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Microstructural Analyses of Topopah Spring Tuff from the Large Block Test at Fran Ridge, Nevada

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Lawrence Livermore National Laboratory

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Microstructural Analyses of Topopah Spring Tuff from the Large Block Test at Fran Ridge, Nevada

Eric D. Carlberg and Jeffery J. Roberts

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Introduction

Microstructural information (e.g., porosity, pore size distribution, and surface area) of porous media is critical to understanding water transport mechanisms and physical properties and their bearing on geophysical measurements. We report microstructural data obtained by mercury injection porosimetry (MIP) on 33 samples of densely welded Topopah Spring tuff from Fran Ridge, Yucca Mountain, Nevada Test Site (NTS), Nevada. The characterization of these samples is also important for the interpretation and analysis of the Large Block Test (LBT) performed in support of the Yucca Mountain Project (YMP). This report includes previously published data on samples from the same location (Roberts and Lin, 1996). We also present information from the Yucca Mountain Site Characterization Project/Lawrence Livermore National Laboratory (YMSCP/LLNL) Large Block Test Engineering Plan (Wilder, 1995) to allow correlation of our data directly to various planes within the Large Block.

The Large Block Test

Thorough descriptions of the LBT are available in numerous reports and articles (e.g., Lin et al., 1994; Blair and Wood, 1997; Lin et al., 1997; Ramirez and Daily, 1997; Wilder et al., 1997). Since the purpose of this paper is to report detailed microstructural results, only a brief description of the test is presented here.

Location of the Large Block Test, borehole nomenclature, and sampling

The LBT is a coupled thermo-hydrological-mechanical-chemical field test of a 3 meter square by 5 meter tall block of densely welded Topopah Spring Tuff. The block is located on an eastern facing slope at Fran Ridge, Nevada, at the Nevada Test Site. Prior to excavation of the Large Block, detailed fracture mapping of the surface was performed in an effort to find the best location for the test. Vertical boreholes were drilled with nearly continuous coring after an area with suitable fracture density was located and roughly graded with a bulldozer (Fig. 1).

An approximately 3 meter square (10 foot by 10 foot) horizontal aluminum template was positioned over the site as a borehole guide. All borehole depths are reported as depth below this template. The template was not parallel to the uneven rock surface, thus, the cores for each borehole start at a different depth. The elevation of the template as well as the borehole elevations at the final cut block were surveyed (Table 1).

Borehole designations correlate to a borehole diameter (N=3 inch or 7.6 cm; E=1.5 inch or 3.8 cm) and a sequential number. Boreholes were renamed after final excavation of the Large Block to reflect location and use (e.g., N1 became TN1 for Top Neutron 1; see Table 1 for remaining names).

Video logging of boreholes was performed, the videos examined and described in detail (Wagoner, 1999). Recovered core was logged and packaged at the YMP Sample Management Facility (SMF) at the NTS. Representative sections from each hole were sent to LLNL (nearly 12 meters of the approximately 45 meters total recovered core). Samples for laboratory core plug tests and microstructural analyses were selected and prepared. Samples with large cavities and inhomogeneous inclusions were excluded from these tests. Subcores were sent to an outside facility for MIP testing while gravimetric analyses as described by Roberts and Lin (1996) were conducted on other samples from approximately the same location as the subcores. Gravimetric test data including dry density, wet density and porosity from Roberts and Lin (1996) are presented in Table 2.

Results and Discussion

Since our data are from boreholes that predate the final excavation of the Large Block, Table 3 is provided to allow cross referencing of our data to significant horizons within the block. Table 4 contains summary data for each sample where MIP testing was conducted.

The appendix contains the plots of incremental pore surface and incremental pore volume. Some plots were not available due to the lack of electronic data. Each data table lists the incremental values for pressure, pore diameter, intrusion volume of mercury, pore surface area, as well as the mean and standard deviation for pore diameter. In Table 4 we report total pore area, median pore diameter by volume, median pore diameter by area, average pore diameter by 4V/A where V is volume and A is area, bulk density, skeletal density, and porosity as determined by mercury injection porosimetry.

Mercury Injection Porosimetry

Mercury injection porosimetry is a commonly used tool for the analysis of microstructural properties of porous media, including rocks and soils. Since mercury is a non-wetting fluid (for most materials), it is forced into the pore space by applying pressure rather than by capillary action. By accurately measuring pressure and volume of mercury incrementally intruded into a sample, information is obtained regarding the porosity and pore size distribution in the sample. The simplest equation to model the rate of capillary penetration into a porous medium is attributed to Washburn (1921; cited in Dullien, 1992). Simply stated, the equation describes how far the meniscus of a fluid penetrates into a capillary for a given pressure differential.

Bulk volume of a sample is determined by immersion of the sample in mercury (Dullien, 1992). After evacuating the sample vessel, hydrostatic pressure is incrementally increased. At each pressure, the size and total volume of pores invaded by mercury is calculated. The maximum pressure is 60,000 psia (414 MPa). At this pressure, only a very small amount of the pore space remains unfilled by the mercury. Penetration is never quite complete because it would take infinite pressure to perfectly fill all the edges and corners of the pores (Dullien, 1992).

Total pore area is the surface area within the pores based on the assumption of cylindrical pore geometry and summing over the pressure range of mercury injection into the pores. Median pore diameters are taken as the 50% values from the pressure vs. area and volume curves (assuming cylindrical pores). By comparing the cumulative pore surface area vs. pore diameter and the cumulative pore volume vs. pore diameter plots, it can be seen that area distribution tends to shift towards the smaller pore sizes when

compared to the volume distribution. This is caused by the relatively larger contribution to surface area made by small pores.

Average pore diameter by 4V/A is calculated by dividing the formulas for volume and area then solving for diameter. Equation 1 gives the formula for the volume (V) of a cylindrical pore having diameter (d) and length (h); Equation 2 gives the cross-sectional area (A) of such a pore. Therefore, the pore diameter can be estimated using equation 3.

$$V = \pi d^2 h/4 \qquad (1)$$

$$A = \pi dh \qquad (2)$$

$$d = 4V/A \qquad (3)$$

Bulk density (ρ_{bulk}) is calculated using the sample weight together with the sample volume obtained during initial filling of the mercury porosimeter chamber. Skeletal density ($\rho_{skeletal}$) is determined by adjusting the bulk density for the volume of the injected mercury (Hg inj);

$$\rho_{skeletal} = \rho_{bulk} - (M_{Hg\ inj}/ V_{sample}), \qquad (4)$$

where M is mass.

Statistical Analyses

For 33 samples tested, mean total pore area is 7.3715 ±1.5795 m^2/g. Skeletal density mean value is 2.5591 ±0.0456 g/cm^3. With few exceptions, MIP data closely match gravimetric data in Table 2. Bulk density by MIP results provide a mean value of 2.2633 ±0.0596 g/cm^3. Compare this to gravimetric results from Table 2 which has a mean dry density of 2.25 ±0.03 g/cm^3. Mean porosity from Table 2 is 0.104 ±0.013 as compared to MIP results which is 0.1154 ±0.0228. Sample N1-13.4 was resubmitted due to suspect data; secondary testing results are reported as sample N1-13.4b (Table 4). Mean and standard deviation data exclude sample N1-13.4a. Refer to Tables 2 and 4 as well as appendix data for further analysis.

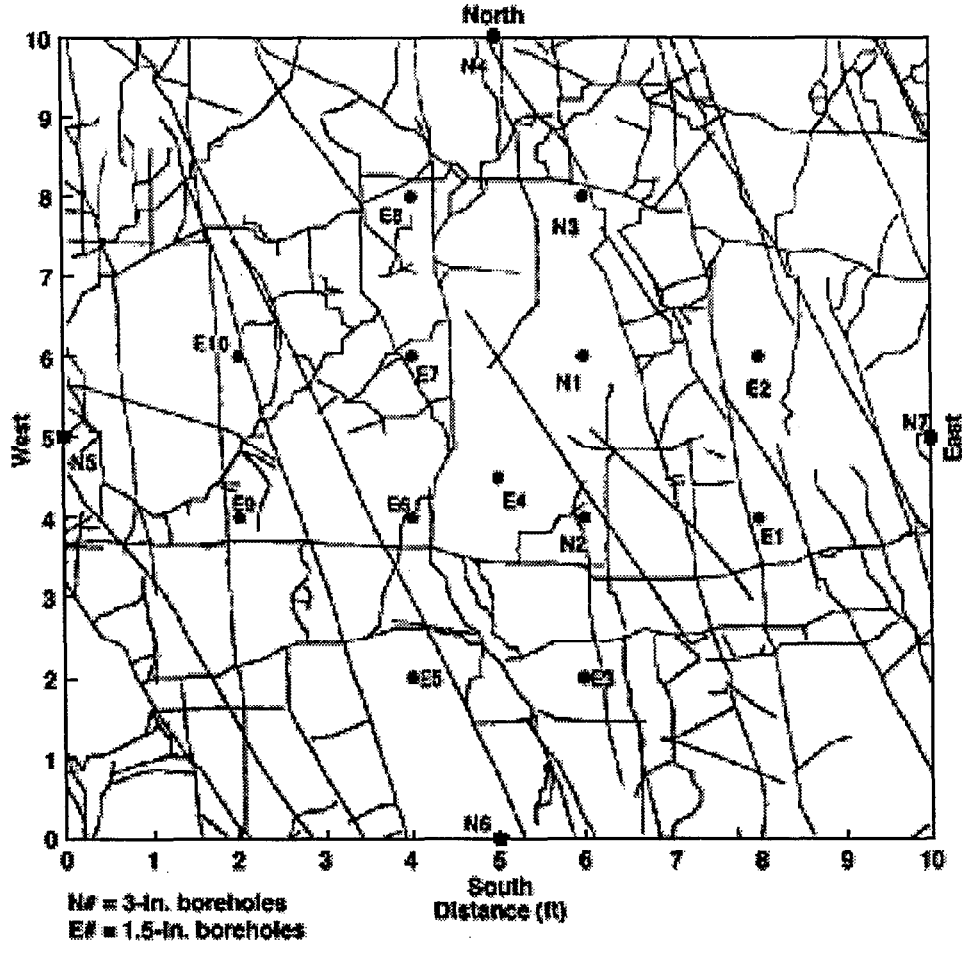


Figure 1 Fracture map of the top surface of large block with top borehole locations (Wilder et al., 1997).

Table 1. Borehole Names and Elevations

Borehole[1]	LBT borehole reference	Distance, template to rock surface[2]		Surface elevation[3]		Surveyed final elevation[4]	
		(feet)	(meters)	(feet)	(meters)	(feet)	(meters)
N1	TH1	0.30	0.09	3417.40	1041.62	3416.34	1041.30
N2	TM1	0.56	0.17	3417.14	1041.54	3416.32	1041.29
N3	TM2	0.53	0.16	3417.17	1041.55	3416.35	1041.30
N4	TERT1 (N rockbolt)	0.37	0.11	3417.33	1041.60	3416.37	1041.31
N5	TERT16 (W rockbolt)	0.42	0.13	3417.28	1041.59	3416.37	1041.31
N6	TERT11 (S rockbolt)	0.28	0.09	3417.42	1041.63	3416.36	1041.31
N7	TERT25 (E rockbolt)	1.00	0.30	3416.70	1041.41	3416.38	1041.31
E2	TN4	0.56	0.17	3417.14	1041.54	3416.34	1041.30

[1] Prefix N is for a 3 inch borehole; E is for 1.5 inch hole.

[2] Surveyed template elevation was 3417.7 ft (1041.71 m) at all boreholes.

[3] Surveyed elevation of rough surface prior to cutting of the Large Block.

[4] Surveyed final elevation is in reference to the cut surface of the Large Block.

Table 2. LBT Samples Prepared for Moisture Retention Experiments (Roberts and Lin, 1996)

Sample†	Sample ID	Depth, m	Dry wt, g	Wet wt, g	Dry density, g/cm^3	Wet density, g/cm^3	Porosity
N1-6.3	0032079.3	1.92	1.5352	1.6111	2.23	2.35	0.110
N1-6.3A	0032079.3A	1.92	1.7890	1.8680	2.26	2.36	0.0997
N1-6.3B	0032079.3B	1.92	1.6358	1.7098	2.28	2.39	0.103
N1-11.0	0032081.3	3.35	1.6352	1.7181	2.25	2.37	0.114
N1-11.0A	0032081.3A	3.35	1.5920	1.6734	2.26	2.38	0.116
N1-11.0B	0032081.3B	3.35	1.6762	1.7525	2.30	2.41	0.105
N1-13.45	0032082.3	4.10	1.4982	1.5752	2.27	2.39	0.117
N1-13.45A	0032082.3A	4.10	1.7118	1.7951	2.27	2.38	0.110
N1-13.45B	0032082.3B	4.10	1.6954	1.7781	2.26	2.37	0.110
N1-16.9	0032083.3	5.15	1.6499	1.7522	2.20	2.33	0.136
N1-16.9A	0032083.3A	5.15	1.6094	1.6987	2.23	2.35	0.124
N1-16.9B	0032083.3B	5.15	1.6885	1.7670	2.27	2.38	0.106
N1-20.3	0032084.3	6.19	1.5438	1.6133	2.22	2.32	0.0998
N1-20.3A	0032084.3A	6.19	1.5567	1.6244	2.26	2.36	0.0982
N1-20.3B	0032084.3B	6.19	1.5109	1.5849	2.21	2.32	0.108
N4-11.6	0032104.3	3.54	1.5429	1.6036	2.26	2.34	0.0887
N4-11.6A	0032104.3A	3.54	1.6222	1.6864	2.24	2.33	0.0886
N4-11.6B	0032104.3B	3.54	1.6375	1.6969	2.27	2.35	0.0823
N5-4.9	0032107.3	1.49	1.6998	1.7687	2.25	2.34	0.0911
N5-4.9A	0032107.3A	1.49	1.6501	1.7104	2.28	2.37	0.0834
N5-4.9B	0032107.3B	1.49	1.8818	1.9569	2.31	2.40	0.0922
N5-20.4	0032111.3	6.22	1.5230	1.5909	2.22	2.32	0.0992
N5-20.4A	0032111.3A	6.22	1.4883	1.5593	2.21	2.32	0.106
N5-20.4B	0032111.3B	6.22	1.4765	1.5463	2.22	2.32	0.105
N6-4.75	0032112.3	1.43	1.7549	1.8228	2.25	2.33	0.0869
N6-4.75A	0032112.3A	1.43	1.6761	1.7374	2.29	2.37	0.0837
N6-4.75B	0032112.3B	1.43	1.7136	1.7755	2.27	2.35	0.0819
N6-14.2	0032116.3	4.33	1.6590	1.7398	2.26	2.37	0.110
N6-14.2A	0032116.3A	4.33	1.6869	1.7706	2.24	2.35	0.111
N6-14.2B	0032116.3B	4.33	1.6285	1.7137	2.23	2.35	0.117
N7-5.7	0032120.3	1.74	1.6161	1.7003	2.24	2.36	0.117
N7-5.7A	0032120.3A	1.74	1.6320	1.7051	2.29	2.39	0.102
N7-5.7B	0032120.3B	1.74	1.7091	1.7834	2.28	2.38	0.0991
N7-11.0	0032123.3	3.35	1.5850	1.6705	2.25	2.37	0.121
N7-11.0A	0032123.3A	3.35	1.6353	1.7171	2.26	2.38	0.113
N7-11.0B	0032123.3B	3.35	1.6318	1.7112	2.27	2.38	0.110
mean *	36 samples				2.25±0.03	2.36±0.02	0.104±0.013

† Sample name consists of borehole designation followed by depth in feet below the template used to locate vertical boreholes.

* Statistical mean for 36 samples. Errors represent one standard deviation for all samples collectively.

Table 3. Cross References for Borehole Data to Large Block Horizons

Horizon	Surveyed elevation		Borehole depth below template		Large Block reference depth	
	(feet)	(meters)	(feet)	(meters)	(feet)	(meters)
Template	3417.7	1141.7	0	0	N/A	N/A
Top of LB	3416.3	1141.29	1.4	0.43 m	0	0
Heated plane	N/A		10.4	3.17	-9	-2.74
Bottom of LB	N/A		15.4	4.69	-14	-4.27

Table 4. Mercury Injection Porosimetry Summary Data

Sample†	Total pore area (m^2/g)	Median pore diameter by volume (μm)	Median pore diameter by area (μm)	Average pore diameter by 4V/A (μm)	Bulk density (g/cm^3)	Skeletal density (g/cm^3)	Porosity
N1-5.7 to 6.3	4.6429	0.0932	0.0080	0.0350	2.3372	2.5825	0.0950
N1-10.9 to 11.5	6.9868	0.0611	0.0171	0.0345	2.2427	2.5930	0.1351
N1-11.0	8.8620	0.0303	0.0148	0.0224	2.3089	2.6081	0.1148
N1-13.4a	8.3196	37.8102	0.0180	0.0931	1.7272	2.5948	0.3344
N1-13.4b	9.6257	0.0272	0.152	0.0207	2.3102	2.6113	0.1153
N1-16.9	4.0976	0.2434	0.0116	0.0589	2.2421	2.5927	0.1352
N1-20.3	11.1302	0.0513	0.0063	0.0212	2.2239	2.5595	0.1311
N2-4.0	5.5900	0.1616	0.0071	0.0367	2.2850	2.5883	0.1172
N2-4.3	8.7110	0.0383	0.0070	0.0169	2.2967	2.5088	0.0845
N2-11.1	8.2266	0.0570	0.0075	0.0231	2.2461	2.5150	0.1069
N2-11.25	5.8431	0.1435	0.0073	0.0362	2.2900	2.6057	0.1211
N2-13.9	6.3615	0.2336	0.0071	0.0469	2.1707	2.5894	0.1617
N2-19.2	8.4895	0.0480	0.0085	0.0224	2.2567	2.5277	0.1072
N3-4.5	5.4111	0.2110	0.0068	0.0389	2.2894	2.6029	0.1204
N3-4.75	6.9874	0.0665	0.0081	0.0263	2.2555	2.5167	0.1038
N3-11.0	9.0228	0.0728	0.0073	0.0227	2.3177	2.6305	0.1189
N3-15.2	7.2965	0.1026	0.0074	0.0325	2.2679	2.6196	0.1343
N3-20.4	9.4214	0.0339	0.0087	0.0187	2.2528	2.5019	0.0996
N4-5.3	8.9013	0.0544	0.0059	0.0200	2.2611	2.5135	0.1004
N4-11.6	6.9084	0.0505	0.0084	0.0235	2.2616	2.4903	0.0918
N4-14.5	6.0849	0.1298	0.0075	0.0316	2.3096	2.5983	0.1111
N4-19.0	7.4861	0.0456	0.0125	0.0266	2.2459	2.5281	0.1116

Table 4 (cont'd). Mercury Injection Porosimetry Summary Data

Sample†	Total pore area (m^2/g)	Median pore diameter by volume (μm)	Median pore diameter by area (μm)	Average pore diameter by 4V/A (μm)	Bulk density (g/cm^3)	Skeletal density (g/cm^3)	Porosity
N5-4.9	6.5621	0.0476	0.0085	0.0232	2.3276	2.5534	0.0884
N5-11.15	5.7744	0.0889	0.0082	0.0360	2.2889	2.5981	0.1190
N5-14.8	5.9586	0.0911	0.0087	0.0378	2.2465	2.5717	0.1265
N5-20.1	9.2912	0.0457	0.0076	0.0196	2.2422	2.4963	0.1018
N6-4.8	7.6122	0.0371	0.0078	0.0188	2.3001	2.5065	0.0823
N6-11.0	6.6135	0.0515	0.0106	0.0275	2.2825	2.5464	0.1036
N6-14.5	6.4598	0.1186	0.0065	0.0338	2.2666	2.5861	0.1235
N6-20.2	8.7303	1.0908	0.0062	0.0464	1.9941	2.4982	0.2018
N7-5.0	8.1133	0.0536	0.0071	0.0212	2.2718	2.5177	0.0977
N7-10.9	6.4128	0.0682	0.0105	0.0310	2.3060	2.6045	0.1146
N7-14.3	7.2915	0.0543	0.0146	0.0301	2.2768	2.6013	0.1248
E2-19.5	8.3521	0.0552	0.0086	0.0235	2.2147	2.4850	0.1087
mean*	7.3715 ±1.5795				2.2633 ±0.0596	2.5591 ±0.0456	0.1154 ±0.0228

† Sample name consists of borehole designation followed by depth in feet below the template used to locate vertical boreholes.

* Statistical mean for 33 samples. Errors represent one standard deviation for all samples collectively. Sample N1-13.4a has been excluded from statistical analyses.

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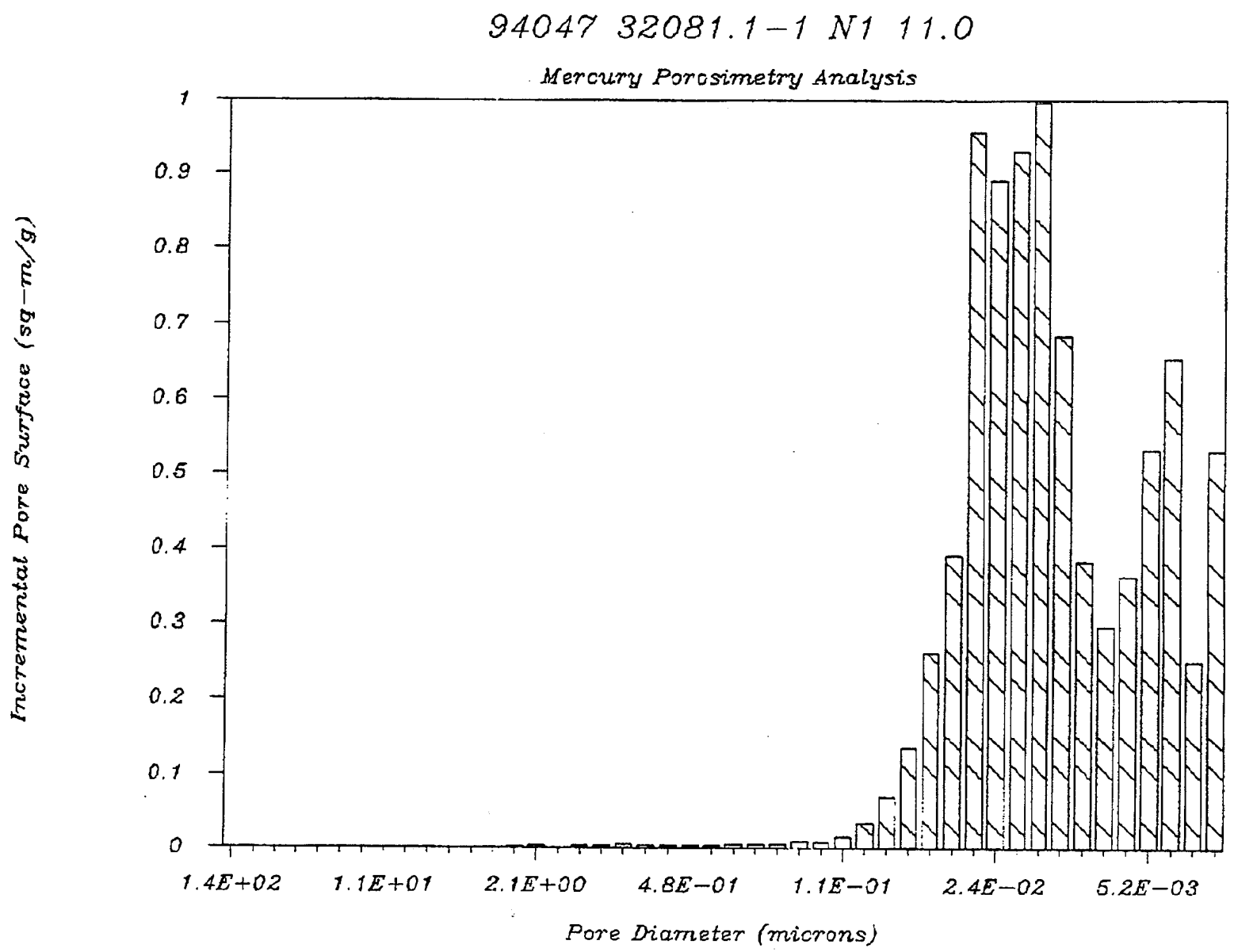
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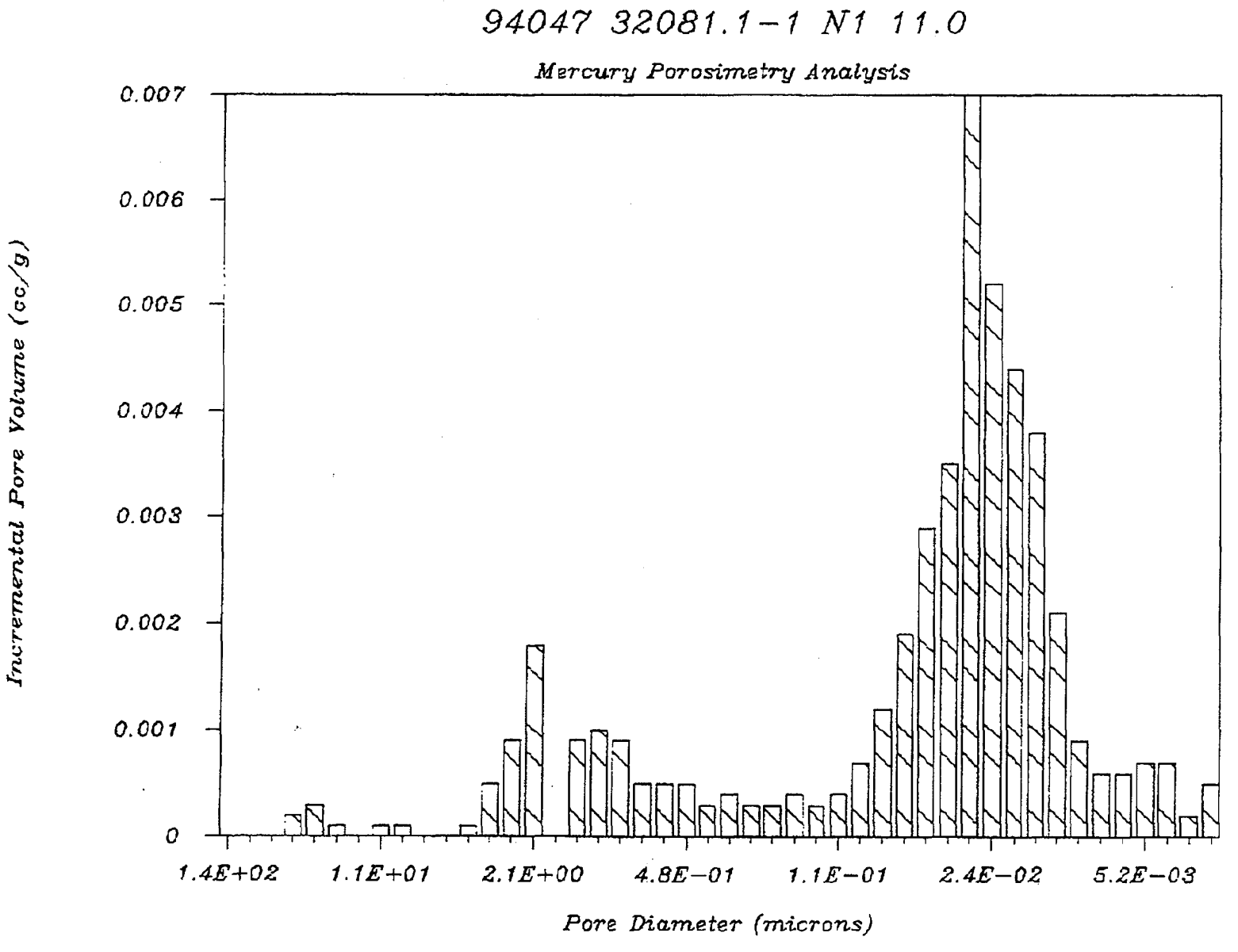
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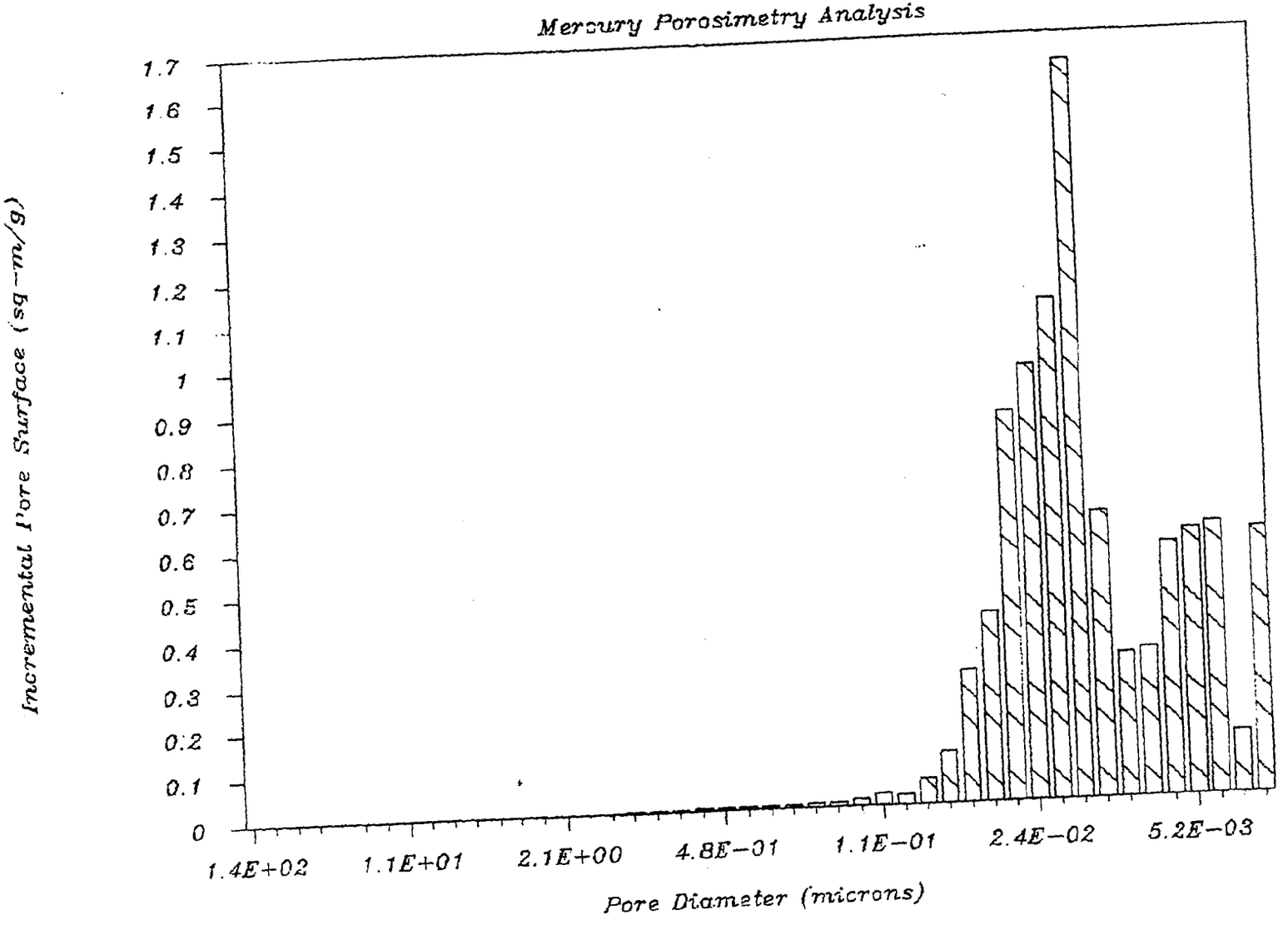
Appendix A

Available Plots of
Incremental Pore Surface and
Incremental Pore Volume

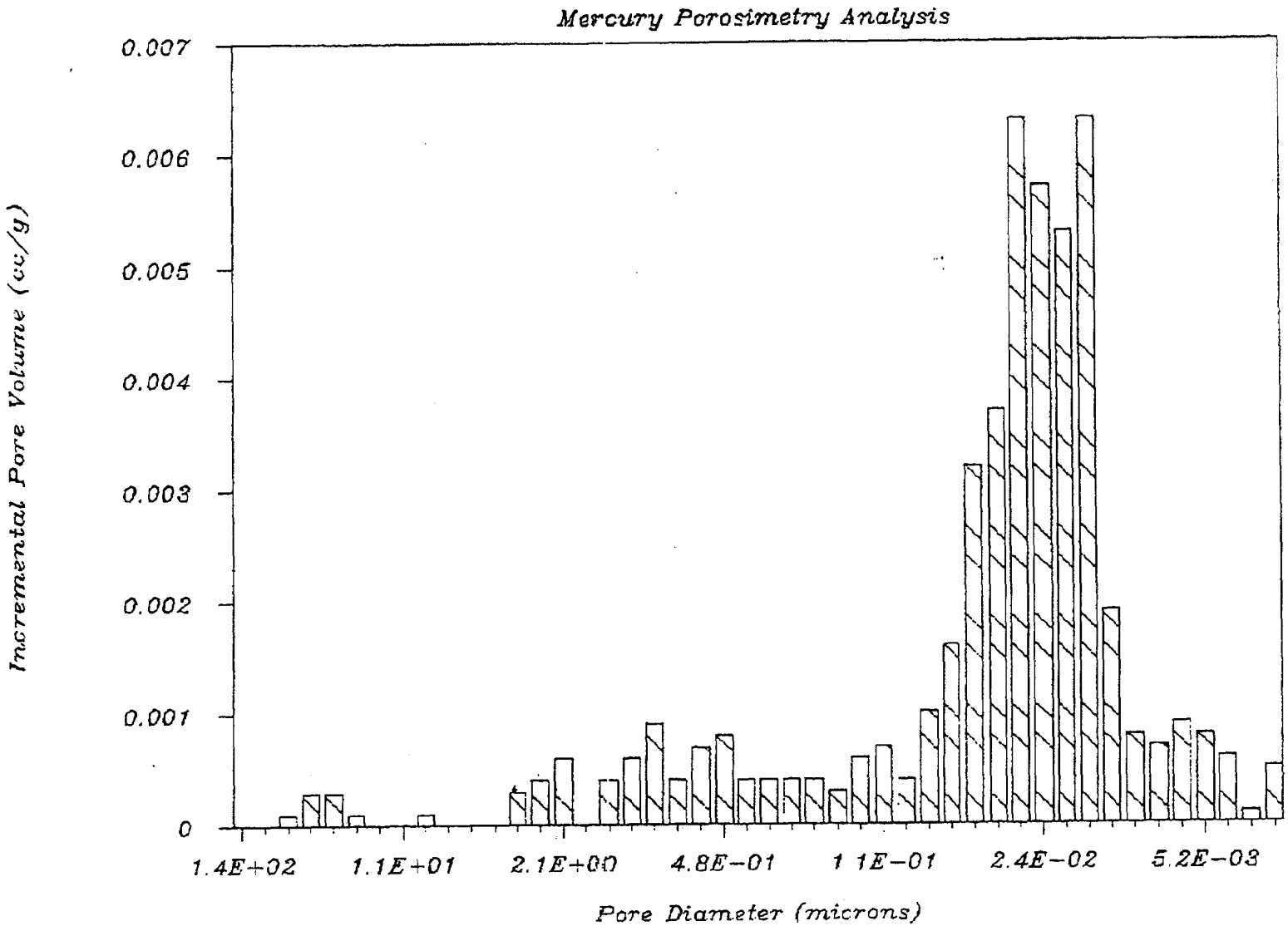

94047 32081.1-1 N1 11.0
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

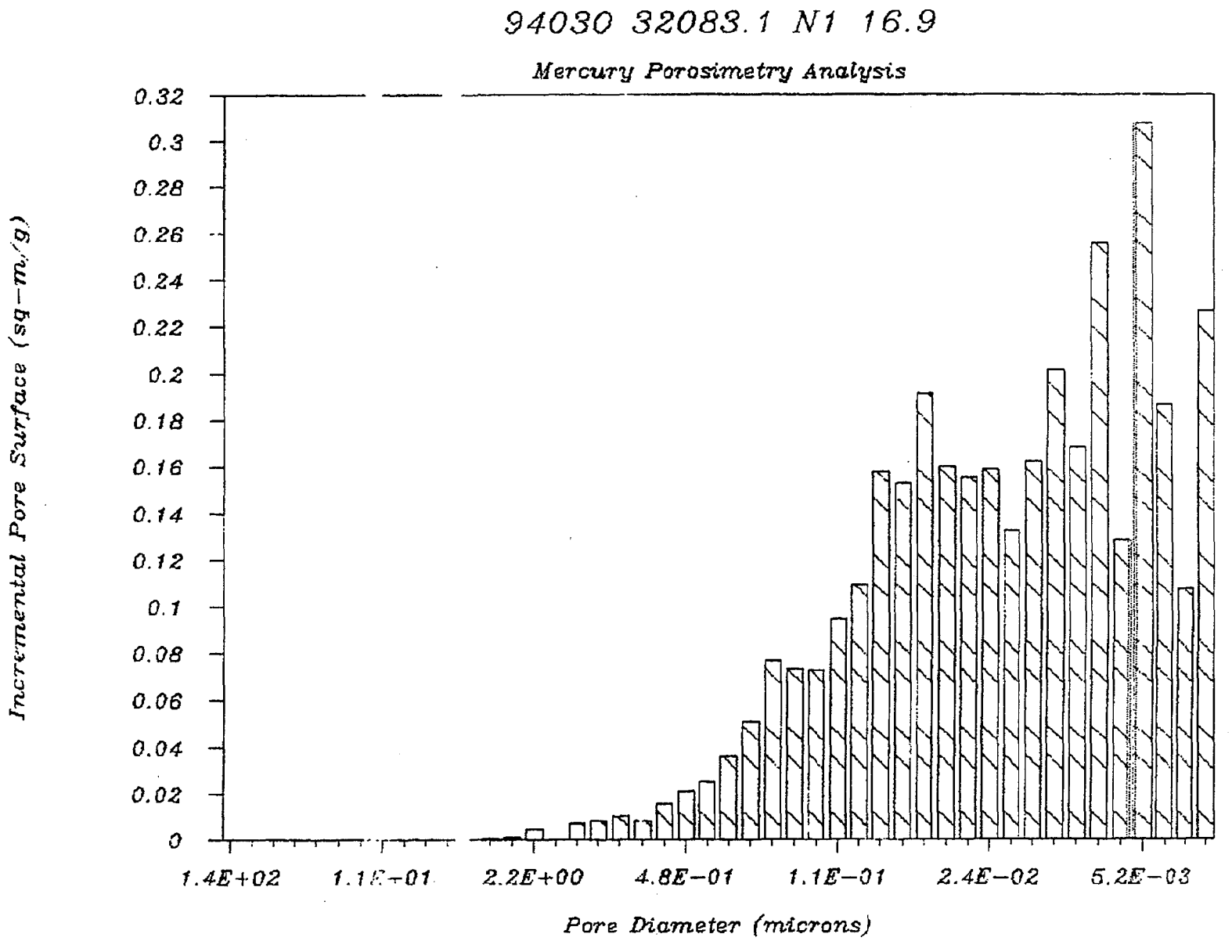

94047 32081.1-1 N1 11.0
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

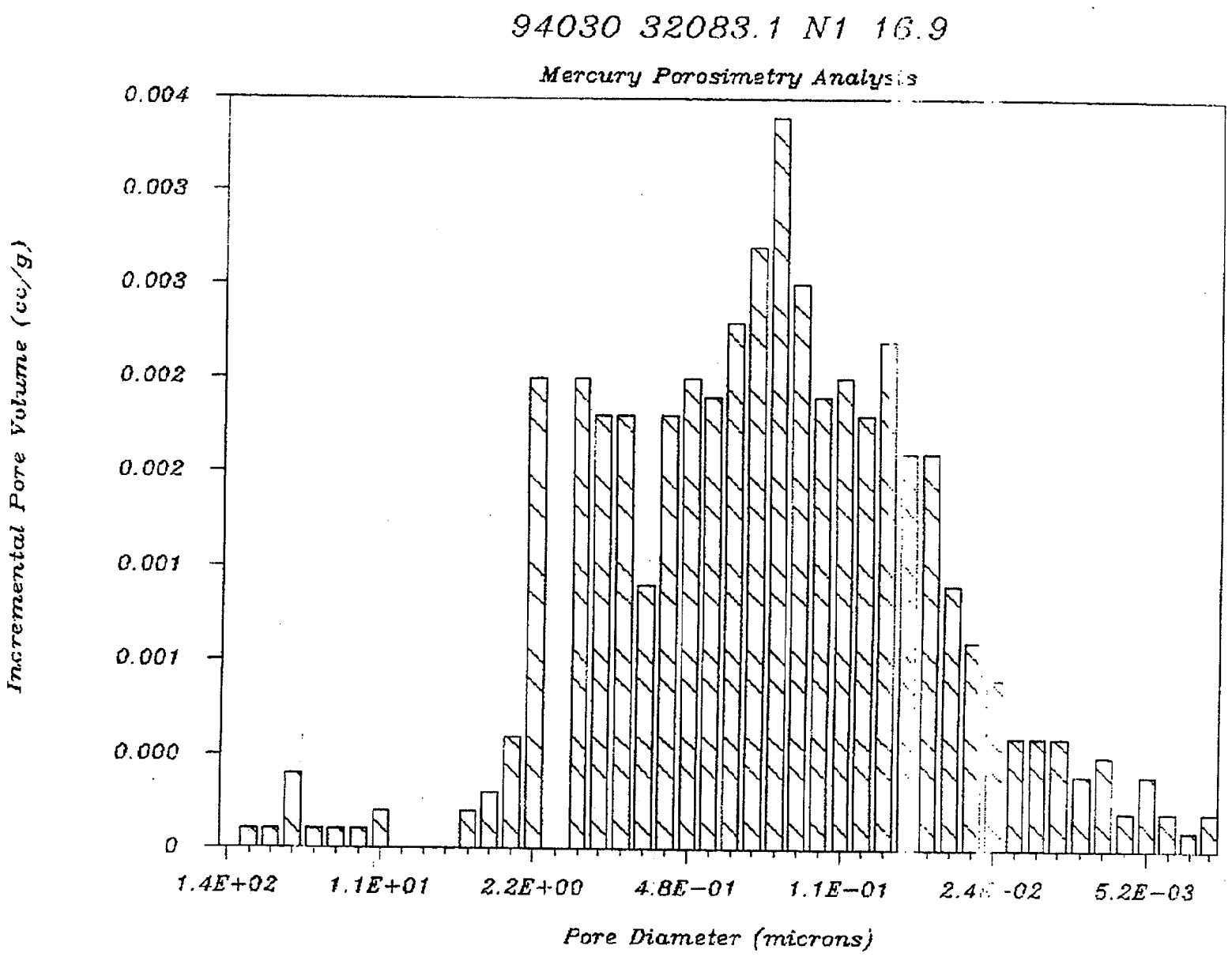
94050 32082.1-1 N1 13.4

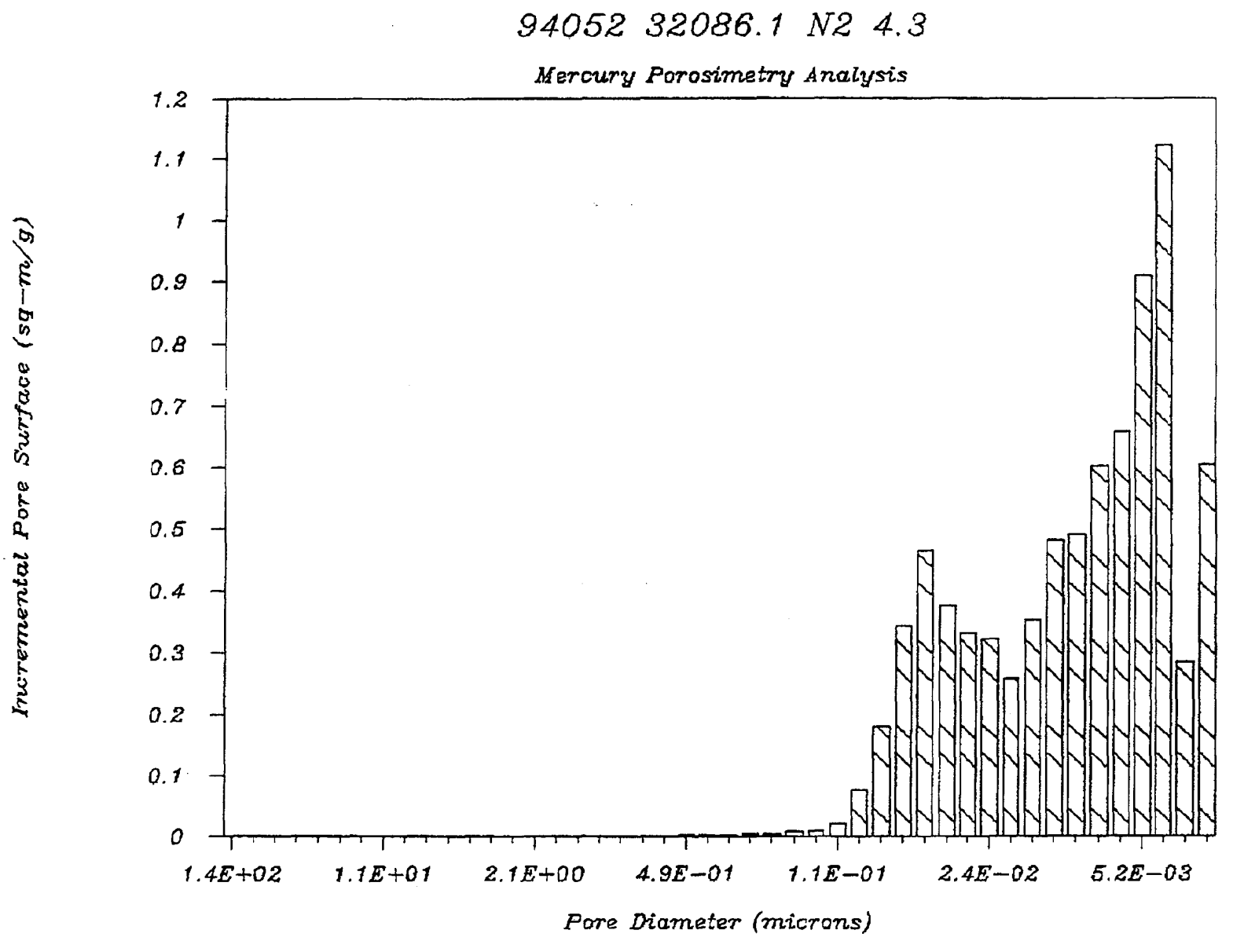


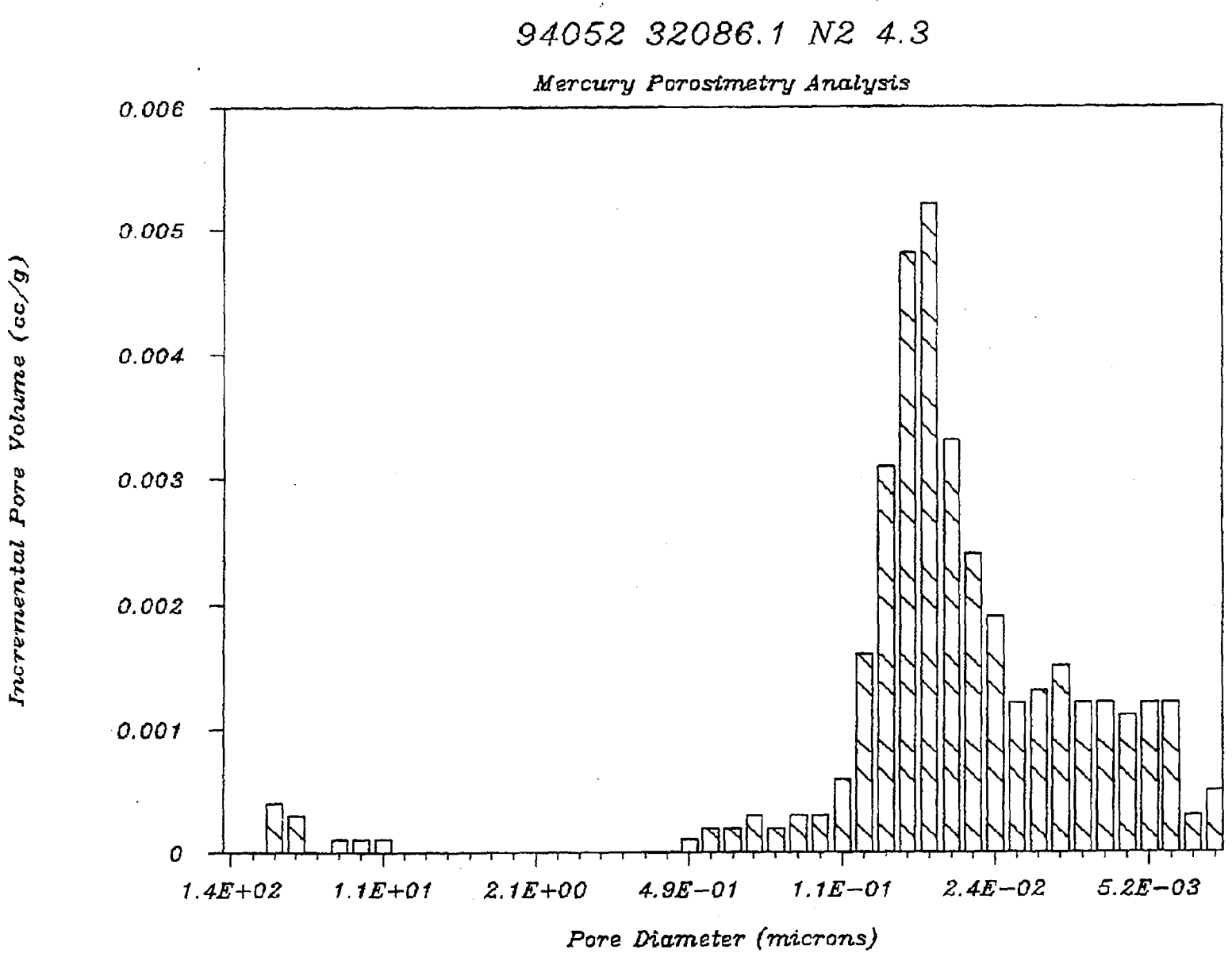
94050 32082.1-1 N1 13.4

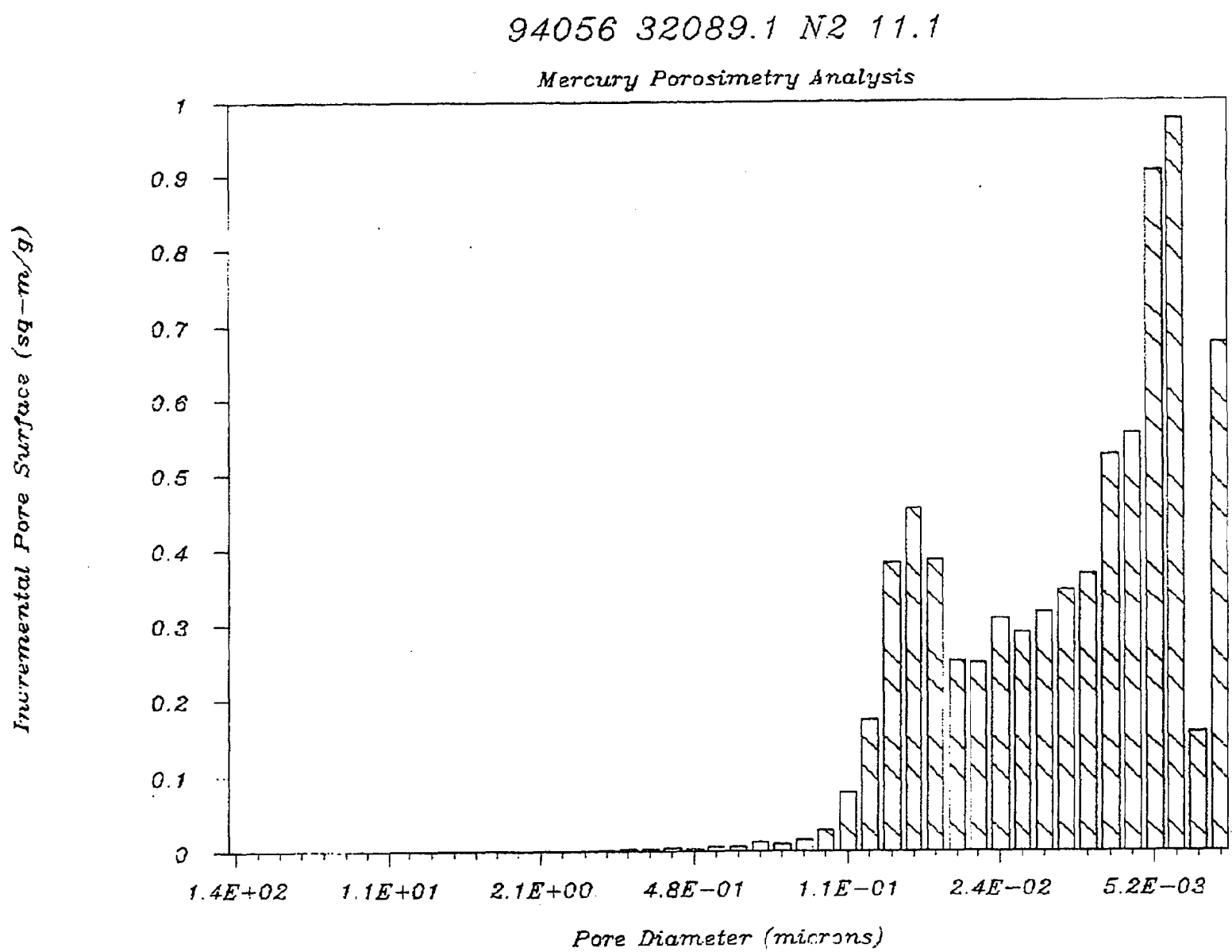


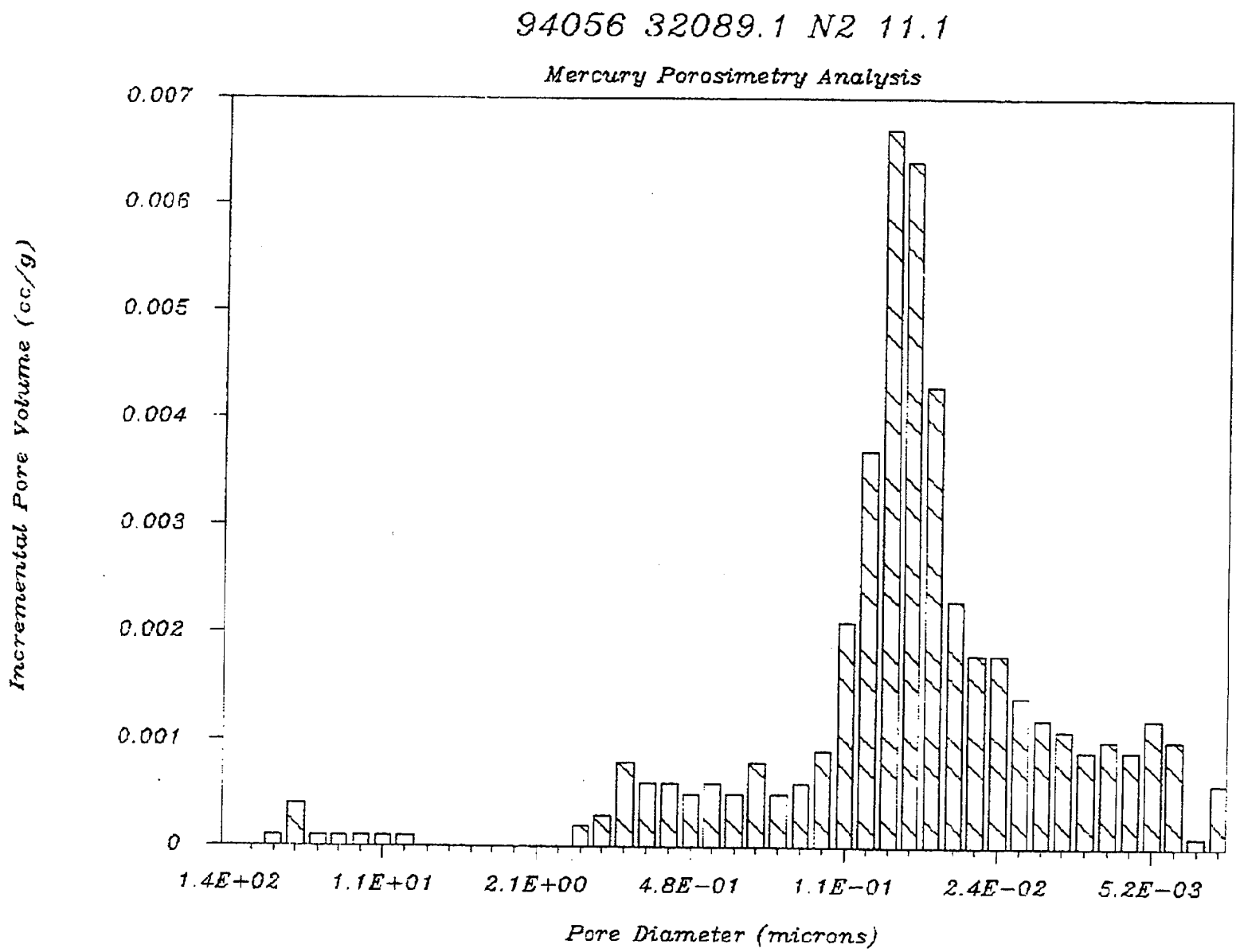

94030 32083.1 N1 16.9
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1.4E+02
1.1E-01
2.2E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

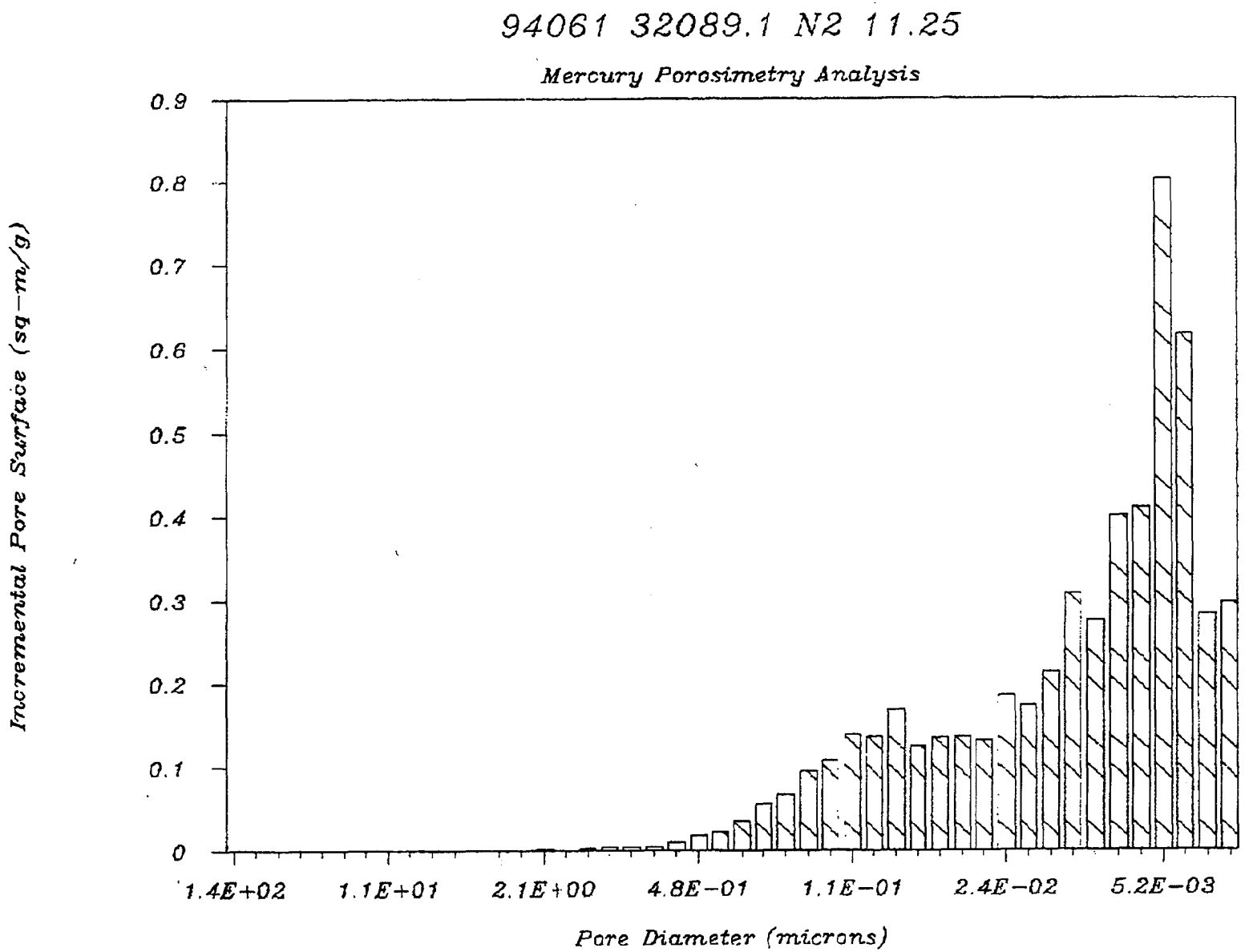

94030 32083.1 N1 16.9
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

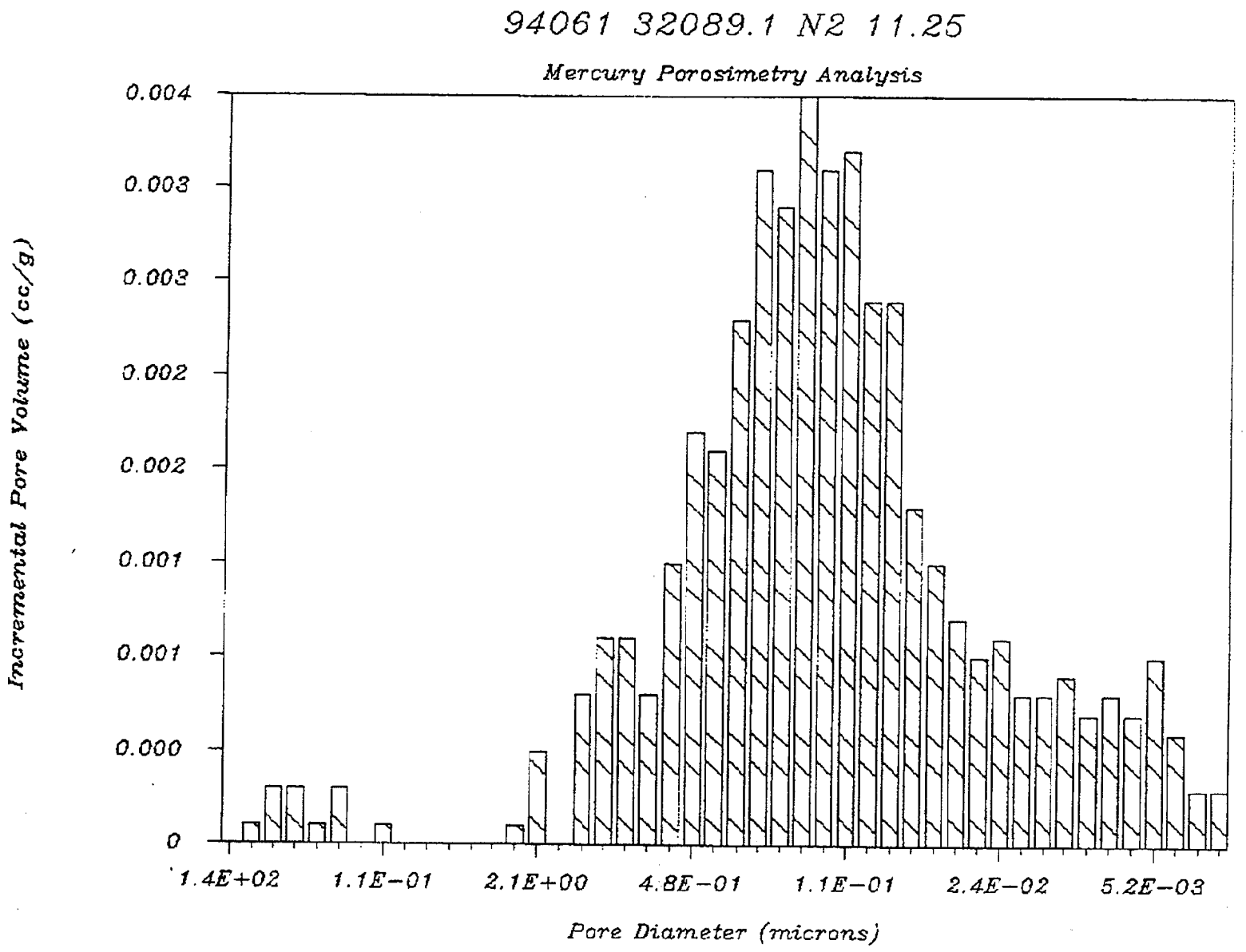

94052 32086.1 N2 4.3
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

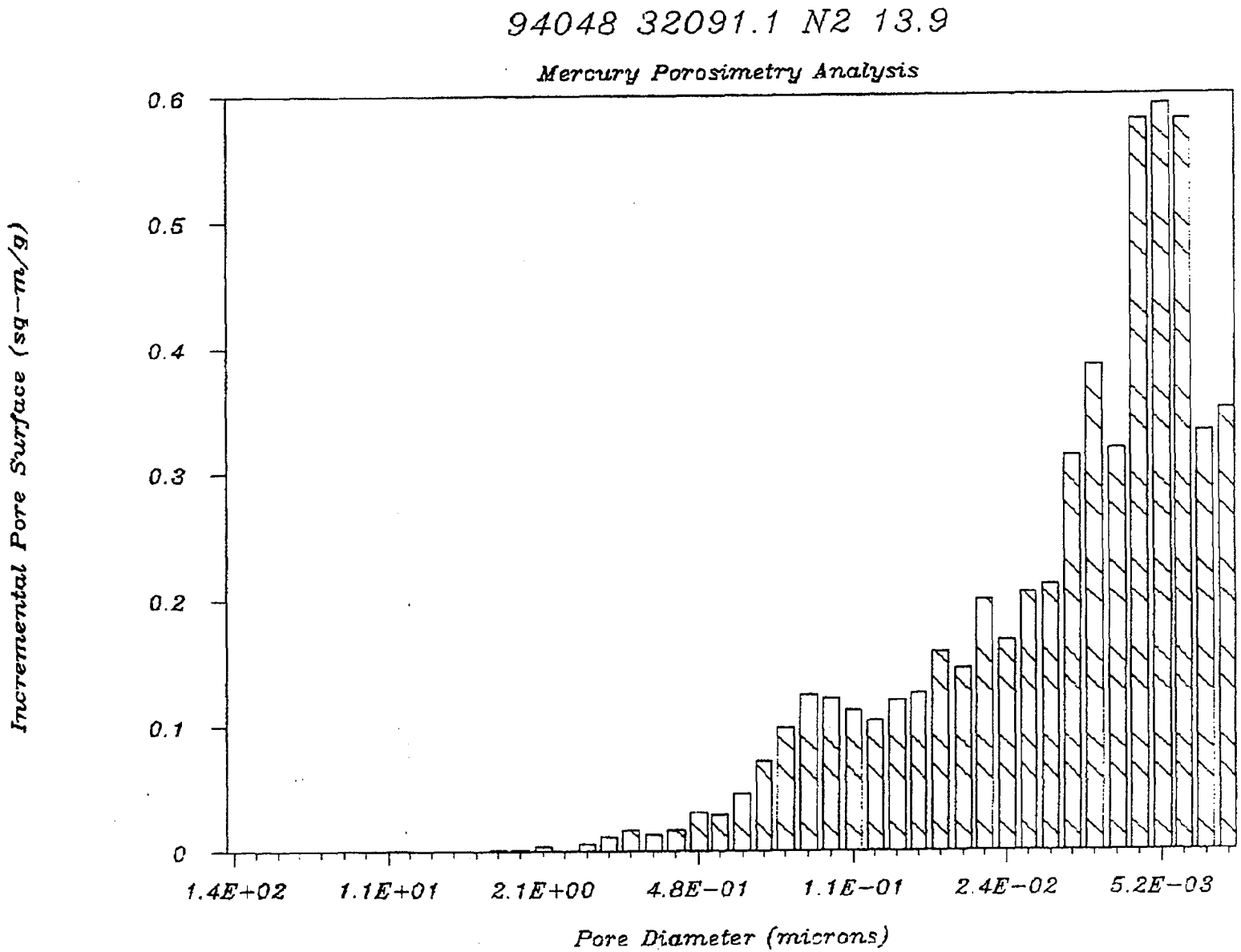

94052 32086.1 N2 4.3
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

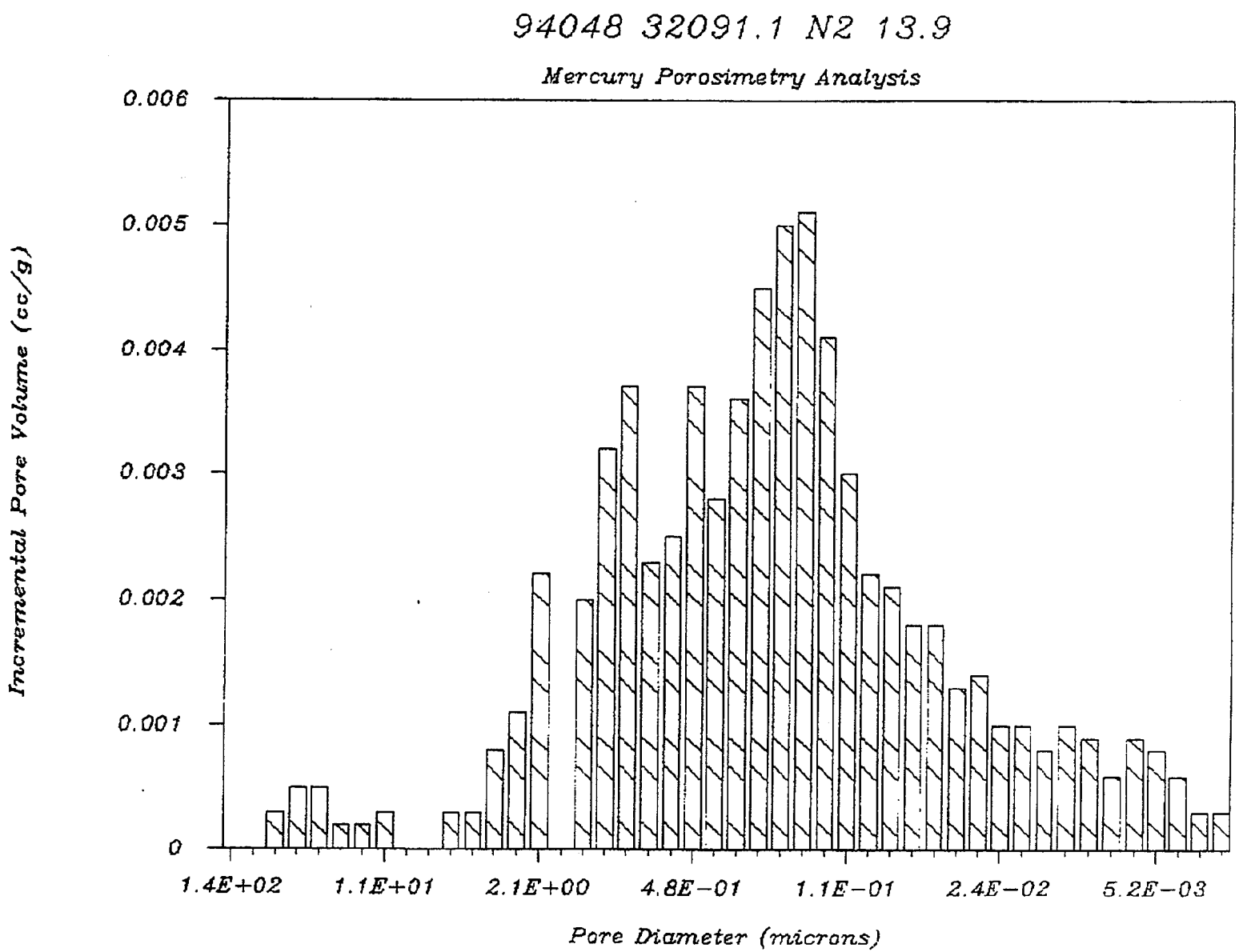

94056 32089.1 N2 11.1
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

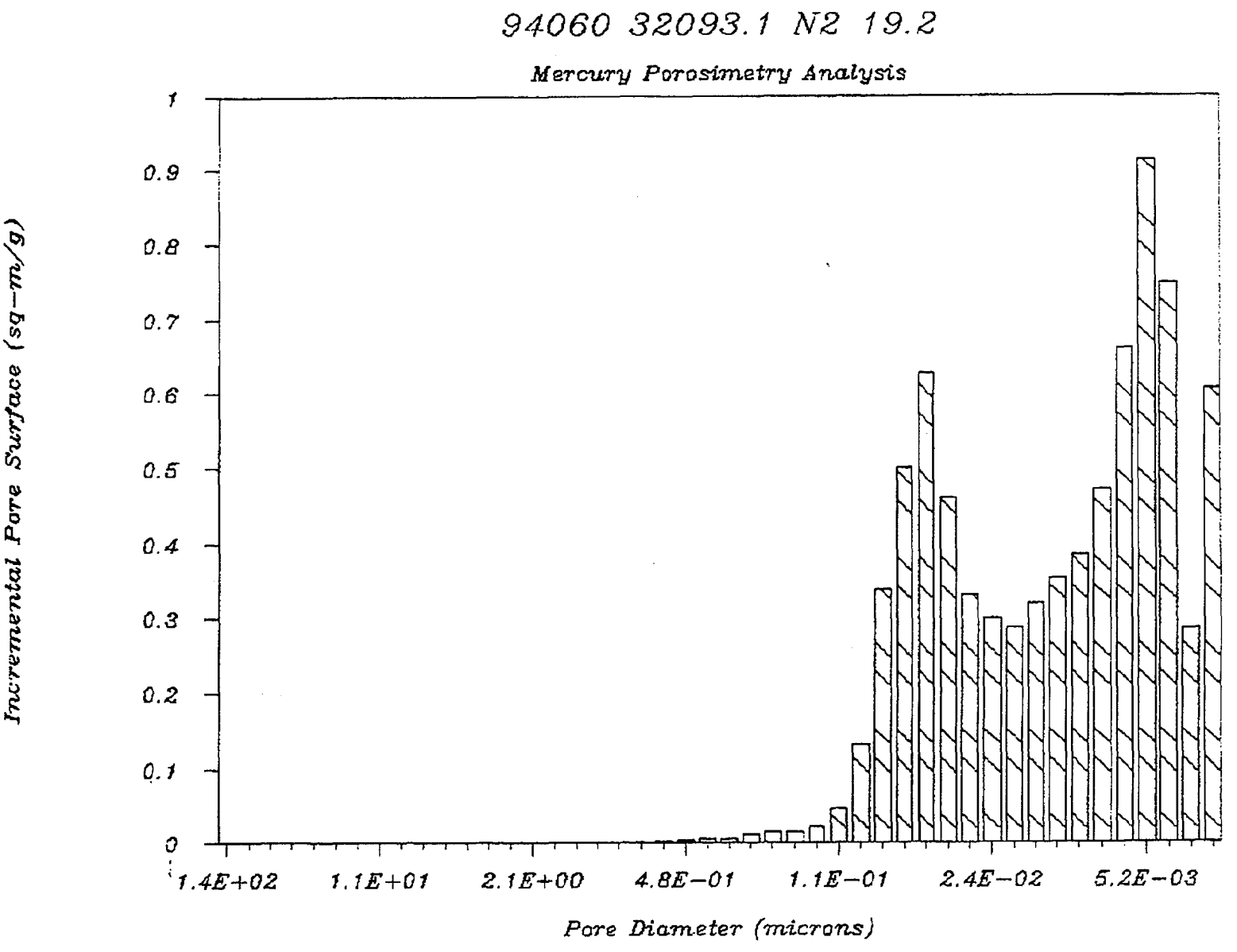

94056 32089.1 N2 11.1
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

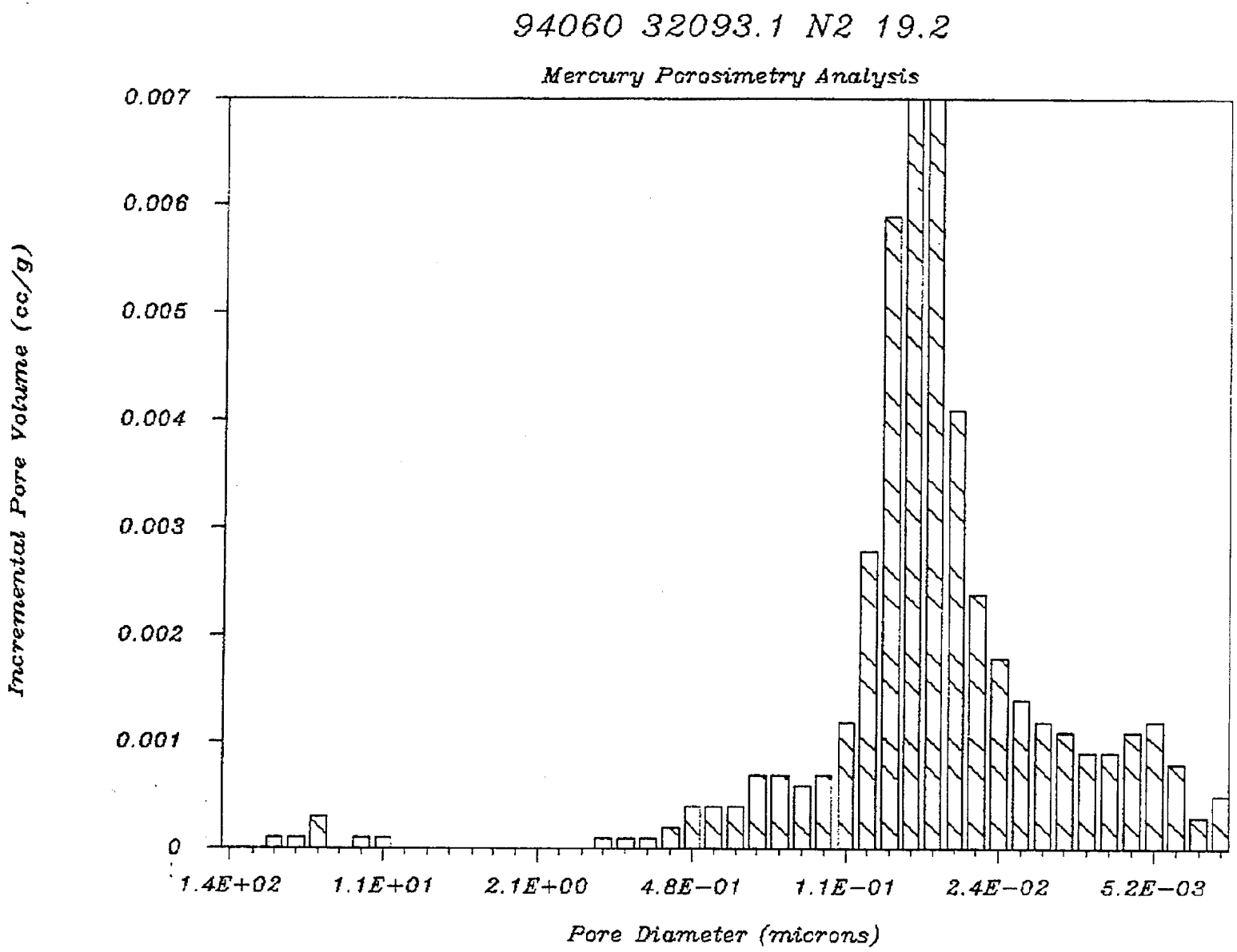

94061 32089.1 N2 11.25
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

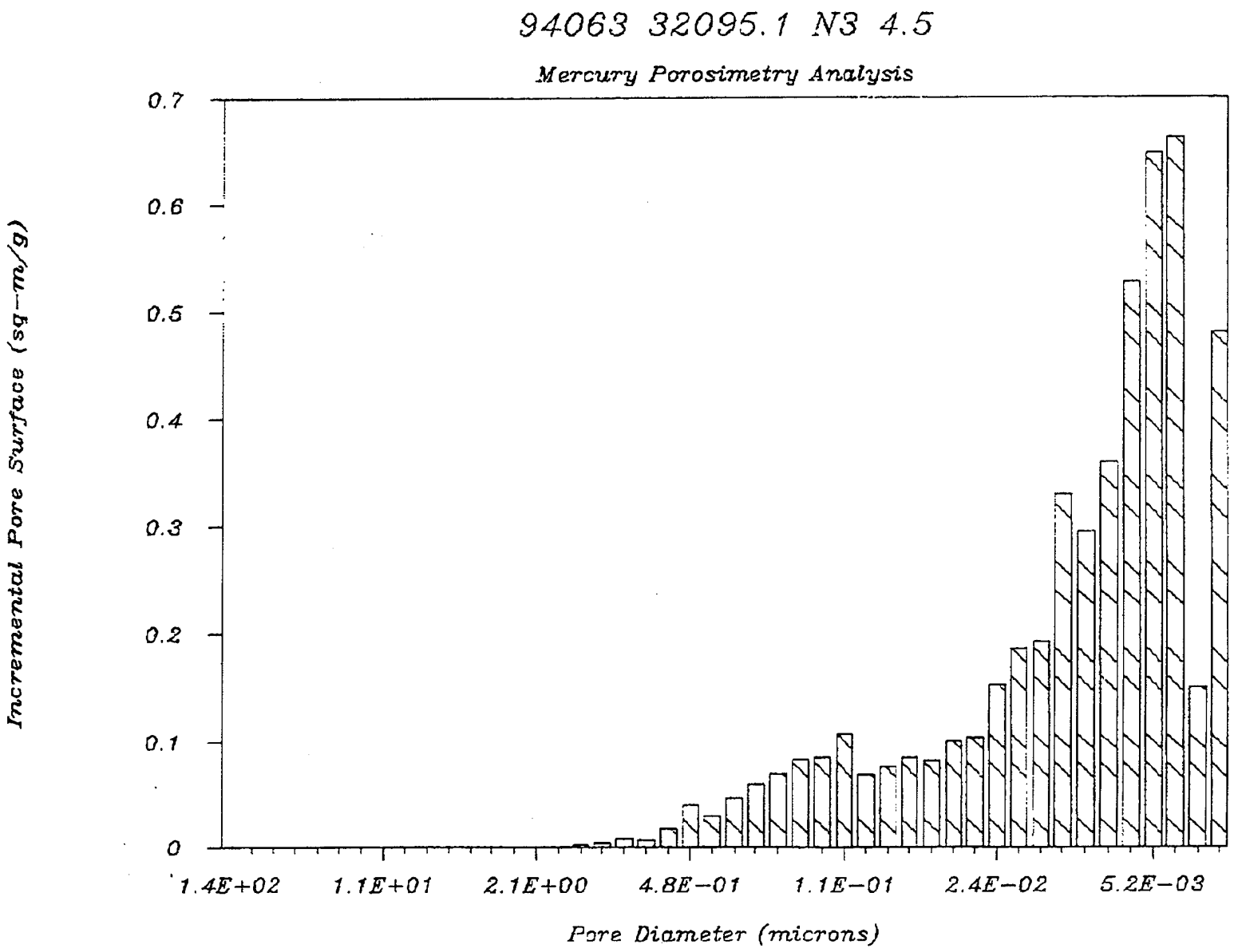

94061 32089.1 N2 11.25
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E-01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

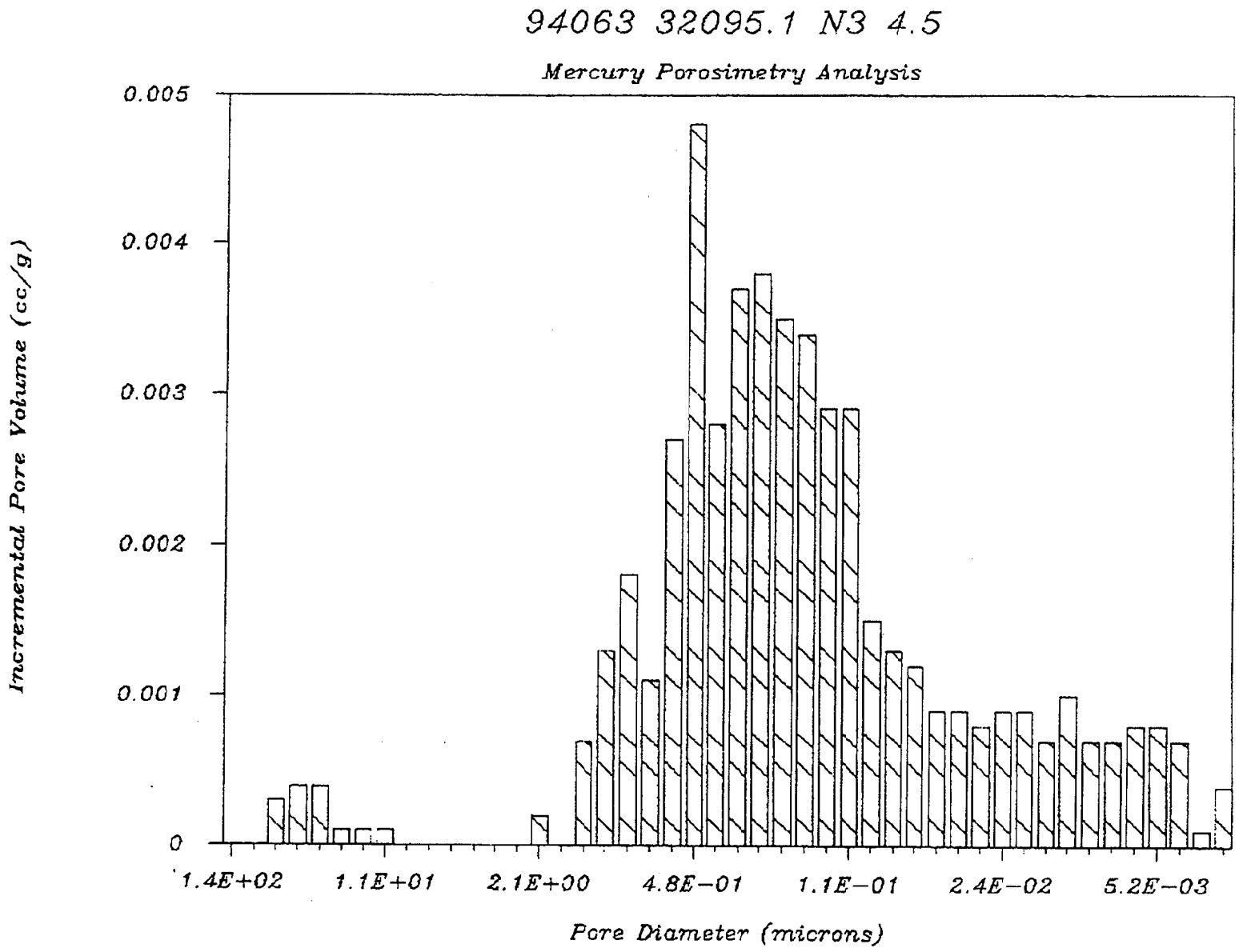

94048 32091.1 N2 13.9
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

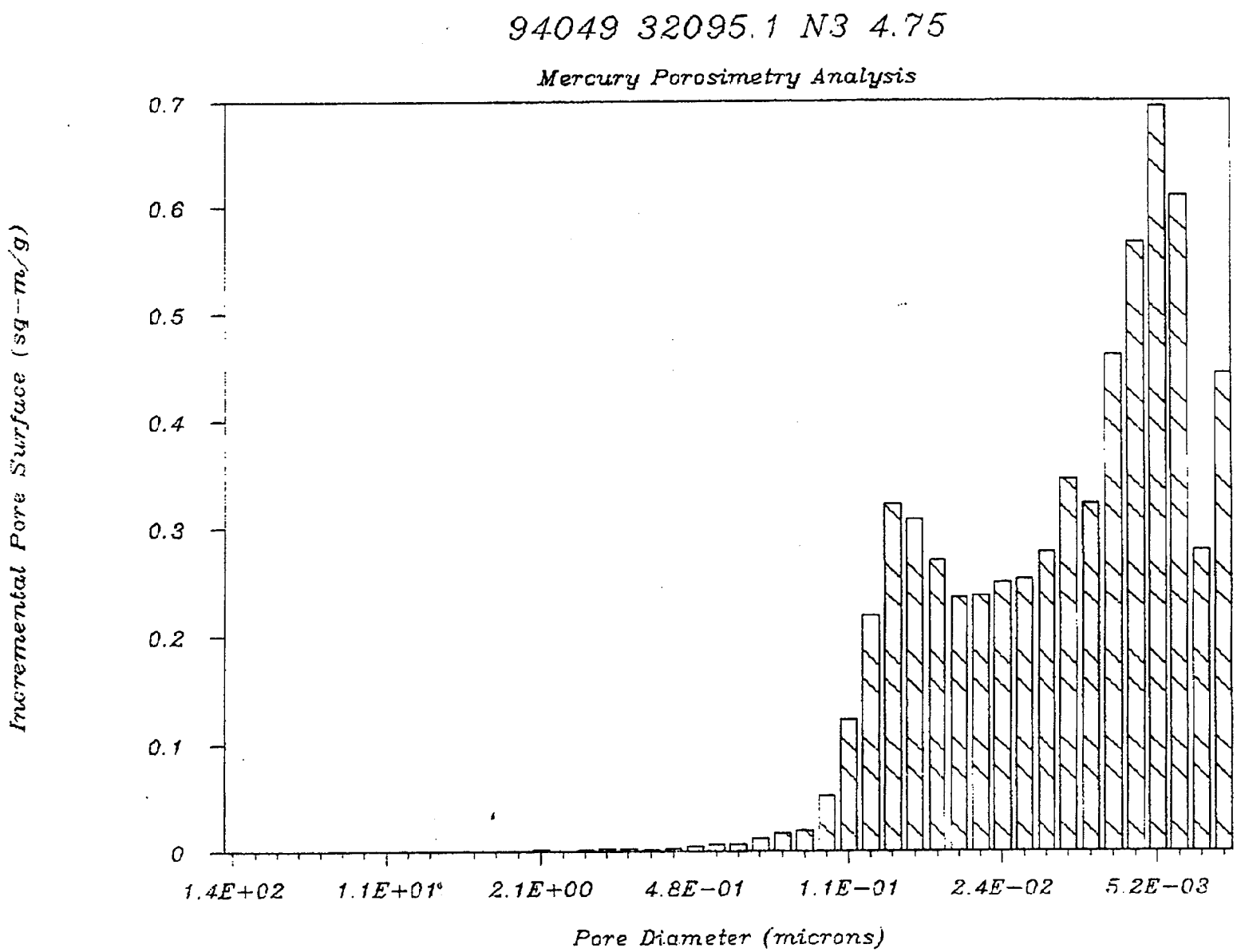

94048 32091.1 N2 13.9
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

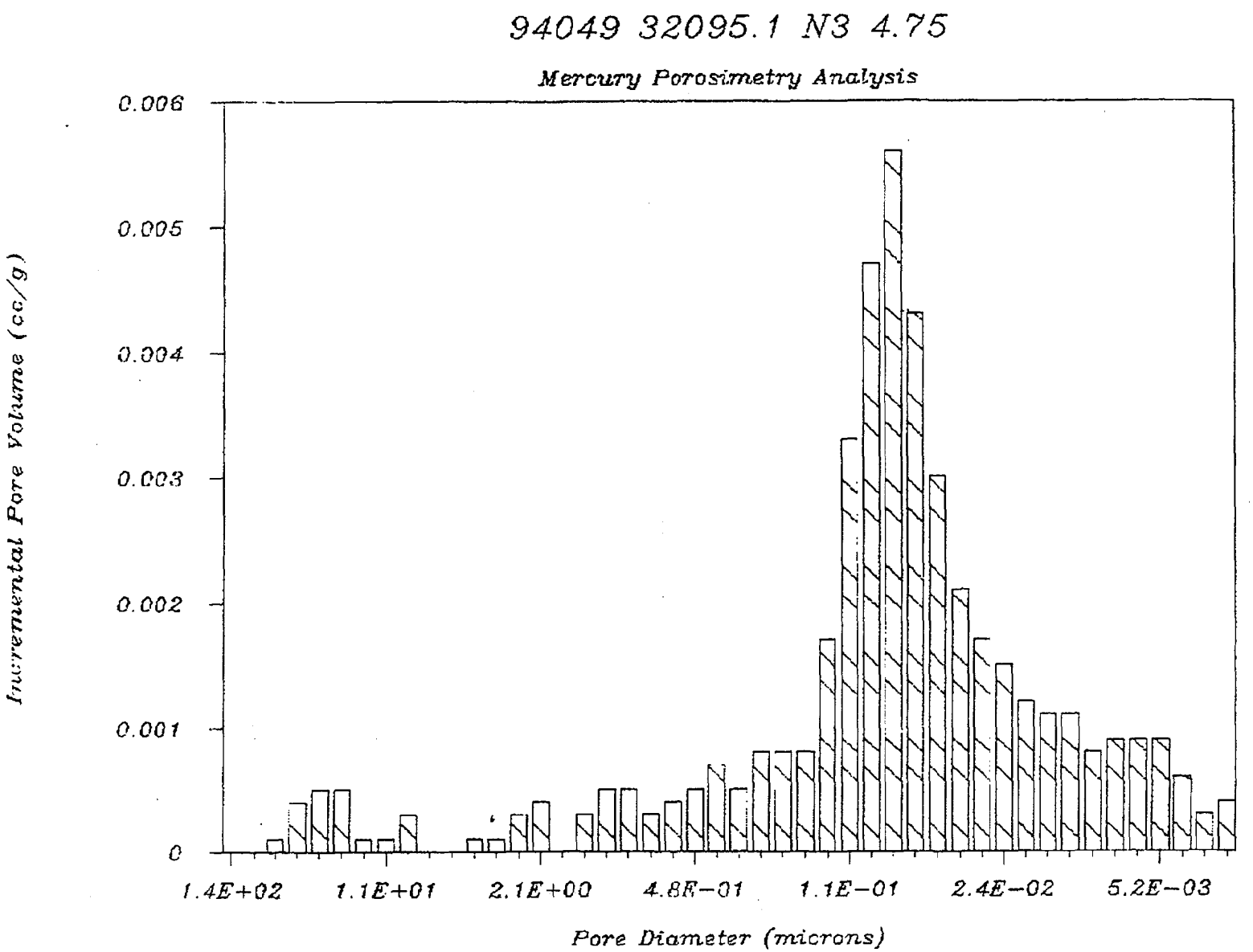

94060 32093.1 N2 19.2
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

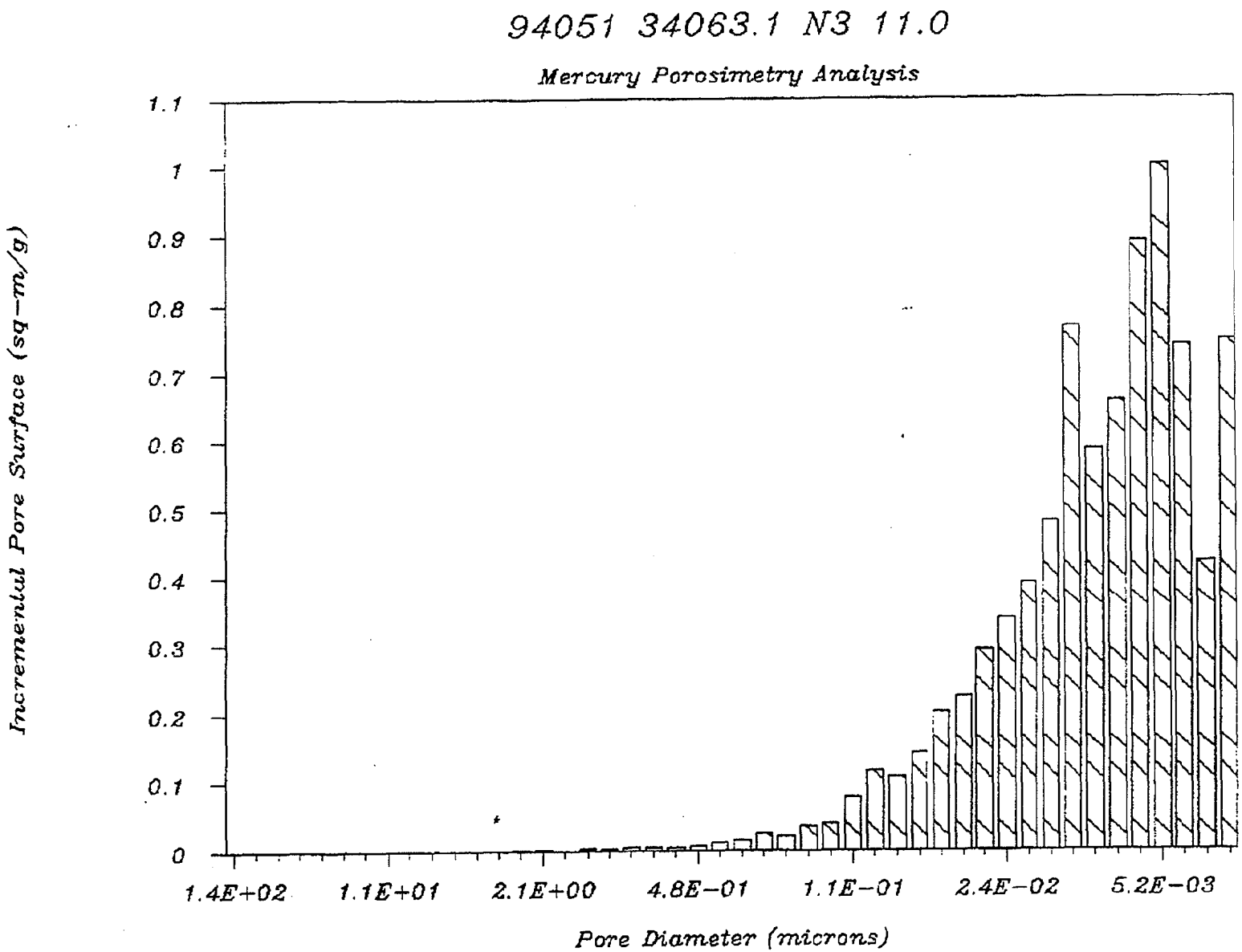

94060 32093.1 N2 19.2
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

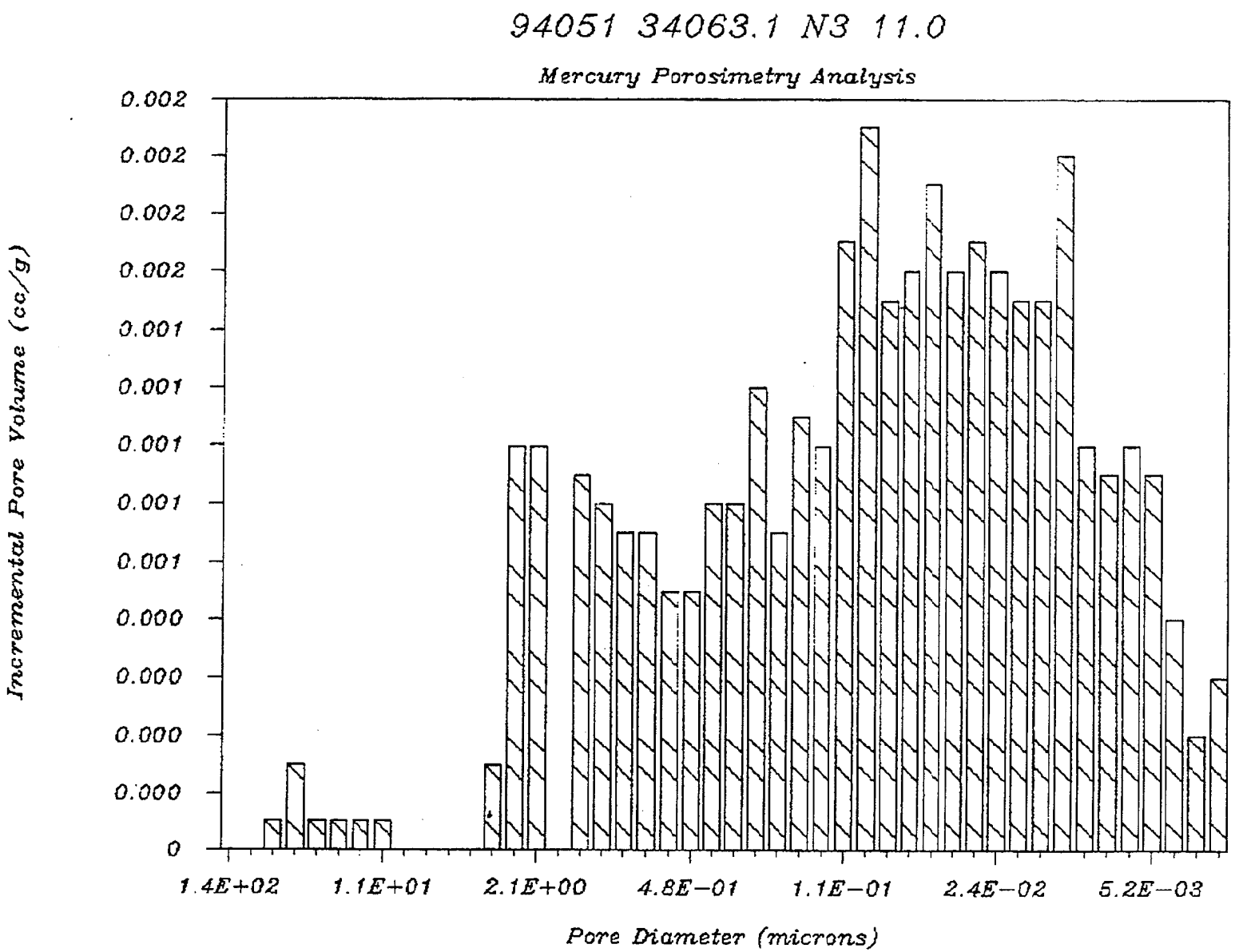

94063 32095.1 N3 4.5
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

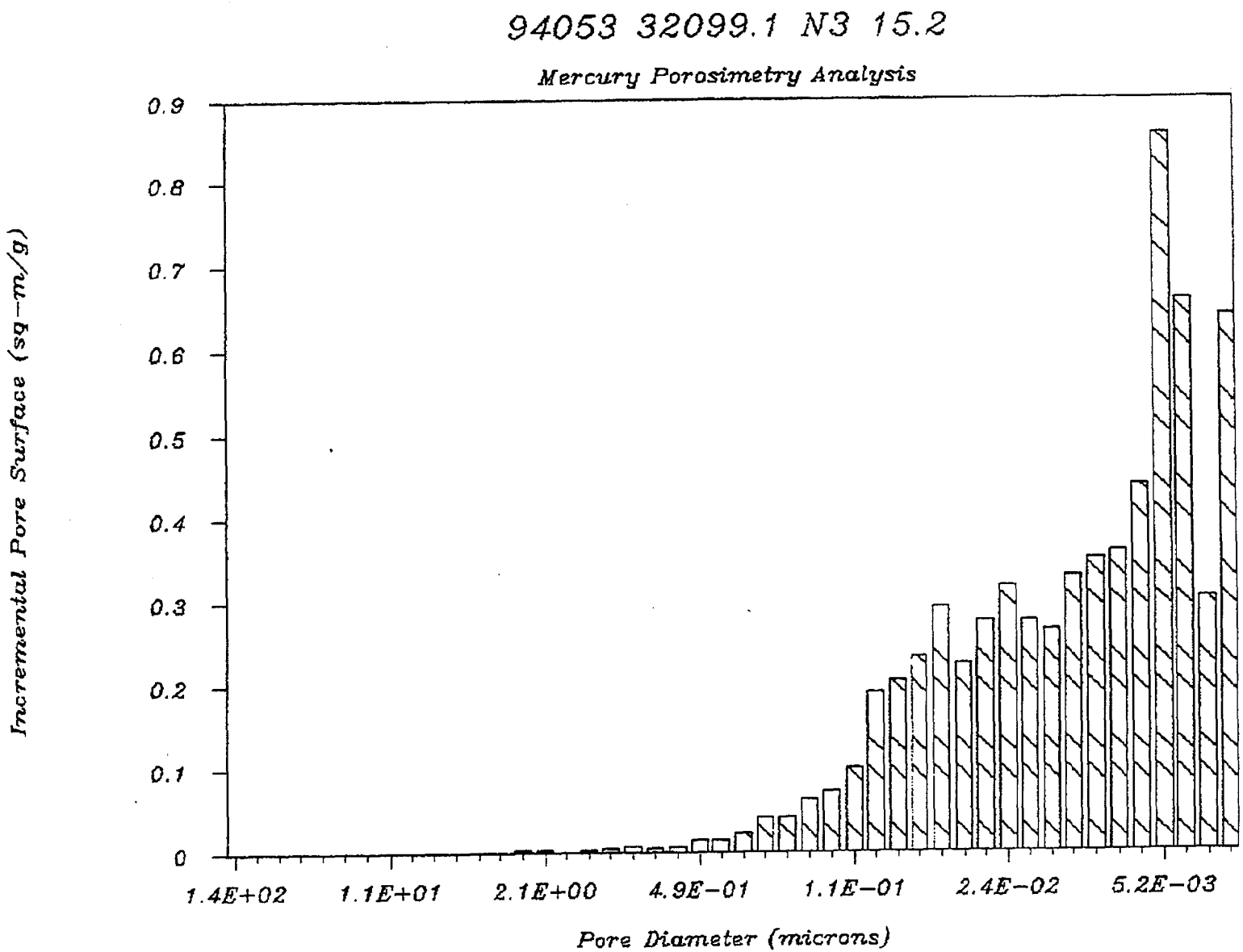

94063 32095.1 N3 4.5
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

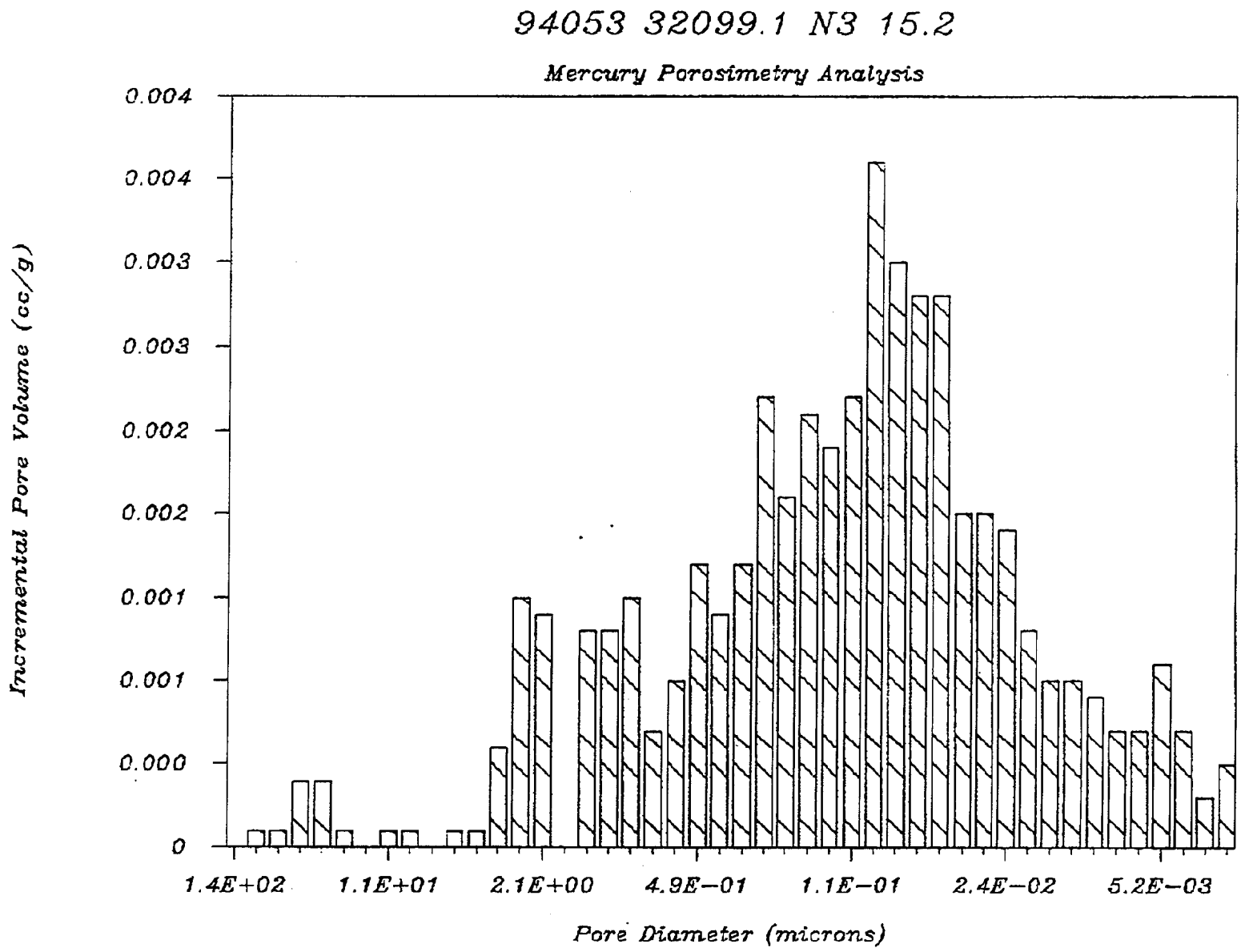

94049 32095.1 N3 4.75
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

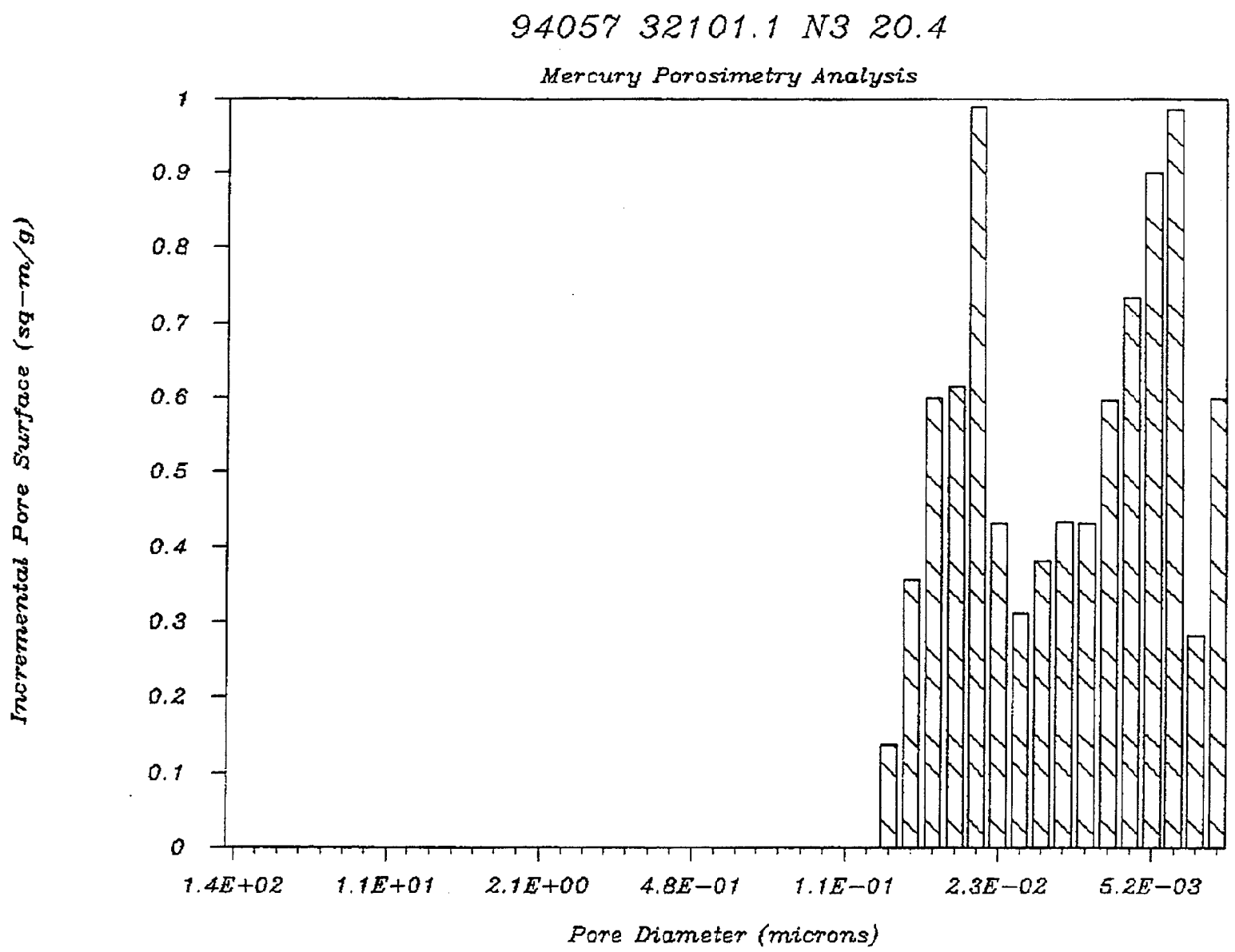

94049 32095.1 N3 4.75
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

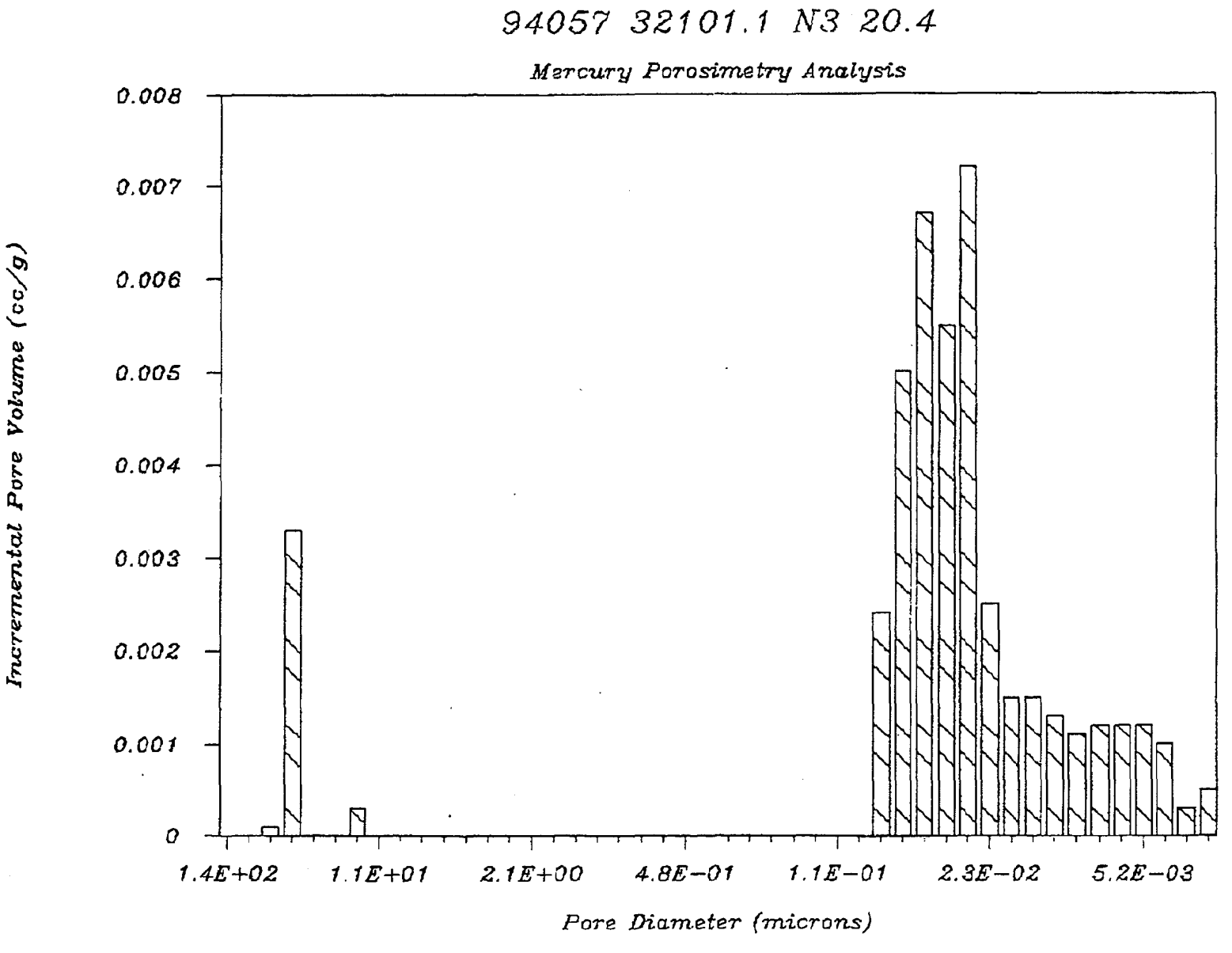

94051 34063.1 N3 11.0
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

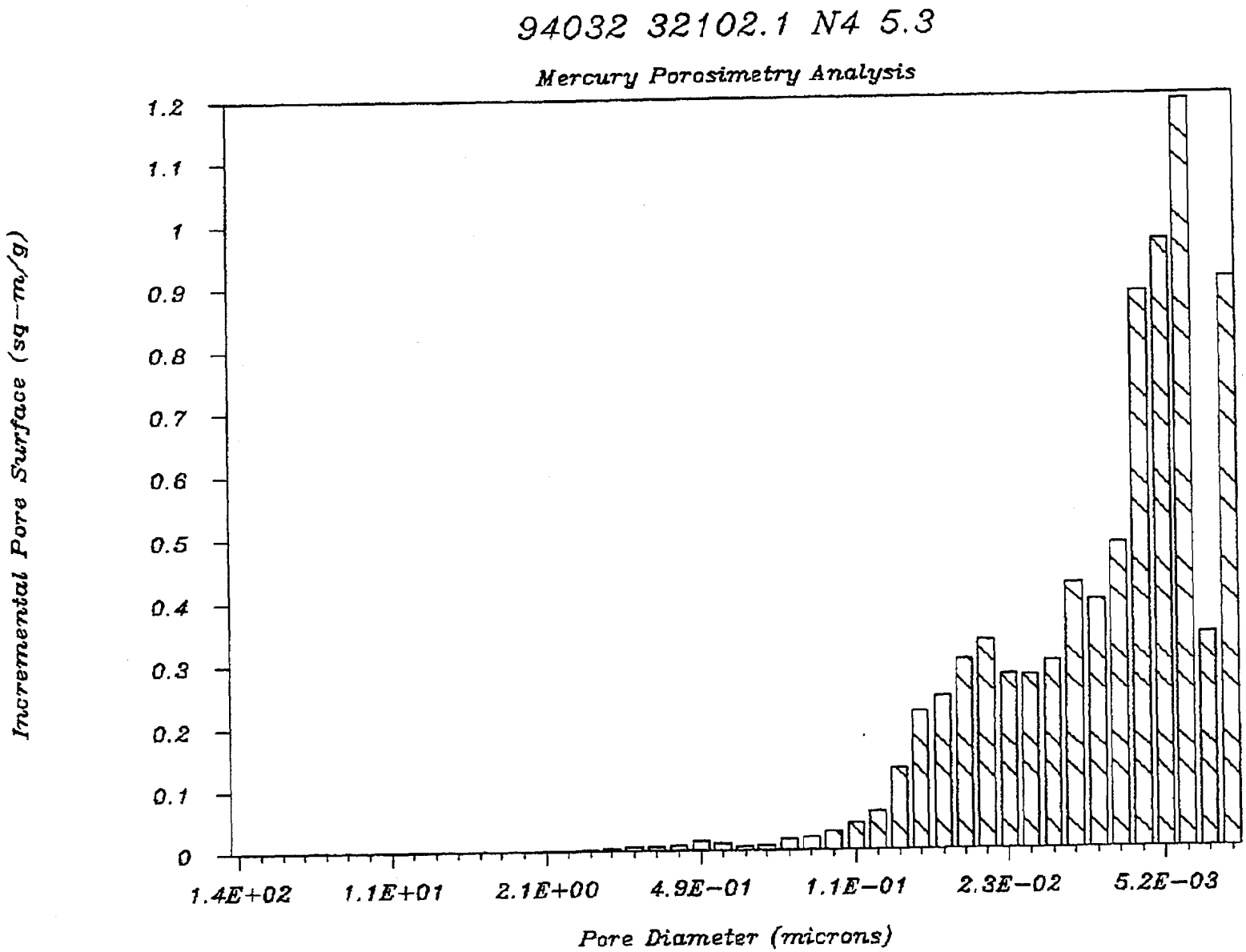

94051 34063.1 N3 11.0
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.002
0.002
0.002
0.002
0.001
0.001
0.001
0.001
0.001
0.000
0.000
0.000
0.000
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

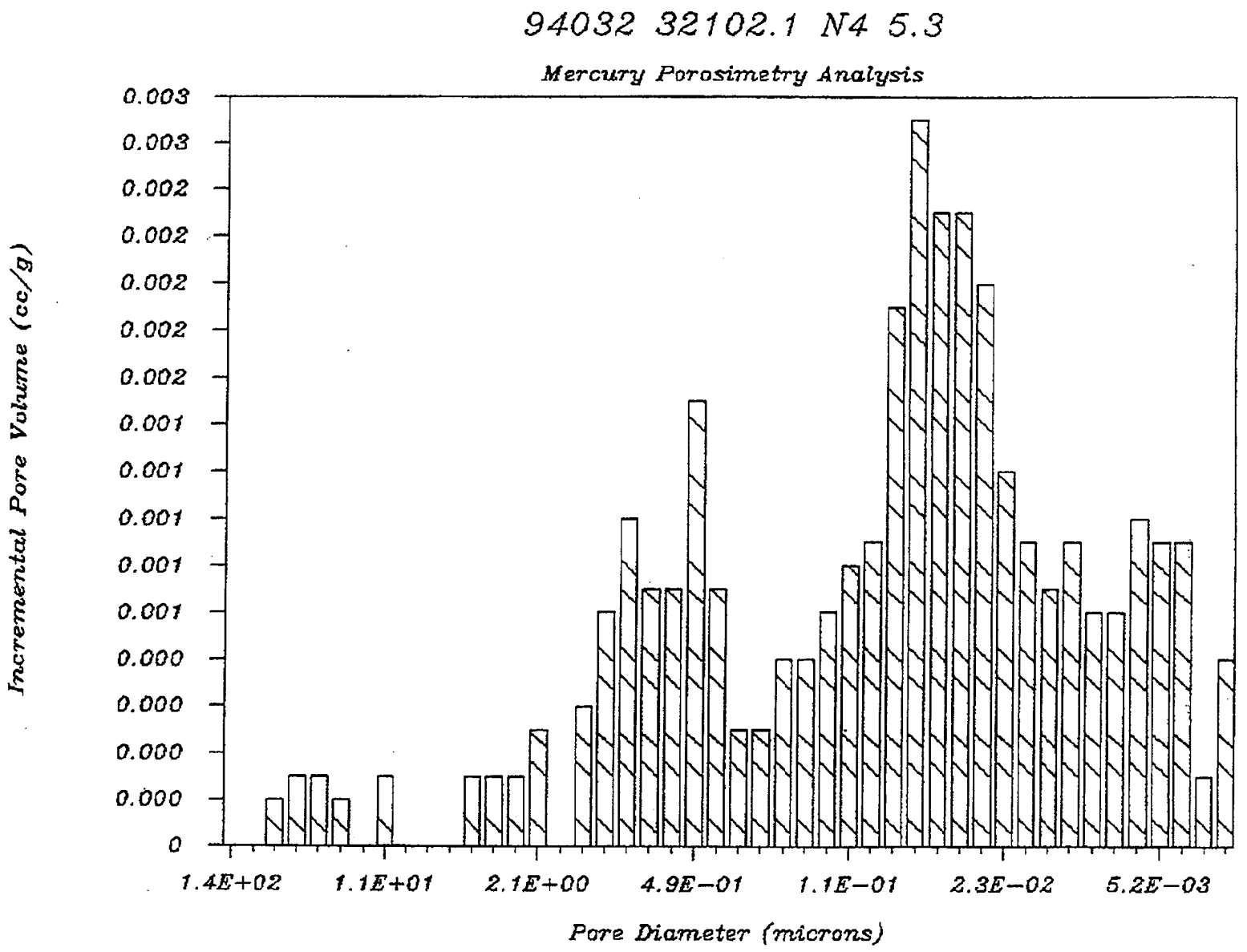

94053 32099.1 N3 15.2
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

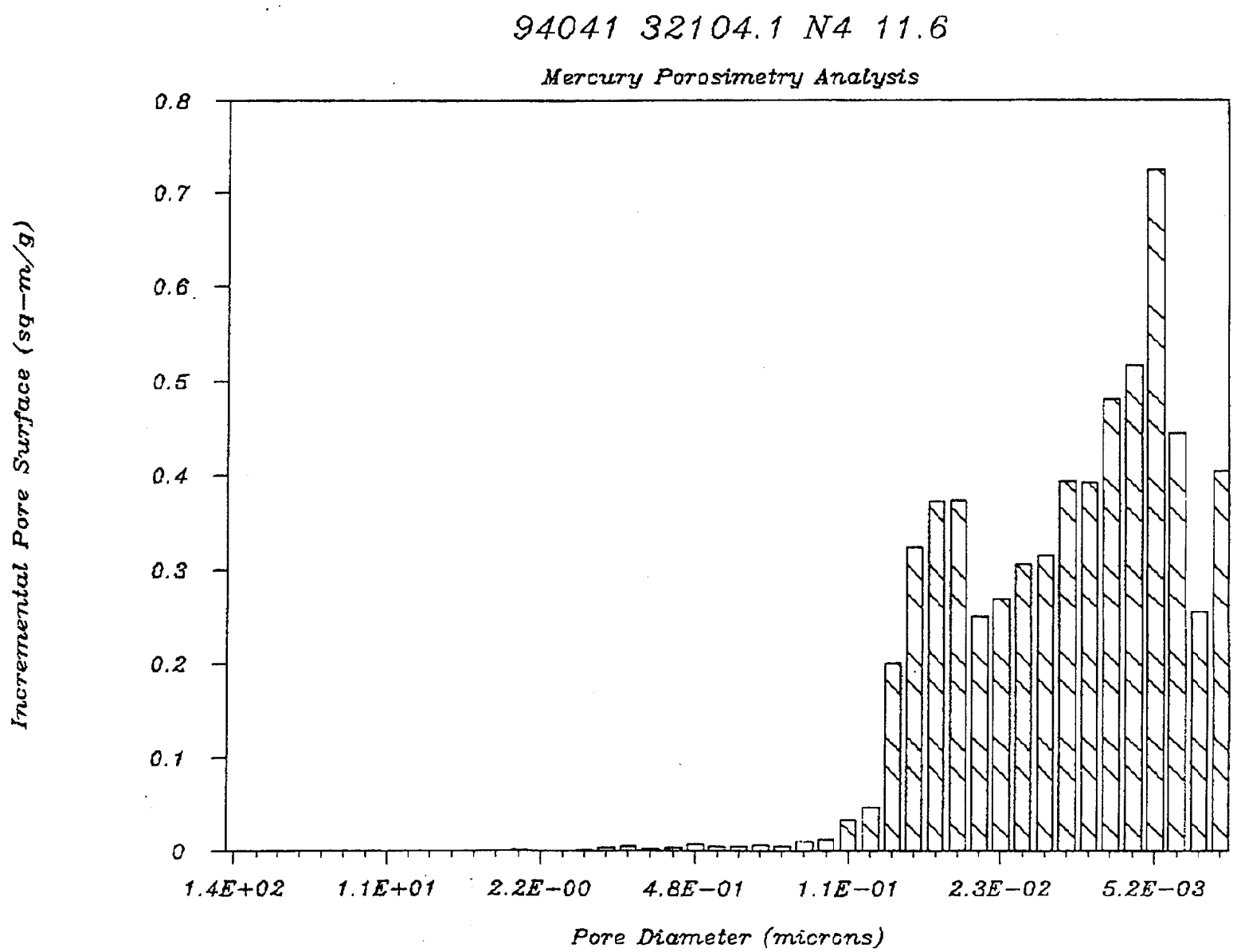

94053 32099.1 N3 15.2
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

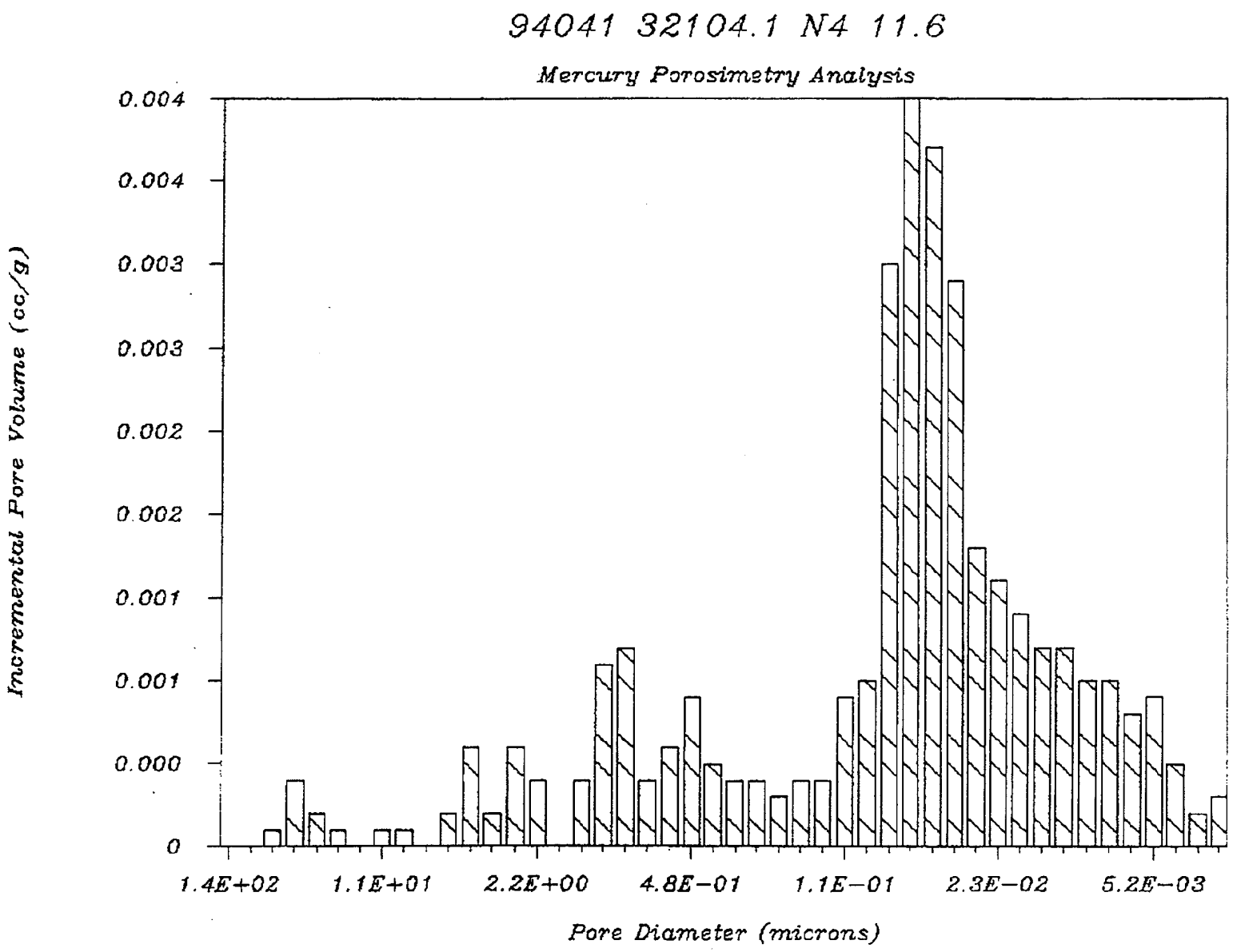

94057 32101.1 N3 20.4
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

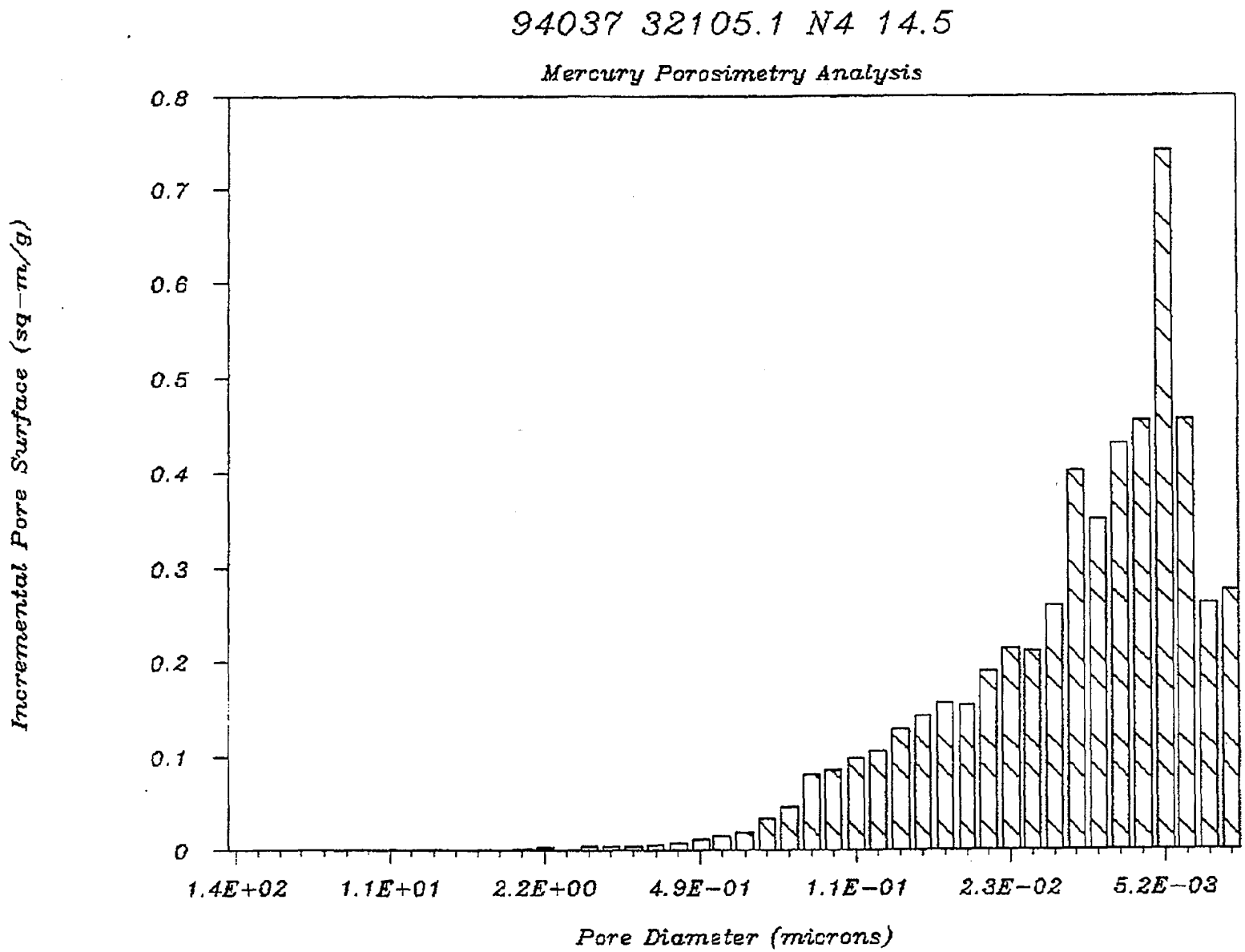

94057 32101.1 N3 20.4
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

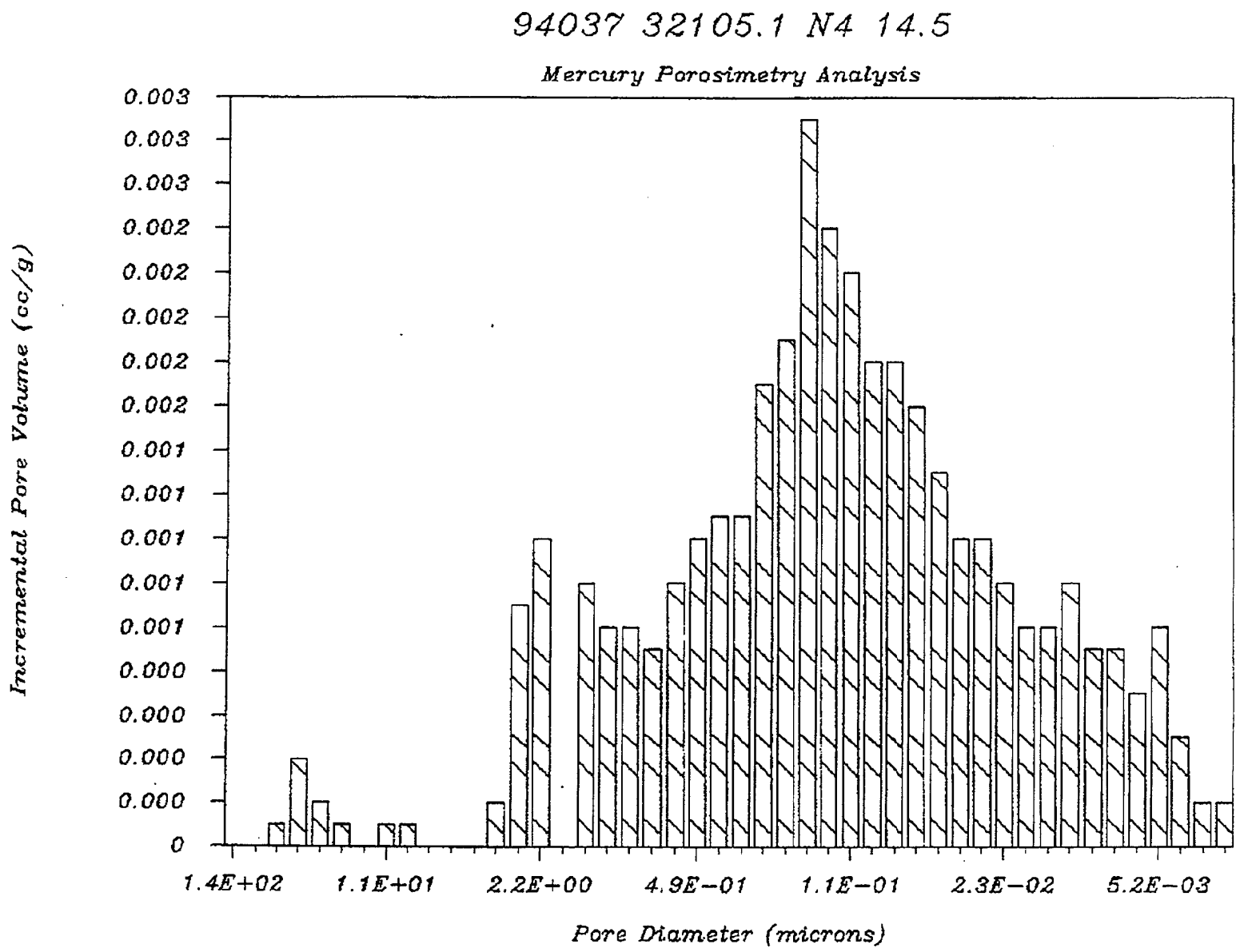

94032 32102.1 N4 5.3
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

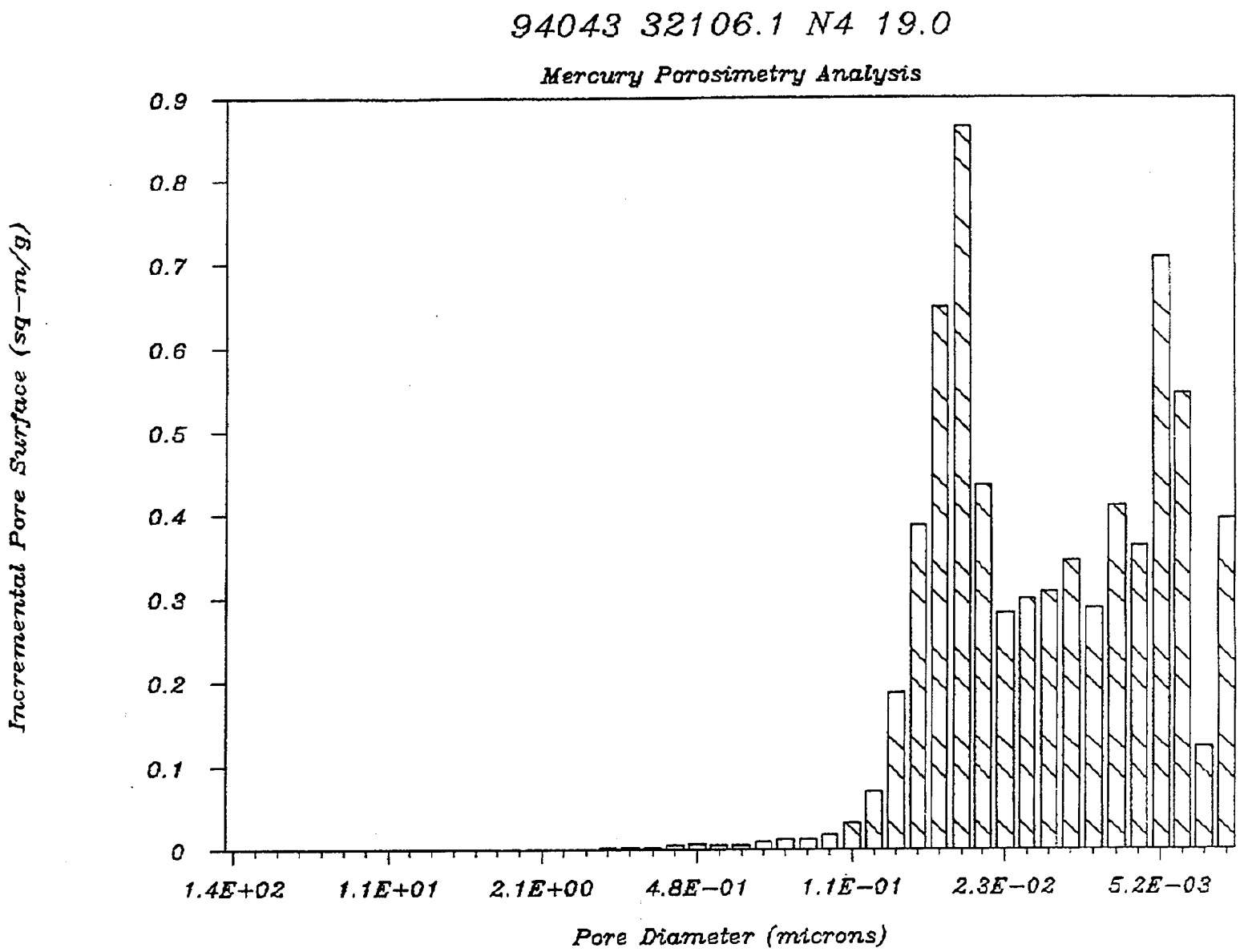

94032 32102.1 N4 5.3
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.003
0.003
0.002
0.002
0.002
0.002
0.001
0.001
0.001
0.001
0.001
0.000
0.000
0.000
0.000
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

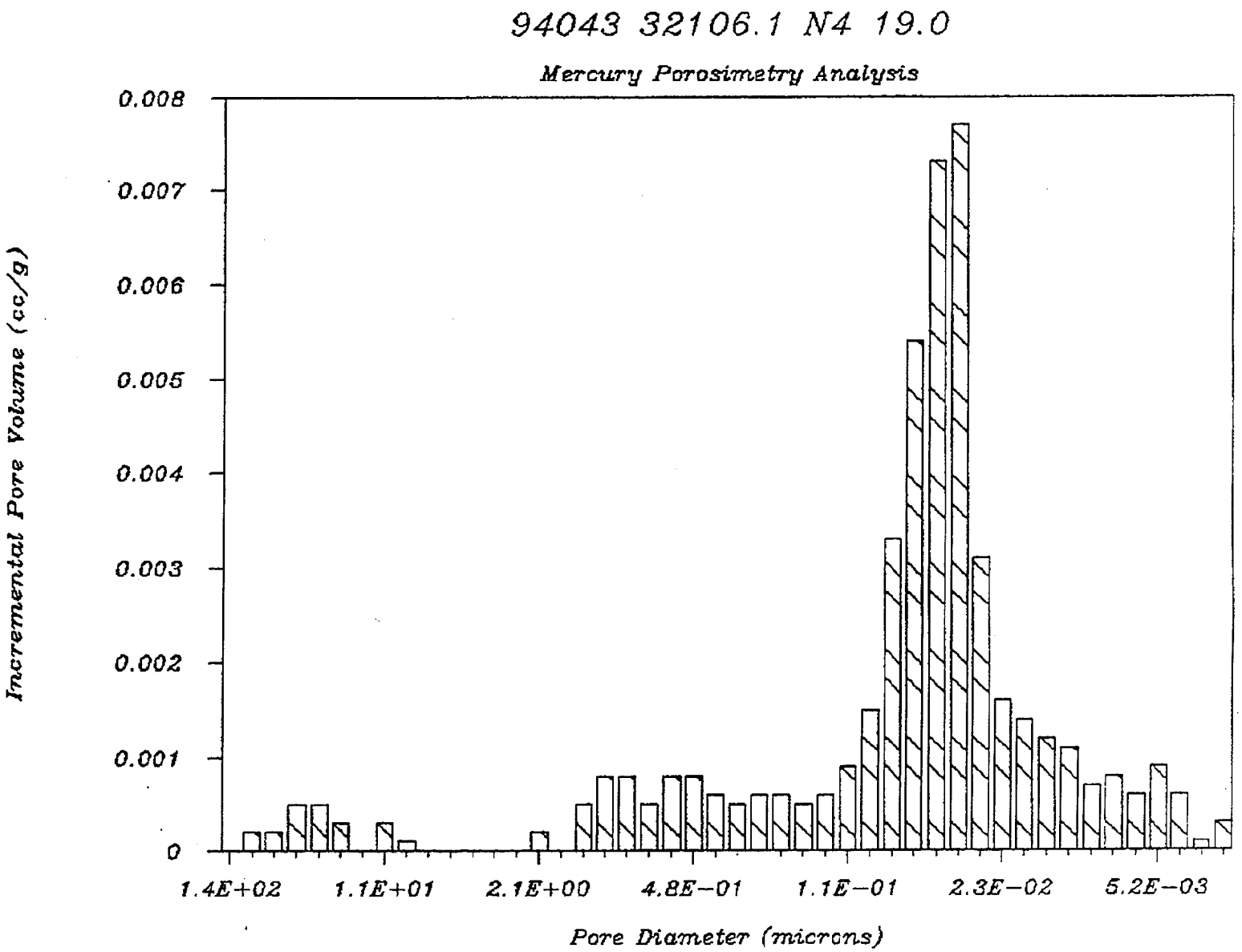

94041 32104.1 N4 11.6
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.2E-00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

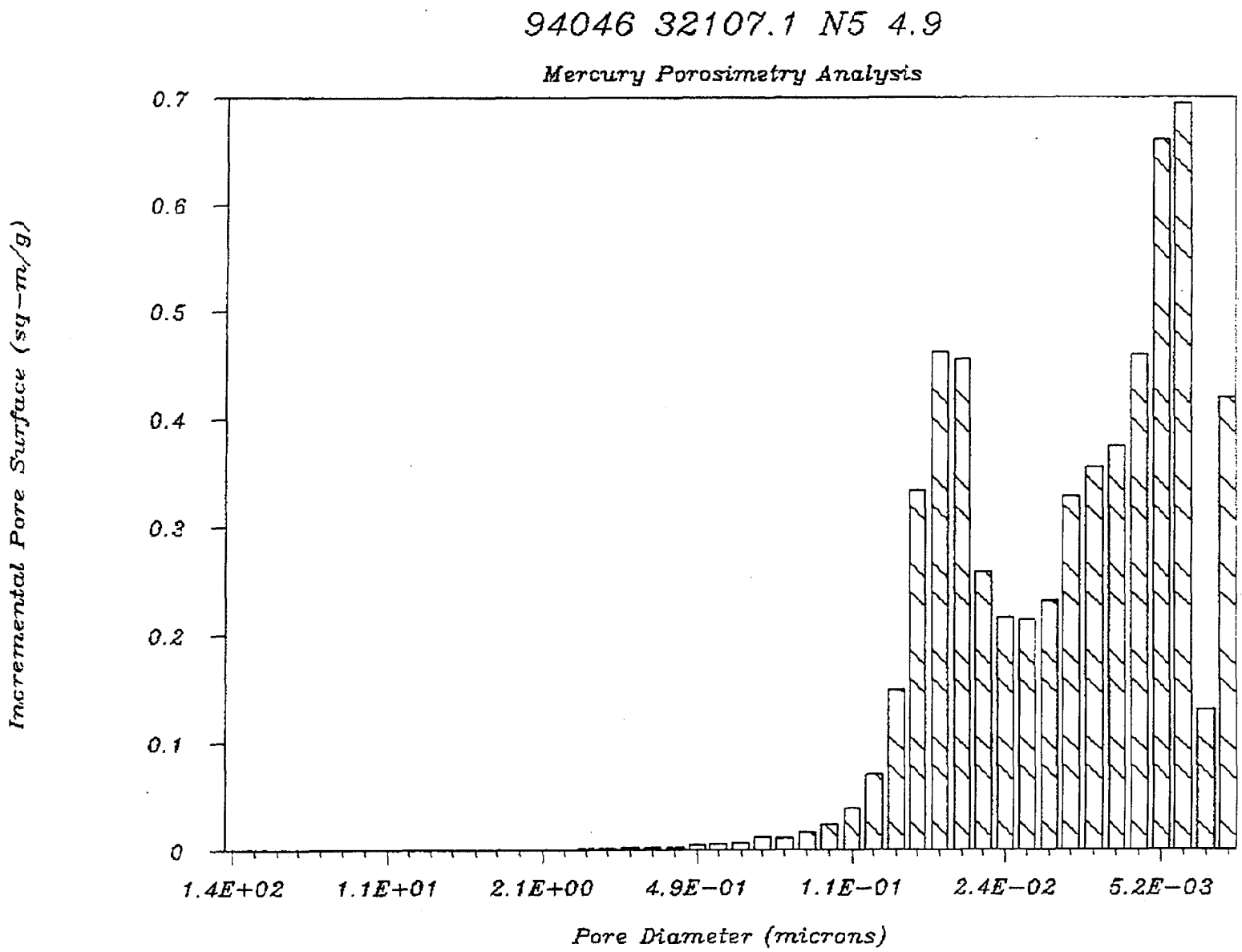

94041 32104.1 N4 11.6
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

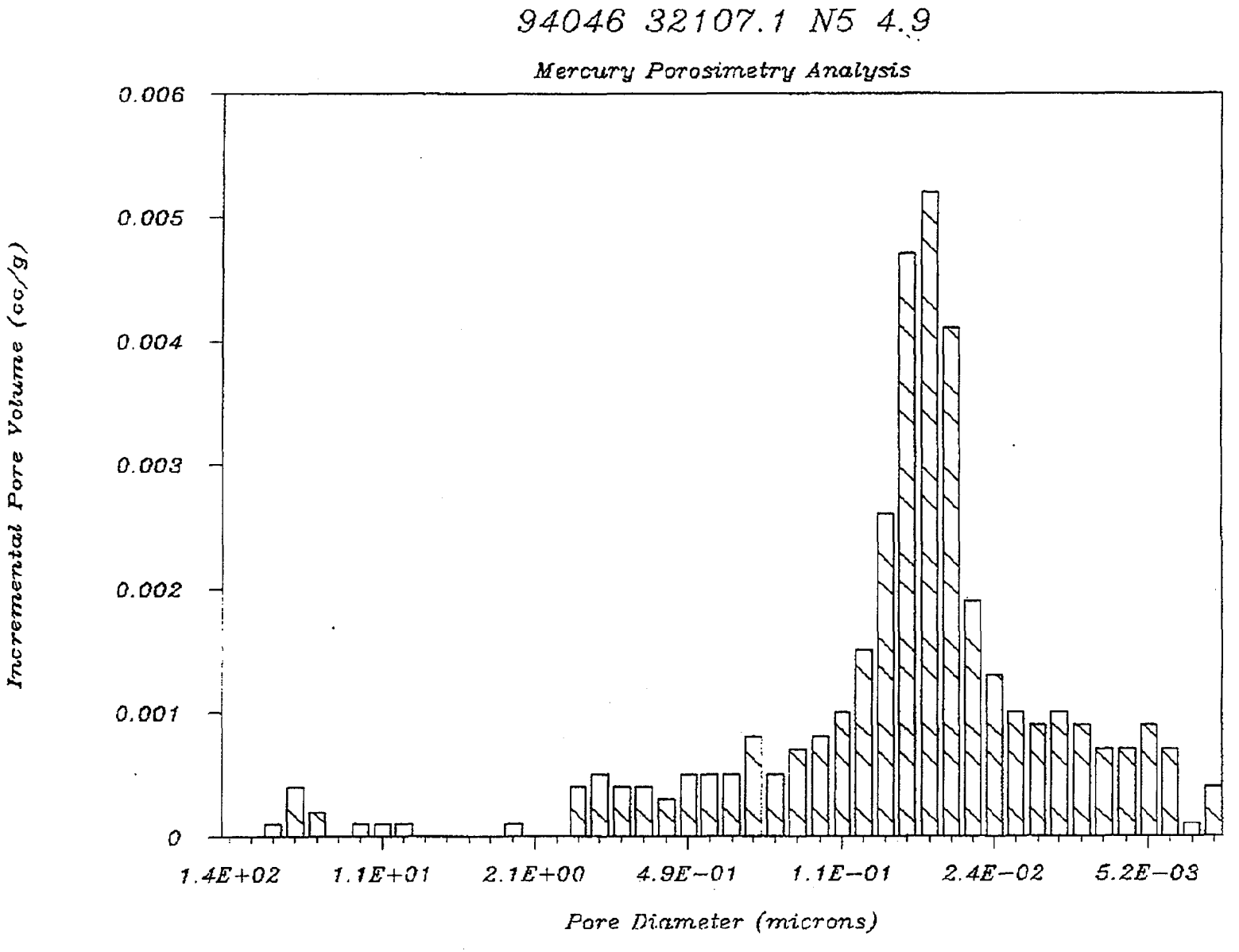

94037 32105.1 N4 14.5
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.2E+00
4.9E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

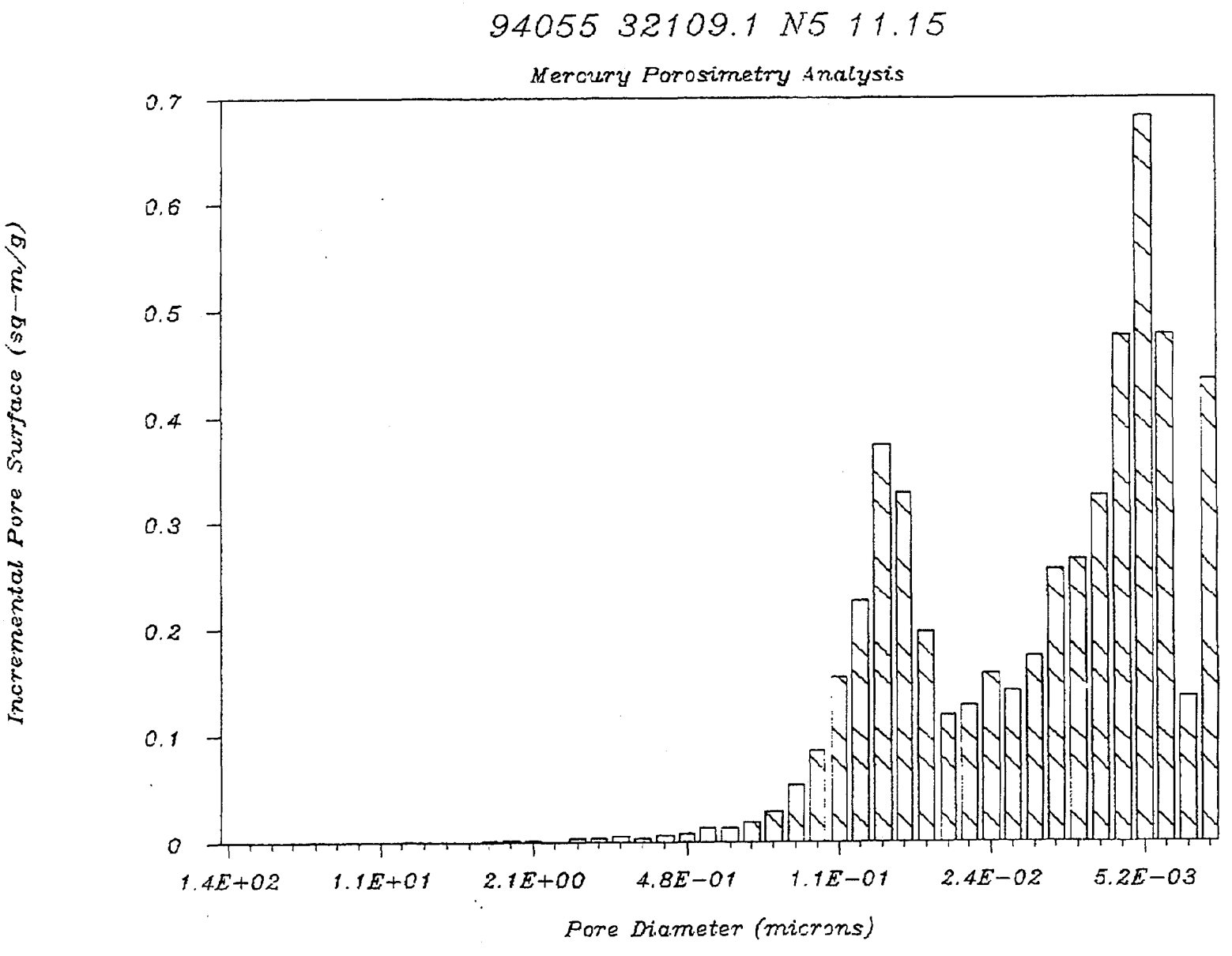

94037 32105.1 N4 14.5
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.003
0.003
0.003
0.002
0.002
0.002
0.002
0.002
0.001
0.001
0.001
0.001
0.001
0.000
0.000
0.000
0
1.4E+02
1.1E+01
2.2E+00
4.9E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

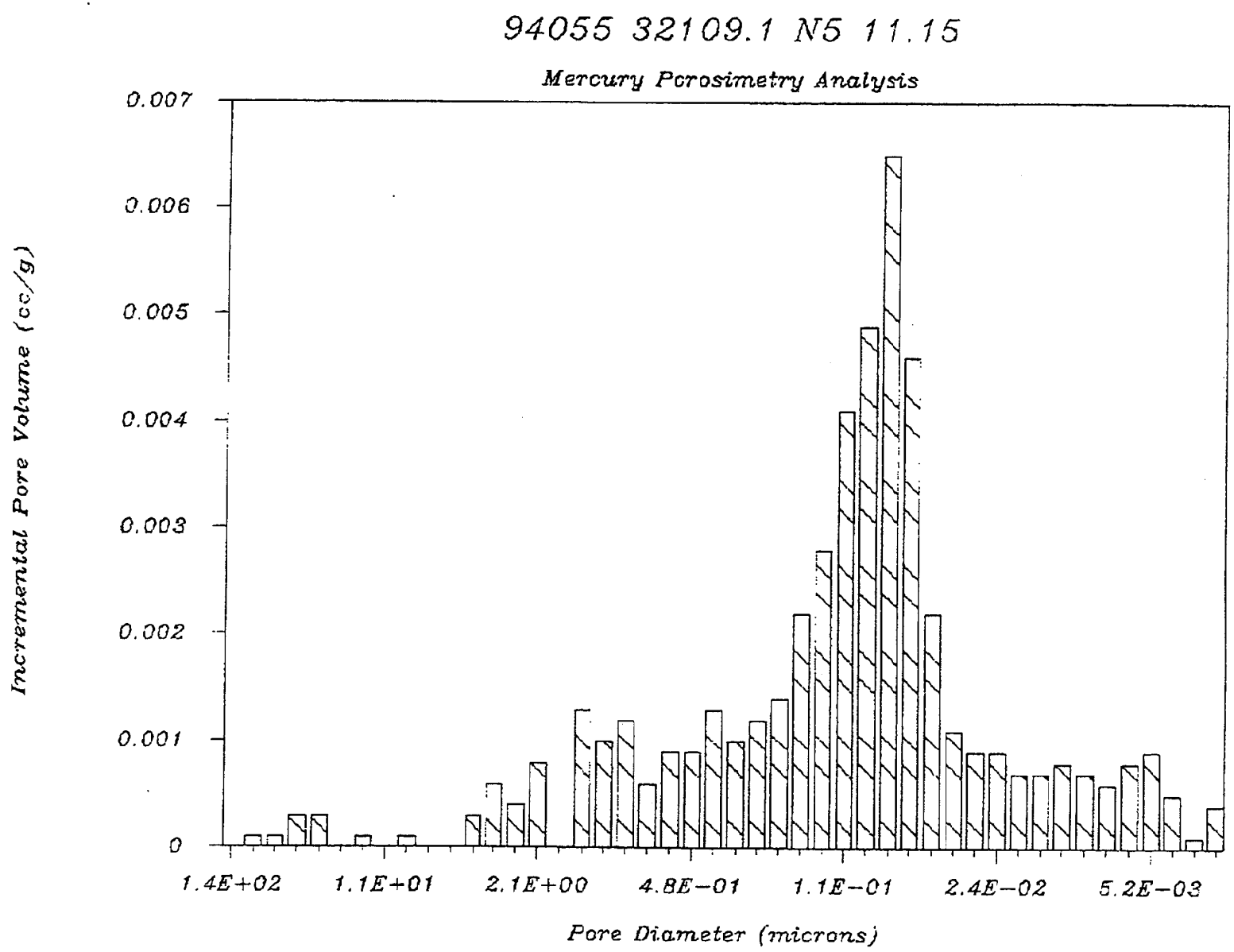

94043 32106.1 N4 19.0
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

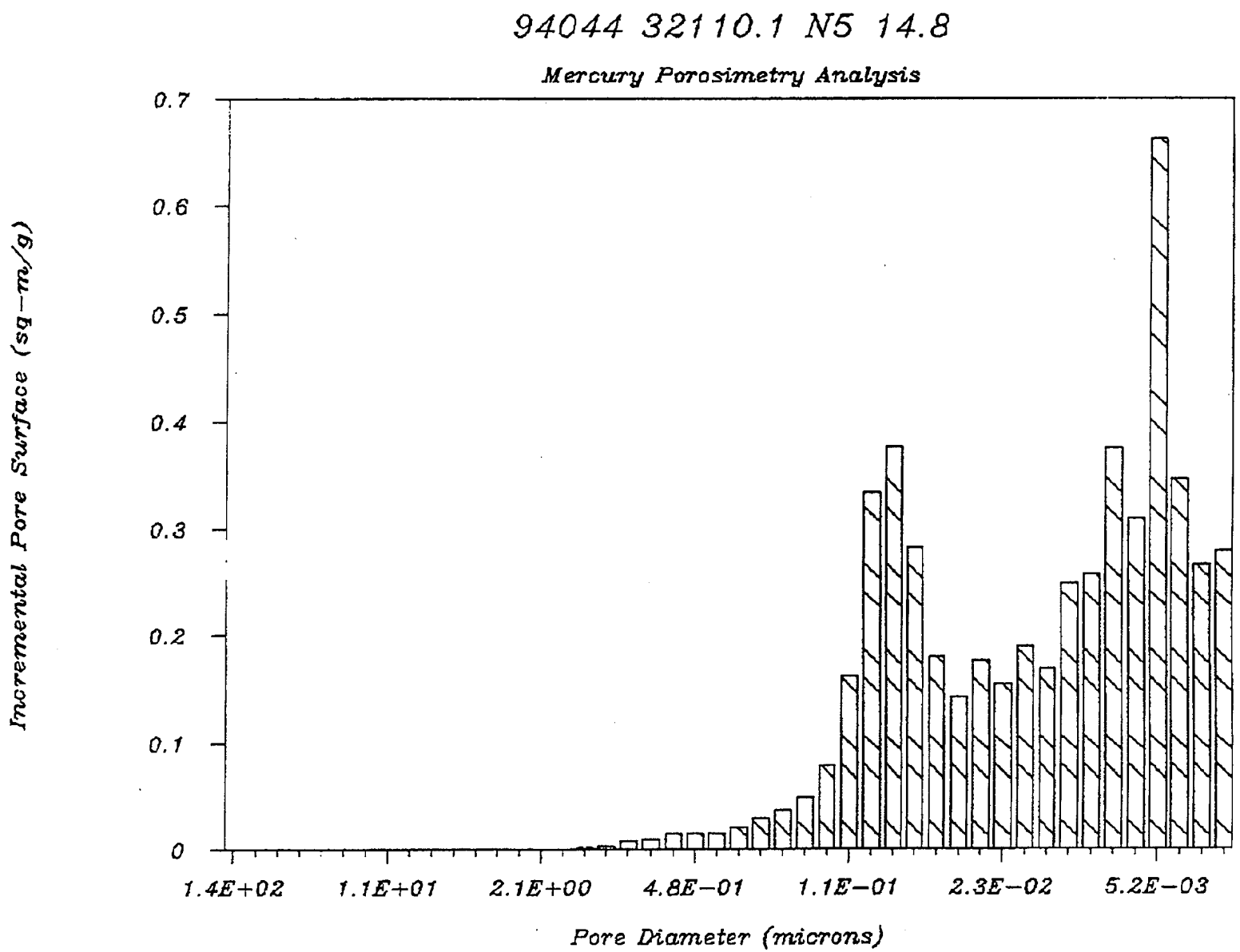

94043 32106.1 N4 19.0
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

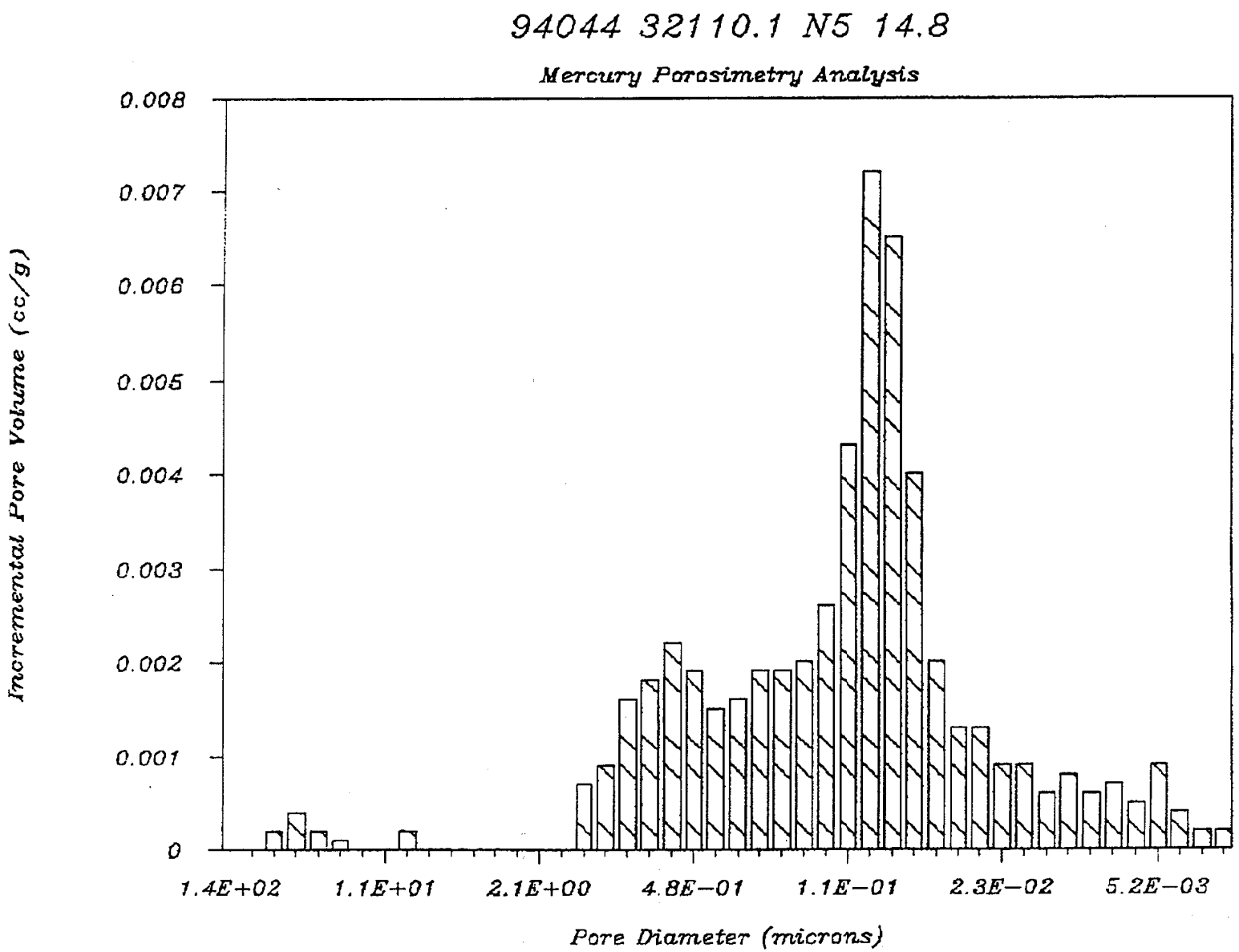

94046 32107.1 N5 4.9
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

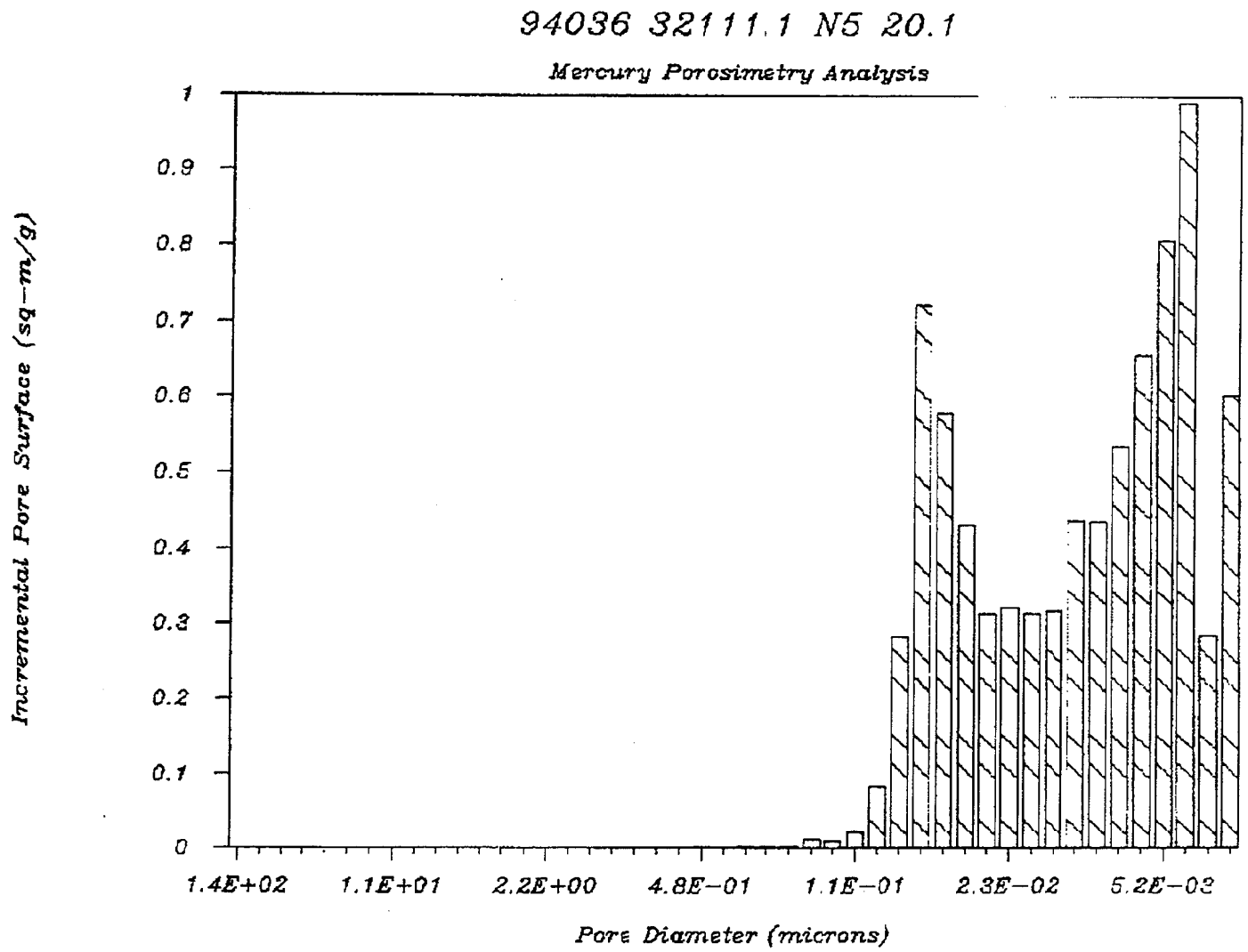

94046 32107.1 N5 4.9
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

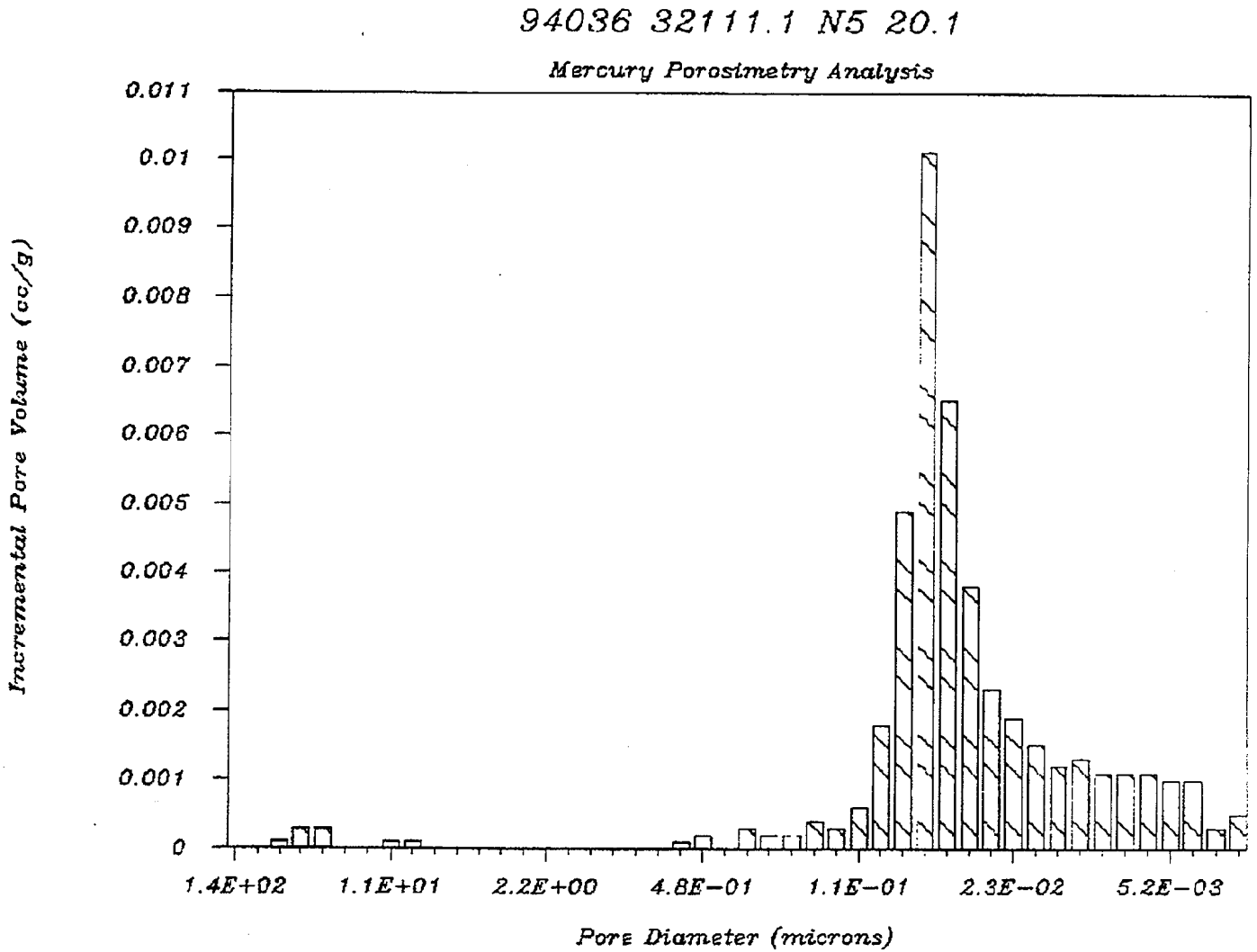

94055 32109.1 N5 11.15
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

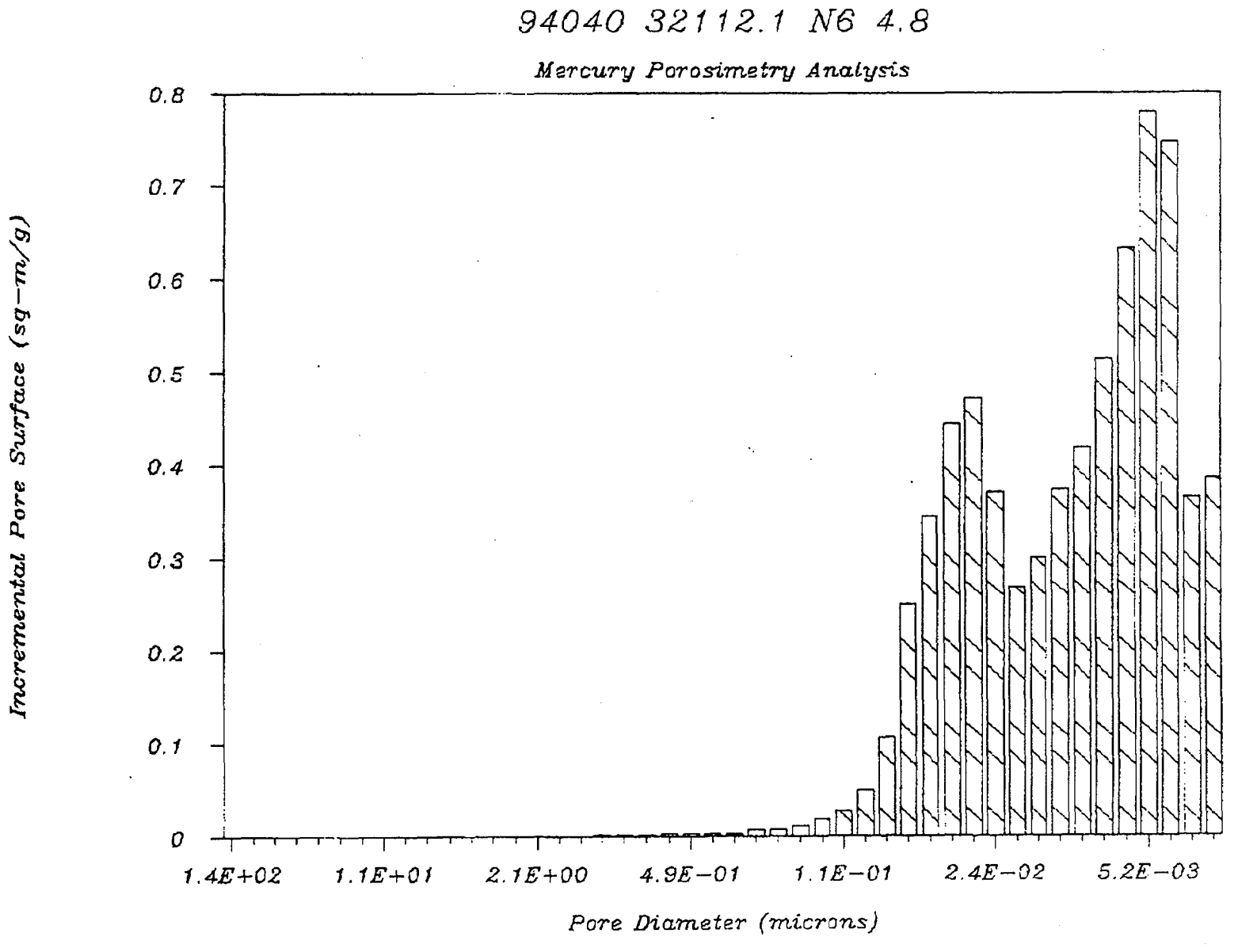

94055 32109.1 N5 11.15
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

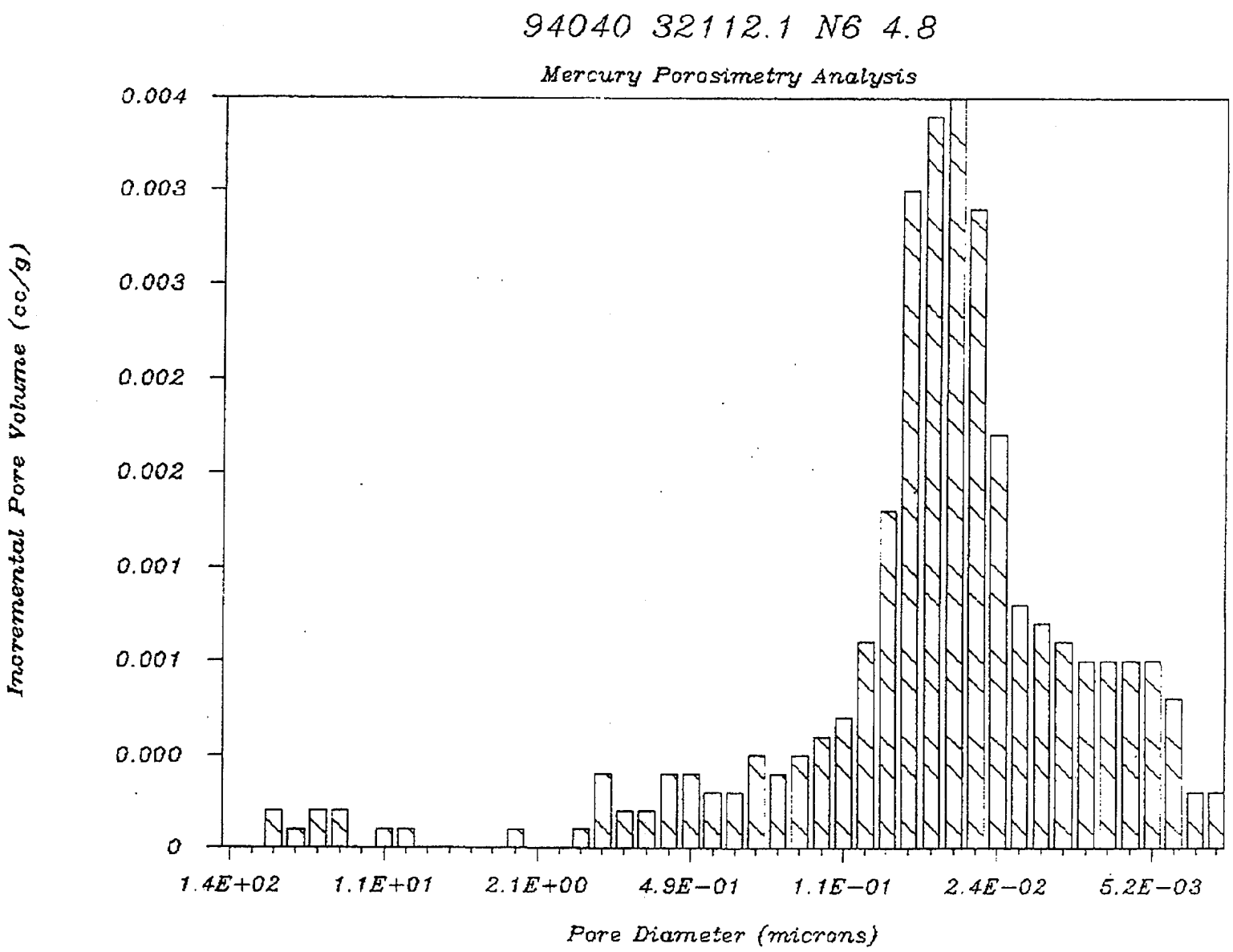

94044 32110.1 N5 14.8
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

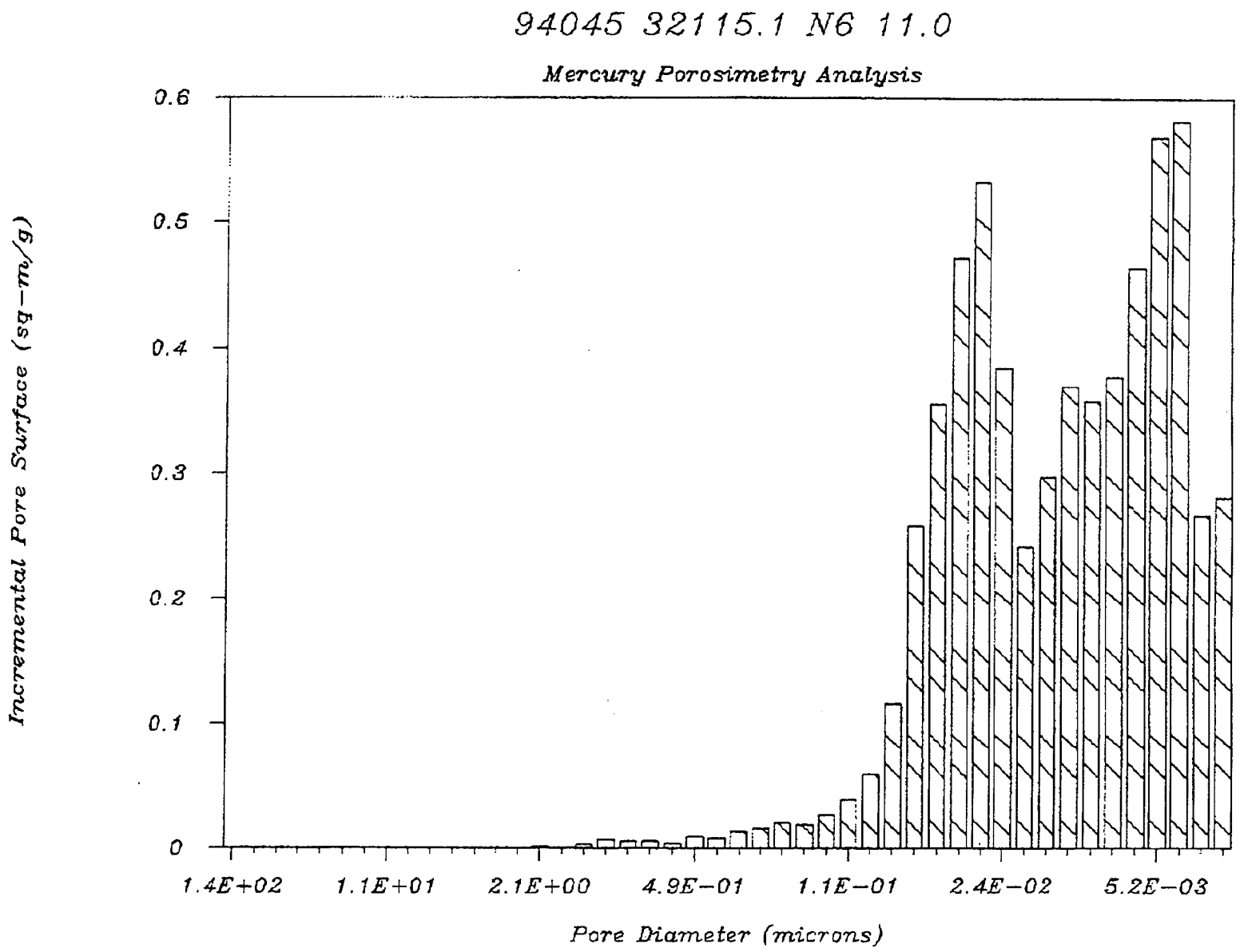

94044 32110.1 N5 14.8
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

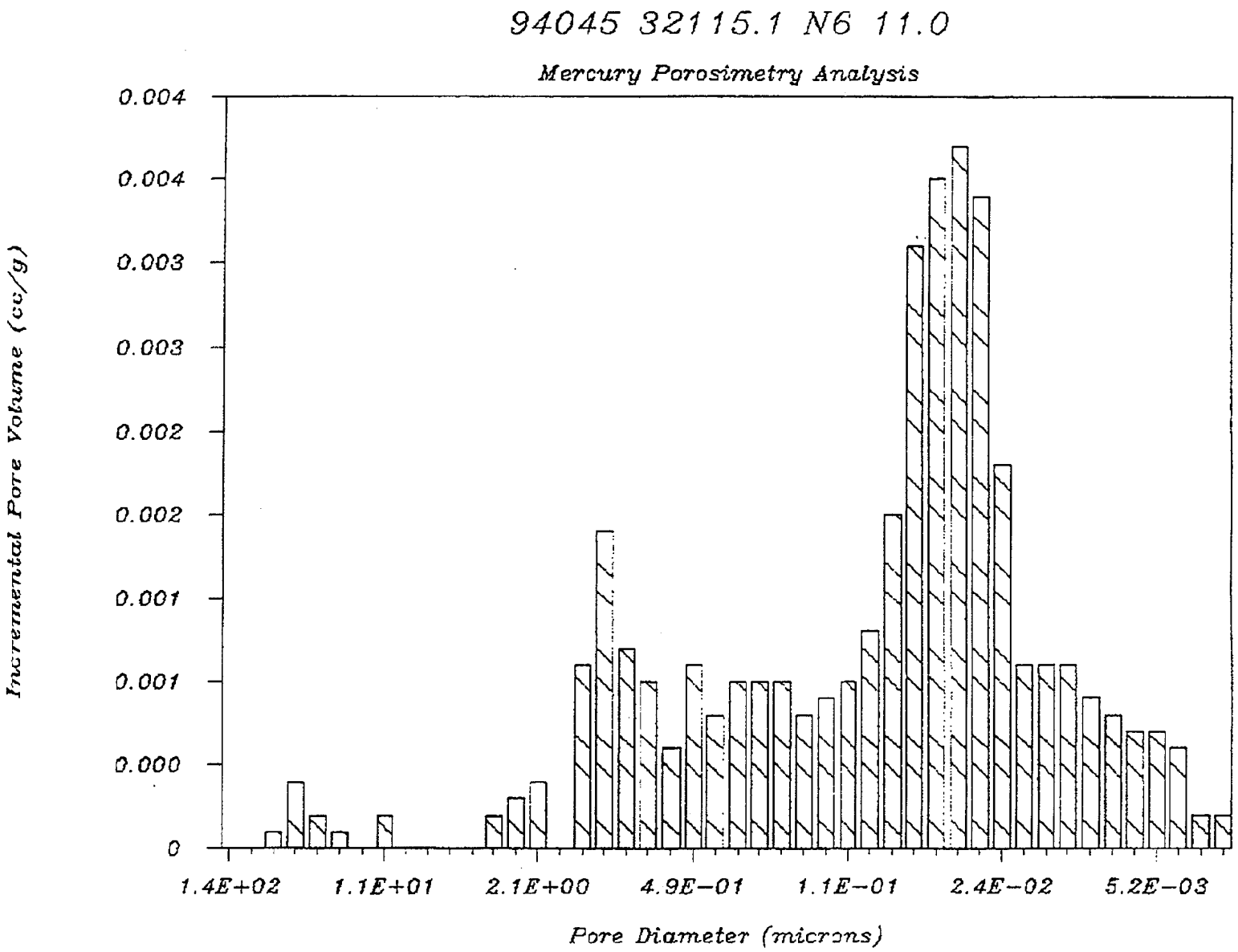

94036 32111.1 N5 20.1
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

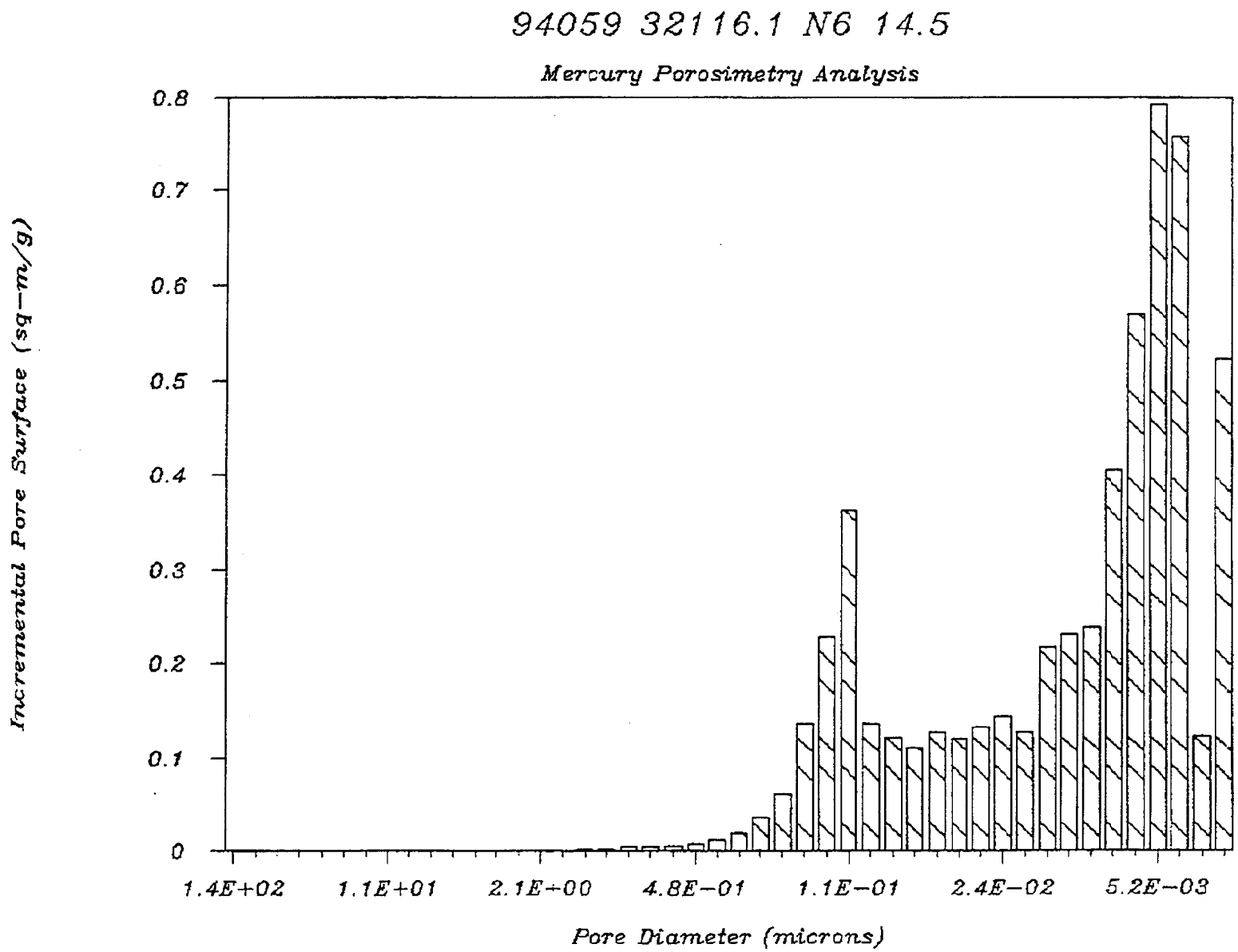

94036 32111.1 N5 20.1
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)

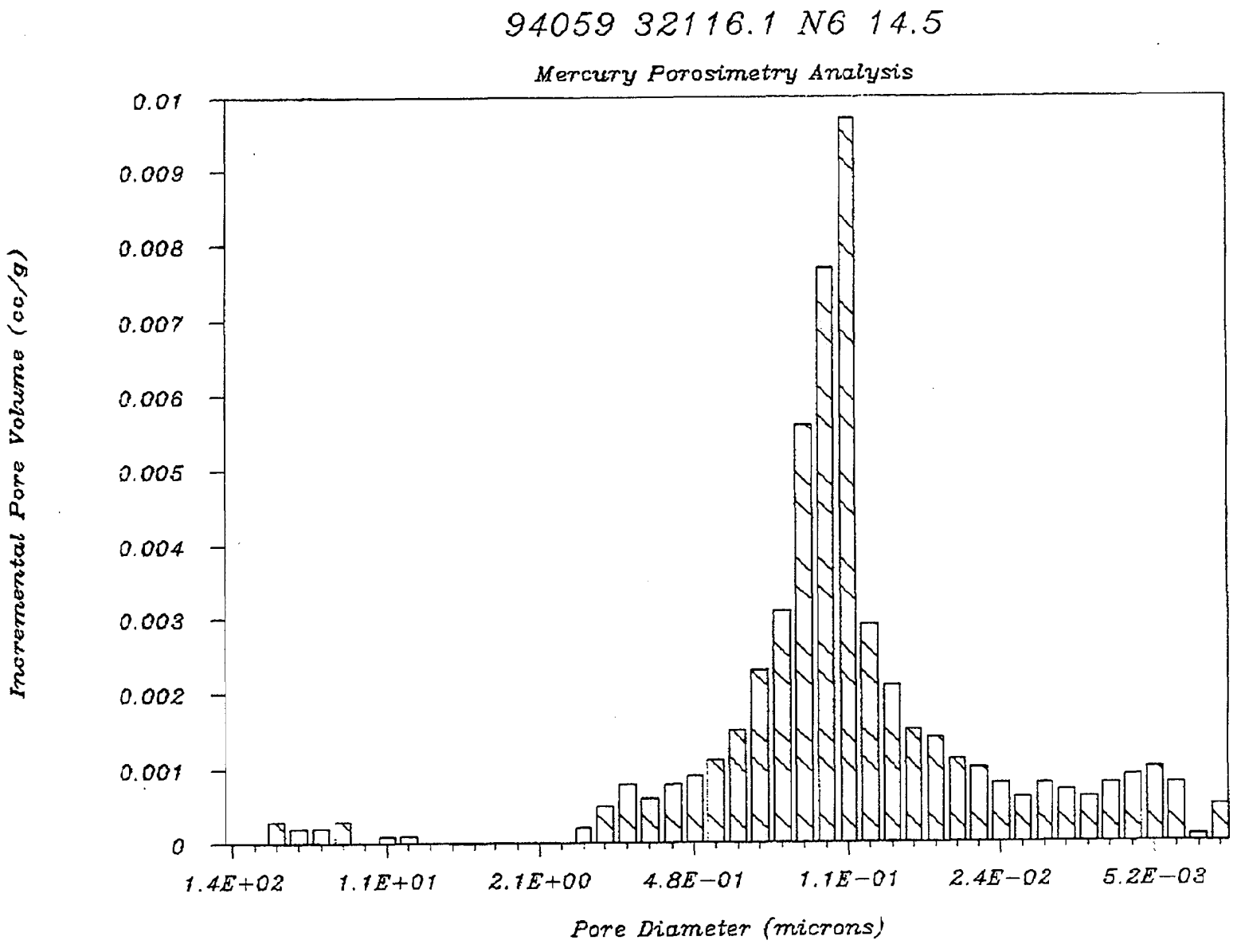

94040 32112.1 N6 4.8
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

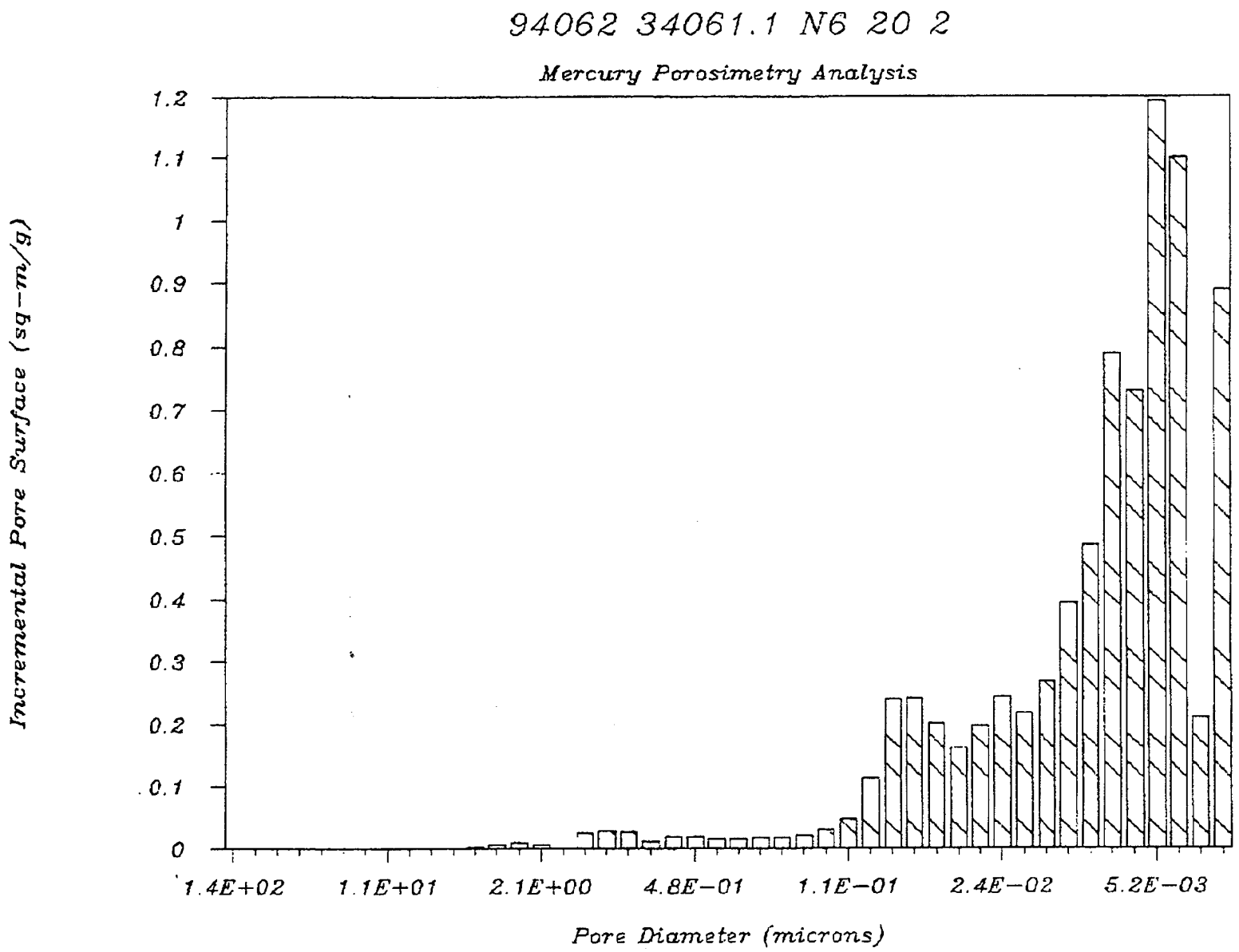

94040 32112.1 N6 4.8
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

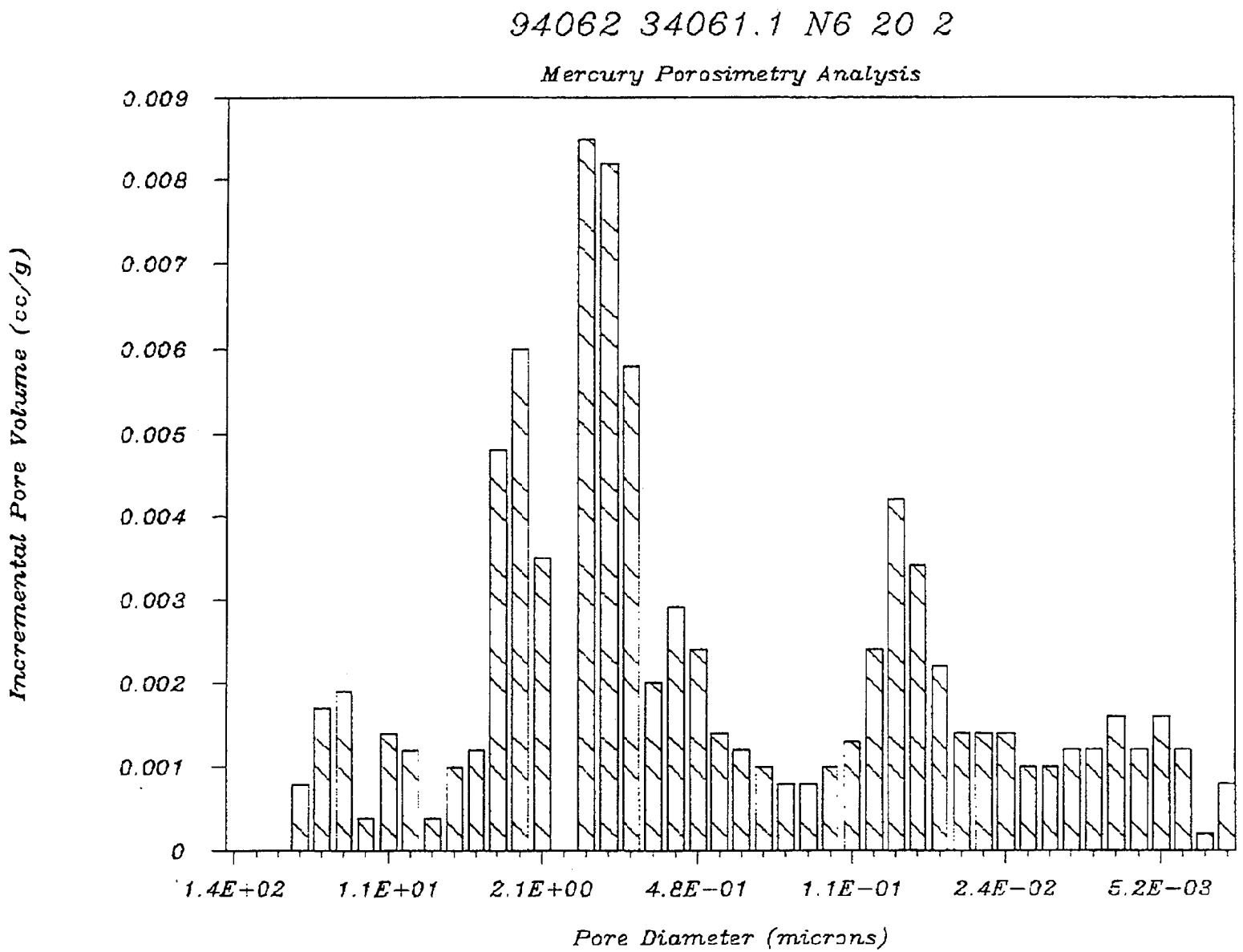

94045 32115.1 N6 11.0
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

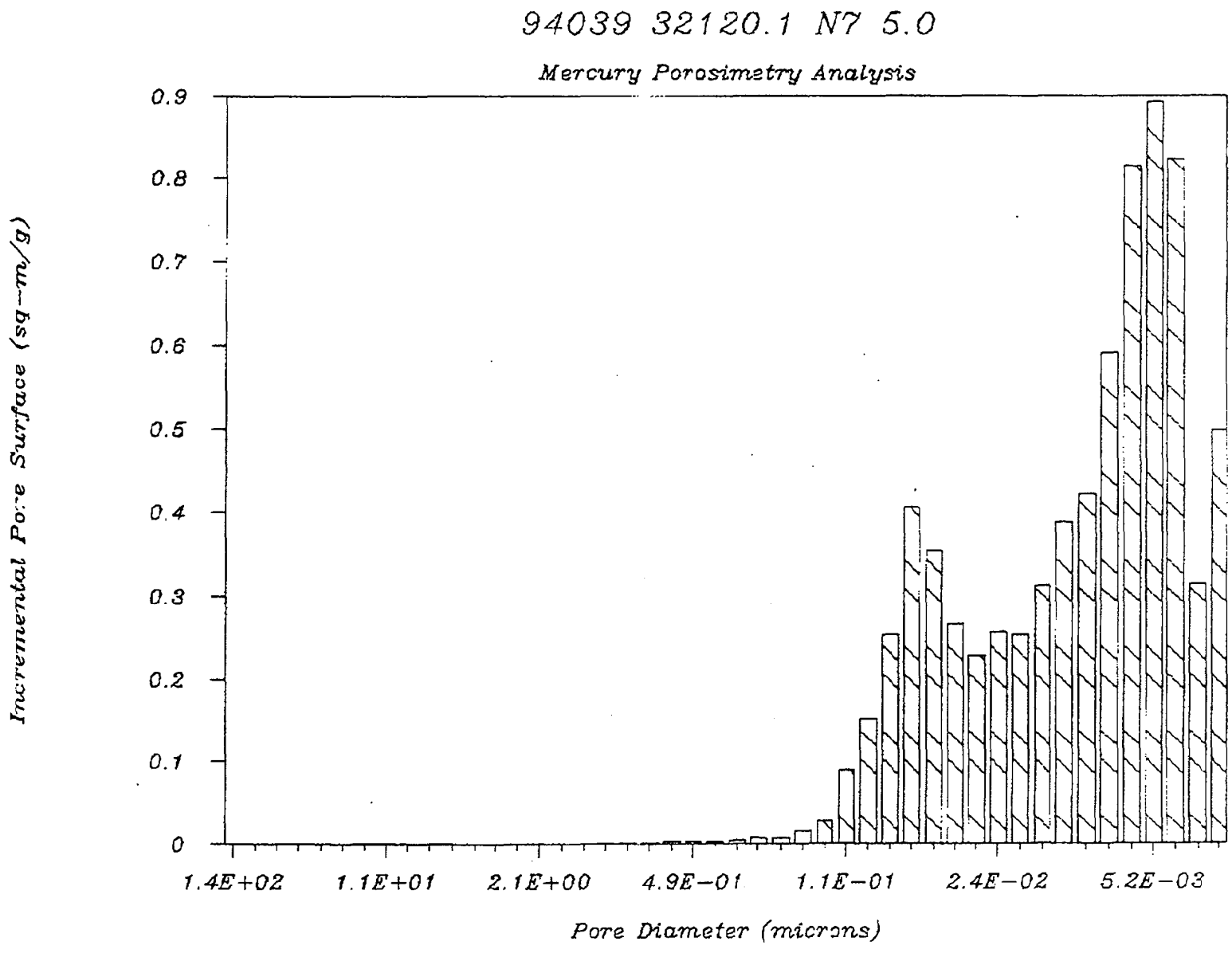

94045 32115.1 N6 11.0
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

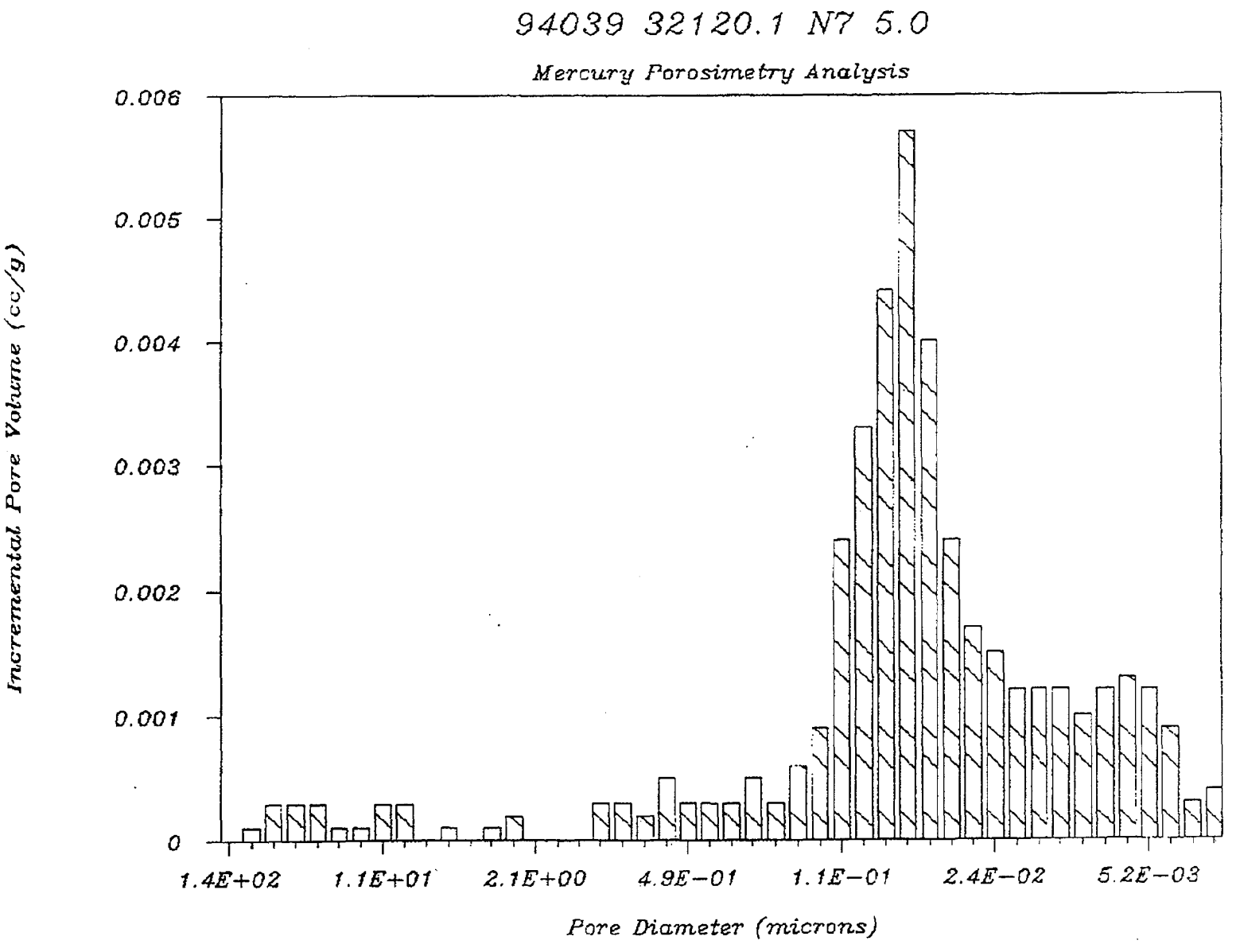

94059 32116.1 N6 14.5
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

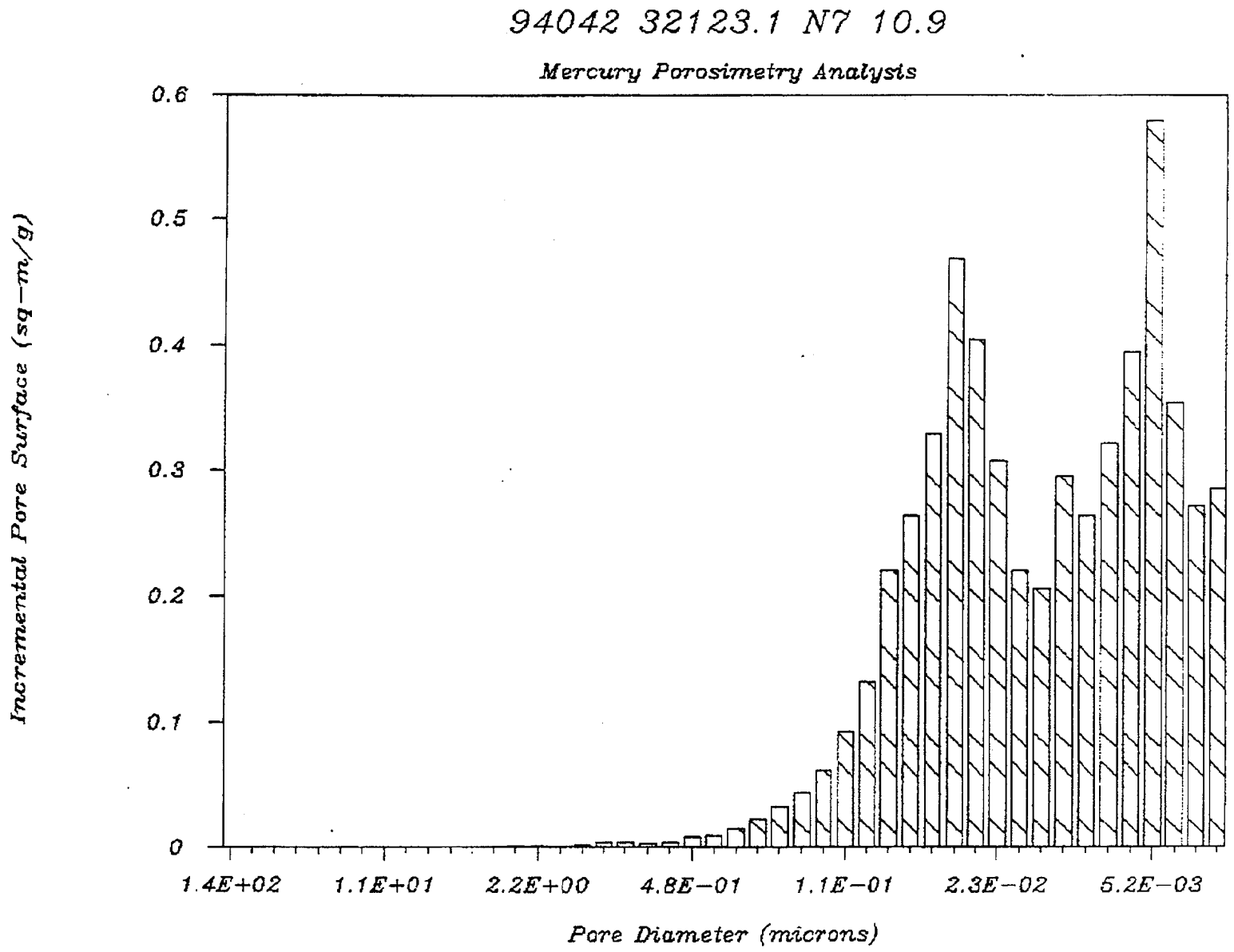

94059 32116.1 N6 14.5
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

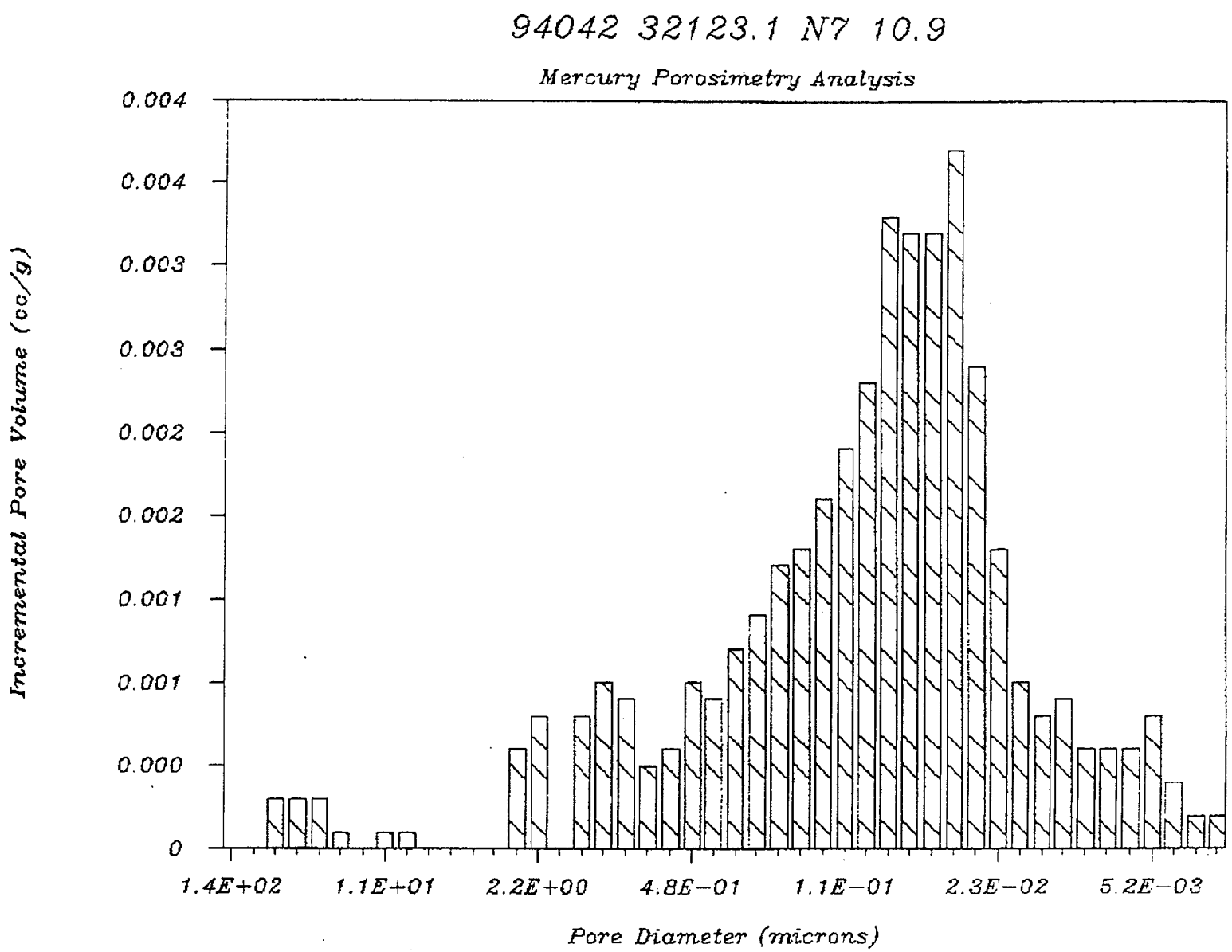

94062 34061.1 N6 20 2
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

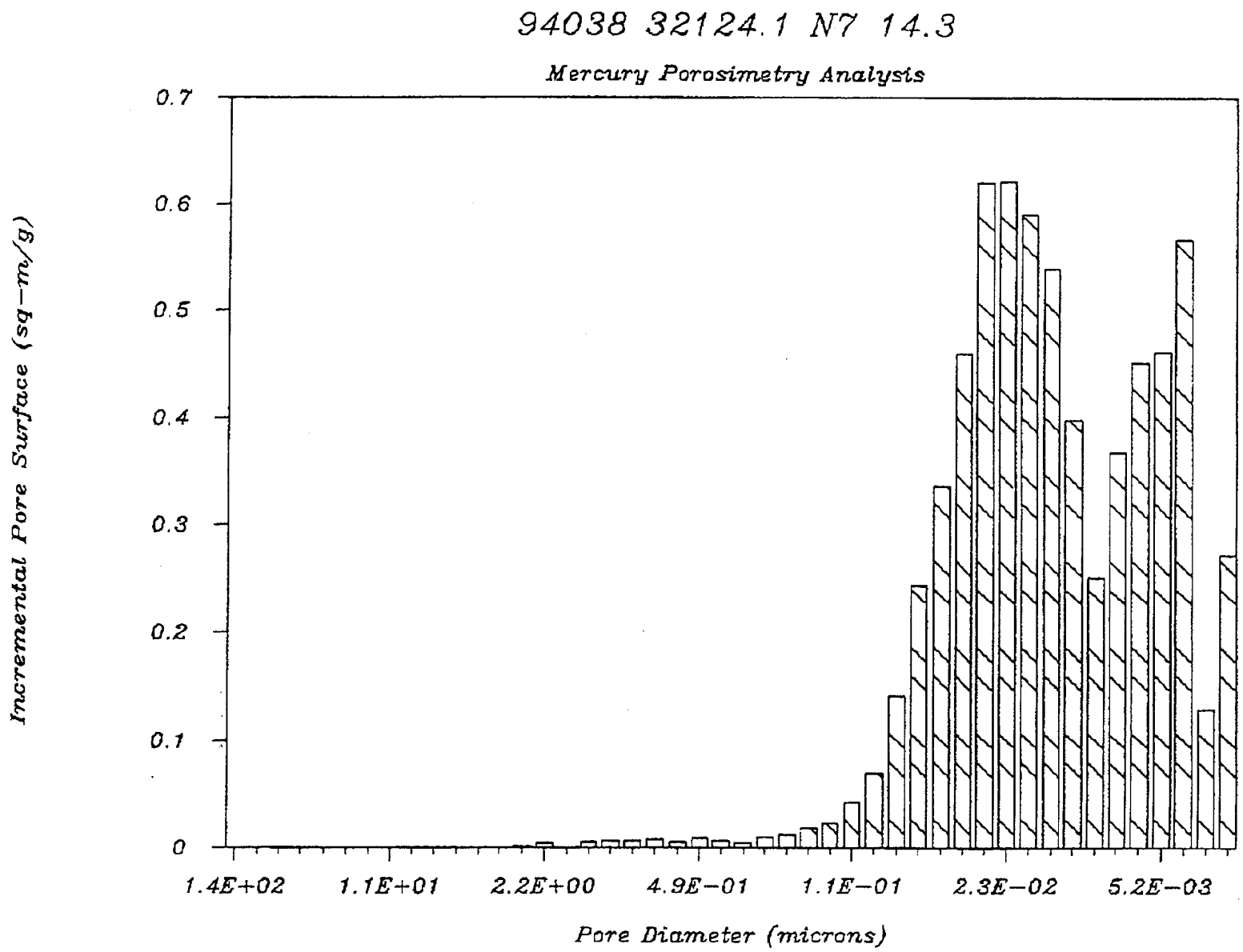

94062 34061.1 N6 20 2
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.8E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

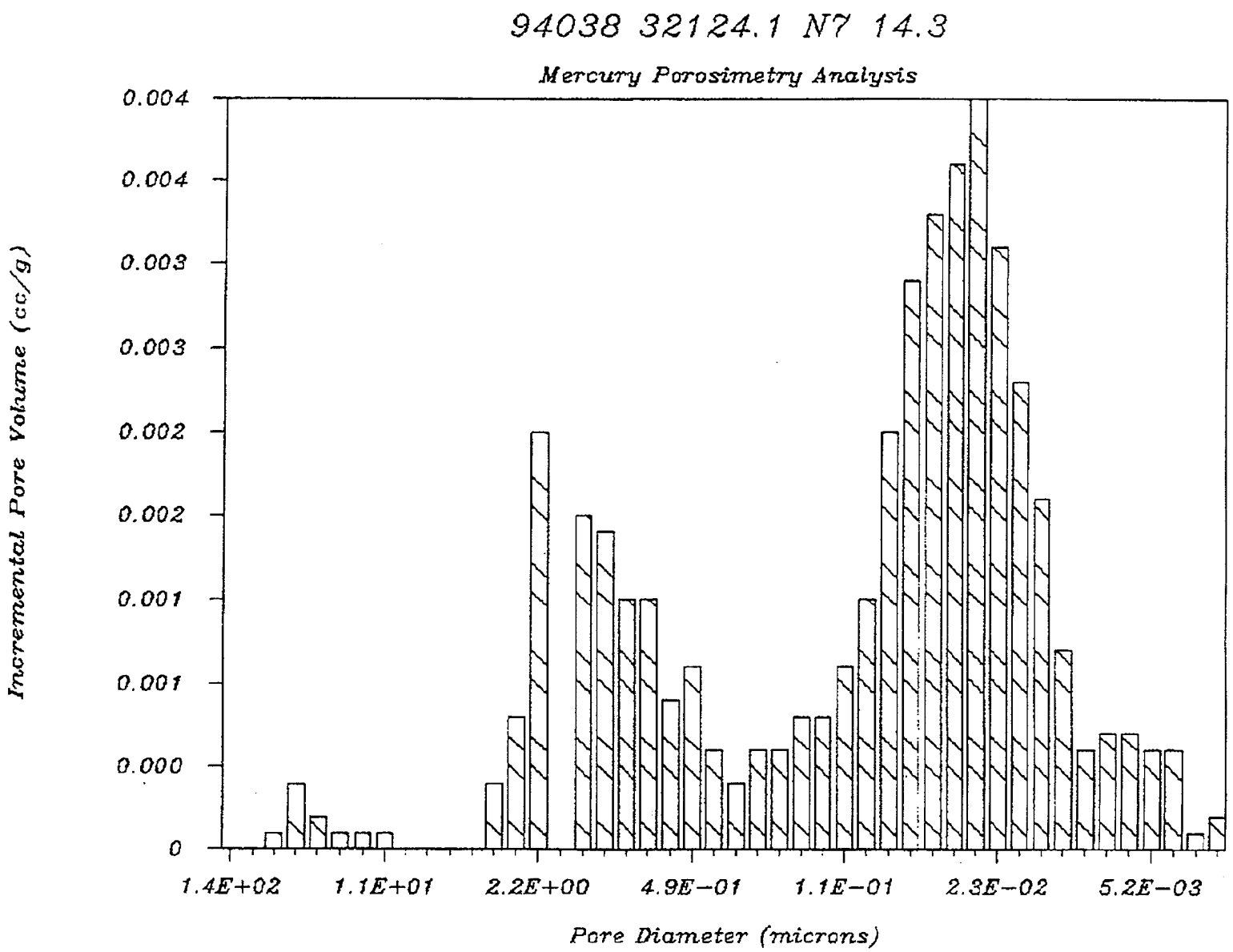

94039 32120.1 N7 5.0
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

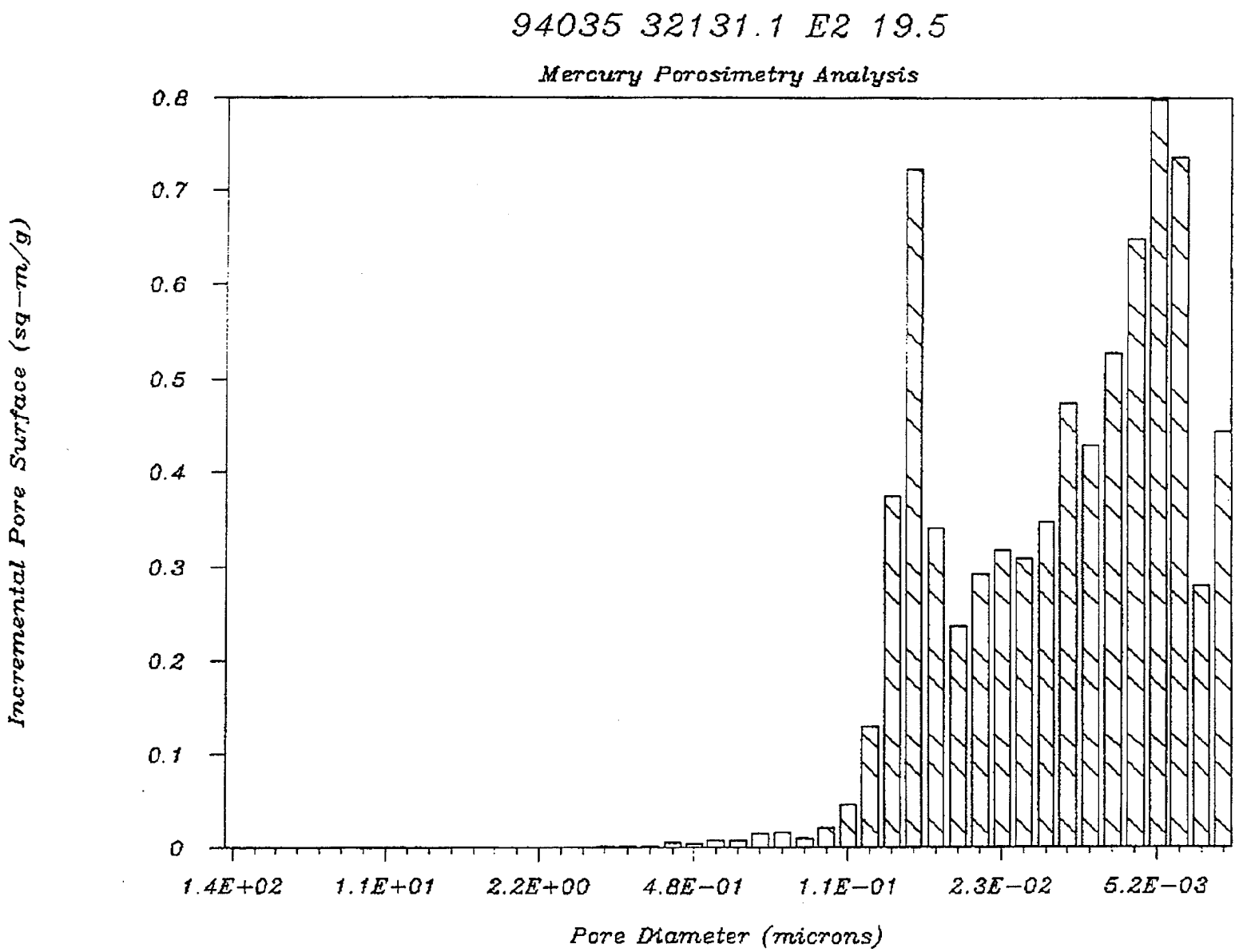

94039 32120.1 N7 5.0
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.1E+00
4.9E-01
1.1E-01
2.4E-02
5.2E-03
Pore Diameter (microns)

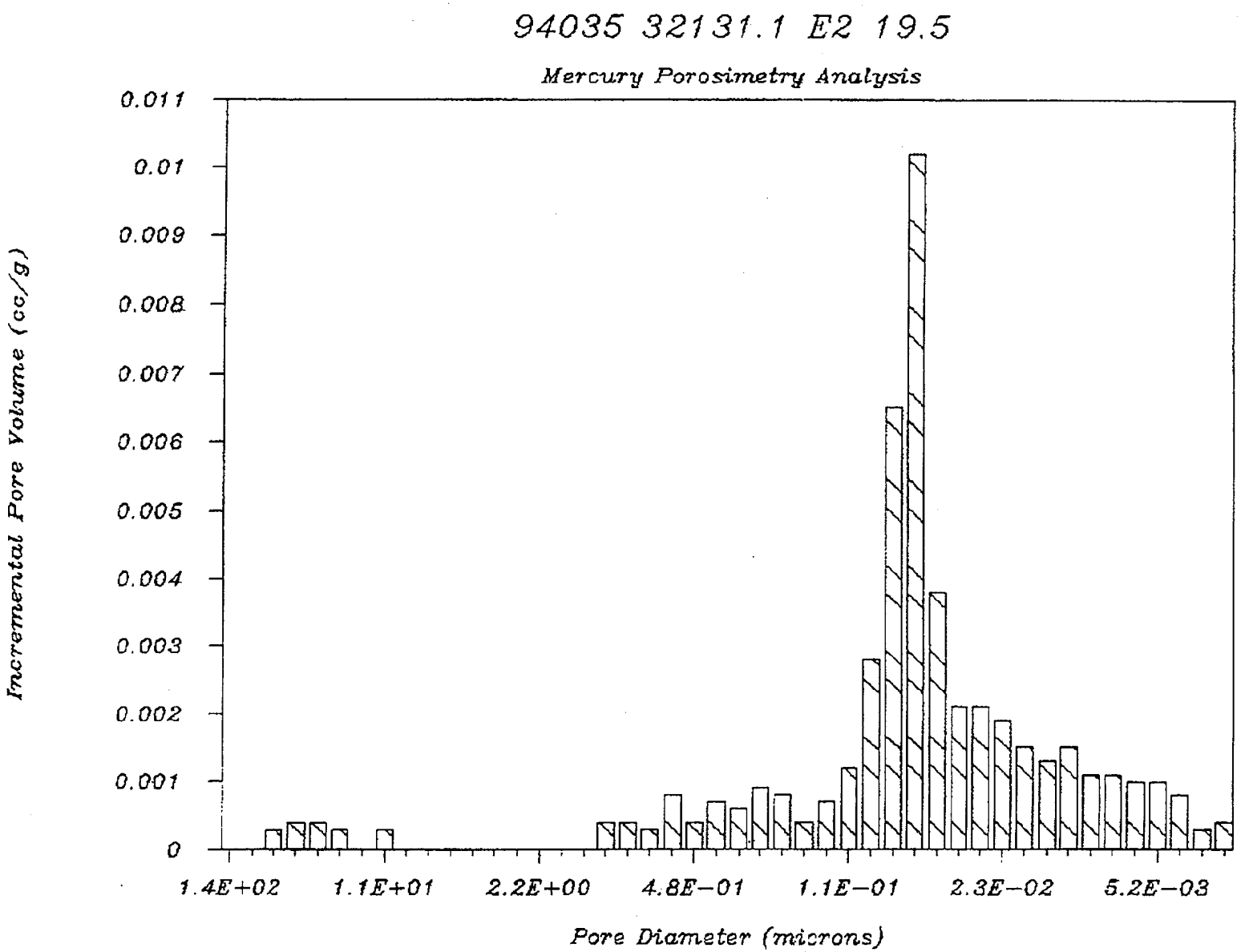

94042 32123.1 N7 10.9
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)


94042 32123.1 N7 10.9
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)


94038 32124.1 N7 14.3
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.2E+00
4.9E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)


94038 32124.1 N7 14.3
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.004
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
1.4E+02
1.1E+01
2.2E+00
4.9E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)


94035 32131.1 E2 19.5
Mercury Porosimetry Analysis
Incremental Pore Surface (sq-m/g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)


94035 32131.1 E2 19.5
Mercury Porosimetry Analysis
Incremental Pore Volume (cc/g)
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1.4E+02
1.1E+01
2.2E+00
4.8E-01
1.1E-01
2.3E-02
5.2E-03
Pore Diameter (microns)