of the water removal and gas treatment bundles: insulated housing for meters, filters and separators to prevent freezing, water flow lines, water meters, PVC line to water treatment pits, vacuum breakers to prevent a vacuum lock from stopping water flow in the line, gas meters, gas dehydrator, compressor, gas scrubber. Table 5.3 provides details of these costs.

Table 5.3 Capital Costs of Surface Facilities/Pipeline to Relocated Power Utility

	Process Equipment Cost	**Fort Yukon Installed Module Cost**
Water Removal		
Two-phase Separator -Water KO Drum (2' OD *6'H)	$2,100	$11,000
Water Re-injection Pump (400BWPD, 1000psi, 10HP)	$5,250	$26,000
Total:		**$37,000**
Gas Treatment		
Mole Sieve incl. Regeneration	$52,500	$263,000
Total Processing Building		**$299,000**
Pipeline to Relocated Power Utility		$184,000
(Nominal 3.5" line ~ 1 mile from well locations)		
Total:		**$483,000**

D.) Fuel gas distribution system

This is the system of pipelines which will carry the methane to individual houses and businesses for heating needs. The costs associated with constructing the distribution system are shown in Table 5.4.

Table 5.4 Fuel Gas Distribution System

Components	Anchorage Installed cost	Fort Yukon Installed Cost	Total Costs
2" Main trunk line through town (3 miles)	$5.25/ft	$10.5/ft	$166,000
1" Lateral lines to buildings (30 miles)	$1.05/ft	$2.1/ft	$333,000
Pressure regulatory station			$26,000
Building tie-in/metering (300 @ $525/building)			$158,000
Total:			**$683,000**

E.) Utility conversion costs

The power generation facilities need to be converted to burn methane. These costs include additional modules for gas-fired plant, an additional footprint, and the conversion of existing diesel power generators (Table 5.5).

The capital costs described in A.) through E.) are summarized in Figure 5.1.

Table 5.5 Gas Power Utility Conversion Costs

Modules	**Costs**
Additional modules for gas fired plant (additional footprint)	$856,000
Conversion of existing diesel power generators	$1,628,000
Total:	**$2,483,000**

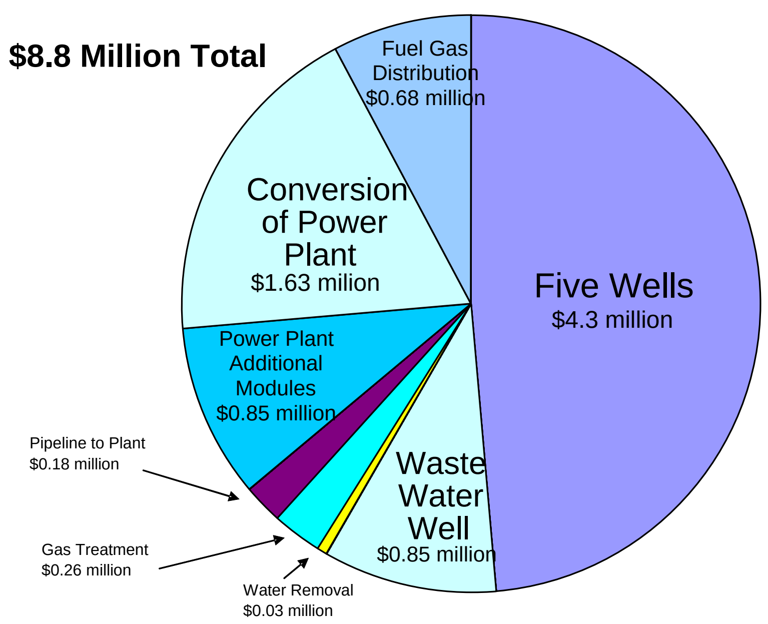

Figure 5.1: Pie Chart of Costs for Wells and Capital

F.) Power plant move (optional)

Costs include the relocation of the existing power plant. The plant is scheduled to be moved due to flood plain considerations. Therefore, this is not a typical expense when comparing a Fort Yukon project to other villages. However, one model run was done with this expense included. The cost is projected at over $7.1 million, which would almost double the costs of a Fort Yukon project.

G.) Operating costs

Operating costs comprise the costs of operating the node and surface facilities as well as the costs of operating water re-injection facilities. This is based on direct annual operating costs for CBM production in Powder River Basin in Montana and Wyoming Here, there are 10 wells dewatering from 1,000 ft. Since the FY-CBM project is first of its kind in Alaska, no operating cost estimates for remote Alaskan location are available. Thus, data from Montana and Wyoming, which are somewhat similar to Alaska in terms of rural nature and population density, was used. The operating cost estimates are listed in Table 5.6.

Table 5.6 Operating Costs

Expenses:	**Yearly Costs**
Supervision and Overhead	$5,300
Labor (pumper)	$8,100
Auto Usage	$2,400
Chemicals	$0
Fuel, Power & Water	$23,600

Operative Supplies	$1,900
Subtotal	**$41,300**
Surface Maintenance, Repair & Services:	
Labor (roustabout)	$11,600
Supplies & Services	$7,300
Equipment Usage	$4,100
Subtotal	**$23,000**
Subsurface Maintenance, Repair & Services:	
Well Servicing	$25,100
Remedial Services	$5,700
Equipment Repair	$11,800
Subtotal	**$42,600**
Total	**$106,900**

H.) Cost multiplier

It is expected that costs for a village CBM project will be higher than the estimates above because of Alaska's extreme remoteness and weather. Therefore, the economic model includes a multiplier that will run the costs at multiples of the base case of 1, 1.5, 2, 2.5, and 3. This will take into account the higher costs of a commercial project in Alaska. Experience from other projects in Alaskan villages suggests that rural Alaska's total project costs will end up being in the 1.5 to 2.5 cost multiplier range.

i) Taxes

Taxes are determined assuming the final value of natural gas at the burner tip and of electricity at the transformer. Tables 5.7 gives specific taxes.

Table 5.7 Taxes

Taxes	Rates
Federal Income Tax	35%
State Income Tax	9.4%
Severance	10%
Royalty	6%
Depreciation	
MACRS	7 years for well costs
MACRS	15 years for utility and gas distribution

5.4 RESULTS

Table 5.8 summarizes the results from the base case economic model runs. Detailed plots for the different economic scenarios are shown in Appendix A.

Table 5.8 Economic Model Results

Base Case Costs (with no cost overruns)	$/MSCF	$/kWH
3 year ramp up to dewater		
5% ROI	$14	14¢
10% ROI	$24	24¢

15% ROI	$35	35¢
2 year ramp up to dewater		
5% ROI	$14	14¢
10% ROI	$21	21¢
15% ROI	$31	31¢
1 year ramp up to dewater		
5% ROI	$13	13¢
10% ROI	$19	19¢
15% ROI	$26	26¢

Conclusions

The equivalent total fuel consumption for both electrical and heating needs in the Fort Yukon community has been estimated by this study to be 220 MSCF/D with a projected slow increase in demand for fifteen years. The cost for initial capital and wells is estimated at $8.8 million with an initial operating and maintenance cost of $107,000 per year that will increase with inflation. These costs and consumption figures were used in the economic model to estimate fuel prices for a given return on investment (ROI). Based on current energy costs for liquid fuels ($29/MMBTU), there is the potential for significant savings to the consumer converting this alternate energy source. The final price for electricity generated from CBM gas will be between 35¢ and 50¢ per kWH assuming a 10% ROI and a three year start up. This price is comparable, but not competitive with the price of electricity (45 cents/kWH) generated using diesel, based on a diesel price of $4 per gallon at the time of this analysis. However, power generation from CBM is likely to be more environmentally friendly than using diesel.

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CHAPTER 6

USE OF DRILLING WASTE

An unanticipated and positive outcome of the drilling process at Fort Yukon was innovative use of drilling waste as sealant for landfill site. This was neither part of the initial project objectives nor the anticipated tasks. The use of drilling waste as a sealant is described below.

6.1 Beneficial Use of Drilling Waste as a Sealant for Old Landfill Site

Drilling waste, predominately bentonite, that was generated by the project was used as a sealant for an old landfill site southwest of Fort Yukon's airport runway (Figure 6.1). It was determined that surface disposal of the solid waste would not present a threat to the public heath, safety, or welfare, or to the environment, but rather would provide a beneficial seal to an old problem that existed in the Fort Yukon area. This opportunity provided for convenient disposal of the product and would help to protect the water table and Yukon River from possible contaminants from the old landfill. The State of Alaska, Div. of Geological & Geophysical Surveys in a July 9, 2004, memorandum from the project team, DGGS, U.S. Geological Survey (USGS), University of Alaska Fairbanks and Bureau of Land Management, to The State of Alaska Department of Environmental Conservation (ADEC), Div. of Environmental Health, requested approval to manage drilling waste to help seal an old landfill site, known as the Old City Garbage Dump, at Fort Yukon near the barge landing site. The location of this site is in the SE ¼, SE ¼ of Section 12, T20N, R11E Fairbanks Meridian. Fannie Carroll, City Manager of Fort Yukon submitted a letter to ADEC (dated June 27, 2004) requesting this beneficial use of the drilling mud at the Old City Garbage Dump. The plan for sealing the old Fort Yukon landfill using drilling waste is shown schematically in Figure 6.2.

The drilling waste that was generated by this exploration project consisted of bentonite clay, drill cuttings, water, and cellulose polymer-quick-gel high yield bentonite (used for hole stability, circulation control, clay-shale control); Aqua-gel bentonite (hole stability, circulation control, mud weight); Pac-L powdered cellulose polymer (clay-shale control); EZ mud liquid polymer (clay-shale control); and Pennetrol liquid detergent (to prevent clay balling around drill bit). Art Clark, U.S. Geological Survey in Denver, CO supervised the landfill seal operations. Drilling activities were anticipated to produce 10,000 to 20,000 gallons (1,336-2,673 cubic feet) of drill mud/additives/cuttings that would dehydrate to approximately half its original volume leaving a total of approximately 750-1250 cubic feet of dry product. 1250 cubic feet will then cover a 100' X 50' area to a depth of 3 inches. A vacuum-truck was rented from the City of Fort Yukon to collect the mud and cuttings from the drill site's ADEC-permitted temporary containment pit during drilling operations and driven to the old landfill site. The drilling mud waste was then sprayed through a hose evenly across the old landfill site. The disposal covered up to ½ of the old landfill site, or approximately 100 feet long by 50 feet wide. The wet mud subsequently generated about 15 cubic feet of dry product once dehydrated and provided between 2 to 4 inches of seal. When the bentonite and cuttings dried out, the area was covered with about 2 inches of soil/gravel seal. Figure 6.3 shows a sample photograph of the landfill area after it was successfully sealed with drilling waste.

Figure 6.1 Fort Yukon's old landfill near airport

2004 drilling mud seal plan at old Fort Yukon landfill site for 2004

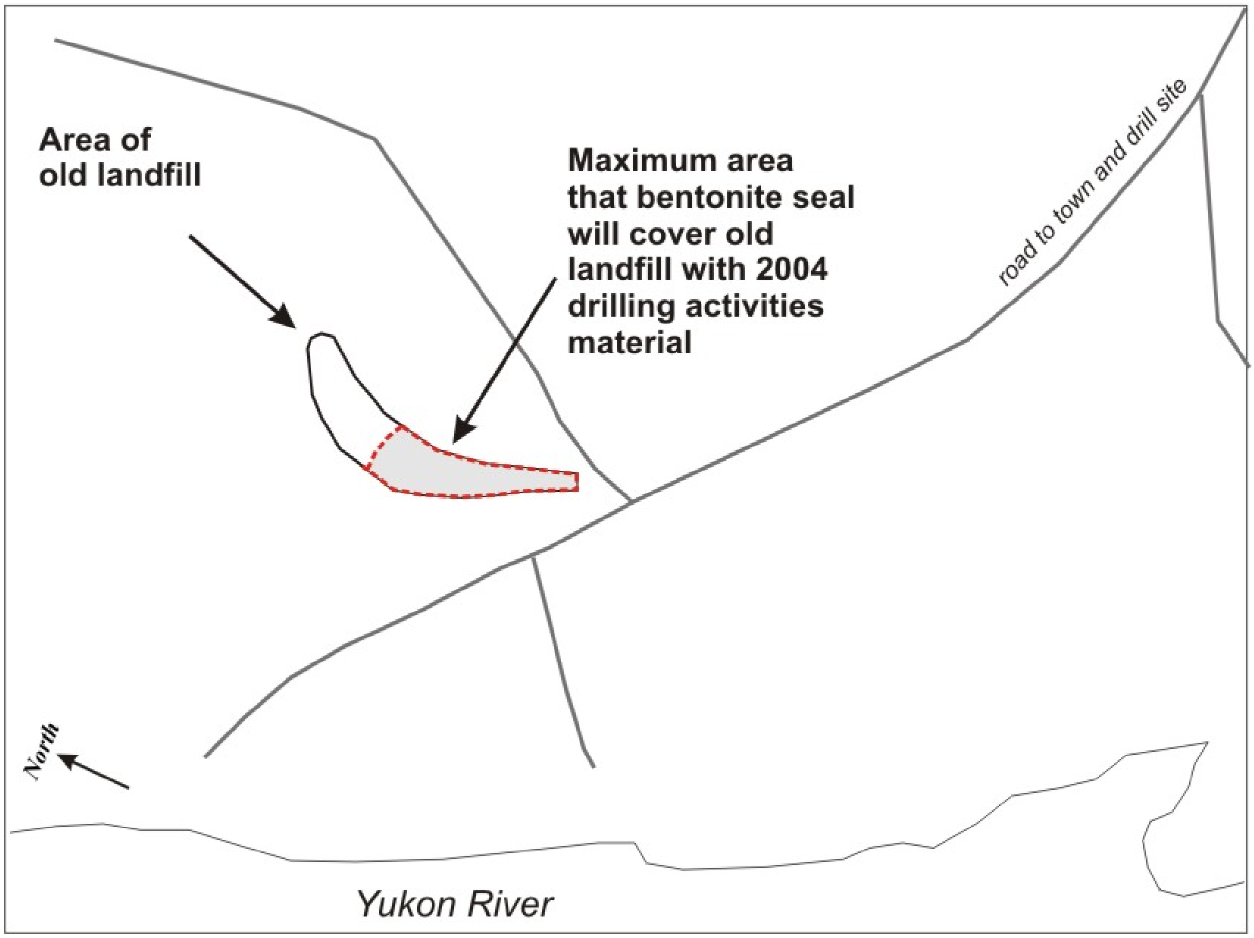

Figure 6.2 Plan for sealing part of old landfill at Fort Yukon

Figure 6.3 Successful use of drilling waste as sealant for landfill

Conclusion

Drilling waste generated from a water-based drilling fluid system, drilling through non-oil bearing zones, can be successfully used as sealant for landfill areas without any significant environmental risks.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The re-entry well DOI-04-1A at Fort Yukon drilled in 2004 using a lightweight, portable rig cut through two coal zones of tertiary age. Core samples of coal from both zones were recovered and analyzed for geological and petrophysical properties, and methane gas content. Reservoir simulation for gas production rate forecast and economic analysis of power generation from CBM gas at Fort Yukon using actual drilling cost data were performed. The following conclusions are drawn from this study.

1. The project demonstrated that use of lightweight, portable drilling rigs is a viable way for drilling slim holes for CBM production and dewatering in remote locations of Alaska.
2. Production of CBM gas in sufficient quantity to meet the energy needs of Fort Yukon is not feasible because of very low gas content and very low permeability of the coal beds. Even with close well spacing, CBM production rate at Fort Yukon would fall far short of the amount of gas needed.
3. Economic analysis of power generation from CBM at Fort Yukon, using actual drilling cost data, shows that the cost of electricity generated via CBM is comparable, but competitive with the cost of electricity generated traditionally using diesel. This conclusion is based on the prevailing price of diesel at the time of analysis. If the price of diesel goes up significantly, power generation from CBM may become economically attractive. On the other hand, power generation

by using CBM, a clean fuel, always has intangible benefits in the form of reducing environmental damage.

4. Drilling waste generated in a drilling process using water-based drilling fluid system and drilling through non-oil bearing zones can be successfully used as sealant for landfill areas without any significant environmental risks. This is likely to help reduce drilling waste disposal costs in remote areas.

7.2 RECOMMENDATIONS

Additional work should investigate the synergy of combining the GZ Power Utility with the U.S. Air Force Power House to reduce overall relocation and gas conversion costs. RSA Engineering considered some of these options for a diesel plant. More detailed analysis is needed to explore gas-fired generator conversion costs for the existing utilities. In addition, investigations should analyze the potential to utilize waste heat recovery to enhance energy efficiency and reduce heating fuel needs.

Further work must focus on the response of variations in reservoir rock permeability and the drainage area of each well (acreage). Also it would be wise to analyze how produced water can be processed for significant amounts of drinking-quality water. Finally for the Fort Yukon Coal-Bed Methane Economic Model (FY-CBM-EM) to provide even better results, we need additional industry cost estimates which are difficult to obtain because these are proprietary.

The cost for residents and commercial buildings to convert to gas heating systems will vary for each consumer. A future study should be performed to determine the best options available to the primary commercial consumers (i.e., Yukon Flats School District, Water Supply and Treatment, and other key municipal/tribal government facilities) as well as to the various residential consumers. This will help establish the upper limit of the gas price that the overall project investor(s) can reasonably expect to charge for his product.

If a similar project is done for another Alaskan village, detailed work needs to be done to ascertain design requirements and costs of all the elements of such a project. The largest area of uncertainty is the number of wells and the costs to meet the projected gas supply and demand. Future well gas rates and deliverability will be critical to calculation of the well costs. The associated water rates will also represent a key design and cost factor. The best site for the coal-bed methane wells and processing facilities must be determined. The associated pipeline routing and gas distribution network should be included in a site evaluation. The impact of soil conditions on the pipeline route and on the gas distribution network needs to be investigated to better establish design requirements and project costs.

APPENDIX A

Tables and Figures from Economic Analysis

Appendix A includes fuel demand table, and results from specific economic model runs based on different cost options.

Table A.1 Fort Yukon Diesel Fuel Demand Projection and its Equivalent Gas Requirement

Year	Total Gallons Of Diesel Fuel	Gas Equivalent (MSCF/D)
2004	527,337	209
2005	534,039	211
2006	541,038	214
2007	548,093	217
2008	555,205	220
2009	562,375	223
2010	569,602	225
2011	576,888	228
2012	584,232	231
2013	591,635	234
2014	599,098	237
2015	606,620	240
2016	614,203	243
2017	621,846	246
2018	629,551	249
2019	637,317	252
2020	645,145	255

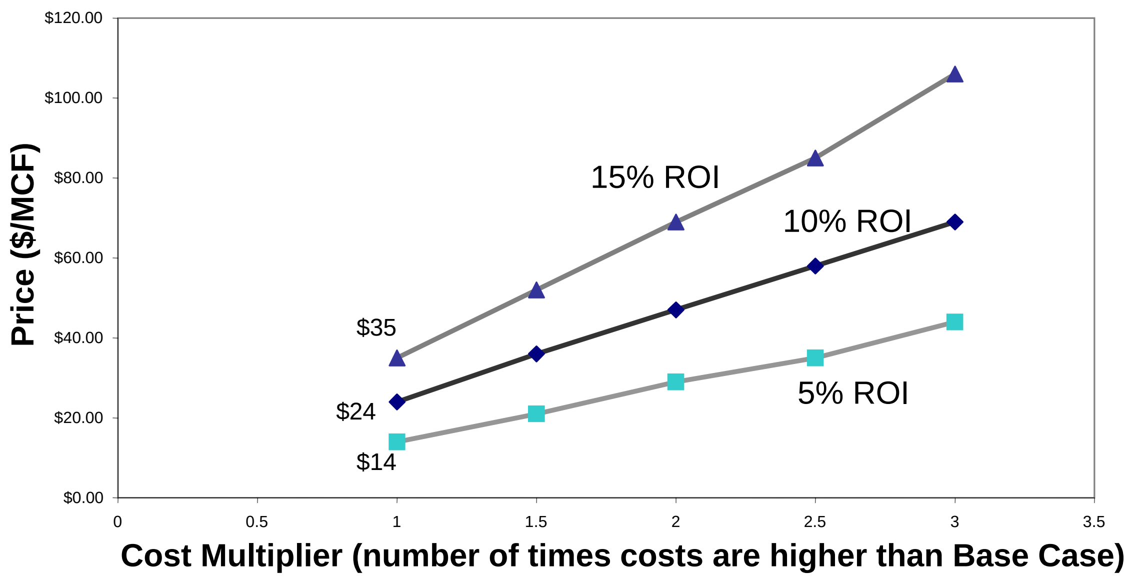

Figure A.1 Price to cost Multiplier Relationship with no Plant Relocation Cost (Start in 3rd year-price/MCF)

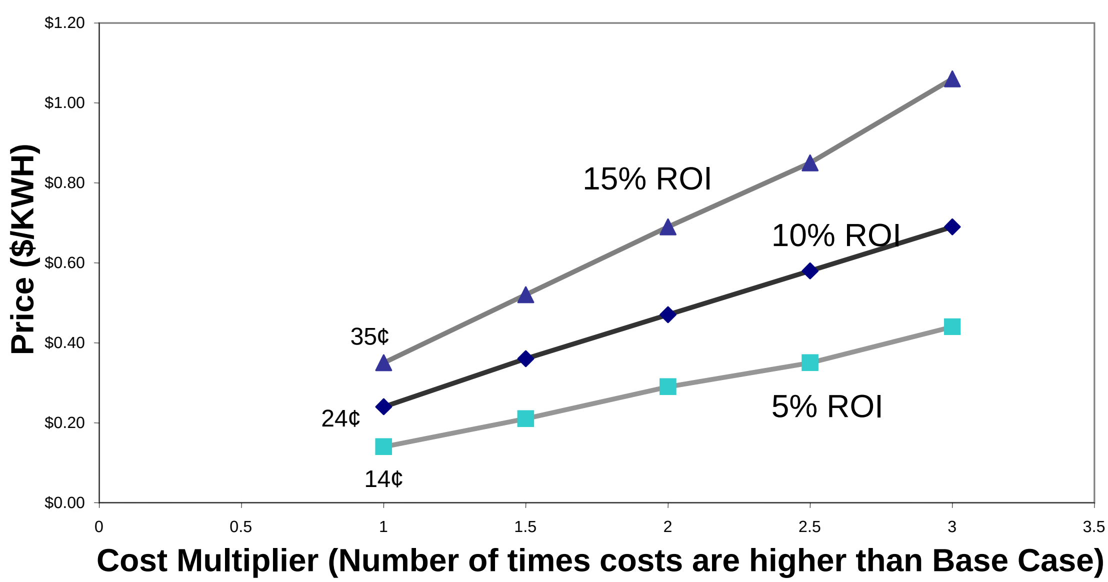

Figure A.2 Price to Cost Multiplier Relationship with No Plant Relocation Costs (Start in 3rd Year-price/kWH)

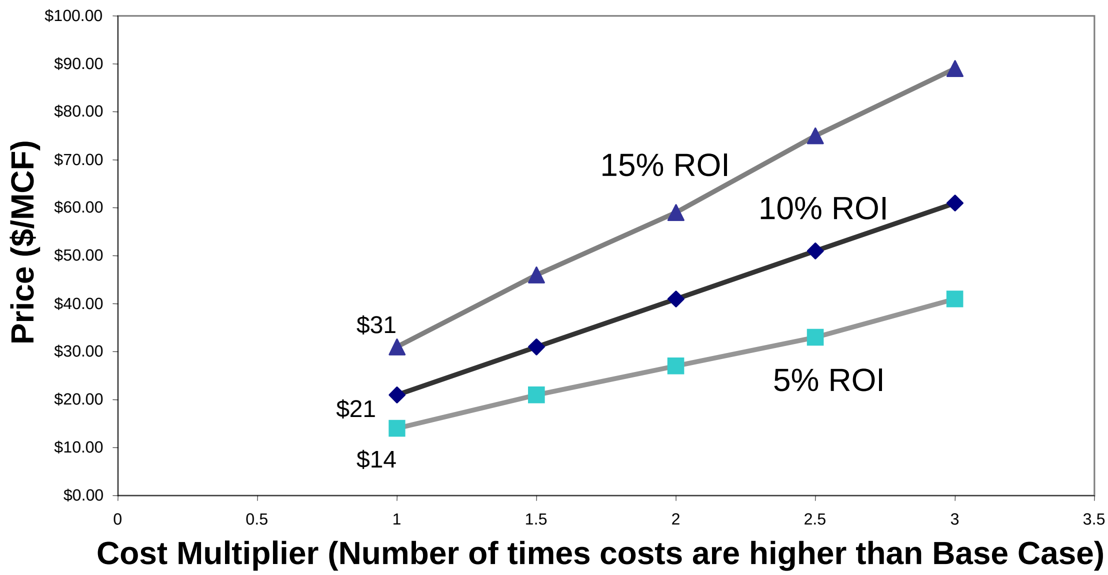

Figure A.3 Price to Cost Multiplier Relationship with No Plant Relocation Costs(Start in 2nd Year-Price/MCF)

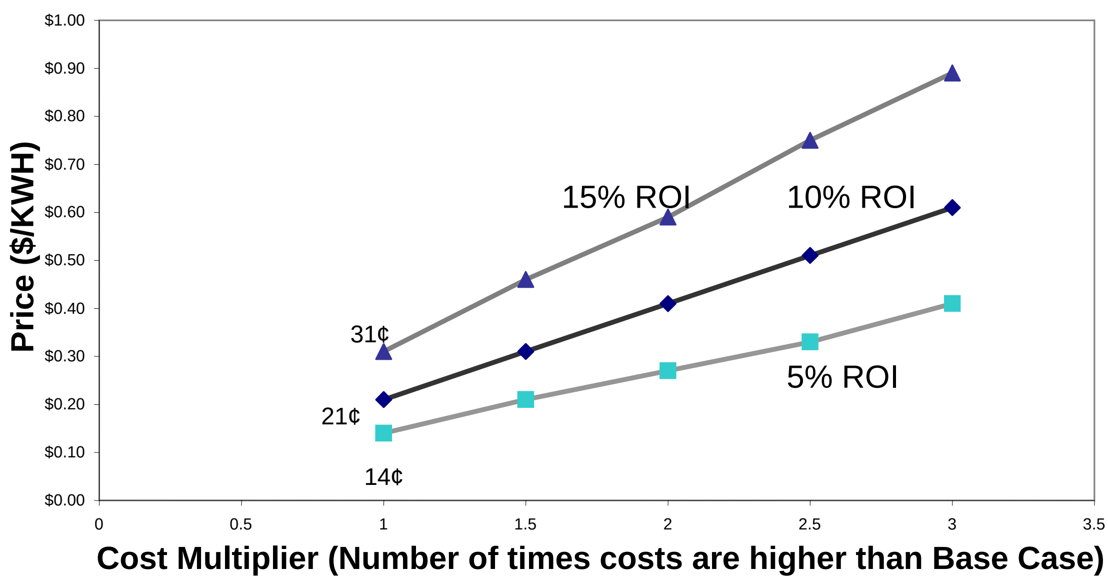

Figure A.4 Price to Cost Multiplier Relationship with No Plant Relocation Costs(Start In 2nd Year-Price/kWH)

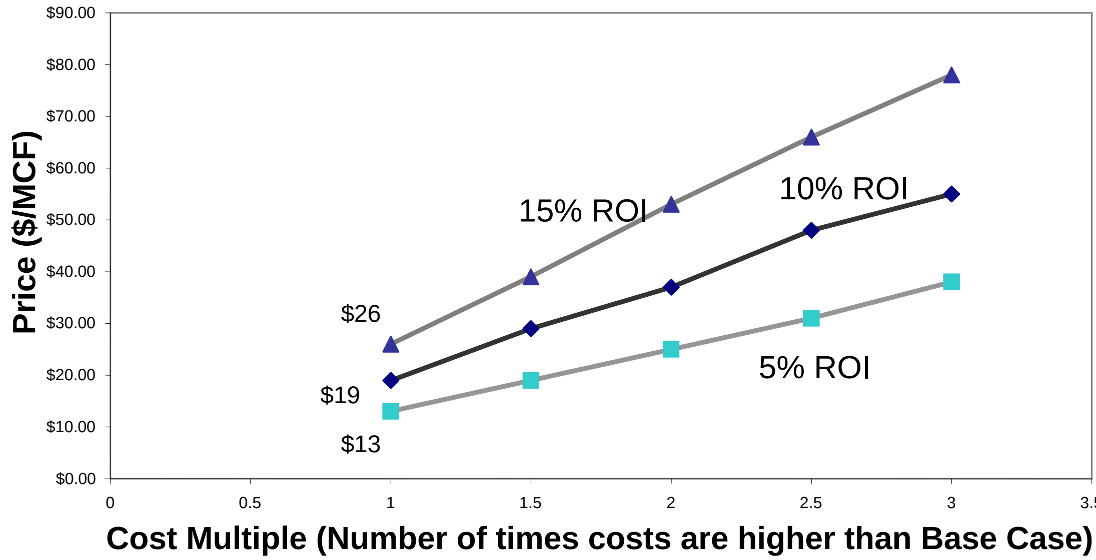

Figure A.5 Price to Cost multiplier relationship with no Plant Relocation Costs(Start In 1st Year-Price/MCF)

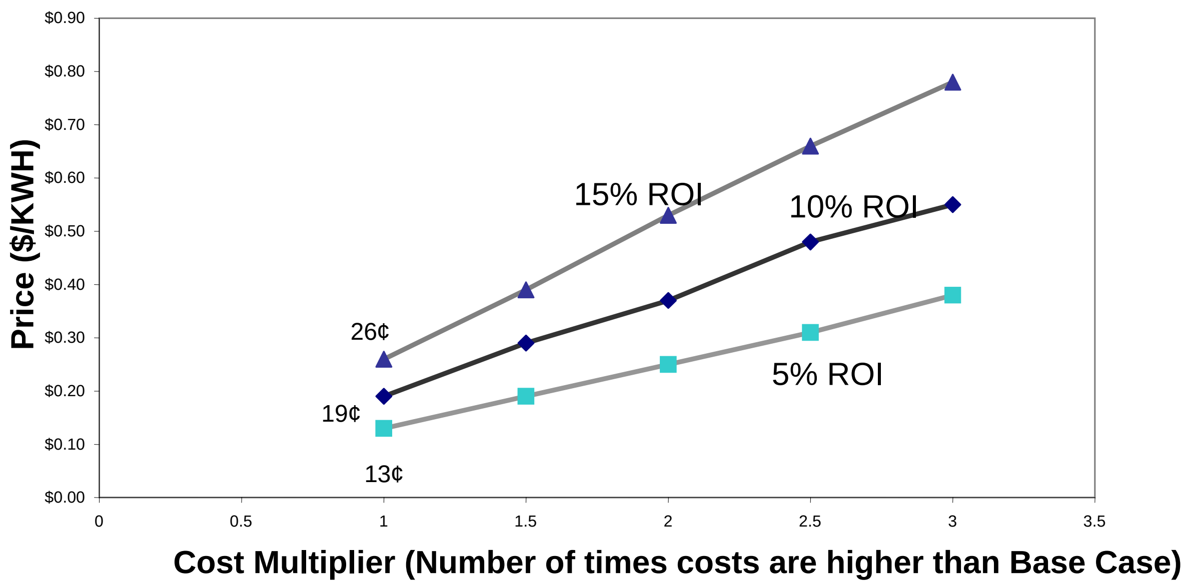

Figure A.6 Price to Cost Multiplier Relationship with No plant Relocation Costs (Start In 1st Year-Price/kWH)

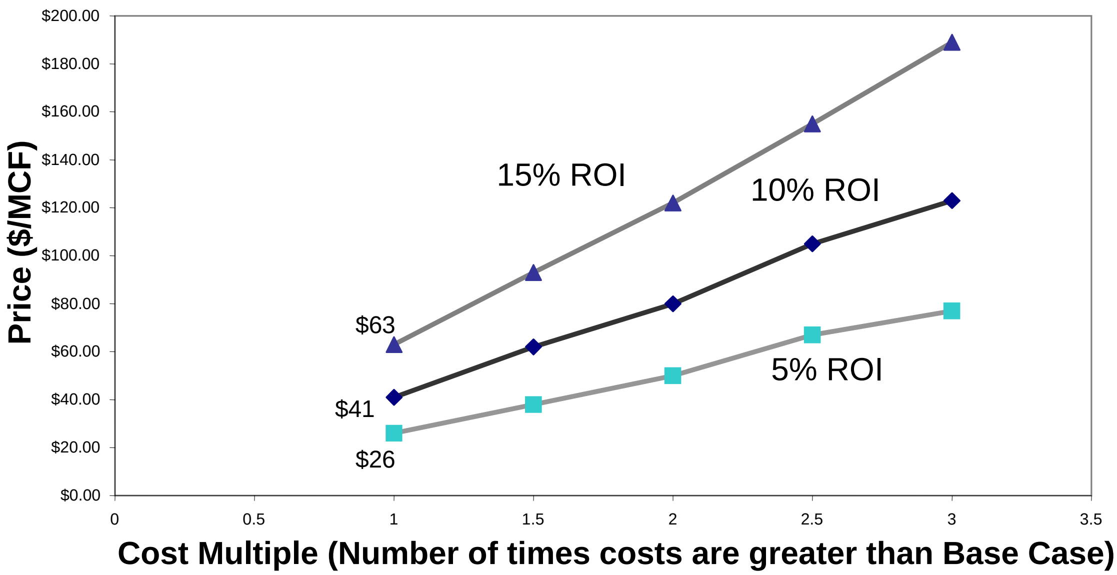

Figure A.7 Price to Cost Multiplier Relationship with Plant Relocation Costs (Start in 3rd Year-Price/MCF)

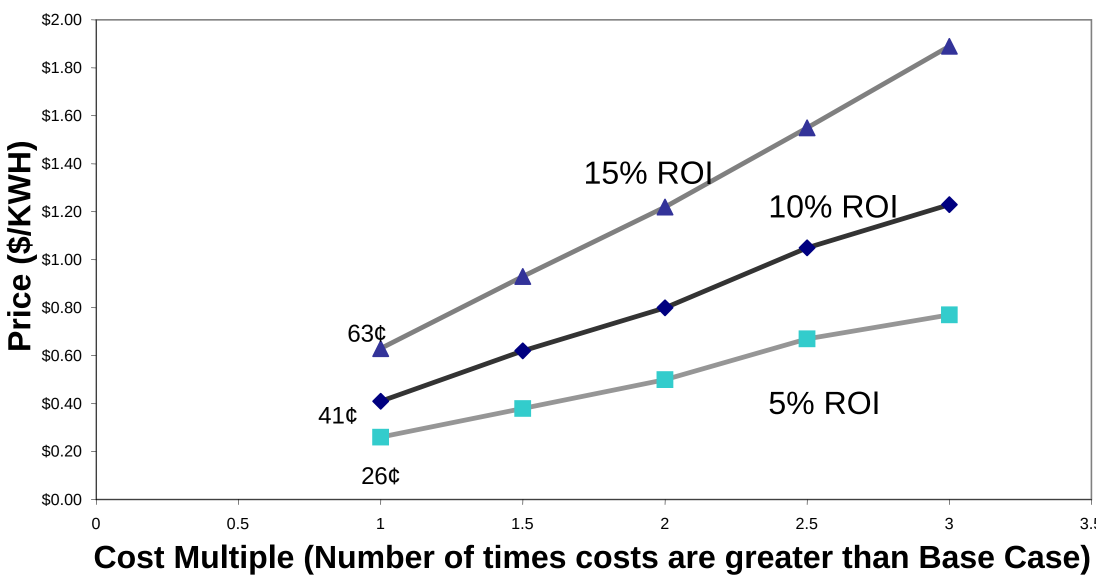

Figure A.8 Price to Cost Multiplier Relationship with Plant Relocation Costs (Start in 3rd Year-Price/kWH)

Stratigraphy and Depositional Setting of the Nonmarine Tertiary (Miocene) Sedimentary Succession in the 2004 Lower Drill Core, Fort Yukon, Alaska

Final Report

for

Arctic Energy Office
Fairbanks, Alaska
National Energy Technology Lab
US Department of Energy

Through

Arctic Energy Technology Development Laboratory
University of Alaska Fairbanks
Fairbanks, Alaska 99775

For grant DE-FC26-01NT41248

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Stratigraphy and Depositional Setting of the Nonmarine Tertiary (Miocene) Sedimentary Succession in the 2004 Lower Drill Core, Fort Yukon, Alaska

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ABSTRACT

Tertiary non-marine sedimentary rocks beneath Fort Yukon, Alaska were drilled and cored in 2004 as part of a joint effort between the Alaska Division of Geological & Geophysical Surveys, U.S. Geological Survey, U.S. Bureau of Land Management-Alaska, University of Alaska Fairbanks, and U.S. Department of Energy-Arctic Energy Office to evaluate the shallow gas potential of lignite seams beneath Fort Yukon. This effort reentered a 1994 U.S. Geological Survey drill hole that was originally drilled and cored to 1,283 feet to study Tertiary paleoclimates. The 2004 drilling operations drilled to a total depth of 2,287 feet and recovered about 650 feet of core from core drilling, and cuttings were collected from about 330 feet of rotary drilling. We studied the lower Fort Yukon 2004 core in order to describe its stratigraphy and interpret its depositional settings.

The 1994 and 2004 drilling combined encountered two major coal zones, an upper coal zone about 58 feet thick (from 1,257 to 1,315 feet) and a lower 45-ft-thick coal zone (from 1,875 to 1,920 feet). The upper coal zone is middle Miocene in age (16-18 Ma) and the age of the lower coal zone is likely Miocene in age as well (T. Ager, USGS, personal communication). Lithologies within the Fort Yukon core are organized into eight general lithofacies that are: coal (lignite), carbonaceous shale, claystone, silty claystone, siltstone, silty sandstone, sandstone, and pebble sand. Grain types within the silty claystone to sandstone include polycrystalline and monocrystalline quartz, chert, white mica, lithic clasts, and traces of plagioclase. Beginning at ~2,170 feet are pebbly sand interbeds of unknown thickness that coincide with a prominent reflector recognized in a 2001 shallow seismic study of Fort Yukon.

Generally, the lower Fort Yukon core consists of stacked sequences of sandstone, siltstone and claystone, ±carbonaceous shale and/or coal. We interpret these sediments to represent a meandering river to lacustrine and sometimes poorly drained swamp system. The fluvial settings fine upwards from sand- to silt-dominated facies into eventual lake and sometimes a poorly-drained swamp environment above, represented by carbonaceous shale or lignite. Parallel laminations in some claystone horizons suggest varved lake deposits representing seasonal variations in sedimentation.

INTRODUCTION

Drill core collected during 2004 operations at Fort Yukon, Alaska (figs. 1 and 2) to test the methane content of Tertiary-age lignite was studied for general lithology, characteristics and depositional settings. Fort Yukon, Alaska was determined to be a priority site for testing the potential for shallow coalbed gas as a rural energy source based on village demographics, geologic setting, and the presence of potentially gassy coal beneath the community (Tyler and others, 2000). The drilling operations and coal desorption are described in Clark (in press), Barker and others (in press), along with an aquifer test assessment (Weeks and Clark, in press). The 2004 project reentered a 1994 U.S. Geological Survey (USGS) climate study drill hole located at the U.S. Air Force Fort Yukon Long Ranger Radar Site (LRRS) that was initially drilled to a depth of 1283 feet. The drill hole, now named DOI-1a-04 well (API no. 50-091-20001) is located at latitude 66.55949° N and longitude 145.20616° W on the southeast end of the community site (fig. 1). In 2001, high-resolution shallow seismic reflection data was acquired to determine the thickness of the coal seam encountered in the 1994 coring operations and its lateral extent (Miller and others, 2002). Hereafter we refer to the 2004 core study as the "lower Fort Yukon core".

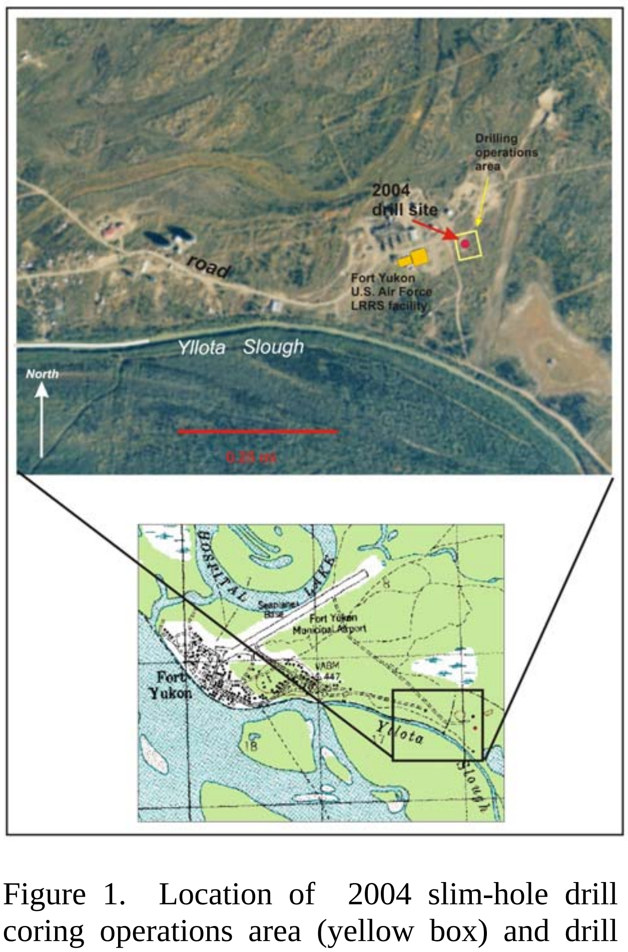

Figure 1. Location of 2004 slim-hole drill coring operations area (yellow box) and drill hole location (shown as red circle) to the southeast of the community of Fort Yukon.

Figure 2. Photograph of lower Fort Yukon core removed from core barrel.

GEOLOGIC SETTING

The community of Fort Yukon, is situated approximately in the northeast center of the Yukon Flats basin (fig. 3), an alluvial and marshy, lake-dotted lowland of more than 13,600 mi^2, that is confined by the arcuate Tintina-Kaltag fault system to the south, to the west by the Kokrine-Hodzana highlands, to the east by the Kandik thrust belt, and the southern foothills of the Brooks Range to the north. On the basis of gravity modeling, it is suspected that the Yukon Flats basin may have almost 2 mi of Cenozoic fill, with portions along the Yukon River as thick as 2.8 mi (Hite and Nagayama, 1980) (30-50 mgal gravity lows, fig. 3). The metamorphic basement in the Yukon Flats basin consists of two main terranes, the Tozitna and Porcupine terranes. The Porcupine terrane contains Precambrian metamorphic rocks and Cambrian-Devonian to Pennsylvanian-Permian structurally complex marine and non-marine sedimentary strata (Kirchner, 1994).

Structurally, the Yukon Flats basin has been interpreted as an extensional graben complex indicated by topography representing normal faults and divergent magnetic patterns are observed beneath the Tertiary fill (Kirchner, 1994). Till and others (2004) cite geophysical evidence of major crustal-scale splays of the Tintina system that cut through the entire thickness of the crust. Using new apatite fission track data, they have documented uplift events that correlate with similar eastern Brooks Range events that suggest a continental-scale linkage of crustal deformation during the Tertiary (Till and others, 2004).

Three cycles of Tertiary sediments of nonmarine affinity are exposed around the perimeter of the Yukon Flats and within the Tintina trench. Tertiary coal outcrops at several localities (fig. 3) including the Mudbank on the Hodzana River (See fig. 4), Drew Mine near Rampart, Schieffelin Creek, and Coal Creek. Reifenstuhl (2006) reports a few hundred feet of Eocene to Oligocene fluvial sandstone, pebbly sandstone with lesser conglomerate, and minor coal are exposed at Schieffelin Creek. The first sedimentary cycle is represented by latest Cretaceous-early Tertiary strongly folded conglomerate, sandstone, shale, and minor coals in the Tintina trench (Brabb and Churkin, 1969). In mid-Tertiary time, Miocene coal bearing formations exposed at Coal and Mudbank Creeks, outcrops in the Tintina trench, and northeast of Fort Yukon are evident typically consisting of conglomerate, sandstone, coal bearing siltstone-shale, and fine grained lacustrine sediments. The final Tertiary sedimentary cycle is composed of sand and gravel deposits that may extend into the Quaternary (Brosgé and others, 1973).

Farmer and others (2003) suggests that the Paleocene-early Eocene strata deposited in the southwest perimeter of the Yukon Flats basin, notably near Rampart, may be the result of extension related to early Tertiary strike-slip displacement on the Tintina fault. During this stage of basin development, regional tectonic subsidence led to the development of poorly organized, internally drained watersheds with intermittent ponding of water within the basin (Farmer and others, 2003).

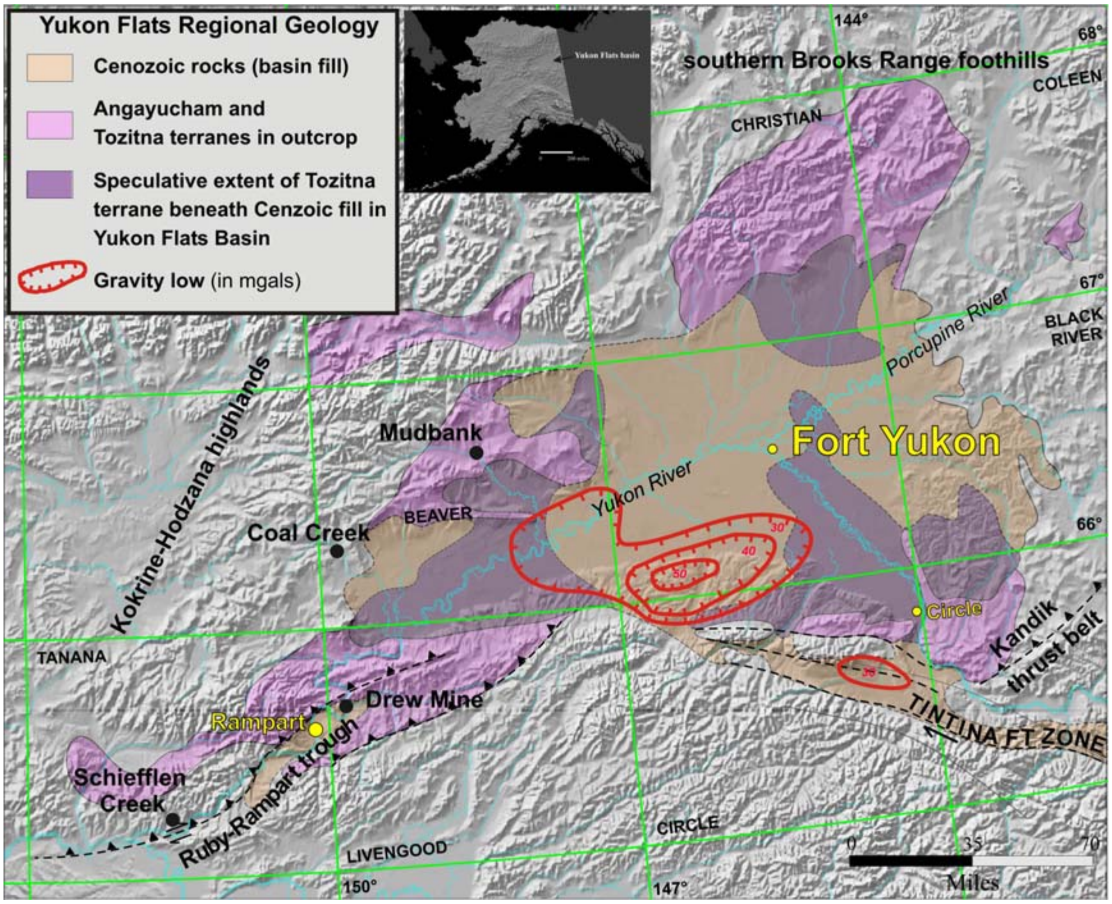

Figure 3. Regional geology of the Yukon Flats basin. Green lines delineate 1:250,000-scale quadrangles. Geology modified from Kirchner (1994) and Troutman and Stanley (2003).

Thickness of the Tertiary section beneath Fort Yukon is likely on the order of 6000-7000 feet based on a recent gravity inversion (J.D. Phillips, U.S. Geological Survey, unpublished data). The lithology and depth of basement rocks beneath Fort Yukon are uncertain. Aeromagnetic and gravity data, together with regional geologic relationships, suggest that the basement at Fort Yukon consists of Devonian to Jurassic oceanic rocks related to the Tozitna and Angayucham terranes (Saltus and others, 2004). On the basis of gravity modeling, it is suspected that the Yukon Flats basin may have almost 2 mi of Cenozoic fill, with portions along the Yukon River as thick as 2.8 mi (Hite and Nagayama, 1980).

Figure 4. Photograph of Tertiary outcrop containing thin lignite seams at the "Mudbank" on the Hodzana River, a tributary to the Yukon River. Approximately 80 air miles from Fort Yukon.

CORE DESCRIPTION PROCEDURE

Continuous 2.4 inch diameter core was collected from 1283 to 1835 feet during drilling operations. Rotary drilling only was conducted from 1835 to 1900 feet where a deeper, significant lignite was encountered and the rig returned to continuous coring from 1900 to 1965 feet. Rotary drilling operations resumed from 1965 to the final depth of 2287 feet. For the non-core intervals, cuttings that were collected during drilling operations were utilized for this study. Art Clark, USGS-Denver, provided preliminary interpretations of the gamma ray log which conveyed additional information on the lithology of the non-cored intervals. The core and cuttings were stored in 10-foot cardboard core boxes (fig. 5) and subsequently shipped to Anchorage, Alaska.

The approximately 650 feet of core (2.4 inch diameter) collected from the 2004 drilling operations was processed and described in detail during May and June, 2005 at the USGS storage facility in Anchorage. Processing of the core included removal of residual drilling mud where necessary to show representative sedimentary features, lithologic mineralogy and grain size variations. Detailed descriptions of the core lithologies were recorded, starting from the base to the top of the core. In addition to detailed lithologic descriptions, the core was photographed (under sunlight) at core box-, sedimentary contact- and macro-scales to illustrate the various depositional environments. Representative samples of the pertinent lithologies were collected for thin section study and photomicrographs. The foot-by-foot descriptions and subsequent thin section descriptions are provided in Appendix A. Lithologies, brief core descriptions, interpreted depositional settings, and relevant thin section photographs are in figures 7 to 18. Future core studies may include porosity and permeability measurements, palynological, and geochemical analyses.

Figure 5. Composite photograph of lower Fort Yukon core boxes with drill core and cuttings from 2004 drilling operations at Fort Yukon, Alaska.

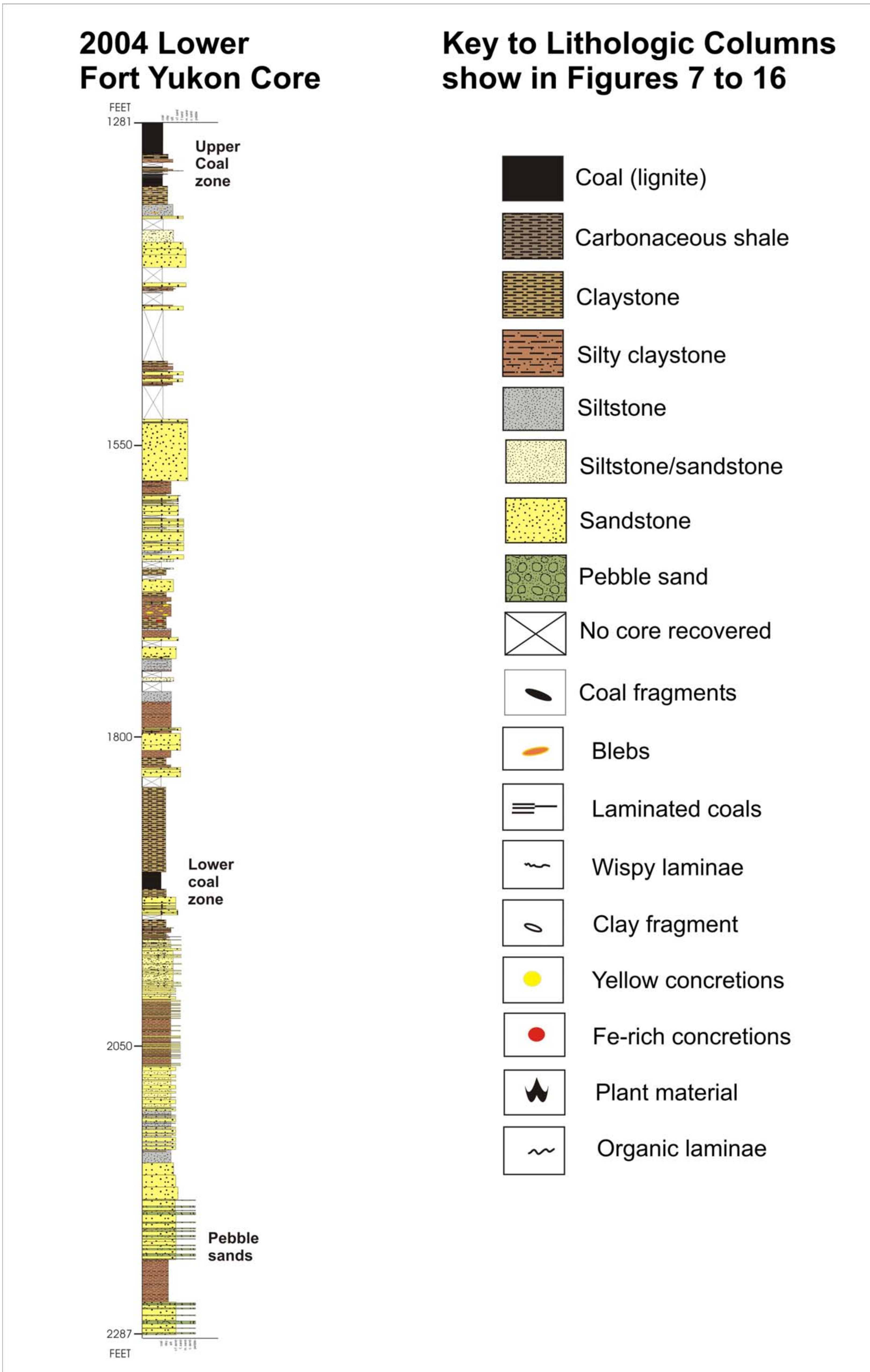

Figure 6. Generalized 2004 lower Fort Yukon core (left) and Key to lithologic columns (right) shown in figures 7 to 16.

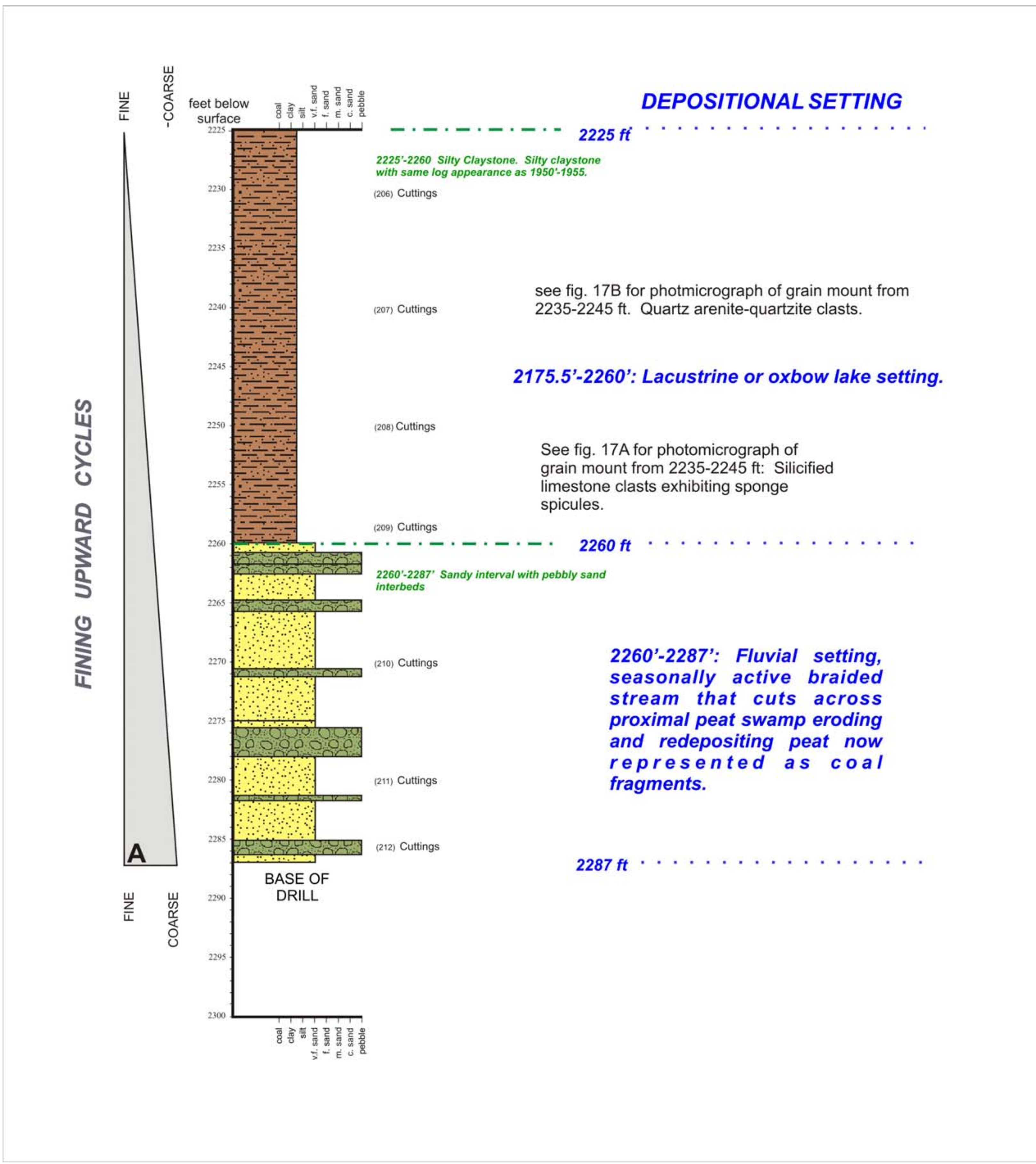

Figure 7. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycle A , 2225 to 2287 feet below surface. See fig. 6 for lithologic legend.

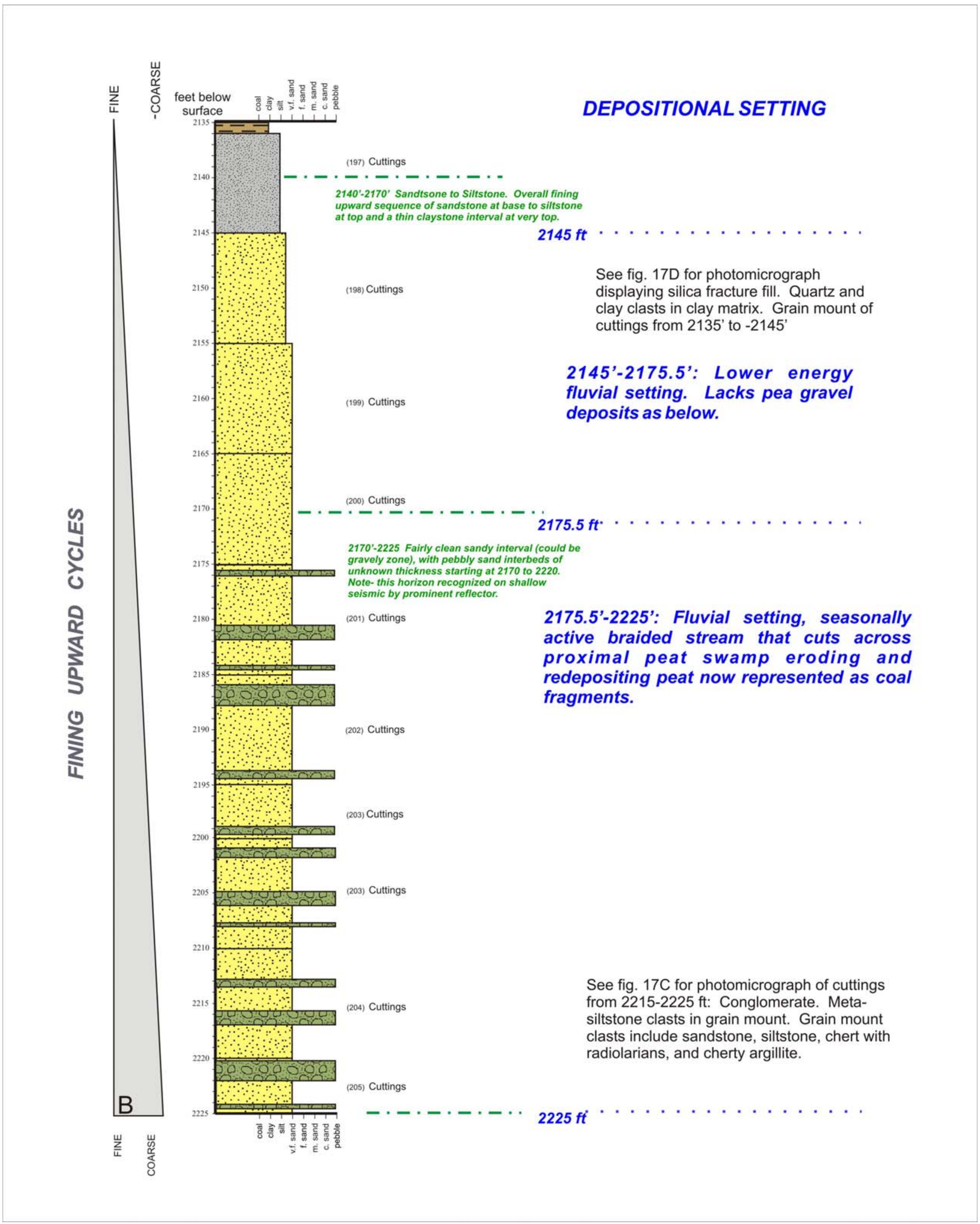

Figure 8. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycle B, 2135 to 2225 feet below surface. See fig. 6 for lithologic legend.

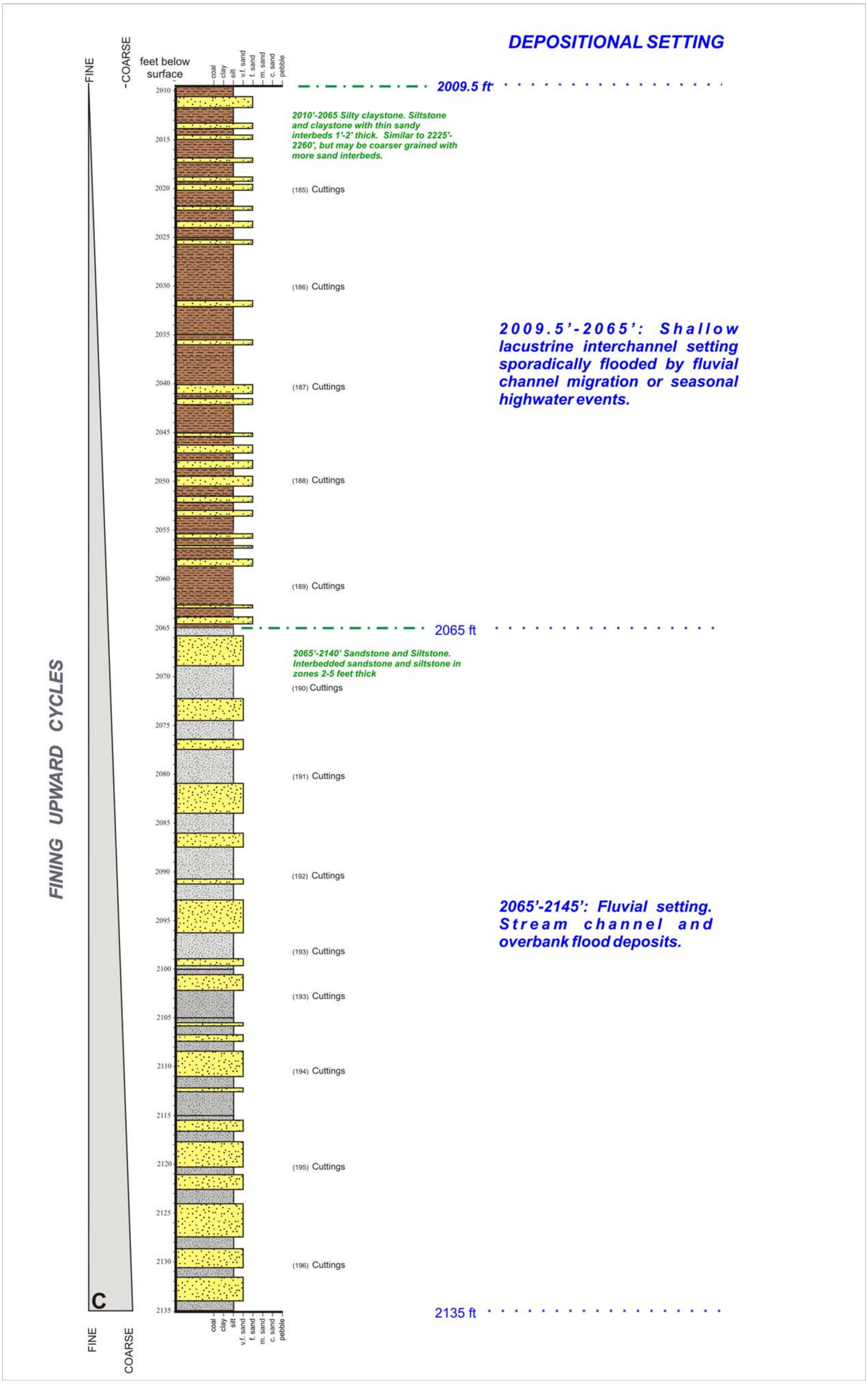

Figure 9. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycle C, 2010 to 2135 feet below surface. See fig. 6 for lithologic legend.

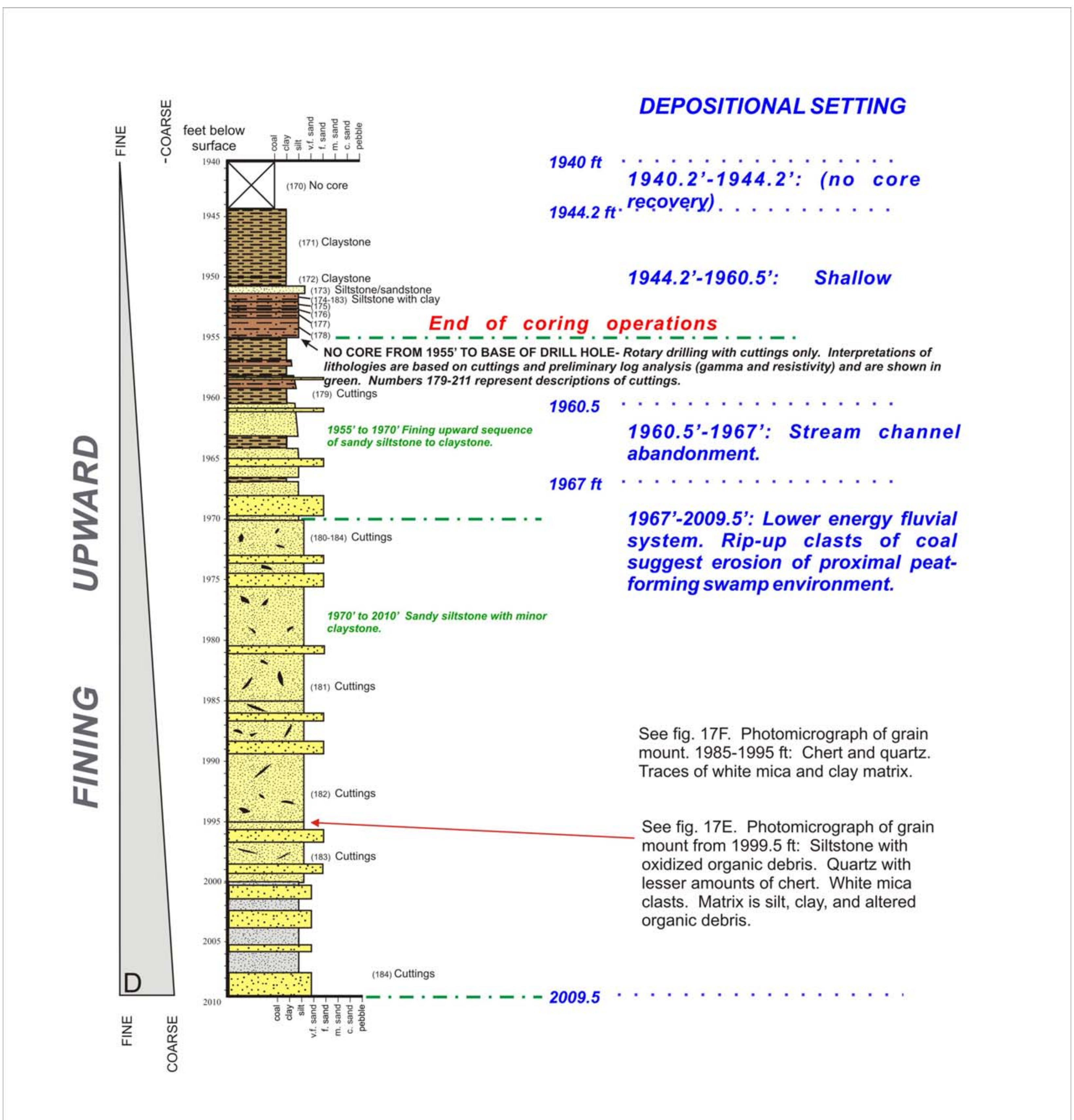

Figure 10. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycle D, 1940 to 2010 feet below surface. See fig. 6 for lithologic legend.

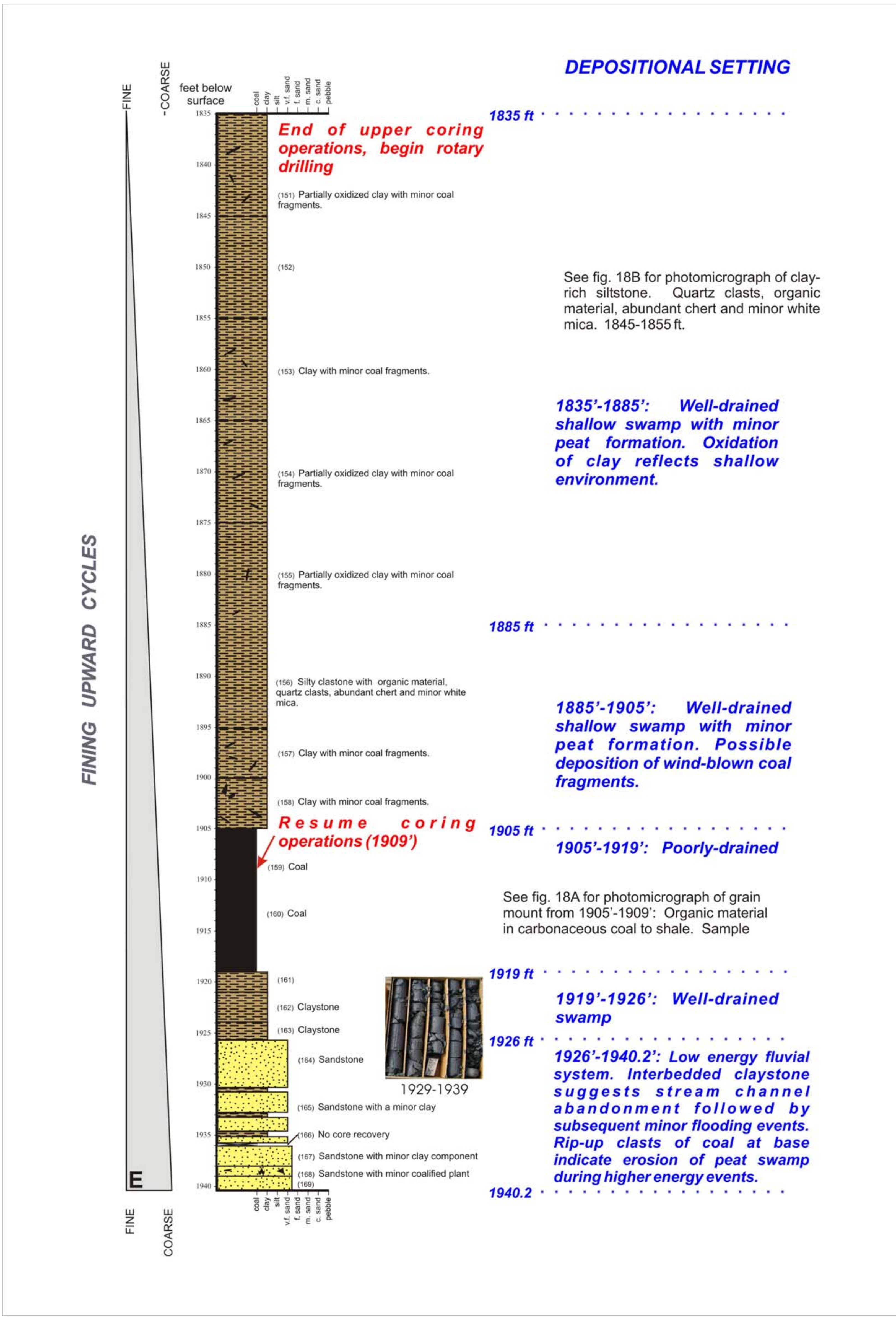

Figure 11. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycle E, 1835 to 1940 feet below surface. See fig. 6 for lithologic legend.

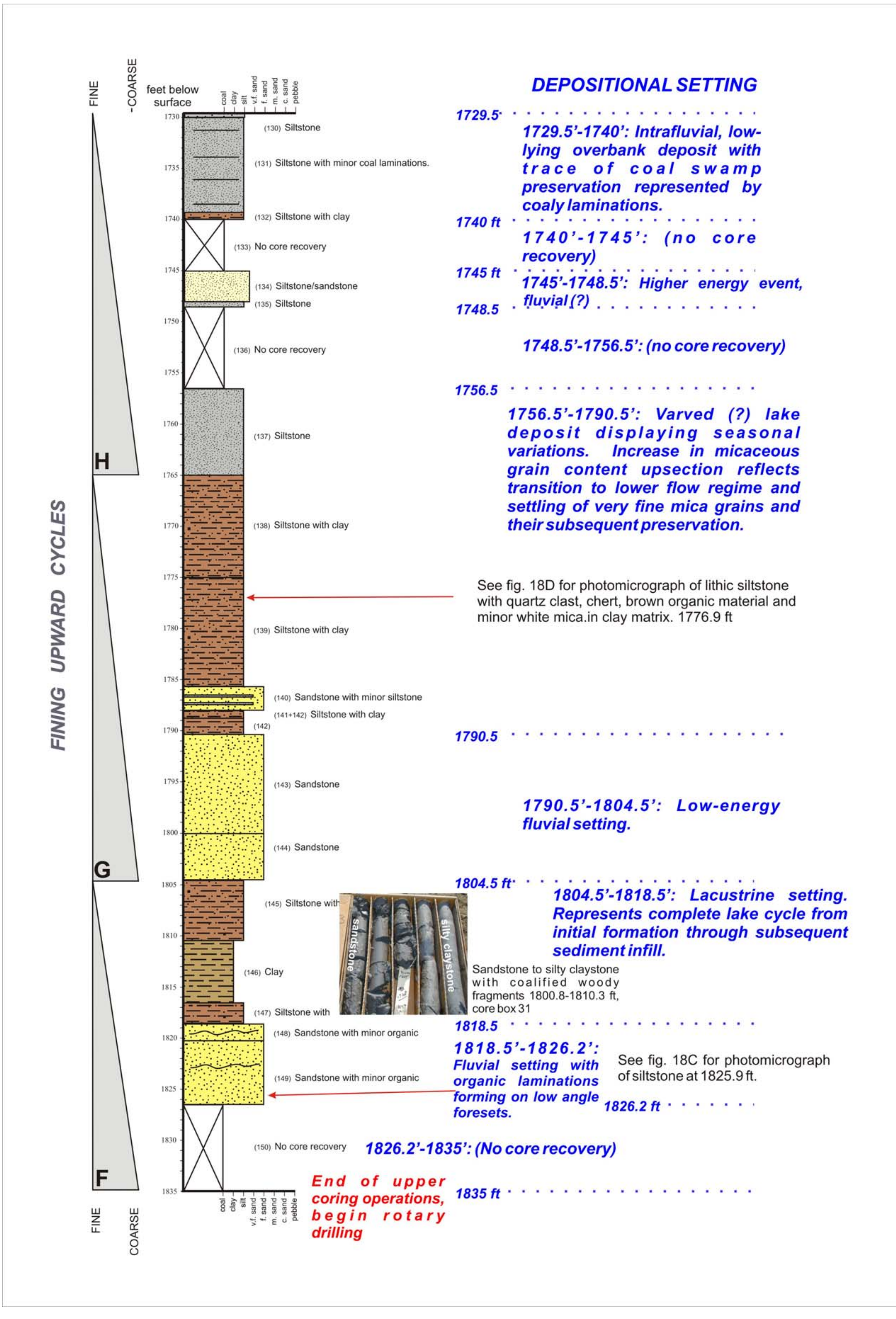

Figure 12. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycles F, G and H, 1730 to 1835 feet below surface. See fig. 6 for lithologic legend.

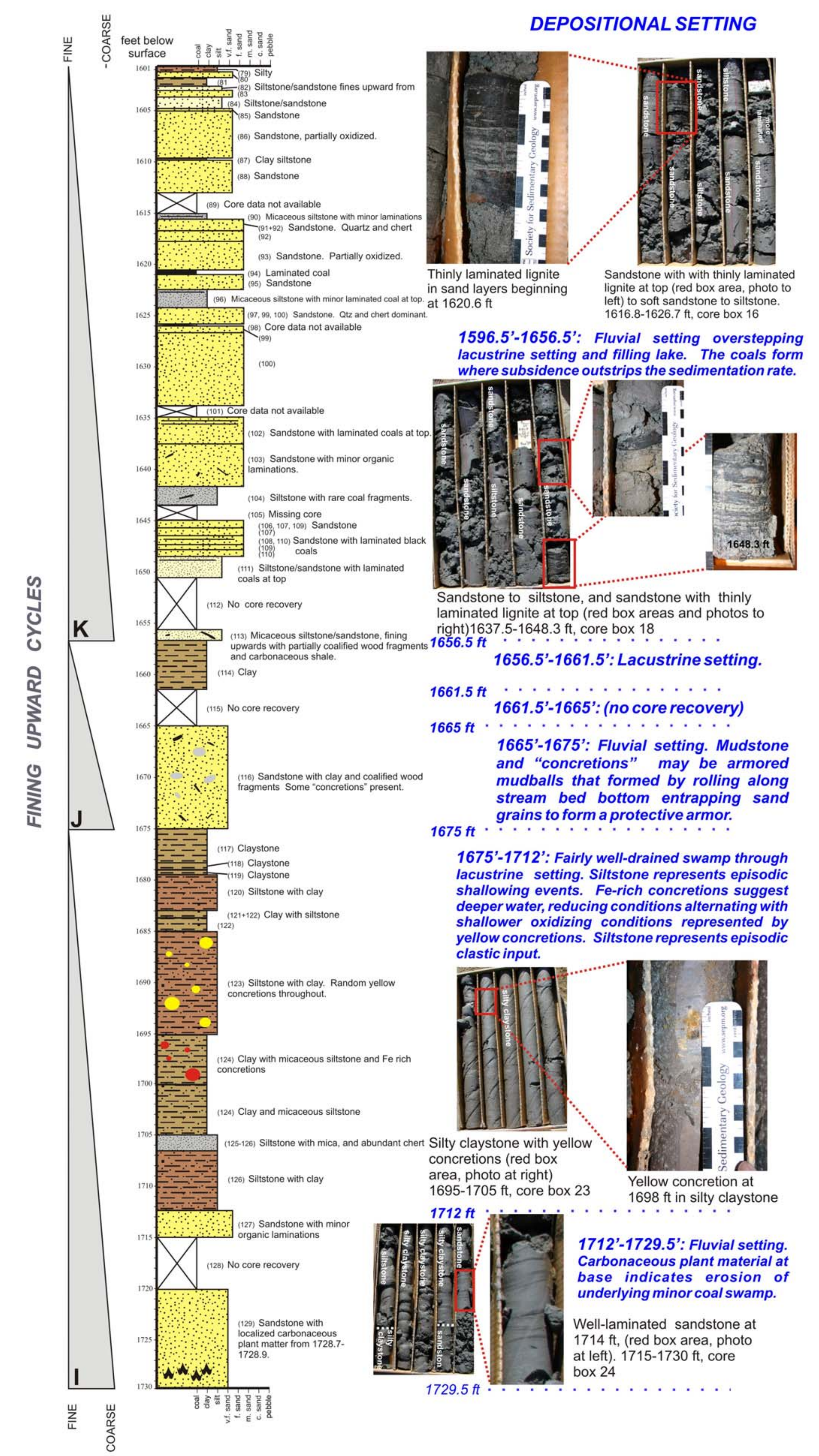

Figure 13. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycles I, J and K, 1601 to 1730 feet below surface. See fig. 6 for lithologic legend.

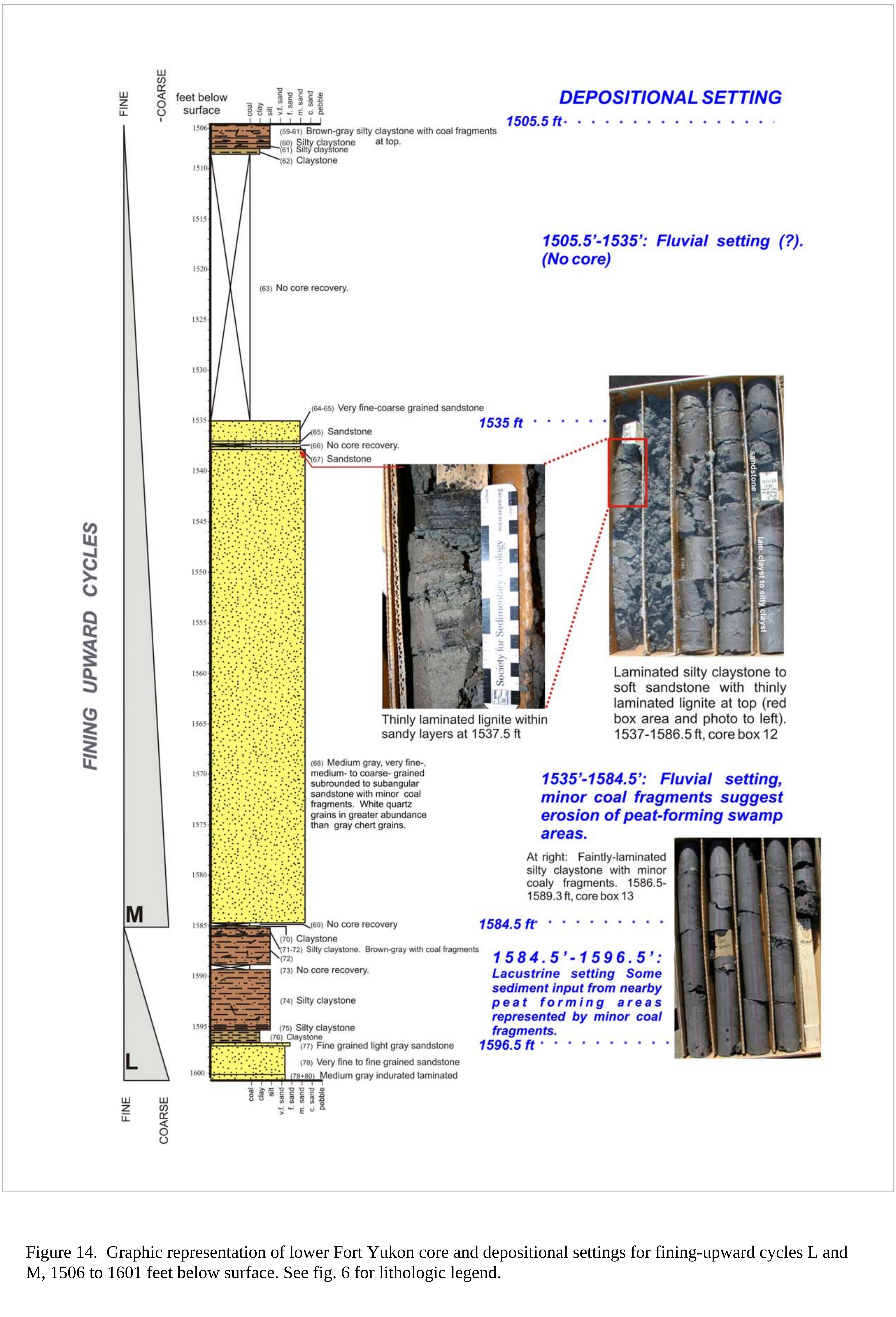

Figure 14. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycles L and M, 1506 to 1601 feet below surface. See fig. 6 for lithologic legend.

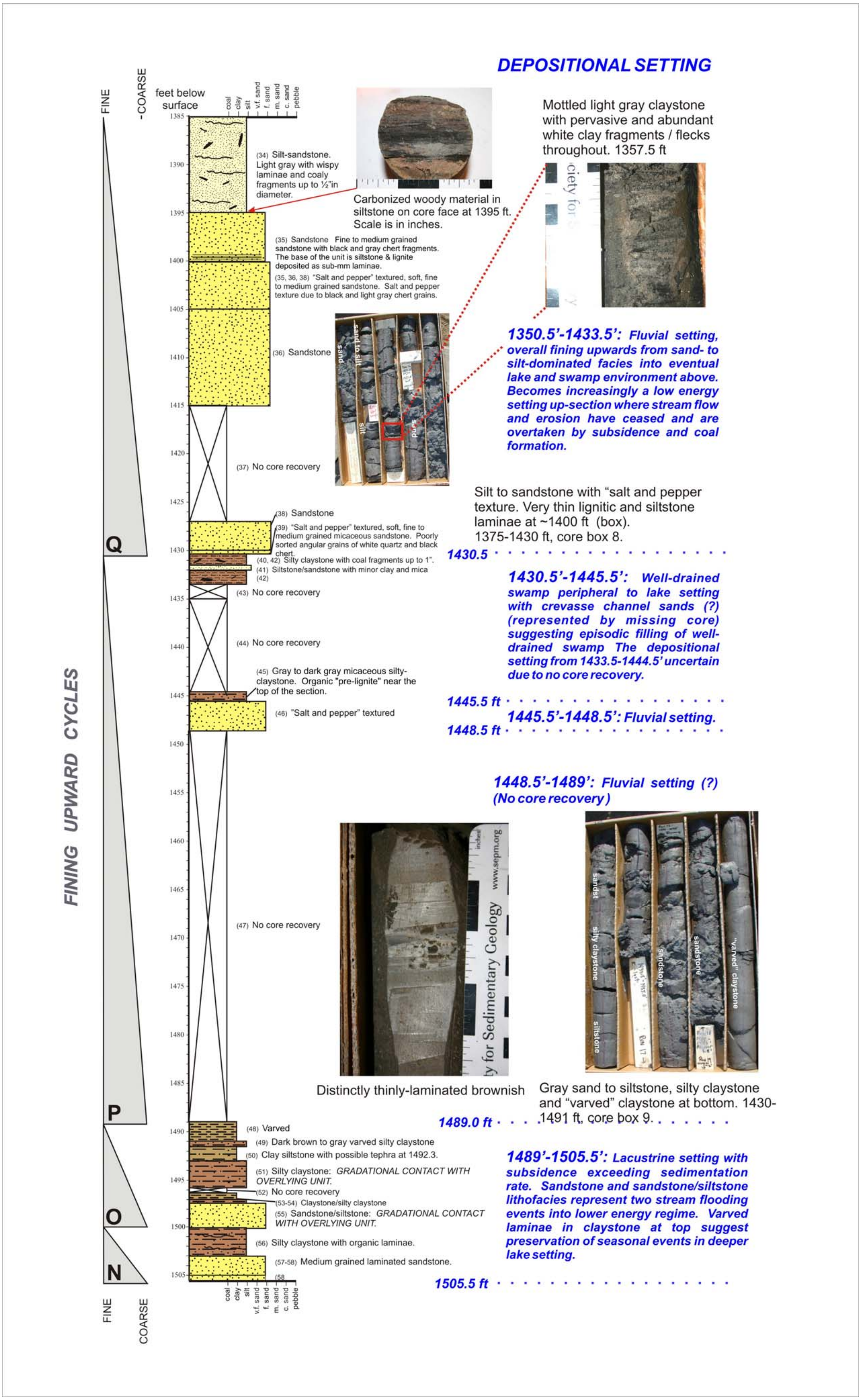

Figure 15. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycles N, O, P, and Q, 1385 to 1505.5 feet below surface. See fig. 6 for lithologic legend.

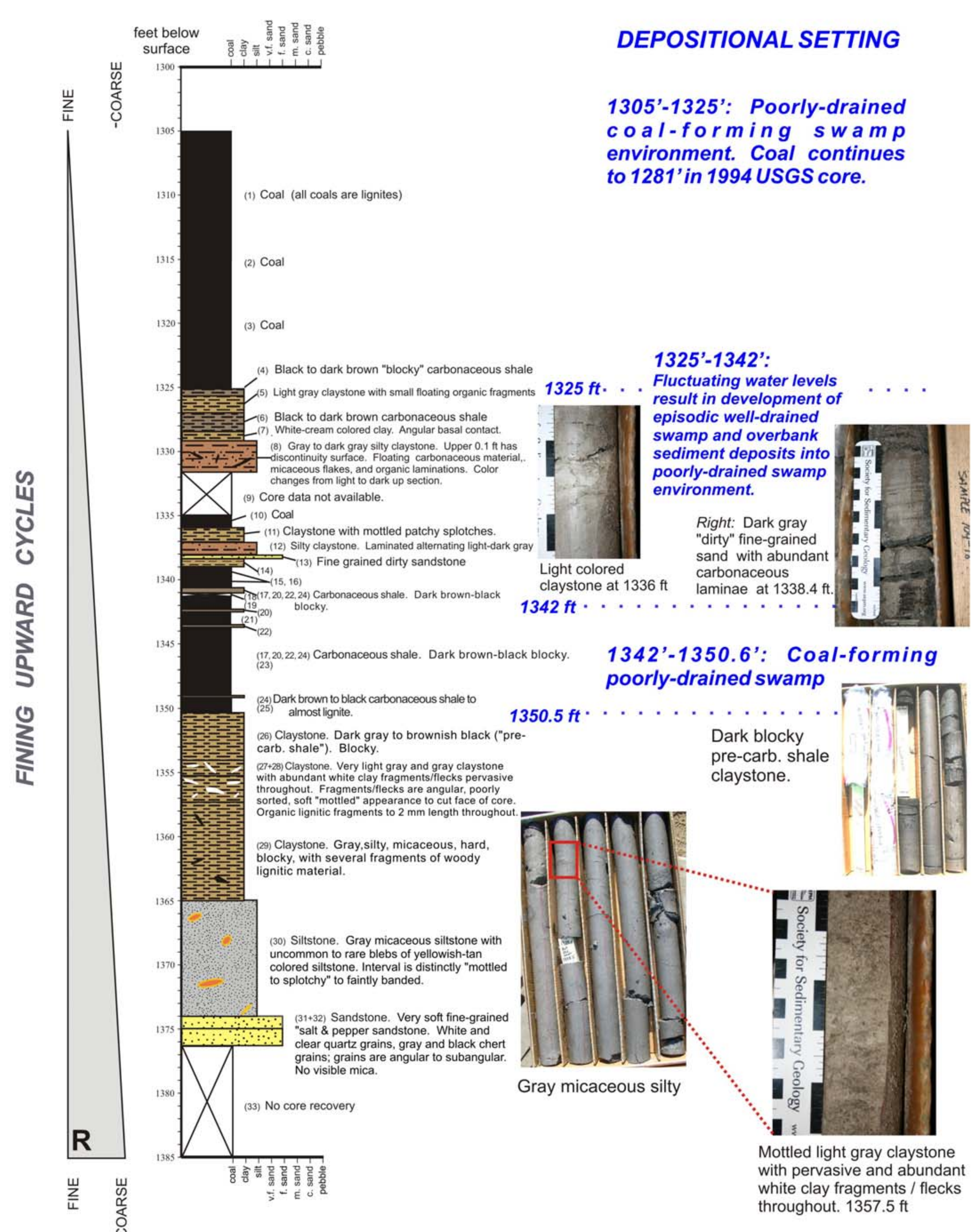

Figure 16. Graphic representation of lower Fort Yukon core and depositional settings for fining-upward cycle R, 1305 to 1385 feet below surface. See fig. 6 for lithologic legend.

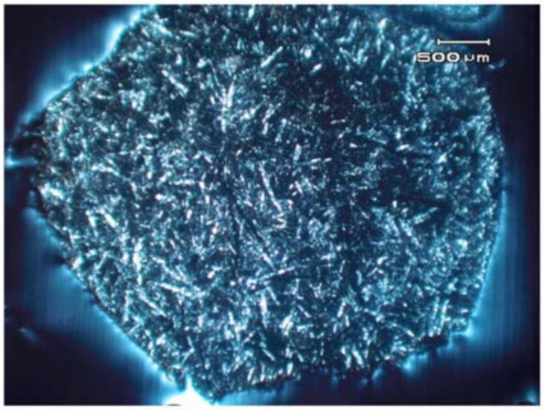

Figure 17A. Photomicrograph of grain mount from 2235-2245 ft:

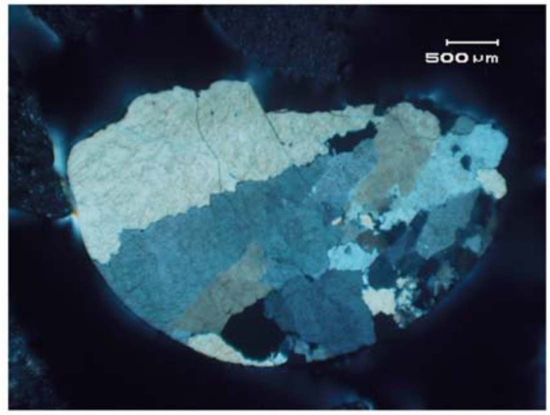

Figure 17B. Photomicrograph of grain mount from 2235-2245 ft: Quartz arenite-quartzite clasts.

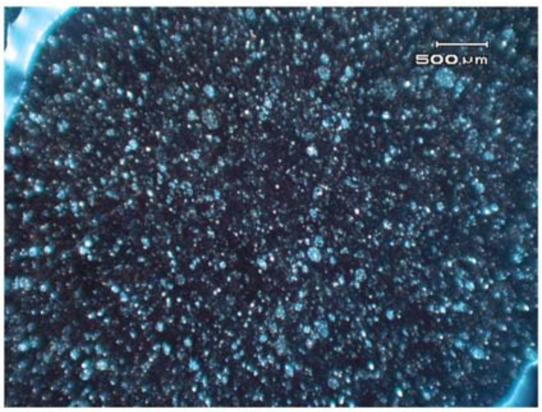

Figure 17C. Photomicrograph of cuttings from 2215-2225 ft: Conglomerate. Meta-siltstone clasts in grain mount. Grain mount clasts include sandstone, siltstone, chert with radiolarians, and cherty argillite.

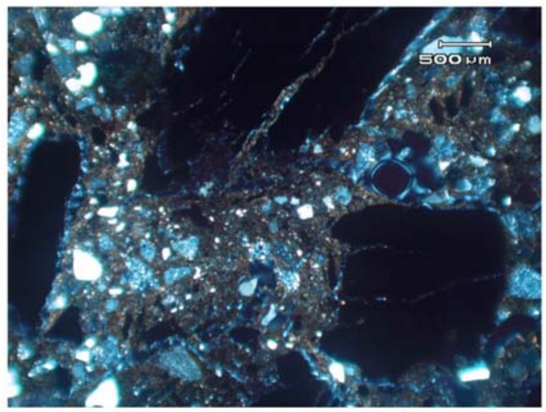

Figure 17D. Photomicrograph of grain mount from cuttings from 2135-2145: Silica fracture fill. Quartz and clay clasts. Clay matrix.

Figure 17E. Photomicrograph of grain mount from 1999.5 ft: Siltstone with oxidized organic debris. Quartz with lesser amounts of chert. White mica clasts. Matrix is silt, clay, and altered organic debris.

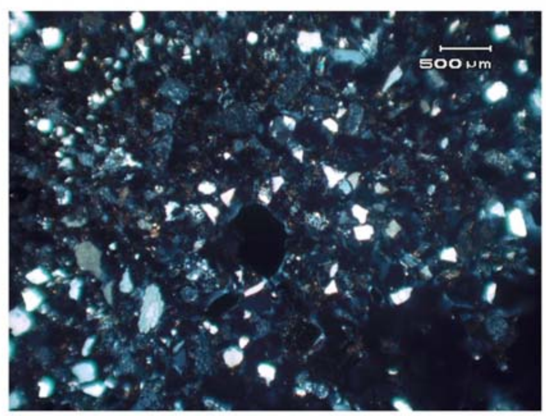

Figure 17F. Photomicrograph of grain mount. 1985-1995 ft: Chert and quartz. Traces of white mica and clay matrix.

Figure 17A-F. Photomicrographs of grain mounts from lower Fort Yukon core. See figures 7, 8, and 10 for stratigraphic position in core.

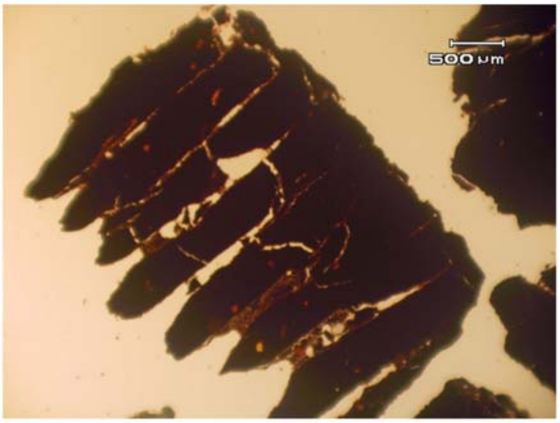

Figure 18A. Photomicrograph of grain mount from 1905'-1909': Organic material in carbonaceous coal to shale. Sample consists of 90-90% black to black-red organic debris with quartz clasts and clay.

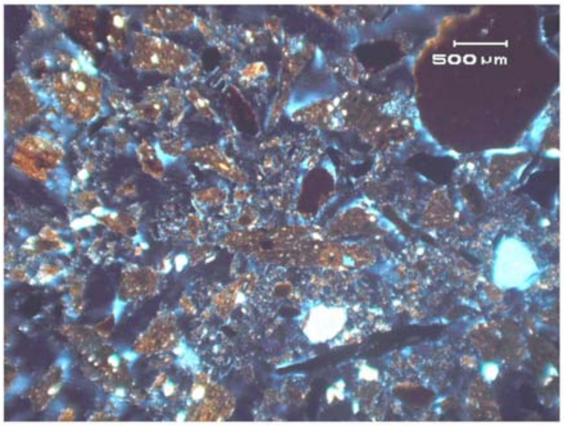

Figure 18B. Photomicrograph of clay-rich siltstone. Quartz clasts, organic material, abundant chert and minor white mica. 1845-1855 ft.

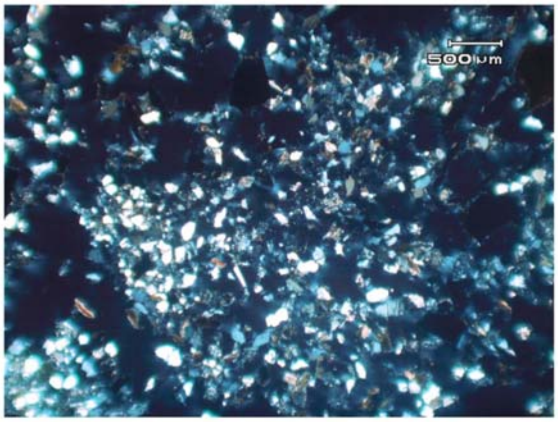

Figure 18C. Photomicrograph of siltstone with quartz chert and abundant organic debris. Minor white mica also present. 1825.9 ft.

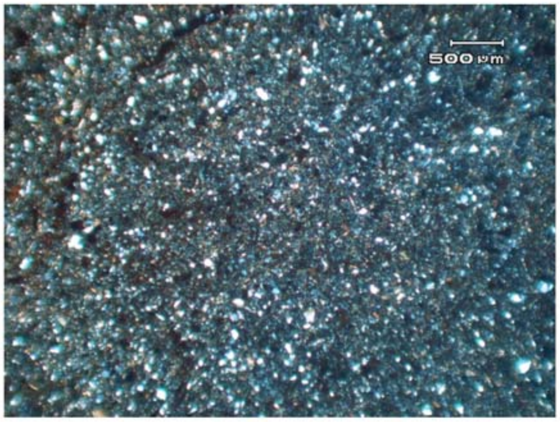

Figure 18D. Photomicrograph of lithic siltstone with quartz clast, chert, brown organic material and minor white mica.in clay matrix. 1776.9 ft

Figure 18A-D. Photomicrographs of grain mounts from lower Fort Yukon core. See figures 11 and 12 for stratigraphic position in core.

DISCUSSION

We recognize 18 fining upward cycles (A-R) within the lower Fort Yukon core and cuttings that reflect episodic changes in base level within a fluvio-lacustrine-mire setting (see conceptual depositional model, fig. 19). Overall, the general pattern of sedimentation is fining upwards from sand- to silt-dominated fluvial deposits into eventual claystone to silty-claystone lacustrine or marsh deposits, and/or lignite or carbonaceous shale deposits representing a poorly-drained swamp environment. The fining upward cycles represent a decrease in energy up-section whereby stream flow and erosion cease and are overtaken by a rise in base level and subsequent peat formation.

The summary suite of depositional settings and their corresponding lithofacies [in brackets] recognized during this preliminary investigation of the lower Fort Yukon core Tertiary sediments are:

- Fluvial high-energy active channel [pebble sand conglomerate]
- Fluvial- seasonally active braided stream [sandstone and silty sandstone]
- Overbank crevasse splay [siltstone, clayey siltstone]
- Lacustrine or oxbow lake, ± varves [silty claystone, claystone]
- Well-drained shallow marsh [claystone, carbonaceous shale]
- Poorly-drained peat-forming mire [lignite, carbonaceous shale]

Our interpretations are based on a single core and it is difficult to establish the lateral extent of these facies. However, based on the seismic survey of Miller and others (2002), the major subsurface reflectors extend across the entire Fort Yukon area suggesting that the major facies are laterally extensive. Were a three-dimensional view of the Fort Yukon Tertiary possible with multiple drill holes, we would likely see lateral accretion of stream channel sands, overbank flood deposits, stream channel abandonment and the development of well-drained marsh, lacustrine and poorly-drained swamp (mire) environments. Rip-up clasts of coal at the base of channel sands suggest erosion of peat-forming swamp during higher energy lateral stream migration during base level fall.

Analysis of the sedimentary record preserved in this drill core and outcrops on the periphery of the basin will help to constrain depositional models that provide insight on the hydrocarbon potential of the Tertiary within the Yukon Flats.

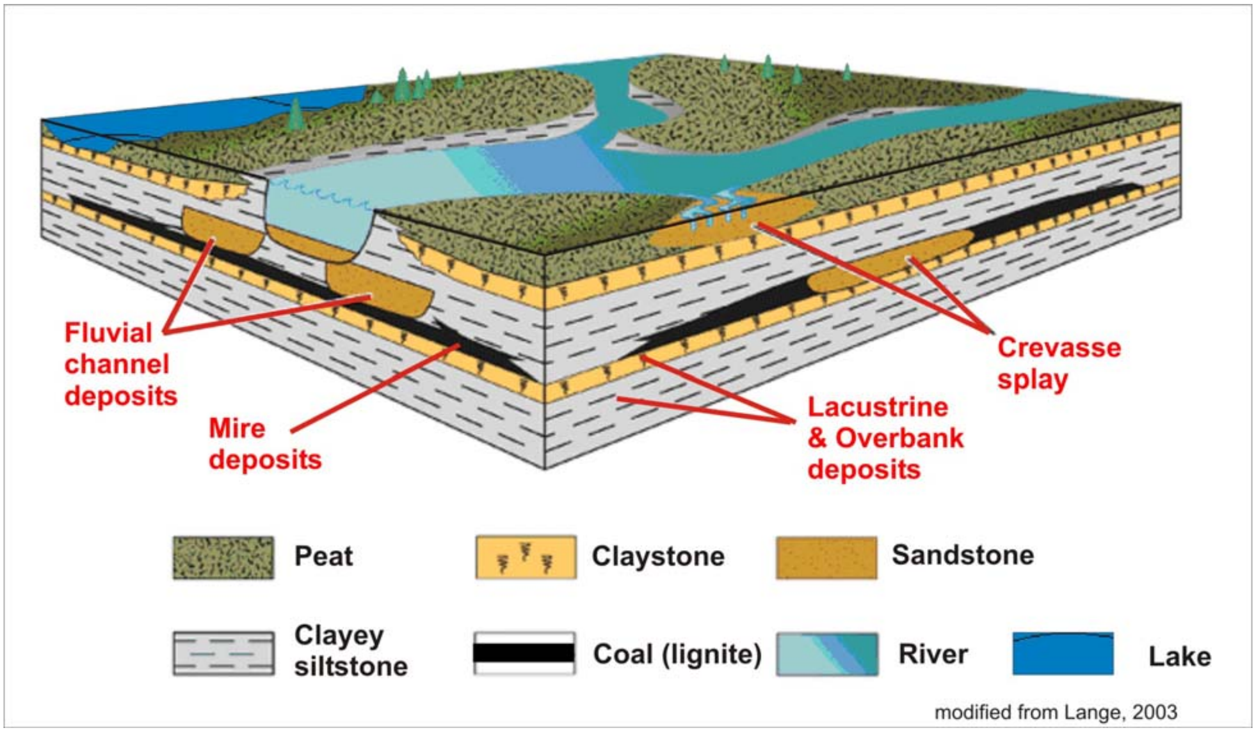

Figure 19. conceptual model for the Tertiary fluvial, lacustrine, and peat-forming mire settings represented in the lower fort Yukon core.

ACKNOWLEGMENTS

We gratefully acknowledge the efforts of many people that have contributed to the drilling program at Fort Yukon Alaska. Charles Barker and Art Clark, U.S. Geological Survey, Denver CO. (USGS) were instrumental in planning, executing and completing the drilling project in Fort Yukon. Without their expertise and efforts, obtaining the 2004 drill core at Fort Yukon would not have been possible. Also participating in the on site coring operation geology were Beth Maclean, U.S. Bureau of Land Management-Alaska; Steve Roberts (USGS), Karen Clautice, Alaska Div. of Geological & Geophysical Surveys (retired); and Amy Rodman, Univ. of Alaska Fairbanks.

We thank Brent Sheets and James Hemsath from the U.S. Department of Energy, National Energy Technology Laboratory, Arctic Energy Office in Fairbanks, Alaska who provided both funding through a Federal grant (DE-FC26-01NT41248) and additional advice and support along the way. Dennis Witmer, Arctic Energy Technology Development Laboratory (AETDL) of the University of Alaska Fairbanks administered the grant and was also helpful throughout the process.

Robert Fisk, U.S. Bureau of Land Management-Alaska has been an integral part of the ongoing efforts in rural Alaska and his agency provided considerable financial support to make the project possible.

Without the considerable help and support of the U.S. Air Force 611th Air Support Group, based at Elemedorf Air Force Base (Anchorage) for the use of the drill site and facilities at the Fort Yukon Long Range Radar Site (LRRS) this project would not have been possible. We particularly thank Major James A. McCoy, Captain Trevis Bergert, Senior Master Sargent Miranda, Master Sargent Jeffrey Herrick, and Sue Striebich, along with all of the USAF people behind the scenes that helped to make this project feasible.

Curt McEwan, Operations Manager for ARCTEC Alaska, contractors for the Fort Yukon LRRS, along with Clay Shaw, Station Mechanic at the Fort Yukon LRRS, were extremely helpful to the process.

Rick Miller from the Kansas Geological Survey, who successfully completed a high-resolution shallow seismic survey at Fort Yukon in 2001, provided valuable interpretations on the subsurface geology.

A great deal of thanks goes to Dave Lee Thomas from the Village of Fort Yukon who provided invaluable assistance with advice and site logistics for the project. His help through the years has been immense and we are indebted to him for all he’s done. James Kelly and Clarence Alexander of the Gwitchya Zhee Corporation were crucial in completing our work through all their help and assistance. Fannie Carroll, Fort Yukon City Manager, made possible the use of an old city dump for the drilling waste disposal and also made our work go smoothly with the help of city equipment and facilities. Assistance from the Gwitchyaa Gwichin Tribal Government’s Davey James was greatly appreciated. Jim Mery and Norm Phillips from Doyon Limited have continually provide information and support for our efforts in Fort Yukon. Finally, we would like to acknowledge all the help and the gracious reception from the people of Fort Yukon, especially Bonnie Thomas, Fannie Carroll, Rocky James, and Richard Carroll.

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APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
1	1	1304.5 1314.5	10.0	**COAL**					Lignite (wrapped in plastic)	
2	1	1314.5 1315.0	0.5	**X**					Wooden block- Lost core (0.5 ft)	
3	2	1315.0 1325.0	10.0	**COAL**					Lignite (wrapped in plastic)	
4	3	1325.0 1325.6	0.6	**CARB SHALE**			Black to dark brown	med. hard	Black to dark brown "blocky" carbonaceous shale	
5	3	1325.6 1327.3	1.7	**CLAYSTONE**	04FY1327.0-1327.3	photos not recorded	light gray	med hard	Light gray claystone with small floating organic fragments at 1326.3. Grades upsection from lt gray to dk gray. White layer at 1327.0-1327.3. Gradational into carb "shale" above	04FYU 1327-1327.3 Organic claystone/organic shale. Epiclastic, massive, very well sorted. Brown and dark brown organic rich shale.
6	3	1327.3 1328.4	1.1	**CARB SHALE**			black to dark brown	med hard	Black to dark brown carbonaceous shale with abundant clay towards top and bottom	
7	3	1328.4 1328.8	0.4	**"CLAYSTONE"**	04FY1328.8-1329.0	photos not recorded	white to cream colored	med hard	White to cream colored clay . Angular basal contact.	
8	3	1328.8 1331.6	2.8	**SILTY CLAYSTONE**	04FY1331.3		gray to dark gray	med hard	Micaceous flakes and organic lamination. Gray to dark gray silty claystone. Upper 0.1 ft has discontinuity surface. Floating fragments of carbonaceous material 0.2" to 1" wide. Increases in darkness and mottling upsection.	
9	3	1331.6 1335.0	3.4	**X**					Wooden Block (lost 3.4 ft)	
10	4	1335.0 1336.0	1.0	**COAL**						
11	4	1336.0 1337.2	1.2	**CLAYSTONE**	04FY1336.3	833, 834	light tannish gray	med hard	light tanish gray claystone with organic (lignitic) fragments to flecks ranging in size from 1/2 mm to 1/2". Interval has mottled patchy splotches. Claystone similar to claystone below. White possible tepha (ash) at 1336.3 (0.1 ft thick). Interval has little to no silt.	04FYU 1336.3 Organic rich siltstone. Quartz siltstone. 80% material.
12	4	1337.2 1338.3	1.1	**SILTY CLAYSTONE**		see core box photo for good picture	light gray to dark gray	med hard	Parallel-laminated light gray silty claystone and darker gray silty claystone varying amounts of small grain-sized organic material.	
13	4	1338.3 1338.5	0.2	**SANDSTONE**		835	dark gray	hard	Dark gray "dirty" fine-grained sand with very abundant carbonaceous material	
14	4	1338.5 1339.0	0.5	**CLAYSTONE**			dark gray and tan	med hard	Dark gray and tan mottled to "wispy" claytone (as below)	
15	4	1339.0 1339.7	0.7	**COAL**					Lignite (wrapped in plastic)	
16	4	1339.7 1340.7	1.0	COAL SAMPLE (wooden block)					presumed lignite	
17	4	1340.7 1341.0	0.3	**CARB. SHALE**		PHOTO 835 of whole core box	black to brownish black	med hard	Blocky black to brownish black carbonaceous "shale" or siltstone (similar to 1338.3 to 1338.5 interval	
18	4	1341.0 1341.2	0.2	**X**					Wooden block (lost 0.2 ft)	
19	4	1341.2 1342.2	1.0	**COAL**				med hard	Lignite (wrapped in plastic)	
20	4	1342.2 1342.5	0.3	**CARB. SHALE**			dark brown to black	med hard	Dark brown to black carbonaceous "shale" with gray discontinuous "coallY" laminae	

APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
21	4	1342.5 1343.5	1.0	**? COAL ?**			?	?	Wooden block Sample 104-19	
22	4	1343.5 1343.7	0.2	**CARB. SHALE**			dark brown to black	med hard	Dark brown to black blocky carbonaceous shale same as 1342.2 to 1342.5 above.	
23	5	1345.0 1349.0	4.0	**COAL**	04FY1347.7-1348.0	PHOTO of whole core box	brownish black		Coal (lignite) wooden block in middle states Sample 104-20 for sample from 1346-1347	
24	5	1349.0 1349.25	0.25	**CARB. SHALE**			dark brown to black	med hard	Dark brown to black carbonaceous shale to almost lignite	
25	5	1349.25 1350.25	1.0	**COAL**					Coal sample 104-21 represented by Wooden block	
26	5	1350.25 1354.1	1.1	**CARB. CLAYSTONE**		828, 829, 830	dark gray to brownish blask	med	Dark gray to brownish black carbonaceoous claystone ("pre-carb. shale"). Blocky instead of fissile.	
27	5	1354.1 1355.0	1.1	**CLAYSTONE**			light grayish tan	med	Light grayish tan claystone (as below) with angular to rounded coal frasgments from 1/2 mm to 3 " distributed throughout. Minor amount of gray clay "matrix". No bedding discernable but some mottling near top of interval.	
28	6	1355.0 1357.2	2.2	**CLAYSTONE**	04FY1356.5	825,826,827	very light gray and gray	med hard	Very light gray and gray claystone with abundant white clay fragments/flecks pervasive throughout. Fragments/flecks are angular, poorly sorted, soft and lend a "mottled" overallappearance to cut face of core. Organic lignitic fragments to 2 mm length throughout.	04FYU 1356.5 Organic-rich siltstone. Epiclastic. Massive. Moderately sorted. Very fine, sub-rounded. Traces of white mica and organic rich siltstone.
29	6	1357.2 1365.0	7.8	**CLAYSTONE**			gray	hard	Gray silty micaceous claystone. Claystone is hard and block and has several fragments of woody lignitic material, particularly at 1361	
30	7	1365 1374	9.0	**SILTSTONE**			gray	hard	Gray micaceous siltstone with uncommon to rare blebs of yellowish-tan coloroed siltstone. Interval is indistinctly "mottled to splotchy" to faintly banded.	
31	7	1374.0 1375.0	1.0	**SANDSTONE**			S&P gray	very soft	Very soft fine-grained "salt & pepper sandstone. White and clear quartz grains, gray and black chert grains; grains are angular to subangular. No visible mica.	
32	8	1375.0 1376.2	1.2	**SANDSTONE**	04FY1375-1385		S&P gray	very soft	Very soft fine-grained salt & pepper sandstone. Finer-grained than at 1375 in core box 7. Bottom 0.2 ft mostly gray siltstone with carbonaceous woody material. Last 0.2 is carb. shale. NOTE- this interval is from somewhere between 1375 and 1385. Some consolidation.	04FYU 1375-1385 Grainmount fine grained sandstone. 10% very fine grained, 60% fine grained, 30% medium grained. Sub-angular. Siltstone fragments 20-30%. Plagioclase feldspar 1-3% with good looking twins. Quartz 70-80%.
33	8	1376.2 1385.0	8.8	**X**					Wooden block- Lost 9 feet of core in interval 1375-1385. Interval not determined run 13 below.	
34	8	1385.0 1395.0	10.0	**SILTSTONE/SANDSTONE**		823, 824	light gray	hard	Light gray siltstone, with wispy laminae and coaly fragments to 1/2"	
									wooden block- run 13 above, run 14 below	
35	8	1395.0 1405.0	10.0	**SANDSTONE w siltstone at base**		821, 822	light gray	soft	1 ft soft S&P fine to medium grained sandstone with black and gray chert. Bottom 0.7 feet is laminated siltstone & lignite in sub-mm laminae NOTE: lost core from this interval, presumable because of soft sand	

APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
36	8	1405.0 1415.0	10.0	**SANDSTONE**			medium gray	soft	0.45 of soft S&P sandstone same as above. NOTE: don't know where this sand is from, somewhere between 1405-1415 (see drilling notes)	
37	8	1415.0 1427.0	12.0	**X**					Wooden block. Lost 1415 to 1427, no recovery	
38	8	1427.0 1430.0	3.0	**SANDSTONE**			medium gray	soft	Salt & pepper sandstone same as below and above	
39	9	1430.0 1430.2	0.2	**SANDSTONE**			medium gray	soft	soft medium gray "salt and pepper look" sandstone; pooerly sorted, white qtz, black chert, very angular grains, micaceous.	
40	9	1430.2 1431.4	1.2	**SILTY CLAYSTONE**			brownish gray	medium	Brownish gray silty, sandy claystone with sandy horizons near top of interval. Coal fragments from 1/2" to over 1". Coarsens upward.	
41	9	1431.4 1432.0	0.6	**SILTSTONE/SANDSTONE**			light gray	medium	Light gray slitstone to very fine sandstone with minor clay present. Faintly laminated (?). Salt & pepper: white qtz, black chert, micaceous, very angular grains	
42	9	1432.0 1433.5	1.5	**SILTY CLAYSTONE**		817, 818, 819	brownish gray	medium	Brownish gray silty, sandy claystone with sandy horizons near top of interval. Coal fragments to couple of inches. (same as in interval 1430.2-1431.4)	
43	9	1433.5 1435.0	1.5	**X**					Wooden block Lost core 1433.5 to 1435.0	
44	9	1435.0 1445.0	10.0	**X**					Wooden block: Run 17 1435-1445 No recovery	
45	9	1445.0 1445.5	0.5	**CLAYSTONE**			gray to dark gray	medium	Gray to dark gray silty claystone, micaceous. Organic "prelignite" at top	
46	9	1445.5 1448.7	3.2	**SANDSTONE**			medium to dark gray	soft	Medium to dark gray salt & pepper sandstone, soft; with white and clear qtz grains and dark gray to black chert grains NOTE: this part of core from 1445-1448.7 is from somewhere between 1445-1490, we don't know where.	
47	9	1448.7 1489.0	40.3	**X**					Wooden block: Run 18 1445-1490 Recover 3.5 ft (above) Run 19 (below) recover 2 ft	
48	9	1489.0 1491.0	2.0	**CLAYSTONE**		813, 814, 815, 816 of mold growth in core	dark brownish gray	medium	Varved claystone as below	
49	10	1491.0 1491.6	0.6	**CLAYSTONE/SILTY CLAYSTONE-MUD**	04FY1491.0	809, 810, 811, 812	dark brownish gray	medium	Dark brownish gray claystone alternating with (lighter) brownish gray silty claystone on 1 to 2 mm scale. Has "varved" look. Distincly laminated.	04FYU 1491 Siltstone, shale, claystone, organic rich. Epiclastic. Very fine grained material. Silt sized quartz and white mica.
50	10	1491.6 1493.0	1.4	**CLAY-SILTSTONE**	04FY1492.3	805, 806, 807, 808	brownish gray	medium	Brownish gray clayey siltstone. Distinctly laminated on 1 mm scale. Possible tephra at 1492.3, sampled for ash. Partially oxidized.	04FYU 1492 Siltstone/claystone. Epiclastic. Plane laminated. Poorly sorted. 90% very fine grained material, 10% fione grained material. Quartz 60% (90% monocrystalline, 10% polycrystalline chert), orgainc debris 20-30%. White mica 2-3%. Clay matrix?
51	10	1493.0 1495.85	2.85	**SILTY CLAYSTONE**			brownish gray	medium	GRADATIONAL CONTACT TO ABOVE Brownish gray claystone with varying amount of silt throughout, but minor. Has 1-2 mm laminatioons in places evident on "cut" surface. Appears to increase in silt content upward.	
52	10	1495.85 1496.1	0.25	**X**					Wooden block	
53	10	1496.1 1497.0	0.9	**CLAYSTONE**			dark brownish gray	medium	Dark brownish gray claystone (perhaps fiantly laminated, very minor silt)	

APPENDIX A.   FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
54	10	1497.0 1497.3	0.3	**SILTY CLAYSTONE**			brownish gray	medium	GRADES UP INTO INTERVAL ABOVE brownish gray silty claystone	
55	10	1497.3 1501.0	3.7	**SANDSTONE to SILTSTONE**	04FY1499.0		brownish gray	medium	GRADES UP INTO INTERVAL ABOVE Very fine, sub-rounded to sub-angular consolidated siltstone-sandstone. Gray to brownish gray very fine sandstone to siltstone with minor clay content. Visible white quartz, clear quartz, black chert grains.	04FYU 1499 Very fine sandstone. Epiclastic. 60% quartz, traces of biotite, hornblende, white mica. Clay matrix. Igneous or metamorphic provenance?
56	11	1501.0 1503.0	2.0	**SILTY CLAYSTONE**	04FY1502.0		medium gray	hard	Medium gray silty claystone (or clayeye siltstone), nondescript but perhaps laminated with organics. Fairly hard core (indurated)	04FYU 1502 Rock thin section. 20% silt, 45% very fine grained material, 25% fine grained material, and 5-18% medium grained material. 65% poly quartz, 35% mono quartz, trace plagioclase, white mica, siltstone clasts. Clay matrix with high birefringence. Lithic recycled with chert, siltstone, and minor plagioclase.
57	11	1503.0 1505.0	2.0	**SANDSTONE**			medium gray	soft	Medium gray sand with white quartz and chert (?). Soft sediment with laminations	
58	11	1505.0- 1505.6	0.6	**SANDSTONE**			medium gray	soft	Same as above	
59	11	1505.6- 1507	1.4	**SILTY CLAYSTONE**			brownish gray	medium	Brownish-gray claystone becoming more silty in the upper 1m. Coaly fragments and darker brown color in the upper portiuon of the interval.	
60	11	1507- 1507.5	0.5	**SILTY CLAYSTONE**			brownish gray	medium	Brownish gray claystone becoming more silty in the upper 1m. Coaly fragments and darker brown color in the upper portiuon of the interval.	
61	11	1507.5- 1508	0.5	**SILTY CLAYSTONE**			brownish gray	medium	Medium gray to brownish silty clay with minor lignite fragments.	
62	11	1508- 1508.5	27.0	**CLAYSTONE**			dark brownish gray	hard	Darker color than above.	
63	11	1508.5- 1535	26.5						Wooden Block	04FYU 1509.3 Very fine grained sandstone and siltstone thin section. Epiclastic, massive, 80% silt, 20% very fine grained material. Sub rounded. 1% pore space. 80% quartz/chert, 20% micacoeus clay matrix with traces of white mica. Lithic recycled.
64	11	1535- 1537	2.0	**SANDSTONE**	04FY1537		medium gray		Very fine grained to coarse grained sub rounded to sub angular unconsolidated sands. Medium gray white quartz sand (chert?)	04FYU 1537 Grainmount. Epiclastic. 10% very fine material, 30-40% fine material, 35-40% medium grained material. 60-70% chert (locally with white mica attached), 30% quartz, 3-4% plagioclase, 1-2% meta-siltstone and traces of white mica. Clay cement? Lithic recycled.
65	12	1537- 1537.2	0.2	**SANDSTONE**				soft	Medium gray sandstone	
66	12	1537.2- 1537.5	0.3						Wooden block (Art QW sample (coal?))	
67	12	1537.5- 1537.9	0.4	**SANDSTONE**		801, 802, 803, 804	medium gray		GRADES UP INTO INTERVAL ABOVE Medium gray sandstone grades into laminated lignite	
68	12	1537.9- 1584.8	46.9	**SANDSTONE**	04FY1584.0		medium gray	soft	Medium grained to coarse grained sub rounded to sub angular unconsolidated sands. Medium gray soft sand, gray to medium gray with small grains sized coaly fragments. White quartz in greater abundace than lean quartz and gray chert. Coal fragments or lignite?	04FYU 1584 Grainmount. Epiclastic. Moderately sorted. 10-20% very fine grained material, 25-30% fine grained material, 50% medium grained material. 70% chert, 25% quartz, 1-3% plagioclase. Traces of white mica and minor schist. Lithic recycled with minor metamorphic rock component.
69	12	1584.8- 1585	0.2						Wooden Block	

APPENDIX A.   FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
70	12	1585- 1585.1	0.1	**CLAYSTONE**			brownish gray		Brownish gray claystone with mm laminations of lignite. Organic-lignitic layers and fragments	
71	12	1585.1- 1586.0	0.9	**SILTY CLAYSTONE**			medium gray to brown	medium	Medium gray to brownish gray silty claystone, faintly laminated up to 1mm thick throughout. Rare swells. Coaly fragments up to 4mm in length. Minor yellowish-tan weathering "concretions".	
72	13	1586- 1588.9	2.9	**SILTY CLAYSTONE**			medium gray to brown	medium	Medium gray to brwonsih gray silty claystone, faintly laminated up to 1mm thick throughout. Rare swells. Coaly fragments up to 4mm in length. Minor yellowish-tan weathering "concretions".	
73	13	1588.9- 1589.3	0.4						Wooden Block (Art QW sample)	
74	13	1589.3- 1595.0	5.7	**SILTY CLAYSTONE**	04FY1589.3		medium gray to brown	medium	Consolidated medium gray to brown-gray silty claystone, faintly laminated up to 1mm thick throughout. Rare small coaly fragments up to 4mm in length. Minor yellowish-tan weathering "concretions".	
									Missing core? See lith log box 13 at the bottom	
75	14	1595- 1595.2	0.2	**SILTY CLAYSTONE**			medium-dark gray		Medium to dark gray silty claystone	
76	14	1595.2- 1596.65	1.9	**CLAY-SILTSTONE-SANDSTONE**			medium gray		Medium gray clayey siltstone to very fine sandstone. POORLY SORTED white quartz, gray quartz, and clay	
77	14	1596.65- 1596.9	0.3	**SANDSTONE**		795	light gray	soft	Light gray fine sandstone, faintly laminated, with sub-angular white quartz, clear quartz, and dark gray chert. Induarated.	
78	14	1596.9- 1600.7	3.6	**SANDSTONE**			olive gray	soft	Medium gray fine to very fine sandsteon. More indurated that the coarser soft sandstone mentioned above. Minor olive gray color. Occasional very faint lamination.	
79	14	1600.7- 1601.3	0.6	**SILTY CLAYSTONE**			medium to dark gray		Medium to dark gray silty claystone	
80	14	1601.3- 1601.8	0.5	**SANDSTONE**			medium gray		Very soft medium gray fine sand with white quartz, clear quartz, and micaceous flakes	
81	14	1601.8- 1602.6	0.8	**SILTY CLAYSTONE with SAND**	04FY1602.6-1603.0		medium to dark gray		Clay, silt, and very fine grained sub rounded to sub angular micaceous sand. Medium to dark gray silty micaceous claystone.	
82	14	1602.6- 1603	0.4	**SANDSTONE and SILTSTONE**	04FY1602.6-1603.0	793 to 800	medium gray		Laminated medium gray sand and silt layers with clay. Fines upward with minor carbonaceous material within the laminations	04FYU 1602.6-1603 Very fine sandstone and siltstone grain mount. Epiclastic. 10% silt, 40% very fine grained material, 50% fine grained material. 40% quartz, 50% chert, 10 % organic material and traces of white mica. Lithic recycled.
83	14	1603.0- 1603.7	0.7	**SANDSTONE**	04FY1603.0-1603.2		medium gray		Fine grained sub rounded sand. Very soft medium gray fine sand with white quartz, clear quartz, and micaceous flakes	04FYU 1603-1603.2 Very fine grained sandstone, siltstone, and shale grain mount. Epiclastic. 40% silt. 60% very fine grained material. 80% chert/quartz. Traces of white mica, plagioclase, and clay. Lithic recycled.
84	14	1603.7- 1604.8	1.1	**SANDSTONE and SILTSTONE**					Faintly laminated medium gray fine sanstone fines upward into medium dark gray silty sandstone with clay.	

APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
85	14	1604.8-1605.0	0.2	**SANDSTONE**	04FY 1604.8-1605.0	791, 792	Light gray	very soft	Silt and very fine grained sub rounded to sub angular unconsolidated sandstone. Light gray very fine grained sand with subangular white quartz, clear quartz, and dark gray chert.	04FYU 1604.8-1605. Very fine sandstone/siltstone grain mount. Epiclastic. 50% silt, 50% very fine grained material. 80% chert/quatrz, plagioclase 1%, mica-clay, schistose fragments, 19%. Lithic recycled and metamorphic fragments.
86	15	1605.0-1609.6	4.6	**SANDSTONE**	04FY1605.0		gray to dark gray		Very fine grained to fine grained sub rounded to sub angular unconsolidated and partially oxidized sandstone. Soft, poor core preservation. Gray to dark gray.	04FYU 1605 Grain mount. Epiclastic. 50% very fine grained material, 50% fine grained material. 80% chert/quatrz. 20% micas-clay. Lithic recycled.
87	15	1609.6-1609.8	0.2	**CLAY-SILTSTONE**					Coarsens upwards	
88	15	1609.8-1613	3.2	**SANDSTONE**			gray		Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert	
89	15	1613-1615							MISSING CORE	
90	15	1615-1615.5	0.5	**SILTSTONE**			gray to dark gray		Gray to dark gray micaceous siltstone with carbonaceous laminations up to 3mm thick	
91	15	1615.5-1616.8	1.3	**SANDSTONE**			gray		Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert	
92	16	1616.8-1617.7	0.9	**SANDSTONE**			gray		Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert	
93	16	1617.7-1620.6	2.9	**SANDSTONE**	04FY1617.7	786-789	gray		Fine to medium grained sub rounded to subangular unconsolidated gray sandstone with white quartz, clear quartz, and gray chert. Partially oxidized.	04FYU 1617.7 Grain mount. Epiclastic. 40% very fine grained material, 60% fine grained material. 80% chert/quartz, 20% white mica, plagioclase, and clay. Lithic recycled.
94	16	1620.6-1621.0	0.4	**COAL**			black		Laminated coals	
95	16	1621.0-1622.4	1.4	**SANDSTONE**			gray		Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert.	
96	16	1622.4-1624.1	1.7	**SILTSTONE**			gray to dark gray		Gray to dark gray micaceous siltstone with coaly laminations near the tom of the interval	
97	16	1624.1-1625.9	1.8	**SANDSTONE**			gray		Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert.	
98	16	1625.9-1626.0							Wooden Block	
99	16	1626.0-1626.7	0.7	**SANDSTONE**			gray		Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert. Laminated coals and slits near the top of the interval	
100	17	1626.7-1633.8	7.1	**SANDSTONE**	04FY1631.0		gray	very soft	Fine to medium grained	
101	17	1633.8-1635	1.2						MISSING CORE	
102	17	1635-1637.5	2.5	**SANDSTONE**					Upper portion of interval has distinct sub mm laminations of coal. Fine to medium grained sand with white, clear, and gray quartz	
103	18	1637.5-1641.6	4.1	**SANDSTONE**	04FY1638.0		gray		Fine to medium grained sub rounded unconsolidated gray sandstone with organic laminations, white quartz, clear quartz, and gray chert.	04FYU 1638 Grain mount. 10% silt, 40% very fine grained material, 60% fine grained material. 80% chert/quartz, 20 % minor white mica, plagioclase, and organic material. Lithic recycled.
104	18	1641.6-1643.5	1.9	**SILTSTONE**			gray		Gray silt with rare and very thin coaly laminations and fragments	
105	18	1643.5-1645.0	1.5	**X**					MISSING CORE	

APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
106	18	1645.0-1645.8	0.8	**SANDSTONE**					Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert.	
107	18	1645.8-1646.4	0.4	**SANDSTONE**					Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert.	
108	18	1646.4-1647.3	0.9	**SANDSTONE with COAL**					Laminated dull black coals with fine grained silty sandstone. White quartz with dark gray chert and coaly particles.	
109	18	1647.3-1647.9	0.6	**SANDSTONE**					Fine to medium grained gray sandstone with white quartz, clear quartz, and gray chert.	
110	18	1647.9-1648.3	0.4	**SANDSTONE**					Laminated dull black coals with fine grained silty sandstone. White quartz with dark gray chert and coaly particles.	04FYU 1648.1 Grain mount. 10% silt, 50 % very fine grained material, 40 % fine grained material. Chert 80%, 10% white mica and plagioclase, 10% organic material.
111	19	1648.3-1650.3	2.7	**SILTSTONE and SANDSTONE**	04FY1648.1-1648.3		gray	soft	Very fine grained sub rounded to sub angular unconsolidated sandstone with organics. Mostly fine to medium grained sandstone with white and clear quartz, dark chert, and coaly laminations in the top portion of the interval	
112	19	1650.3-1655.4							MISSING CORE	
113	19	1655.4-1656.9	2.5	**SILTSTONE and SANDSTONE**	04FY1655.7	778-779	gray		Micaceous gray siltosone grading upwards in the interval into dark gray to gray fine grained sandstone with subangular white, clear, and gray quartz and chert with fragments of partially coalified wood to carbonaceous shale. Uncommon concretions (see photo).	04FYU 1655.7 Grain mount. Epiclastic. 40% silt, 50% very fine grained material, 10% fine grained material. 80% chert. 10-20% organic debris. Lithic recycled?
114	19	1656.9-1661.3	4.2	**CLAY**			medium to dark gray	soft	Medium to dark gray clay with low silt content.	
115	19	1661.3-1665.0	3.7						LOST	
116	20	1665.0-1675	10.0	**SANDSTONE with CLAY**	04FY1665.7		gray to dark gray		Very fine grained to fine grained unconsolidated sands, silts, and clay with plant material. Gray to medium gray clay with monor silt and rare coalified wood fragments and uncommon yellowish-tan concretions	
117	21	1675-1678.2	3.2	**CLAYSTONE**			gray to dark gray		Gray to dark gray clay with variable silt content	
118	21	1678.2-1679.0	0.8	**CLAYSTONE**			gray		Gray clay with yellowish tan concretions	
119	21	1679-1679.4	0.4	**CLAYSTONE**			gray		Gray clay only	
120	21	1679.4-1683	3.6	**SILTSTONE with CLAY**	04FY1680-1680.2	777	light to dark gray		Alternating light and dark gray siltone and clay laminations. Grades into grayish to yellowish siltstone with local coaly fragments. Unconsolidated with organics.	04FYU 1681.6 Grain mount. 80% very fine grained material. 80% chert, 20% quartz, 20% organics, clay matrix. Lithics recycled. 04FYU 1680-1680.2 Grain mount. Epiclastic, plane laminated. 20% very fine grained material. 80% chert, 10-20% organic material and clay. Lithic recycled
121	21	1683-1684.6	1.6	**CLAY-SILTSTONE**	04FY1683.6-1683.7				DISCREPENCY WITH SAMPLE #, see lith log box 21	
122	21	1684.6-1685	0.4	**CLAY-SILTSTONE**	04FY1684.7-1684.8		light gray		Unconsolidated light gray clay rich siltstone. Distinctly lighter than above and below.	
123	22	1685-1695	10.0	**SILTY CLAYSTONE**	04FY1686.7-1686.8		gray to dark gray		Predominantly gray to dark gray silty clay with variable amounts of silt. Several random yellow concretionary zones.	

APPENDIX A.   FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
124	23	1695-1705	10.0	**SILTY CLAYSTONE**	04FY 1697.4-1697.5	774-775	light to dark gray		Unconsolidated light gray to gray micaceous clay-siltstone with small iron rich concretions cm in size.	04FYU 1697.4 Shale with siltstone and organic material. Epiclastic, plane laminated, very poorly sorted. 95% very fine grained materal. 60% quartz, 10% chert, 30% clay and white mica. Shale with visible white mica, some chert, and recycled lithic fragments.
125	24	1705-1706.5	5.5	**SILTSTONE**	04FY1705		gray		Micaceous in upper portion of the interval	04FYU 1705.9 Siltstone and very fine sandstone. Epiclastic, plane laminated, poorly sorted. 85% very fine grained material. 40% quartz, 40% chert, 10% clay and white mica, 10% organic debris.
126	24	1706.5-1712.3	5.7	**SILTY CLAYSTONE**			dark gray		Gray to dark gray silty clay with thin laminations of tan siltstone and fine grained gray to dark gray micaceous silts with abundant chert	
127	24	1712.3-1715	2.7	**SANDSTONE**					Gray to medium gray sand with minor organic laminations	
128	25	1715-1720	5.0						MISSING CORE	
129	25	1720-1729.7	9.7	**SANDSTONE**	04FY1726.6		medium gray to dark gray	very soft	Very fine grained sub rounded to sub angular sandstone. Medium gray to dark gray fine to medium grained sand with white and clear quartz and gray chert grains. Core is shattered and very soft. Localized carbonaceous plant material from 1728.7-1728.9.	
130	25	1729.7-1730	0.3	**SILTSTONE**			tan		Carbonaceous fragments and micaceous laminations	
131	26	1730-1739.3	9.3	**SILTSTONE**	04FY1734.9-1735.2	771-773	gray-tan		Grayish tan clay-siltstone. Carbonaceous material and clay laminations from 1734.9-1735.2. Micaceous clay with coal seams.	
132	26	1739.3-1740	0.7	**SILTSTONE with CLAY**			gray		Mostly gray silty clay	
133	26	1740-1745	0.5						MISSING CORE	
134	27	1745.0-1748.0	3.0	**SANDSTONE**	04FY1747.2-1747.3		gray to dark gray		Silt to very fine grained to medium grained unconsolidated sandstone. Fine to meduim grained gray to dark gray sand.	
135	27	1748.0-1748.5	5.0	**SILTSTONE**	04FY1748.25	BANET	tan to medium gray		Silt to very fine grained sub rounded to angular sands.Tan to gray micaceous siltstone with carbonized plant fragments on bedding planes (laminated organics).	
136	27	1748.5-1756.5							MISSING CORE	
137	27	1756.5-1765	9.5	**SILTSTONE**			gray to dark yellowsh tan	soft	Gray to dark yellowish tan micaceous siltstone lacking sedimentary structure	
									DESCREPANCY between lith log box 27 and 28 concerning lost core	
138	28	1765-1775	10.0	**SILTSTONE with CLAY**					Micaceous increase from below	
139	29	1775-1785.6	10.6	**SILTSTONE with CLAY**					Micaceous. Minor Brownish wood fragments	0fFYU 1784.7-1784-8 Siltstone. Quartz 60-70%. White mica 10%. Feldspar (?). Brown organic material. Clay matrix.
140	29	1785.6-1788	2.4	**SANDSTONE**			medium gray		Medium gray fine grained sand with minor silt laminations	
141	30	1788-1788.8	0.8	**SILTSTONE with CLAY**			medium to dark gray		Very minor organic partings	
142	30	1788.8-1790.2	1.4	**SILTSTONE with CLAY**			medium to dark gray		Very minor organic partings	
143	30	1790.2-1800.8	10.6	**SANDSTONE**			medium to dark gray		Fine grained sand with rare woody plant fragments	
144	31	1800.8-1804.6	3.8	**SANDSTONE**	04FY1802.2		medium to dark gray		Fine grained sand with rare woody plant fragments	

APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
145	31	1804.6-1810.3	6.2	**SILTSTONE with CLAY**			olive gray		Light olive gray to medium gray silty clay with rare woody and coalified plant fragments cm's in length. Woody fragments are visible on some bedding surfaves. Micaceous flakes in clay layers.	
146	32	1810.3-1816.9	6.6	**CLAYSTONE**	4FY1816.9 and 04FY1815.2		medium gray		Clay	
147	32	1816.9-1818.6	1.8	**SILTSTONE with CLAY**			light to medium gray		Fining upward medium to light gray silty clay	
148	32	1818.6-1820.1	1.5	**SANDSTONE**		22-23	light to medium gray		Same as below	
149	33	1820.1-1826.2	6.1	**SANDSTONE**	04FY1825.9				Silty sand with sparse organic laminations	Siltstone with quartz and abundant chert fragments. Abundant organic debris, minor white mica, and clay matrix.
150	33	1826.2-1835	8.8	**?**					MISSING CORE	
151-158	34	1835-1905	70.0	**CLAYSTONE**	04FY 1845-1855				End of upper coring…rotary down, box 34 is all cuttings	Clay rich silstone. Quartz clasts, organic material, abundant chert, and minor white mica.
159	34	1905-1909	4.0	**COAL**	04FYU 1905-1909				COAL	Organic material and carbonaceous coal/shale. 90-90% black to black-red organic debris with quartz clasts and clay.
160	35	1909-1919	10.0	**COAL**					COAL	
161	36	1919-1921	3.0	**CLAYSTONE**	04FY1919.5	20-21	medium to light gray		Black organic laminations and colified wood fragments	
162	36	1921-1924	3.0	**CLAYSTONE**			medium to dark gray		WOOD BLOCK AT 1924.2-1925	
163	36	1924-1925.5	1.5	**CLAYSTONE**	04FY1924					
164	36	1925.5-1929.4	3.9	**SANDSTONE**	04FY1925.5					
165	37	1929.4-1935.8	6.4	**SANDSTONE**	04FY1935.8		olive to medium gray		Fine to very fine sand with clay	
166	37	1935.8-1936.0	0.2						WOODEN BLOCK	
167	37	1936.0-1938.0	2.0	**SANDSTONE**			olive to medium gray		Fine to very fine sand with clay	
168	37	1938-1939	1.0	**SANDSTONE**	04FY 1938.3		olive to yellow		Olive gray to yellowish sand with gravel lag deposits. Pebbles are sub rounded and appear to be siltstone	Siltstone with very fine sandstone. Chert clasts are more abundant than chert, argillite, traces of plagioclase, traces of white mica, and clay rims on clasts.
169	37-38	1939-1940.2	1.2	**SANDSTONE**	04FY1939.9		olive to yellow		Olive gray to yellowish tan fine grained sand with silt. Organics consist of coalified plant material.	
170	38	1940.2-1944.2							MISSING CORE	
171	38	1944.2-1950	5.8	**CLAYSTONE**			olive gray		Olive gray to yellowish tan fine grained sand with silt. Organics consist of coalified plant material.	
172	38	1950-1950.8	0.8	**CLAYSTONE**			olive gray		Olive gray to yellowish tan fine grained sand with silt. Organics consist of coalified plant material.	
173	38	1950.8-1951.3	0.5	**SILTSTONE to SANDSTONE**	04FY1951		olive gray		Wavy laminations and thin carbonaceous plant fragments	Silstone with quartz, minor chert, organic material, traces of white mica, and clay matrix.
174	38	1951.3-1952.0	0.8	**SILTSTONE with CLAY**	04FY1951.3		medium gray		Sub mm partings of fine sand	Siltstone with quartz and chert. Minor white mica and abundant clay matrix.
175	38	1952.0-1952.5	0.5	**SILTSTONE with CLAY**			gray brown		Organic partings	
176	38	1952.5-1952.9	0.4	**SILTSTONE with CLAY**	04FY1952.6		light brown		Salt and pepper texture	Siltstone with very fine sandstone. Clasts of chert and quartz with traces of white mica and plagioclase.

APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
177	38	1952.9-1953.3	0.4	**SILTSTONE with CLAY**			light brown		Amber?	
178	39	1953.3-1955	1.7	**SILTSTONE with CLAY**	04FYU 1954.8	13-14	light brown		Coal fragments	Chert, quartz, traces of white mica and plagioclase in a clay matrix.
179		1955-1970	15.0	**SANDY-SILTSTONE TO CLAYSTONE**					Based on gamma ray log interpretation. Fining upward sequence from siltstone to claystone.	
		1970-2010	40.0	**SANDY-SILTSTONE**					Siltstone to claystone with thin sandy interbeds 1'-2' thick.	
180	cuttings	1965-1975	10.0	**SILTSTONE with CLAY**	04FY1965-1975					
181	cuttings	1975-1985	10.0	**SILTSTONE with CLAY**	04FY1975-1985				Minor coal fragments	
182	cuttings	1985-1995	10.0	**SILTSTONE with CLAY**	04FY1985-1995		olive gray			Chert and quartz. Traces of white mica and clay matrix.
183	cuttings	1995-2005	10.0	**SILTSTONE with CLAY**	04FY1995-2005		olive gray		Minor coal fragments	Siltstone with oxidized organic debris. Quartz with lesser amounts of chert. White mica clasts. Matrix is silt, clay, and altered organic debris.
184	cuttings	2005-2015	10.0	**SILTSTONE with CLAY**	04FY2005-2015		olive gray		Silty claystone with coarse sand interbeds, minor coal fragments	
185	cuttings	2015-2025	10.0	**CLAYSTONE**	04FY2015-2025					
186	cuttings	2025-2035	10.0	**CLAYSTONE**	04FY2025-2035		olive gray		Minor coal fragments	
187	cuttings	2035-2045	10.0	**CLAYSTONE**	04FY2035-2045		medium to dark gray			
188	cuttings	2045-2055	10.0	**CLAYSTONE**	04FY2045-2055		white to medium gray		Minor coal fragments	
189	cuttings	2055-2065	10.0	**SILTSTONE with CLAY**	04FY2055-2065		medium gray		Minor coal fragments	
		2065-2140		**SANDSTONE and SILTSTONE**					Interbedded sandstone and siltstone in zones 2-5 feet thick.	
190	cuttings	2065-2075	10.0	**SILTSTONE with CLAY**	04FY2065-2075		medium gray		Minor coal fragments	
191	cuttings	2075-2085	10.0	**SILTSTONE with CLAY**	04FY2075-2085		medium gray		Minor coal fragments	
192	cuttings	2085-2095	10.0	**SILTSTONE with CLAY**	04FY2085-2095		medium gray		Minor coal fragments	
193	cuttings	2095-2105	10.0	**SILTSTONE with CLAY**	04FY2095-2105		medium gray		Minor coal fragments	
194	cuttings	2105-2115	10.0	**SILTSTONE with CLAY**	04FY2105-2115		medium gray		Minor coal fragments	
195	cuttings	2115-2125	10.0	**SILTSTONE with CLAY**	04FY2115-2125		medium gray		Minor coal fragments	
196	cuttings	2125-2135	10.0	**SILTSTONE with CLAY**	04FY2125-2135		medium gray		Minor coal fragments	Silica fracture fill. Quartz and clay clasts. Clay matrix.

APPENDIX A. FORT YUKON CORE DESCRIPTION

Interval	Core Box	Depth	Interval Thickness	Predominant Lithology	Sample #	Photos	Color	Induration	Description	Thin Section Descriptions
*		2140-2170		**SANDSTONE to SILTSTONE**					Interbedded sandstone and siltstone in zones 2-5 feet thick. Overall, this interval is a fining upward sequence of sandstone at the base to a siltstone at the top and a thin claystone interval at the very top. Based on geophysical log interpretation.	
197	cuttings	2135-2145	10.0	**CLAYSTONE**	04FY2135-2145		medium gray		Minor coal fragments and random quartz grain	
198	cuttings	2145-2155	10.0	**CLAYSTONE**	04FY2145-2155		medium gray		Minor coal fragments	
199	cuttings	2155-2165	10.0	**CLAYSTONE**	04FY2155-2165		medium gray		Minor coal fragments and random quartz grain	
*		2175-2225		**SANDSTONE with PEBBLES**					Fairly clean sand interval (could be a gravel zone) with pebbly sand interbeds of unknown thickness starting at 2170'-2220'. This horizon on shallow seismic data is a prominent reflector. Based on geophysical log interpretation.	
200	cuttings	2165-2170	10.0	**CLAYSTONE**	04FY2165-2175		medium gray		Minor coal fragments	
201	cuttings	2175-2185	10.0	**GRAVEL**	04FY2175-2185		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel	
202	cuttings	2185-2195	10.0	**GRAVEL**	04FY2185-2195		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel	
203	cuttings	2195-2205	10.0	**GRAVEL**	04FY2195-2205		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel	
204	cuttings	2205-2215	10.0	**GRAVEL**	04FY2205-2215		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel	
205	cuttings	2215-2225	10.0	**GRAVEL**	04FY2215-2225		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel	Conglomerate. Meta-siltstone clasts in grain mount. Grain mount clasts include sandstone, siltstone, chert with radiolarians, and cherty argillite.
206	cuttings	2225-2260	35.0	**SILTY CLAYSTONE**					Silty claystone with same log appearance as 1950'-1955'	
207	cuttings	2225-2235	10.0	**GRAVEL**	04FY2225-2235		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel	
208	cuttings	2235-2245	10.0	**GRAVEL**	04FY2235-2245		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel	Conglomerate. Same as 04FYU2215-2225 including silicified limestone clasts exhibiting silicified sponge spicules. Quartz arenite-quartzite clasts also present.
209	cuttings	2245-2255	10.0	**GRAVEL**	04FY2245-2255		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel. Coal fragments present.	Conglomerate. Same as 04FYU2235-2245 yet lacks limestone clasts and includes traces of white mica, chert, cherty argillite, and organic materials.
210	cuttings	2260-2287	27.0	**SANDSTONE with PEBBLES**					Sandy interval with pebbly sand interbeds	
211	cuttings	2255-2256	1.0	**No Data**						
212	cuttings	2265-2275	10.0	**GRAVEL**	04FY2265-2275		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel. Coal fragments present.	
213	cuttings	2275-2285	10.0	**GRAVEL**	04FY2275-2285		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel. Coal fragments present.	Epiclastic, very poorly sorted to poorly sorted medium grained sub-angular to sub-rounded radiolarian cherts. Clay and white mica.
214	cuttings	2285-2287	10.0	**GRAVEL**	04FY2285-2287		multi-colored		Black, gray, white, yellow, brown angular to sub-angular pea gravel. Coal fragments present.	Epiclastic, poorly sorted, very course angular to sub-rounded sandstone to conglomerate chert and sandstone.