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PYROCHROMATOGRAPHIC STUDY OF MICHIGAN ANTRIM SHALE

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Topical Report

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A B S T R A C T

Pyrochromatographic analyses were performed on samples of Antrim shale from 35 wells and nine outcrops in the Michigan Basin. Hydrocarbon components from C_5 to C_{30} were measured. The majority of the analyses indicate the Antrim to be potentially gas productive.

The total hydrocarbon count for each well was divided by the number of samples analyzed to obtain the average hydrocarbon count per sample. Hydrocarbon counts per sample generally increase with depth and toward the center of the Michigan Basin.

A bar graph for each well, showing the total hydrocarbon count for each sample, by depth, was plotted and compared with the gamma ray log. A correlation coefficient of 0.696 between increased hydrocarbon counts and increased radioactivity was calculated based on data from five wells.

D I S C U S S I O N

INTRODUCTION

This report is concerned with the pyrochromatographic analysis of residual hydrocarbons in the Antrim shale, specifically to determine what type of hydrocarbon may be produced; to investigate relationship of gamma ray logs to hydrocarbon enrichment and to determine trends of hydrocarbon content areally and stratigraphically.

Data made available for this study are summarized in Table I. Thirty five wells listed have pyrochromatographic analyses. One hundred and fourteen core samples were available from four wells and 549 cuttings samples from the remaining 31 wells. These samples were analyzed in our Mt. Pleasant, Michigan laboratories. Individual reports on each well analysis were sent to Dow Chemical U.S.A. during the course of the laboratory work. In addition, pyrochromatographic analyses were run on nine outcrop samples of Antrim shale. Well logs were available for 35 wells, including mainly radioactivity logs; with some electric and mud logs. Only the gamma ray curve was considered in this study as it was available for the majority of wells with pyrochromatographic data.

PYROCHROMATOGRAPHIC ANALYSIS

Pyrochromatography is basically the chromatographic analysis of the residual hydrocarbon components retained in drill cuttings or core chips, as discussed by M. Maness and J. G. W. Price[1]. The analyses data are used to determine the type of hydrocarbons, that can be expected to be produced from a reservoir. The concept is based on the premise that petroleum hydrocarbons that can, will escape from drill cuttings during flushing and pressure reduction associated with drilling operations, that portions of those hydrocarbons that cannot readily escape will remain in the samples, and that the concentration and carbon number distribution of these hydrocarbons can be determined by gas chromatography.

The general procedure is as follows: samples are washed free of drilling mud and marked by drill depth at the wellsite; at the laboratory samples are crushed, washed, screened for uniformity and then dried at room temperature. A specific volume of sample is measured and put into a test vessel which is placed into a low, dead volume pyrolysis unit which is coupled to a gas chromatograph. The hydrocarbons in the samples are swept by chromatographic carrier gas into the gas chromatograph column to separate hydrocarbons into the various components. The areas of peaks produced by material eluted from the gas chromatograph are calculated by an electronic computing integrator and expressed in units of microvolt seconds, referred to in this report as hydrocarbon counts. Hydrocarbons are detected and grouped by carbon number from C_5 to C_{30}, or the last measurable carbon number. The percent hydrocarbon component with respect to total hydrocarbon count is computed. The results of the analysis yield total and normal hydrocarbon count. Economic type hydrocarbons are not confined to the normal or straight chained hydrocarbons, therefore, this report deals only with the total hydrocarbon counts. Measured data are plotted on bar graphs showing the total hydrocarbon count expressed in units of microvolt seconds (MVS) for each sampled increment. Bar graphs from each well sampled and of the nine surface samples are included in the Appendix to this report. Data are then plotted as cumulative percent of each hydrocarbon component and can be used to determine the type of hydrocarbon, oil or gas, which may be produced and to predict the permeability of the formation. Fig. 1 illustrates the ideal cumulative percent curves for non-productive, oil-productive, and gas-productive formations. Analysis of a non-productive formation ideally yields a low total hydrocarbon count, a high concentration of light components, C_5 to C_{10}, illustrated by the steep slope of the curve in that interval and an abbreviated range of hydrocarbon components indicating productive type hydrocarbons were not originally present in the formation. Analysis of a gas-productive formation results in a higher total hydrocarbon count, and a steep curve slope over the intermediate range of hydrocarbons indicating a high concentration of C_{10} to C_{18} components. The curve resulting from analysis of an oil-productive formation exhibits a high concentration of intermediate com-

ponents, a low concentration of light components with a relatively high concentration of heavy components, C_{18+}, and the analysis yields a high total hydrocarbon count.

The cumulative percent curves may also be used to infer permeability. Low permeability may be indicated by a high concentration of light components along with a wide range of components. Light components would be the most likely to escape; therefore, their presence in the residual hydrocarbons indicates a "tight" formation. Good formation permeability may be indicated by a high total hydrocarbon count accompanied by a high concentration of heavy components, and a low concentration of intermediate and light componenets.

A cumulative percent curve representative of the Antrim Shale is shown on Fig. 2 from the Mi 27 well. The total hydrocarbon count is high, 48.8 million counts, and the high concentration of light to intermediate components is exhibited by the steep slope in the range from C_6 to C_{16}. The relatively high concentration of the lighter components indicates low formation permeability. The distribution of components illustrates characteristics of a gas-productive formation. This well is located approximately five miles from Amoco Production Co. No. 1-28 Swift (Mi 28) which is gas productive in the Antrim shale. The analysis of cuttings from Mi 28 results in a similar curve as illustrated on Fig. 3; however, this curve exhibits a steep slope in the range from C_9 to C_{16}. This slight decrease in the light component fraction may be indicative of slightly greater permeability in Mi 28 than in Mi 27. The majority of the pyrochromatographic analyses indicates the Antrim to be gas productive.

GEOLOGY

The Antrim Shale has been noted for its rich organic content. The bituminous nature of the Antrim shale was reported by C. C. Douglass[2] in 1841. A. C. Lane[3] assigned the name Antrim to the black bituminous shale and first discussed it in the Geological Survey of Michigan, Annual Report for 1908. The most accepted description of the Antrim shale is by G. V. Cohee, et al[4]: "Dark gray to black,

hard, thin bedded brittle carboniferous shale interbedded with some gray shale in the lower part. Dark brown bituminous limestone concentrations ranging 2 to 5 ft in diameter are common near the base."

G. D. Ells[5] conducted a study of the stratigraphic relationship of the Antrim shale over the Michigan Basin on the basis of gamma ray log correlations. He has subdivided the Antrim into units apparently related to lithological variations. The units in a specified area of the basin exhibit gamma ray log signatures which can be traced over a vast area throughout the Michigan Basin. The subdivisions of the Antrim shale are illustrated on Fig. 4, a stratigraphic section, taken from Ells' report. The Antrim shale exhibits a highly radioactive character. In some wells the highly radioactive zone corresponds with the entire Antrim interval but in others the highly radioactive zone occurs only in the lower portion of the Antrim. This highly radioactive zone is represented by the zone in which the gamma ray response increases significantly from the overlying shale. In most cases the average gamma ray reading for the highly radioactive zone is at least 45 percent greater than the average gamma ray reading for the overlying shale. The Antrim shale overlies the Traverse Group and is exposed in the northern and southeastern parts of the basin. The maximum thickness is located along a north-south trending axis through the center of the basin, thinning abruptly to the west where the Antrim shale grades laterally into Ellsworth shale. Thinning is gradual to the south and east.

INTERPRETATIONS

The results of the pyrochromatographic analyses yield a total hydrocarbon count for each sample given in 1000 counts. The electronic computing integrator calculates arbitrary units of area from the chromatographic plots and expresses the results in microvolt seconds (MVS) which are referred to as counts. Only the highly radioactive zone within the Antrim shale was considered. A tabulation of the geological and sampling data by well, Table I I, lists the percentage of the highly radioactive zone in the total Antrim thickness. The log depths of the top and base of the zone for each sampled well, or near-

by well, and the sampled depths of the top and base of the zone for each well are listed. The sampled wells with a log available from a nearby well are designated by an asterisk. The difference in log depths from a nearby well and the sample depths from the sampled well is probably due to the difference in locations. Also listed is the percentage of the highly radioactive zone which was sampled in each well, and the total hydrocarbon count of the samples within the highly radioactive zone. The total hydrocarbon count for each well was divided by the number of samples within the zone of each well to obtain an average hydrocarbon count per sample. For ease in mapping, these values were divided by 1000 before posting to the maps. The values listed in Table II, are in millions of counts per sample.

Analyses of nine outcrop samples are included in the mapping. They generally conform to trends established by the subsurface samples. Discrepancies are due to the various states of weathering and their unknown stratigraphic position. In any case, they neither confirm nor contradict any trend derived from the mapping of the subsurface samples.

Hydrocarbon counts for the highly radioactive zone were mapped and are presented on Fig. 5. Twenty-nine wells having greater than 80 percent of the interval sampled are shown with slanted datum values; six wells having less than 80 percent sampling are designated by underlined upright numerals. All values were believed to be representative of the highly radioactive zone and were used in mapping. The greater values of hydrocarbon counts are generally located near the central deeper part of the Michigan Basin.

LOG ANALYSIS

Gamma ray logs were available for 35 wells as listed in Table I. The logs were correlated following Ells' subdivision. Bar graphs of the total hydrocarbon for each sample were plotted on a depth scale equivalent to the corresponding log depths. Visual comparison of the gamma ray log and the bar graph indicates an increase in hydrocarbon per sample with increased radioactivity. A section of gamma ray log from the Mi 27 well in Otsego County, Michigan, approximately 5 miles south

of the producing Antrim Gas Pool A is shown on Fig. 6. The units of the Antrim shale are shown numbered on the left edge of the log. Total hydrocarbon in millions of counts for each sample is plotted on the bar graph. Visual comparison illustrates a good correlation between gamma ray log response and the total hydrocarbon count per sample. The Mi 27 well is representative of all the wells studied in this project; all exhibit an increase in hydrocarbon count with increased gamma ray log radioactivity.

A correlation of gamma ray counts, API units, versus total hydrocarbon counts was made and presented on Fig. 7. Five wells with standard calibrated gamma ray logs and a full suite of cuttings samples through the highly radioactive interval were used in developing the correlation. The correlation coefficient for these data calculated 0.696, which is considered a good correlation considering the inherent uncertainty in lag time and in depth adjusting the cutting samples to the logs. Data points used in the correlation were arithmetic average values for each unit of Antrim shale based on Ells' subdivisions.

PRODUCTION

The Michigan Department of Natural Resources reports Antrim gas production from three fields in the Michigan Basin. Antrim Gas Pool A in Otsego County which has a total of nine wells, three of which are active and produced 789,034 Mcf gas through January of 1979. Production from Chester Field totaled 1,078,411 Mcf gas through January of 1979 from 16 active wells. Approximately 8 MMcf of gas was produced from two wells in the Algonac Field, St. Clair County, but were abandoned in 1951. Shows of gas from the Antrim shale were also reported from three areas of the Michigan Basin but no production was reported. These areas are Dover and Otsego Lake in Otsego County and Mayfield in Grand Traverse County. Gas wells and gas shows reported from the Antrim shale, are shown on Fig. 8. Two Antrim gas wells in Jackson County and shows of gas along the southern and northern flanks of the basin were reported by Cohee et al and are also indicated on Fig. 8. Comparison of this map and the total hydrocarbon map, Fig. 5, shows

that production is found in areas with hydrocarbon values as low as 30 to 50 million units. It can be concluded, therefore, that essentially all of the Michigan Basin is potentially hydrocarbon productive in the Antrim shale.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The Antrim shale is generally divisable into an upper low radioactive zone and a lower highly radioactive zone.

The highly radioactive zone contains high concentrations of hydrocarbons measured by pyrochromatographic techniques.

There is a good correlation between gamma ray log API counts and total hydrocarbons measured pyrochromatographically.

The hydrocarbon concentration generally increases with depth and is generally conformable to the structure and thickness of the Michigan Basin. Essentially all the Michigan Basin has hydrocarbon potential in the Antrim shale.

RECOMMENDATIONS

Additional samples of cuttings or cores be analyzed using pyrochromatography in recently drilled wells that also have modern gamma ray logs.

Detailed reservoir engineering studies of producing Antrim fields be made to determine recovery and deliverability characteristics of the reservoir.

Pyrochromatography should be run on currently producing wells completed in the Antrim shale.

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4. Cohee, G.V., Macha, Carol, and Holk, Margery: "Thickness and Lithology of Upper Devonian and Carboniferous Rocks in Michigan," U. S. Geol. Surv., Oil and Gas Inv. Ser., Chart OC-41 (1951).

5. Ells, Garland D.: "Stratigraphic Cross Sections Extending from Devonian Antrim Shale to Mississippian Sunbury Shale in the Michigan Basin," Report of Investigation 22, Geological Survey Division, Michigan Department Natural Resources (1979).

TABLE I

DATA AVAILABILITY
ANTRIM SHALE

Michigan Basin
Michigan

Well Identification		Drill Cuttings No. Samples Analyzed	Drill Cuttings Depth Increment ft	Core Chips No. Samples Analyzed	Core Chips Depth Increment ft	Gamma Ray Log	Gross Thickness Antrim Shale ft
Mi 1	Dow Chem. Co/ ERDA No. 100	-	-	22	1	X	224
Mi 2	Dow Chem. Co/ ERDA No. 101		-	21	10	X	214
Mi 3	Dow Chem. Co/ ERDA No. 102			18	10	X	216
Mi 4	Consumers Power Co. No. 1 Marsh	45	10	-	-	X	436
Mi 5	Mich. Consolid. Gas CC 770	19	10	-	-	X	176
Mi 6	E. E. Brehm No. 1-36 Cosens	25	10	-	-	X	249
Mi 7	Merrill Drill. Co. No. 2-5 L. Bazaire	16	10	-	-	X	555
Mi 8	Dow/ERDA - Dow No. 105	18	10	-	-	X	160+
Mi 9	Kulka & Schmidt No. 1-7 Round-Jones	8	10	-	-	X	277
Mi 10	Reef Pet. Corp. No. 4-1 Smitha	15	10	-	-	X	151
Mi 11	Elek-Bartlett No. 1 Schrade	35	9-10	-	-	X*	331*

• Estimate based on thickness from nearby well.

X* Log of nearby well.

DATA AVAILABILITY - ANTRIM SHALE (Cont'd.)

Well Identification	Drill Cuttings No. Samples Analyzed	Drill Cuttings Depth Increment ft	Core Chips No. Samples Analyzed	Core Chips Depth Increment ft	Gamma Ray Log	Gross Thickness Antrim Shale ft
Mi 12 Marathon Oil No. K-6 Baumchen	15	10	-	-	X	416
Mi 13 Hunt Energy Corp. No. 1-3 Wild	14	10	-	-	X	402
Mi 14 Amoco. Prod. Co. No. 1-28 Patrick	20	10	-	-	X	198
Mi 15 Hunt Energy Corp. No. 1-26 Weber	13	10	-	-	X	172
Mi 16 Amoco Prod. Co. No. 3-24 Fawcett	18	10	-	-	X	590
Mi 17 Amoco Prod. Co. No. 1-2 Tompkins	16	10	-	-	X	150
Mi 18 D. Scott Drill. Co. No. 1-12 Collier	21	10	-	-	X	220
Mi 19 Kulka & Schmidt No. 1-21 Guldemond	10	10	-	-	X	92
Mi 20 Crystal Explor. Co. No. 1 Ulrich	20	10	-	-	X*	210*
Mi 21 Aztec Prod. Co. No. 3-2 State Manistee Unit	16	10	-	-	X	160
Mi 22 A.T.E. Dart-Wiser No. 1-9 Broderick	33	10	-	-	X	330
Mi 23 Dart Oil & Gas No. 1-7 Bruggers-Lawrence	21	10	-	-	X	206

* Estimate based on thickness from nearby well.

X* Log of nearby well.

DATA AVAILABILITY - ANTRIM SHALE (Cont'd.)

Well Identification	Drill Cuttings No. Samples Analyzed	Drill Cuttings Depth Increment ft	Core Chips No. Samples Analyzed	Core Chips Depth Increment ft	Gamma Ray Log	Gross Thickness Antrim Shale ft
Mi 24 Reef Pet. Corp. No. 1-1 Wussow	14	10	-	-	X	134
Mi 25 Richard Beeson No. 1-17 Turner	16	10	-	-	X	580
Mi 26 Nor. Mich. Expl. Co. No. 3-21 State Blair	13	10	-	-	X	130
Mi 27 M. Welch et al No. 1-15 State Otsego Lake	26	5	-	-	X	500+
Mi 28 Amoco Prod. Co. No. 1-28 Swift			53	2-3	X	444
Mi 29 Dow No. 3-21 XII Moore	11	10	-	-	X	108
Mi 30 Mich. Nat. Resc. No. 1-2 Staudacher-Shaw	11	10	-	-	X	312
Mi 31 Dart Oil & Gas No. 1-22 Leon Hemming et. al.	9	10	-	-	X	190
Mi 32 M. Welch et. al. No. 1-16 State Otsego Lake	17	10	-	-	X	500
Mi 33 M. Welch et. al. No. 1-22 State Otsego Lake	11	10	-	-	X	458+
Mi 34 Sun Oil Co. No. 15-35 St. Helen	17	10	-	-	X	444
Mi 35 V.E. East No. 1 Woods	7	10	-	-	X*	70*

• Estimate based on thickness from nearby well.

X* Log of nearby well.

TABLE II

GEOLOGIC AND SAMPLING DATA
HIGHLY RADIOACTIVE ZONE
ANTRIM SHALE

Michigan Basin
Michigan

Well Identification	Log Depth Top ft	Log Depth Base ft	Sampled Depth Top ft	Sampled Depth Base ft	Thickness ft	Percent of Total Antrim	Percent Sampling of Zone	Total HC Count M Counts	Average HC MM Counts/Sample
Mi 1	1208	1432	1212	1434	224	100	100	1,315,636	59.8
Mi 2	1198	1412	1200	1410	214	100	100	940,885	44.8
Mi 3	1204	1420	1245	1415	216	100	79	925,365	51.4
Mi 4	2580	3016	2590	3010	436	100	100	3,140,057	69.8
Mi 5	1188	1364	1190	1380	176	100	100	825,563	43.5
Mi 6	1763	2012	1770	2020	249	100	100	1,502,226	57.8
Mi 7	3221	3375	3210	3370	154	28	100	1,618,677	101.2
Mi 8	1190	NP	1200	1380	160+	100	100	1,009,939	56.1
Mi 9	2002	2128	1860	2070	126	45	63	423,150	52.9
Mi 10	825	976	840	990	151	100	100	655,604	43.7
Mi 11*	710	1041	845	1190	331	100	100	1,557,456	44.5
Mi 12	1574	1734	1570	1720	160	37	100	690,446	46.0
Mi 13	2974	3150	2960	3100	176	44	80	1,464,786	104.6
Mi 14	1482	1680	1490	1690	198	100	100	1,861,602	93.1

* Available log from nearby well.

NP Not penetrated.

GEOLOGIC AND SAMPLING DATA - HIGHLY RADIOACTIVE ZONE (Cont'd.)

Well Identification	Log Depth Top ft	Log Depth Base ft	Sampled Depth Top ft	Sampled Depth Base ft	Thickness ft	Percent of Total Antrim	Percent Sampling of Zone	Total HC Count M Counts	Average HC MM Counts/Sample
Mi 15	1028	1200	1070	1200	172	100	76	1,157,084	89.0
Mi 16	1787	1952	1780	1960	165	28	100	1,149,917	63.9
Mi 17	1570	1720	1570	1730	150	100	100	1,651,242	103.2
Mi 18	1545	1765	1550	1760	220	100	100	1,044,164	49.7
Mi 19	1205	1297	1210	1300	92	100	100	562,623	56.3
Mi 20*	1830	2040	1770	1970	210	100	100	1,895,332	94.8
Mi 21	750	910	750	910	160	100	100	1,052,432	65.8
Mi 22	1815	2145	1820	2150	330	100	100	2,705,458	81.9
Mi 23	2612	2818	2620	2830	206	100	100	2,075,560	98.9
Mi 24	1068	1202	1070	1210	134	100	100	868,109	62.0
Mi 25	3014	3164	3010	3170	150	26	100	979,546	61.2
Mi 26	1270	1400	1270	1400	130	100	100	806,395	62.0
Mi 27	1493	NP	1495	1625	167+	33	78+	1,269,846	48.8
Mi 28	1411	1564	1409	1565	153	34	100	1,723,002	32.5
Mi 29	122	230	122	231	108	100	100	489,419	44.5
Mi 30	1890	2010	1890	2000	120	38	100	878,569	79.9

* Available log from nearby well.

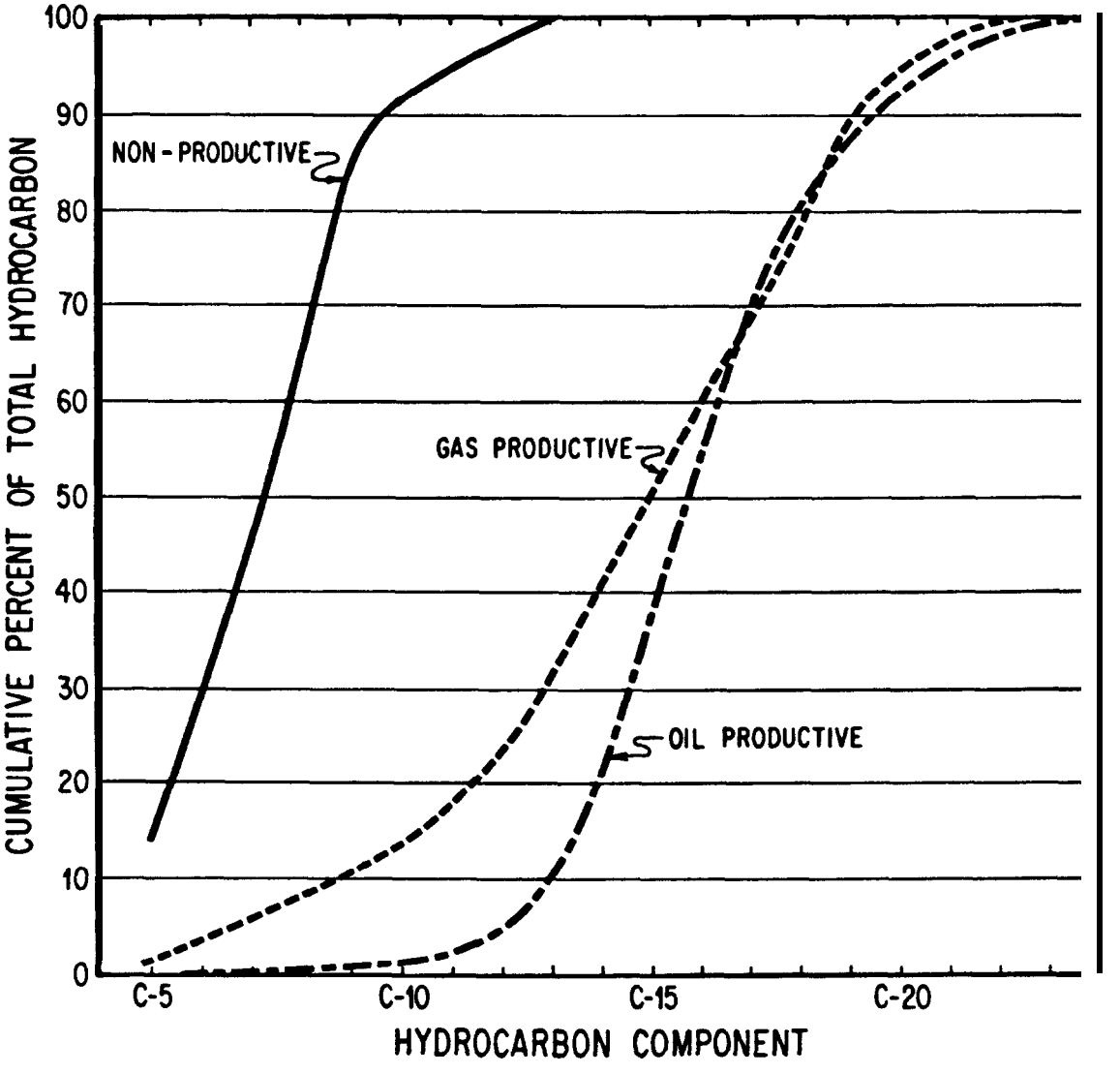
NP Not penetrated.

GEOLOGIC AND SAMPLING DATA - HIGHLY RADIOACTIVE ZONE (Cont'd.)

Well Identification	Log Depth Top ft	Log Depth Base ft	Sampled Depth Top ft	Sampled Depth Base ft	Thickness ft	Percent of Total Antrim	Percent Sampling of Zone	Total HC Count M Counts	Average HC MM Counts/Sample
Mi 31	2970	3160	2970	3070	190	100	56	647,402	71.9
Mi 32	1493	1650	1485	1645	157	31	100	768,887	45.2
Mi 33	1477	NP	1475	1575	155+	32	65	423,750	38.5
Mi 34	1940	2110	1940	2110	170	38	100	1,021,700	60.1
Mi 35*	595	665	610	680	70	100	100	408,527	58.4
OUTCROP SAMPLES									
SUR 1	-	-	-	-	-	-	-	17,745	17.7
SUR 2	-	-	-	-	-	-	-	11,152	11.2
SUR 2A (Re-run of SUR 2)	-	-	-	-	-	-	-	11,175	11.2
SUR 3	-	-	-	-	-	-	-	14,705	14.7
SUR 4	-	-	-	-	-	-	-	17,462	17.5
SUR 5	-	-	-	-	-	-	-	2,352	2.4
SUR 6	-	-	-	-	-	-	-	24,005	24.0
SUR 7	-	-	-	-	-	-	-	22,313	22.3
SUR 8	-	-	-	-	-	-	-	22,796	22.8
SUR 9	-	-	-	-	-	-	-	14,272	14.3

* Available log from nearby well.

NP Not penetrated.



DEALIZED CUMULATIVE FREQUENCY OF HYDROCARBON COMPONENTS

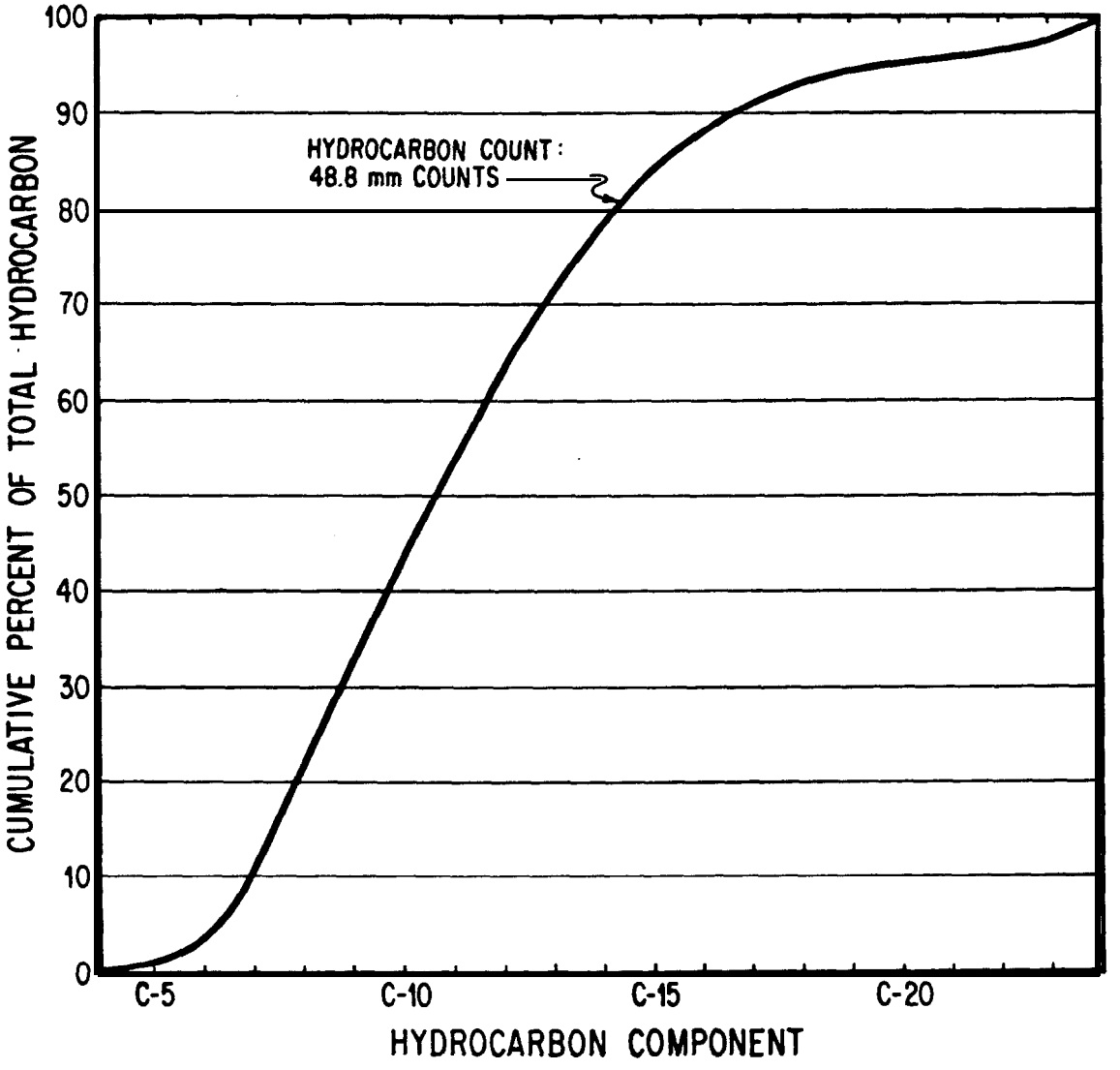
ANTRIM SHALE

MICHIGAN BASIN

MICHIGAN

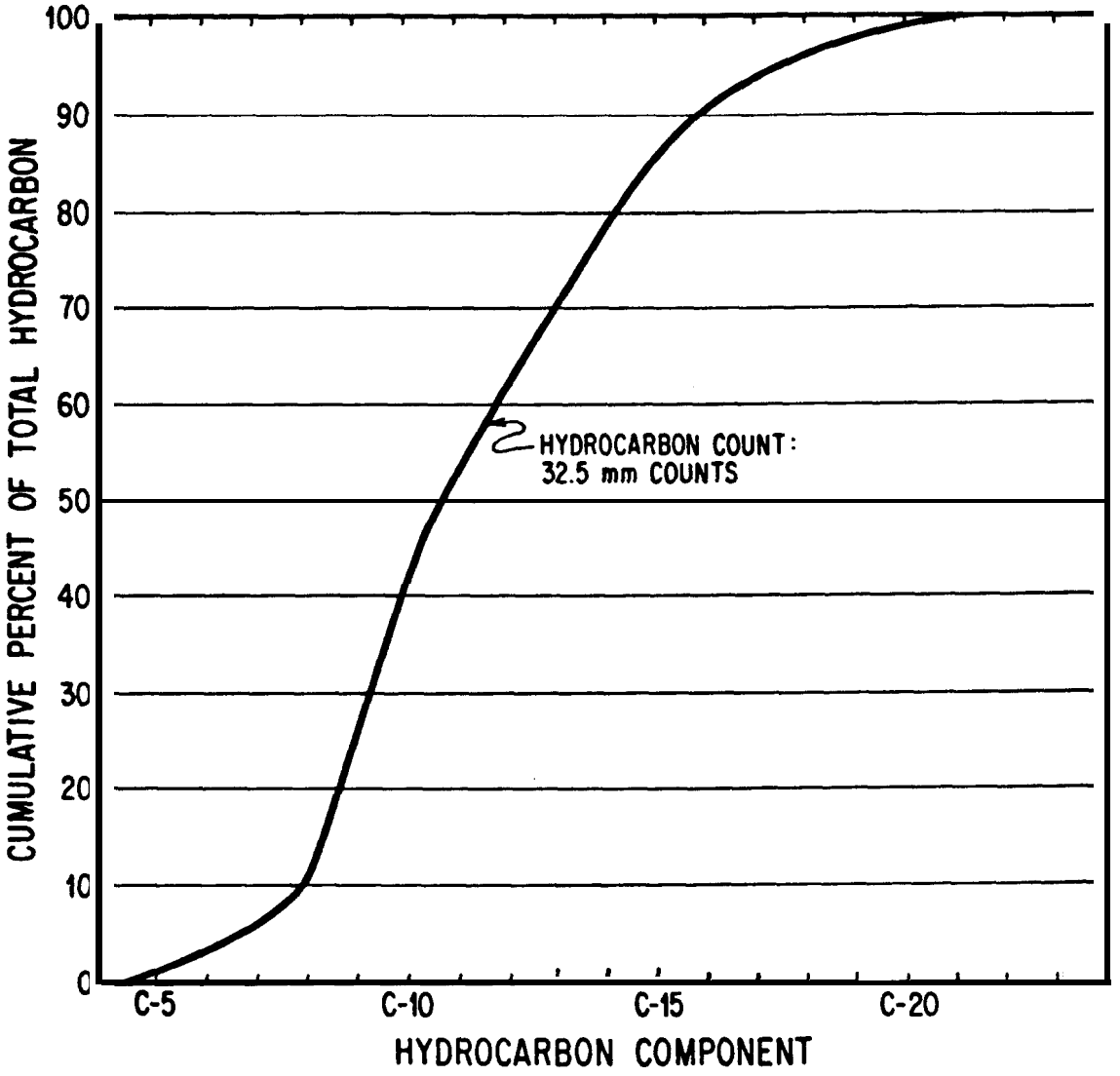
CORE *LABORATORIES, INC.*
ENGINEERING & CONSUL*TING DEPT.*

FIGURE 1



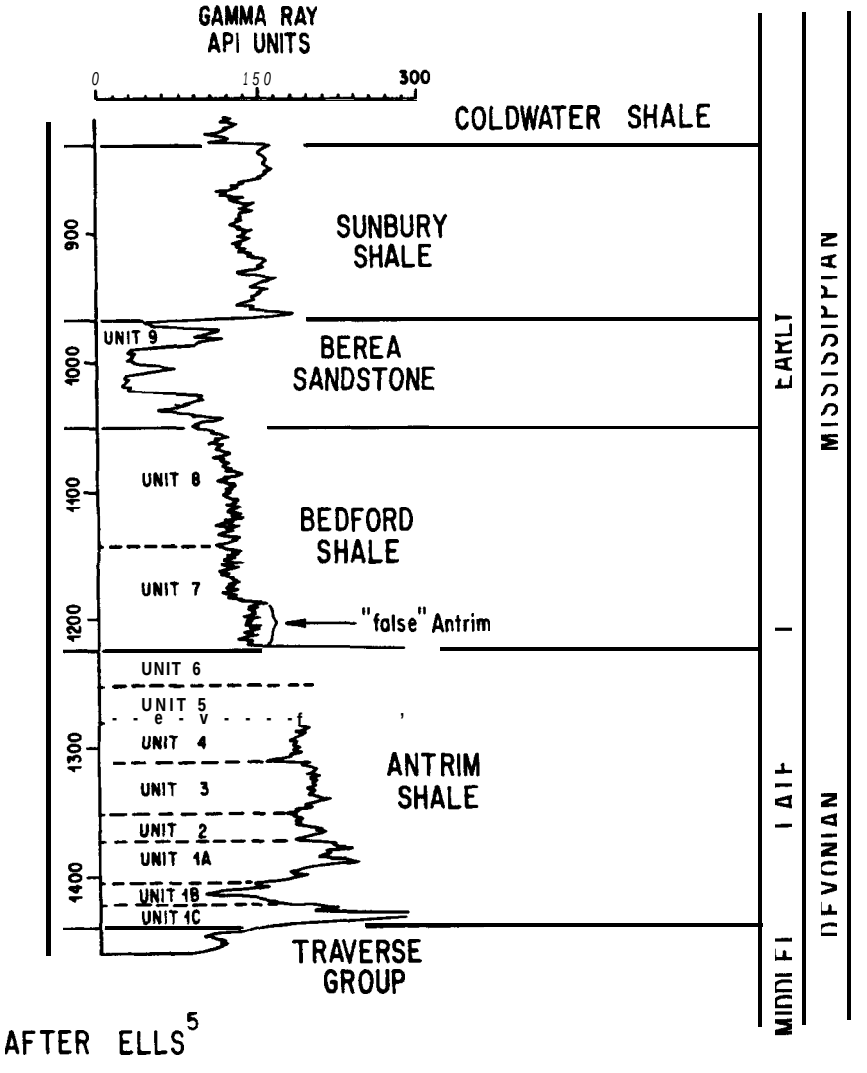
CUMULATIVE FREQUENCY
OF HYDROCARBON COMPONENTS
Mi 27
M. WELCH ET. AL.
NO. 1-15 STATE OTSEGO
ANTRIM SHALE
MICHIGAN BASIN
MICHIGAN
CORE LABORATORIES, INC.
ENGINEERING & CONSULTING DEPT.

FIGURE 2



CUMULATIVE FREQUENCY
OF HYDROCARBON COMPONENTS
Mi 28
AMOCO PRODUCTION CO.
NO. 1-28 SWIFT
ANTRIM SHALE
MICHIGAN BASIN
MICHIGAN
CORE LABORATORIES, INC.
ENGINEERING & CONSULTING DEPT.

FIGURE 3



AFTER ELLS[5]

STRATIGRAPHIC COLUMN

ANTRIM SHALE

MICHIGAN BASIN, MICHIGAN

CORE LABORATORIES, INC.
ENGINEERING & CONSULTING DEPT.

FIGURE 4

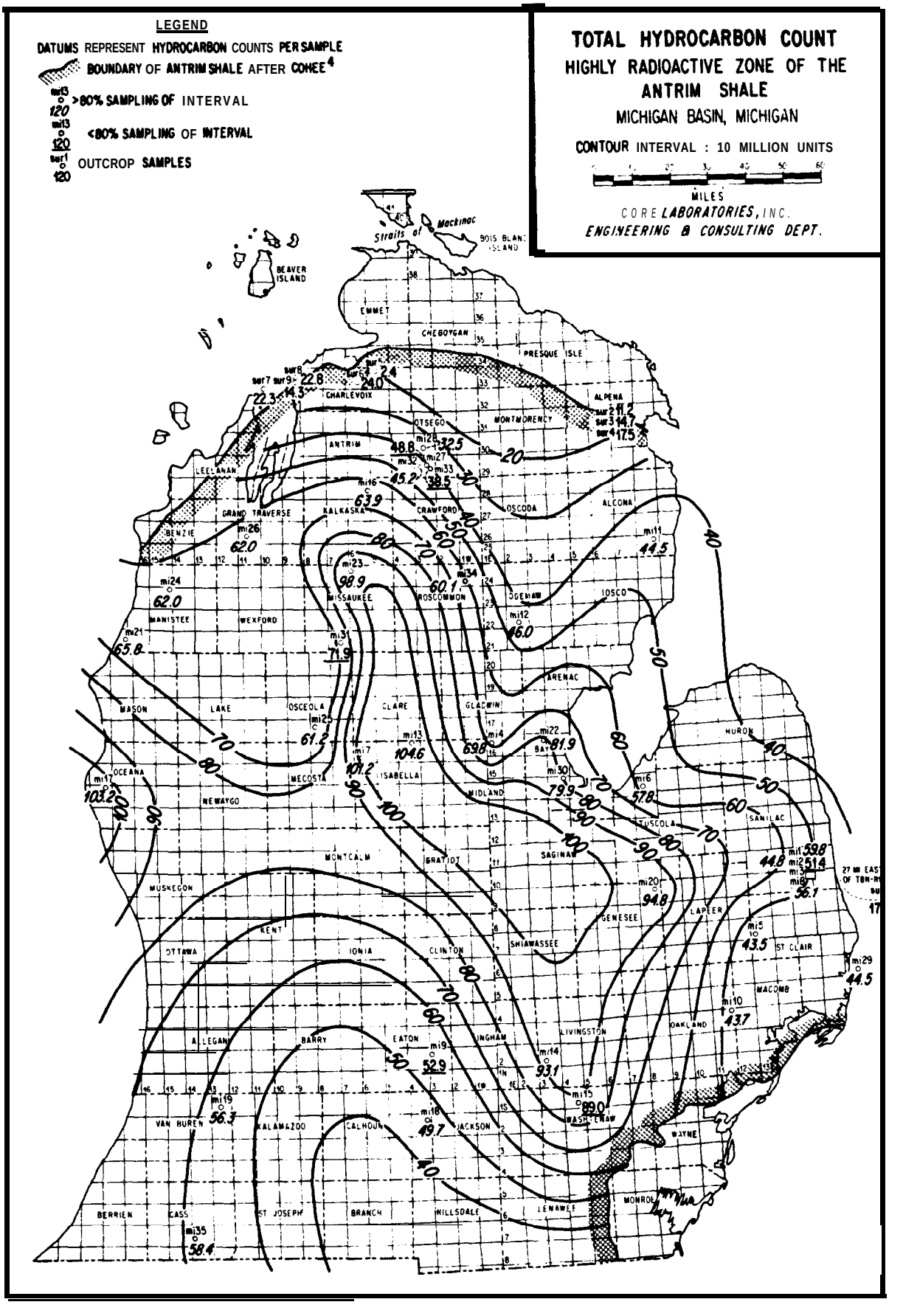
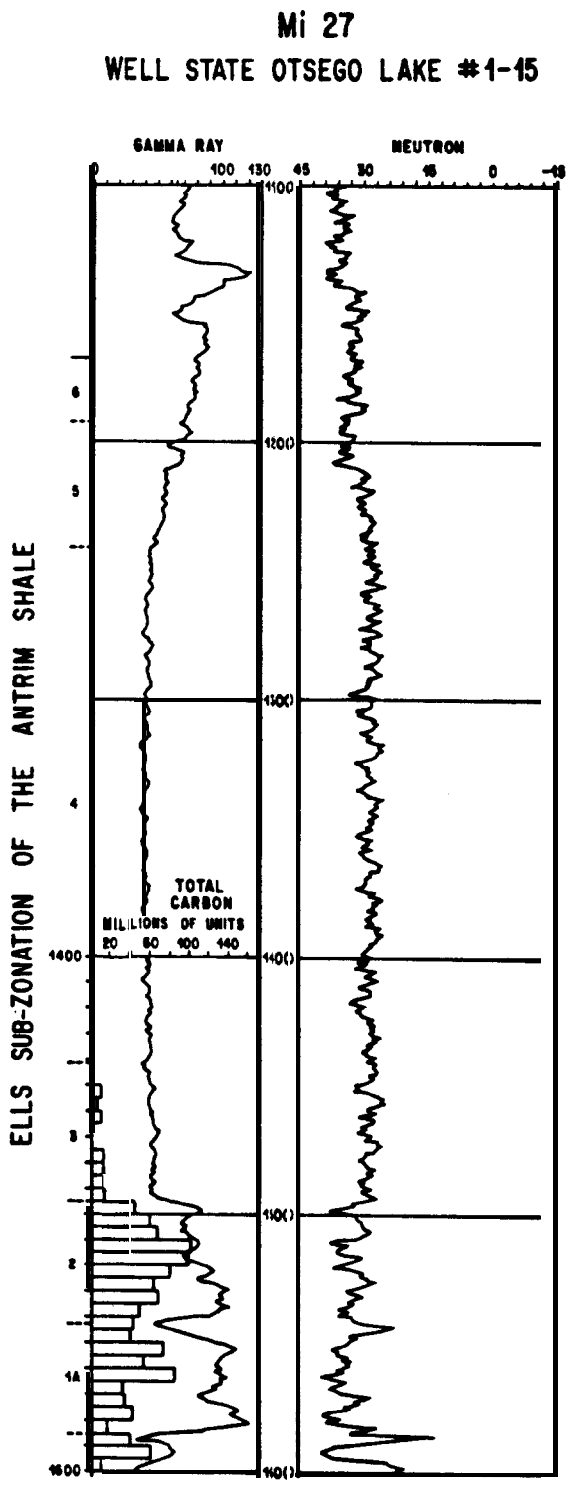

LEGEND
DATUMS REPRESENT HYDROCARBON COUNTS PER SAMPLE
BOUNDARY OF ANTRIM SHALE AFTER COHEE[4]
>80% SAMPLING OF INTERVAL
<80% SAMPLING OF INTERVAL
OUTCROP SAMPLES
TOTAL HYDROCARBON COUNT
HIGHLY RADIOACTIVE ZONE OF THE ANTRIM SHALE
MICHIGAN BASIN, MICHIGAN
CONTOUR INTERVAL : 10 MILLION UNITS
MILES
CORE LABORATORIES, INC.
ENGINEERING & CONSULTING DEPT.
Straits of Mackinac
BEAVER ISLAND
BOIS BLANC ISLAND
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
ALPENA
MONTMORENCY
OTSEGO
ANTRIM
LEELANAU
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
BENZIE
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MANISTEE
WEXFORD
ARENAC
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
HURON
OCEANA
MECOSTA
ISABELLA
BAY
MIDLAND
TUSCOLA
SANILAC
NEWAYGO
MONTCALM
GRATIOT
SAGINAW
MUSKEGON
LAPEER
GENESEE
KENT
OTTAWA
IONIA
CLINTON
SHIAWASSEE
ST CLAIR
MACOMB
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
OAKLAND
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
ST JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE

FIGURE 5



TOTAL HYDROCARBON
VS
GAMMA RAY / NEUTRON LOG
ANTRIM SHALE
MICHIGAN BASIN, MICHIGAN
CORE *LABORATORIES, INC.*
ENGINEERING & CONSULTING DEPT.

FIGURE 6

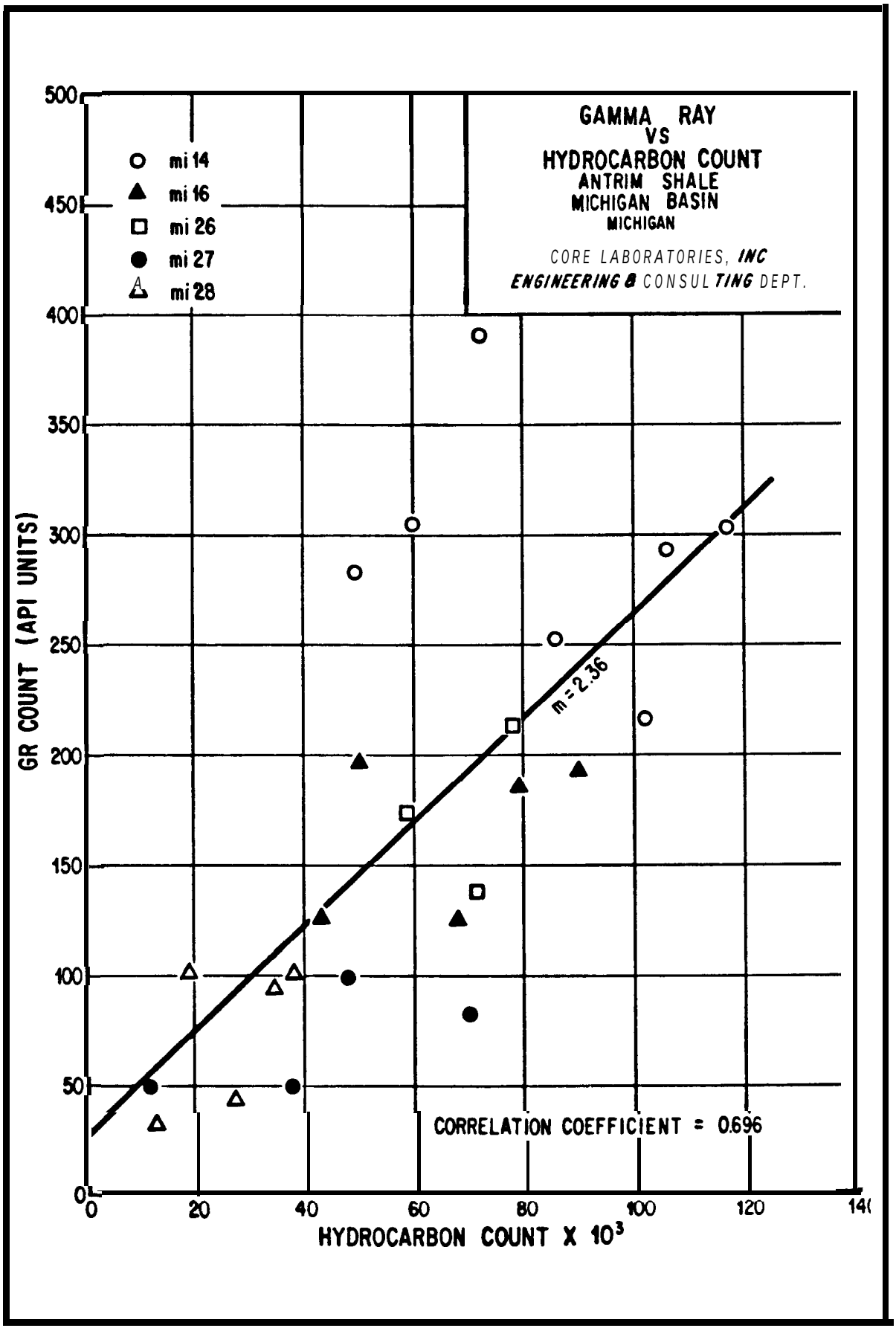

GAMMA RAY
VS
HYDROCARBON COUNT
ANTRIM SHALE
MICHIGAN BASIN
MICHIGAN
CORE LABORATORIES, INC
ENGINEERING & CONSULTING DEPT.
mi 14
mi 16
mi 26
mi 27
mi 28
m = 2.36
CORRELATION COEFFICIENT = 0.696
GR COUNT (API UNITS)
HYDROCARBON COUNT X 10³
0
50
100
150
200
250
300
350
400
450
500
0
20
40
60
80
100
120
140

FIGURE 7

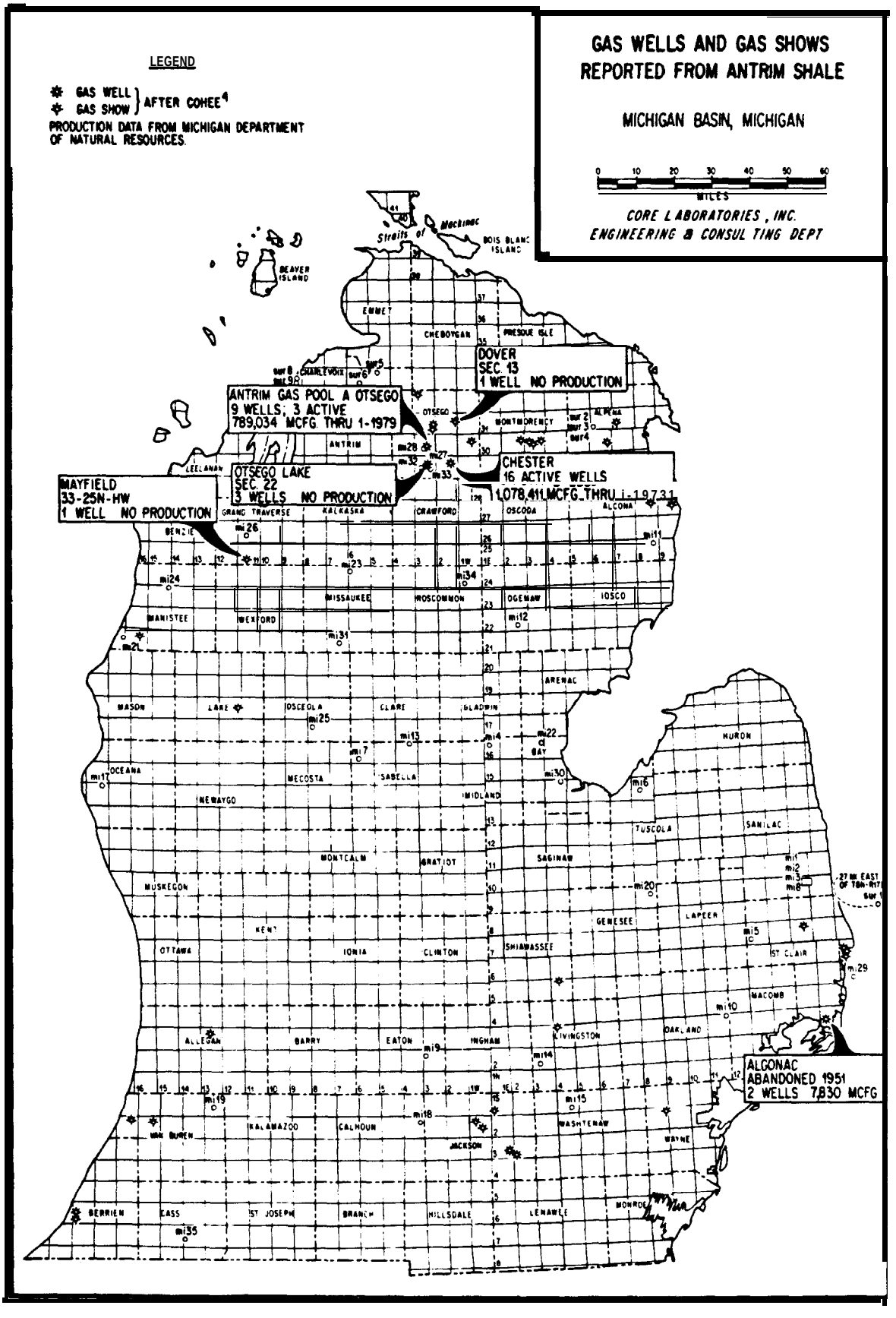
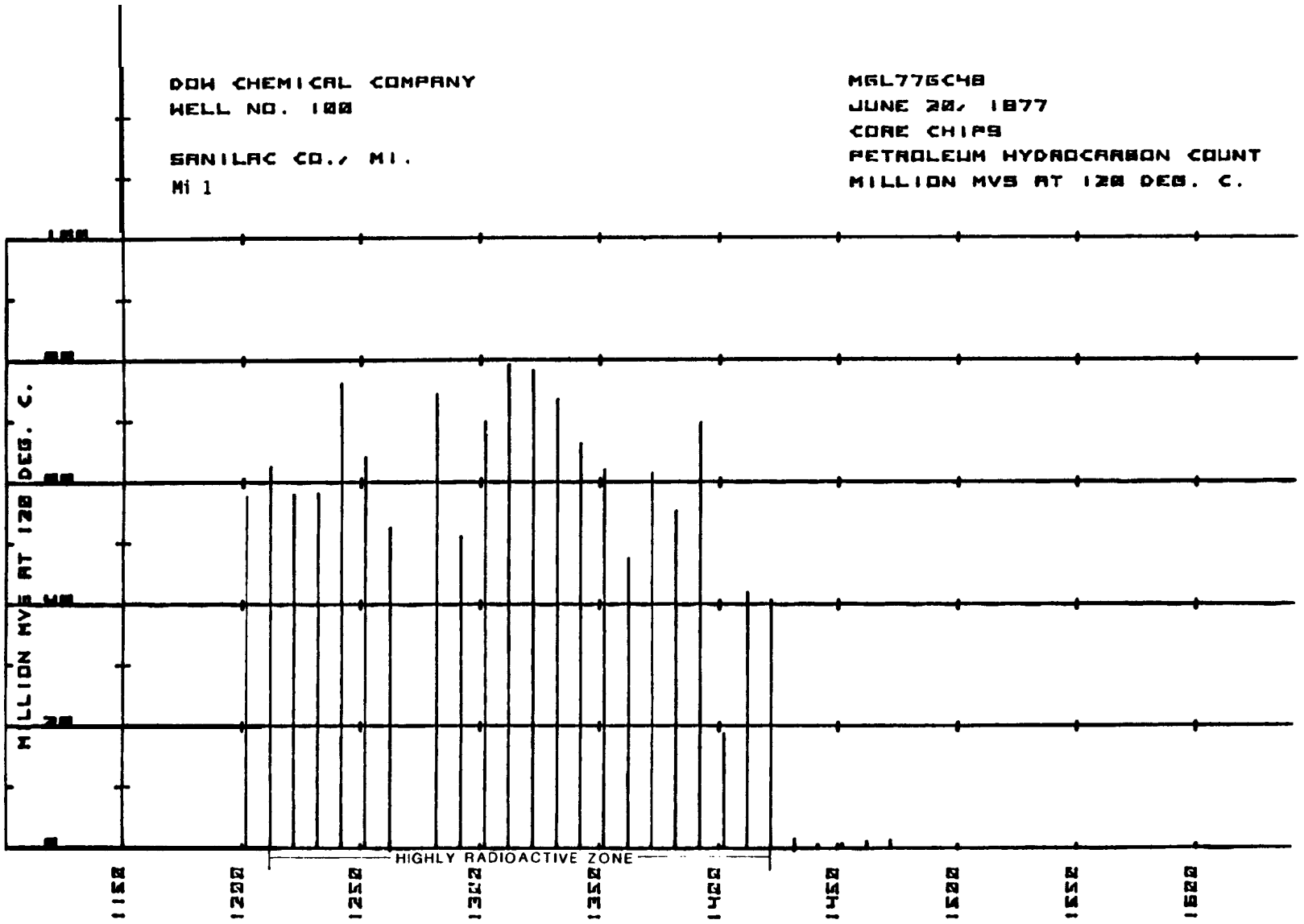

GAS WELLS AND GAS SHOWS
REPORTED FROM ANTRIM SHALE
MICHIGAN BASIN, MICHIGAN
0 10 20 30 40 50 60
MILES
CORE LABORATORIES, INC.
ENGINEERING & CONSULTING DEPT
LEGEND
GAS WELL
GAS SHOW
AFTER COHEE[4]
PRODUCTION DATA FROM MICHIGAN DEPARTMENT OF NATURAL RESOURCES.
Straits of Mackinac
BOIS BLANC ISLAND
BEAVER ISLAND
DOVER
SEC. 13
1 WELL NO PRODUCTION
ANTRIM GAS POOL A OTSEGO
9 WELLS; 3 ACTIVE
789,034 MCFG THRU 1-1979
CHESTER
16 ACTIVE WELLS
1,078,411 MCFG THRU 1-1973
OTSEGO LAKE
SEC. 22
3 WELLS NO PRODUCTION
MAYFIELD
33-25N-HW
1 WELL NO PRODUCTION
ALGONAC
ABANDONED 1951
2 WELLS 7,830 MCFG
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OTSEGO
MONTMORENCY
ALPENA
ANTRIM
LEELANAU
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
BENZIE
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MANISTEE
WEXFORD
ARENAC
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
HURON
BAY
OCEANA
MECOSTA
SABELLA
MIDLAND
NEWAYGO
TUSCOLA
SANILAC
MONTCALM
GRATIOT
SAGINAW
MUSKEGON
KENT
GENESEE
LAPEER
OTTAWA
IONIA
CLINTON
SHIAWASSEE
ST CLAIR
MACOMB
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
OAKLAND
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
ST JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE

FIGURE 8

A P P E N D I X

Bar Graphs of Total Hydrocarbon Count vs Depth

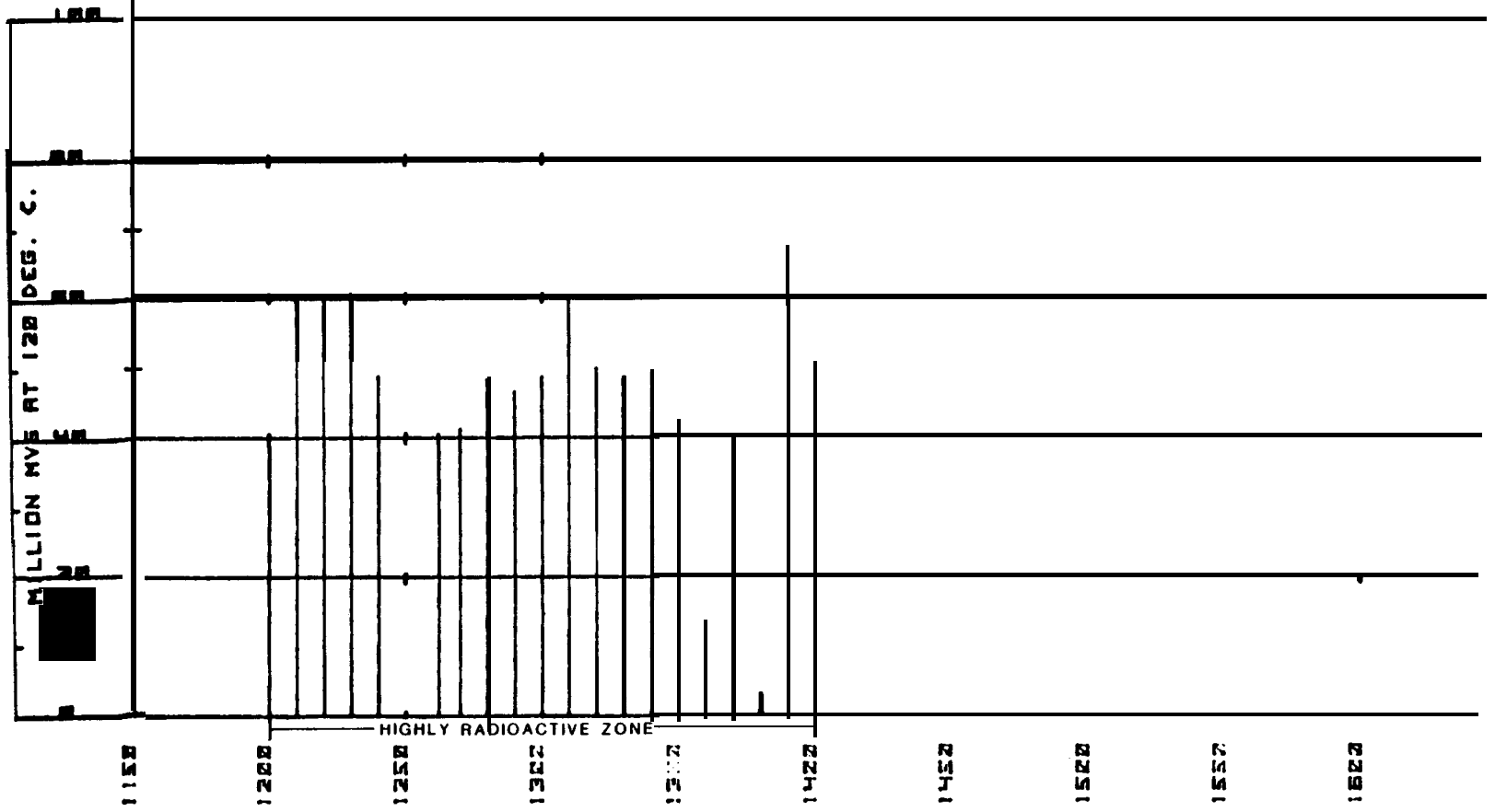
Wells Mi 1 through Mi 35 and Surface Samples


DOW CHEMICAL COMPANY
WELL NO. 100
SANILAC CO., MI.
Mi 1
MGL775C48
JUNE 20, 1977
CORE CHIPS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
MILLION MVS AT 120 DEG. C.
HIGHLY RADIOACTIVE ZONE
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600

DOW CHEMICAL COMPANY
DOW/ERDA NO. 101

GANILAC CO., MI.
Mi 2

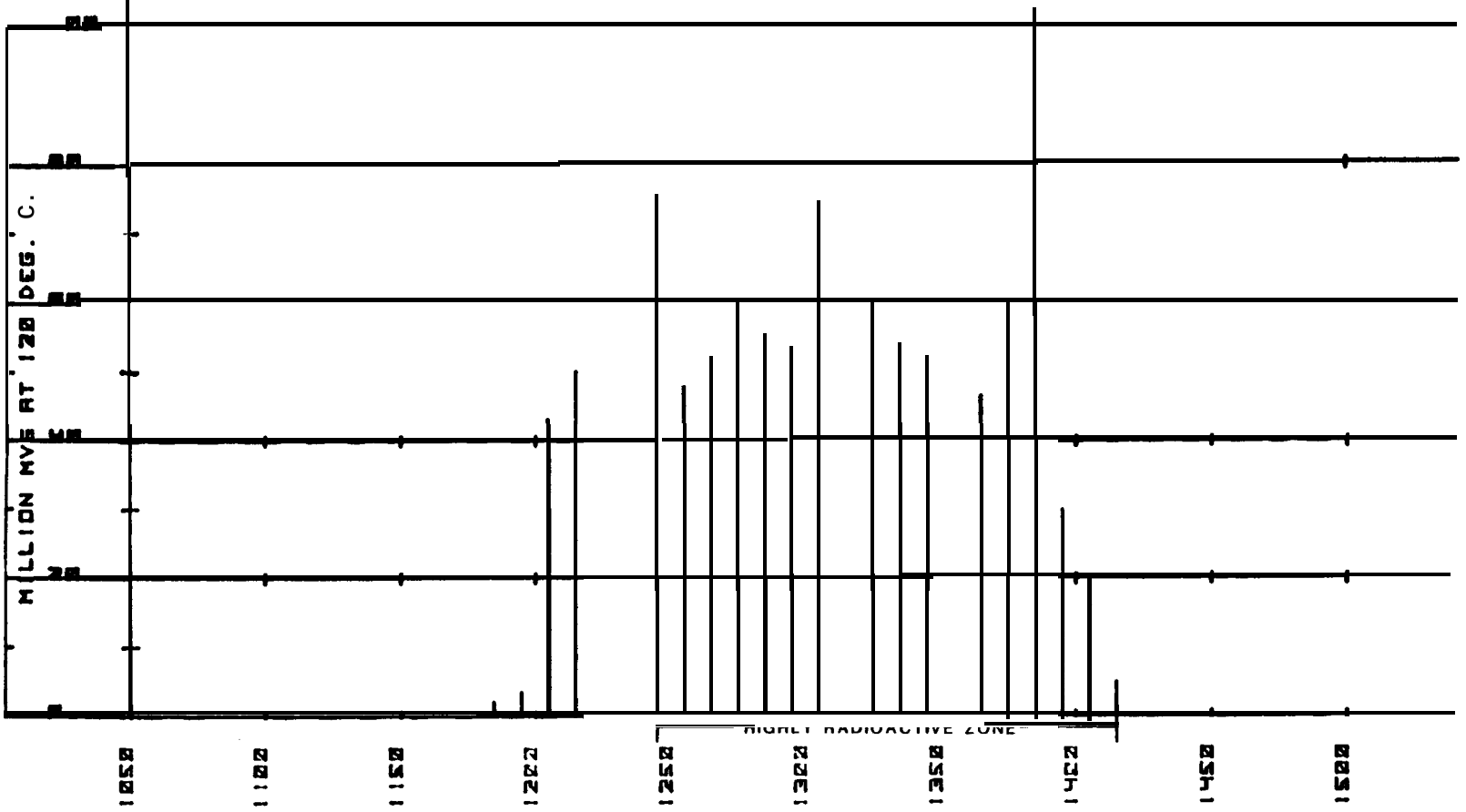
MBL77ACGB
JULY 18, 1977
CORE CHIPS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.

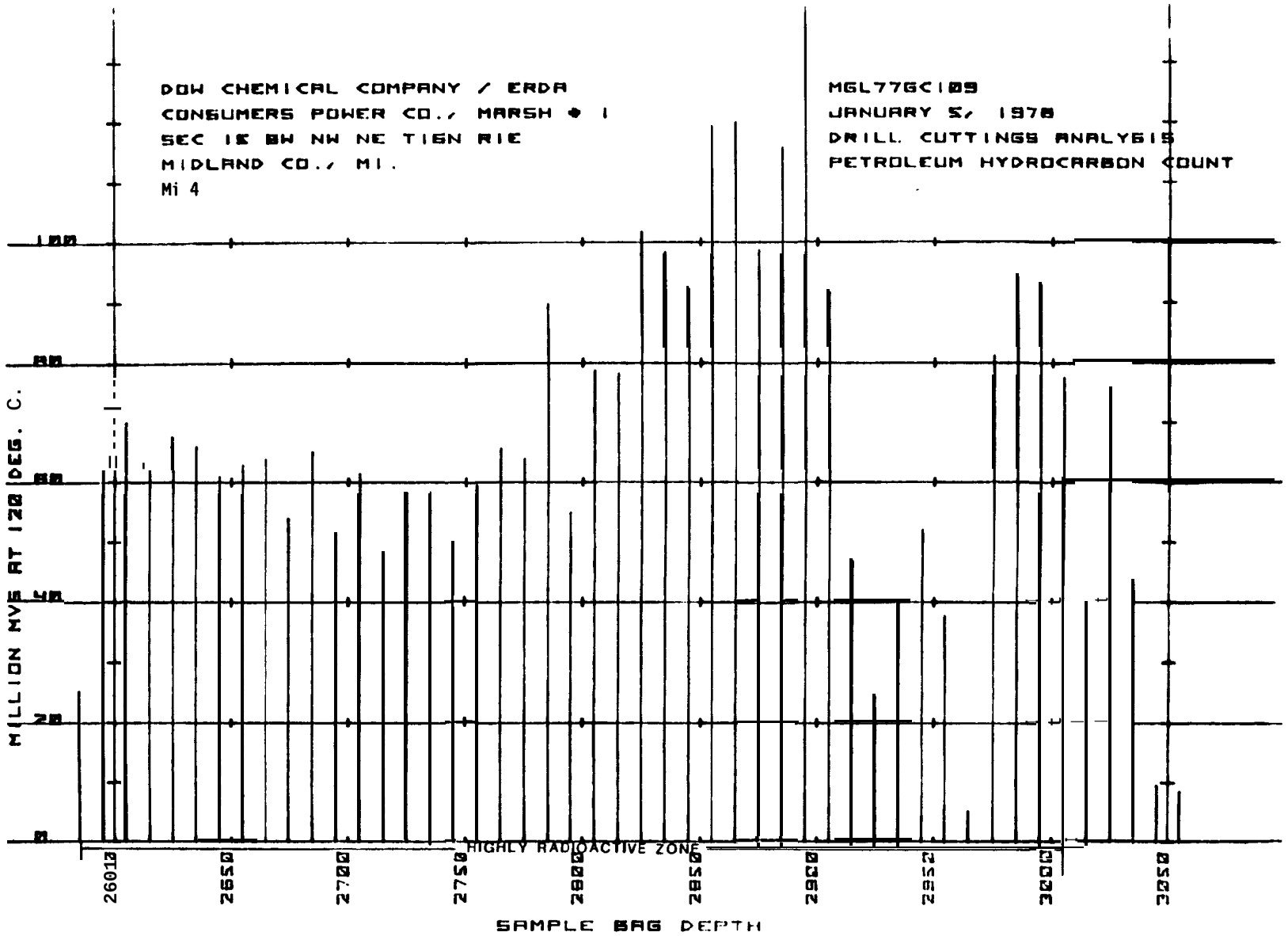


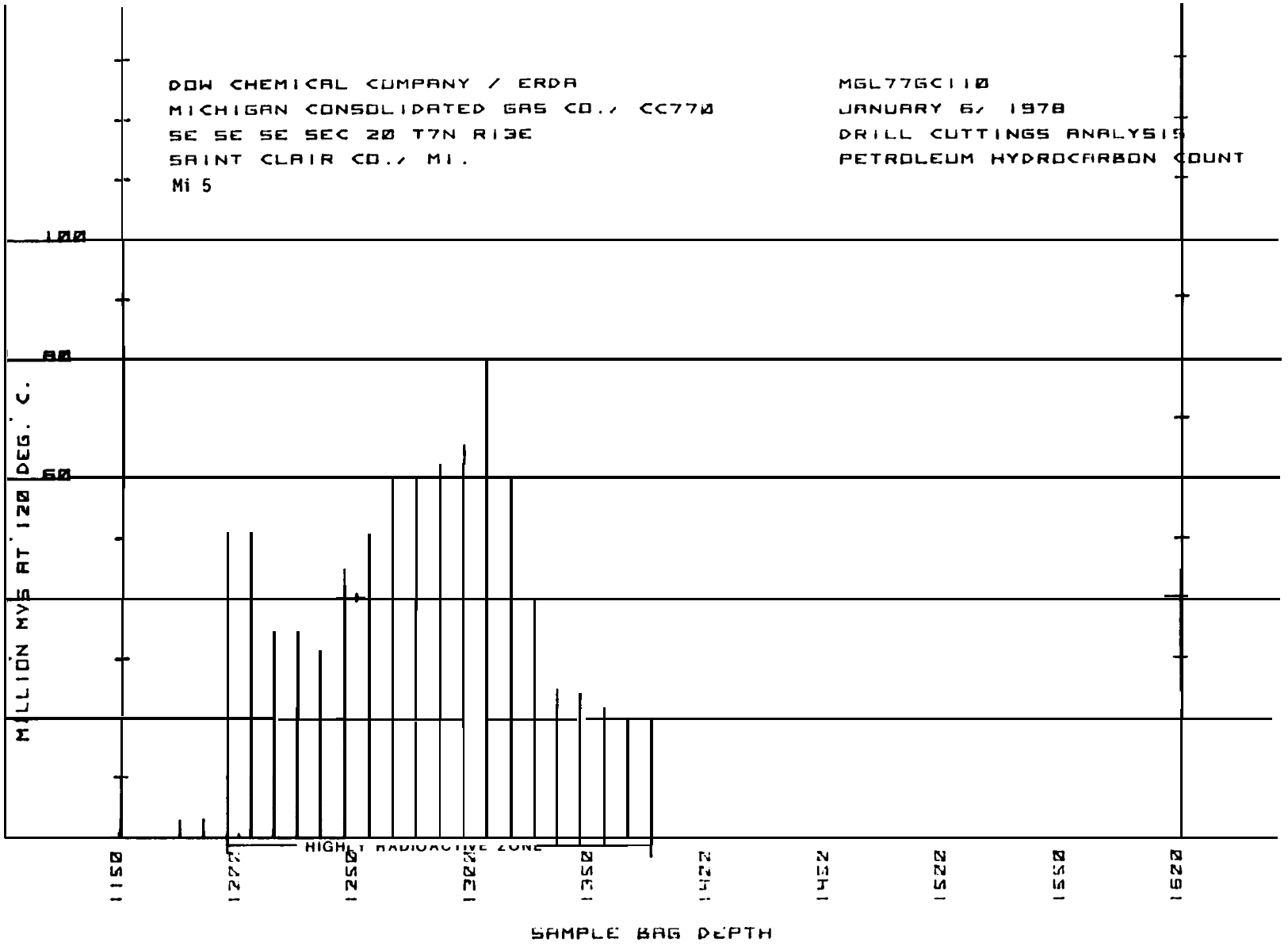
DOW CHEMICAL COMPANY
DOW/ERDA NO.102 WELL

SANILAC CO., MI.
Mi 3

MGL775C64
JULY 7, 1977
CORE CHIPS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.



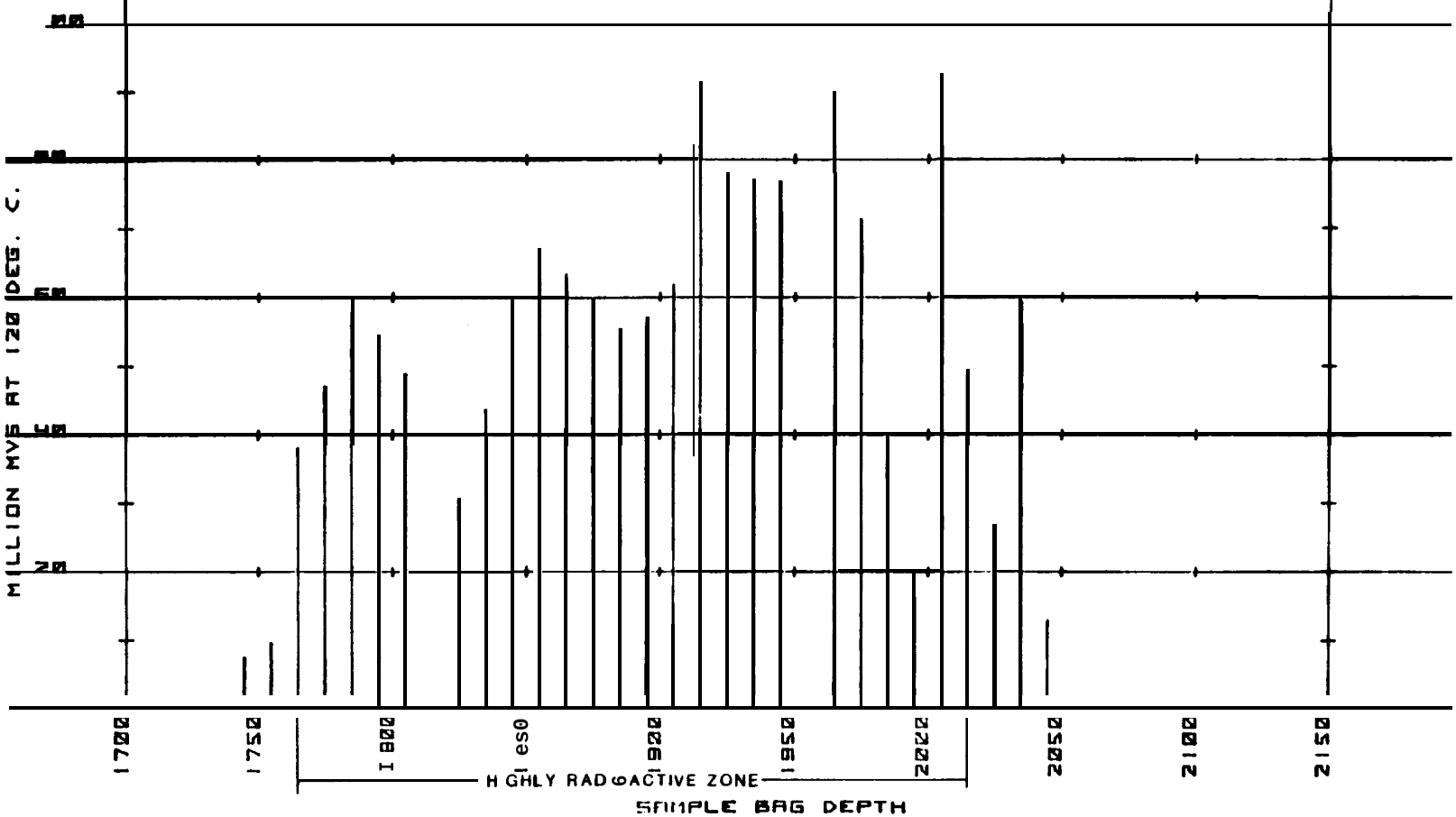

DOW CHEMICAL COMPANY / ERDA
CONSUMERS POWER CO., MARSH # 1
SEC 15 BW NW NE T18N R1E
MIDLAND CO., MI.
Mi 4
MGL77GC109
JANUARY 5, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
2601.0
2650
2700
2750
2800
2850
2900
2950
3000
3050
SAMPLE BAG DEPTH

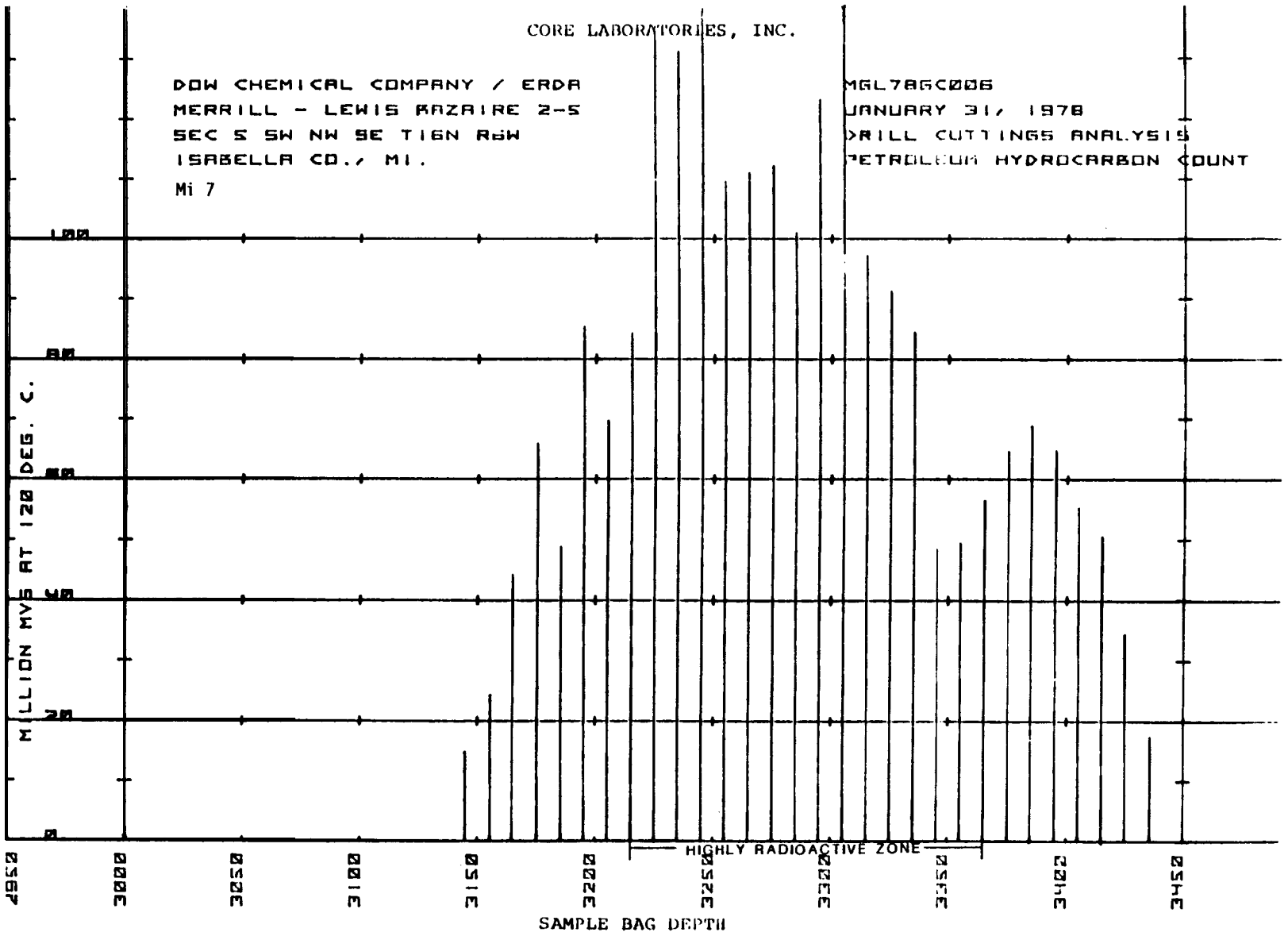

DOW CHEMICAL COMPANY / ERDA
MICHIGAN CONSOLIDATED GAS CO./ CC770
SE SE SE SEC 20 T7N R13E
SAINT CLAIR CO./ MI.
Mi 5
MGL77GC110
JANUARY 6/ 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
100
80
60
MILLION MVS AT 120 DEG. C.
HIGHLY RADIOACTIVE ZONE
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
SAMPLE BAG DEPTH

CORE LABORATORIES, INC.

DOW CHEMICAL COMPANY / ERDA
E.E. BREHM - COSENS 1-36
SW NE NE SEC 36 T14N R7E
TUSCOLA CO., MI.
Mi 6

MGL78GC002
JANUARY 13, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT



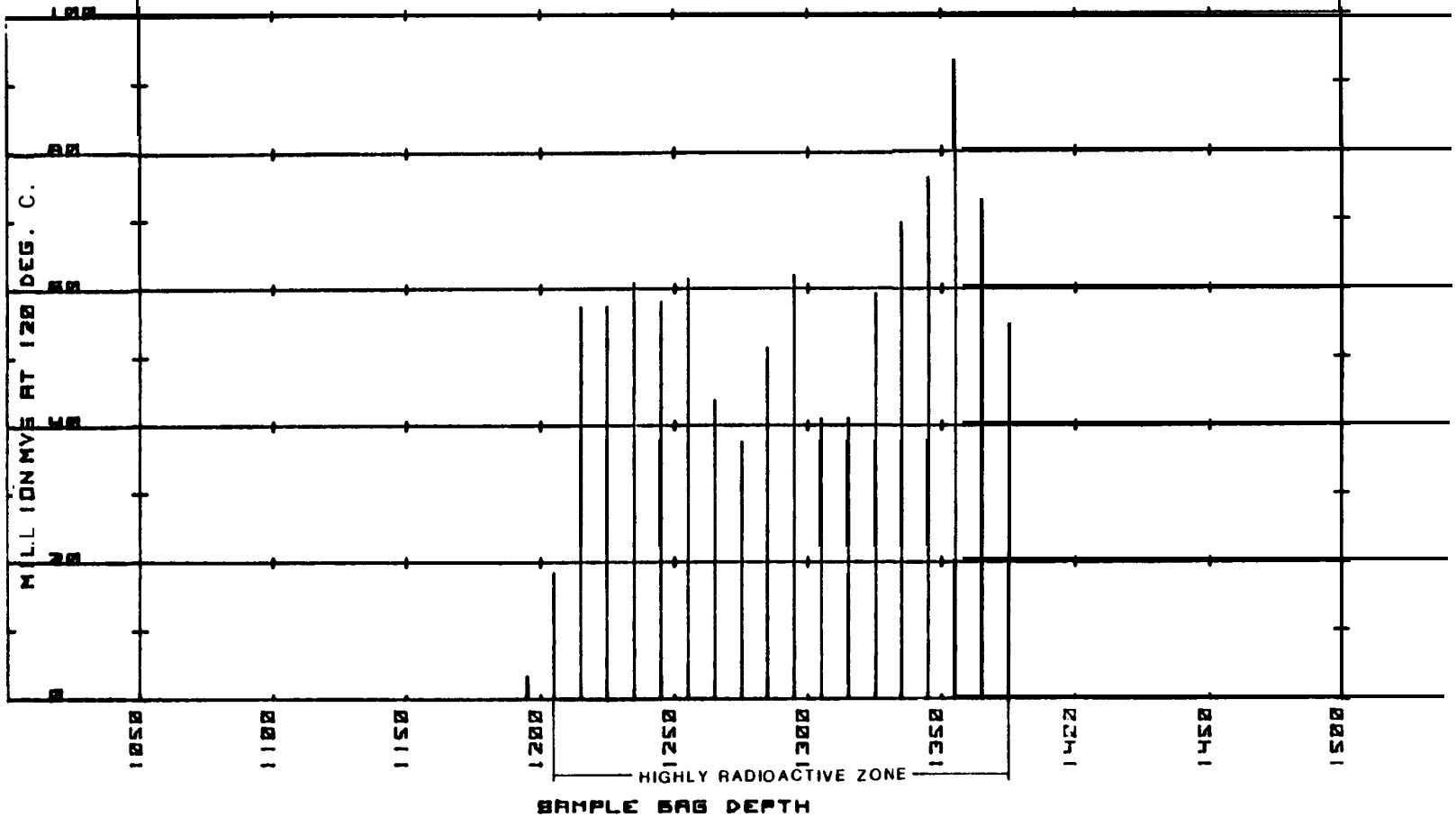

CORE LABORATORIES, INC.
DOW CHEMICAL COMPANY / ERDA
MERRILL - LEWIS BAZAIRE 2-5
SEC 5 SW NW SE T16N R6W
ISABELLA CO., MI.
Mi 7
MGL786C006
JANUARY 31, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
2950
3000
3050
3100
3150
3200
3250
3300
3350
3400
3450
SAMPLE BAG DEPTH

CORE LABORATORIES, INC.

DOW CHEMICAL COMPANY / ERDA
DOW 105

SANILAC CO., MI.
Mi 8

MGL78GC010
FEBRUARY 9, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT

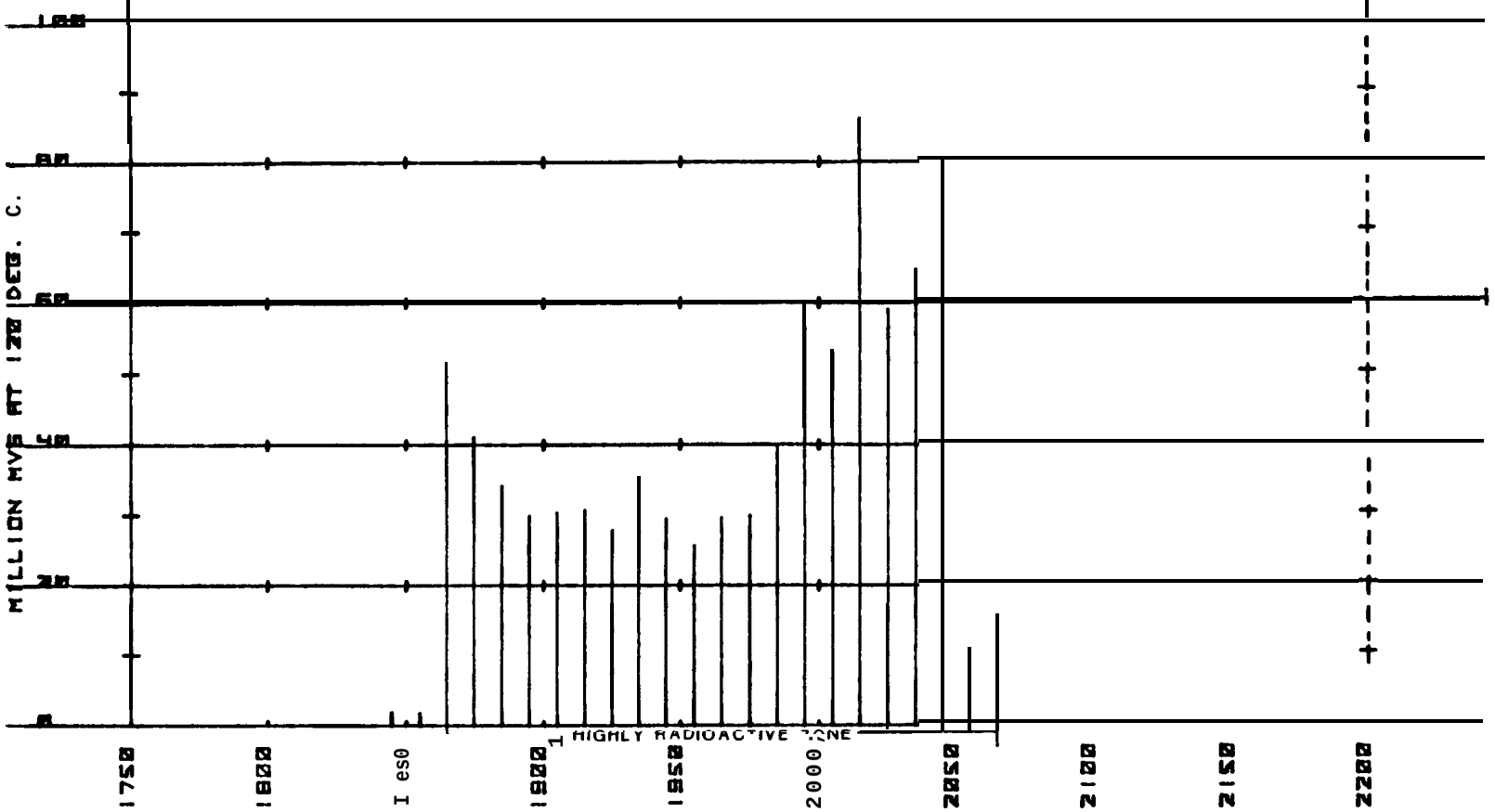


CORE LABORATORIES, INC.

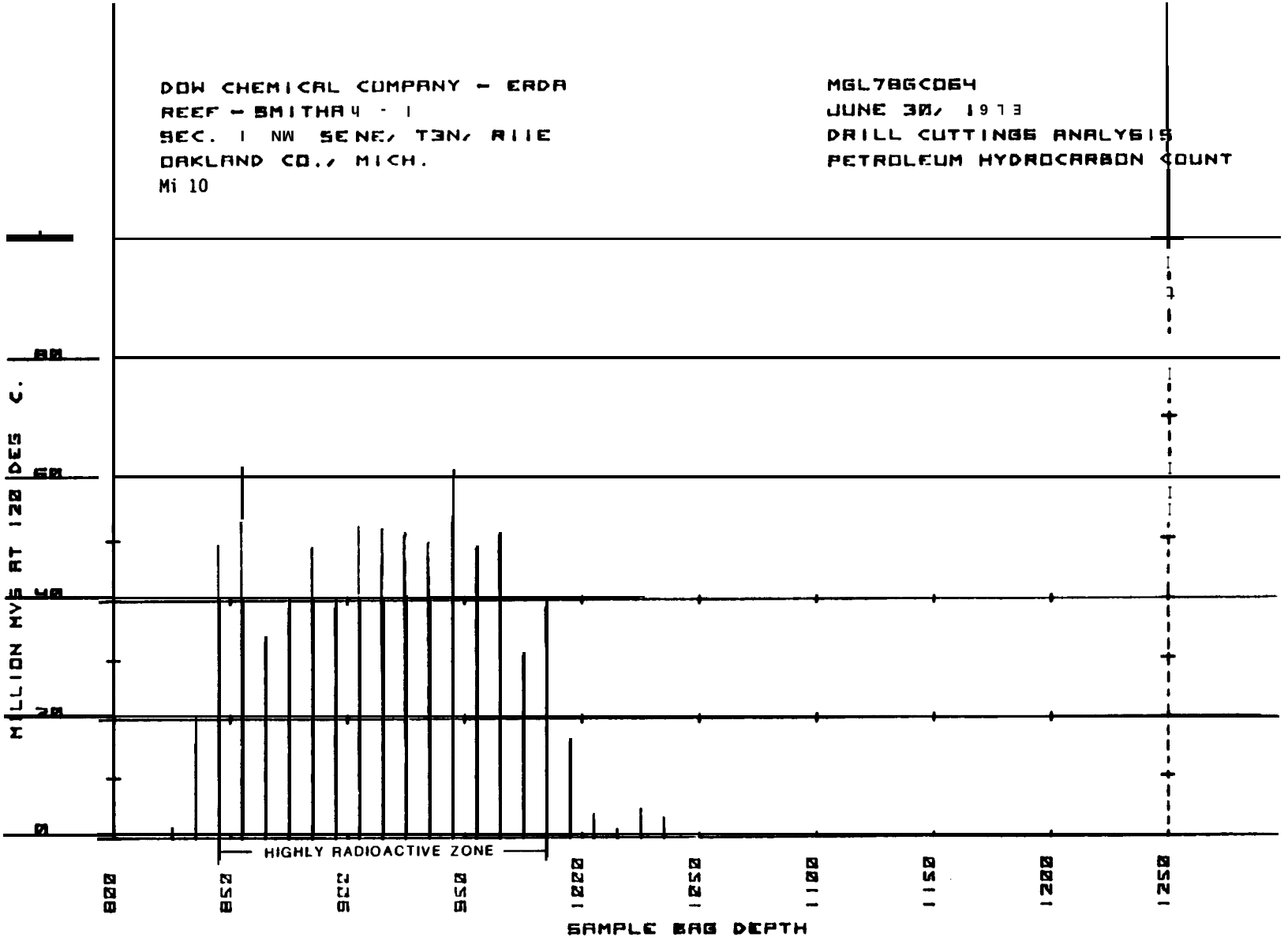
DOW CHEMICAL COMPANY
ROUNDS - JONES 1-7

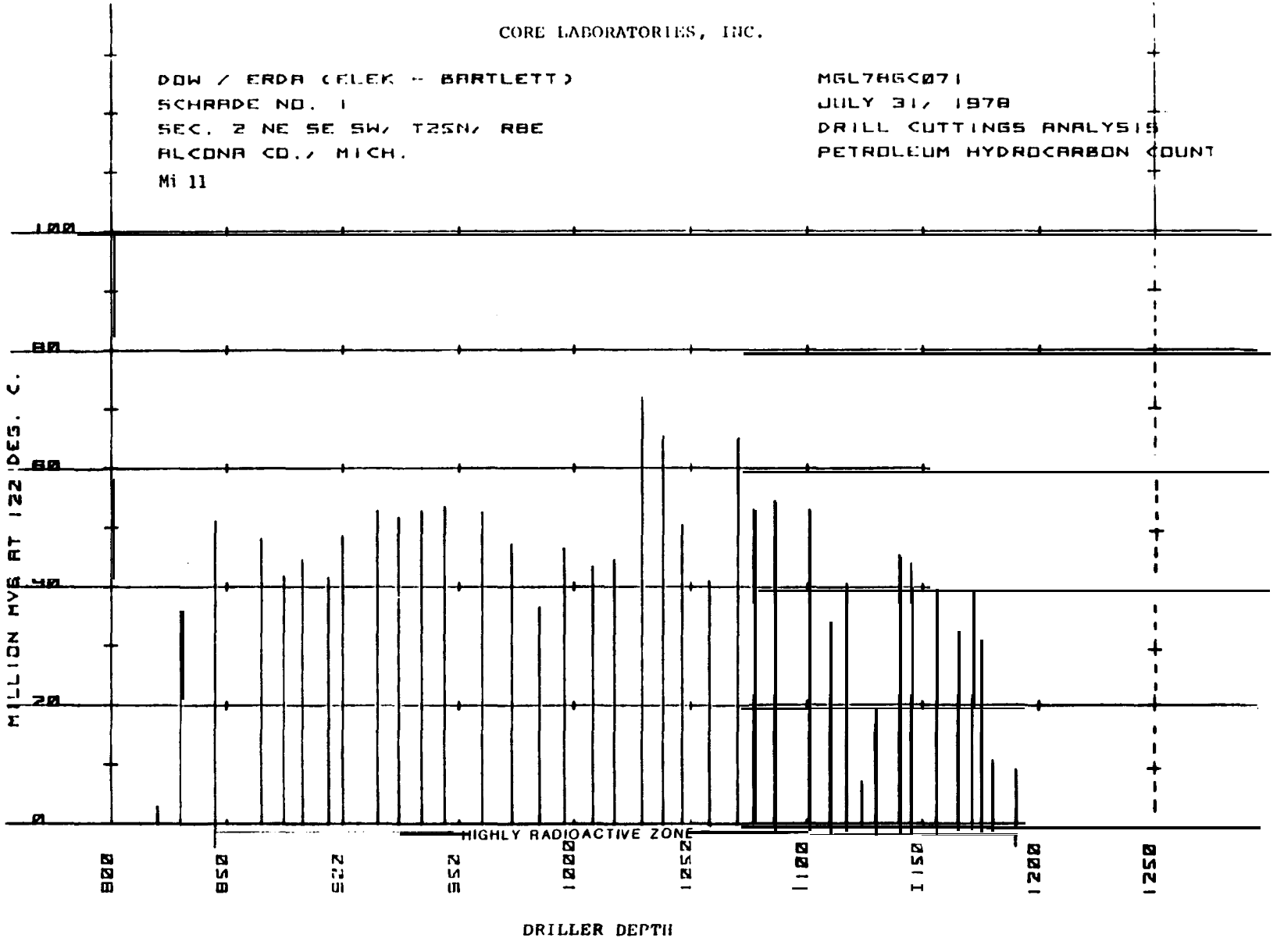
EATON CO., MICH.
Mi 9

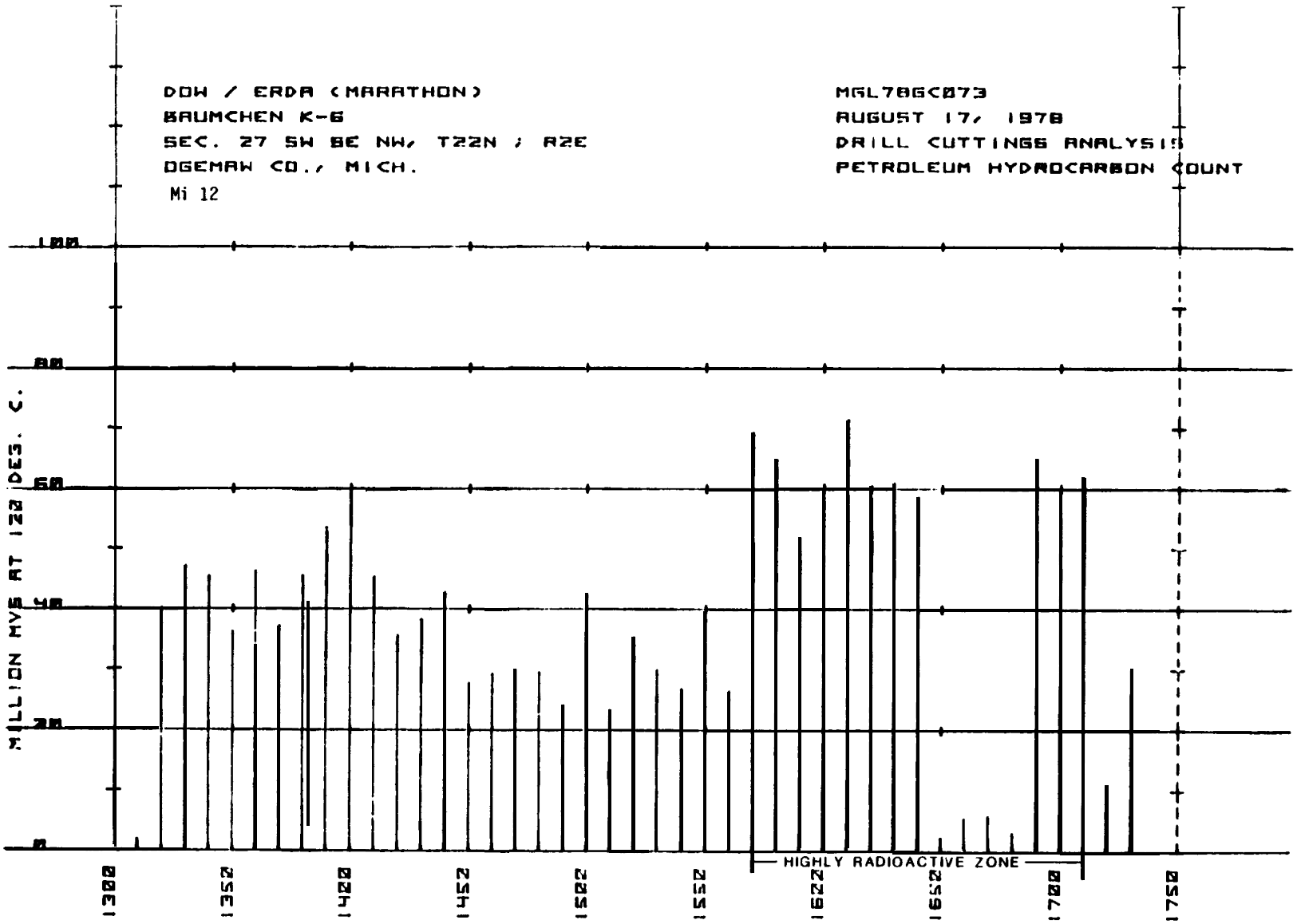
MGL788C045
JUNE 6, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT



SAMPLE BAG DEPTH


DOW CHEMICAL COMPANY - ERDA
REEF - SMITHAY - 1
SEC. 1 NW SENE, T3N, R11E
OAKLAND CO., MICH.
Mi 10
MGL78GC064
JUNE 30, 1973
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION HYS AT 120 DEG C.
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
800
850
900
950
1000
1050
1100
1150
1200
1250
SAMPLE BAG DEPTH

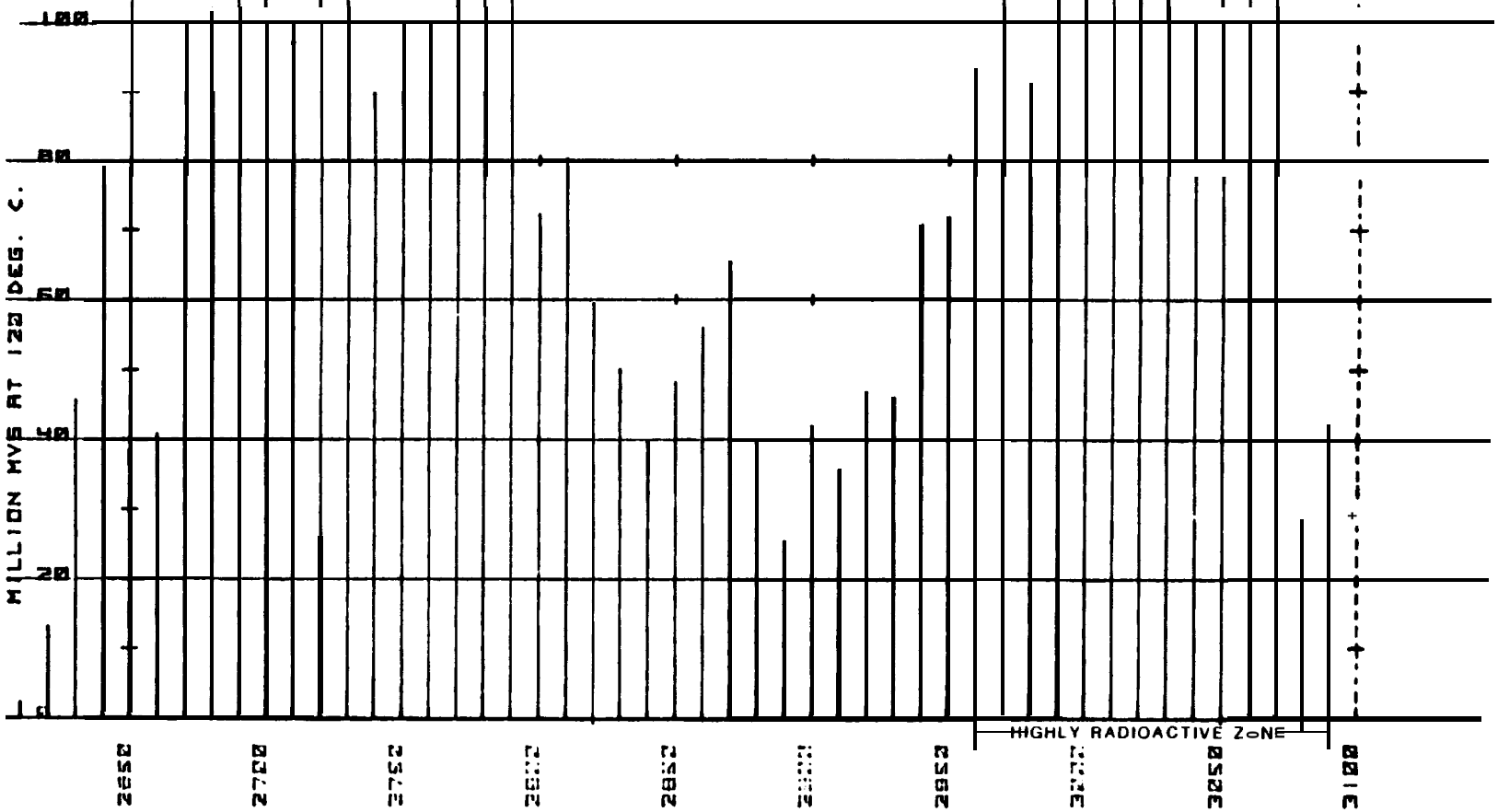

CORE LABORATORIES, INC.
DOW / ERDA (ELEK - BARTLETT)
SCHRADE NO. 1
SEC. 2 NE SE SW/ T25N/ R8E
ALCONA CO./ MICH.
Mi 11
MGL78GC071
JULY 31/ 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVG AT 122 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
800
850
900
950
1000
1050
1100
1150
1200
1250
DRILLER DEPTH


DOW / ERDA (MARATHON)
BAUMCHEN K-6
SEC. 27 SW SE NW, T22N ; R2E
OGEMAW CO., MICH.
Mi 12
MGL78GC073
AUGUST 17, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
1300
1350
1400
1450
1500
1550
1600
1650
1700
1750
HIGHLY RADIOACTIVE ZONE

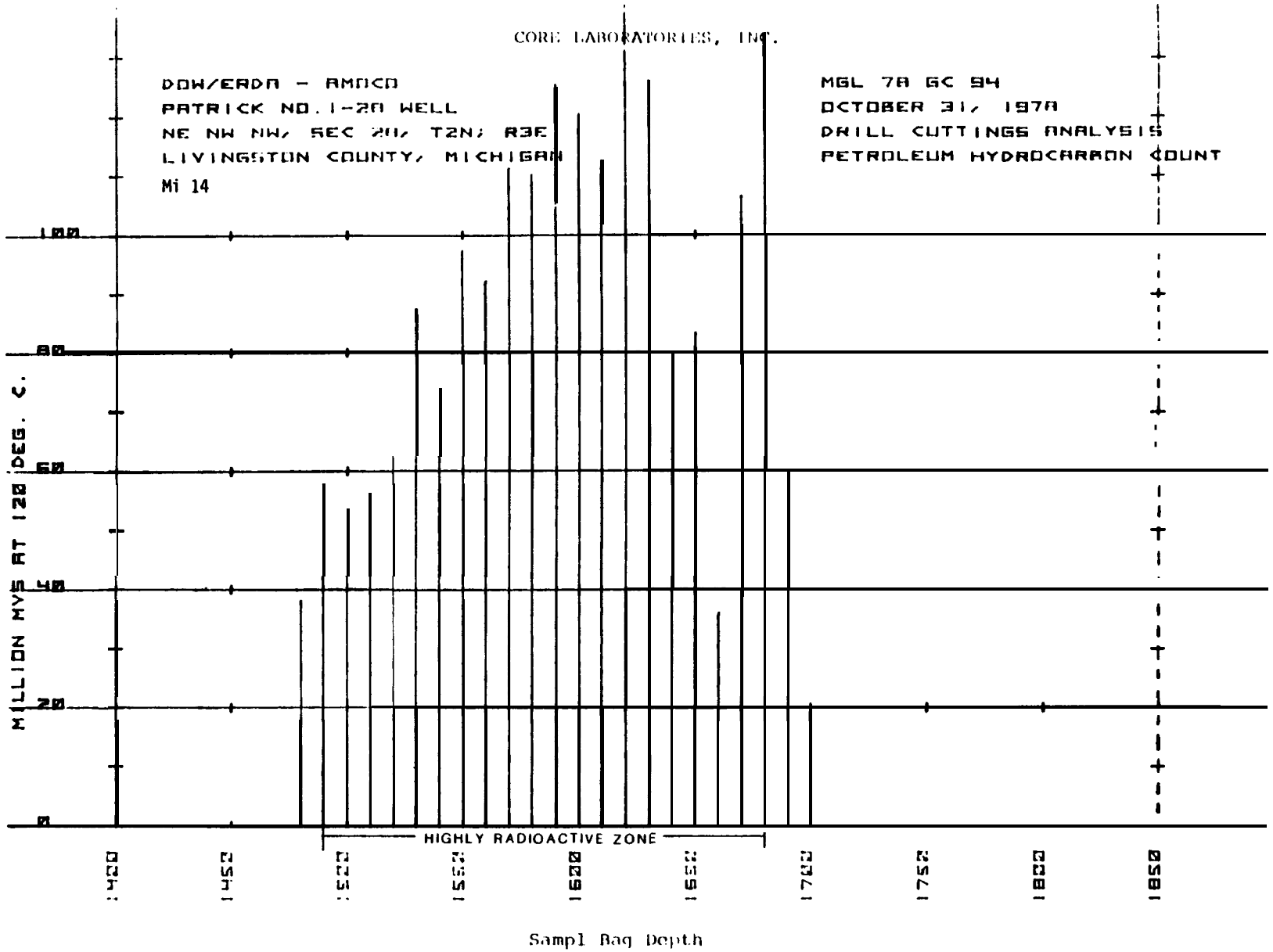
CORE LABORATORIES, INC.

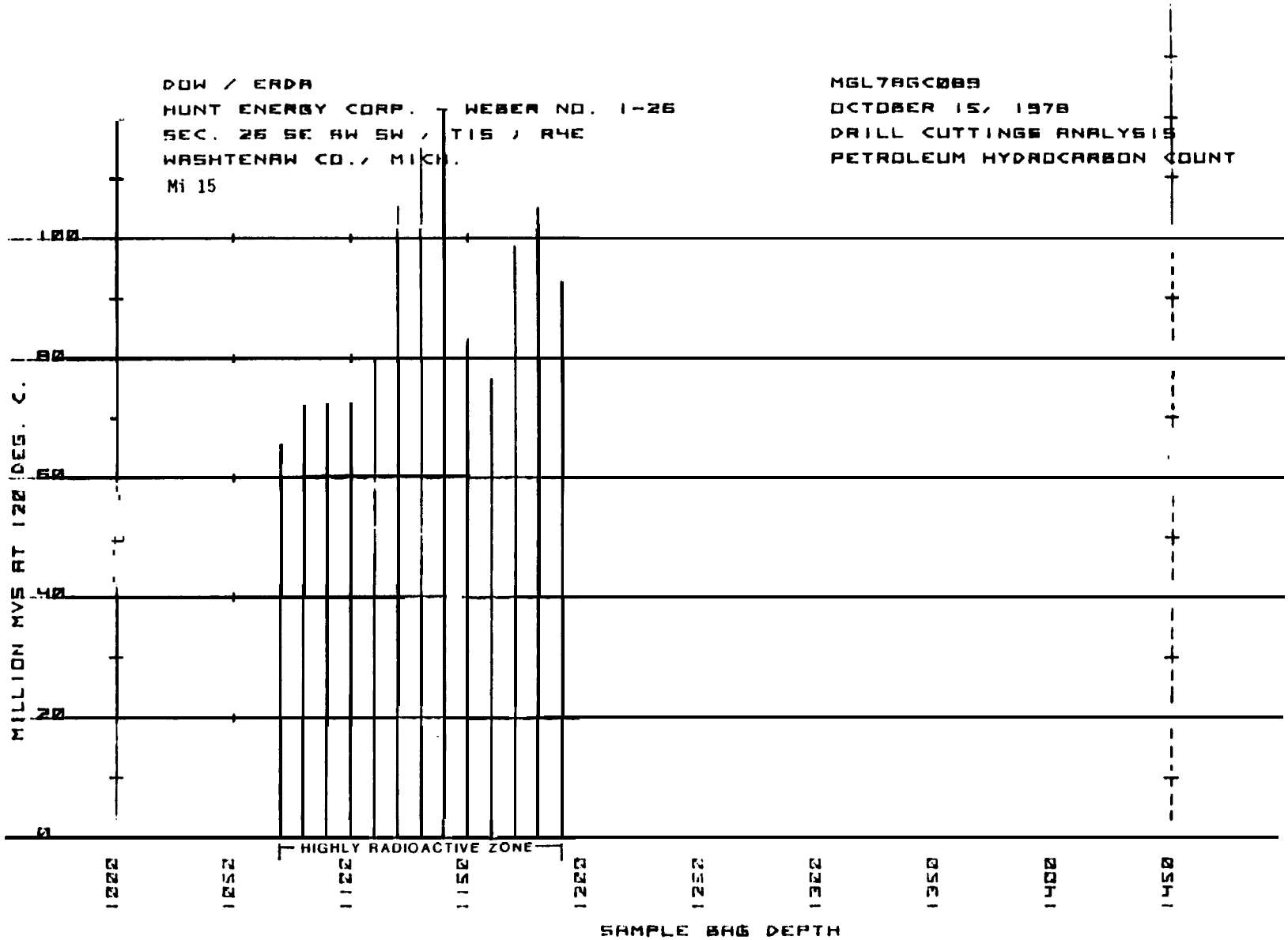
DOW CHEMICAL COMPANY/ERDA
HUNT ENERGY CORP.--WILD NO.1-3
NW SE SE, SEC 3, T16N R4W
ISABELLA COUNTY, MICHIGAN
Mi 13

MGL 7MGC07
OCTOBER 10, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT



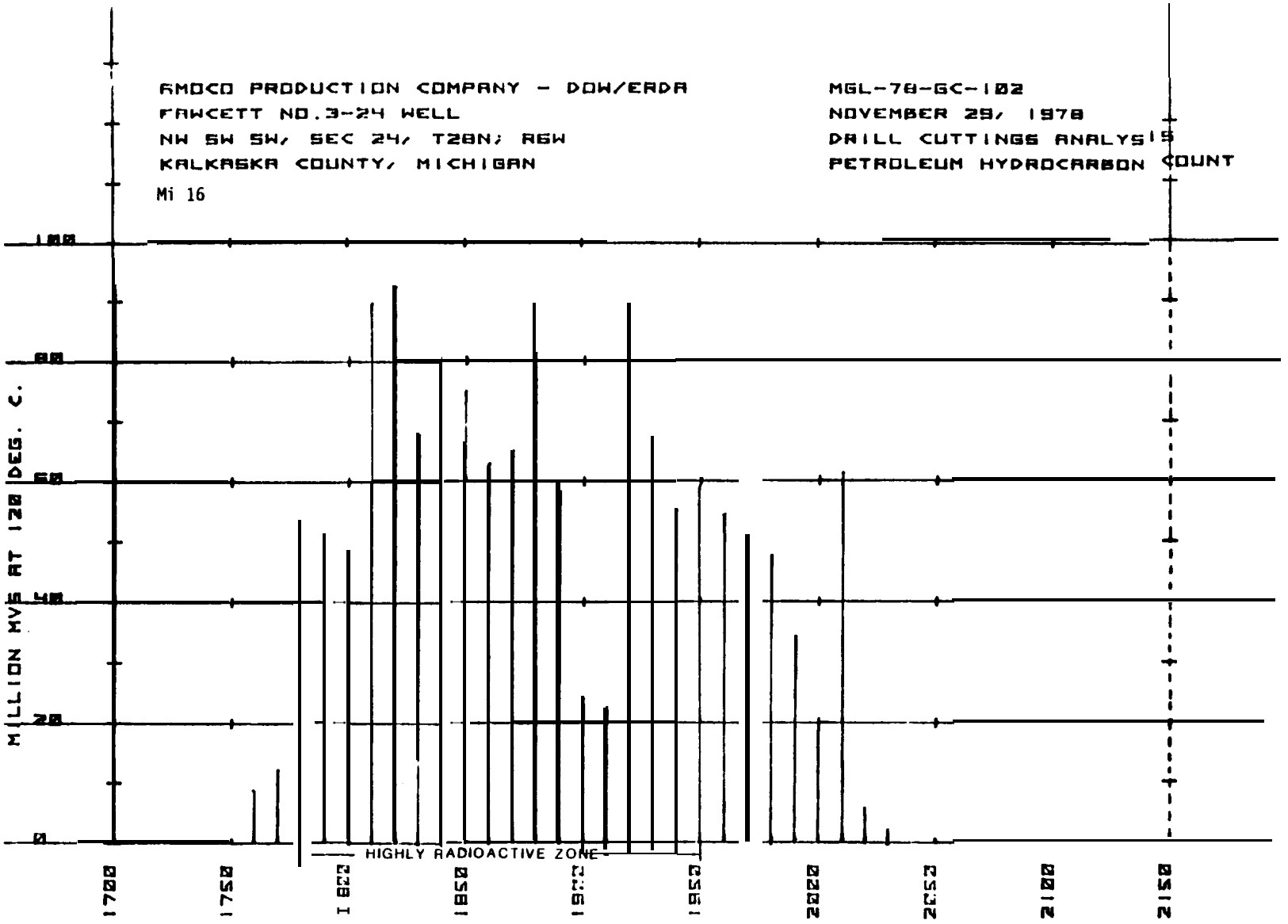
SAMPLE BAG DEPTH

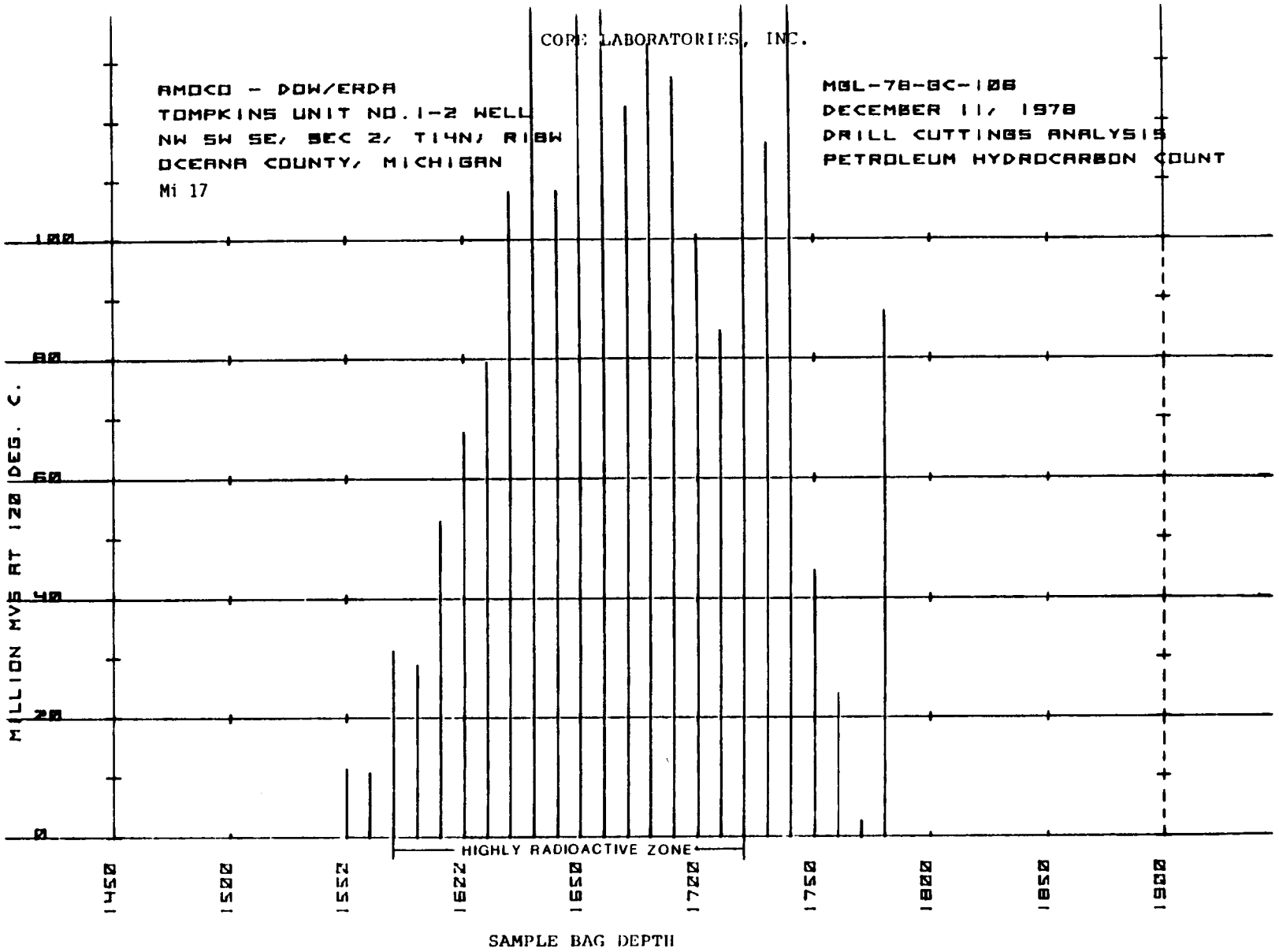

CORE LABORATORIES, INC.
DOW/ERDA - AMOCO
PATRICK NO.1-20 WELL
NE NW NW, SEC 20, T2N, R3E
LIVINGSTON COUNTY, MICHIGAN
Mi 14
MGL 78 GC 94
OCTOBER 31, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MYS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
1450
1500
1550
1600
1650
1700
1750
1800
1850
Sampl Bag Depth


DOW / ERDA
HUNT ENERGY CORP. WEBER NO. 1-26
SEC. 26 SE AW SW / T1S / R4E
WASHTENAW CO., MICH.
Mi 15
MGL78GC089
OCTOBER 15, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
1200
1250
1300
1350
1400
1450
SAMPLE BAG DEPTH

AMOCO PRODUCTION COMPANY - DOW/ERDA
FAWCETT NO.3-24 WELL
NW SW SW, SEC 24, T28N, R6W
KALKASKA COUNTY, MICHIGAN
Mi 16

MGL-78-GC-102
NOVEMBER 29, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT

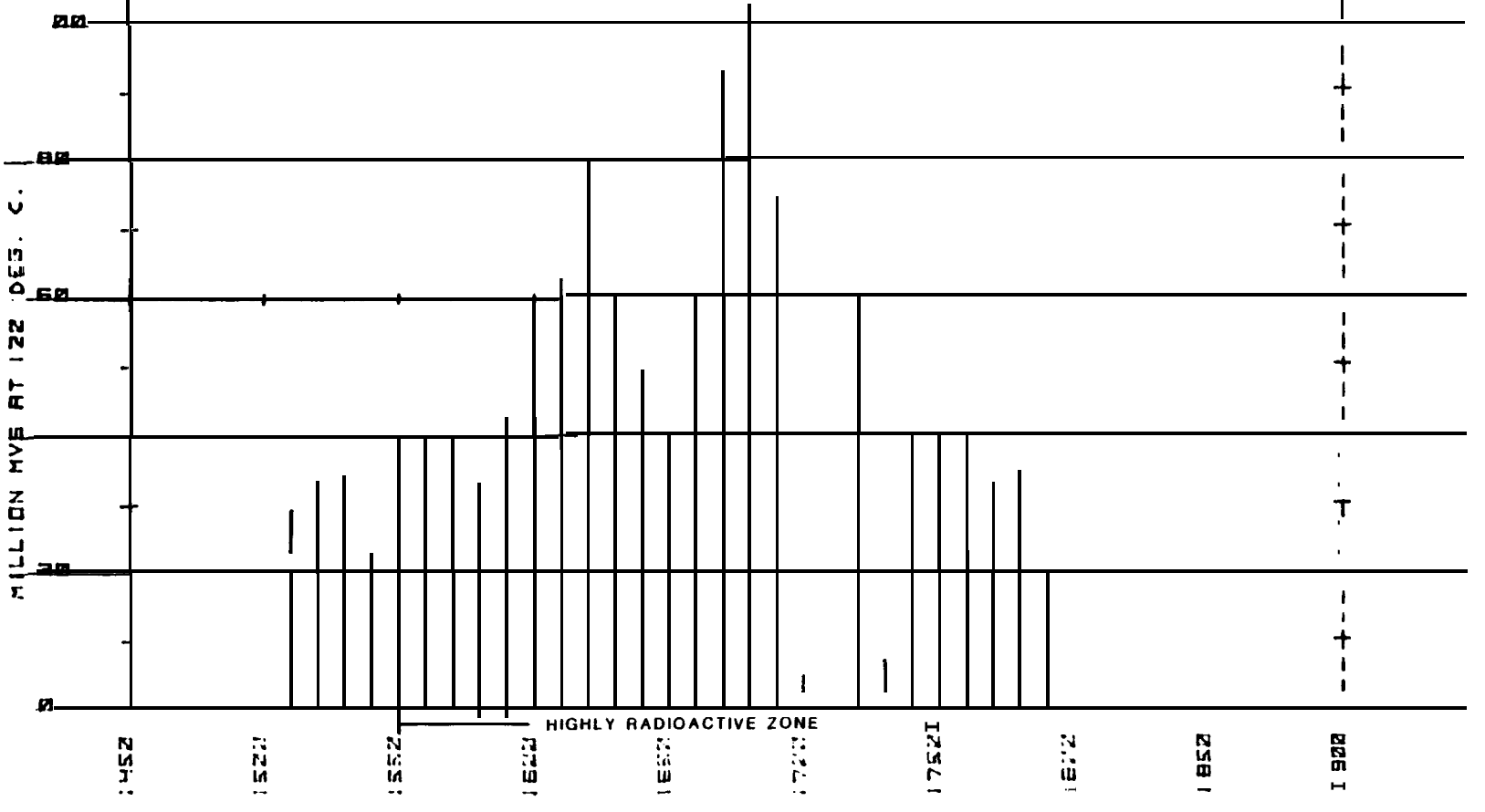



CORE LABORATORIES, INC.
AMOCO - DOW/ERDA
TOMPKINS UNIT NO.1-2 WELL
NW SW SE, SEC 2, T14N, R18W
OCEANA COUNTY, MICHIGAN
Mi 17
MGL-78-GC-108
DECEMBER 11, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
1450
1500
1550
1600
1650
1700
1750
1800
1850
1900
SAMPLE BAG DEPTH

CORE LABORATORIES, INC.

DON SCOTT - DOW/ERDA
COLLIER NO.1-12 WELL
NW SW SE, SEC 12, T25, R4W
CALHOUN COUNTY, MICHIGAN
Mi 18

MGL-78-GC$_H$109
DECEMBER 18, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT

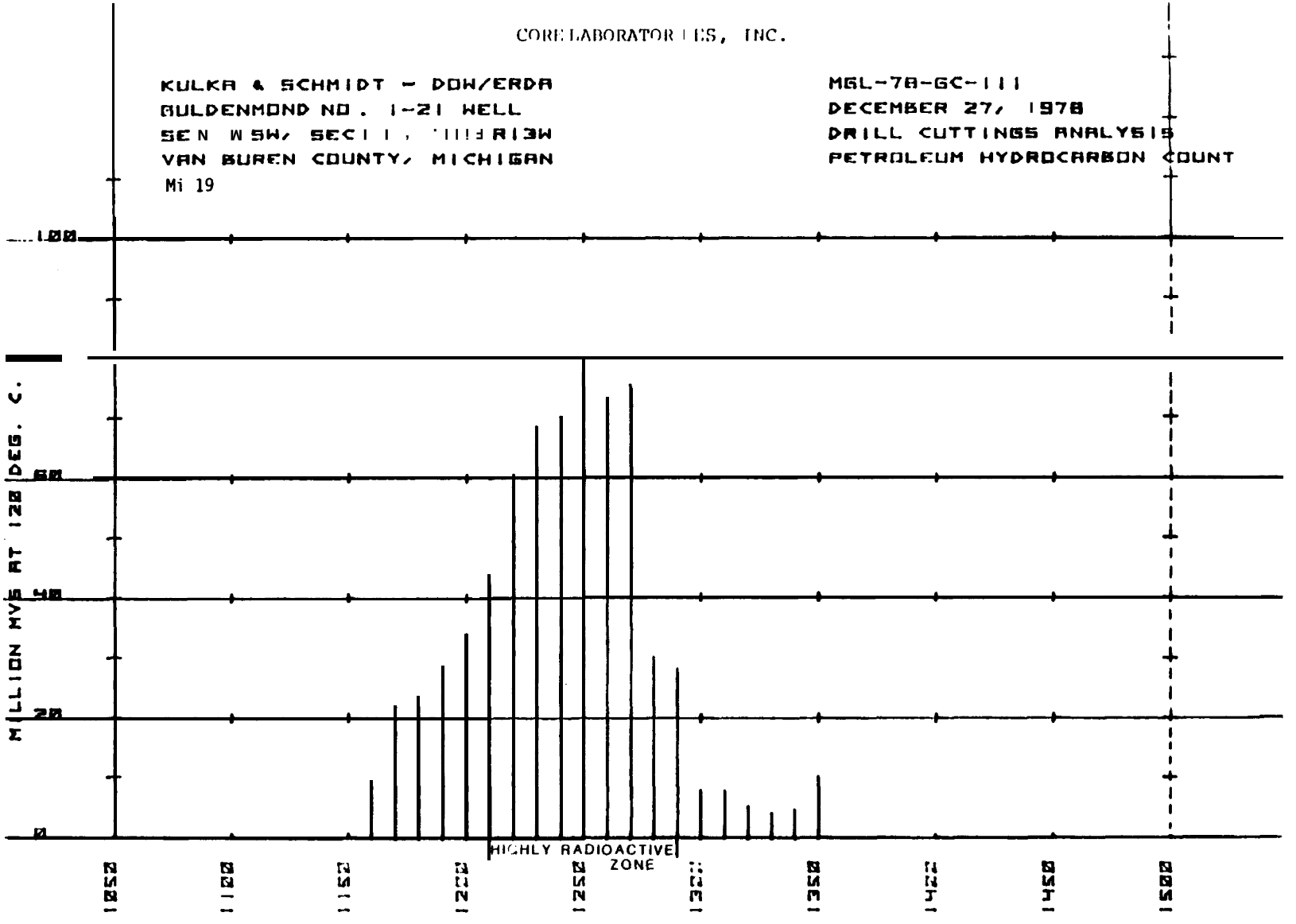


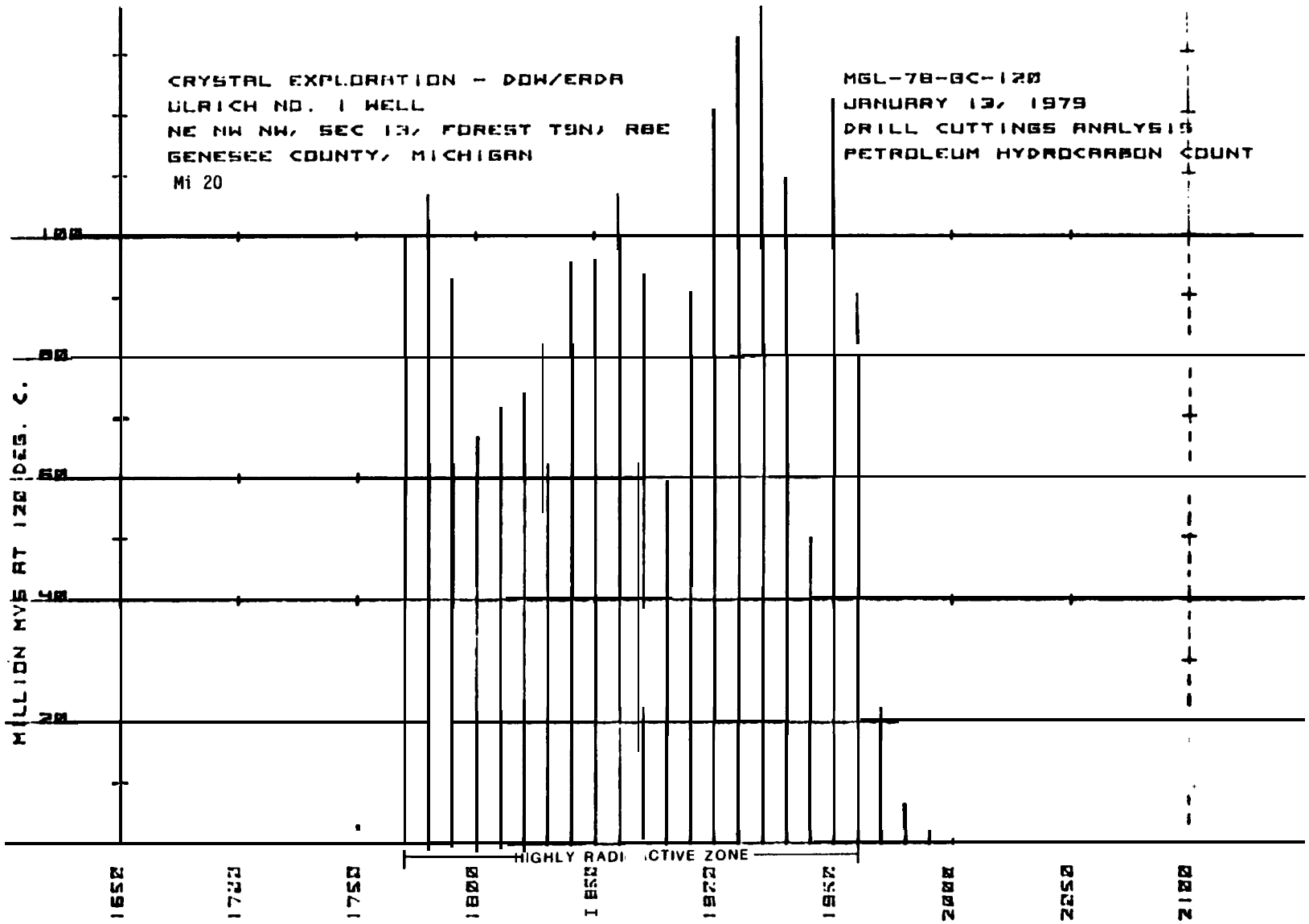
SAMPLE BAG DEPTH

CORE LABORATORIES, INC.

KULKA & SCHMIDT - DOW/ERDA
BULDENMOND NO. 1-21 WELL
SEN W SW, SEC 1 1, T11S R13W
VAN BUREN COUNTY, MICHIGAN
Mi 19

MGL-78-GC-111
DECEMBER 27, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT

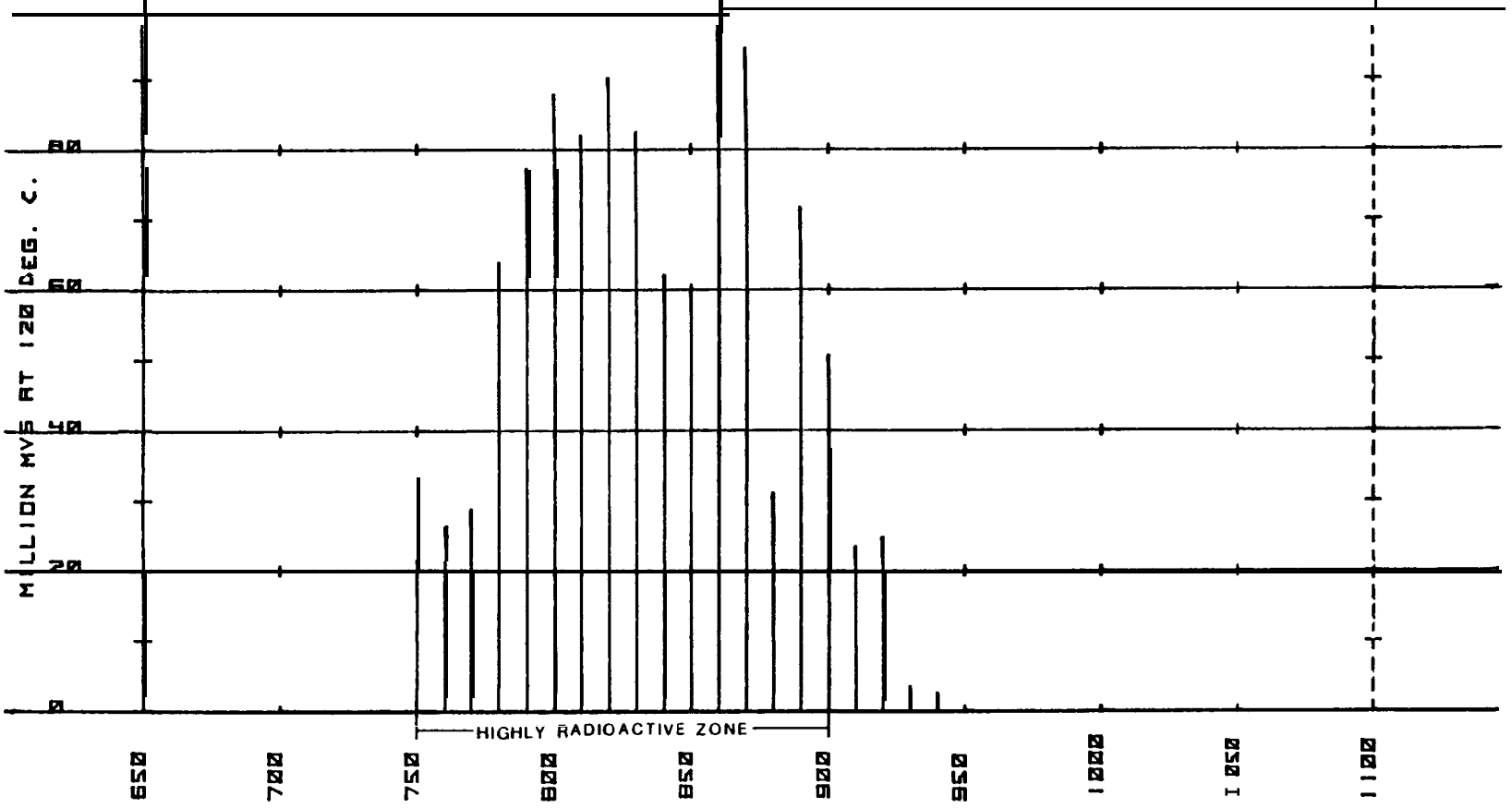


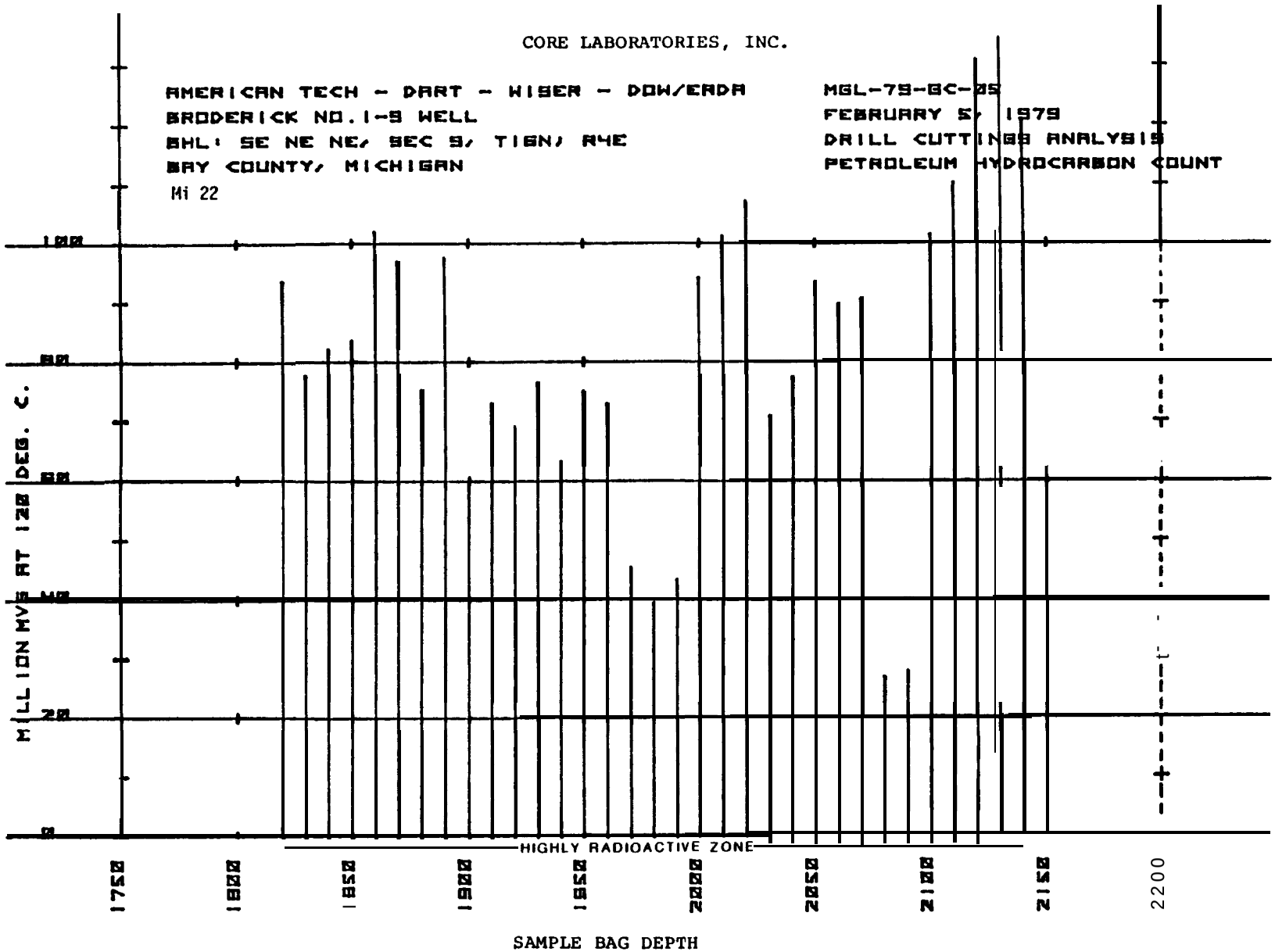

CRYSTAL EXPLORATION - DOW/ERDA
ULRICH NO. 1 WELL
NE NW NW, SEC 13, FOREST T9N, R8E
GENESEE COUNTY, MICHIGAN
Mi 20
MGL-78-GC-120
JANUARY 13, 1979
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
HIGHLY RADIOACTIVE ZONE
1650
1700
1750
1800
1850
1900
1950
2000
2050
2100

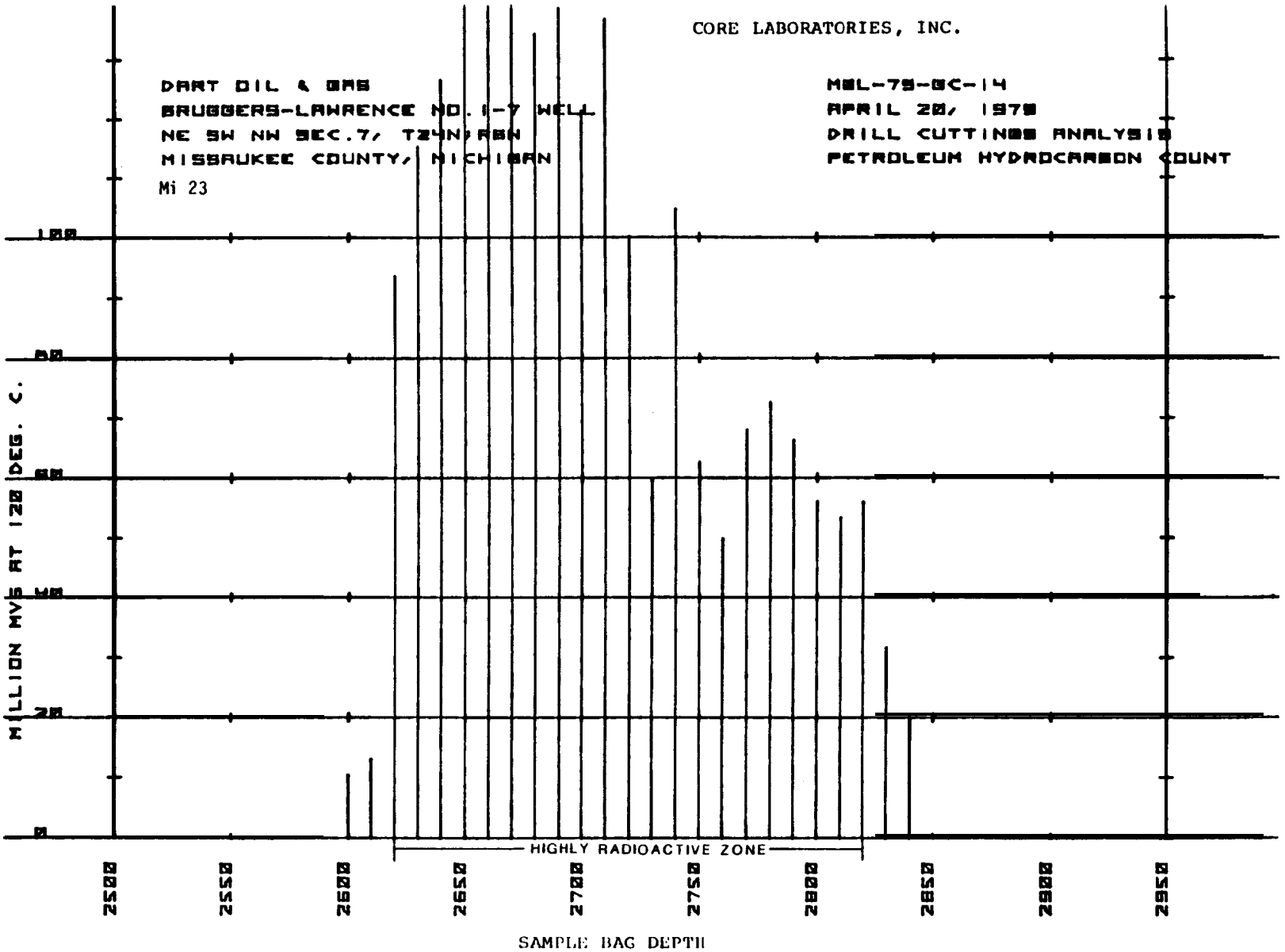
CORE LABORATORIES, INC.

AZTEC - DOW/ERDA
STATE UNIT NO.3-2 WELL
BHL: C E/2 SW, SEC 2, T21N, R17W
MANISTEE COUNTY, MICHIGAN
Mi 21

MGL-79-GC-03
JANUARY 19, 1979
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT



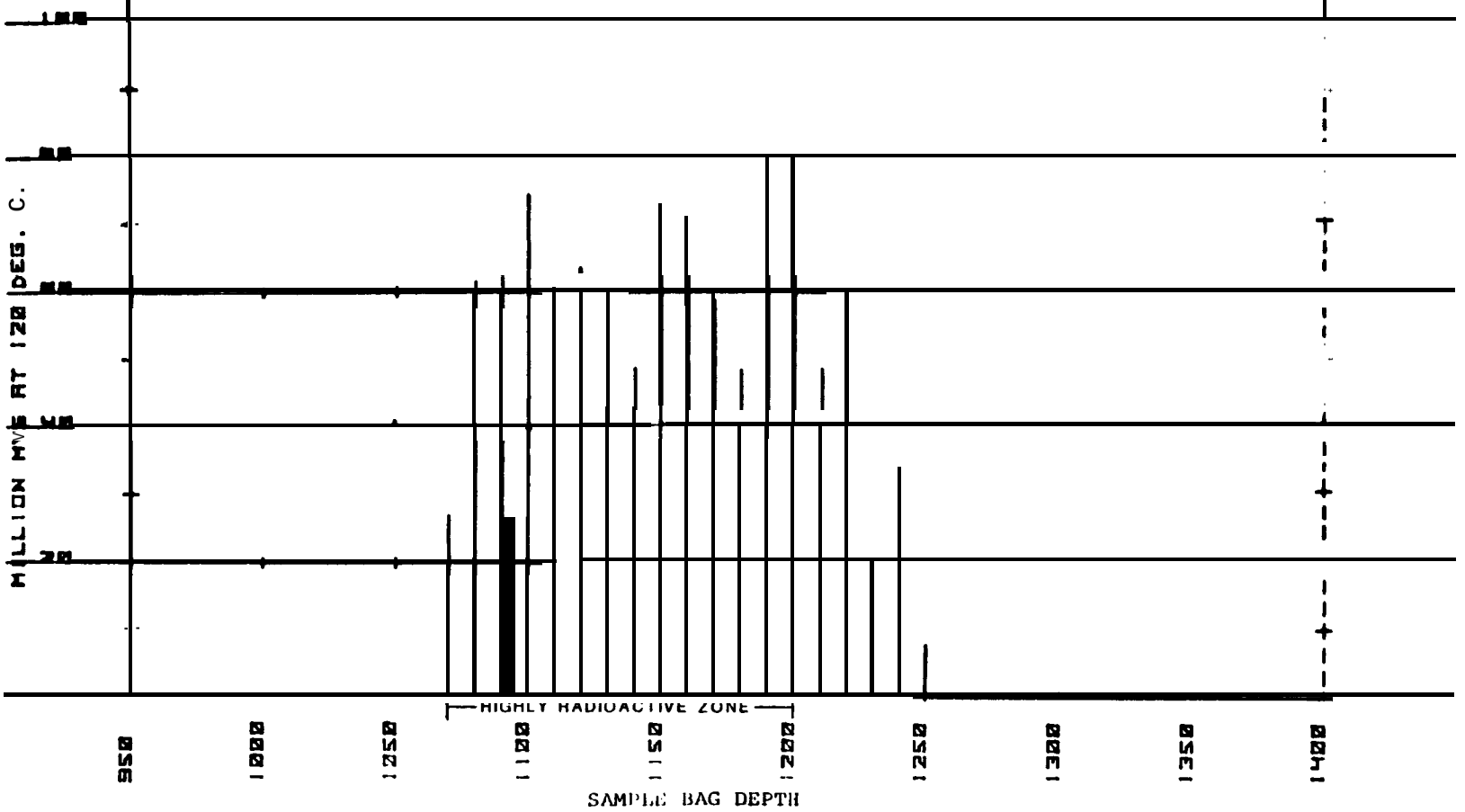

CORE LABORATORIES, INC.
AMERICAN TECH - DART - WISER - DOW/ERDA
BRODERICK NO.1-9 WELL
BHL: SE NE NE, SEC 9, T16N, R4E
BAY COUNTY, MICHIGAN
Mi 22
MGL-79-BC-05
FEBRUARY 5, 1979
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
1750
1800
1850
1900
1950
2000
2050
2100
2150
2200
SAMPLE BAG DEPTH


CORE LABORATORIES, INC.
DART OIL & GAS
BRUGGERS-LAWRENCE NO. 1-7 WELL
NE SW NW SEC.7, T24N, R8W
MISSAUKEE COUNTY, MICHIGAN
Mi 23
MGL-79-GC-14
APRIL 20, 1979
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
2500
2550
2600
2650
2700
2750
2800
2850
2900
2950
SAMPLE BAG DEPTH

CORE LABORATORIES, INC.

REEF PETROLEUM CORPORATION-DOW/D.O.E.
WUSSOW NO.1-1 WELL
SW SW SW, SEC 1, T23N, R15W
MANISTEE COUNTY, MICHIGAN
Mi 24

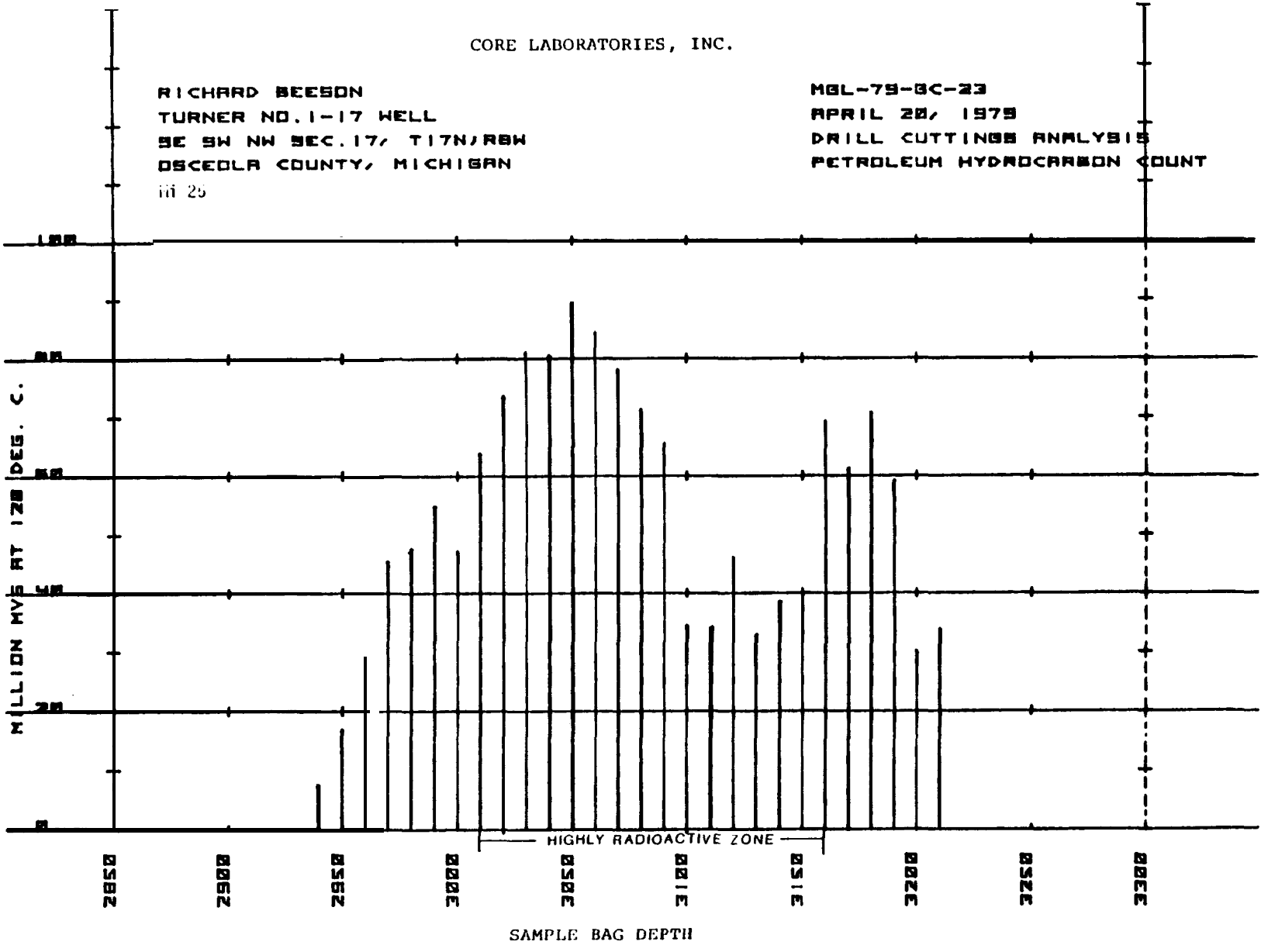
MGL-79-GC-13
MARCH 30, 1979
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT



CORE LABORATORIES, INC.

RICHARD BEESON
TURNER NO.1-17 WELL
SE SW NW SEC.17, T17N,R8W
OSCEOLA COUNTY, MICHIGAN
M 25

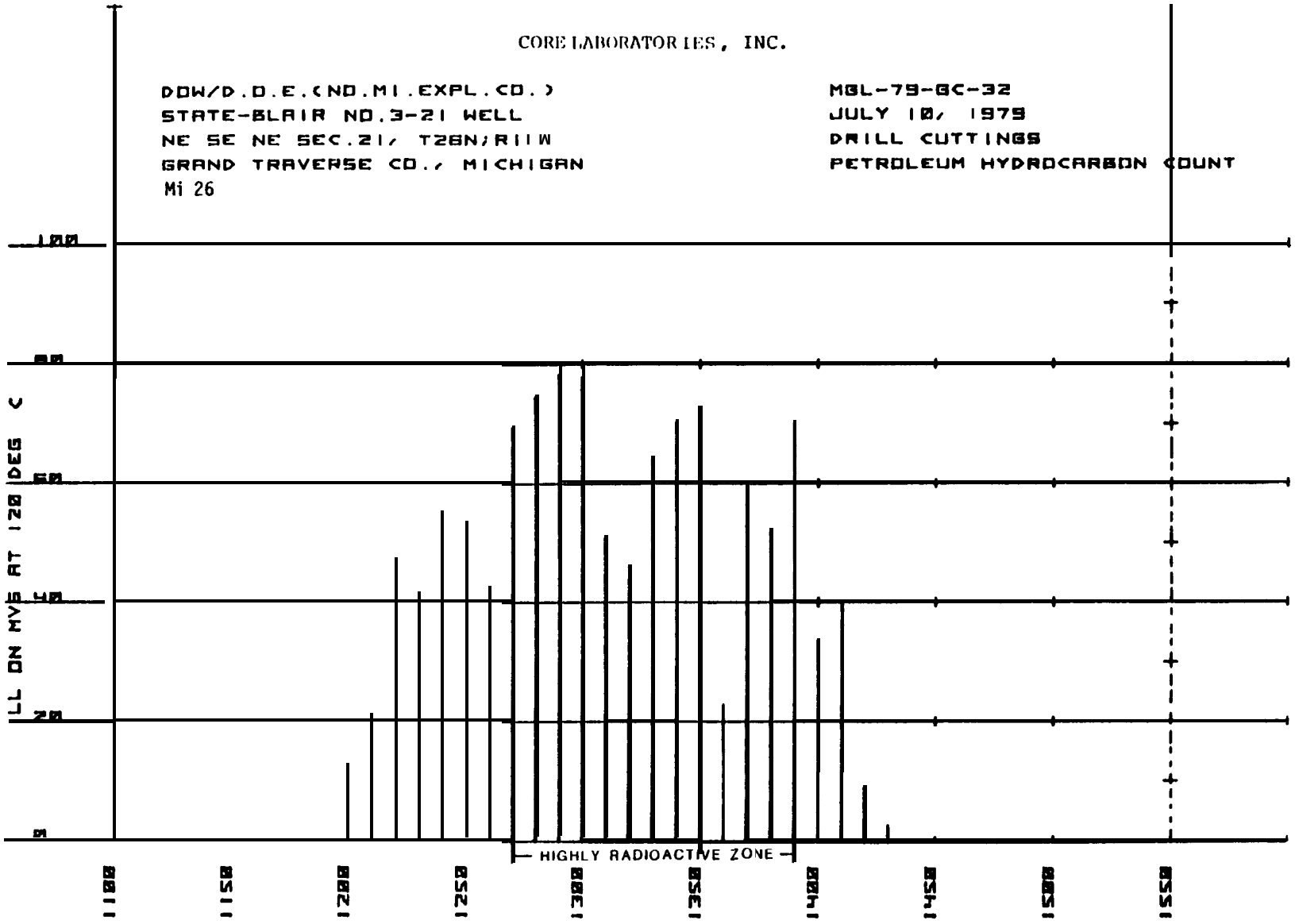
MGL-79-GC-23
APRIL 20, 1979
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT



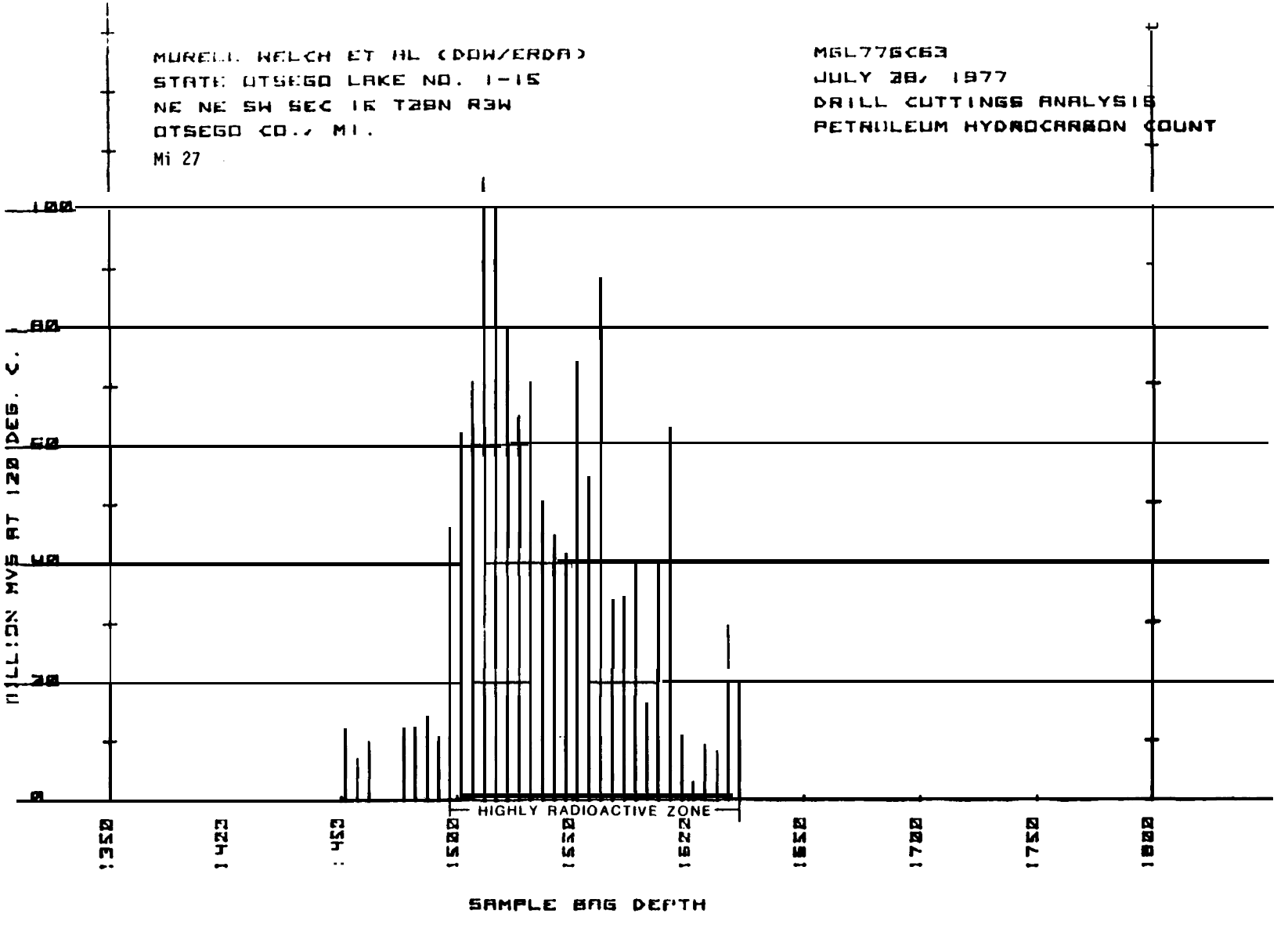
CORE LABORATORIES, INC.

DOW/D.D.E.(ND.MI.EXPL.CO.)
STATE-BLAIR ND.3-21 WELL
NE SE NE SEC.21, T28N,R11W
GRAND TRAVERSE CO., MICHIGAN
Mi 26

MGL-79-GC-32
JULY 10, 1979
DRILL CUTTINGS
PETROLEUM HYDROCARBON COUNT

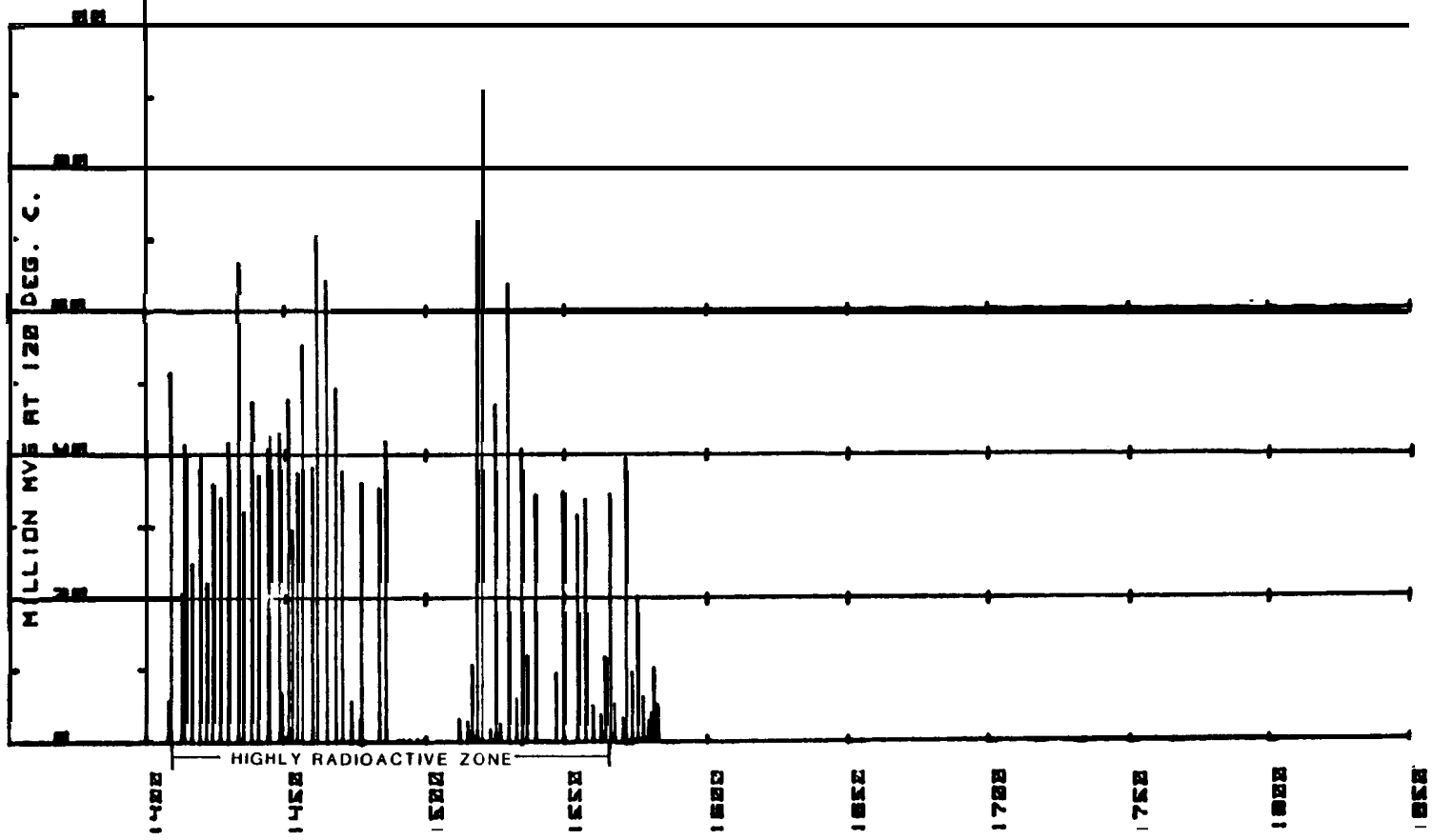


SAMPLE BAG DEPTH


MURELL WELCH ET AL (DOW/ERDA)
STATE OTSEGO LAKE NO. 1-15
NE NE SW SEC 16 T28N R3W
OTSEGO CO., MI.
Mi 27
MGL776C63
JULY 28, 1977
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
HIGHLY RADIOACTIVE ZONE
1350
1400
1450
1500
1550
1600
1650
1700
1750
1800
SAMPLE BAG DEPTH

AMOCO PRODUCTION COMPANY
SWIFT 1-28
SEC 28 SW NE SE T30N R3W
OTSEGO CO., MI.
Mi 28

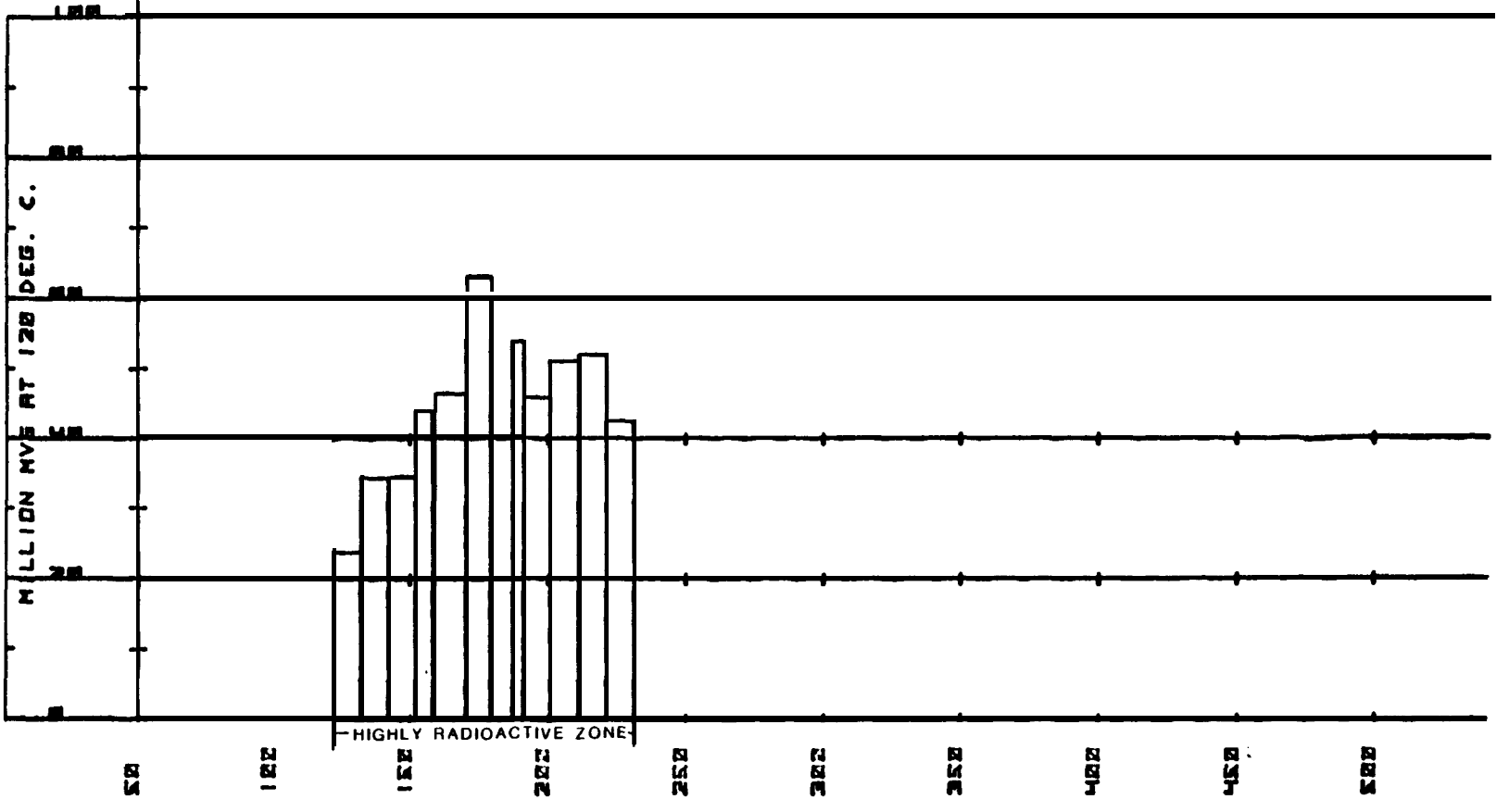
MBL778C78
OCTOBER 11, 1977
CORE CHIPS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.

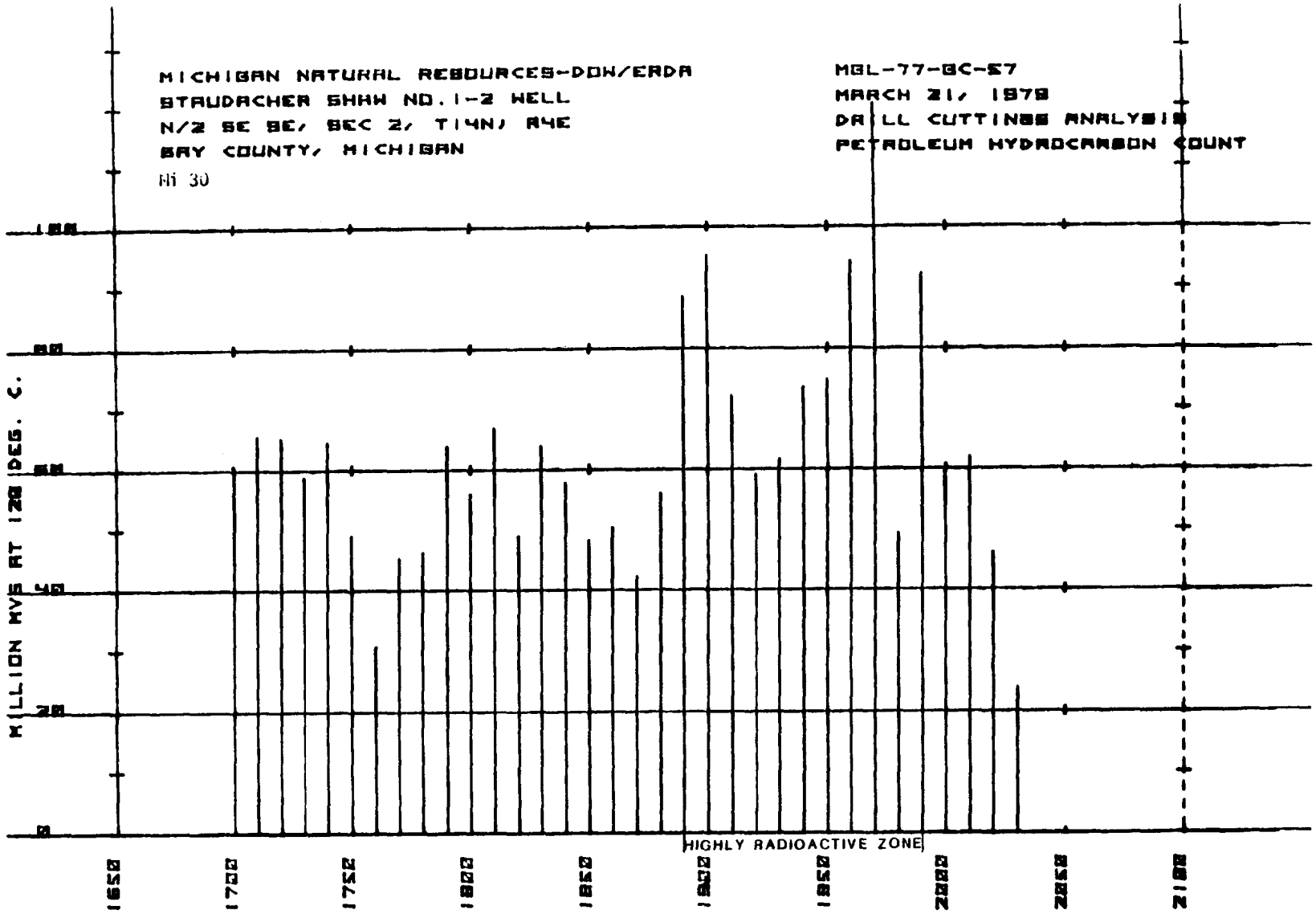


DOW CHEMICAL COMPANY
DOW MOORE 3-21-XII

LAMBTON CO., ONTARIO
Mi 29

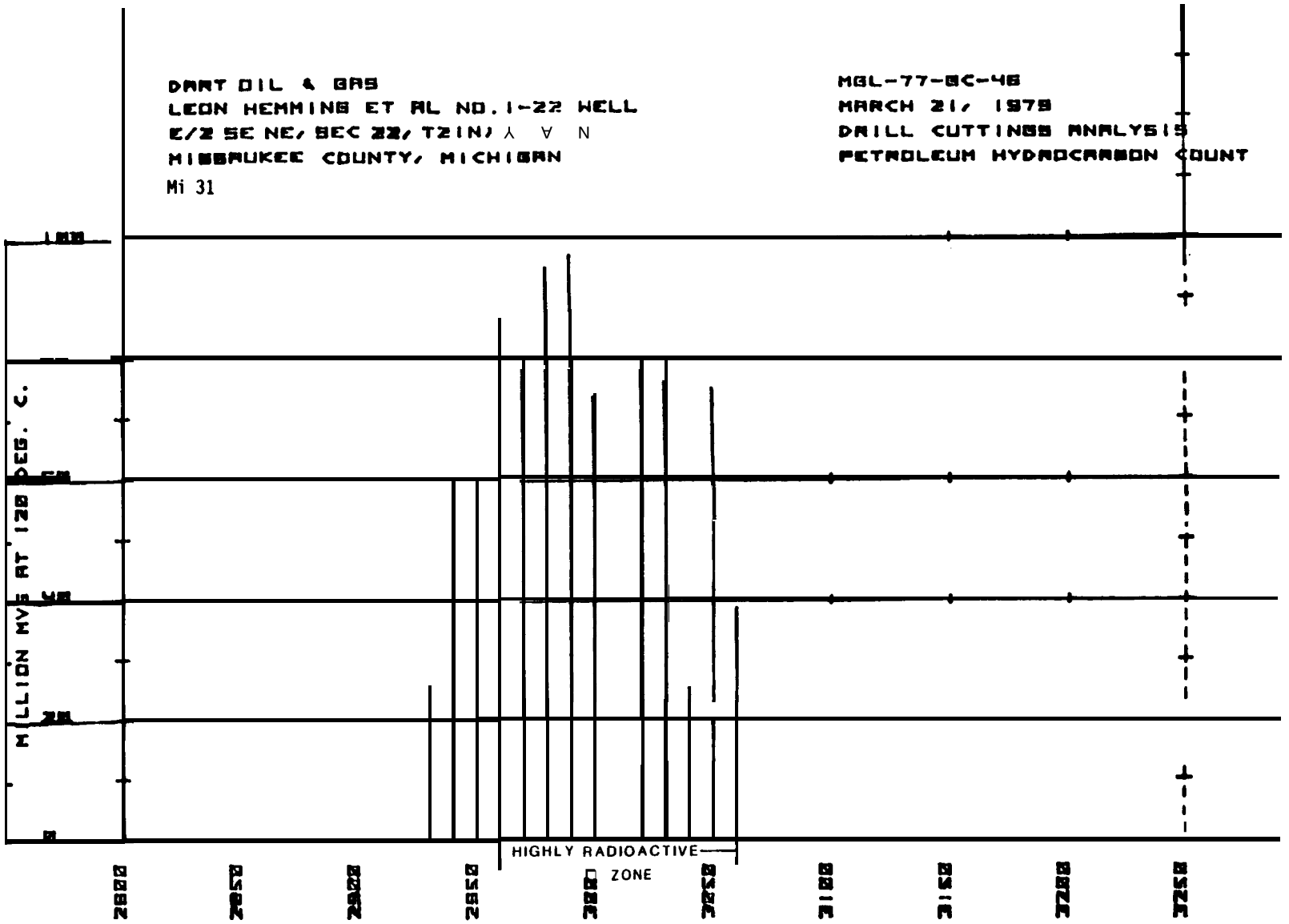
MGL77GC3E
APRIL 28, 1977
DRILL CUTTINGS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.

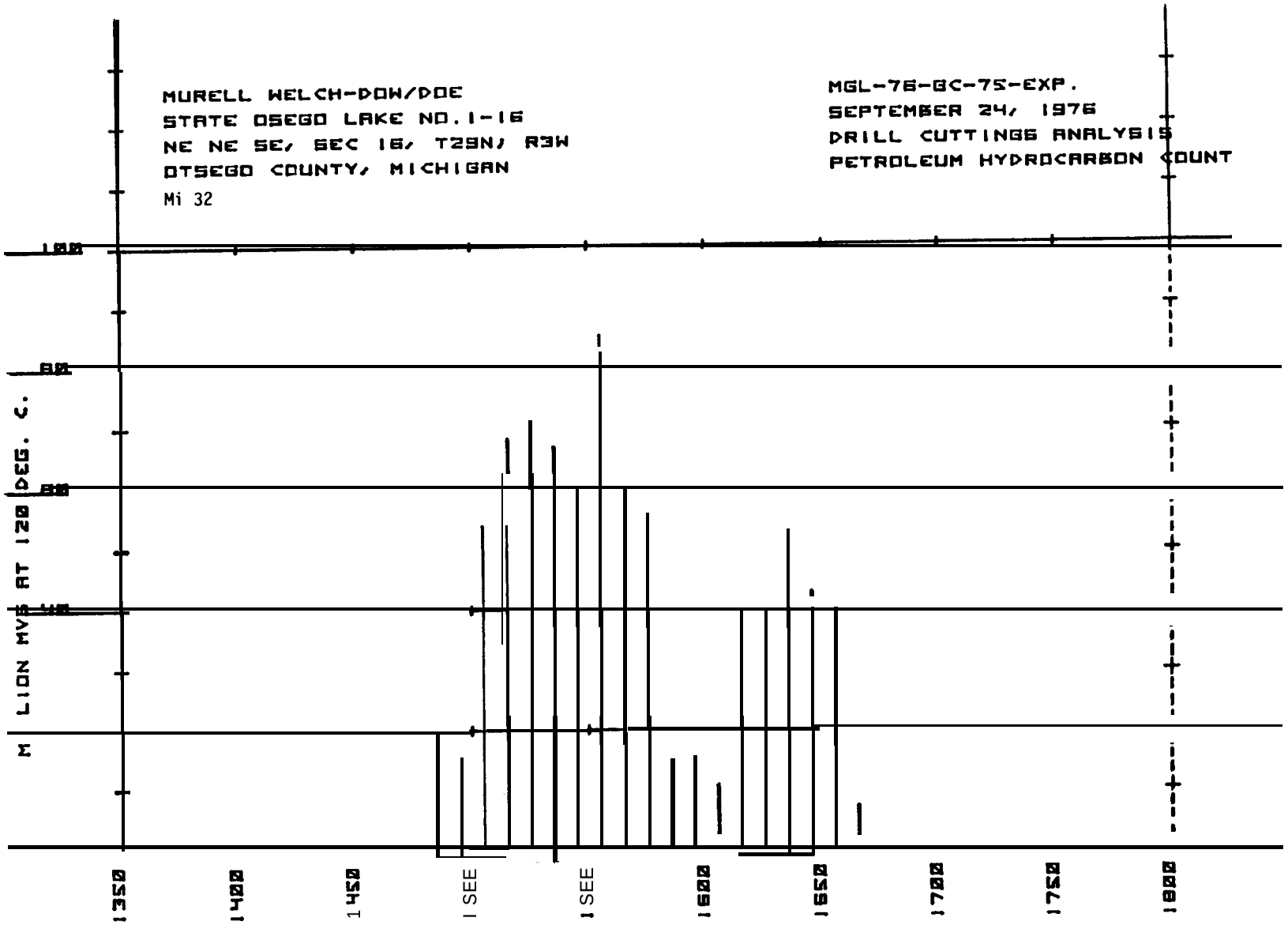



MICHIGAN NATURAL RESOURCES-DOW/ERDA
STAUDACHER SHAW NO.1-2 WELL
N/2 SE SE, SEC 2, T14N, R4E
BAY COUNTY, MICHIGAN
MI 30
MGL-77-GC-57
MARCH 21, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
HIGHLY RADIOACTIVE ZONE
1650
1700
1750
1800
1850
1900
1950
2000
2050
2100

DART OIL & GAS
LEON HEMMING ET AL NO. 1-22 WELL
E/2 SE NE, SEC 22, T21N, λ ∀ N
MILWAUKEE COUNTY, MICHIGAN
Mi 31

MGL-77-GC-46
MARCH 21, 1978
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT

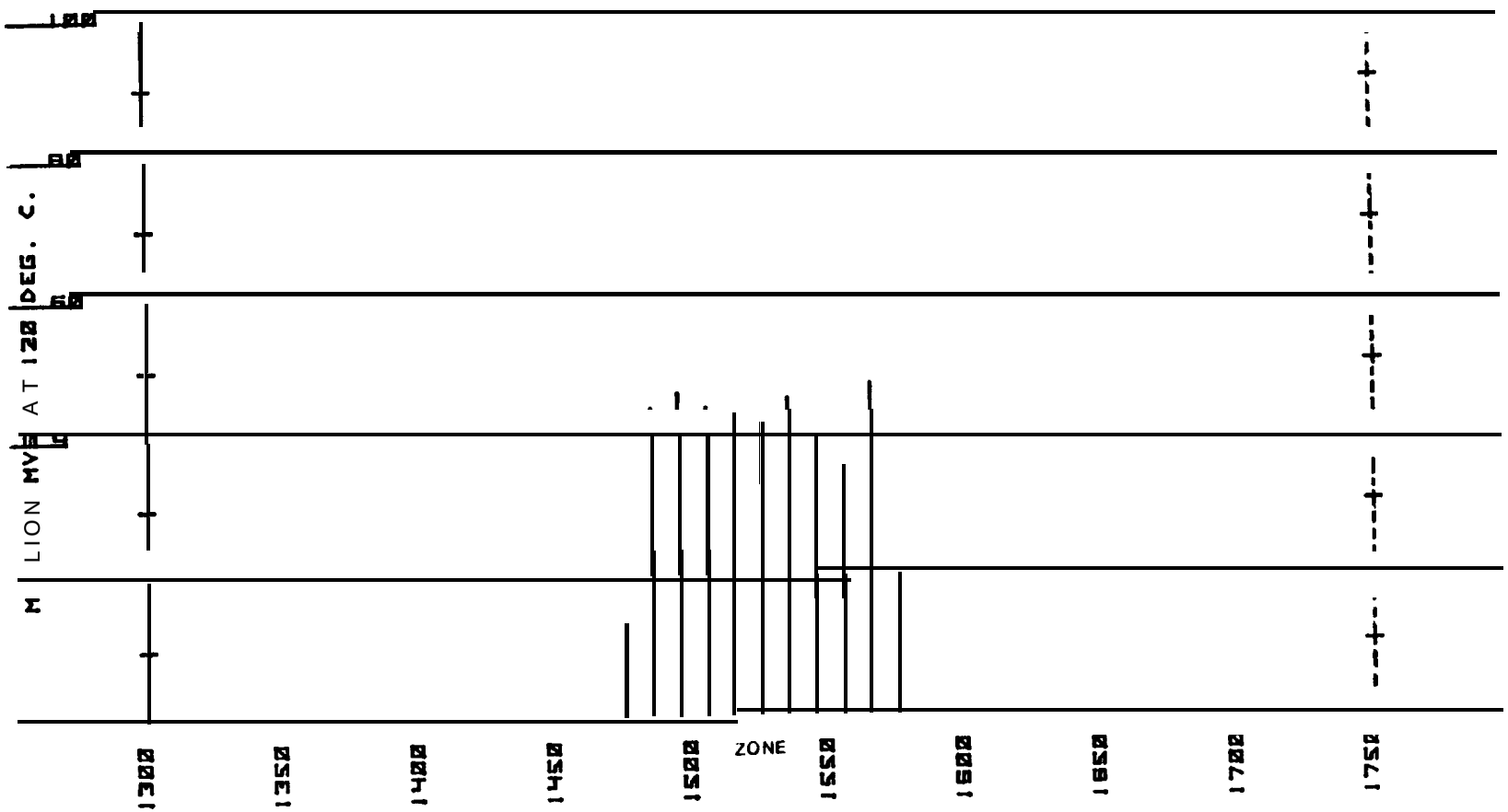


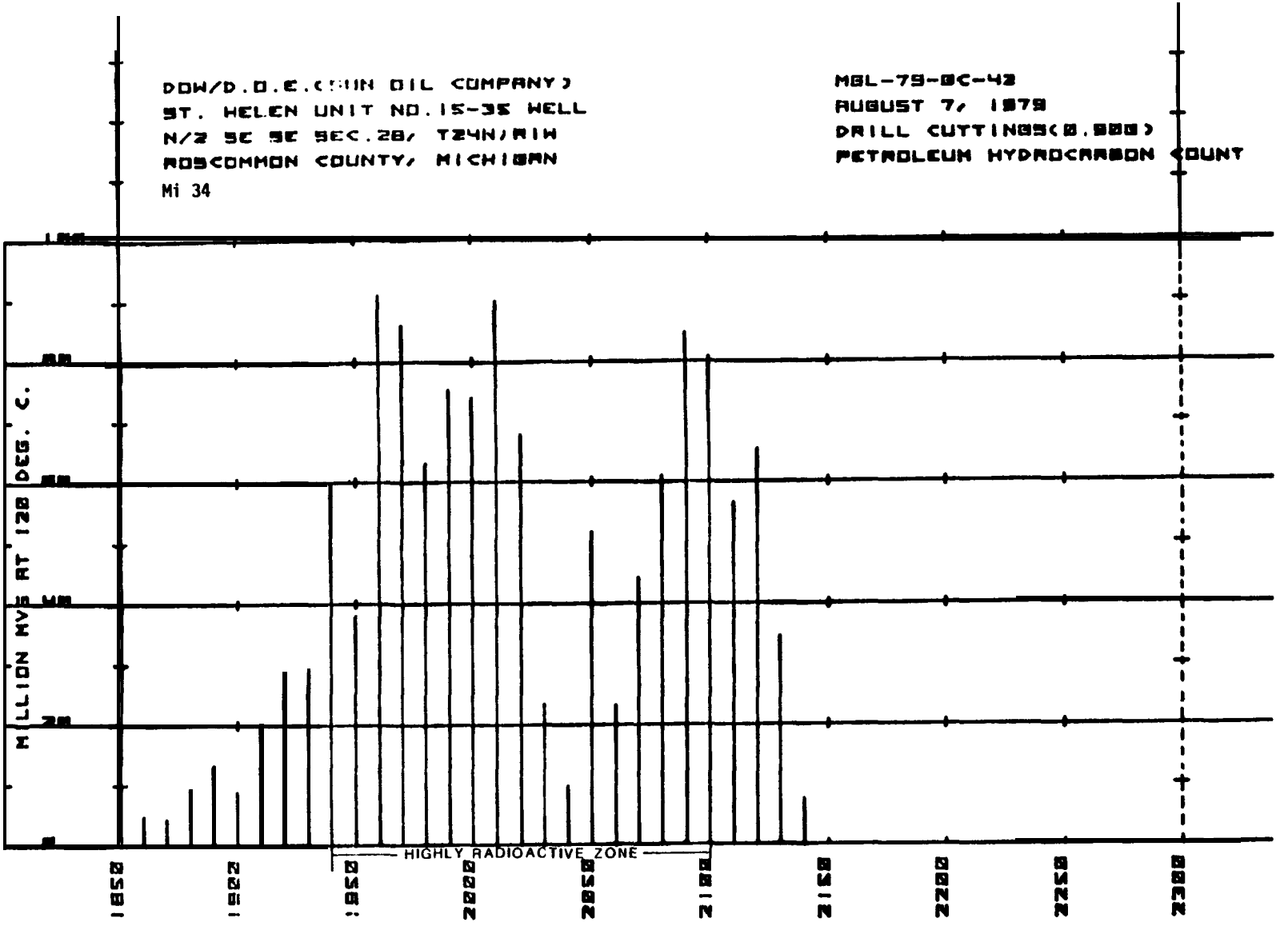

MURELL WELCH-DOW/DOE
STATE OSEGO LAKE NO.1-16
NE NE SE, SEC 16, T29N, R3W
OTSEGO COUNTY, MICHIGAN
Mi 32
MGL-76-GC-75-EXP.
SEPTEMBER 24, 1976
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT
M LION MVS AT 120 DEG. C.
100
80
60
40
1350
1400
1450
1 SEE
1 SEE
1600
1650
1700
1750
1800

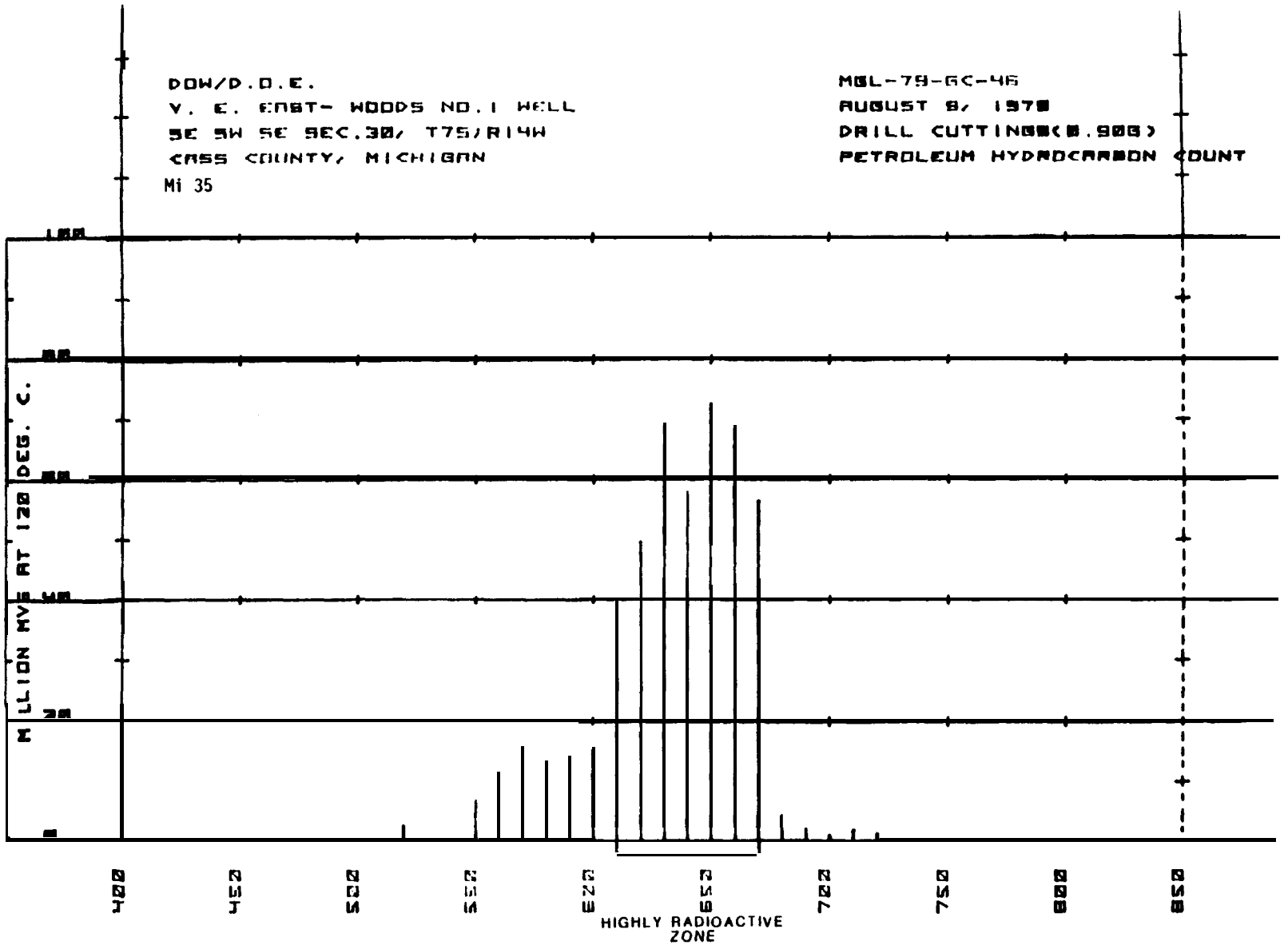
MURELL WELCH-DOW/DOE
STATE OTSEGO LAKE NO.1-22
NE NE NW, SEC 22, T29N, R3W
OTSEGO COUNTY, MICHIGAN

Mi 33

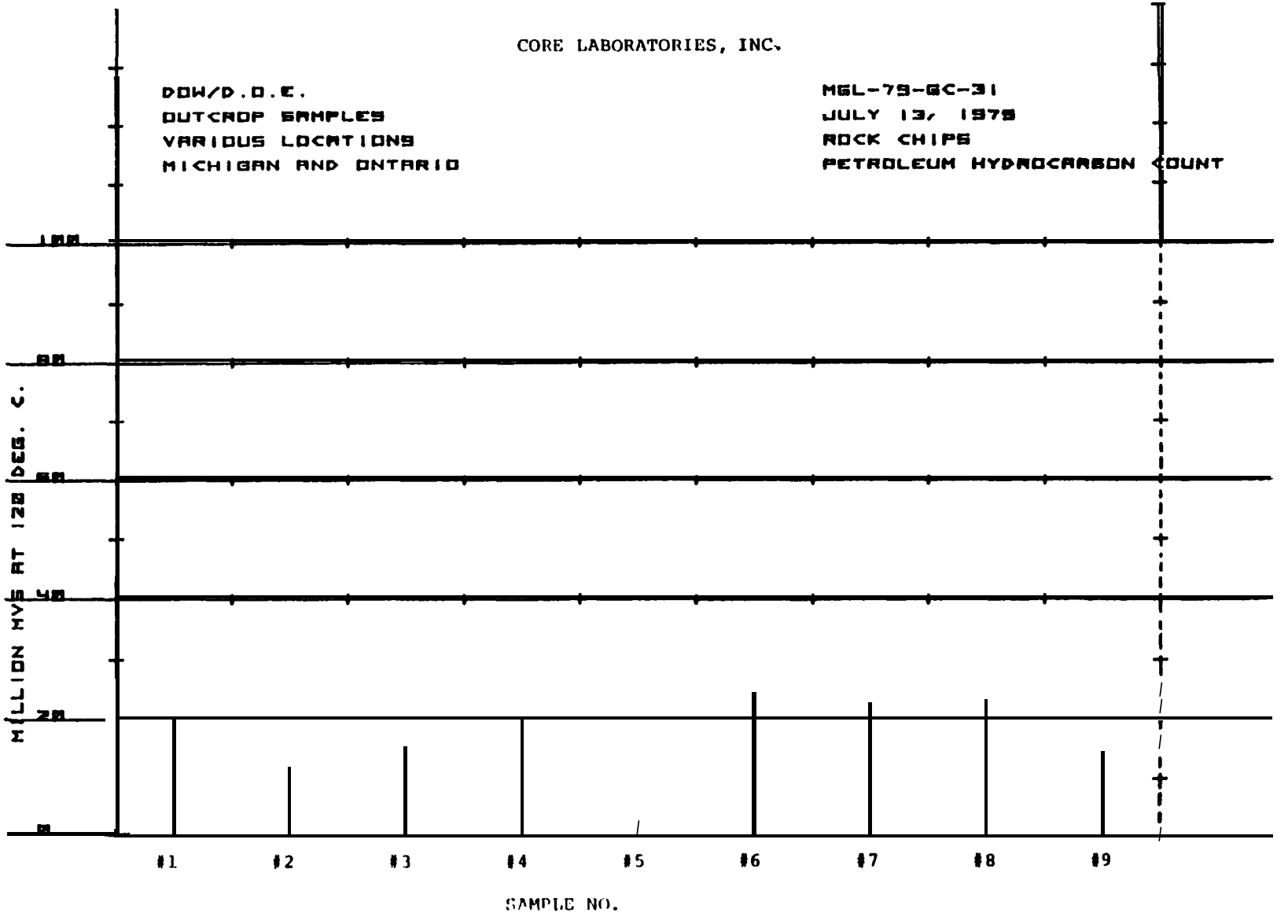
MGL-78-GC-73-EXP
SEPTEMBER 12, 1976
DRILL CUTTINGS ANALYSIS
PETROLEUM HYDROCARBON COUNT




DOW/D.O.E.(SUN OIL COMPANY)
ST. HELEN UNIT NO.15-35 WELL
N/2 SE SE SEC.28, T24N,R1W
ROSCOMMON COUNTY, MICHIGAN
Mi 34
MBL-79-BC-42
AUGUST 7, 1979
DRILL CUTTINGS(0.500)
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
HIGHLY RADIOACTIVE ZONE


DOW/D.O.E.
V. E. EAST- WOODS NO.1 WELL
SE SW SE SEC.30, T7S,R14W
CASS COUNTY, MICHIGAN
Mi 35
MGL-79-GC-46
AUGUST 8, 1978
DRILL CUTTINGS(8.90G)
PETROLEUM HYDROCARBON COUNT
MILLION MVS AT 120 DEG. C.
100
80
60
40
20
0
650
700
750
800
850
HIGHLY RADIOACTIVE ZONE

CORE LABORATORIES, INC.

DOW/D.O.E.
OUTCROP SAMPLES
VARIOUS LOCATIONS
MICHIGAN AND ONTARIO

MGL-79-GC-31
JULY 13, 1979
ROCK CHIPS
PETROLEUM HYDROCARBON COUNT