Oil & Natural Gas Technology

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Quarterly Progress Report
With Summaries of Center-sponsored Research
(April – June 2008)

UTAH HEAVY OIL PROGRAM

Submitted by:
University OF Utah
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Office of Fossil Energy

Quarterly Progress Report
Utah Heavy Oil Program
University of Utah
DE-FC26-06NT15569
Quarter Ended June 30, 2008

Philip J. Smith, Principal Investigator
Project Period June 21, 2006 through October 21, 2008

EXECUTIVE SUMMARY

The mission of the Utah Heavy Oil Program (UHOP) is to provide research support to federal and state constituents for addressing the wide-ranging issues surrounding the creation of an industry for unconventional oil production in the United States. This quarter saw significant steps toward completion of the five UHOP-sponsored research projects. It is anticipated that results and analysis from all five projects will be presented at a UHOP-sponsored technical meeting this fall. The on-line repository for information, data, and software relating to unconventional oil resources in North America is continuing to be repopulated with 1400 documents with documents for which copyright permission has been obtained. Documents can be searched and downloaded at http://ds.heavyoil.utah.edu/dspace/index.jsp.

PROJECT MILESTONES/PROGRESS PERFORMANCE

A. Progress in Program-Sponsored Projects

Brief summaries are provided below for ongoing work in the five UHOP-sponsored projects.

1. Detailed Study of Shale Pyrolysis for Oil Production

Milind Deo, Eric Eddings, Terry Ring

The isothermal (300-600^{o}C) and non-isothermal (0.5 to 50^{o}C/min) decompositions of the crushed Mahogany Oil Shale with a Thermo Gravimetric Analyzer (TGA) in N_2 (pyrolysis) and air (combustion) environments were performed. Data obtained from TGA were analyzed in detail. Different mathematical approaches were used to determine the kinetic parameters (activation energy (E) and pre-exponential factor (A)) with the assumption of first order reaction. Both differential and integral methods were used for the isothermal data and four different approaches were used for the non-isothermal experiments (direct Arrhenius plot, integral method, Friedman approach and the maximum rate method). All of the data with the kinetic parameters obtained is summarized in Appendix 1 and Appendix 2. There is a significant variation in kinetic parameters with different methods used. In general, the activation energy increases as the heating rate increases in the non-isothermal analysis, contrary to some previous observations. Reasons and mechanisms for this difference are being examined.

2. **New Approaches to Treat Produced Water and to Perform Water Availability Impact Assessments for Oil Shale Development**

Steve Burian, Ramesh Goel, Andy Hong, Brian McPherson

Water Resources Sustainability: The water resources GIS database was expanded to included the Piceance basin (to accompany the Uintah basin database already compiled). A presentation on the topic of water requirements for oil shale development in the Uintah-Piceance basin was given by Eric Jones to the American Water Resources Association Utah section annual conference. His talk won the award for the top undergraduate student paper. We developed a proximity tool in GIS to operate on the Piceance-Uintah database to identify water resources within a user defined radius. The tool compiles a summary of the water available, quantifies the amounts, and lists water rights associated with the identified water resources. The tool can be used to locate potential oil shale development locations and help to identify available water resources and water rights controlling those resources. A revised estimate of oil shale reserves was also prepared through a geostatistical analysis performed by Greg Nash. A revised estimate of population growth associated with oil shale industrygrowth in the Vernal, Utah area was produced. Both revised estimates were incorporated into a revised estimate of water requirements for oil shale development in the Uintah-Piceance Basins. An abstract on this work was submitted and accepted to American Society of Civil Engineers Environment and Water Resources Institute international conference scheduled for January 2009 in Thailand.

Integrated Treatment Approach: This quarter of the project focused on bacterial and electrolytic oxidation of MTBE. Combined treatment using electrolytic and biological degradation of naphthalene was also tested. Results show that electrolytic degradation products of naphthalene were further degraded by bacteria, thus providing a complete treatment of PAH containing wastewater. Tests are underway to test the kinetics of MTBE degradation using electrolysis and Fenton-reaction-assisted advanced oxidation techniques. A manuscript is in preparation on the experimental work and results obtained so far. Membrane bioreactors to obtain treated water of reusable quality will be set in the near future.

3. **In Situ Production of Utah Oil Sands**

Pete Rose, Royhan Gani, Jack Hamilton and Milind Deo

No report received.

4. **Depositional heterogeneity and fluid flow modeling of the oil shale interval of the upper Green River Formation, eastern Uinta Basin, Utah**

Royhan Gani and Milind Deo

Cores of well U059 were logged for a total of 958.75 feet (292.23 m) at the Utah Geological Survey (UGS), Utah Core Research Center. Core U059, also known as White River Shale Project P-4, was acquired by UGS from a well in Uinta County, T10S-R25E.

Core lithology and sedimentary and bioturbation structures were determined and logged through visual investigation using HCl and a light microscope when necessary. Photographs were taken at key depths in the core for documentation.

Next, stratigraphic picks were made on the U059 well logs indicating stratigraphically significant surfaces. UGS picks were available for U059 for one rich and two lean oil shale zones, the Mahogany Bed marker, and two dated tuff beds, the Curly Tuff and Wavy Tuff. UGS picks were confirmed to match respective core log intervals at proper measured depths.

Lastly, UGS picks of seven lean and eight rich oil shale zones from seven density logs in the central Uinta Basin are being correlated to the logs of the study area in the eastern Uinta Basin including U059. Stratigraphic surface picks made for U059 are also being extended for the study area. The entire core-log is provided as an appendix (Appendix C).

Preliminary work shows that variation in the thicknesses of rich and lean oil shale zones follow the trend of thicknesses between stratigraphic picks in the subsurface. The implied relationship between the deposition of oil shale and fluctuations in lake level is strong. Furthermore, this study defines a shift in both log characteristics and analogous core lithology and stratigraphy that coincides with a shift from a regime of alternating rich and lean zones to a uniformly rich zone. This shift correlates to the boundary between the transitional interval and the upper member of the Green River Formation defined in outcrop by earlier workers. The process model is being modified based on this new characterization.

5. Analysis of Environmental, Legal, Socioeconomic and Policy Issues Critical to the Development of Commercial Oil Shale Leasing on the Public Lands in Colorado, Utah, and Wyoming under the Mandates of the Energy Policy Act of 2005; Economic Evaluation of Bitumen Upgrading

Robert Keiter, Kirsten Uchitel, Alan Isaacson

Legal and Economic Analysis: We reviewed and analyzed the Bureau of Land Management's PEIS on Oil Shale Leasing. We also began our review and analysis of the public, non-governmental organization, and industry comments on commercial oil shale leasing options as outlined in the PEIS. We also interviewed and discussed oil shale leasing issues and models with various individuals with commercial leasing experience on the public lands. Finally, we reviewed and edited draft sections of the report on commercial oil shale leasing.

Economic Evaluation of Bitumen Upgrading: Alan Isaacson, the PI of this subtask, died in an unfortunate accident in the mountains of northern Utah during a spring snowstorm. We are evaluating how to proceed with this task given the loss of his significant expertise.

B. On-line Repository

Some documents are now available for full-text searching and for downloading at http://ds.heavyoil.utah.edu/dspace/index.jsp. With the recent hiring of an undergraduate student to input metadata for each document that is uploaded to the repository, we anticipate that the repository will be populated with several hundred documents by the end of August 2008.

In anticipation of adding further material to the repository, we met with several employees of the Utah Geological Survey (UGS) to discuss opportunities for collaboration and information dissemination. UGS is anxious to provide the public with multiple avenues for obtaining information from them and has agreed to provide us with additional documents, data, maps, and other materials as they become available.

CONCLUSIONS

The projects funded by UHOP generated a significant quantity of data for review and analysis in this quarter. In addition, the UHOP repository now contains some documents that can be searched and downloaded. Additional materials will be added to the repository through the end of this phase of project funding.

COST PLAN/STATUS

Baseline Reporting Quarter	Year 1							
	Q1		Q2		Q3		Q4	
	6/21/06 - 9/30/06		10/1/06 - 12/31/06		1/1/07 - 3/31/07		4/1/07 - 6/30/07	
	Q1	**Total**	Q2	**Total**	Q3	**Total**	Q4	**Total**
Baseline Cost Plan								
Federal Share	126,295	**126,295**	239,349	**365,644**	41,357	**407,001**	147,911	**554,912**
Non-Federal Share	31,574	**31,574**	34,342	**65,916**	25,969	**91,885**	38,387	**130,272**
Total Planned	157,869	**157,869**	273,691	**431,560**	67,326	**498,886**	186,298	**685,184**
Actual Incurred Cost								
Federal Share	126,295	**126,295**	239,349	**365,644**	41,357	**407,001**	164,491	**571,492**
Non-Federal Share	31,574	**31,574**	34,342	**65,916**	25,969	**91,885**	30,841	**122,726**
Total Incurred Costs	157,869	**157,869**	273,691	**431,560**	67,326	**498,886**	195,332	**694,218**
Variance								
Federal Share	0	**0**	0	**0**	0	**0**	16,580	**16,580**
Non-Federal Share	0	**0**	0	**0**	0	**0**	(7,546)	**(7,546)**
Total Variance	0	**0**	0	**0**	0	**0**	9,034	**9,034**

Baseline Reporting Quarter	Year 2							
	Q5		Q6		Q7		Q8	
	7/1/07 - 9/30/07		10/1/07 - 12/31/07		1/1/08 - 3/31/08		4/1/08 - 6/30/08	
	Q5	**Total**	Q6	**Total**	Q7	Total	Q8	Total
Baseline Cost Plan								
Federal Share	147,911	**702,823**	147,911	**850,734**	147,911	**998,645**	147,911	**1,146,556**
Non-Federal Share	38,620	**168,892**	38,620	**207,512**	38,620	**246,132**	38,620	**284,752**
Total Planned	186,531	**871,715**	186,531	**1,058,246**	186,531	**1,244,777**	186,531	**1,431,308**
Actual Incurred Cost								
Federal Share	161,343	**732,835**	178,570	**911,405**	165,243	**1,076,648**	114,429	**1,191,077**
Non-Federal Share	29,299	**152,025**	10,038	**162,063**	36,285	**198,348**	19,020	**217,368**
Total Incurred Costs	190,642	**884,860**	188,608	**1,073,468**	201,528	**1,274,996**	133,449	**1,408,445**
Variance								
Federal Share	13,432	**30,012**	30,659	**60,671**	17,332	**78,003**	(33,482)	**44,521**
Non-Federal Share	(9,321)	**(16,867)**	(28,582)	**(45,449)**	(2,335)	**(47,784)**	(19,600)	**(67,384)**
Total Variance	4,111	**13,145**	2,077	**15,222**	14,997	**30,219**	(53,082)	**(22,863)**

Baseline Reporting Quarter	Year 3							
	Q9		Q10					
	7/1/08 - 9/30/08		10/1/08 - 12/31/08					
	Q9	Total	Q10	Total				
Baseline Cost Plan								
Federal Share	147,911	**1,294,467**	147,909	**1,442,376**				
Non-Federal Share	38,620	**323,372**	37,222	**360,594**				
Total Planned	186,531	**1,617,839**	185,131	**1,802,970**				
Actual Incurred Cost								
Federal Share								
Non-Federal Share								
Total Incurred Costs								
Variance								
Federal Share								
Non-Federal Share								
Total Variance								

MILESTONE COMPLETION CHART

		Project Duration Start: End:														
		Project Year 1				Project Year 2				Project Year 3						
Task	Critical Path Project Milestone Description	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Planned Start Date	Planned End Date	Actual Start Date	Actual End Date	Comments (notes, explanation of deviation from baseline)
1.1	Identify resources on unconvention-al oil in North America	X										June, 2006	Sept., 2006	June, 2006	Sept., 2006	
1.2	Prepare draft update report on domestic unconvention-al oil resources	X	X									June, 2006	Sept., 2006	June, 2006	Feb. 2007	Identifying personnel & surveying available sources took longer than expected. Added value from the report will be from analysis, which also takes more time.
1.3	Release draft update to public & request input from unconvention-al oil community		X									Sept., 2006	Sept., 2006	Oct., 2006	March 2007	Preliminary draft was released on March 21, 2007 Release delayed by Task 1.2 delay and by problems with report quality from company hired to do page layout.
1.4	Attend the CERI Oil Shale Symposium & provide a summary		X				X					Oct., 2006	Oct., 2006	Oct., 2006	Oct., 2006	

1.5	Develop on-line repository for all types of material pertaining to unconventional oil resources in North America	X	X	X								June, 2006	June, 2008	June, 2006		The repository is being repopulated with the original 1400 documents that were included; expected completion date for this set of documents is Sept. 2008
1.6	Update and release enhanced version of report developed under 1.3, integrating comments received			X								Jan., 2007	Aug., 2007	April, 2007	Sept., 2007	
1.7	Release on-line repository to unconventional oil community			X								Jan., 2007	Jan., 2007	Jan., 2007	Feb, 2007	Release date was Feb. 15, 2007.
1.8	Refine repository, incorporating information provided by user community			X	X	X	X			X	X	Jan., 2007	Oct., 2008	Jan., 2007		
2.1	Identify Center-sponsored research projects areas in consultation with DOE	X				X						Sept., 2006	Sept., 2006	Sept., 2006	Oct., 2006	

2.2	Issue internal RFP to support project areas identified in 2.1		X			X						Sept., 2006	Sept., 2006	Oct., 2006	Nov., 2006	RFP was released on Nov. 20, 2006. Proposals were due Dec. 15, 2006.
2.3	Select 2-3 Center-sponsored research projects		X			X						Oct., 2006	April, 2007	Jan., 2007	April, 2007	Selection of research projects completed in March 2007. Researchers were not notified of project selection before end of quarter three.
2.4	Complete technical reports for Center-based research projects					X						Oct., 2008	Oct., 2008			
2.5	Provide priority listing of research & demonstration needs for domestic production from unconventional oil resources				X	X						June, 2007	Sept., 2007	Nov. 2007		Will address this milestone in the first quarter of 2008

APPENDIX A

ISOTHERMAL

Table : 1 N2_normalized data INTEGRAL APPRAOCH

Exp No	T	Total time	Initial weight	Start_ Isothermal temp		Normalized factor	End_analysis point		Date	N2		Slope	
	°C	min	mg	Time	Weight Loss		Time	Weight Loss			R^2	K	lnK
1	300	720	26.758	3.33	99.17	0.0917	11.24	98.71	28-Feb-08	0.00174	0.5163	0.0008	-7.1309
2	350	240	26.69	3.82	98.75	0.0875	8.8	98.15	27-Feb-08	0.0016	0.8893	0.0045	-5.40368
3	400	240	22.643	4.36	98.21	0.0821	60.04	90.59	27-Feb-08	0.00148	0.9644	0.0311	-3.47055
4	450	240	24.688	4.96	96.01	0.0601	11.23	89.12	28-Feb-08	0.00138	0.8157	0.2973	-1.21301
5	500	240	25.001	5.59	89.29				1-Mar-08				
6	550	180	23.953	6.3	88.38				2-Mar-08				
7	600	30	24.101	6.96	87.89				2-Mar-08				

Table : 2 AIR_ normalized data NTEGRAL APPRAOCH

Exp No	T	Total time	Initial weight	Start_ Isothermal temp		Normalized factor	Date	Air		Slope	
	oC	min	mg	Time	Weight Loss			1/T, K	R^2	K	lnK
1	300	240	23.643	2.7	99.27	0.0927	1-Mar-08	0.00174	0.873	0.0365	-3.31044
2	350	240	23.391	3.82	98.14	0.0814	29-Feb-08	0.0016	0.8752	0.1909	-1.65601
3	400	240	23.241	4.31	96.85	0.0685	29-Feb-08	0.00148	0.8455	0.8725	-0.13639
4	450	180	32.162	4.88	94.32	0.0432	1-Mar-08	0.00138	0.864	2.8006	1.02983

Figure A.1 – Normalized conversion data for N_2

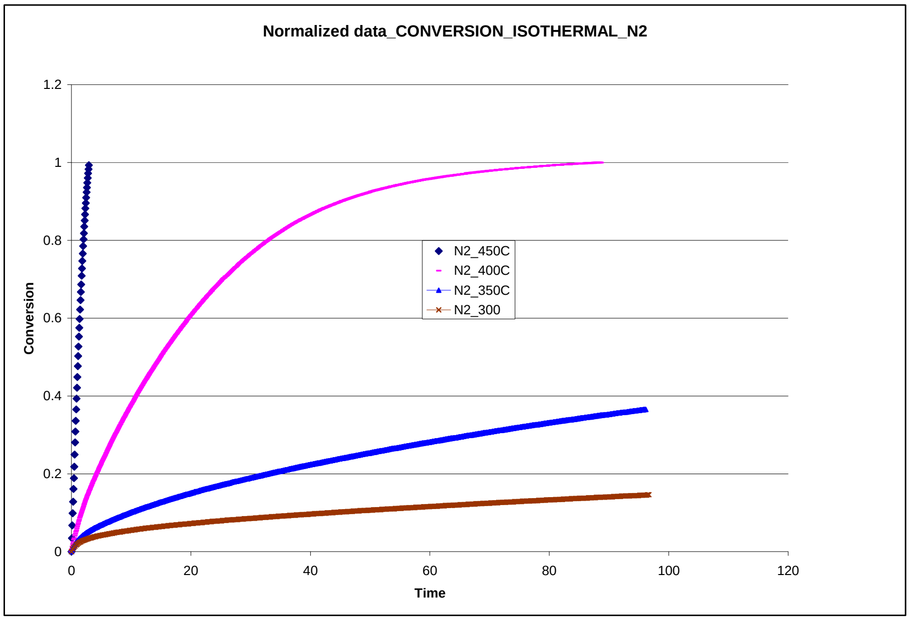


Figure A.2 – Normalized conversion data for air

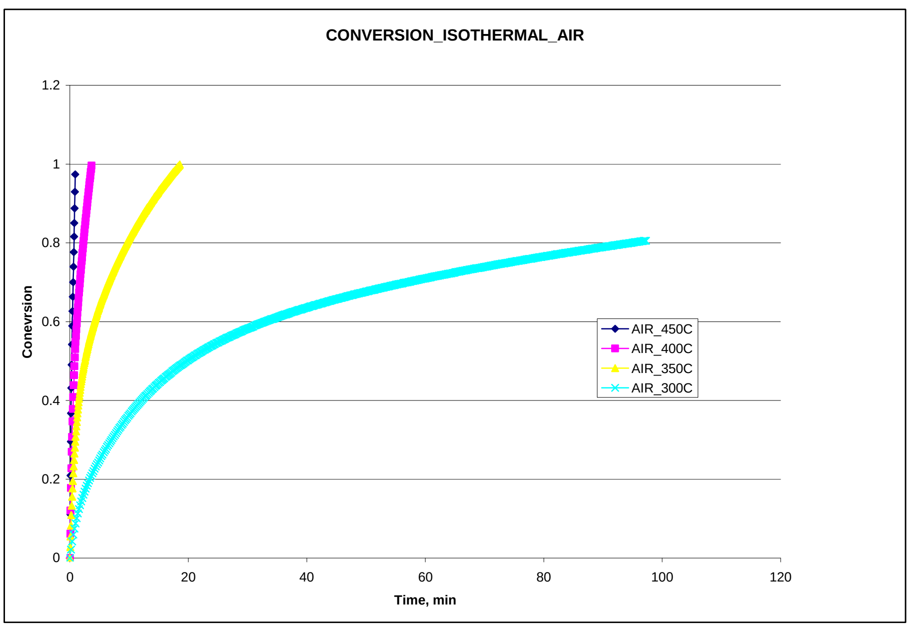


Figure A.3 – Integral method for 1st order N_2

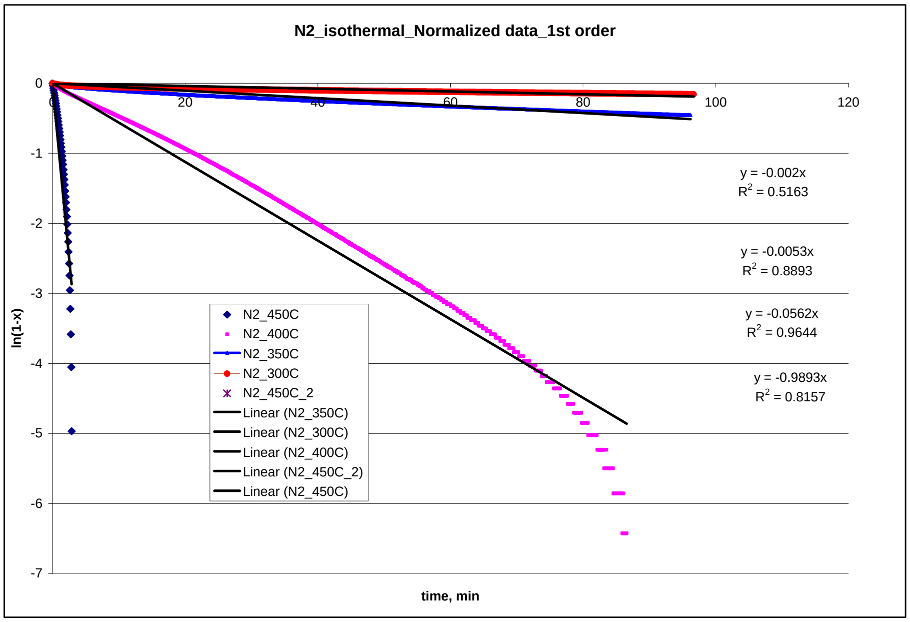


Figure A.4 – Integral method for 1st order air

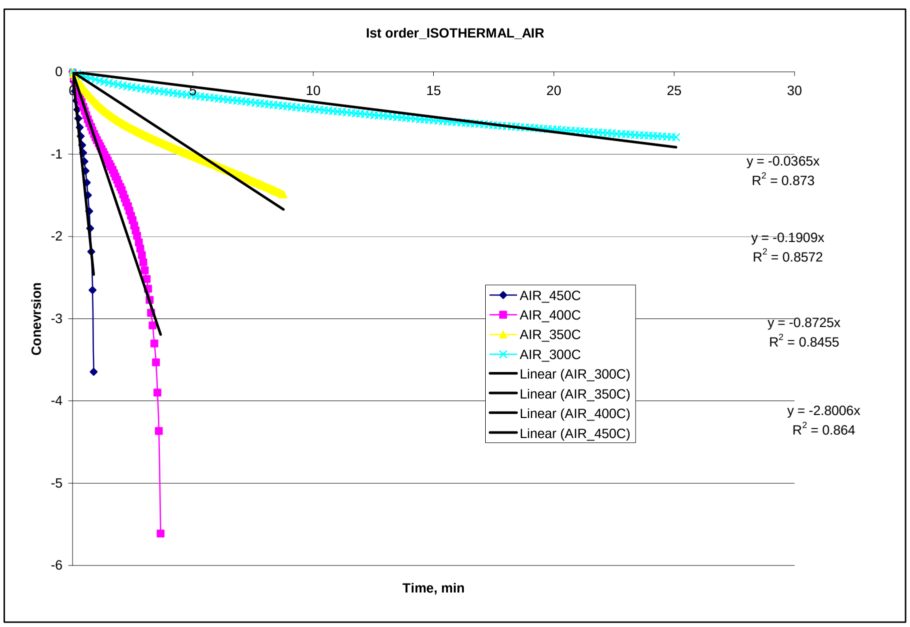
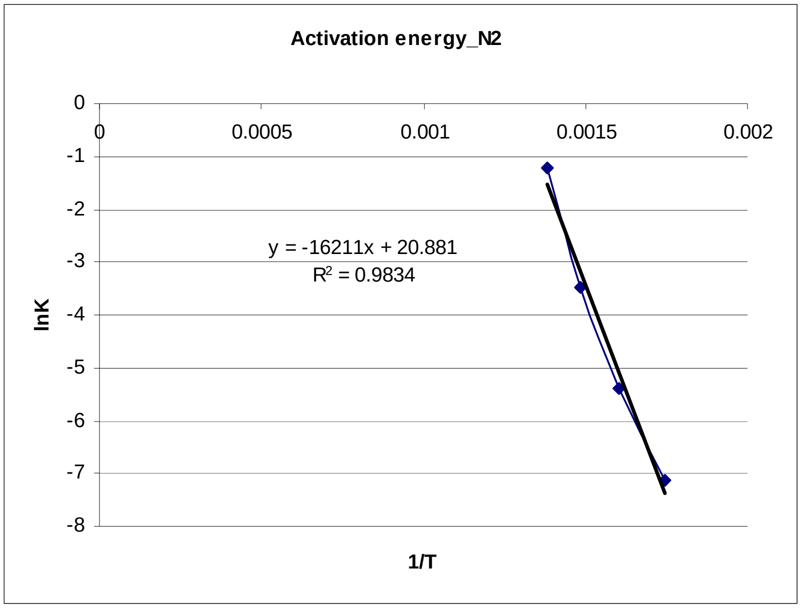
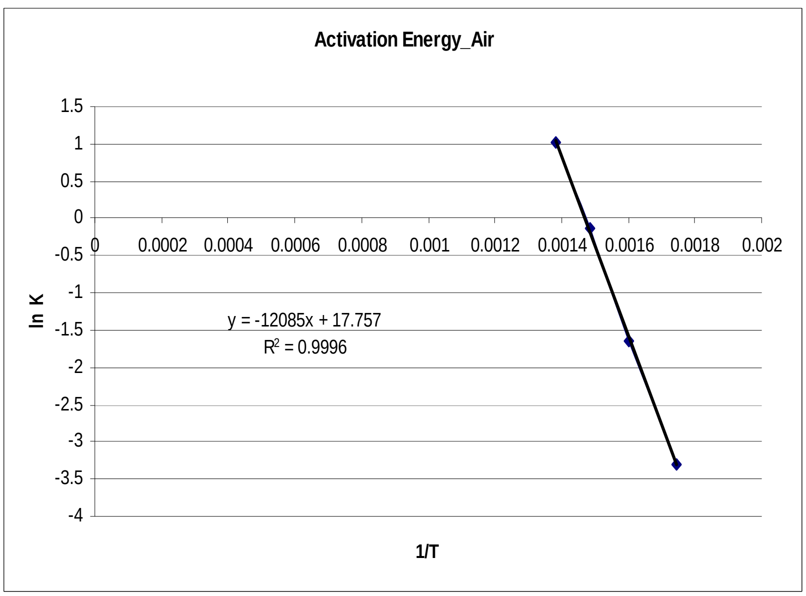


Figure A.5 – Arrhenius plot for 1st order integral data_N_2



N_2		
Activation Energy	A	R2
134.778254	1.2E+09	0.9834

Figure A.6 – Arrhenius plot for 1st order integral data_air



Air		
Activation Energy	A	R^2
100.47469	5.1E+07	0.9996

APPENDIX 2

N2_Differential approach														
Exp No	Heating rate	Initial weight	Start		End		max			R^2	slope	Intercept	Activation energy	A
	Beta	mg	T	wt %	T	wt%	Tmax	wt%	%/min					
1	0.5	22.645	255.66	98.68	421.6	91.98	392.76	93.52	0.039	0.961	9351	10.8	77.744214	24510
2	1	28.642	269.6	98.84	437.6	92.52	398.33	94.21	0.062	0.959	9002	10.07	74.842628	23624
3	2	26.94	280.06	98.67	456.4	91.57	414.15	93.48	0.181	0.962	10379	11.8	86.291006	266505
4	5	25.972	348.93	97.83	474	90.59	432.29	92.83	0.074	0.977	14873	17.93	123.65412	3E+08
5	10	38.452	349.79	98.26	490	90.33	445.62	92.74	1.348	0.972	14905	17.54	123.92017	4E+08
6	20	29.493	371.61	98.42	504	89.32	460.18	92.08	3.549	0.979	17757	21	147.6317	3E+10
7	50	22.374	377.32	98.57	530.6	88.87	477.03	92.11	9.099	0.967	17218	19.56	143.15045	2E+10

AIR _DATA															
			First Peak							Second Peak					
Exp No	Ramp rate	Initial weight	Start		End		max			End		max			weight loss
	Beta	mg	T	wt %	T	wt%	Tmax	wt%	%/min	T	wt%	Tmax	wt%	%/min	%
1	0.5	18.688	179	99.33	311.3	91.84	279.9	94.8	0.11	396.4	87.09	340.2	89.2	0.108	12.91
2	1	20.261	199.1	99.41	323.8	92.05	294.1	94.71	0.1103	400.39	86.98	354.42	89.26	0.107	13.02
3	2	19.981	201.9	99.51	339.1	92.44	305.9	95.2	0.097	421.5	87.71	367.1	90.07	0.094	12.29
4	5	30.562	211.4	99.56	358.5	92.54	323.8	95.32	0.4545	459.65	87.28	392.22	89.87	0.437	12.72
5	10	34.986	216.5	99.98	374.9	92.31	337.1	95.18	0.9074	499.49	86.87	409.59	89.82	0.747	13.13
6	20	21.695	215.5	99.62	389.2	92.42	341.1	95.9	1.697	504.6	86.93	425.93	89.87	1.445	13.07
7	50	30.223	227.7	99.58	395.3	93.19	351.4	95.97	3.466	522.99	86.97	450.45	89.8	3.902	13.03

Figure B.1 – Non-isothermal_N_2_conversion data

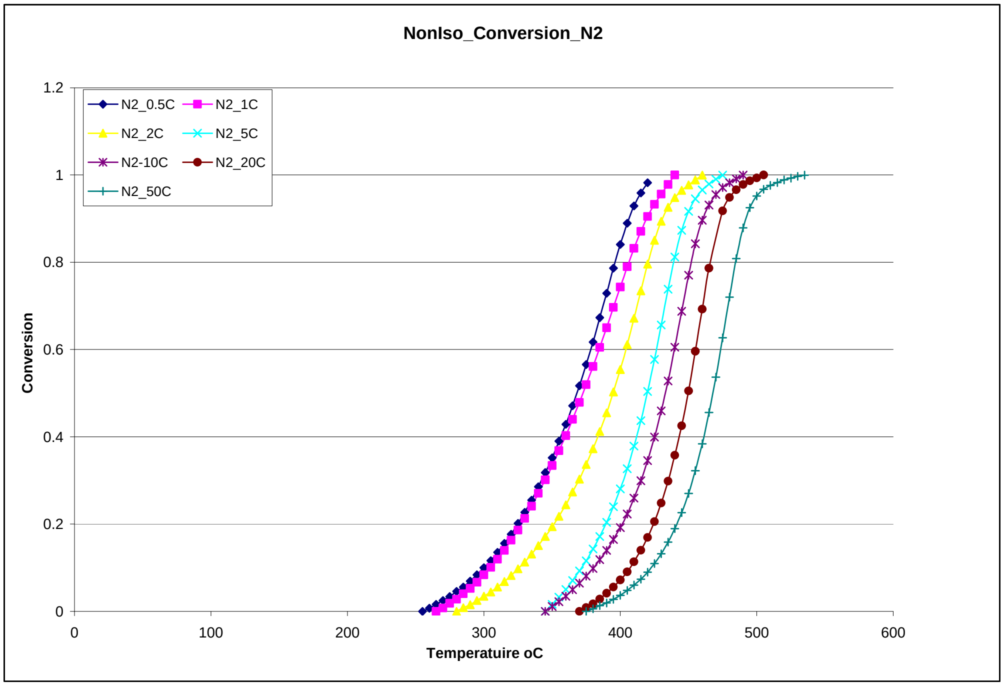
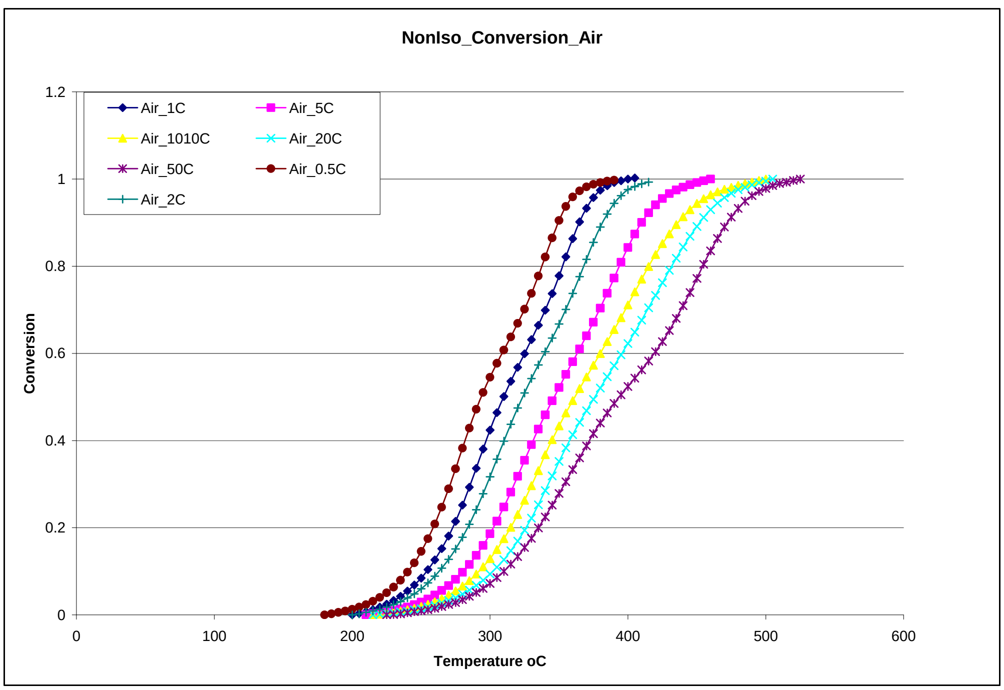


Figure B.2 – Non-isothermal_air_conversion data



	NONISO _N2_Differential APPROACH								
	Exp No		1	2	3	4	5	6	7
	Heating rate	Beta	0.5	1	2	5	10	20	50
	Initial weight	mg	22.645	28.642	26.94	25.972	38.452	29.493	22.374
	Start	T	255.66	269.6	280.06	348.93	349.79	371.61	377.32
		wt %	98.68	98.84	98.67	97.83	98.26	98.42	98.57
	End	T	421.57	437.56	456.35	473.98	489.96	504	530.56
		wt%	91.98	92.52	91.57	90.59	90.33	89.32	88.87
OS_N2	max	Tmax	392.76	398.33	414.15	432.29	445.62	460.18	477.03
		wt%	93.52	94.21	93.48	92.83	92.74	92.08	92.11
		%/min	0.0393	0.06192	0.1814	0.07381	1.348	3.549	9.099
	Date		25-Feb-08	8-Feb-08	10-Feb-08	8-Feb-08	6-Feb-08	4-Feb-08	7-Feb-08
	weight loss	mg	8.02	7.48	8.43	9.41	9.67	10.68	11.13
			0.961	0.959	0.962	0.977	0.972	0.979	0.967
	slope		9351	9002	10379	14873	14905	17757	17218
	Intercept		10.8	10.07	11.8	17.93	17.54	21	19.56
	Activation energy	KJ/mol	**77.744214**	**74.842628**	**86.291006**	**123.6541**	**123.9202**	**147.6317**	**143.1505**
	Preexponential factor		24510.401	23623.565	266504.71	3.06E+08	4.15E+08	2.64E+10	1.56E+10
Literature	Activation	(Spain)Torrent (Fuel 80,2001)				171+_17	171+_16	102+_4	115+-9
	A					1.53E+10	9.23E+09	3.27E+04	2.65E+06
	Activation	wang Quing sample s1					137.67	134.27	124.47
	A						8.58E+09	1.27E+10	1.07E+10

Figure B.3 – Non-isothermal_N_2_1st order_differential approach

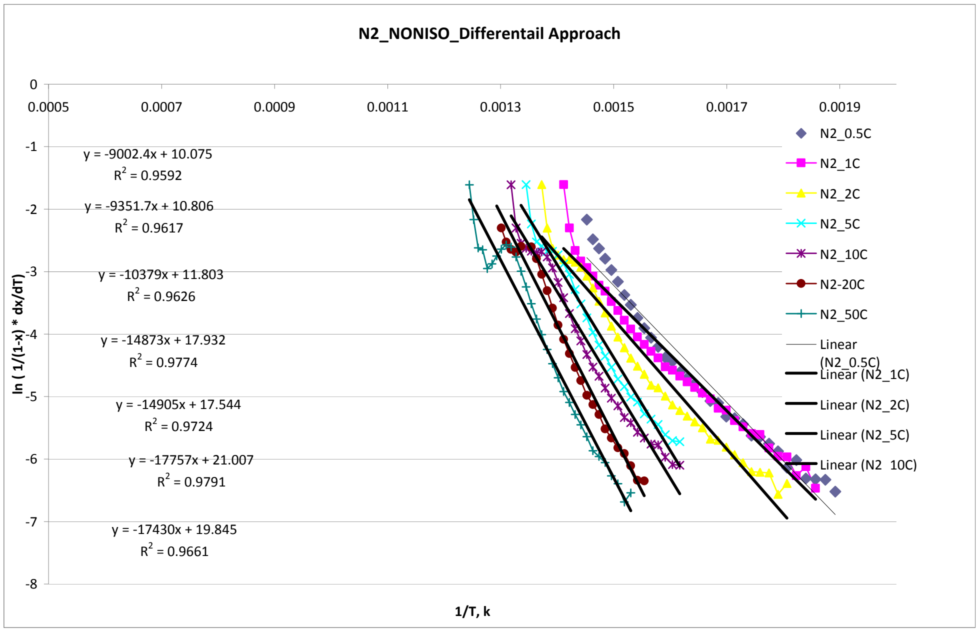
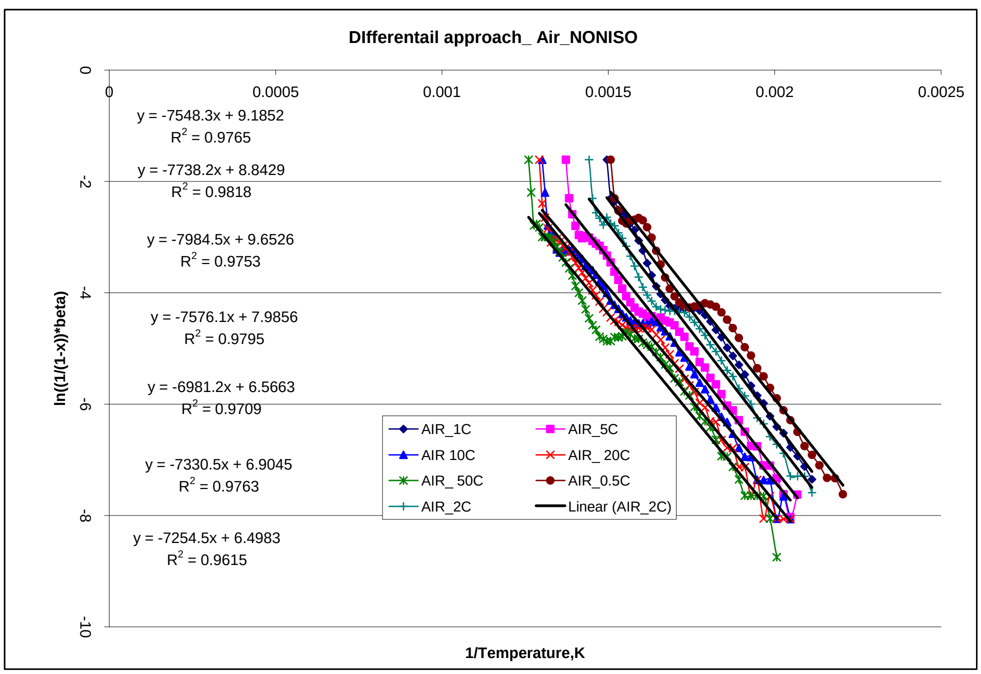


Figure B.4 – Non-isothermal air 1st order differential approach single step



AIR _Differential Approach								
Single step								
Exp No	**Ramp rate**	**Initial weight**	**R2**	**slope**	**Intercept**	**E**	**A**	lnA
	Beta	**mg**				**KJ /mol K**		
1	0.5	18.688	0.977	7548	9.1852	62.76	4876	8.49205
2	1	20.261	0.975	7985	9.652	66.38	15553	9.652
3	2	19.981	0.982	7738	8.8429	64.34	13850	9.53605
4	5	30.562	0.98	7576	7.9856	62.99	14692	9.59504
5	10	34.986	0.971	6981	6.5663	58.04	7107	8.86889
6	20	21.695	0.976	7331	6.9045	60.95	19935	9.90023
7	50	30.223	0.962	7254	6.4983	60.31	33201	10.4103

AIR_Differeantial Approach_Two Steps													
		First peak area						**Second peak area**					
Exp No	**Heating rate**	**R2**	**slope**	**Intercept**	**E**	**A**	ln A	**R2**	**slope**	**Intercept**	**E**	**A**	ln A
	oC/min												
1	0.5	0.963	7762	9.6266	64.536	7581	8.9335	0.87	9639	12.486	80.142	1E+05	11.793
2	1	0.963	7690	9.1047	63.933	8997	9.1047	0.97	12220	17.117	101.6	3E+07	17.117
3	2	0.972	7641	8.6715	63.526	11668	9.3646	0.93	10835	13.352	90.082	1E+06	14.045
4	5	0.97	7875	8.5548	65.469	25958	10.164	0.9	9617	10.928	79.952	3E+05	12.537
5	10	0.966	7797	8.0696	64.821	31958	10.372	0.85	7842	7.6991	65.196	22064	10.002
6	20	0.966	7695	7.5846	63.977	39353	10.58	0.79	9615	10.662	79.942	9E+05	13.658
7	50	0.949	7525	7.023	62.563	56107	10.935	0.95	11607	12.372	96.501	1E+07	16.284

Figure B.5 – Non-isothermal_air_1st order_differential approach_two steps

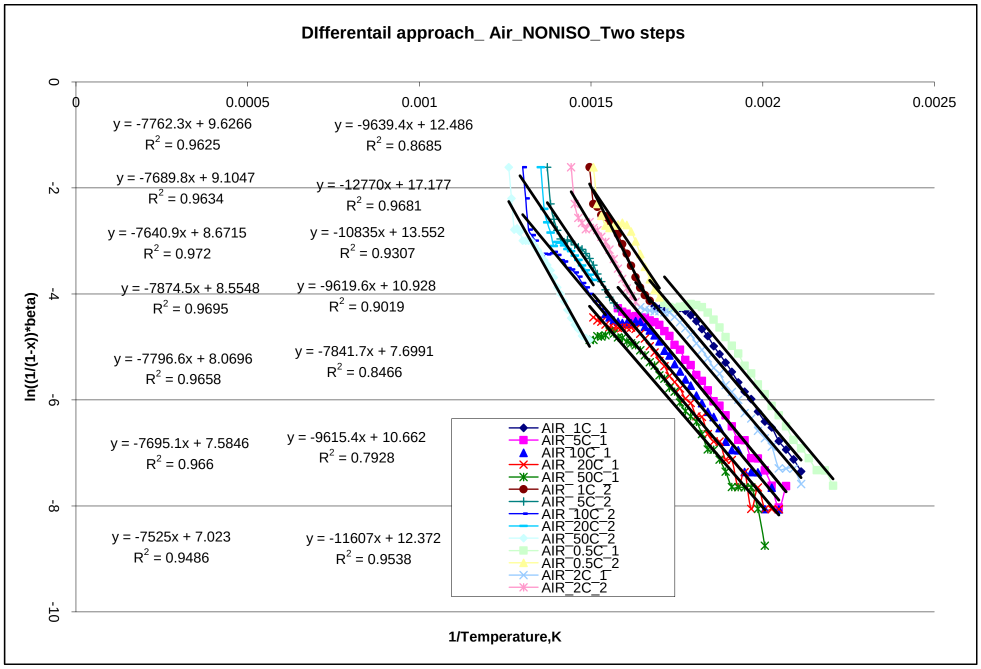
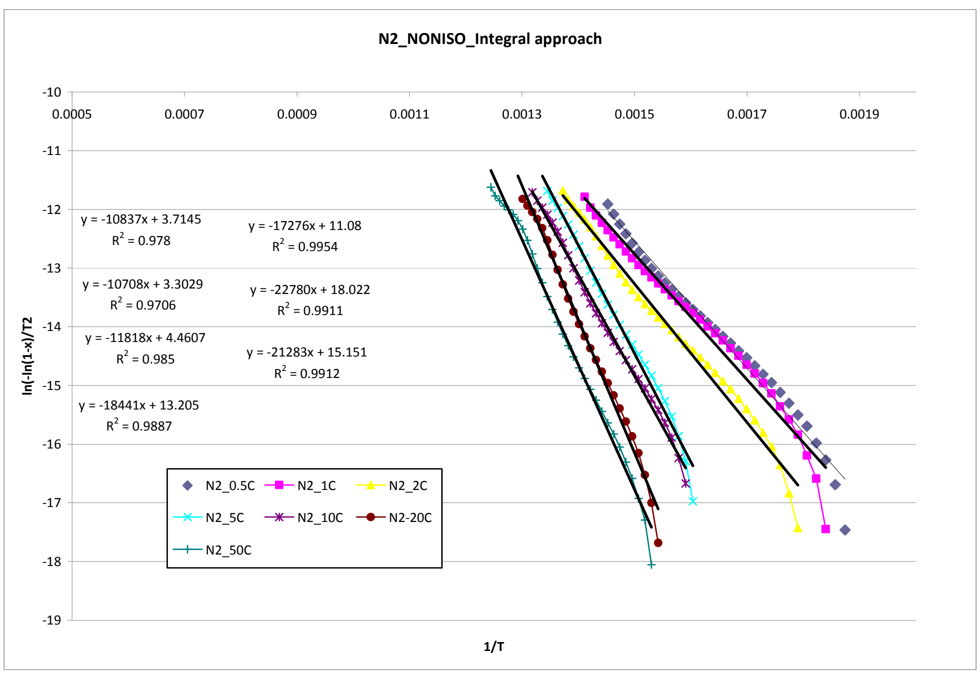
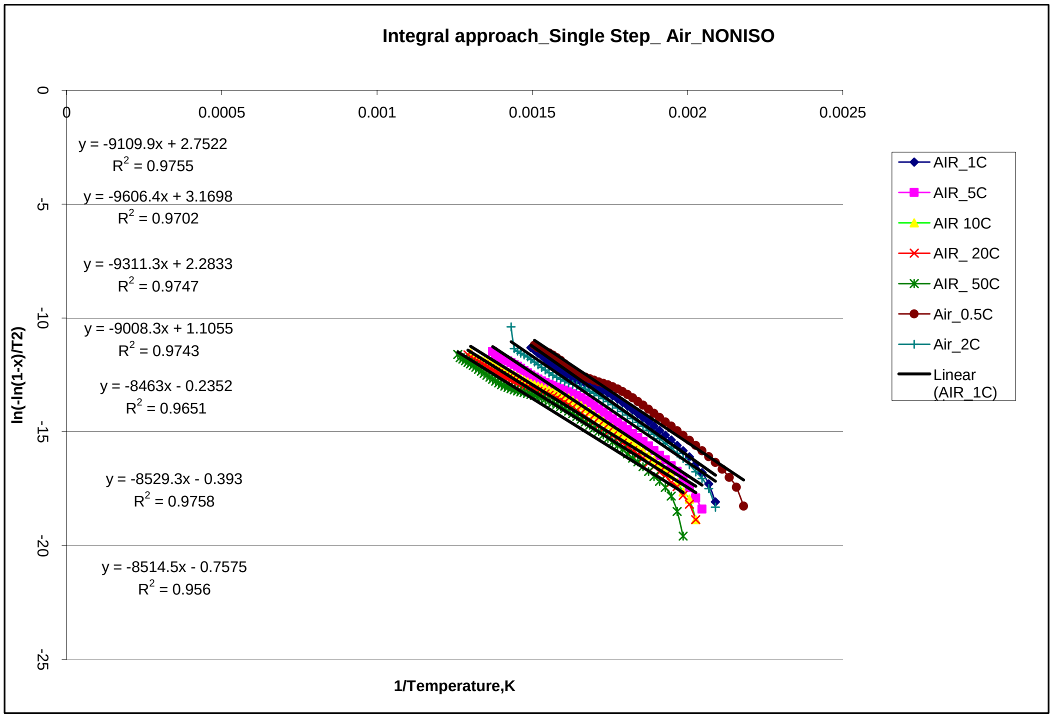


Figure B.6 – Non-isothermal N_2 1st order integral approach single step



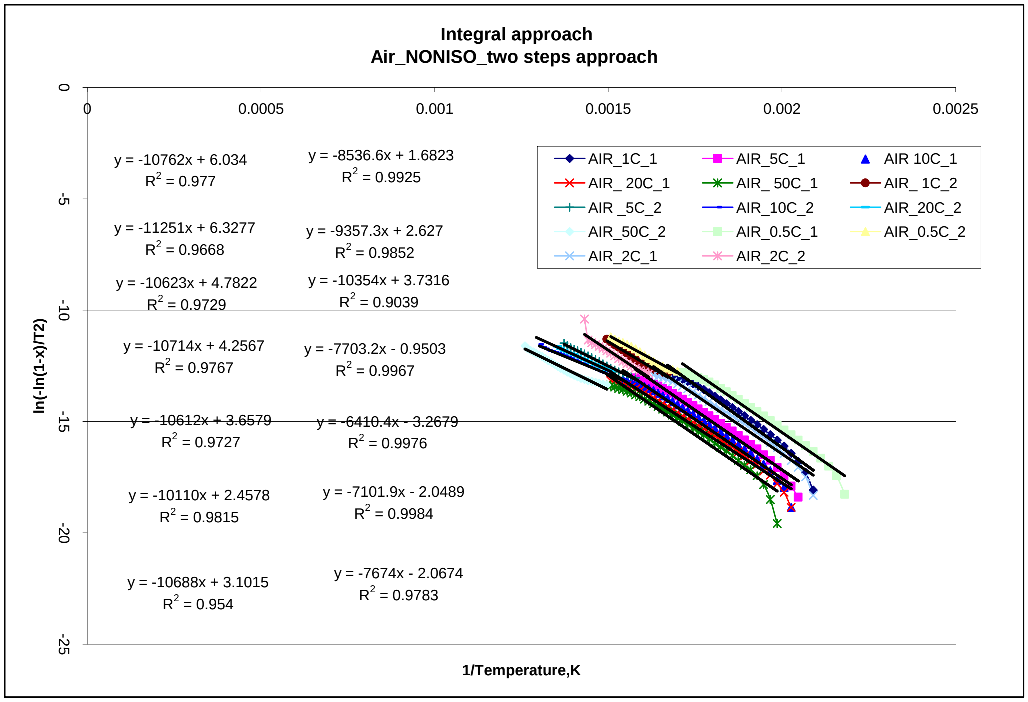
NONISO _N2_INTEGRAL APPROACH								
Exp No		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Heating rate	**Beta**	0.5	1	2	5	10	20	50
Initial weight	**mg**	22.645	28.642	26.94	25.972	38.452	29.493	22.374
Start	**T**	255.66	269.6	280.06	348.93	349.79	371.61	377.32
	wt %	98.68	98.84	98.67	97.83	98.26	98.42	98.57
End	**T**	421.57	437.56	456.35	473.98	489.96	504	530.56
	wt%	91.98	92.52	91.57	90.59	90.33	89.32	88.87
max	**Tmax**	392.76	398.33	414.15	432.29	445.62	460.18	477.03
	wt%	93.52	94.21	93.48	92.83	92.74	92.08	92.11
	%/min	0.0393	0.06192	0.1814	0.07381	1.348	3.549	9.099
date		25-Feb-08	8-Feb-08	10-Feb-08	8-Feb-08	6-Feb-08	4-Feb-08	7-Feb-08
weight loss	**mg**	8.02	7.48	8.43	9.41	9.67	10.68	11.13
	R2	0.978	0.97	0.985	0.988	0.995	0.991	0.991
slope		10837	10708	11818	18441	17276	22780	21283
Intercept		3.714	3.302	4.46	13.2	11.08	18.02	15.15
Activation		90.098818	89.026312	98.254852	153.3185	143.63266	189.39292	176.9469
A		222253.59	290903.363	2044218.8	4.98E+10	1.121E+10	3.052E+13	4.04E+12
Activation	Wang Quing sample s1					80.63	84.18	81.69
A						1.52E+05	2.32E+05	1.01E+06
Activation	Wang S Li C Yue Fuel processing tech 85(2003)				169.1			
A					4.07E+09			
Activation			50.7	47.7	48.7	44.3	39.2	32.9

Figure B.7 – Non-isothermal air 1st order integral approach single step



Air_Integral Approach_Signle step								
Exp No	Heating rate	Initial weight	R2	slope	Intercept	E	A	ln A
	Beta	mg						
1	0.5	18.688	0.976	9109.9	2.7522	75.7397	71408.3	11.17617
2	1	20.261	0.97	9606.4	3.1698	79.8676	228658	12.339985
3	2	19.981	0.975	9311.3	2.2833	77.4141	182669	12.115431
4	5	30.562	0.974	9008.3	1.1055	74.895	136058	11.82084
5	10	34.986	0.965	8463	-0.2352	70.361	66892.6	11.110844
6	20	21.695	0.976	8529.3	-0.393	70.913	115150	11.653995
7	50	30.223	0.956	8514.5	-0.7575	70.79	199596	12.204049

Figure B.8 – Non-isothermal_air_1st order_integral approach two steps

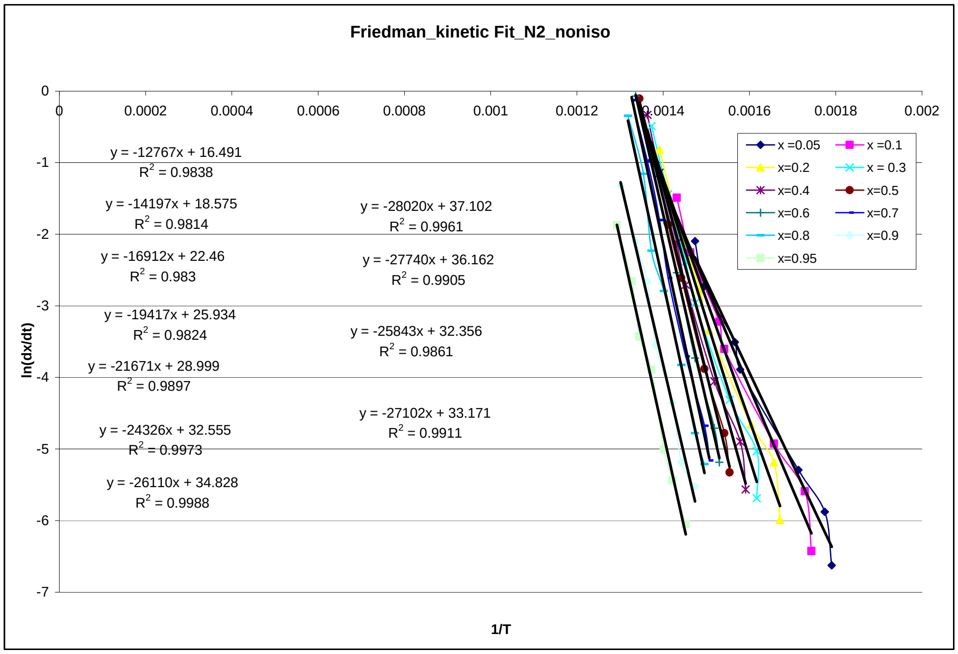


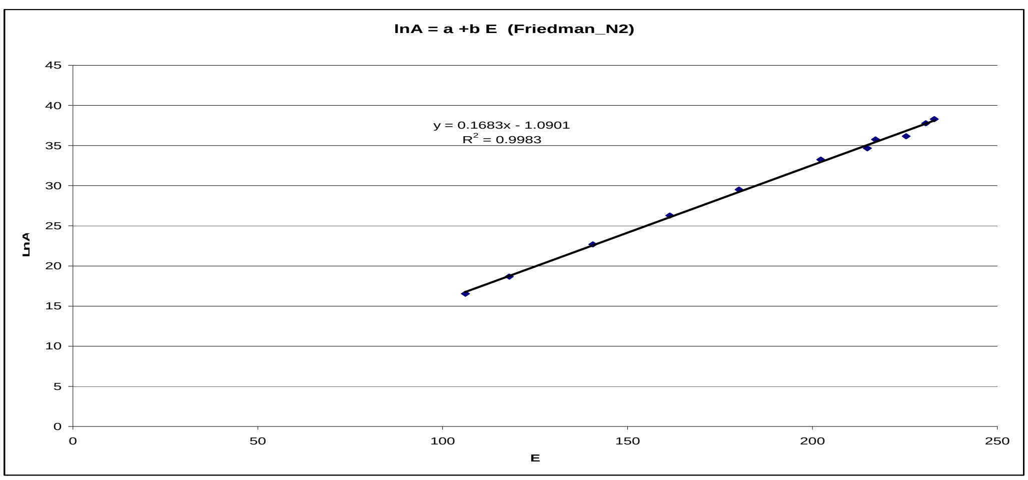
Air_ Integral approach_two steps

Beta	First peak						Second peak					
	slope	Intercept	R^2	E	A	lnA	slope	Intercept	R^2	E	A	ln A
0.5	10762	6.032	0.977	89.48	2E+06	14.623	8536.6	1.6823	0.9925	**70.97**	22955	10.0413
1	11251	6.3277	0.9668	93.54	6E+06	15.656	9357.3	2.627	0.9852	**77.8**	1E+05	11.7709
2	10623	4.7822	0.9729	88.32	3E+06	14.746	10354	3.7316	0.9039	**86.08**	9E+05	13.6699
5	10714	4.2567	0.9668	89.08	4E+06	15.145	7703.2	-0.9503	0.9967	**64.04**	14891	9.60853
10	10612	3.6579	0.9727	88.23	4E+06	15.23	6410.4	-3.2679	0.9967	**53.3**	2441	7.80036
20	10110	2.4578	0.9815	84.05	2E+06	14.675	7101.9	-2.0489	0.9984	**59.05**	18305	9.81495
50	10688	3.1015	0.954	88.86	1E+07	16.29	7674	-2.0674	0.9783	**63.8**	48544	10.7902

Friedman_N2_NonIso						
Kinetic	Slope	Intercept	R2	Activation energy, kJ/mol	A	
Conversion						LnA
0.05	12767	16.491	0.9838	**106.144838**	15283636	16.54229
0.1	14197	18.575	0.9814	**118.033858**	1.3E+08	18.68036
0.2	16912	22.46	0.983	**140.606368**	7.1E+09	22.68314
0.3	19417	25.934	0.9824	**161.432938**	2.62E+11	26.29067
0.4	21671	28.999	0.9897	**180.172694**	6.55E+12	29.50983
0.5	24326	32.555	0.9973	**202.246364**	2.75E+14	33.24815
0.6	26110	34.828	0.9988	**217.07854**	3.34E+15	35.74429
0.7	28020	37.102	0.9961	**232.95828**	4.33E+16	38.30597
0.8	27740	36.162	0.9905	**230.63036**	2.53E+16	37.77144
0.9	25843	32.356	0.9861	**214.858702**	1.13E+15	34.65859
0.95	27102	33.171	0.9911	**225.326028**	5.09E+15	36.16673

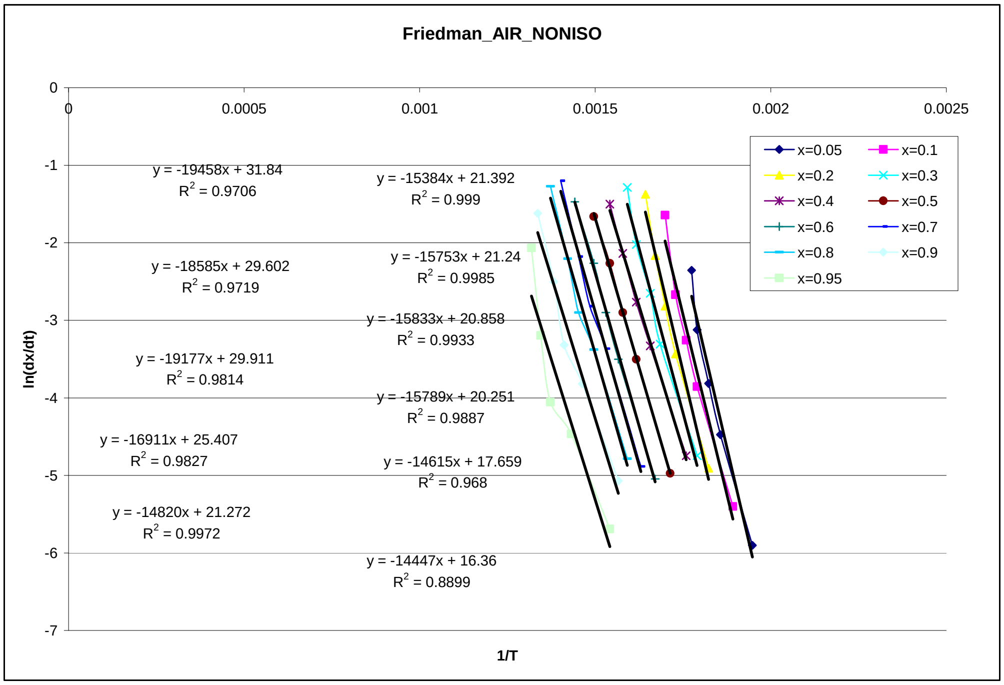
Figure: B.9 – Non-isothermal_N_2_1st order_Friedman approach_

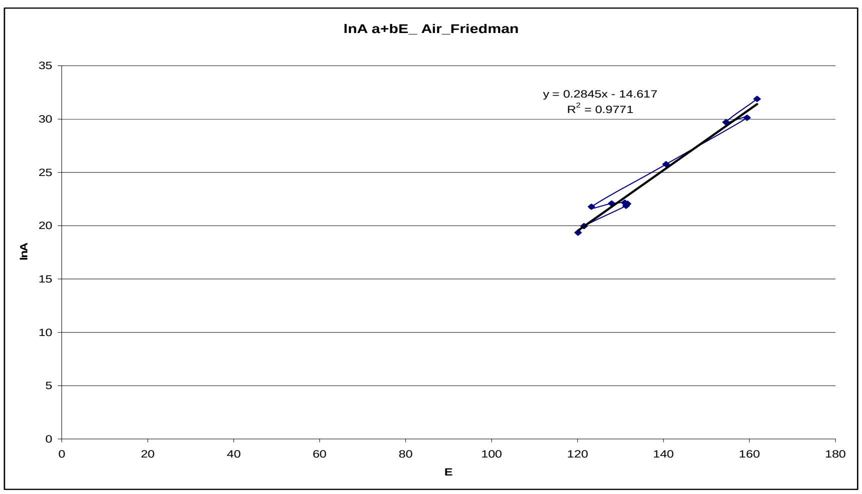


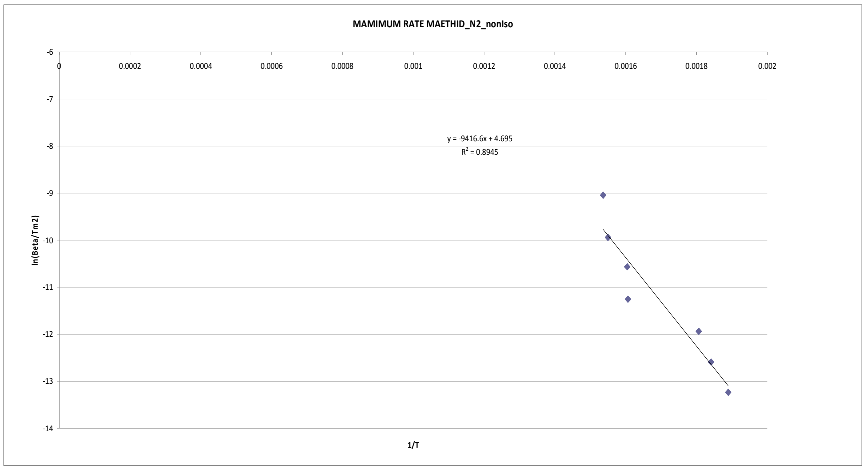


AIR_NONISOTHERMAL_FRIEDMAN						
Kinetic	Slope	Intercept	R2	Activation energy, kJ/mol	A	
Conversion						lnA
0.05	19458	31.84	0.9706	161.77	7.1E+13	31.89129
0.1	18585	29.602	0.9719	154.52	8E+12	29.70736
0.2	19177	29.911	0.9814	159.44	1.2E+13	30.13414
0.3	16911	25.407	0.9827	140.6	1.5E+11	25.76367
0.4	14820	21.272	0.9972	123.21	2.9E+09	21.78283
0.5	15384	21.392	0.999	127.9	3.9E+09	22.08515
0.6	15753	21.24	0.9985	130.97	4.2E+09	22.15629
0.7	15833	20.858	0.9933	131.64	3.8E+09	22.06197
0.8	15789	20.251	0.9887	131.27	3.1E+09	21.86044
0.9	14615	17.659	0.968	121.51	4.7E+08	19.96159
0.95	14447	16.36	0.8899	120.11	2.5E+08	19.35573

Figure B.10 – Non-isothermal_air_1st order_Friedman approach_







Maximum rate method_ N2_ noniso			
	This work	Literature	
Activation	**78.2846**	**230.6**	**219.2**
A	1.03E+06	**2.36E+14**	**3.25E+13**

Figure B.12 – Non-isothermal air 1st order maximum rate method approach 1st peak

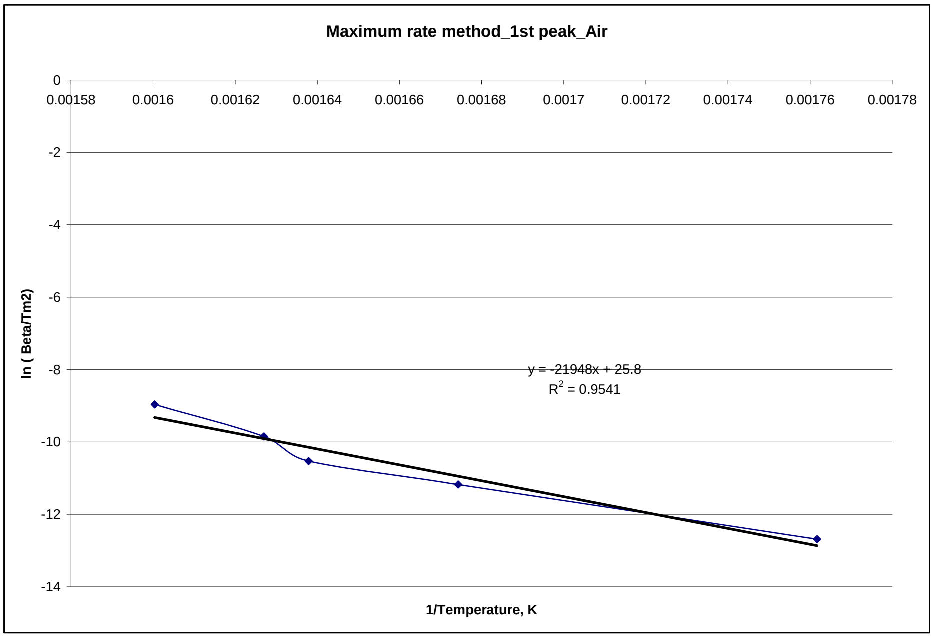
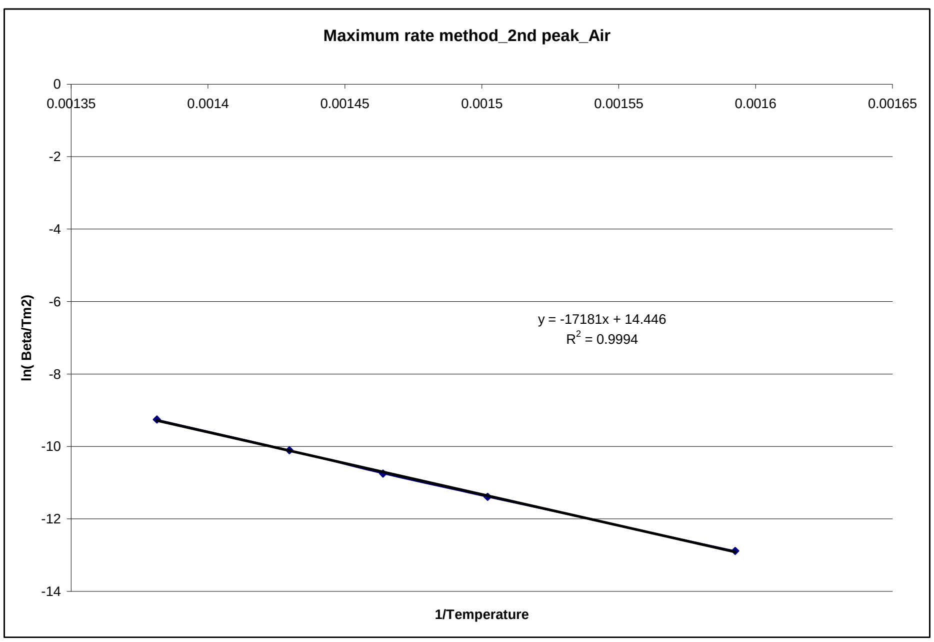


Figure B.13 – Non-isothermal_air_1st order_maximum rate method approach_2nd peak



Maximum rate method for Air			
1st peak		2nd peak	
Slop	21948	Slop	17181
intercept	25.8	intercept	14.446
R2	0.9541	R2	0.9994
Activation	**182.47567**	**Activation**	**142.842834**
A	3.517E+15	A	3.23E+10

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Core Log Key

Lithologies

- Organic-rich Shale or Carbonaceous Shale (excluding oil shale)
- Shale or Silt Mud
- Calcareous Mud
- Dolomite Mud
- Sand
- Tuff, Ash, and Zeolite Sands
- Nahcolite
- Gradational Lithology Change (e.g. coarsening upward from mud to sand)

Sedimentary Structures

- Horizontal Shale Mud Interlaminations
- Convolute Bedding
- Wavey Bedding
- Symmetrical Ripple Cross-lamination
- Ripple-topped Interbed
- Asymmetrical Ripple Cross-lamination
- Marcasite, Pyrite, or Fe-concretion
- Mud Rip-up Clast
- Nahcolite filled (or partially filled) Vug
- Sand with erosional base
- Sand Lens in Fine-grained Sediment

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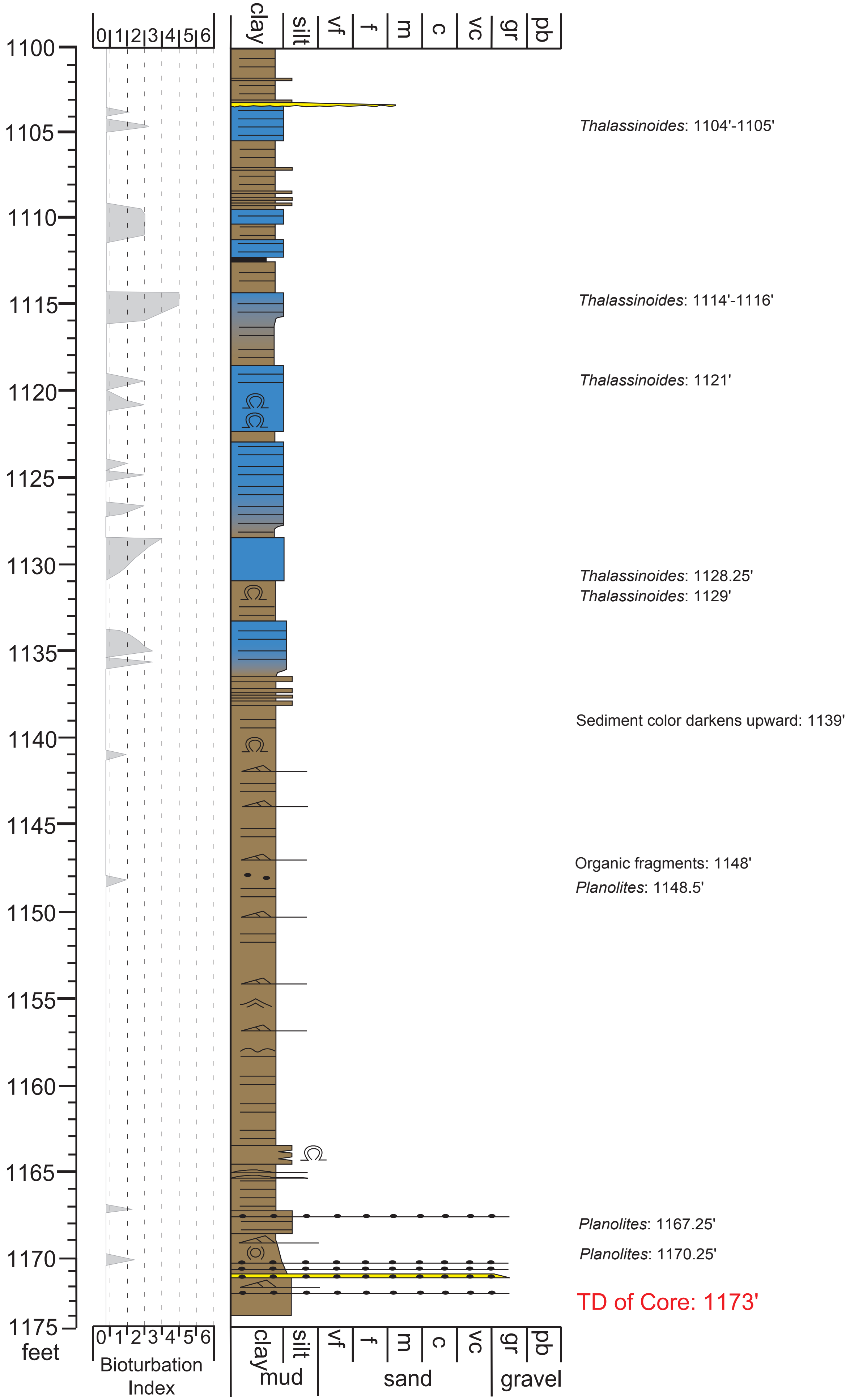

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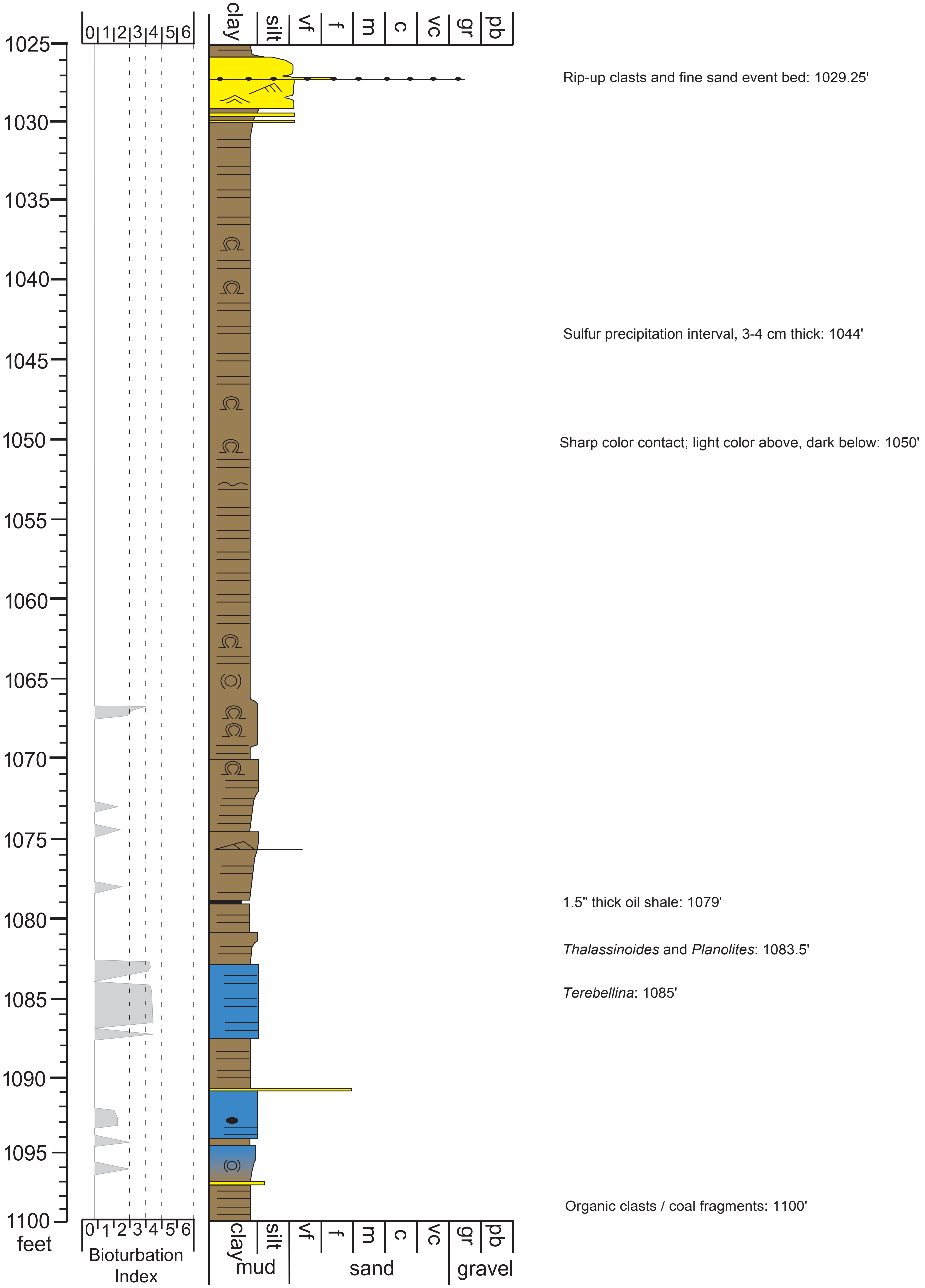

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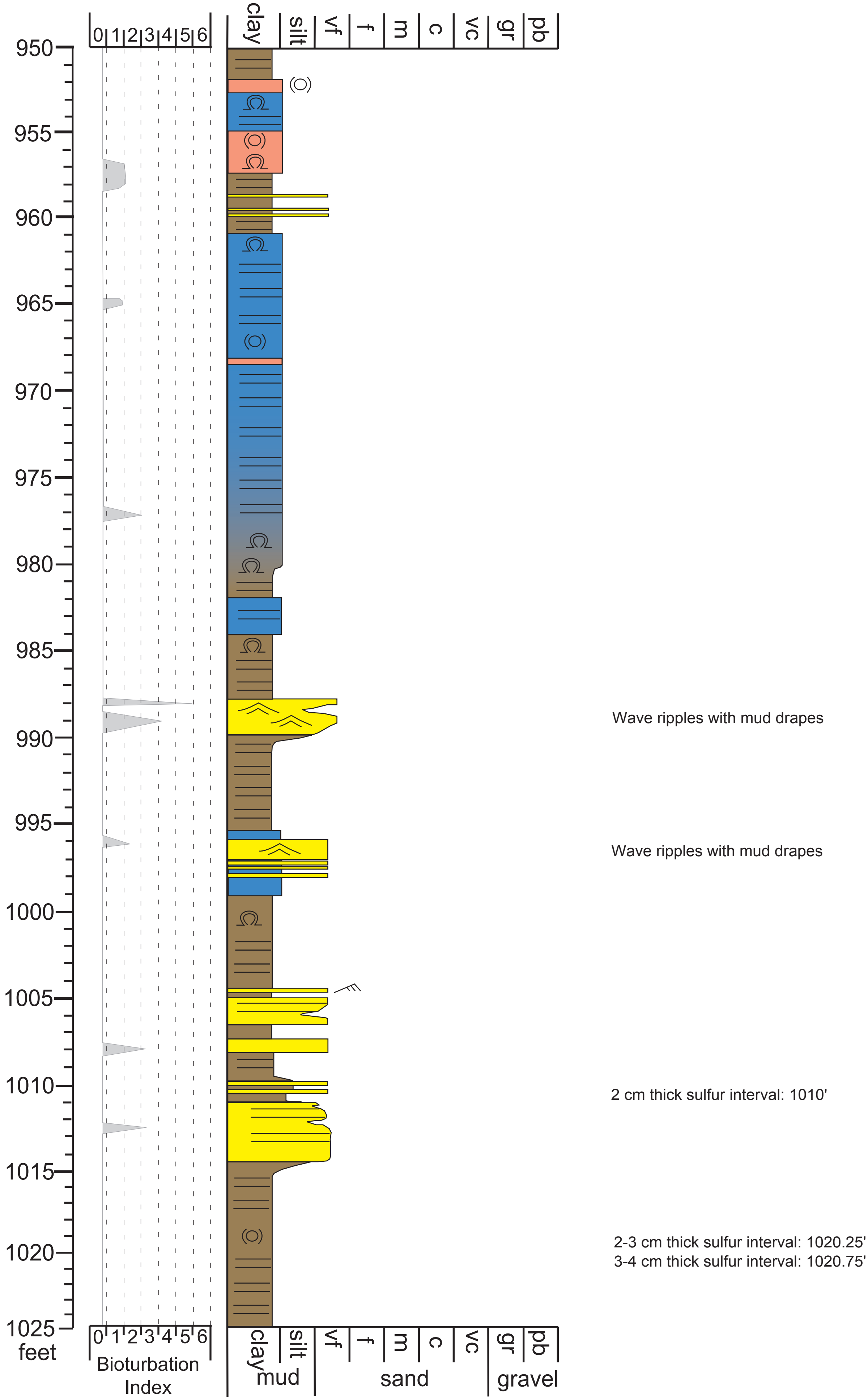

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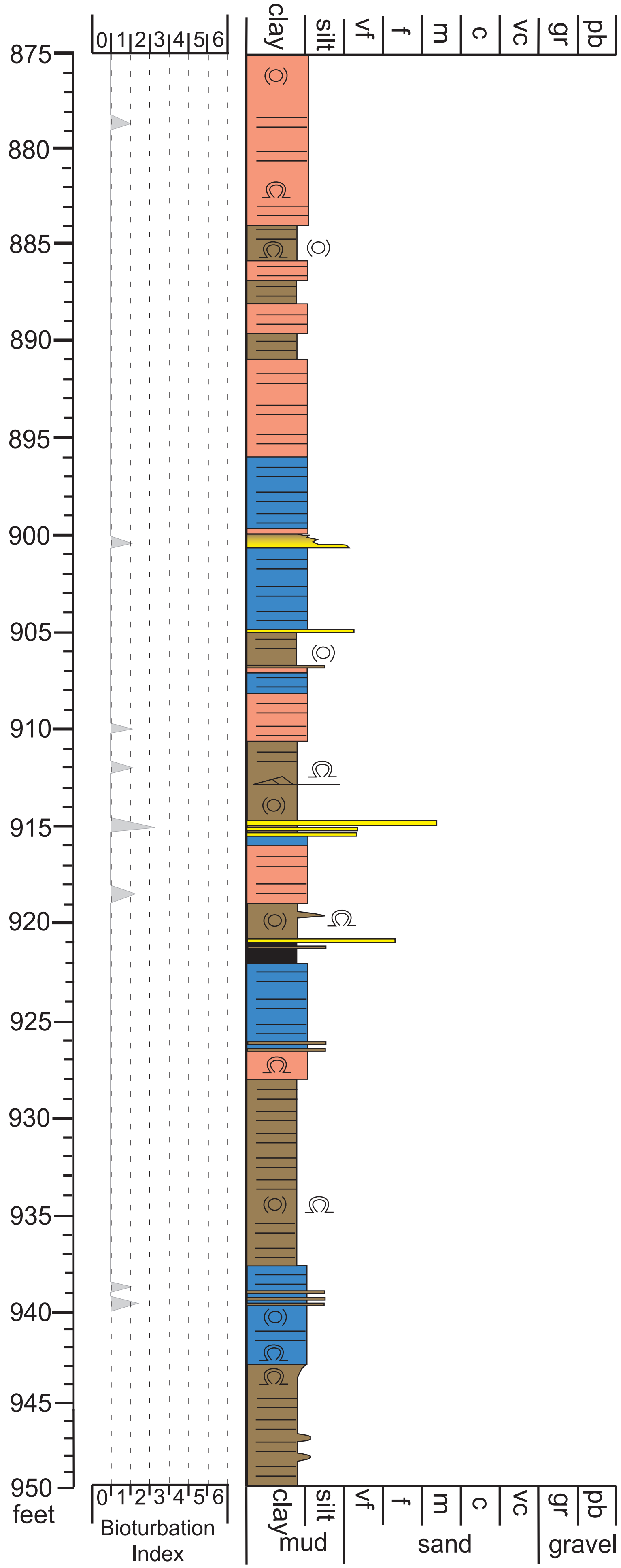

Terebellina: 914.75'-915'

Several 1-2 mm thick red colored clay laminae: 949.75' - 950'

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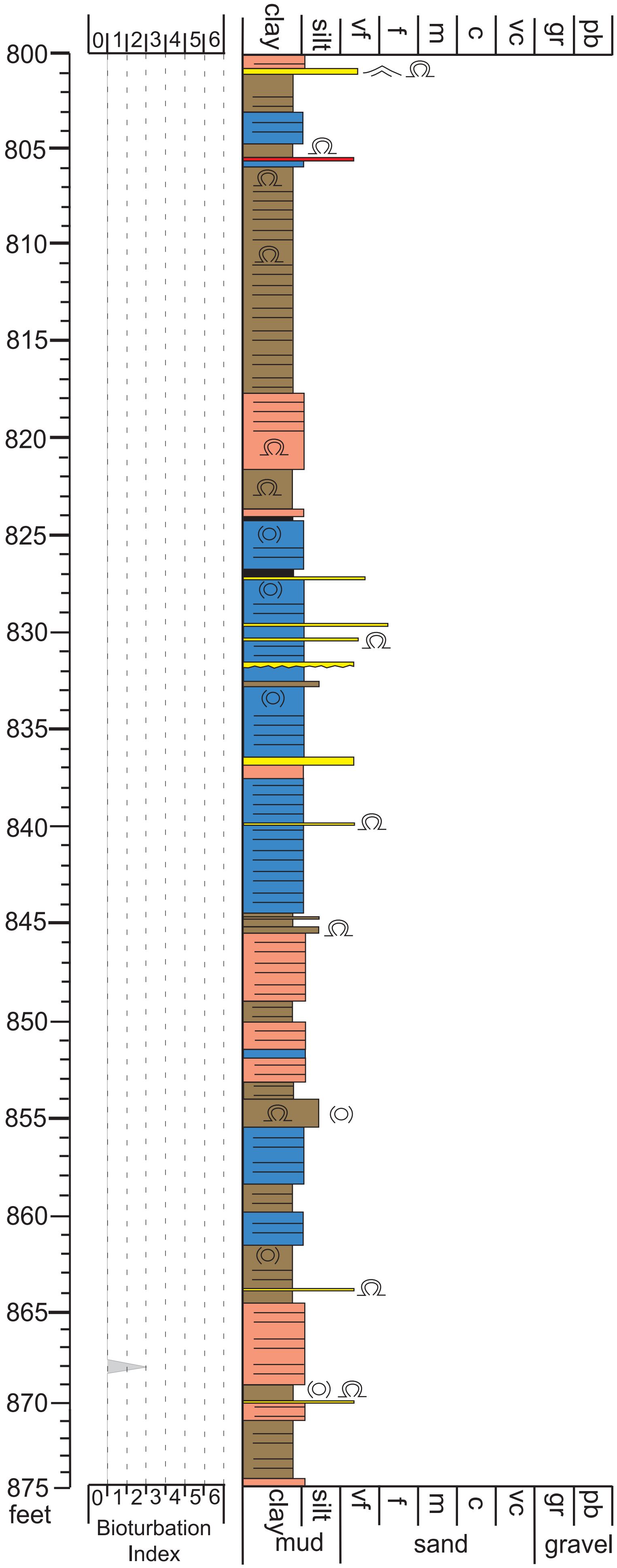

Dark, organic-rich shale interbeds in dolomitic mud: 800.25'-800.75'

Gradational color shift from biege-brown below to gray above; no apparent lithology change: 804.25'

Well-rounded, spherical zeolite sand grains: 805.5'

Sharp color change contact; lime mud dark gray above, lime mud biege-brown below; no apparent lithology change: 834.5'

Very fine sand with oily pore spaces; sulfur precipitation: 836.5'-837'

Heavily deformed, sulfur-rich, silty mudstone with pyritized contacts above and below: 854.75'-855.25'

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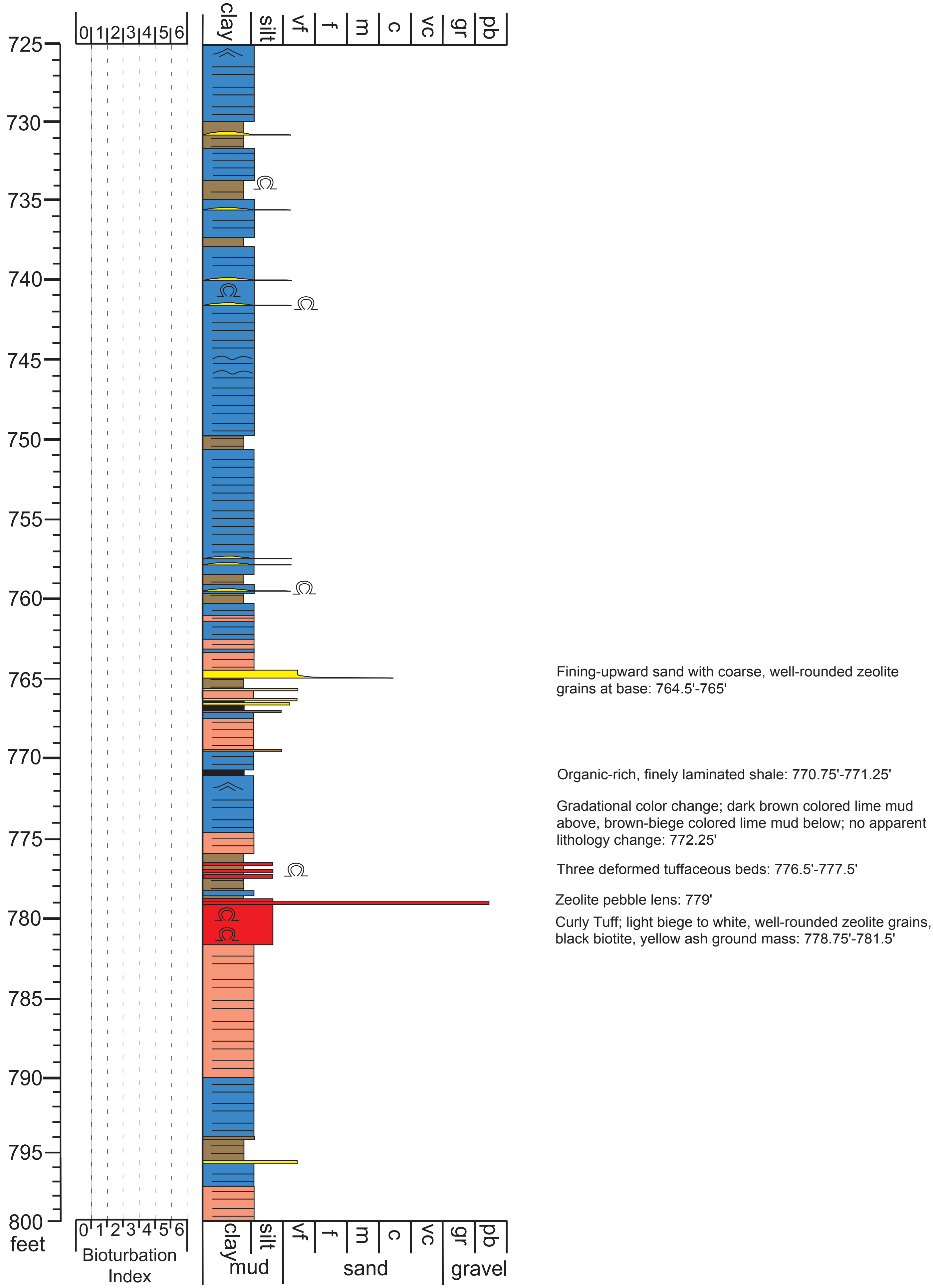

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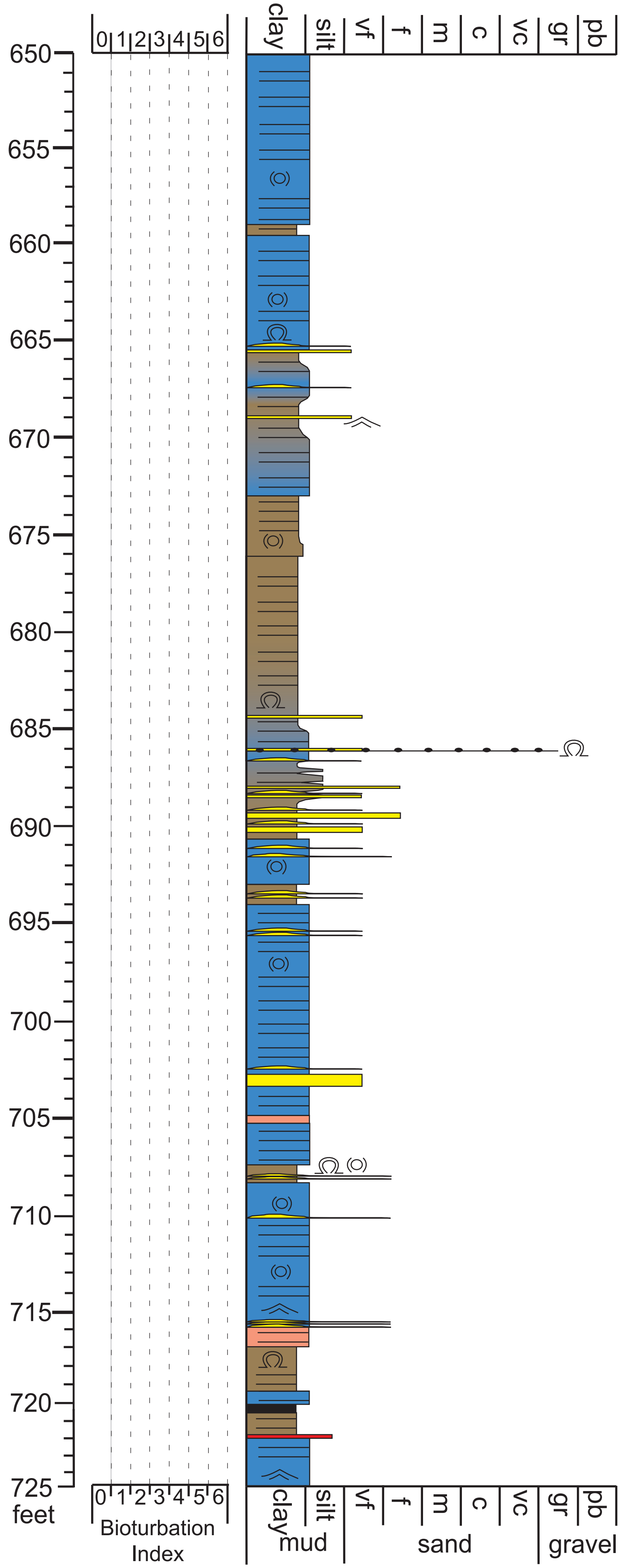

Gradational lithology shifts between carbonate mud and organic-rich shale mud: 665.5'-669.75'

Concretion of white secondary mineral precipitate

Sharp contact; shale mud below, silt mud above contact grading upward to shale mud: 676.25'

Gradational lithology shift upward from predominantly carbonate mud to predominantly shale mud:685'-685.25'

Deformed sand and granule layer, possibly tuffaceous: 686.75'

Gradational lithology shift upward from predominantly shale mud to predominantly carbonate mud:686.75'-687'

Very-fine to fine sand with tar filled pore spaces: 702.75'-703.25'

Several 5-10 mm thick, fine sand lenses; thickness of lenses decreases upward: 715.25'-715.5'

Dark brown to black, organic-rich shale mud interlaminated with biege to yellow dolomitic mud layers (3-7 mm thick): 715.5'-717'

Black, organic-rich shale: 720.25'-720.5'

3 cm thick tuffaceous bed: 721.75'

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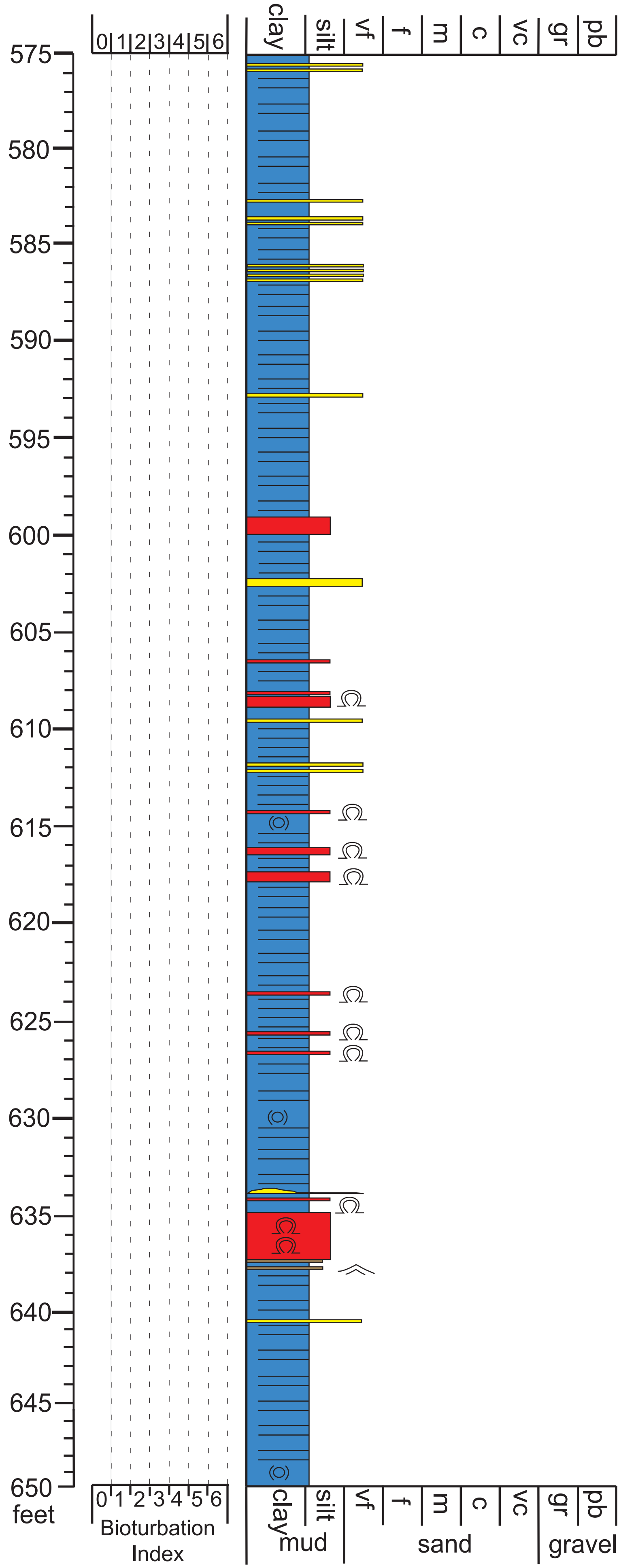

Wavey Tuff; biotite and muscovite in a yellow ash groundmass: 634.75'-637.25'

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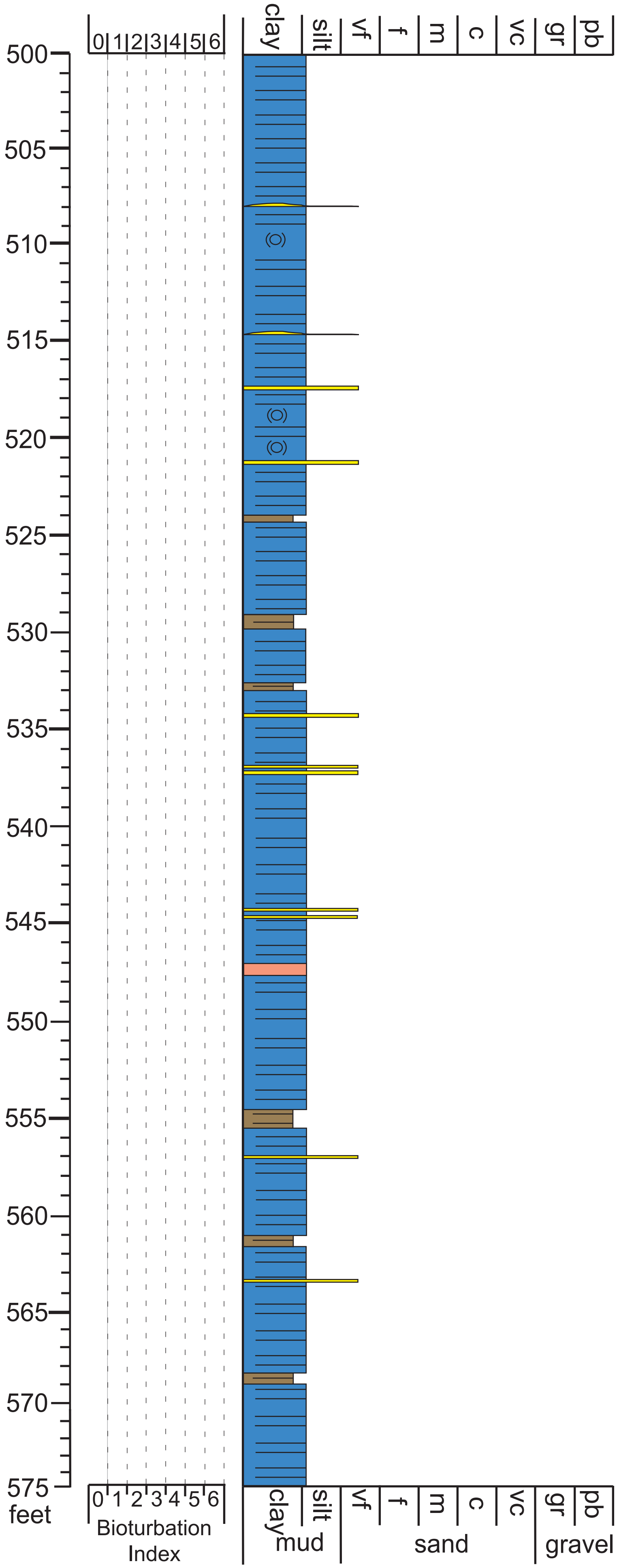

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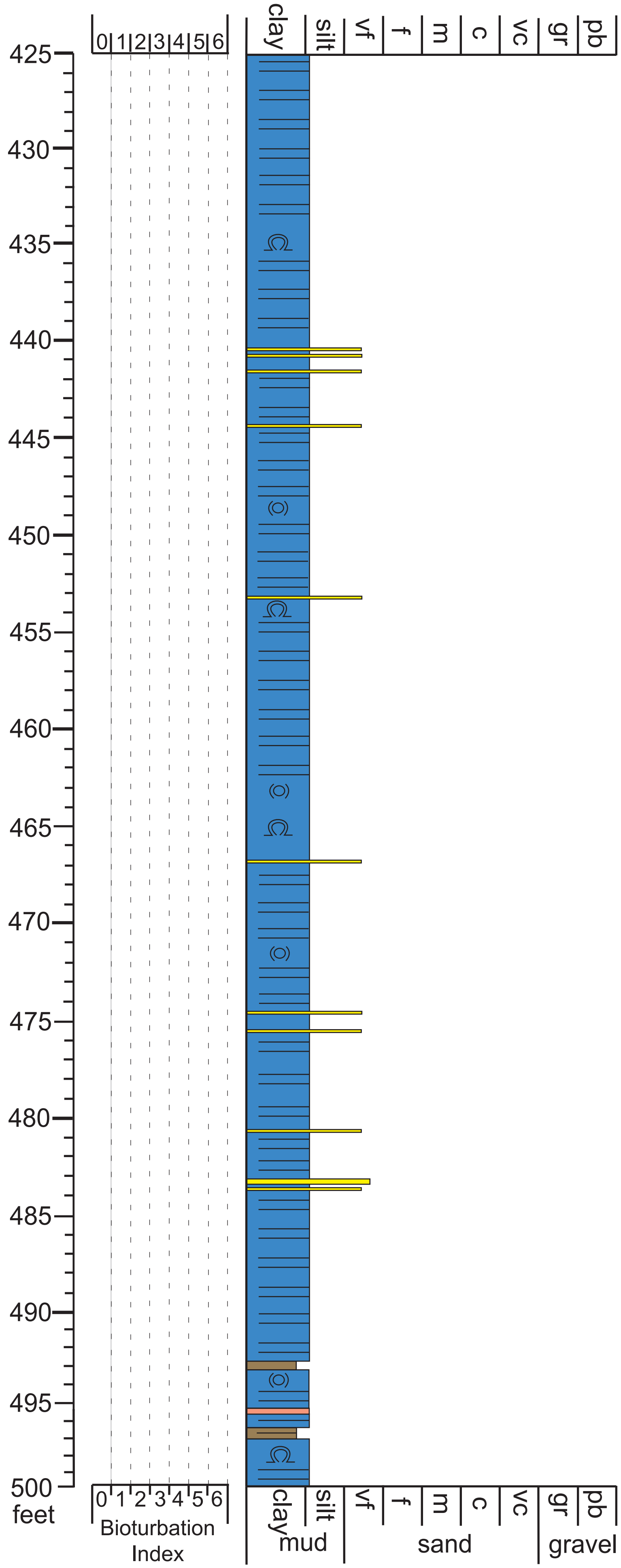

Sharp contact in sediment color change; carbonate mud is a darker shade of biege-brown above and a lighter shade of biege brown below: 477.5'

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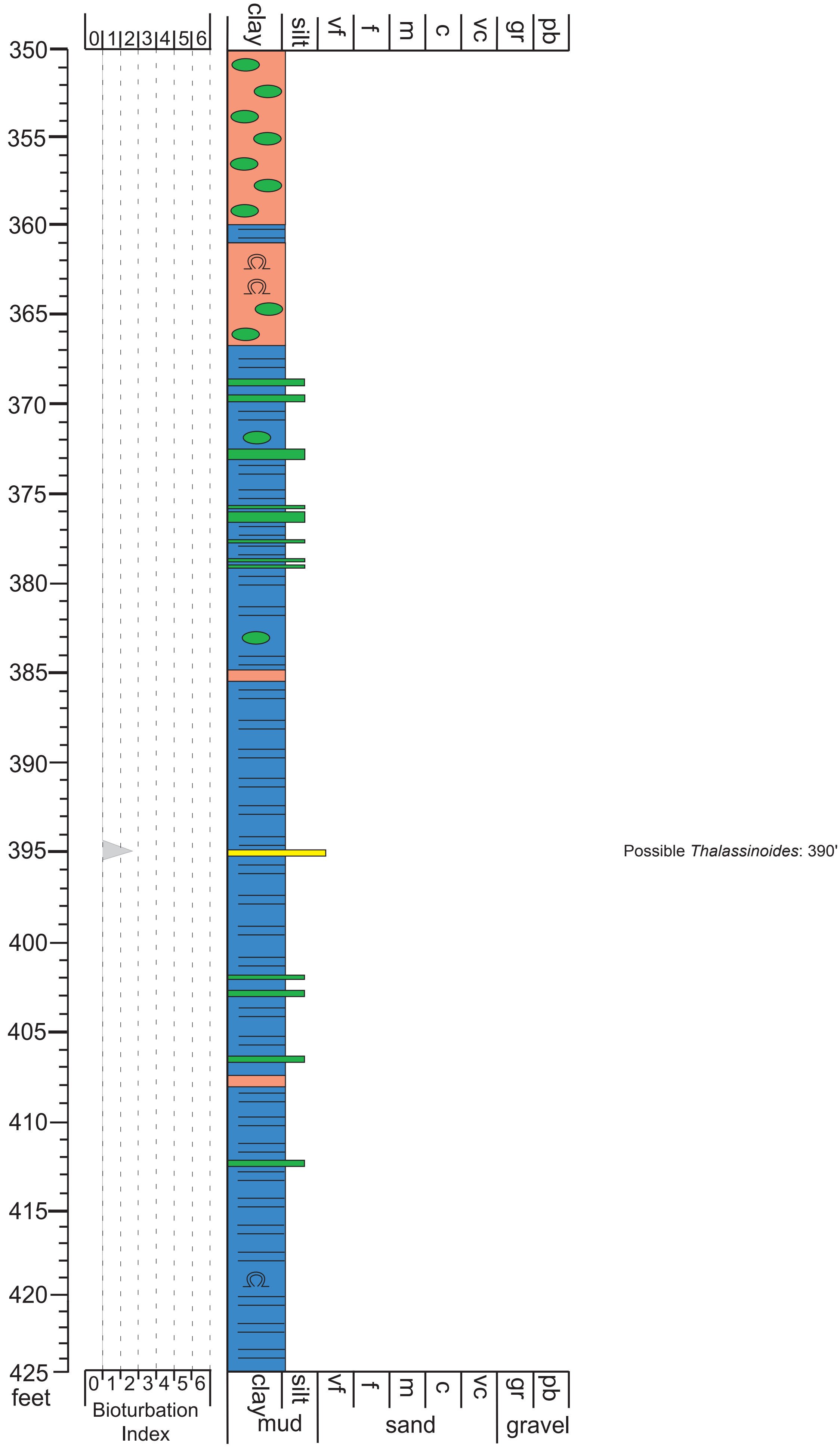

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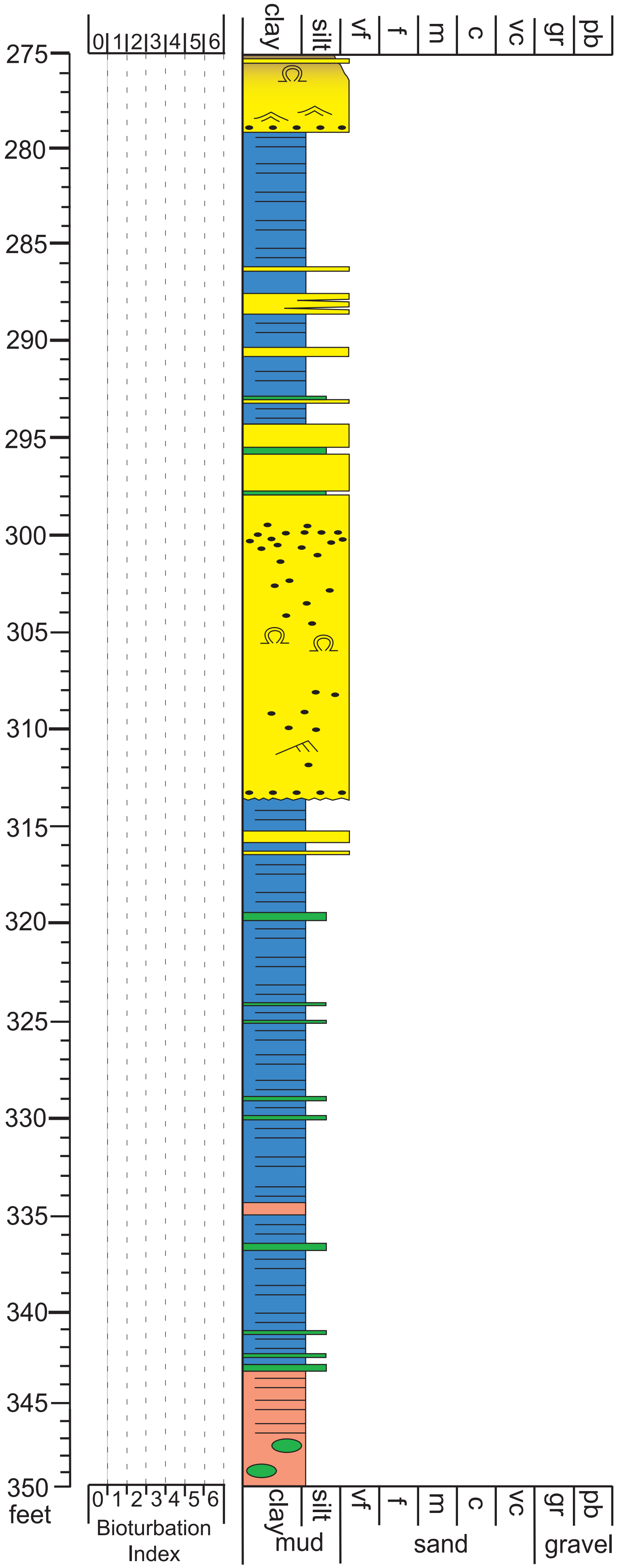

Very fine sand fining upward to silt, interlaminated with very fine sand layers: 276' -274'

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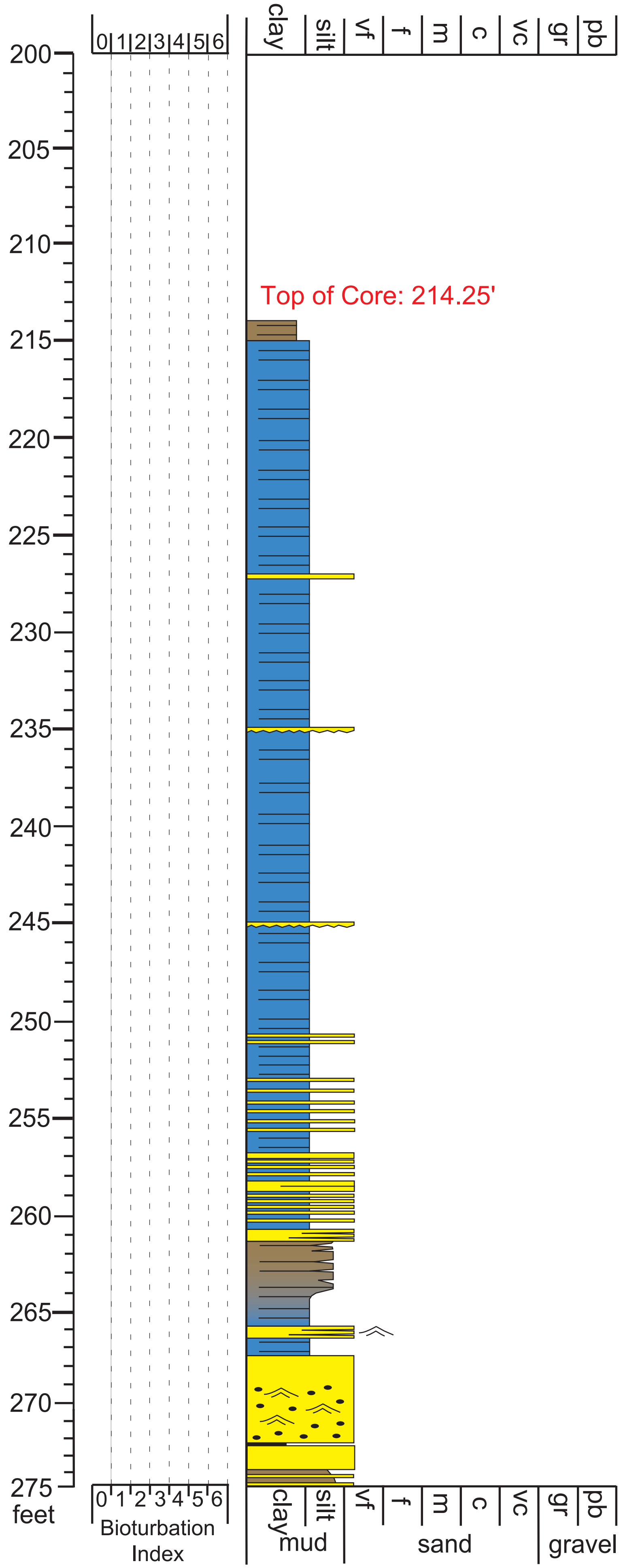

Gradational upward lithology and grain size change from carbonate mud below to silt mud above: 264'

Rippled, very fine sand with coal rip up clasts: 269'-272.5'

Carbonaceous mud / coal layer: 272.5'

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