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Analysis of physical and thermal properties of select Norman Wells Pipeline core specimens - 1989

D.E. Patterson

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ANALYSIS OF PHYSICAL AND THERMAL PROPERTIES OF SELECT NORMAN WELLS PIPELINE CORE SPECIMENS - 1989

Final report
to the
Terrain Sciences Division
Geological Survey of Canada

by

D.E. Patterson
Geotechnical Science Laboratories
Carleton University

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Geotechnical Science Laboratories
Carleton University
Ottawa, Ontario
K1S 5B6)

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FOREWORD

This report documents work undertaken as part of the federal government's Permafrost and Terrain Research and Monitoring Program along the 868 km Norman Wells to Zama oil pipeline. The 324 mm diameter, shallow burial (1 m) pipeline, traverses the discontinuous permafrost zone of northwestern Canada and began operation in April 1985. A joint monitoring program with Interprovincial Pipe Line Inc. was established following the signing of an environmental agreement between the pipeline company and the Department of Indian and Northern Affairs (INAC) in 1983. INAC coordinates the government's monitoring program in which Energy, Mines and Resources' Geological Survey of Canada and Agriculture Canada's Land Resource Research Institute participate.

A major component of this research and monitoring program involves the detailed quantification of changes in the ground thermal regime and geomorphic conditions at a series of instrumented sites along the route. This project was developed in cooperation with the Terrain Sciences Division of the Geological Survey in order to examine and quantify the effects of pipeline construction, operation and maintenance in thaw sensitive terrain. Many components of this research are contracted out.

The work undertaken in this contract report describes but one aspect of these site investigations. Interpretations contained herein are often limited to the specific data base under analysis and may thus not present an integrated or comprehensive analysis of all site observations. The opinions and views expressed by the authors are their own and do not necessarily reflect those of the Geological Survey of Canada or Indian and Northern Affairs.

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Margo Burgess
Scientific Authority
Terrain Sciences Division
Geological Survey of Canada

I INTRODUCTION

This report summarizes the results of physical and thermal properties tests carried out on core specimens from the Norman Wells to Zama oil pipeline. Soil cores from three sites were examined to provide information needed in interpreting geophysical and thermal data. The sites chosen were:

1. 85-7A Table Mountain, 271.2 km from Norman Wells
   Ice rich lacustrine plain (old seismic line)
2. 85-7C Table Mountain, 272.0 km from Norman Wells
   New clearing on level plain
3. 85-8C Manner's Creek, 558.3 km from Norman Wells
   Thin peat with thin permafrost

Other sites from these locations were studied previously (Patterson and Riseborough, 1988). Other information may be found in Patterson et al. (1987).

The following information was obtained for selected core specimens from each borehole location:

1. total density
2. dry density
3. total ice/water content
4. grain size characteristics
5. pore water salinity
6. temperature-dependent phase composition

As in previous reports, the numbering system used to identify specimens gives the borehole, the core and sub-specimen

number. The specimen depths indicated on the summary tables denotes the position of the sub-sample within the soil profile.

The specimens examined in this report showed signs of degradation due long-term storage in the coldroom. Dessication of the specimens was evident and frost had accumulated in the specimen bags. It was assumed that the accumulated frost originated from within the specimen and its mass was included in density and water content determinations.

II Physical Properties Tests

2.1 Introduction

The test methods used were the same as those used in a previous study (Patterson and Riseborough, 1988). The following sections present the test summaries for each borehole.

2.2 Borehole Descriptions

The core descriptions for boreholes 7A, 7C and 8C, as determined in the cold room, are given in Tables 1, 2 and 3 respectively. There is generally no difference in the cold room descriptions and the grain-size characteristics, however, the mineral specimens for borehole 8C should be reclassed as sandy silts rather than sandy clays.

Table 1 Core Description and Ice Classification as Determined in the Cold Room for Borehole 7A

Specimen	Depth (m)	Visual Soil Classification (in cold room)	Inclusions	Ice Type
7A C1	0.3 - 0.6	peat		VC
7A C2a	0.6 - 1.2	peat/silty clay		VS
7A C3b	1.2 - 1.7	peat/silty clay		VS
7A C4	1.7 - 2.2	silty clay	gravel	NB
7A C5	2.2 - 2.5	silty clay	gravel	VS
7A C6a	2.5 - 3.1	silty clay	gravel	VS
7A C7a	3.1 - 3.7	silty clay	gravel	VS
7A C7c	3.1 - 3.7	silty clay	gravel	VS
7A C8c	3.7 - 4.5	clay	gravel	VS
7A C9c	4.5 - 5.2	silty clay	gravel	VS
7A C10b	5.2 - 6.0	silty clay	gravel	VS
7A C11a	6.0 - 6.6	silty clay	gravel	VS
7A C12a	6.6 - 7.2	silty clay	gravel	VS
7A C12c	6.0 - 6.6	silty clay	gravel	VS
7A C13b	7.2 - 7.7	silty clay	gravel	VS
7A C14b	7.7 - 8.0	silty clay	gravel	NB
7A C15a	8.0 - 8.4	silty clay	gravel	VS
7A C17a	10.0 - 10.4	silty clay	gravel	NB
7A C17b	10.0 - 10.4	silty clay	gravel	VS
7A C18a	10.4 - 11.2	silty clay	gravel	VS
7A C20b	12.0 - 12.7	silty clay	gravel	NB
7A C22a	13.5 - 14.3	silty clay	gravel	VS
7A C23a	14.3 - 15.0	silty clay	gravel	VS
7A C24a	15.0 - 15.5	silty clay	gravel	VS
7A C25a	15.5 - 16.3	silty clay	gravel	VR
7A C26a	16.3 - 16.9	silty clay		NB
7A C26c	16.3 - 16.9	silty clay		VS
7A C27a	16.9 - 18.3	silty clay		VS
7A C27c	16.9 - 18.3	silty clay		VS
7A C28b	18.3 - 19.2	silty clay		NB
7A C29c	19.2 - 20.3	clay		VS

Table 2 Core Description and Ice Classification as Determined in the Cold Room for Borehole 7C

Specimen	Depth (m)	Visual Soil Classification (in cold room)	Inclusions	Ice Type
7C C1a	0.0 - 0.8	silty clay	org/grav	VS
7C C2b	0.8 - 1.5	silty clay		VS
7C C3a	1.5 - 2.3	silty clay	gravel	VS
7C C4a	2.3 - 3.2	silty clay	gravel	VS
7C C5b	3.1 - 3.8	silty clay	gravel	VS
7C C6b	3.8 - 4.6	silty clay		VS
7C C7a	4.6 - 5.4	silty clay	gravel	VS
7C C8a	5.4 - 6.1	silty clay	gravel	VS
7C C9a	6.1 - 6.9	silty clay	gravel	VS
7C C10	6.9 - 7.4	silty clay	gravel	VS
7C C11a	10.8 - 11.5	silty clay	gravel	VS
7C C12c	12.1 - 12.9	silty clay		VS
7C C13a	12.9 - 13.7	silty clay		VS
7C C13b	12.9 - 13.7	clayey silt		NBN
7C C14a	13.7 - 14.6	silty clay		VS
7C C14c	13.7 - 14.6	silty clay		VS
7C C16a	15.4 - 16.1	clayey silt		VS
7C C17a	16.1 - 16.9	clay/silt contact		VS
7C C18A	16.9 - 17.4	fine sand	gravel	NB

Table 3 Core Description and Ice Classification as Determined in the Cold Room for Borehole 8C

Specimen	Depth (m)	Visual Soil Classification (in cold room)	Inclusions	Ice Type
8C C1a	0.2 - 0.9	peat		NB
8C C1b	0.2 - 0.9	peat		NB
8C C1c	0.2 - 0.9	peat		NB
8C C3b	1.5 - 2.0	sandy clay		VS
8C C3c	1.5 - 2.0	sandy clay		VR
8C C4a	2.0 - 2.6	sandy clay		VS
8C C5a	2.6 - 3.2	sandy clay		VR

2.3 Physical Properties

The summary of specimen physical properties are given in Tables 4a and 4b. Total (frozen) and dry densities were determined from the specimen masses and volume. Gravimetric water contents were determined and volumetric water/ice contents were calculated from the gravimetric water content and density data. A volumetric water/ice content was also calculated from the volume and density data to reflect the possible effects of specimen dessication (Ov cal). Salinities of pore water extracts were also determined for each specimen.

2.3.1 Borehole 7A

The low densities and high water contents in the top metre in Borehole 7A are associated with the organic layer (see Figures 1 and 2). An ice rich layer was also found at about 6.5-7 m in the profile. The salinity measurements tend to increase to about 1 g NaCl/l at about 3 m depth (see Figure 3). Beyond this depth, the measured values vary between 0.8 and 1.2 g NaCl/l.

2.3.2 Borehole 7C

Borehole 7C is very similar to Borehole 7A except it lacks the prominent organic layer. The high densities at about 11 m can be attributed to the poor condition of the core specimen, making estimates of specimen volume difficult (Figure 4). This is also reflected in the discrepancy in Ov and Ov cal (Figure 5).

Table 4a Physical Properties Summary

depth metres
Pt total density in g cm^{-3}
Pb dry density in g cm^{-3}
w gravimetric water content, g g^{-1}
Ov volumetric ice/water content, cm^3 cm^{-3}
Ov cal calculated Ov, based upon dry density and void space
salinity expressed in g NaCl per litre

	Depth	Pt	Pb	w	Ov	Ov cal	Salinity
7A C1	.41	.902	.3336	1.911	.6377		
7A C2a	.73	.998	.2433	3.437	.8364		
7A C3b	1.55	1.530	1.229	.2451	.3011	.5450	.24
7A C4	1.84	1.944	1.568	.2399	.3761	.4194	.24
7A C5	2.24	1.797	1.430	.2571	.3676	.4705	.41
7A C6a	2.55	1.764	1.380	.2784	.3842	.4890	.68
7A C7a	3.18	1.875	1.496	.2534	.3791	.4459	1.02
7A C7c	3.61	2.035	1.622	.2544	.4126	.3992	1.28
7A C8c	4.30	2.038	1.637	.2448	.4008	.3937	1.13
7A C9c	4.97	1.853	1.454	.2741	.3987	.4613	1.28
7A C10b	5.48	2.005	1.616	.2410	.3895	.4016	.90
7A C11a	6.02	1.697	1.362	.2455	.3344	.4955	1.05
7A C12a	6.67	1.603	1.085	.5270	.5718	.5982	.60
7A C12c	7.17	1.688	1.181	.5248	.6198	.5626	.83
7A C13b	7.51	2.008	1.582	.2689	.4256	.4139	.86
7A C14b	8.00	2.070	1.674	.2368	.3962	.3802	1.21
7A C15a	8.03	2.048	1.610	.2723	.4384	.4038	.75
7A C17a	10.00	1.973	1.614	.2228	.3595	.4022	.75
7A C17b	10.33	1.955	1.587	.2318	.3678	.4123	.83
7A C18a	10.44	1.930	1.527	.2638	.4028	.4344	1.13
7A C20b	12.22	2.041	1.688	.2090	.3528	.3748	.68
7A C22a	13.54	1.912	1.491	.2824	.4211	.4478	1.05
7A C23a	14.31	1.915	1.477	.2964	.4378	.4529	.98
7A C24a	14.98	1.968	1.581	.2450	.3873	.4145	.86
7A C25a	15.54	1.923	1.553	.2387	.3706	.4249	.83
7A C26a	16.25	1.935	1.572	.2310	.3632	.4177	1.13
7A C26c	16.72	1.986	1.564	.2696	.4216	.4208	1.13
7A C27a	16.87	1.977	1.571	.2583	.4057	.4181	.98
7A C27c	17.42	2.017	1.630	.2374	.3870	.3964	.75
7A C28b	18.44	2.011	1.604	.2539	.4073	.4059	.83
7A C29c	19.60	2.002	1.631	.2274	.3708	.3959	1.28

Table 4b Physical Properties Summary

depth metres
Pt total density in g cm^{-3}
Pb dry density in g cm^{-3}
w gravimetric water content, g g^{-1}
Ov volumetric ice/water content, cm^3 cm^{-3}
Ov cal calculated Ov, based upon dry density and void space
salinity expressed in g NaCl per litre

	Depth	Pt	Pb	w	Ov	Ov cal	Salinity
7C C1a	.12	1.874	1.509	.2417	.3648	.4411	.25
7C C2b	1.09	1.974	1.591	.2405	.3826	.4107	.31
7C C3a	1.63	1.930	1.528	.2635	.4026	.4341	.33
7C C4a	2.43	1.872	1.559	.2006	.3128	.4224	.45
7C C5b	3.48	2.079	1.679	.2383	.4001	.3780	.94
7C C6b	4.18	1.944	1.545	.2581	.3987	.4278	1.13
7C C7a	4.68	2.072	1.734	.1945	.3374	.3577	.68
7C C8a	5.47	1.975	1.662	.1884	.3131	.3844	.75
7C C9a	6.25	2.008	1.643	.2223	.3651	.3916	1.28
7C C10	7.01	2.050	1.724	.1890	.3258	.3616	.71
7C C11a	10.80	2.352	1.968	.1948	.3835	.2709	.68
7C C12c	12.75	1.971	1.529	.2895	.4425	.4339	.60
7C C13a	12.95	1.558	1.232	.2641	.3255	.5436	.64
7C C13b	13.21	1.964	1.578	.2440	.3852	.4154	.75
7C C14a	13.67	1.961	1.533	.2791	.4280	.4321	.83
7C C16a	15.38	1.655	1.316	.2573	.3387	.5124	.75
7C C16b	15.65	2.084	1.722	.2100	.3618	.3621	1.02
7C C17a	16.13	1.723	1.388	.2417	.3353	.4861	.98
7C C18a	16.89	1.955	1.614	.2118	.3417	.4023	.75
8C C1a	.22	.863	.1732	3.981	.6896	.9358	
8C C1b	.41	.978	.1994	3.903	.7783	.9261	
8C C1c	.67	1.018	.3470	1.933	.6708	.8715	
8C C3b	1.85	1.480	1.097	.3487	.3826	.5937	.22
8C C3c	2.07	1.623	1.038	.7903	.8204	.6155	.23
8C C4a	2.12	1.668	.9257	1.329	1.231	.6571	.22
8C C5a	2.67	1.588	1.111	.5674	.6304	.5885	.22

Figure 1

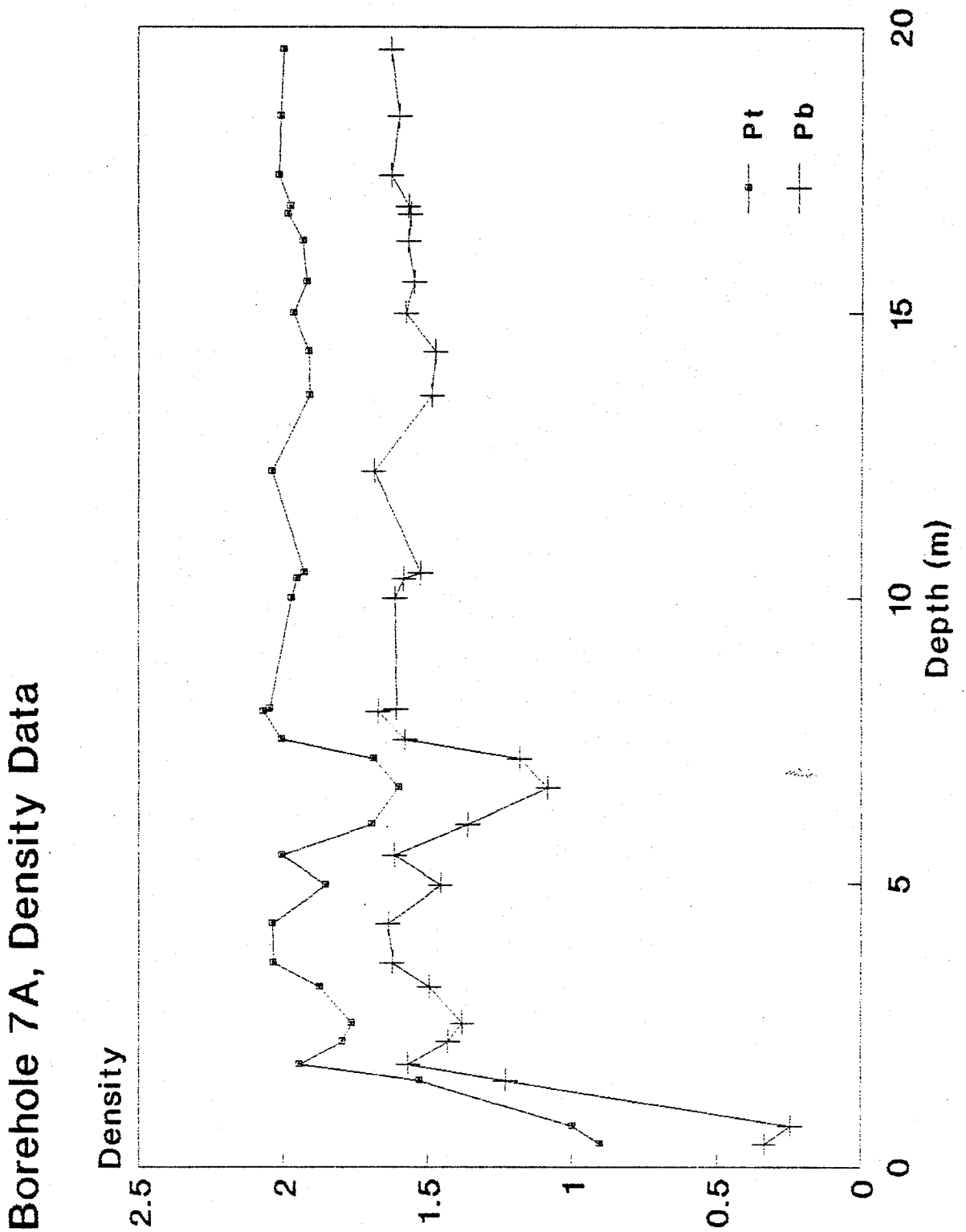

Borehole 7A, Density Data
Density
2.5
2
1.5
1
0.5
0
0
5
10
15
20
Depth (m)
Pt
Pb

Figure 2

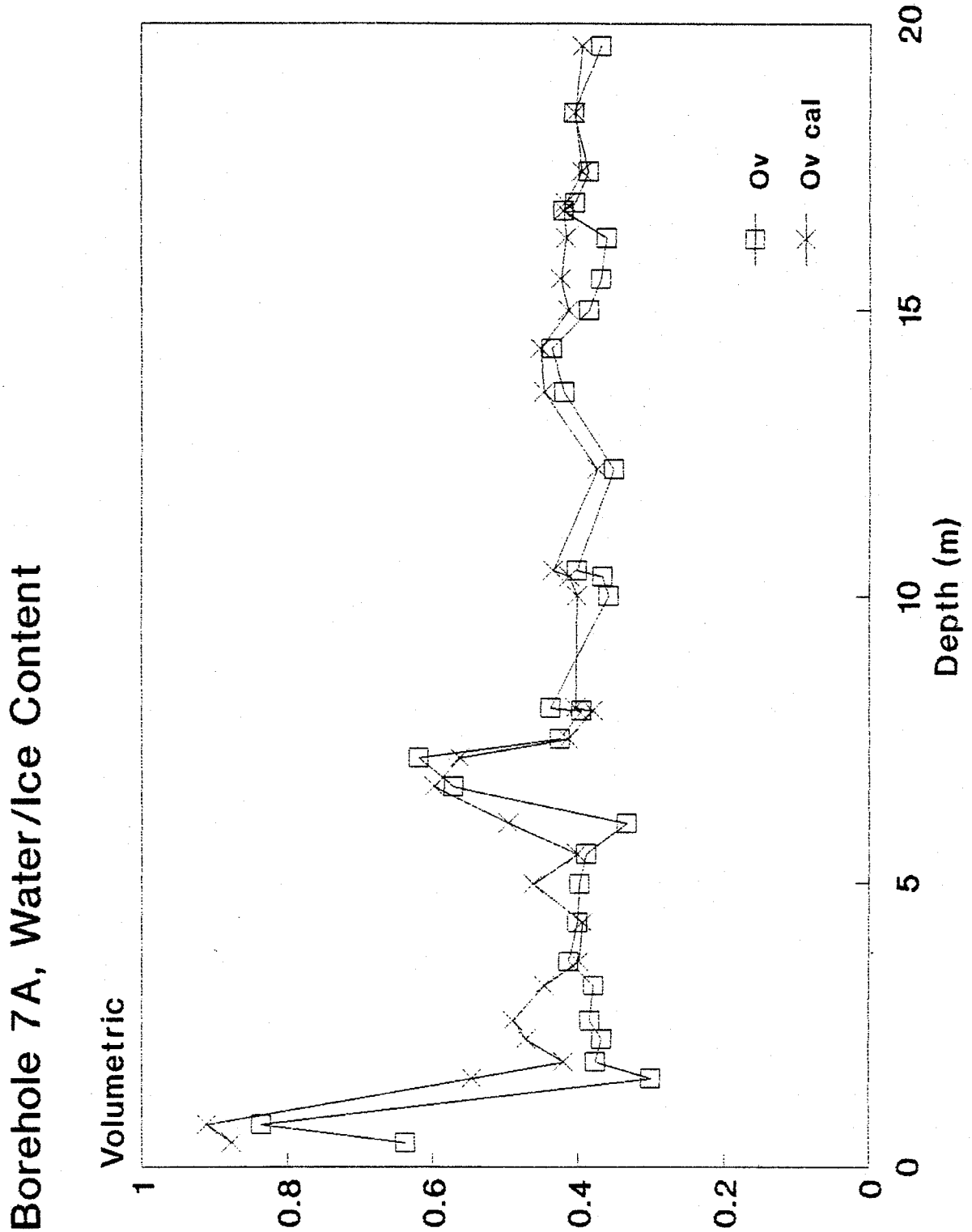

Borehole 7A, Water/Ice Content
Volumetric
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
Depth (m)
Ov
Ov cal

Figure 3

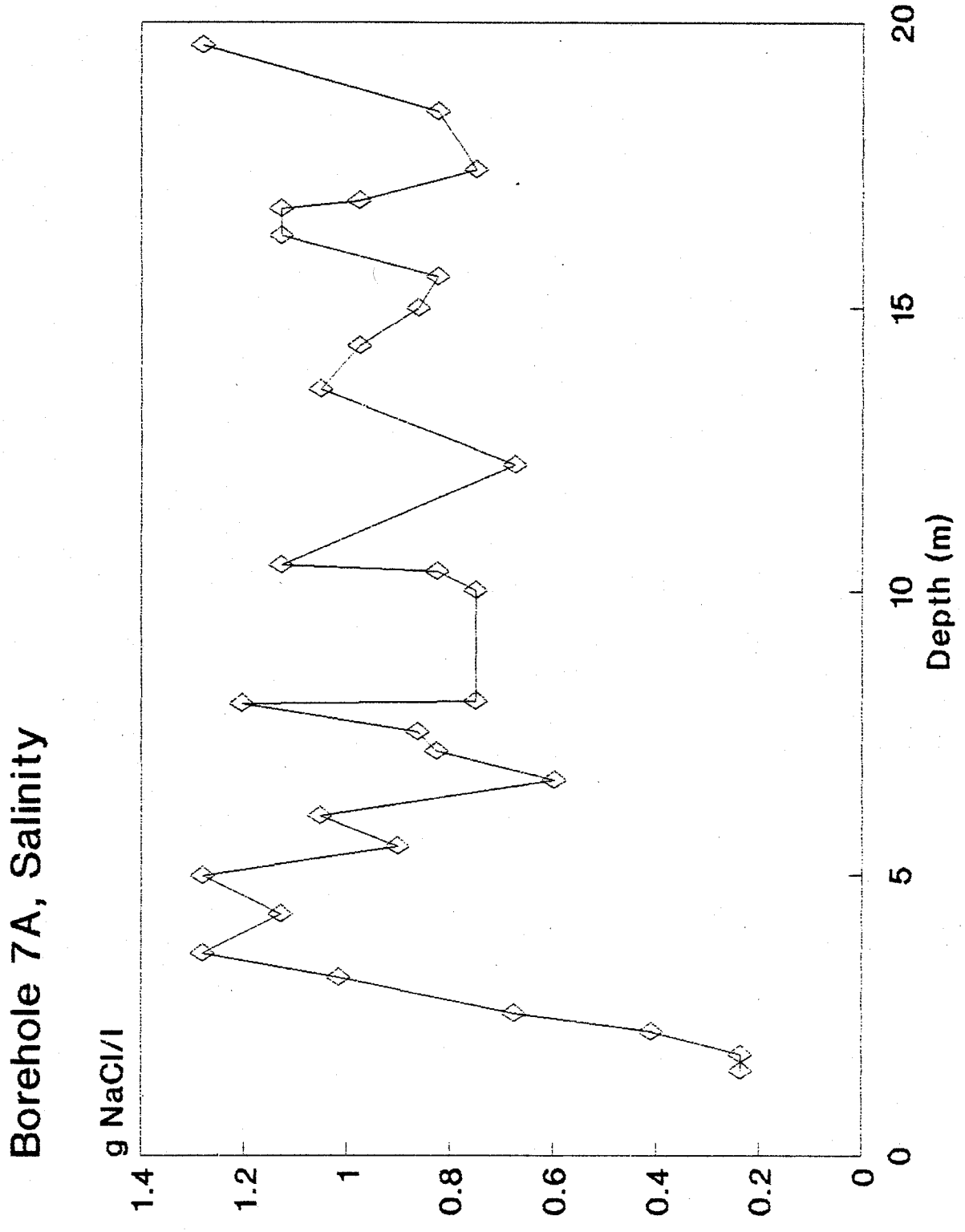

Borehole 7A, Salinity
g NaCl/l
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
Depth (m)

Figure 4

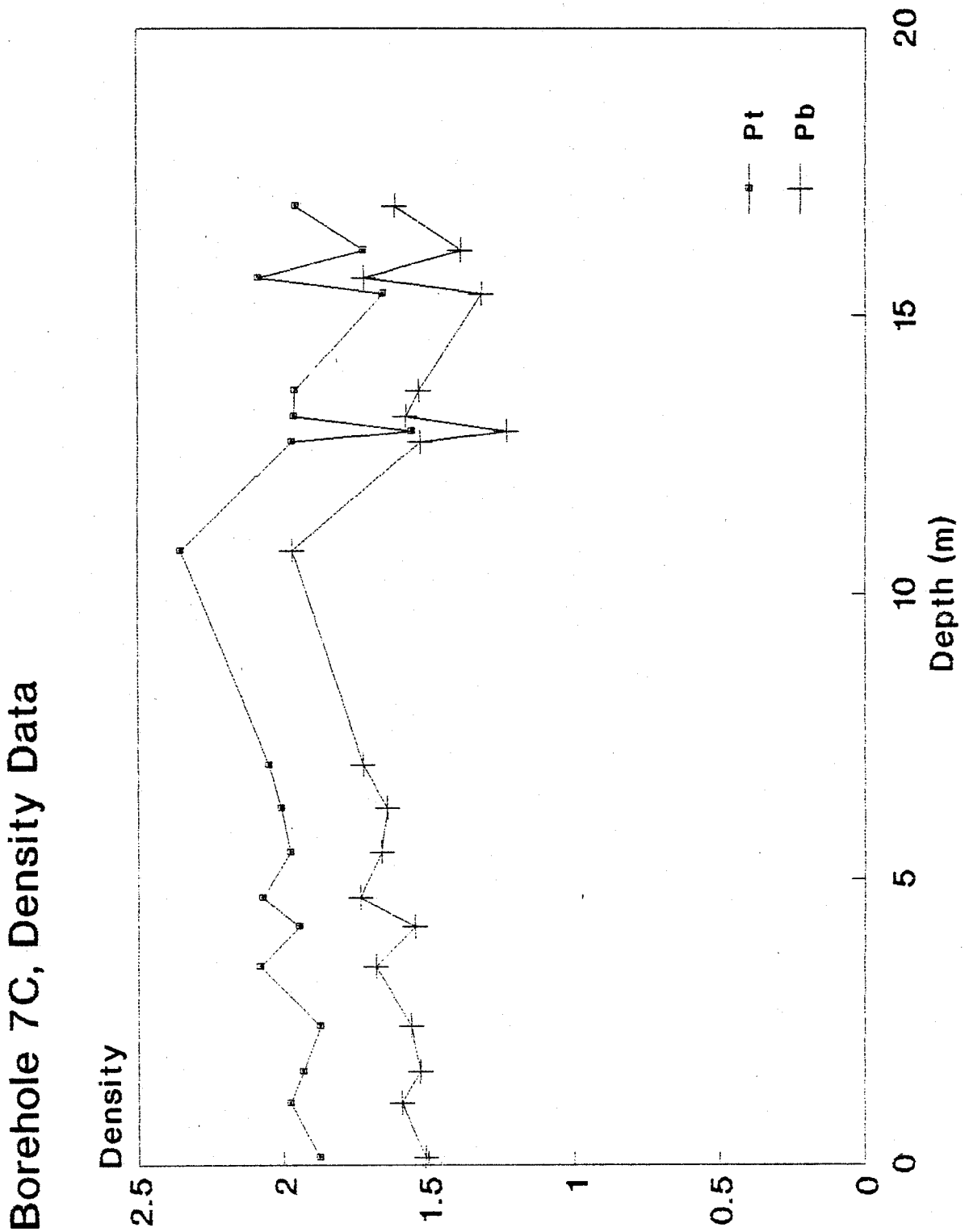

Borehole 7C, Density Data
Density
2.5
2
1.5
1
0.5
0
0
5
10
15
20
Depth (m)
Pt
Pb

Figure 5

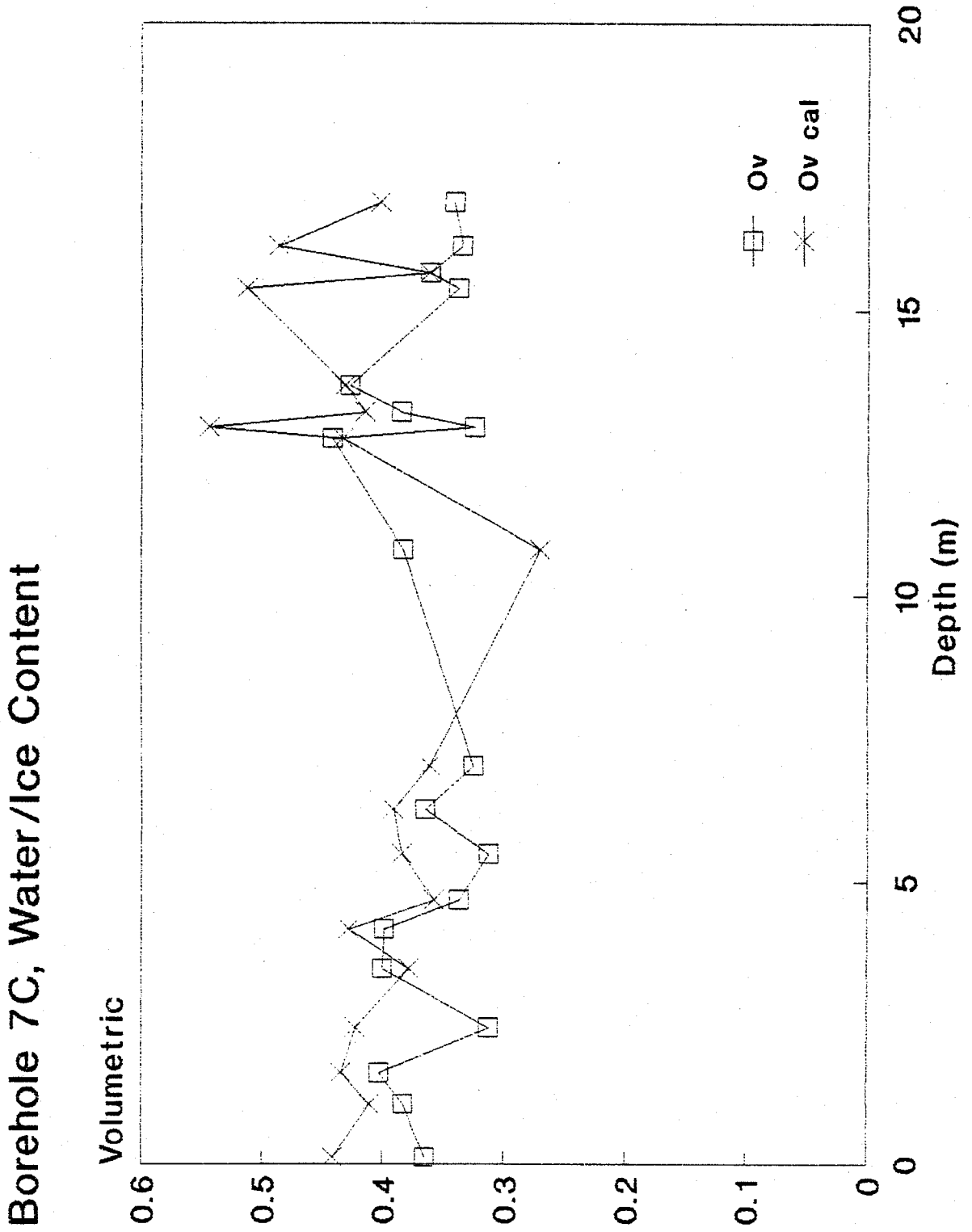
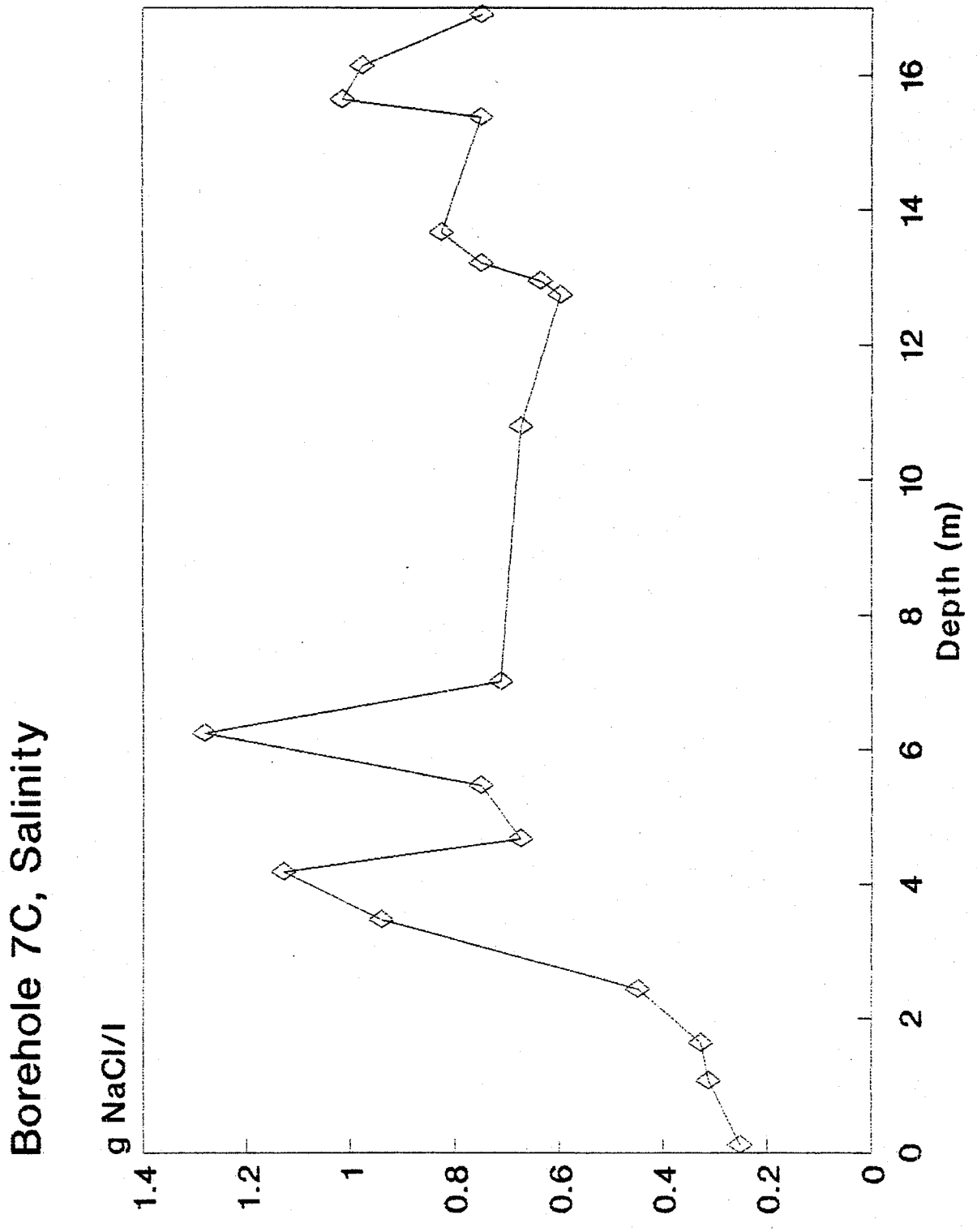

Borehole 7C, Water/Ice Content
Volumetric
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
Depth (m)
Ov
Ov cal

Figure 6


Borehole 7C, Salinity
g NaCl/l
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
Depth (m)

The salinity estimates are similar to those found for Borehole 7A, however, values tend to be somewhat lower (0.8 g NaCl/l) at lower depths (Figure 6).

2.3.3 Borehole 8C

The top metre or so of Borehole 8C is peat; this overlying a layer of silty sand. The silty sand tended to be ice rich and of low natural salinity (see Table 4b)

2.4 Grain-size Characteristics

The summary of specimen grain-size is given in Tables 5 and 6 for all mineral specimens. Grain-size distribution curves for the mineral soils are also given in Appendix I for the mineral soils examined. Only the size fraction less than 2 mm was examined.

Boreholes 7A and 7C tended to consist of layered silt and clay deposits. Stone/gravel inclusions were evident to a depth of about 16 m in Borehole 7A and to about 11.5 m in Borehole 7C. The stone/gravel inclusions varied greatly in size and consisted of angular pieces of rock with a fair amount of well-rounded material in the intermediate to small gravel fraction. The silt-clay fraction tended to be quite stiff and the specimen could be peeled apart at silt-clay contacts. It should also be noted that a fine sand contact was noted in Borehole 7C at a depth of about 17 m.

The grain-size characteristics of Borehole 8C tended to show a well-graded silty sand. Some plastic characteristics were evident but not to the degree noted in Boreholes 7A and 7C.

Table 5 Grain-size Analysis

	Percent finer than									
(mm)	2	1	.5	.25	.10	.05	.02	.005	.002	.001
7A C1	Organic Matter									
7A C2a	Organic Matter									
7A C3b	100.0	100.0	99.9	99.7	98.5	95.9	70.1	47.6	34.4	25.4
7A C4	100.0	99.2	97.4	94.7	90.8	88.5	77.5	59.8	43.1	33.2
7A C5	100.0	99.3	98.8	98.4	97.7	96.5	83.7	74.3	56.9	41.8
7A C6a	100.0	99.5	99.1	98.6	97.7	96.7	89.9	67.8	48.0	33.8
7A C7a	100.0	99.6	99.1	98.6	97.7	96.9	84.1	64.6	47.5	35.1
7A C7c	100.0	99.1	98.6	98.1	97.2	96.3	87.9	62.0	45.0	33.2
7A C8c	100.0	98.9	98.3	97.6	96.5	95.0	89.7	59.9	43.2	32.3
7A C9c	100.0	99.5	99.1	98.6	97.8	97.1	94.1	61.6	43.9	32.0
7A C10b	100.0	99.5	98.8	98.2	97.2	96.1	91.0	63.2	44.9	33.6
7A C11a	100.0	99.7	99.4	99.1	98.6	97.8	93.3	55.7	35.6	27.0
7A C12a	100.0	98.9	98.1	97.4	96.1	94.9	90.4	75.9	58.6	44.7
7A C12c	100.0	98.3	96.7	95.1	92.5	90.1	85.1	68.5	52.6	40.7
7A C13b	100.0	99.8	99.7	99.6	99.3	99.1	92.9	44.8	30.4	22.9
7A C14b	100.0	99.2	98.6	98.1	97.1	96.2	97.7	58.6	41.7	30.3
7A C15a	100.0	98.9	97.9	96.8	95.2	93.9	88.7	66.9	50.6	38.6
7A C17a	100.0	98.4	96.6	94.9	92.1	89.7	83.1	66.4	50.1	37.5
7A C17b	100.0	99.9	99.7	99.6	99.4	99.1	83.6	39.6	27.5	21.3
7A C18a	100.0	97.9	95.8	94.1	91.0	88.4	82.2	68.1	51.2	37.2
7A C20b	100.0	99.4	98.5	97.6	96.1	94.7	87.2	66.1	48.0	36.5
7A C22a	100.0	99.8	99.4	99.1	98.5	96.8	92.9	64.8	45.9	34.4
7A C23a	100.0	99.8	99.1	98.5	97.7	95.6	86.5	51.4	32.1	19.7
7A C24a	100.0	99.9	99.5	99.3	98.8	98.3	93.3	58.1	37.1	20.5
7A C25a	100.0	99.9	99.8	99.6	99.4	98.9	94.2	73.2	41.6	31.6
7A C26a	100.0	100.0	100.0	100.0	100.0	100.0	95.3	33.0	18.2	13.4
7A C26c	100.0	100.0	100.0	100.0	100.0	100.0	98.2	81.2	61.3	45.7
7A C27a	100.0	100.0	100.0	100.0	100.0	100.0	99.0	86.3	65.7	47.6
7A C27c	100.0	100.0	100.0	100.0	100.0	99.9	95.9	66.6	37.9	24.1
7A C28b	100.0	100.0	100.0	100.0	100.0	100.0	98.0	81.2	57.2	36.5
7A C29c	100.0	100.0	100.0	100.0	100.0	99.9	89.4	49.6	37.2	27.1
7C C1a	100.0	99.6	99.2	98.8	97.6	96.2	90.5	59.6	40.4	24.6
7C C2b	100.0	99.8	98.9	98.1	96.9	93.3	68.2	41.1	29.8	20.9
7C C3a	100.0	99.7	98.8	97.8	96.3	95.0	91.4	65.6	48.1	35.0
7C C4a	100.0	99.9	99.4	98.9	98.0	97.2	94.8	63.2	44.4	31.6
7C C5b	100.0	99.7	99.3	98.9	97.8	96.9	90.6	59.5	42.8	31.0
7C C6b	100.0	99.9	99.8	99.6	99.1	98.6	91.2	52.5	35.8	26.3
7C C7a	100.0	99.4	97.2	95.2	91.2	86.5	77.2	55.5	39.9	30.1
7C C8a	100.0	99.4	96.4	93.9	88.8	84.0	75.5	54.6	40.0	29.9
7C C9a	100.0	99.6	99.3	99.0	98.4	97.9	93.6	46.1	31.3	22.8
7C C10	100.0	99.6	98.1	96.8	94.4	92.2	85.6	64.7	48.2	34.8
7C C11a	100.0	99.7	98.1	96.8	94.4	91.9	81.7	52.1	38.4	28.7
7C C12c	100.0	100.0	100.0	100.0	100.0	99.9	99.3	94.5	80.6	61.9
7C C13a	100.0	100.0	100.0	100.0	100.0	99.5	88.3	64.7	42.1	30.5

Table 5 (continued)

	Percent finer than									
(mm)	2	1	.5	.25	.10	.05	.02	.005	.002	.001
7C C13b	100.0	99.9	99.8	99.8	99.6	99.4	90.4	51.8	39.2	29.6
7C C14a	100.0	100.0	100.0	100.0	100.0	99.5	91.7	62.6	48.9	39.6
7C C16a	100.0	99.9	99.8	99.6	99.2	90.8	58.8	19.9	11.2	7.5
7C C16b	100.0	100.0	100.0	99.9	99.4	86.7	52.8	15.0	8.5	5.2
7C C17a	100.0	100.0	100.0	100.0	99.8	94.2	51.6	12.2	6.8	4.8
7C C18a	100.0	100.0	99.9	99.8	81.3	22.9	8.3	4.1	2.8	2.0
8C C1a	organic matter									
8C C1b	organic matter									
8C C1c	organic matter									
8C C3b	100.0	100.0	99.7	98.5	86.1	65.6	52.4	29.6	18.1	11.6
8C C3c	100.0	100.0	100.0	98.9	88.4	73.2	58.6	34.6	14.3	
8C C4a	100.0	100.0	100.0	98.6	87.0	71.2	56.1	32.7	20.1	12.9
8C C5a	100.0	100.0	100.0	99.9	98.9	87.1	68.9	53.9	30.5	13.0

Table 6 Grain-size Summary

Sand 2.0 - 0.05 mm
Silt 0.05 - 0.002 mm
Clay less than 0.002 mm

	%sand	%silt	%clay
7A C1	organic matter		
7A C2a	organic matter		
7A C3b	4.1	61.5	34.4
7A C4	11.5	45.4	43.1
7A C5	3.5	39.6	56.9
7A C6a	3.3	48.7	48.0
7A C7a	3.1	49.4	47.5
7A C7c	3.7	51.3	45.0
7A C8c	5.0	51.8	43.2
7A C9c	2.9	53.2	43.9
7A C10b	3.9	51.2	44.9
7A C11a	2.2	62.2	35.6
7A C12a	5.1	36.3	58.6
7A C12c	9.9	37.5	52.6
7A C13b	.9	68.7	30.4
7A C14b	3.8	54.5	41.7
7A C15a	6.1	43.3	50.6
7A C17a	10.3	39.6	50.1
7A C17b	.9	71.6	27.5
7A C18a	11.6	37.2	51.2
7A C20b	5.3	46.7	48.0
7A C22a	3.2	50.9	45.9
7A C23a	4.4	63.5	32.1
7A C24a	1.7	61.2	37.1
7A C25a	1.1	57.3	41.6
7A C26a	.0	81.8	18.2
7A C26c	.0	38.7	61.3
7A C27a	.0	34.3	65.7
7A C27c	4.1	71.8	24.1
7A C28b	.0	42.8	57.2
7A C29c	.1	62.7	37.2
7C C1a	3.8	55.8	40.4
7C C2b	6.7	63.5	29.8
7C C3a	5.0	46.9	48.1
7C C4a	2.8	52.8	44.4
7C C5b	3.1	54.1	42.8
7C C6b	1.4	62.8	35.8
7C C7a	13.5	46.6	39.9
7C C8a	16.0	44.0	40.0
7C C9a	2.1	66.6	31.3
7C C10	7.8	44.0	48.2
7C C11a	8.1	53.5	38.4
7C C12c	.1	19.3	80.6
7C C13a	.5	57.4	42.1

Table 6 continued

Sand 2.0 - 0.05 mm
Silt 0.05 - 0.002 mm
Clay less than 0.002 mm

	%sand	%silt	%clay
7C C13b	.6	60.2	39.2
7C C14a	.5	50.6	48.9
7C C16a	9.2	79.6	11.2
7C C16b	13.3	78.2	8.5
7C C17a	5.8	87.4	6.8
7C C18a	77.1	20.1	2.8
8C C1a	organic matter		
8C C1b	organic matter		
8C C1c	organic matter		
8C C3b	34.5	47.5	18.1
8C C3c	26.8	51.2	22.0
8C C4a	28.8	51.1	20.1
8C C5a	12.9	56.6	30.5

2.5 Unfrozen Water Contents

Unfrozen water content data were determined using Time-domain Reflectometry over the temperature range 0 to -10 C. The data are expressed as gravimetric unfrozen water content, w.

The silt-clay rich materials of Boreholes 7A and 7C (Figures 7 to 14) tended to exhibit a rapid decline in w between 0 and -0.2 C with w being about 0.15 g g^{-1} at -0.2 C. At -1.0 C, w was about 0.10 g g^{-1} decreasing to about 0.05 g g^{-1} at -10.0 C.

The sandy specimen in Borehole 7C (Figure 15) showed the least unfrozen water as expected. The sandy silts in Borehole 8C (Figure 16) were similar although w values were slightly higher at all temperatures.

Figure 7

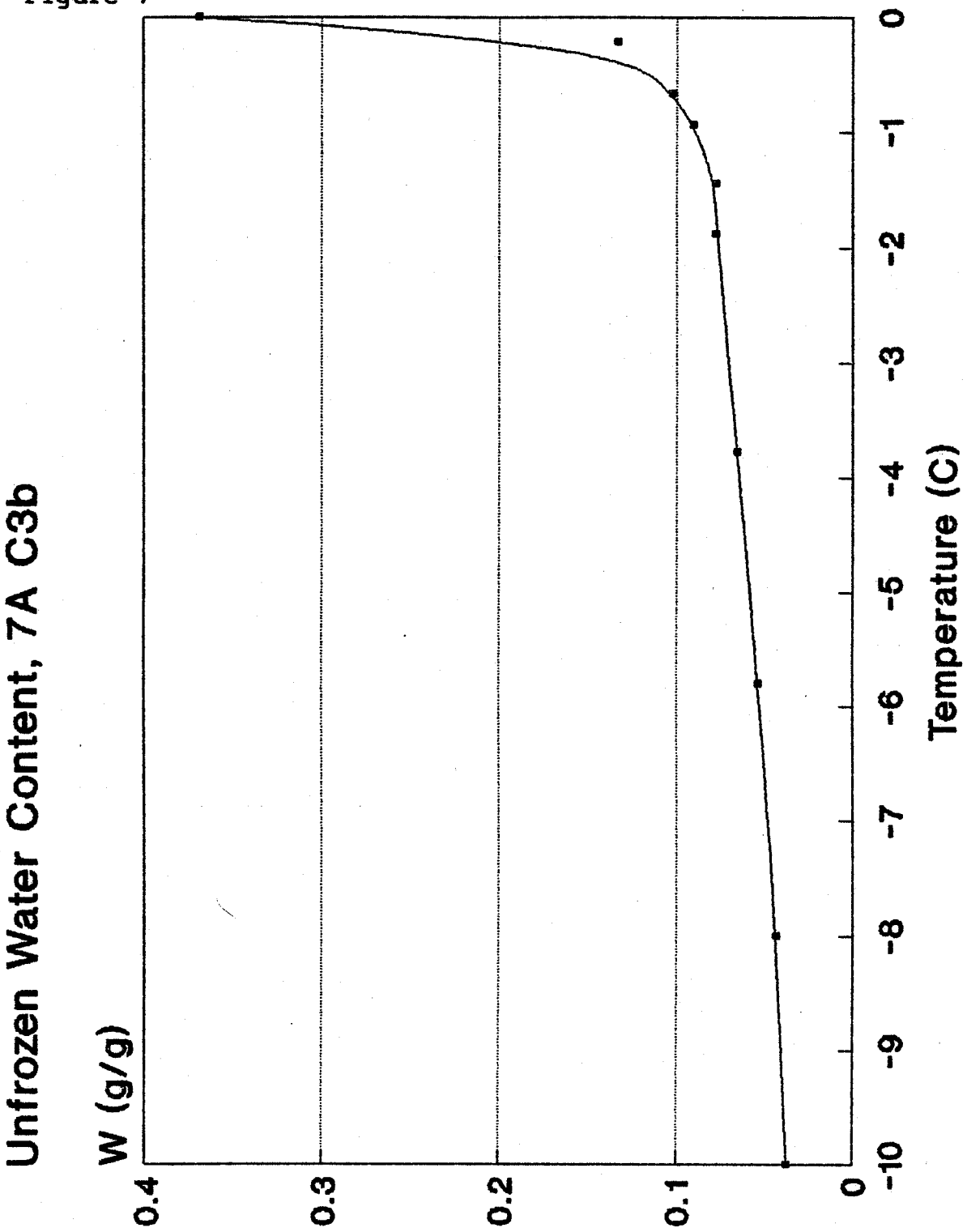

Unfrozen Water Content, 7A C3b
W (g/g)
0.4
0.3
0.2
0.1
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Temperature (C)

Figure 8

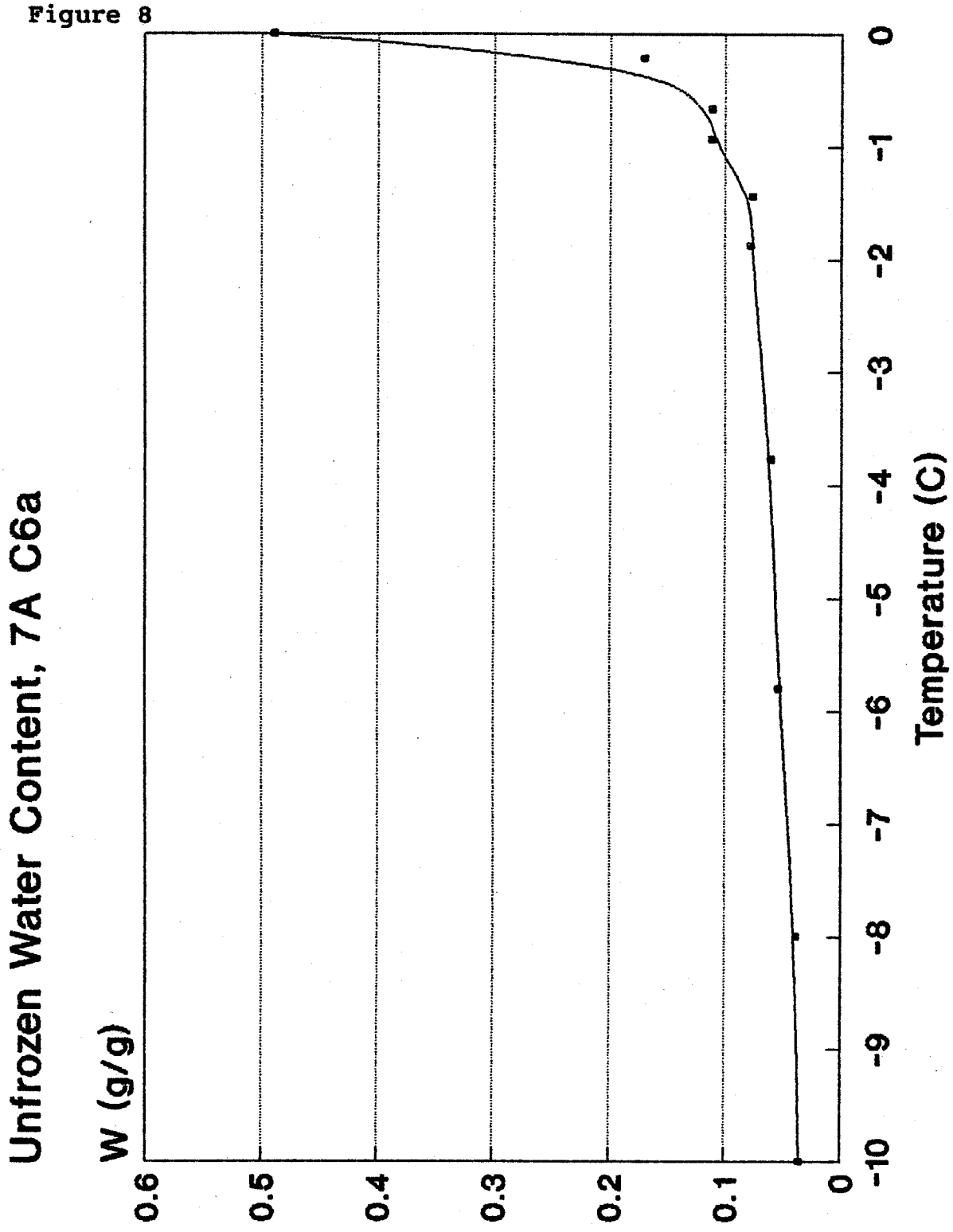

Unfrozen Water Content, 7A C6a
W (g/g)
0.6
0.5
0.4
0.3
0.2
0.1
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Temperature (C)

Figure 9

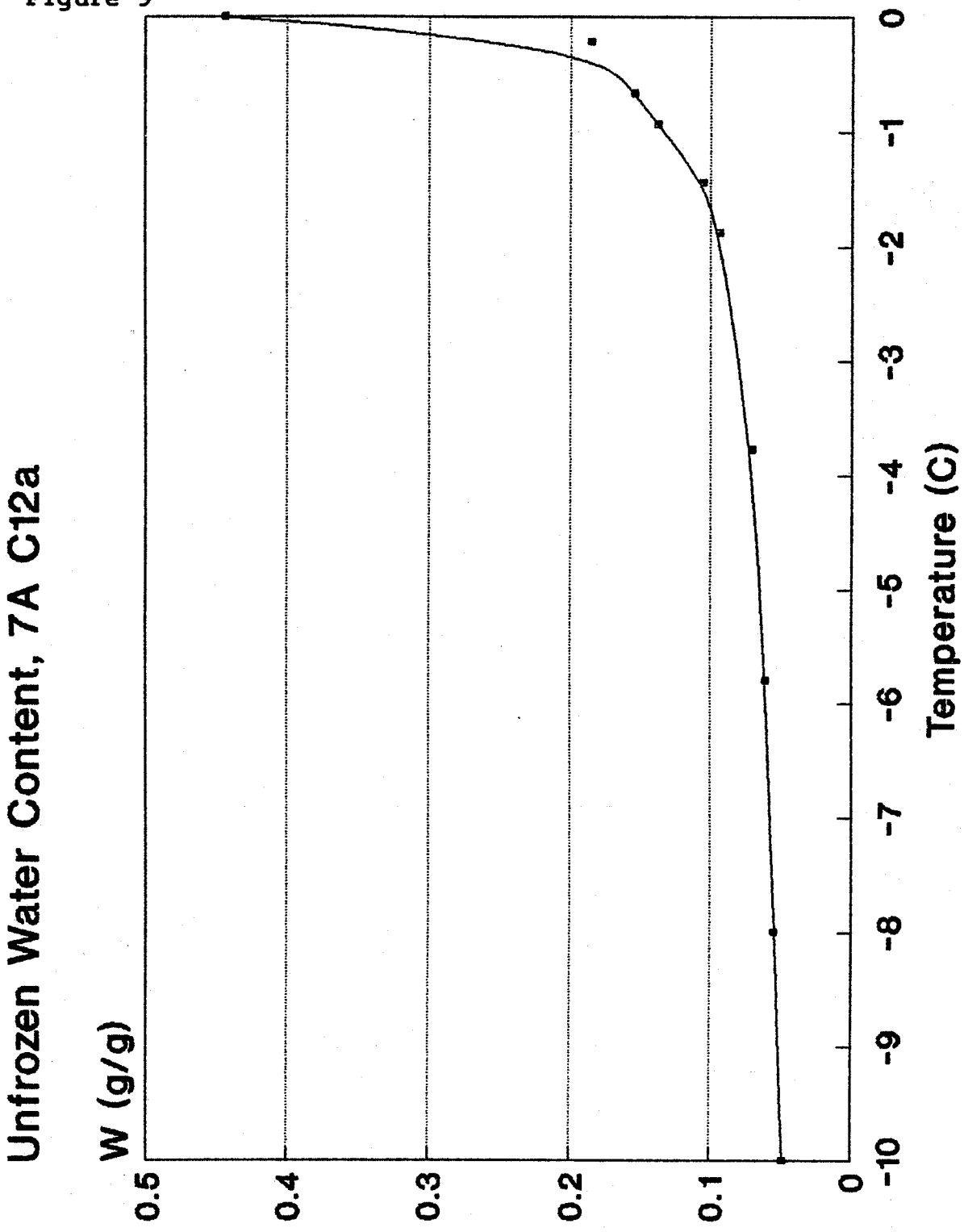

Unfrozen Water Content, 7A C12a
W (g/g)
0.5
0.4
0.3
0.2
0.1
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Temperature (C)

Figure 10

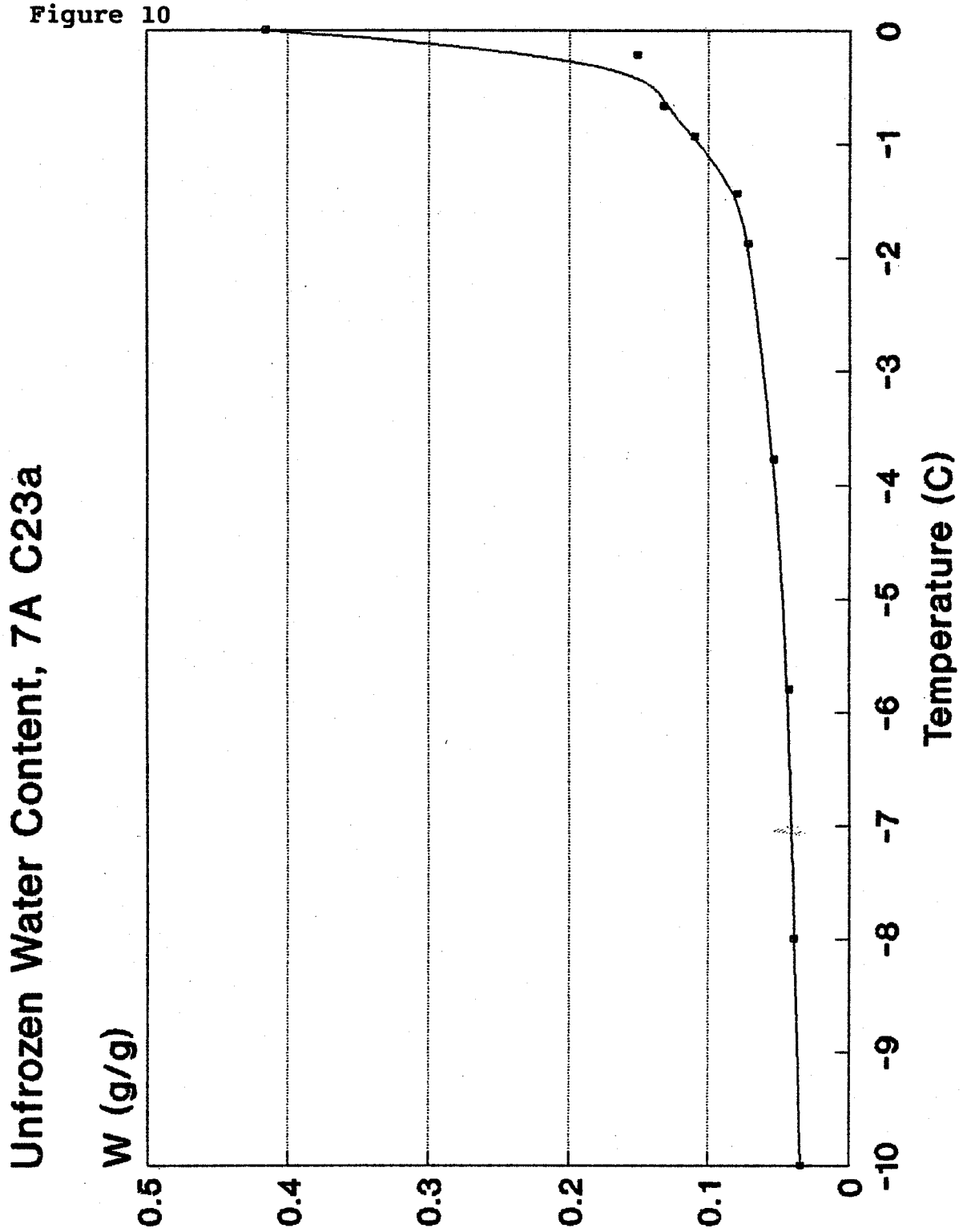

Unfrozen Water Content, 7A C23a
W (g/g)
0.5
0.4
0.3
0.2
0.1
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Temperature (C)

Figure 11

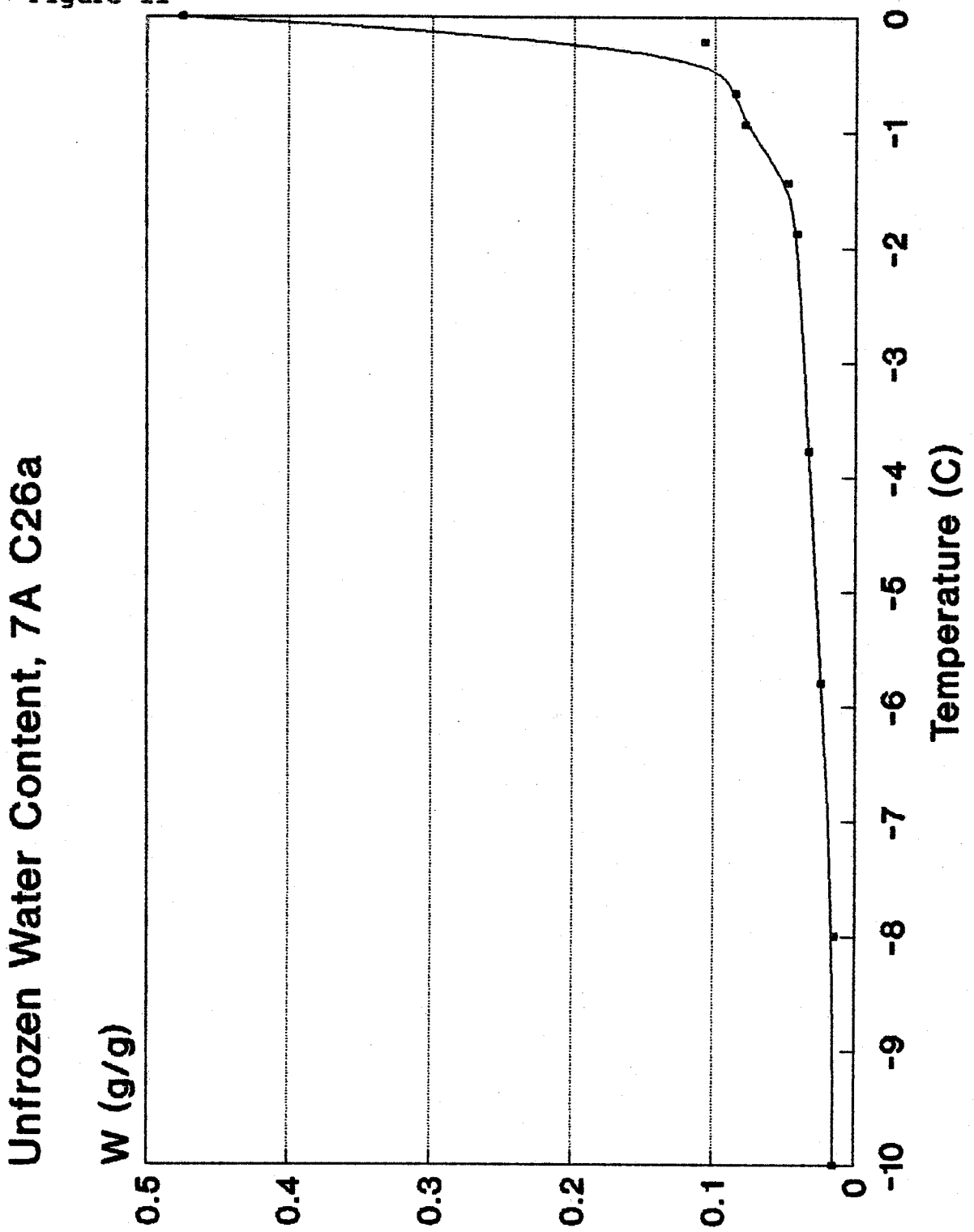

Unfrozen Water Content, 7A C26a
W (g/g)
0.5
0.4
0.3
0.2
0.1
0
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Temperature (C)

Figure 12

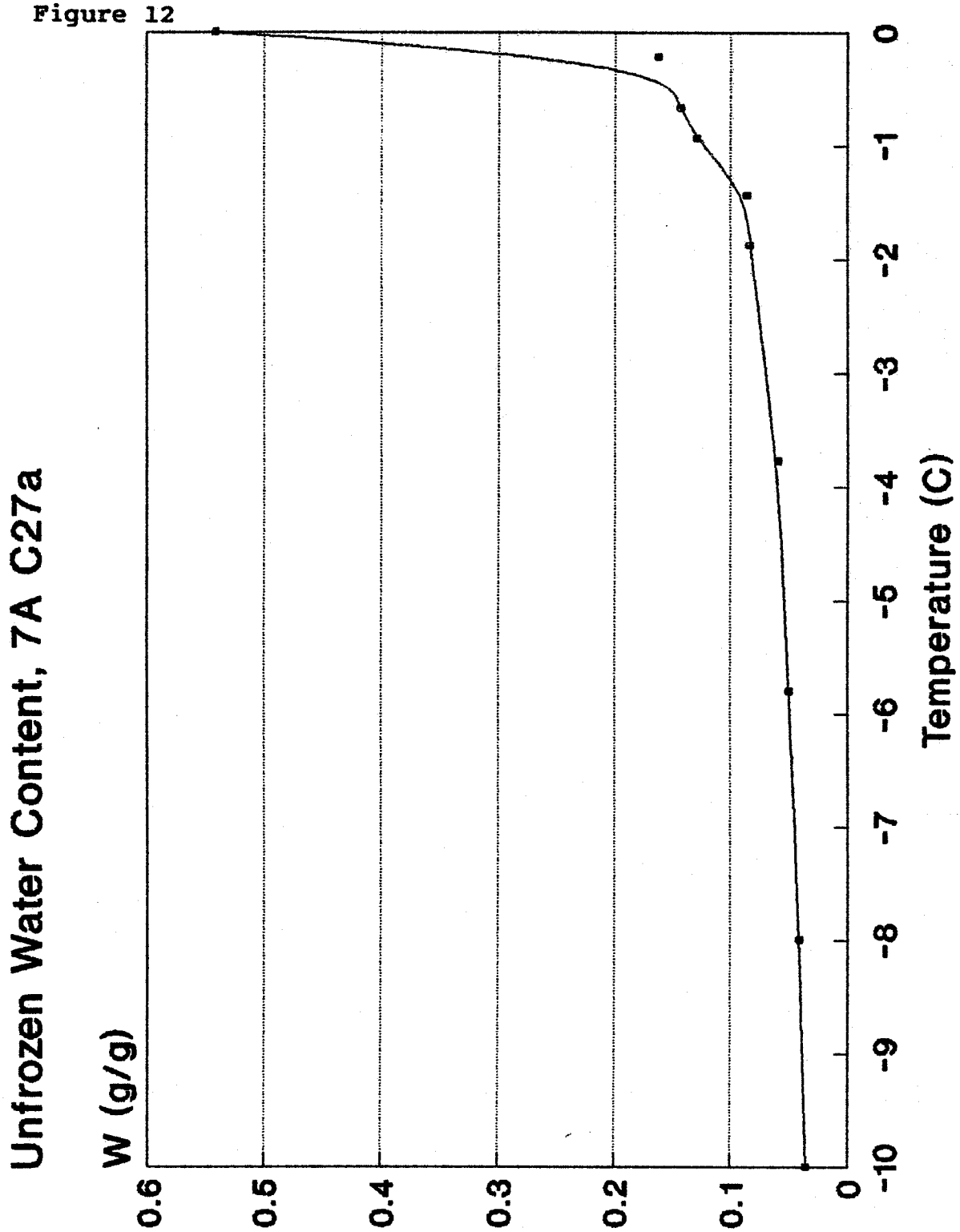

Unfrozen Water Content, 7A C27a
W (g/g)
0.6
0.5
0.4
0.3
0.2
0.1
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Temperature (C)

Figure 13

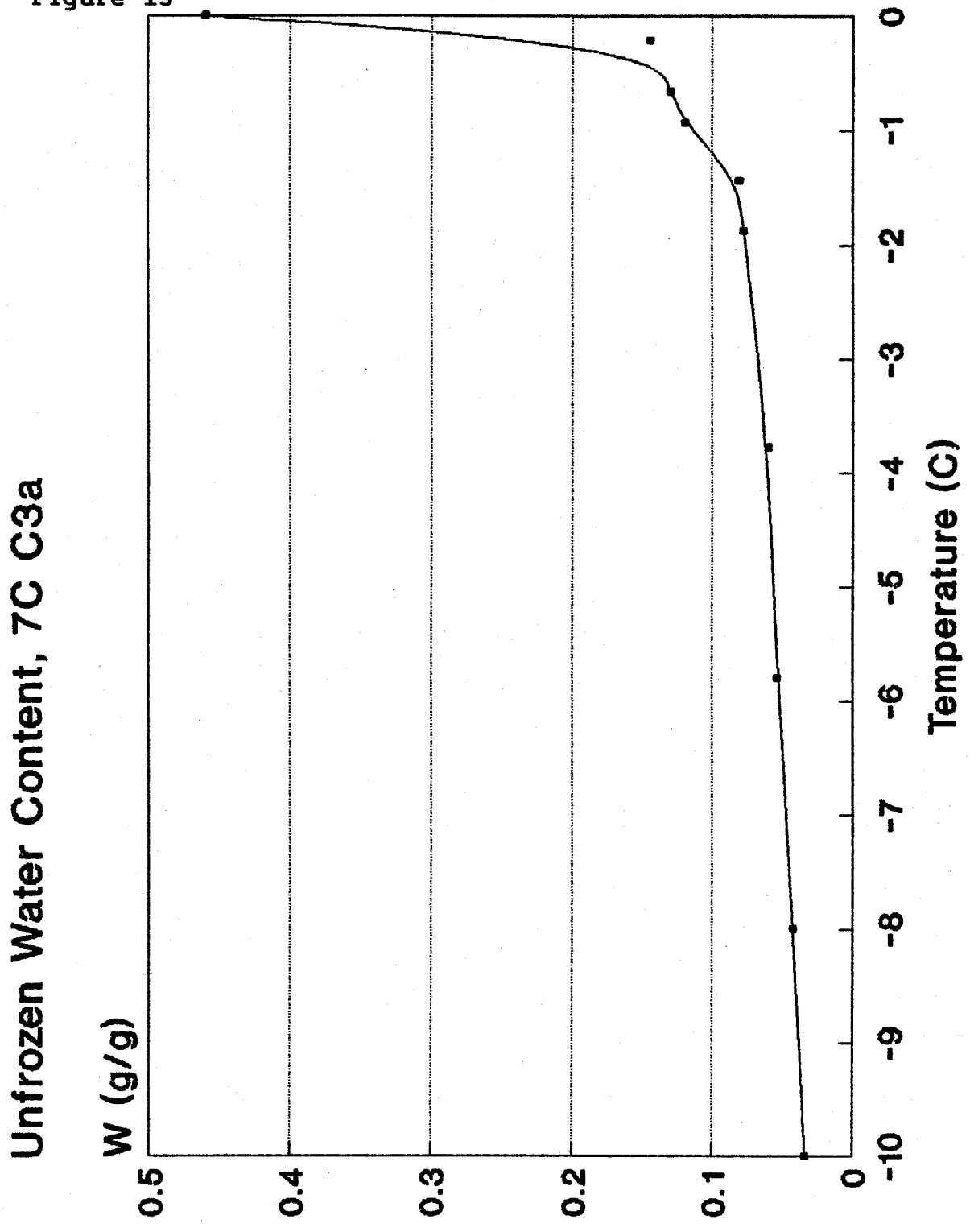

Unfrozen Water Content, 7C C3a
W (g/g)
0.5
0.4
0.3
0.2
0.1
0
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Temperature (C)

Figure 14

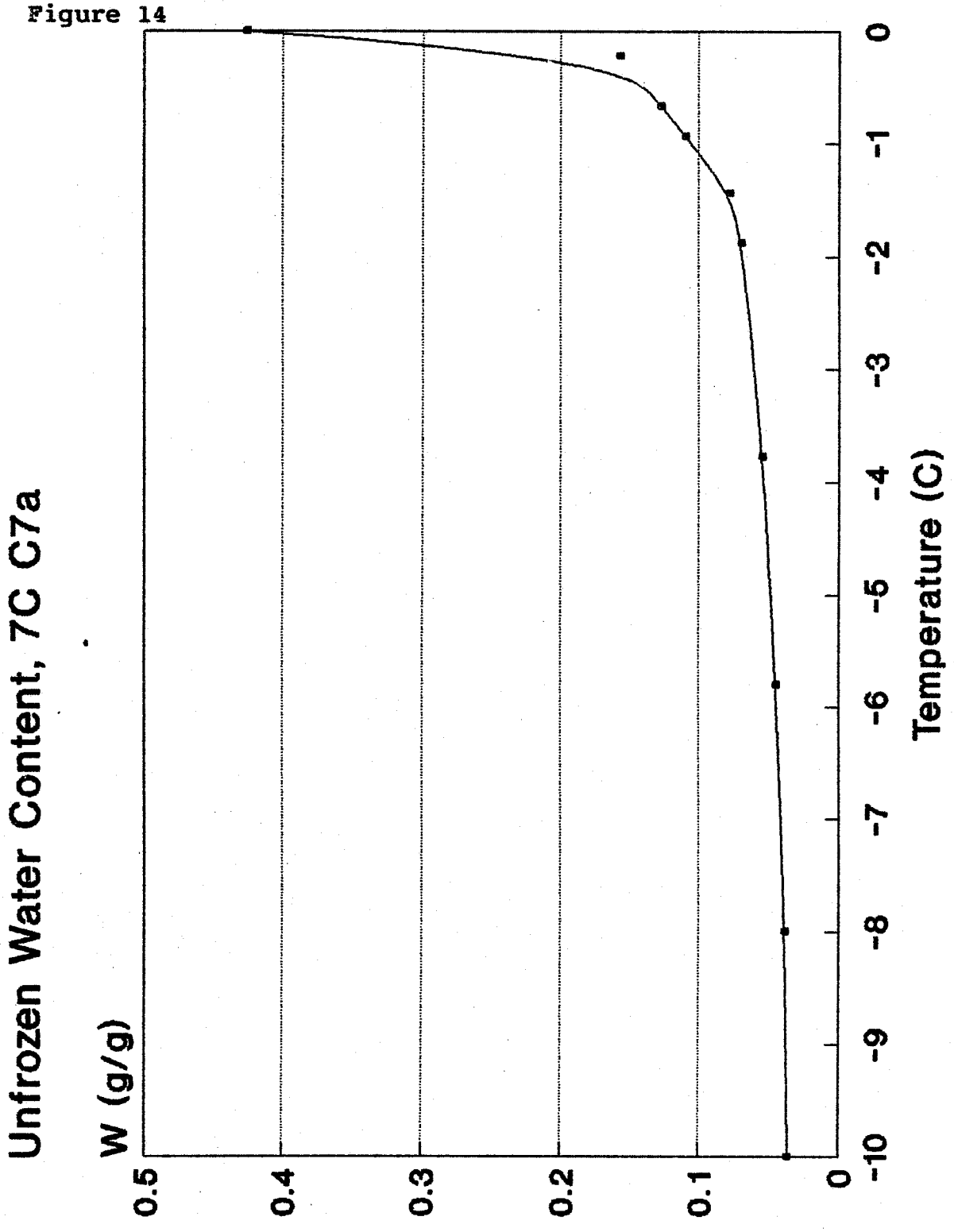

Unfrozen Water Content, 7C C7a
W (g/g)
0.5
0.4
0.3
0.2
0.1
0
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Temperature (C)

Figure 15

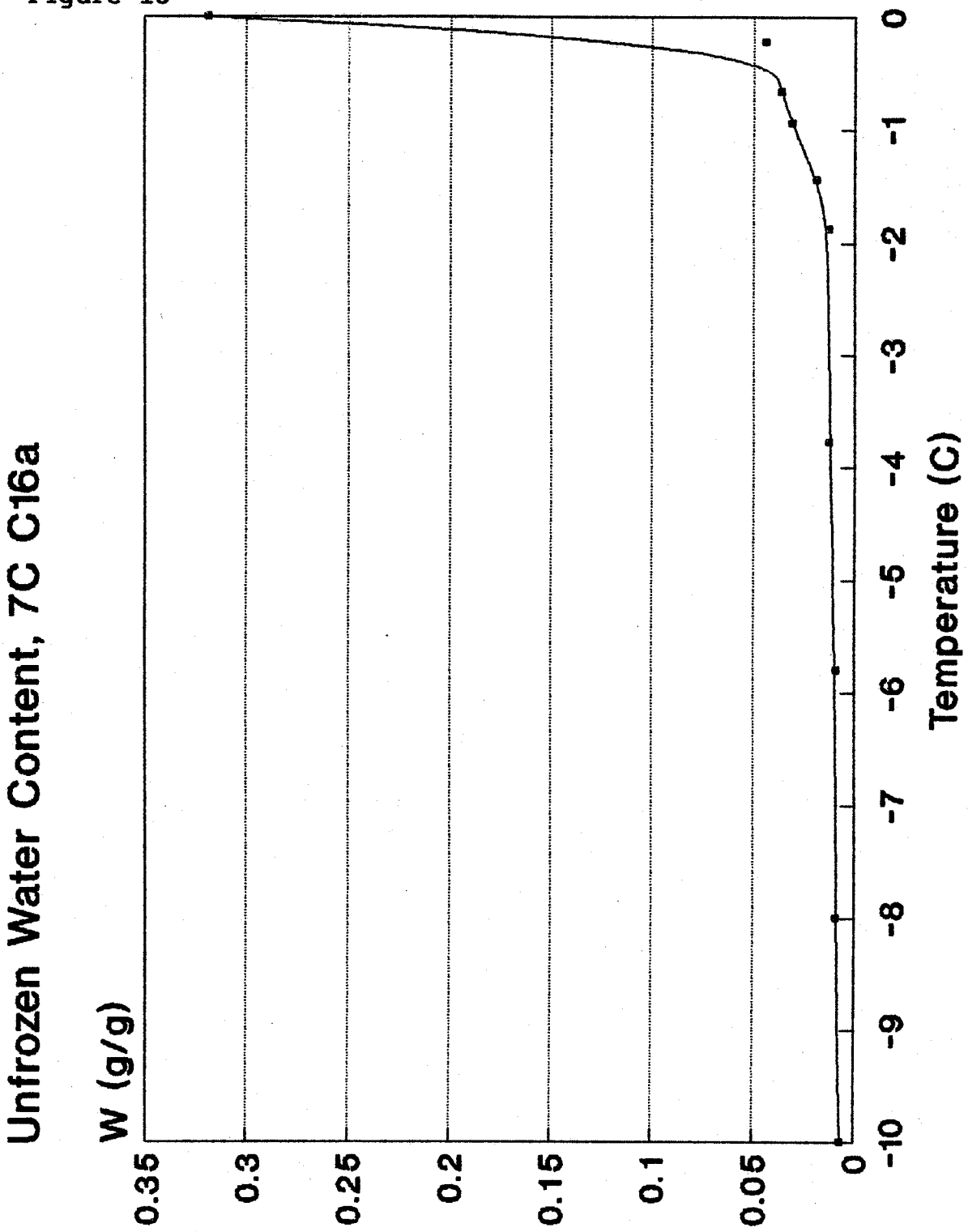
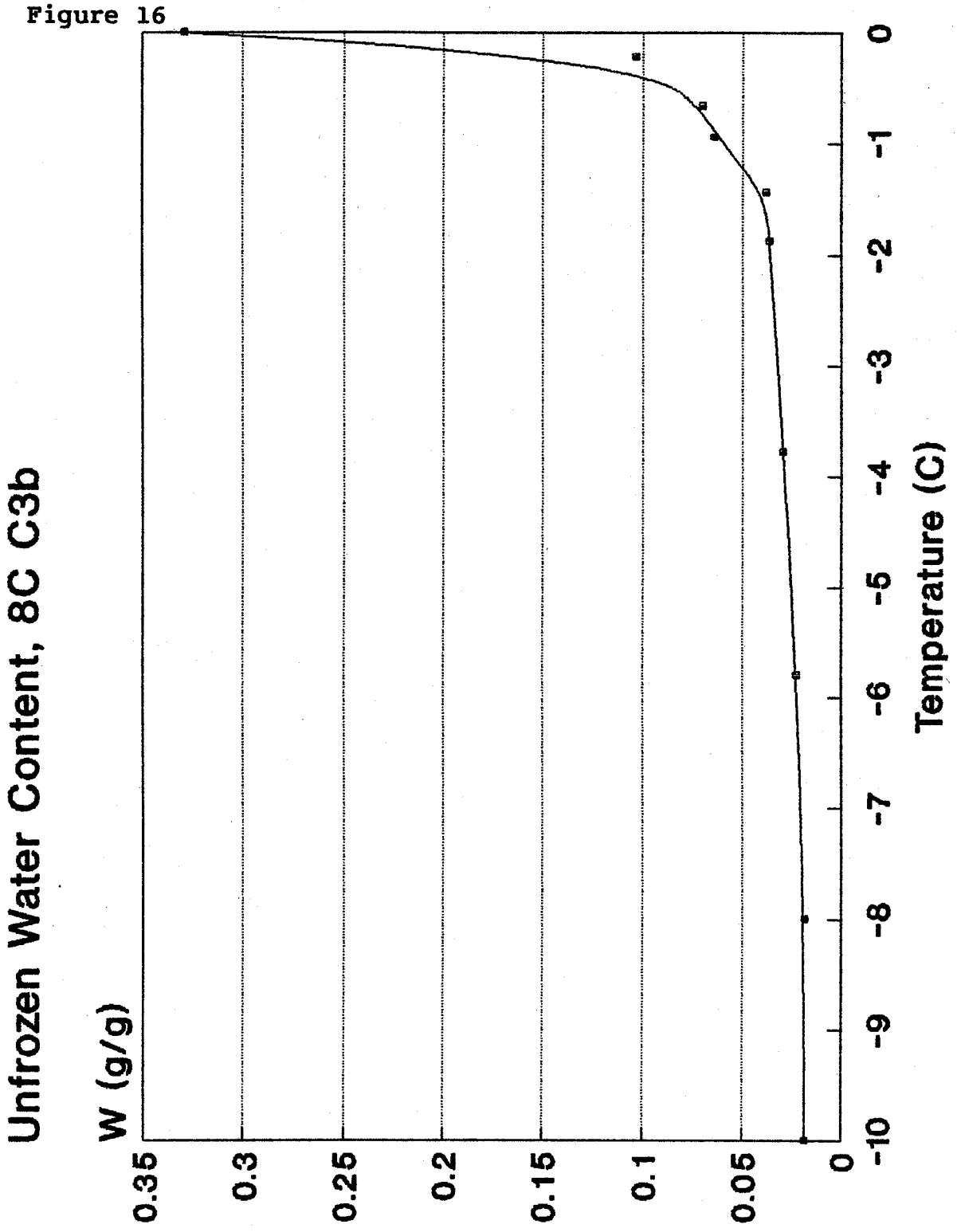

Unfrozen Water Content, 7C C16a
W (g/g)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Temperature (C)

Figure 16

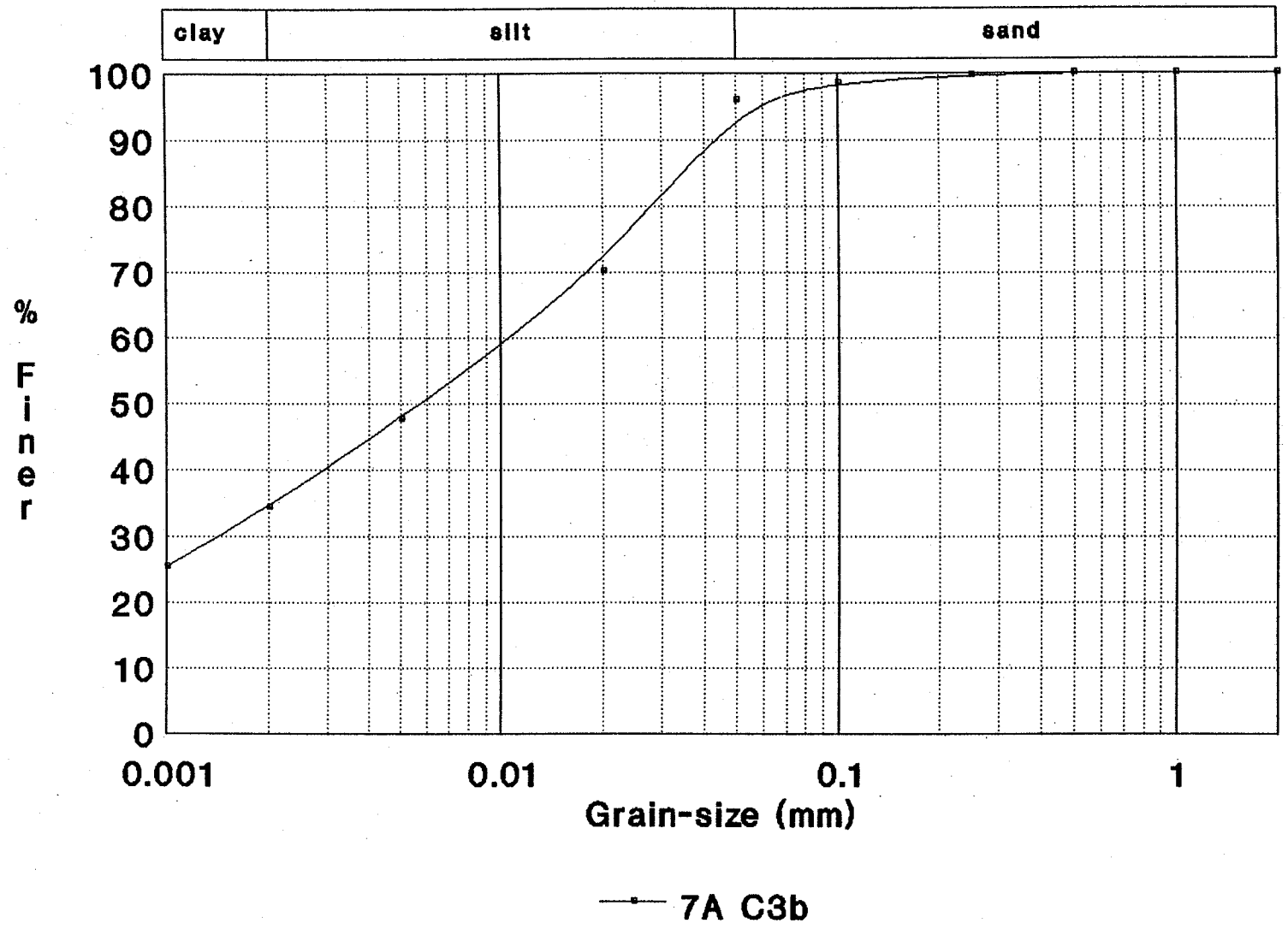

Unfrozen Water Content, 8C C3b
W (g/g)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Temperature (C)

References

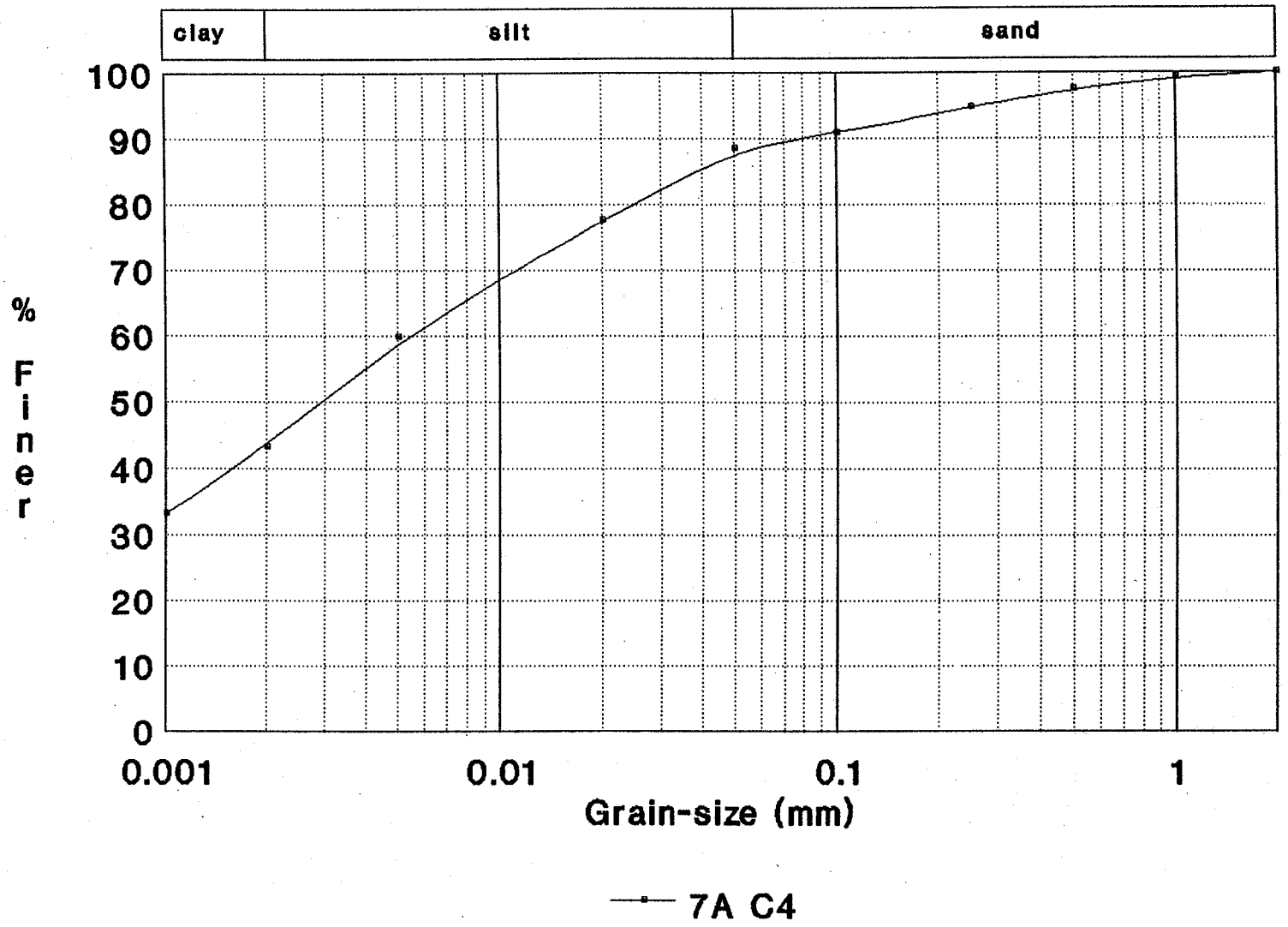
Patterson, D.E., D.W. Riseborough (1988) A Detailed Study of the Physical and Thermal Properties of Norman Wells-Zama Pipeline Core Specimens, Report to Geological Survey of Canada, Energy, Mines and Resources, DSS Contract No. 23233-7-0545/01-ST

Patterson, D.E., D.W. Riseborough and M.W. Smith (1987) Analysis of Norman Wells Core Samples, Report to Geological Survey of Canada, Energy, Mines and Resources, DSS Contract No. 23233-6-0427/01/ST.

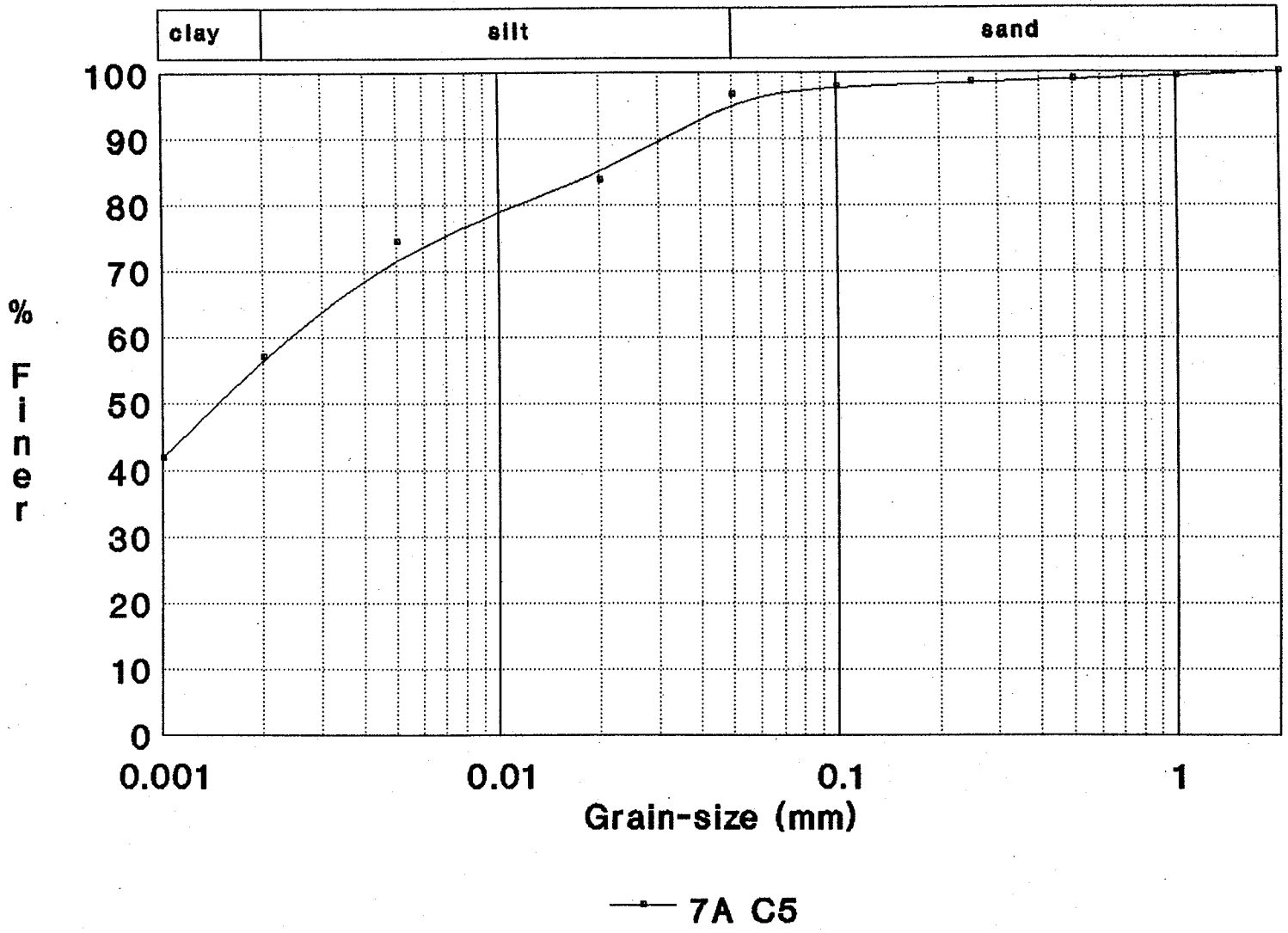
Grain-size Analysis



Grain-size Analysis



Grain-size Analysis



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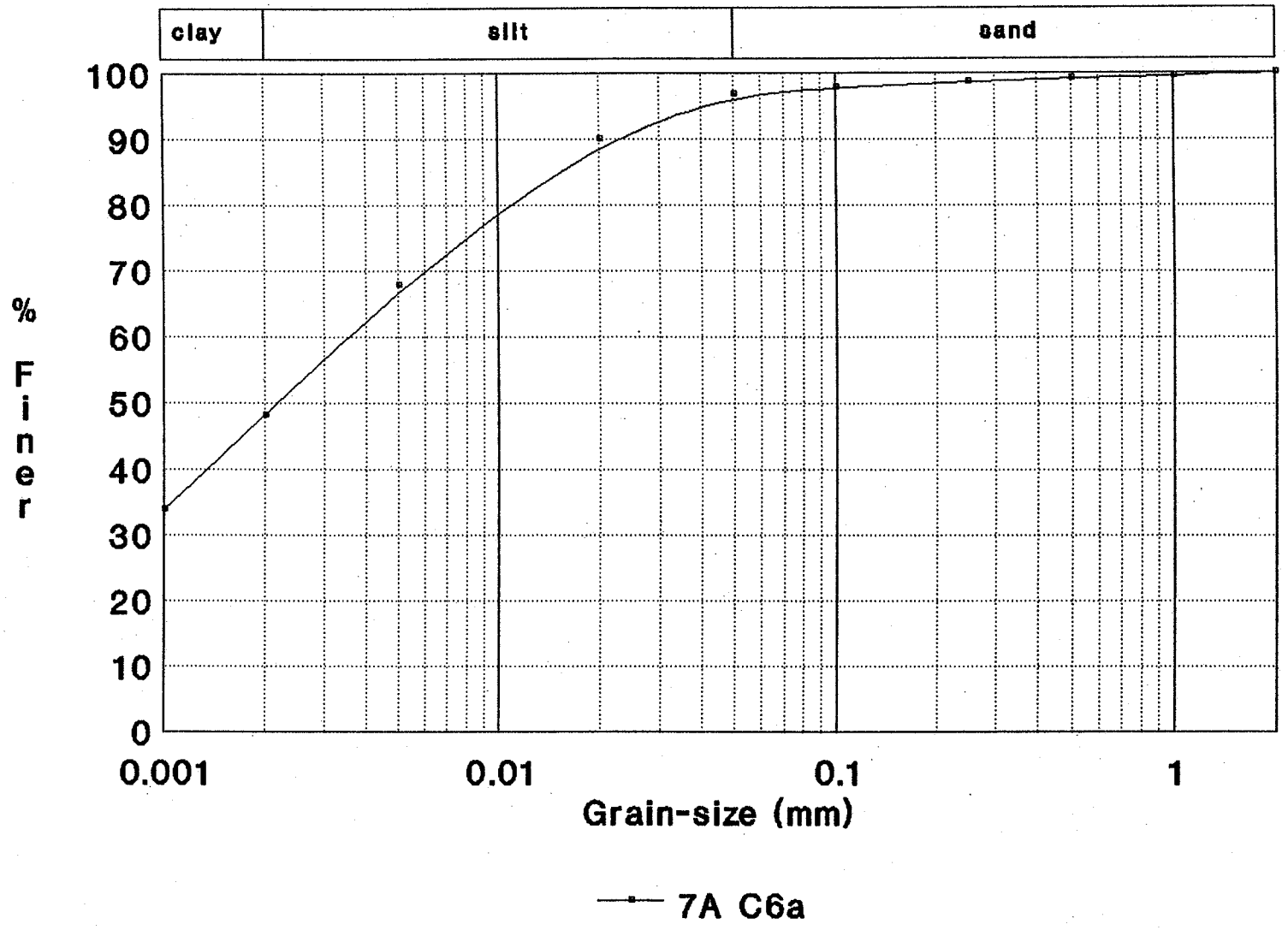

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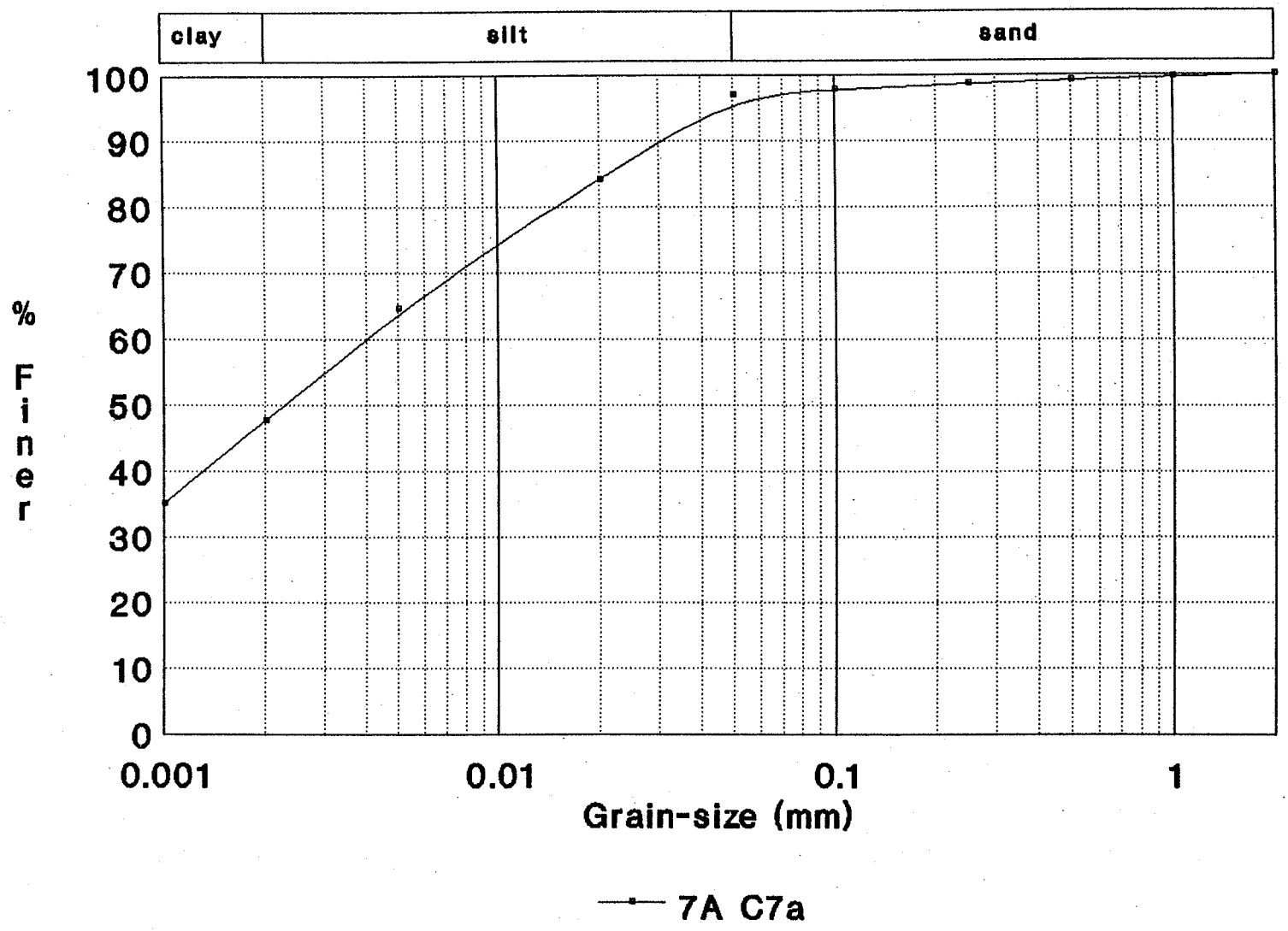
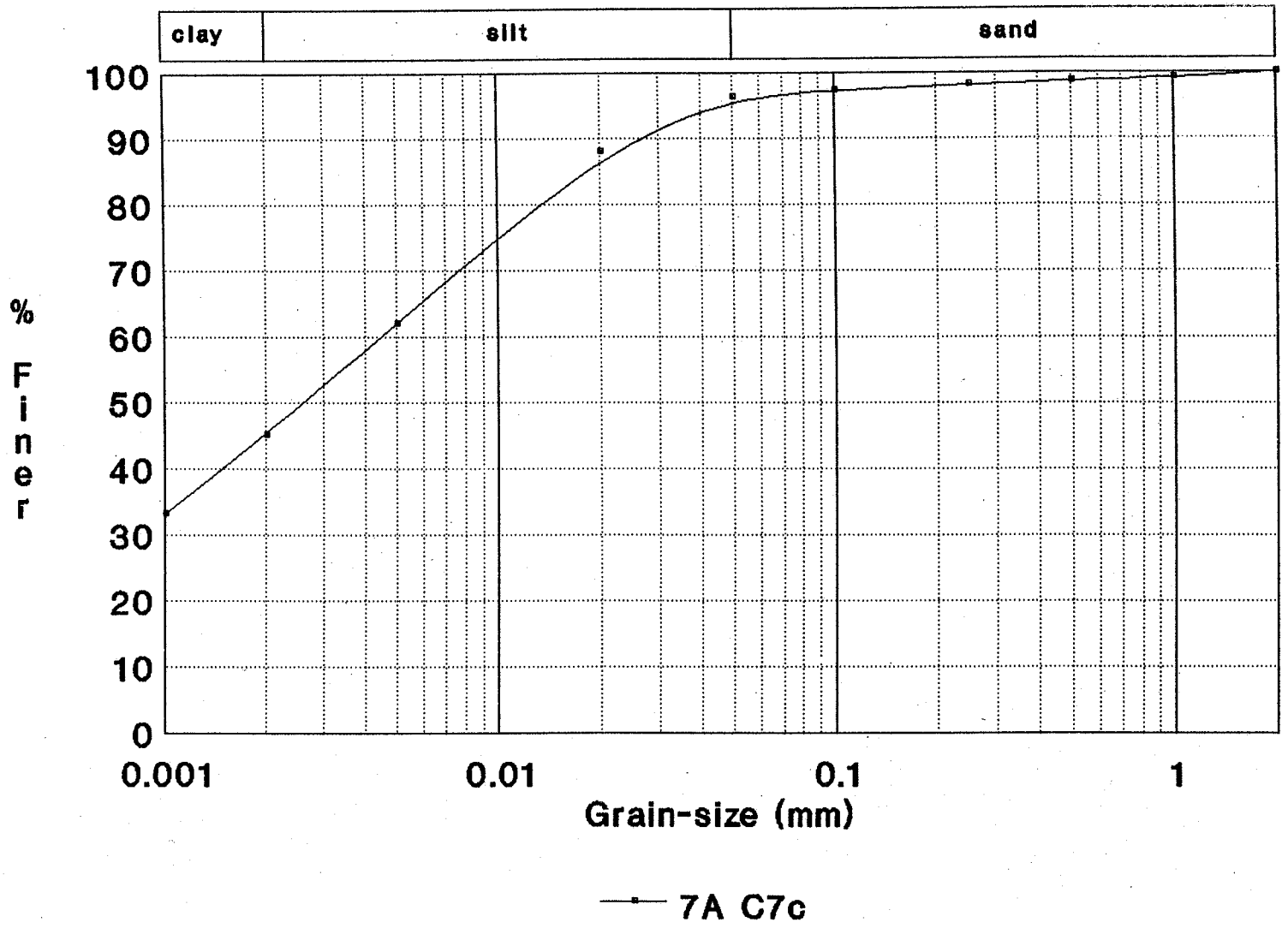


Grain-size Analysis



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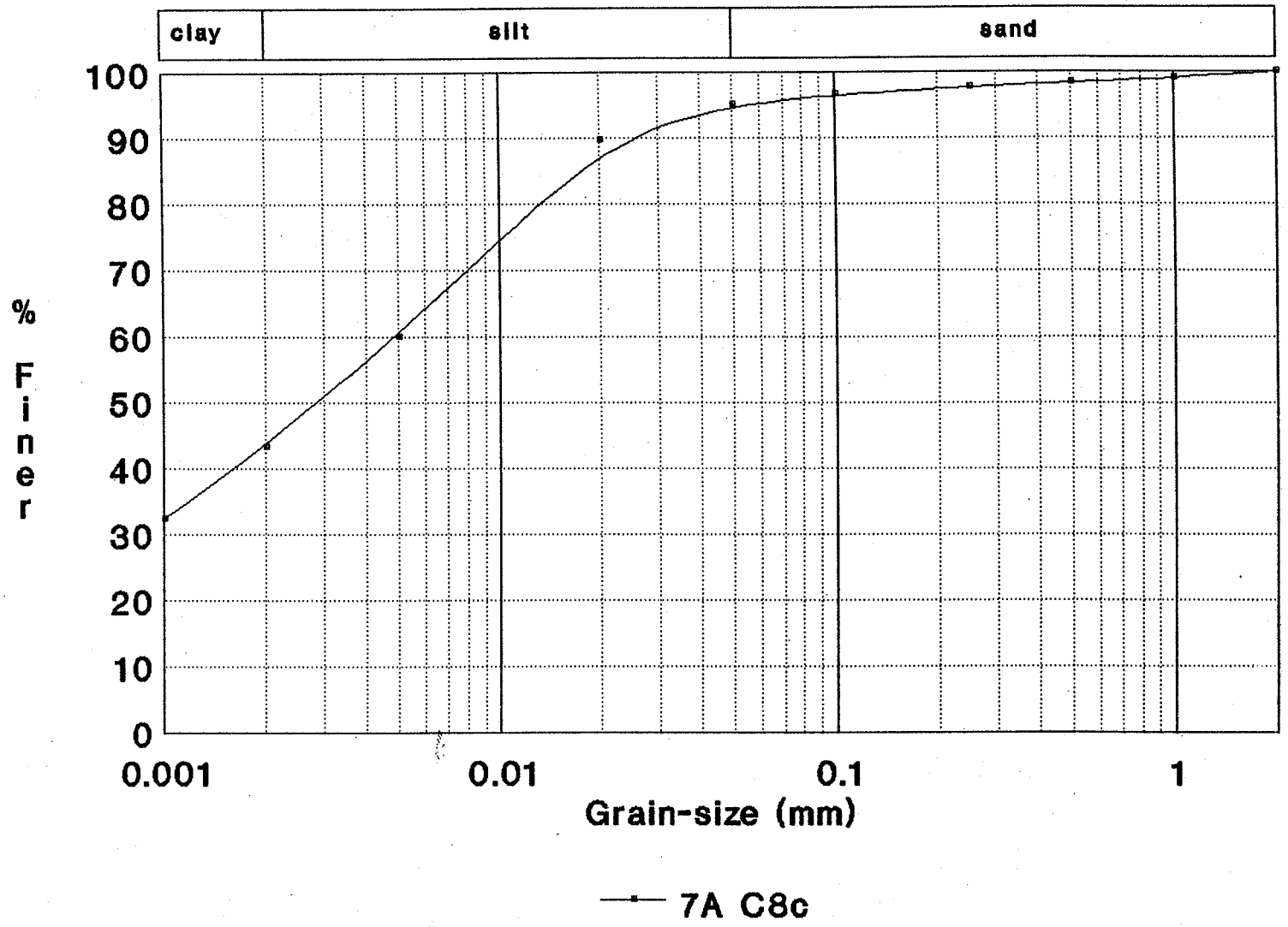

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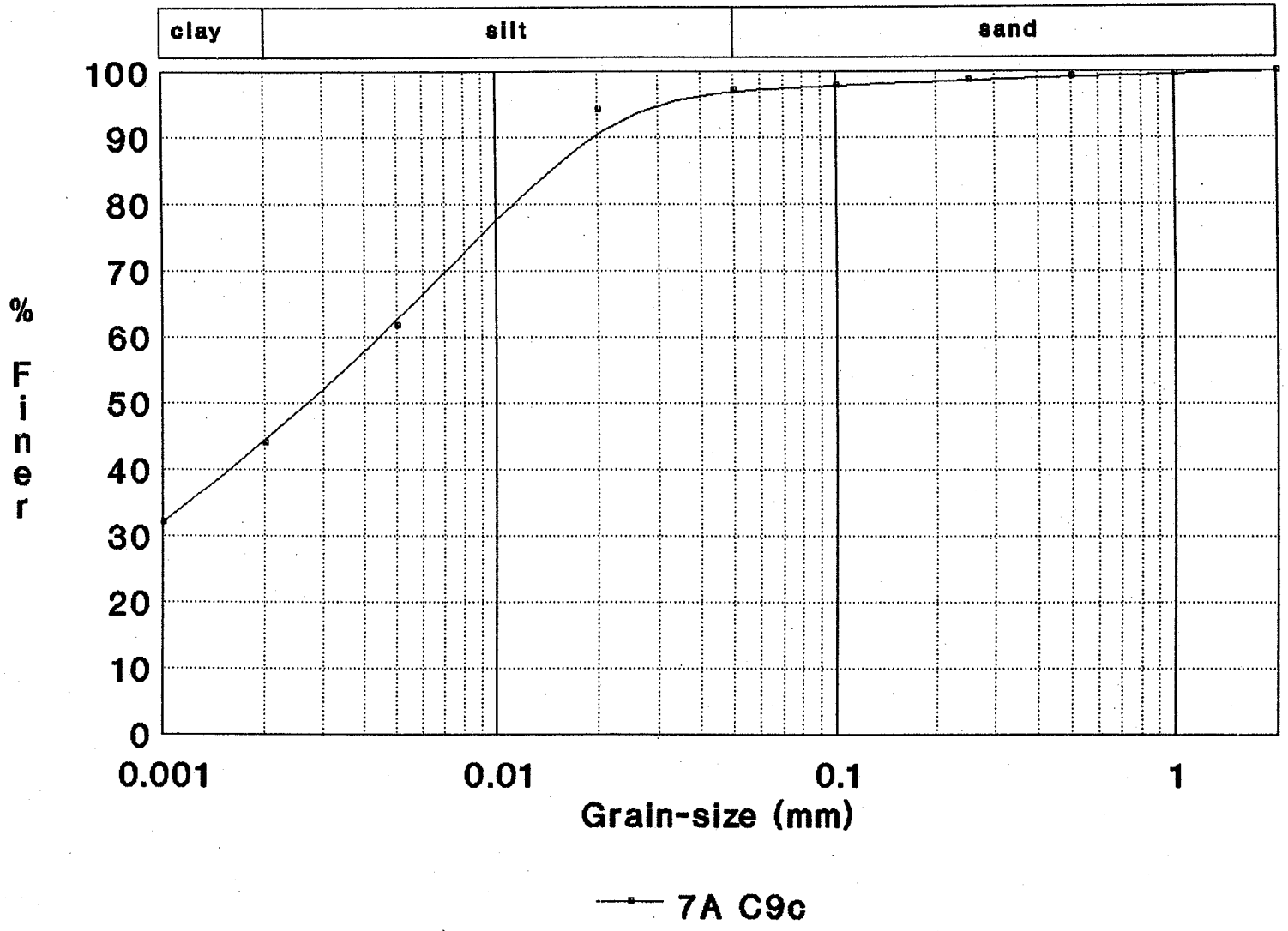

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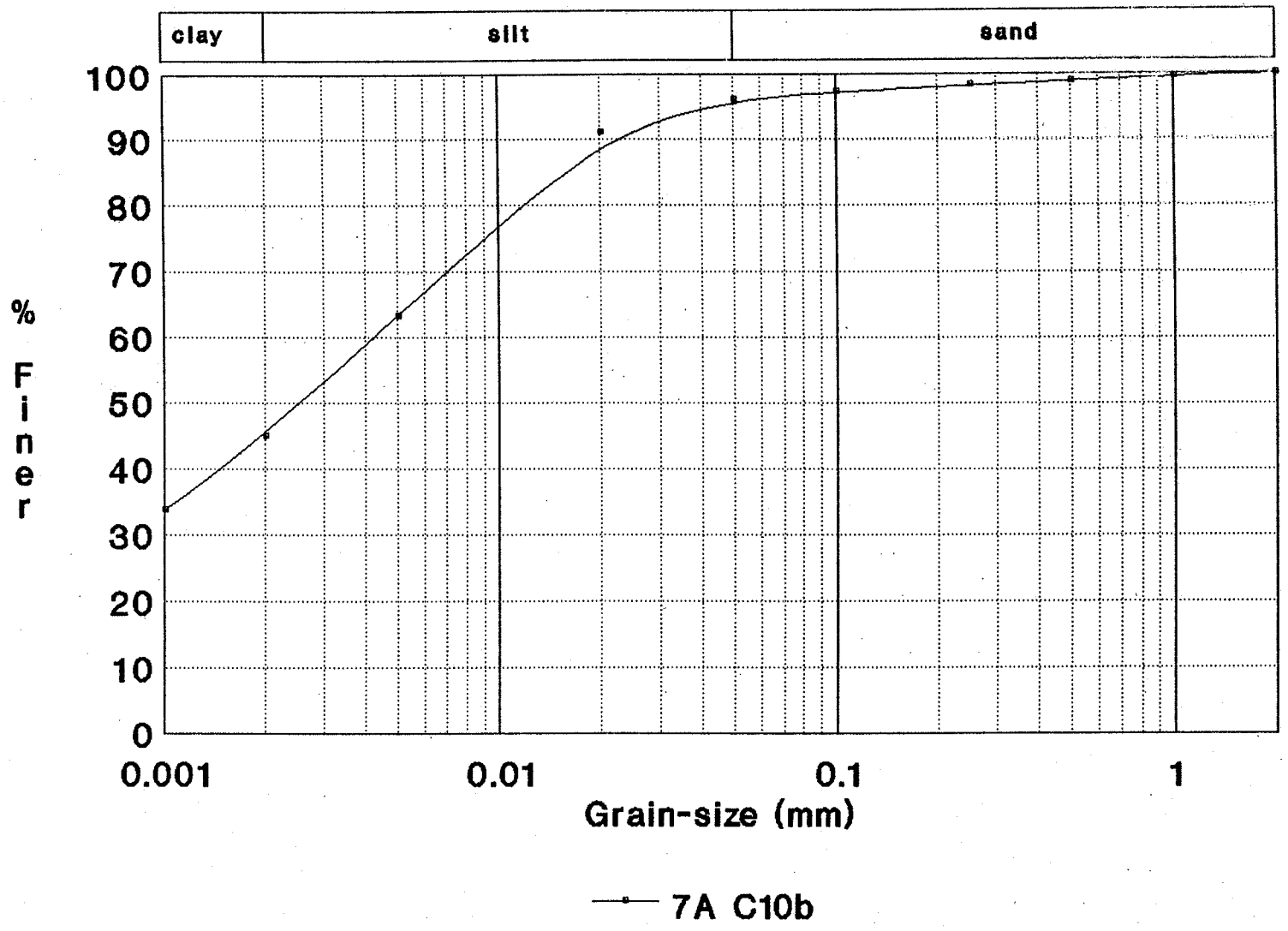

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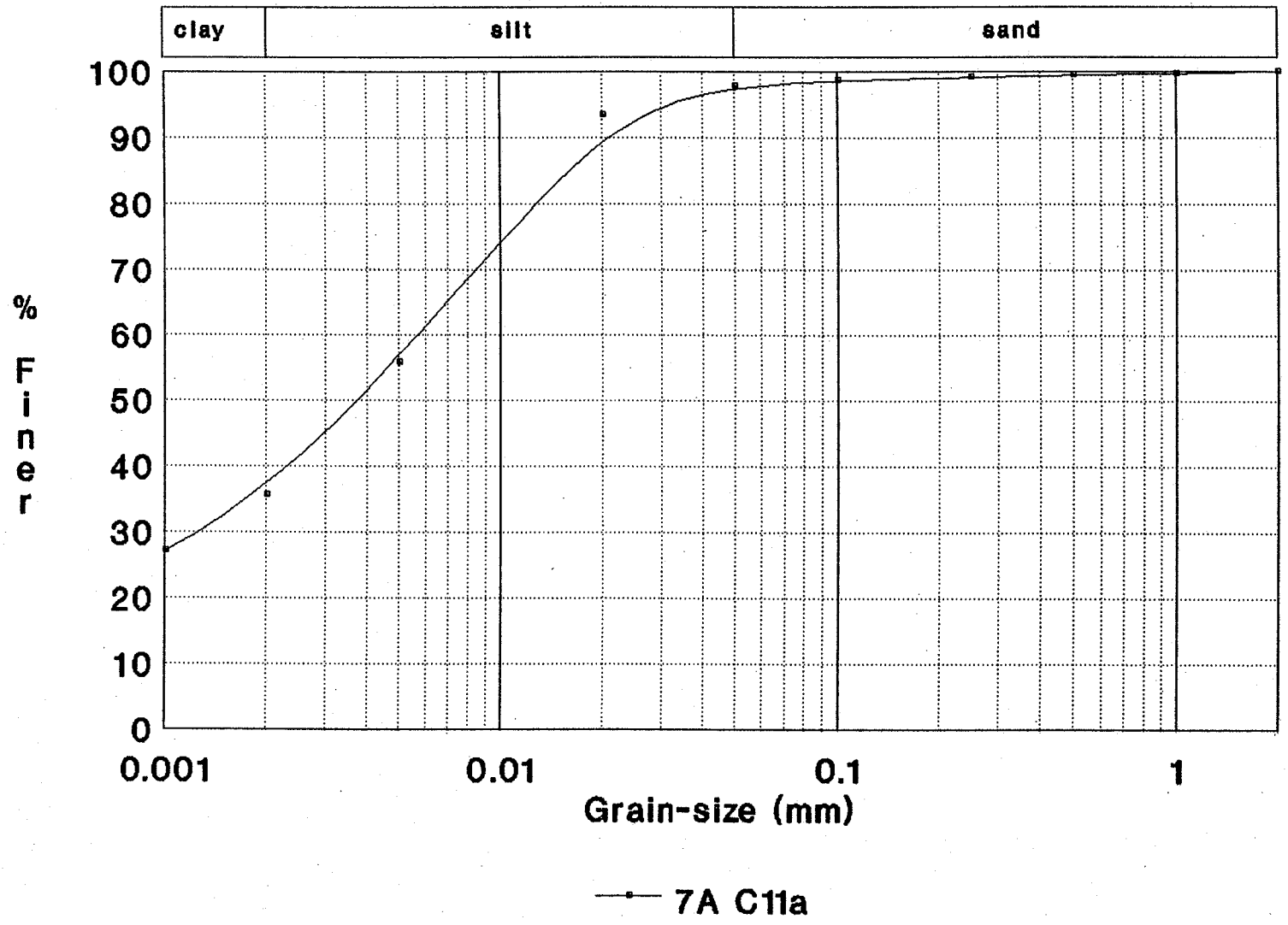

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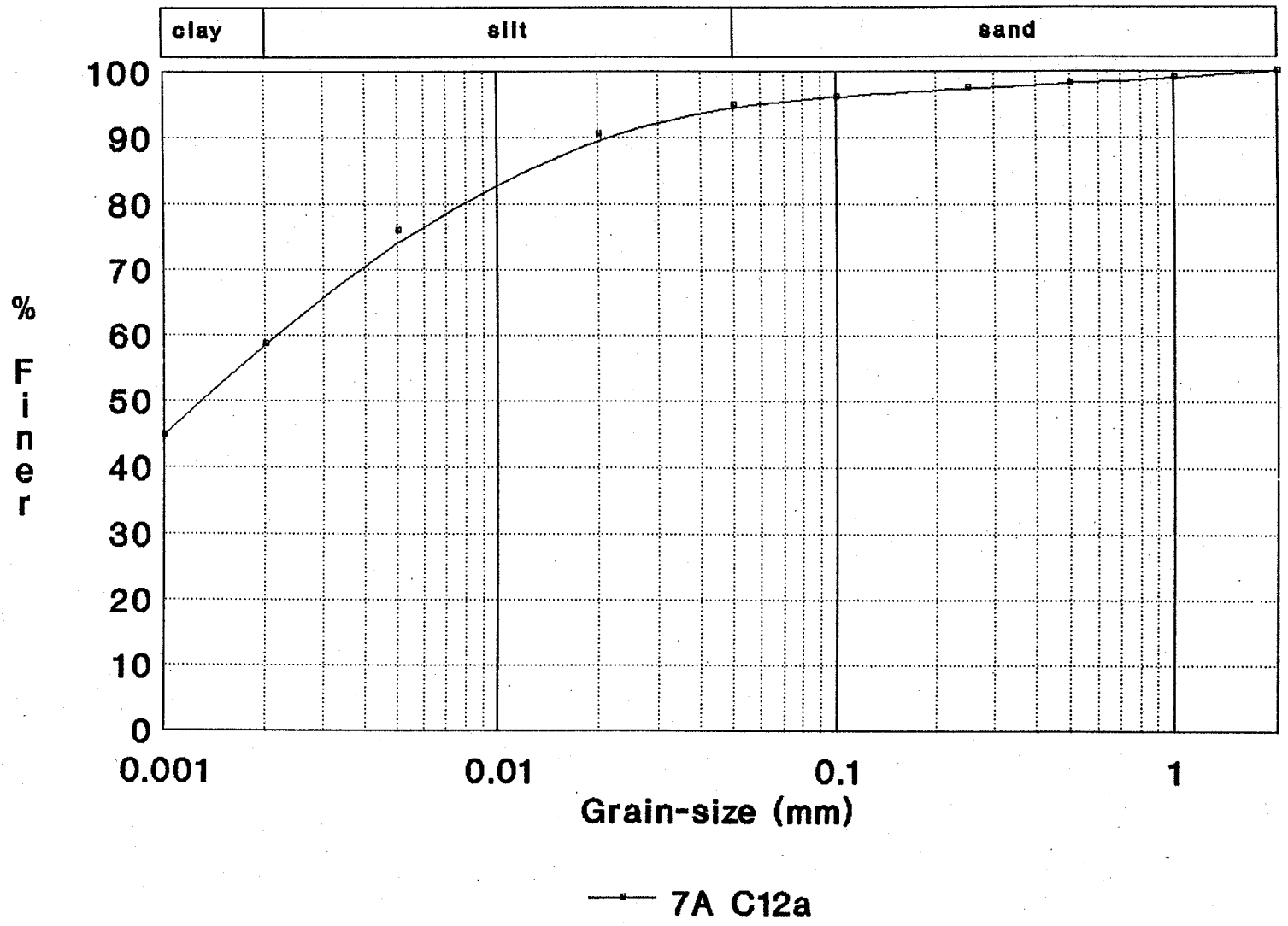

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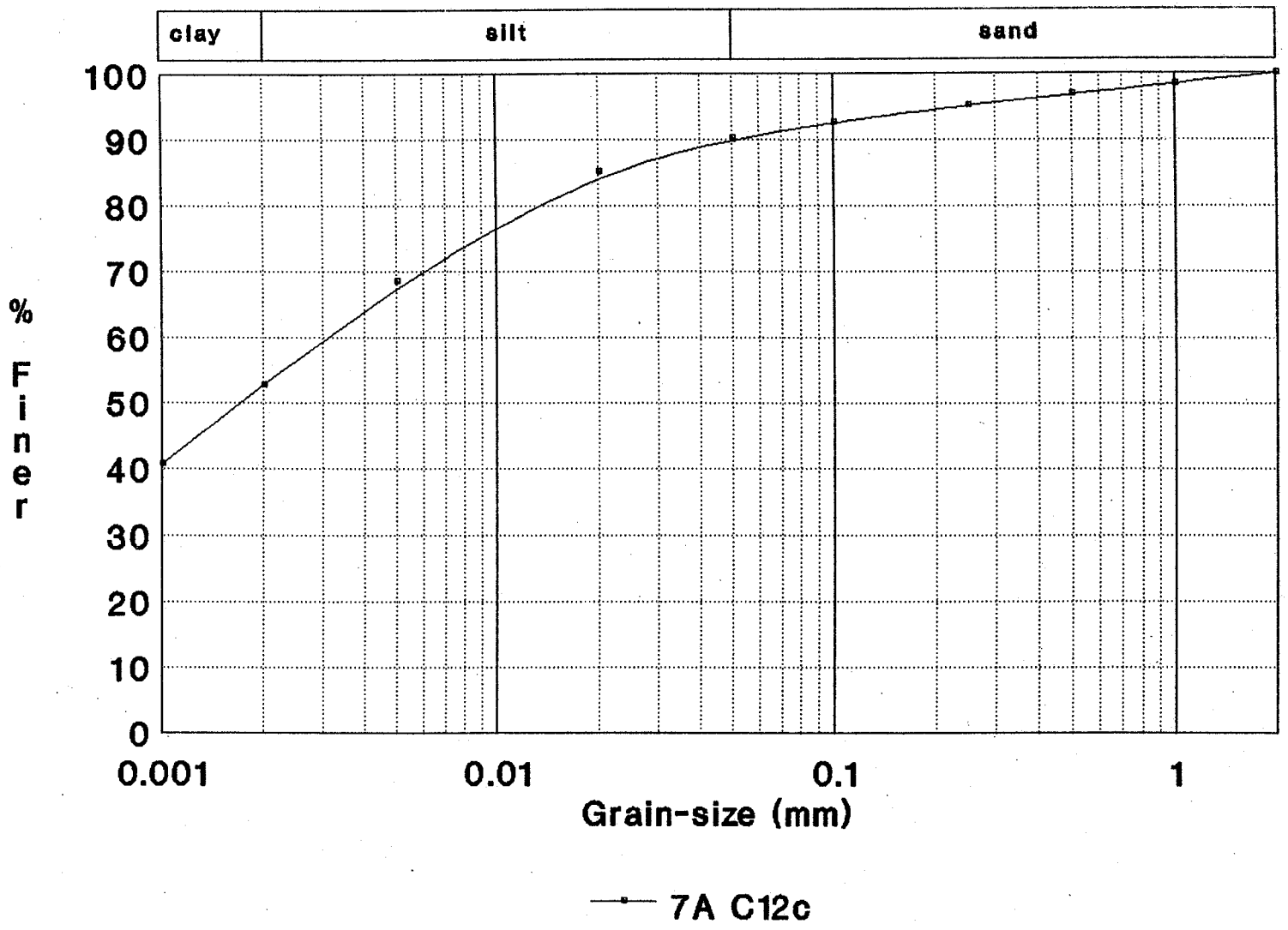

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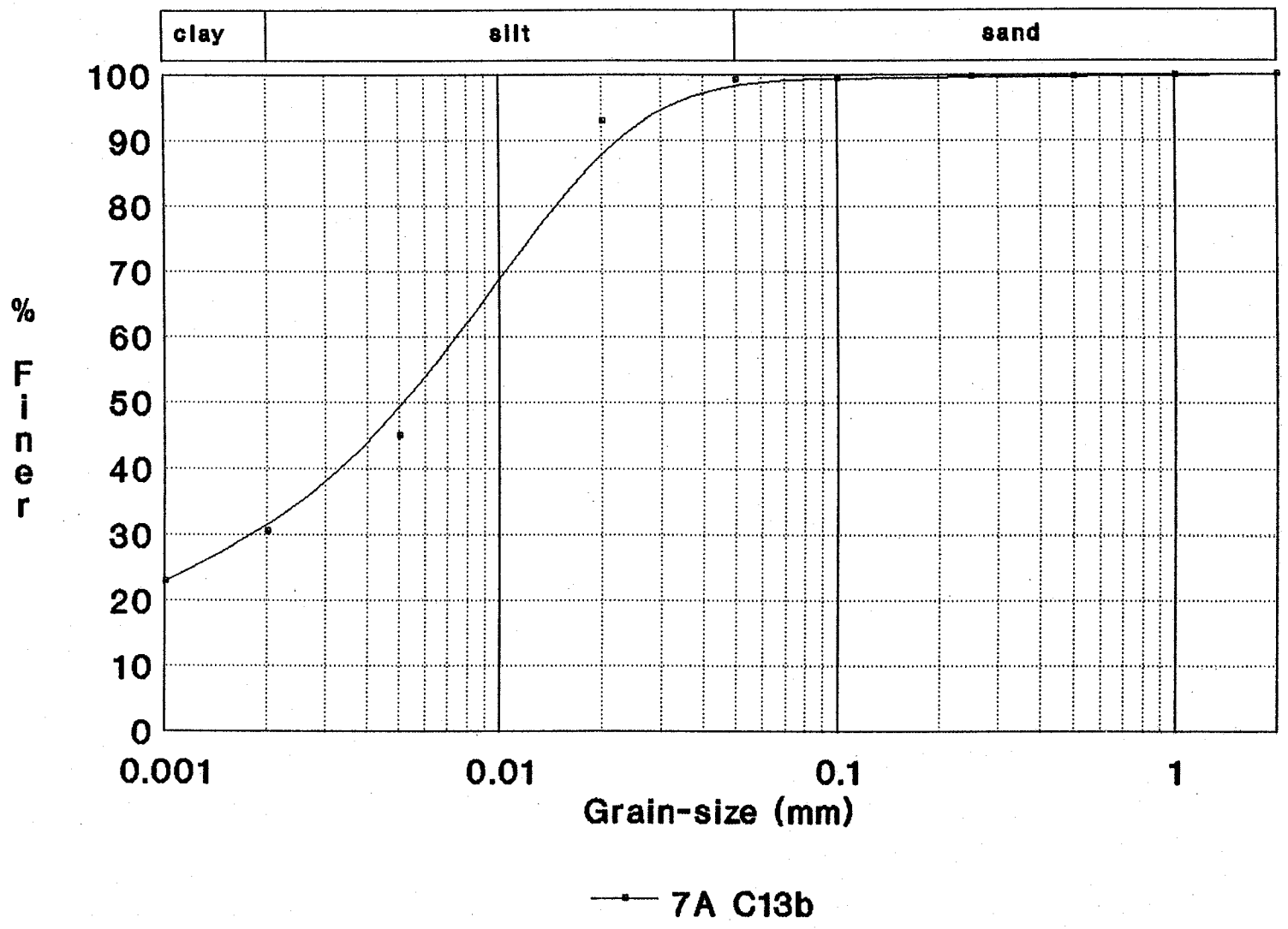

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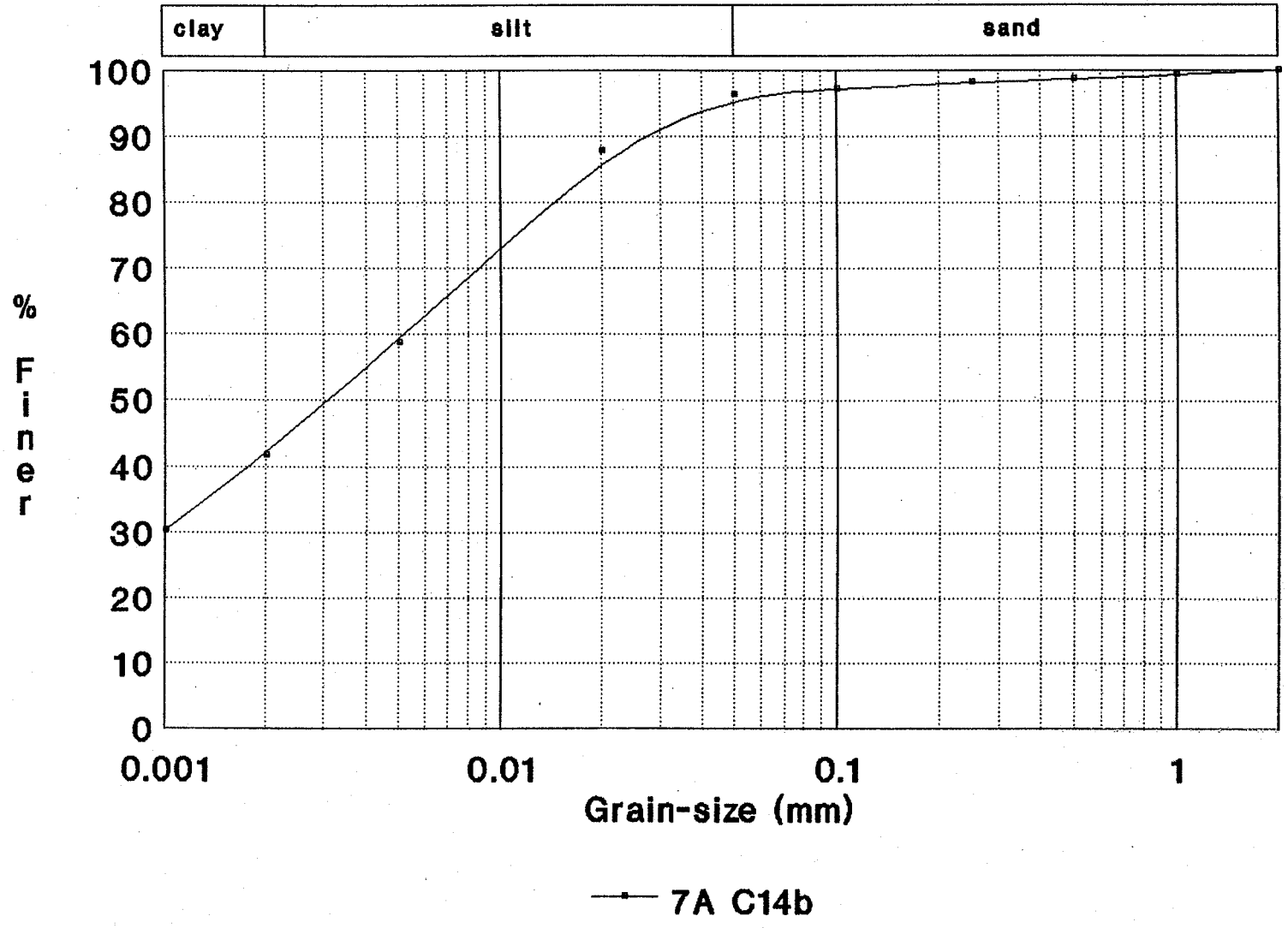
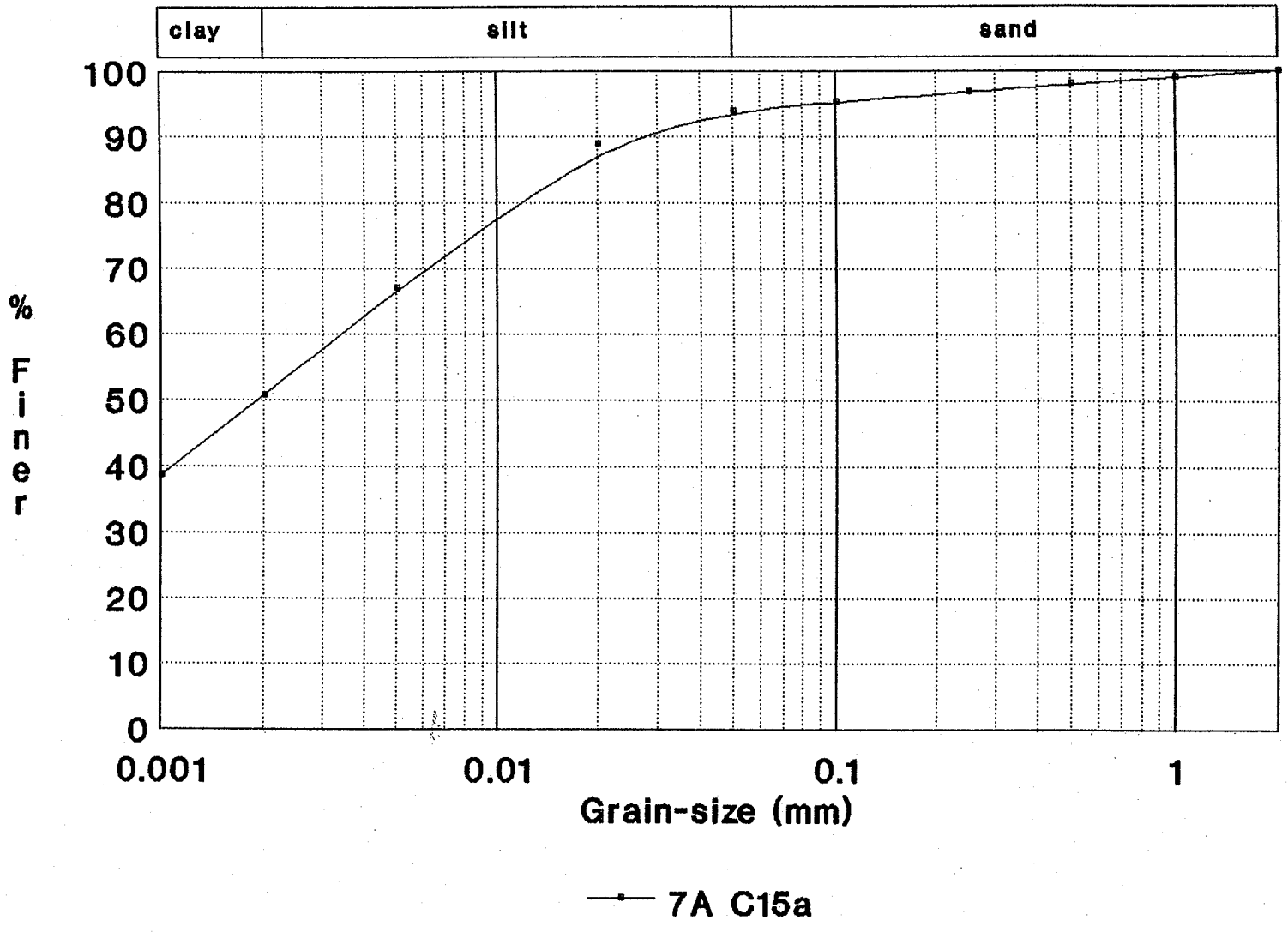
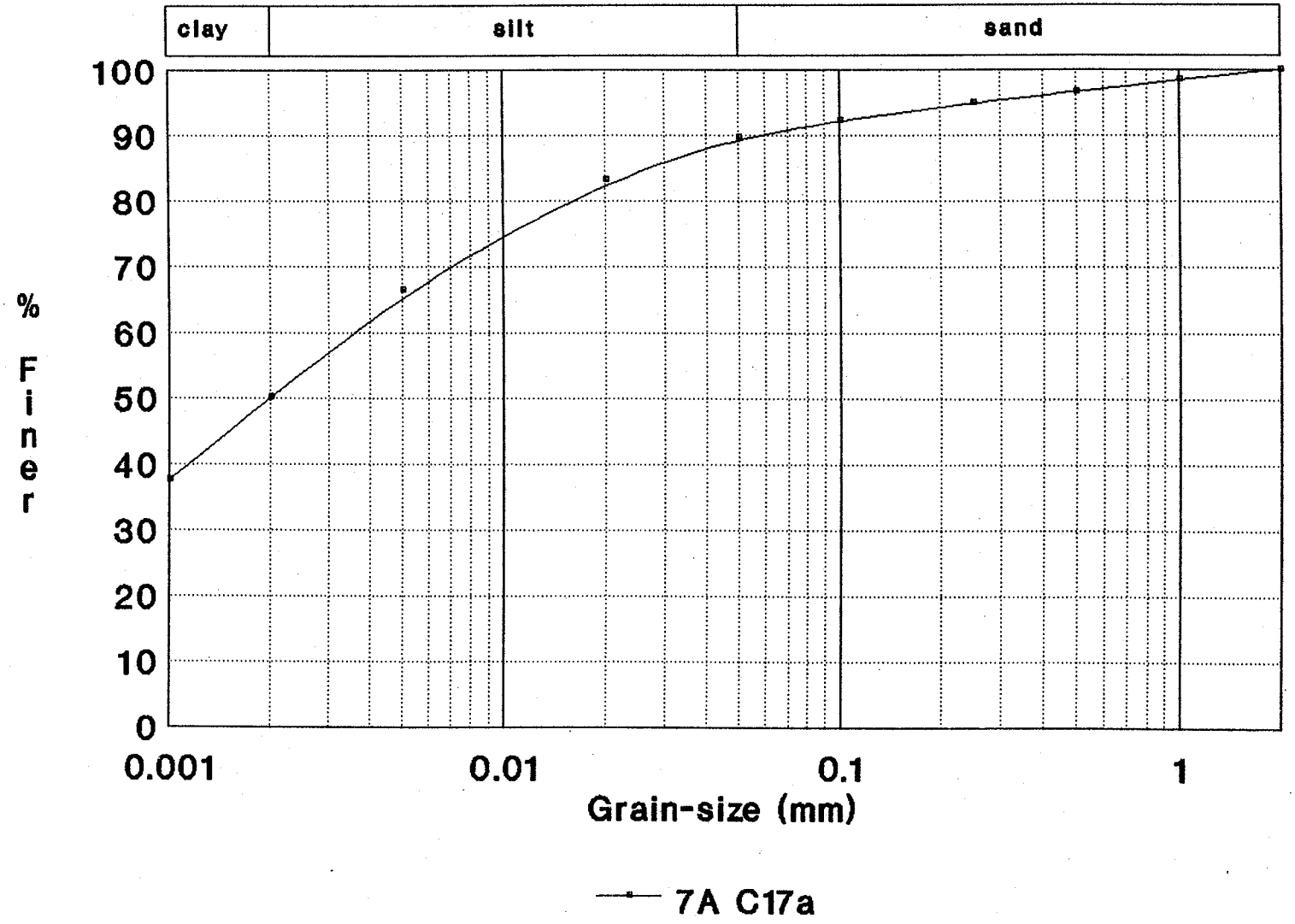


Grain-size Analysis



Grain-size Analysis



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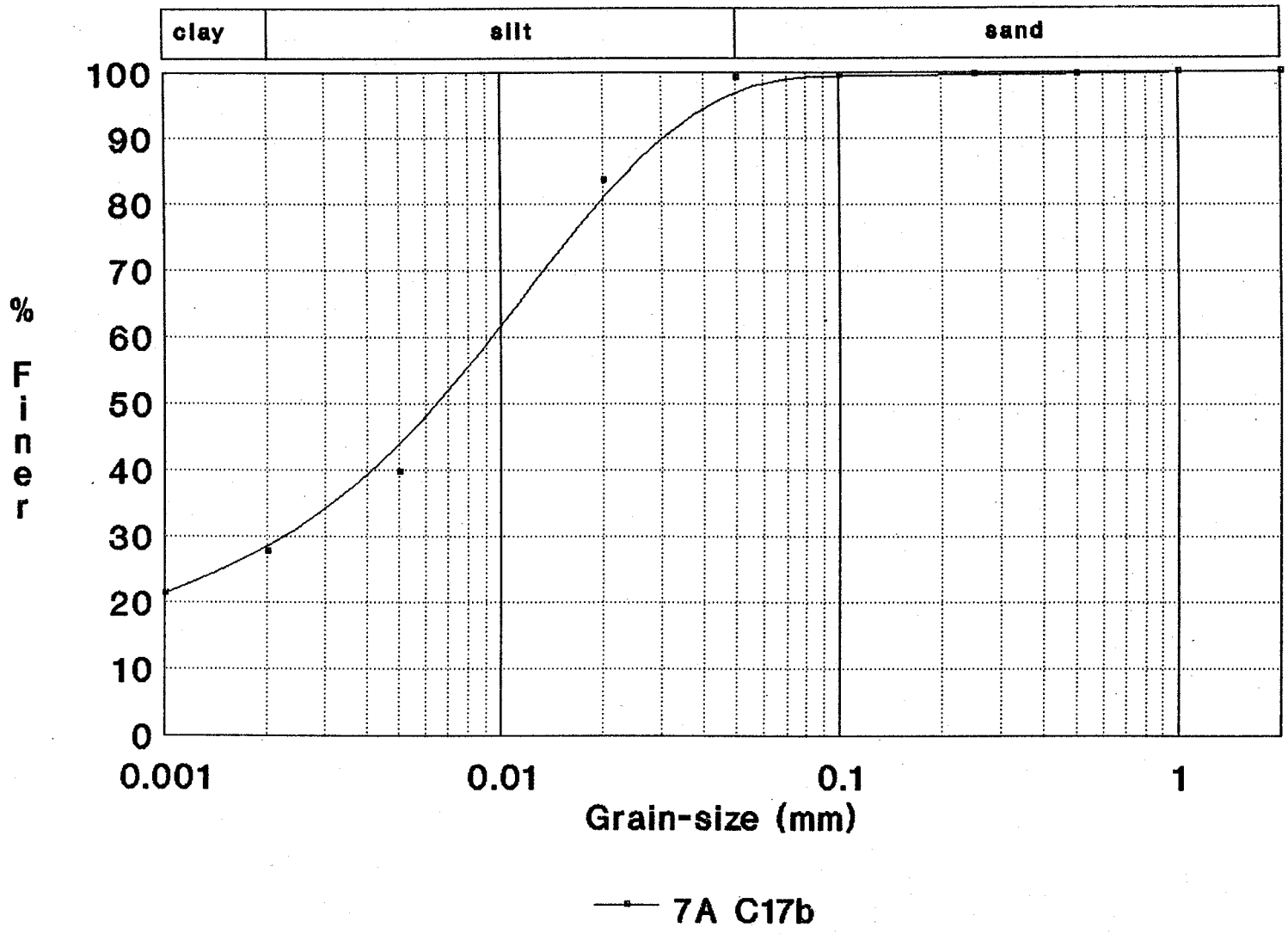

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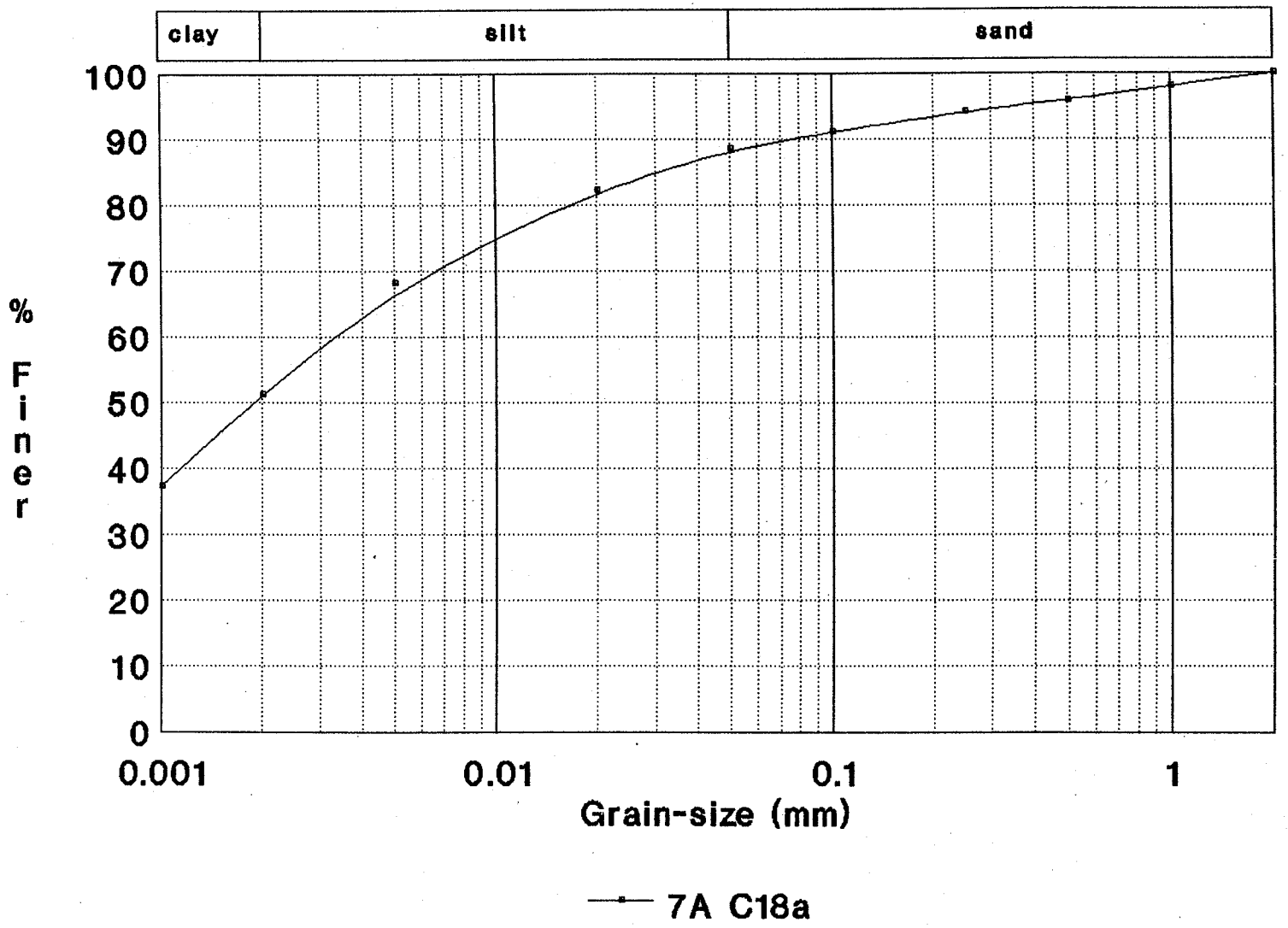

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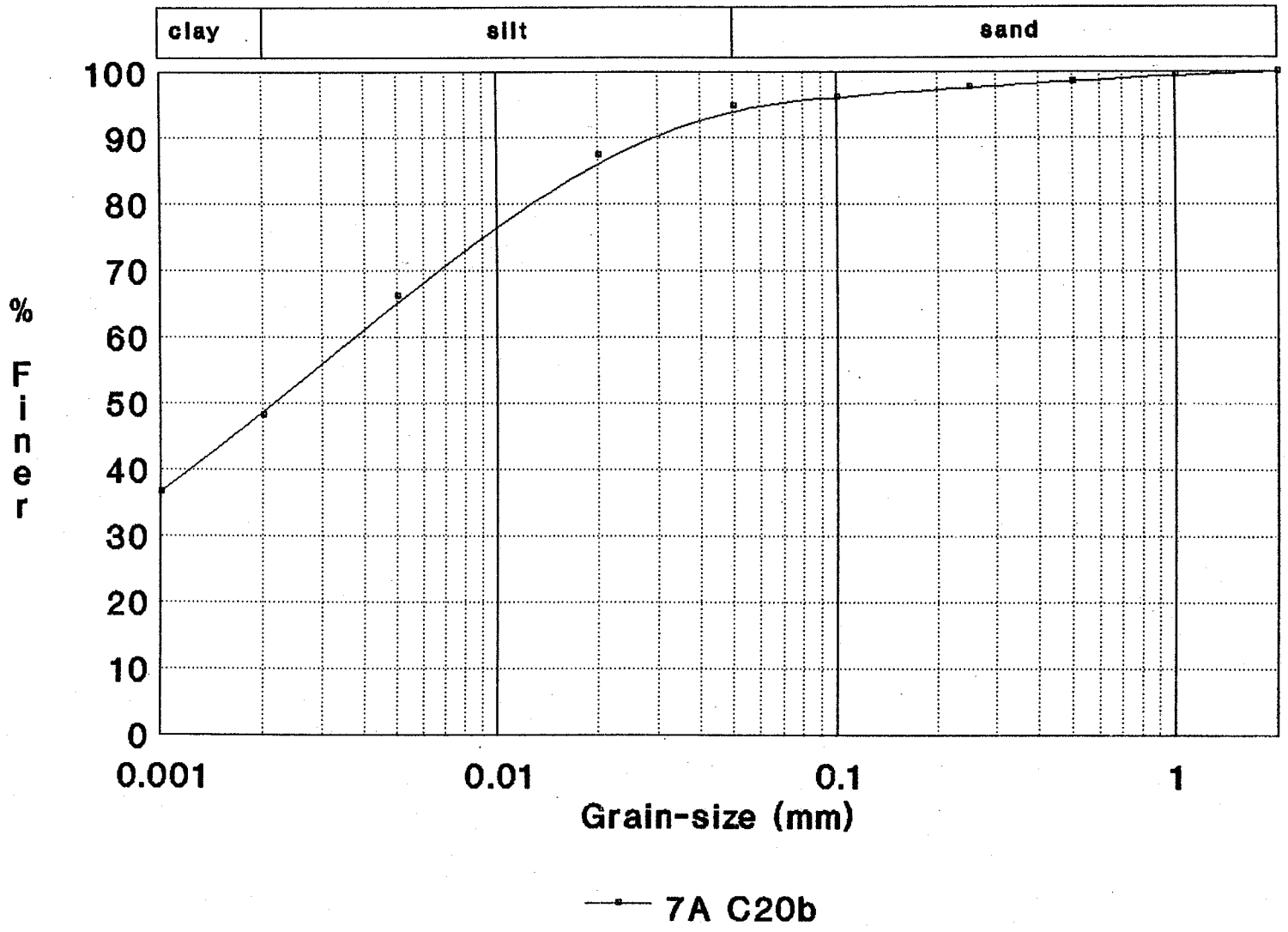

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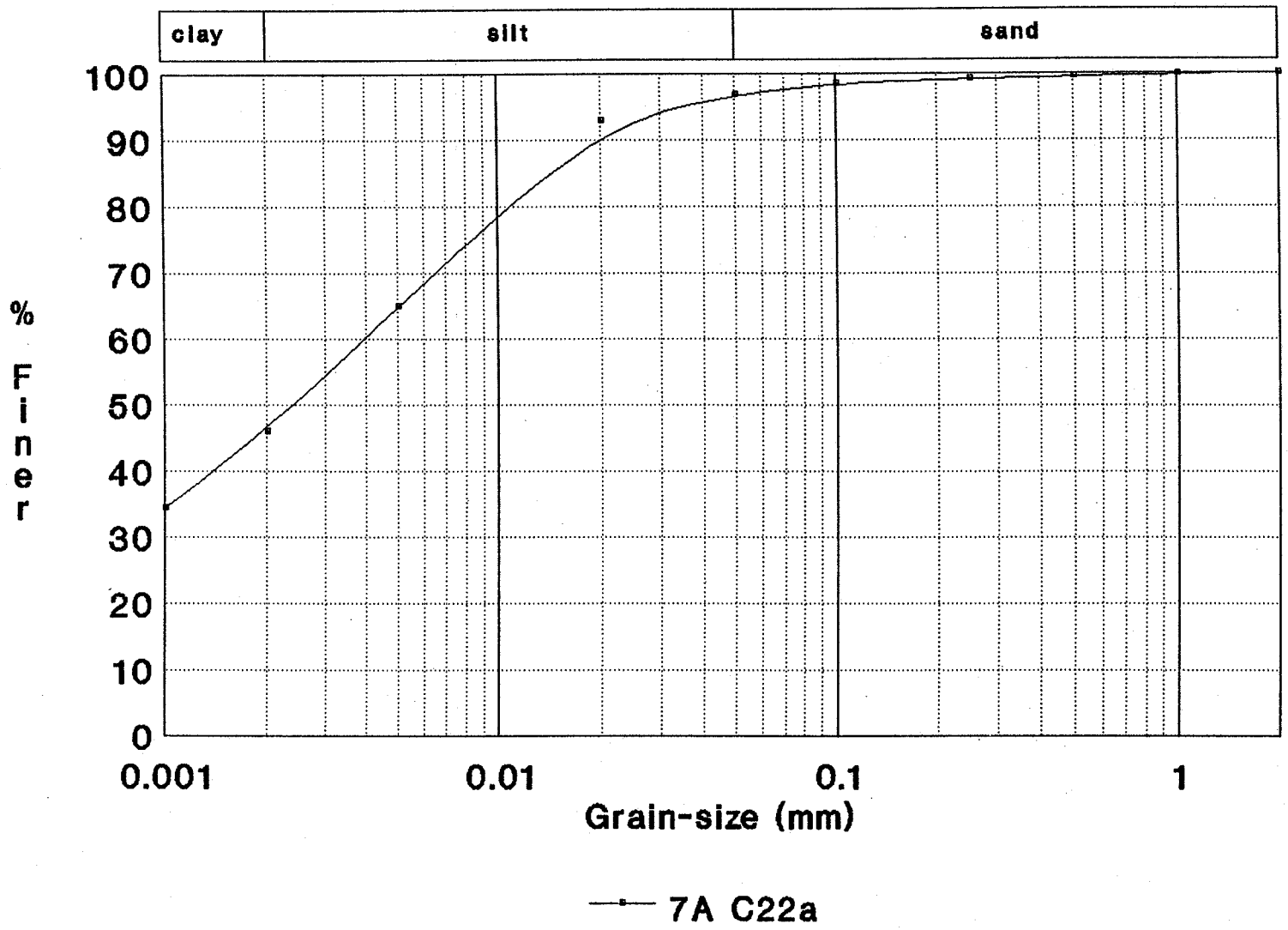

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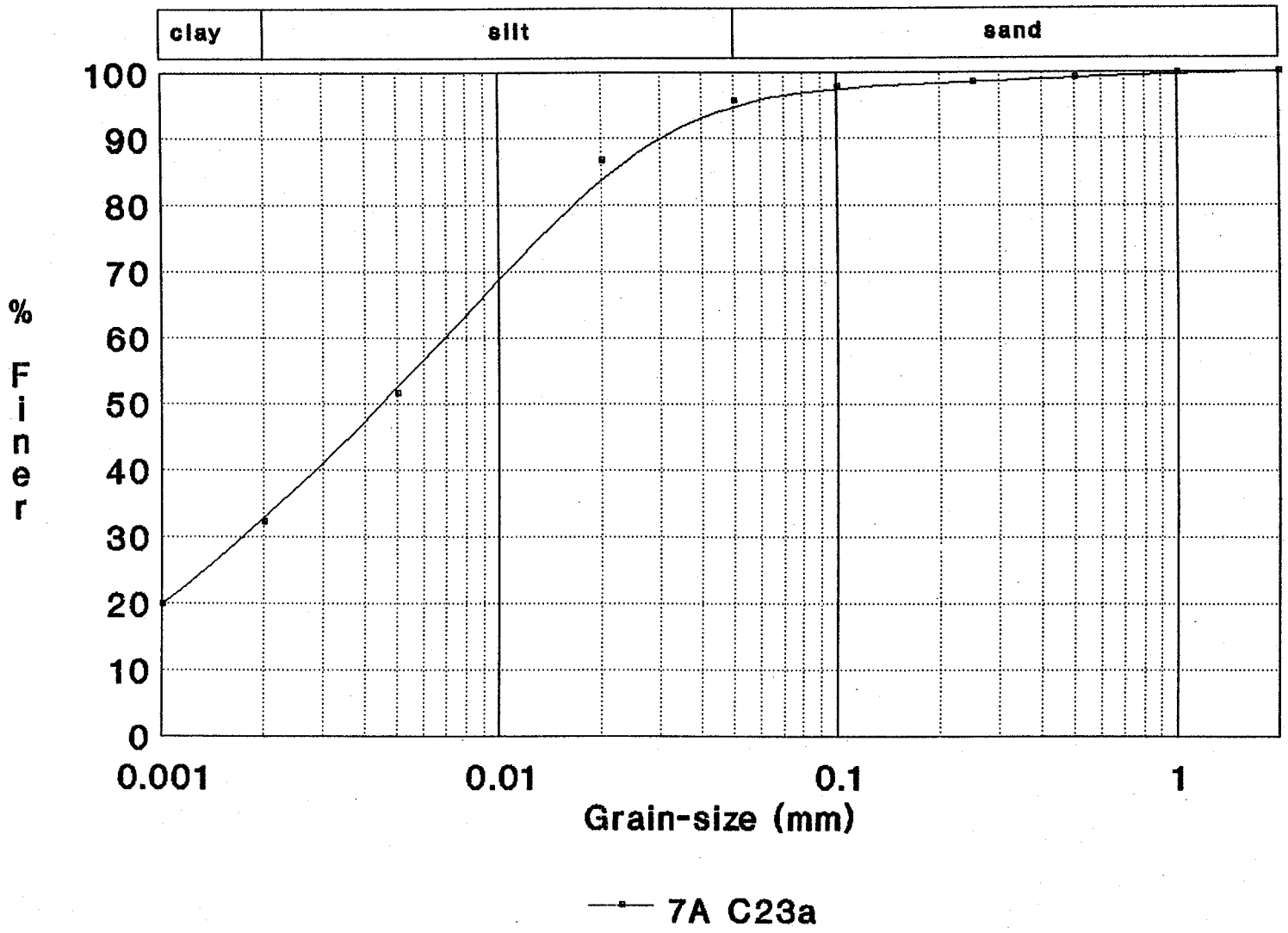

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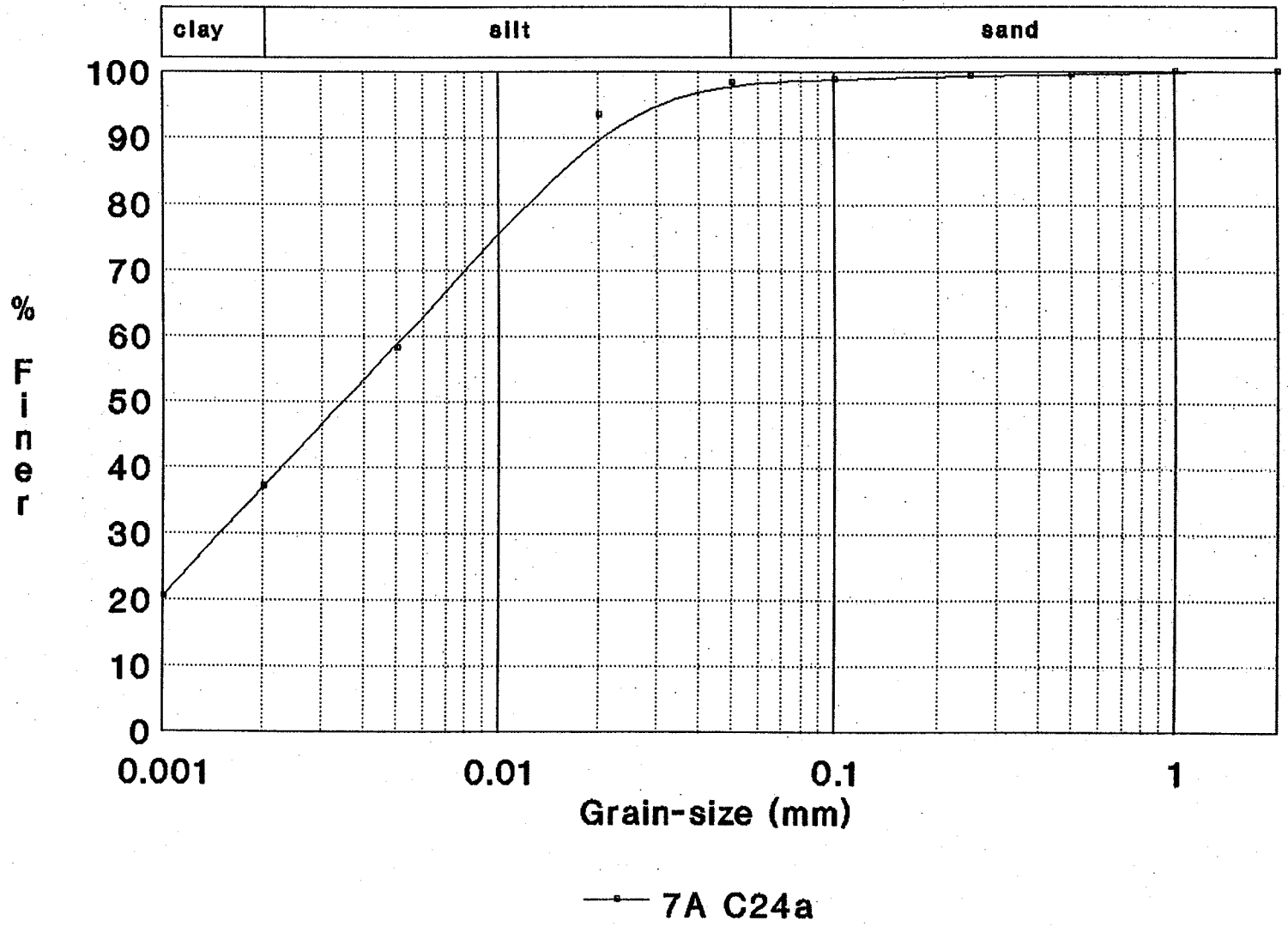

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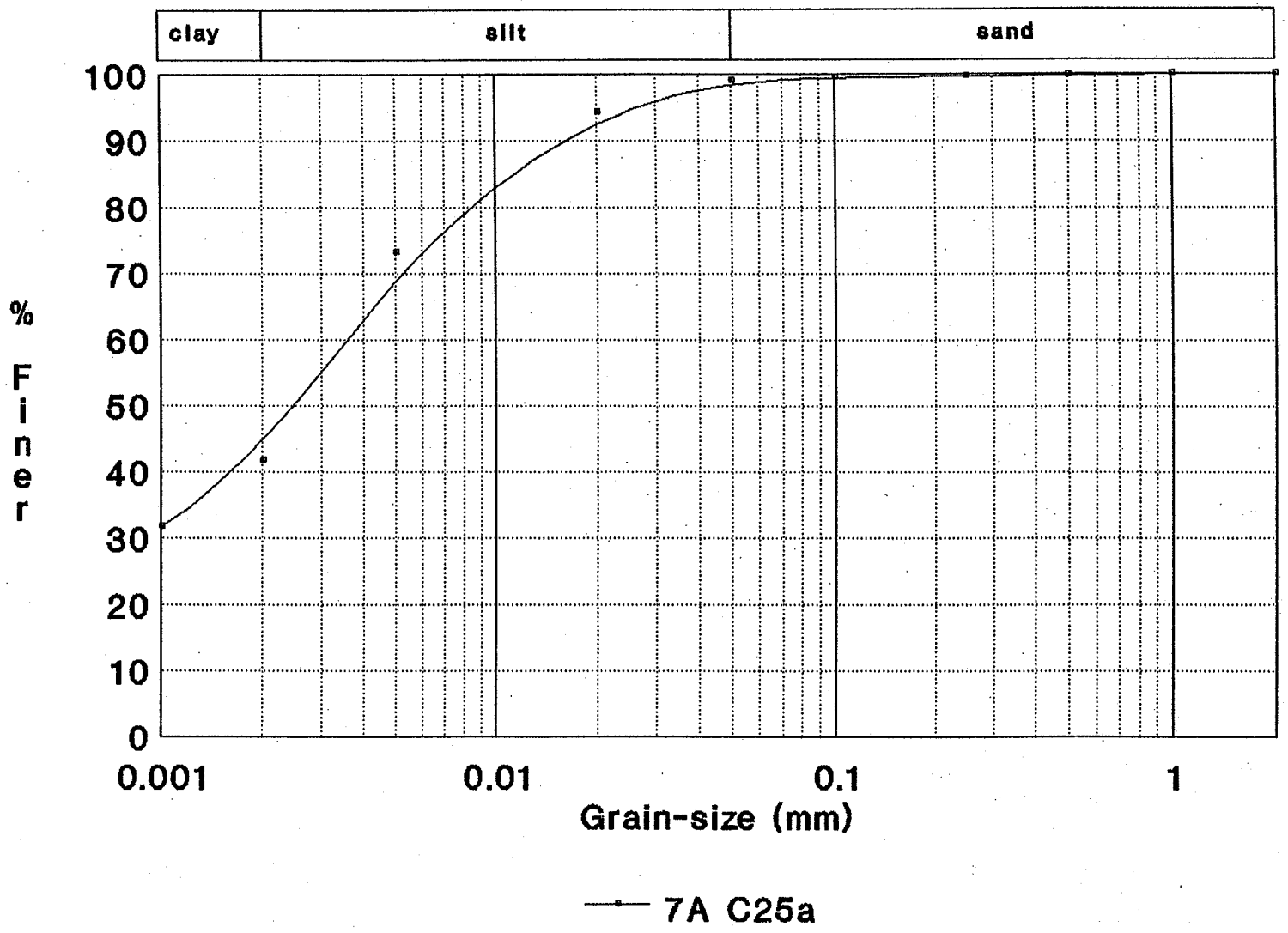
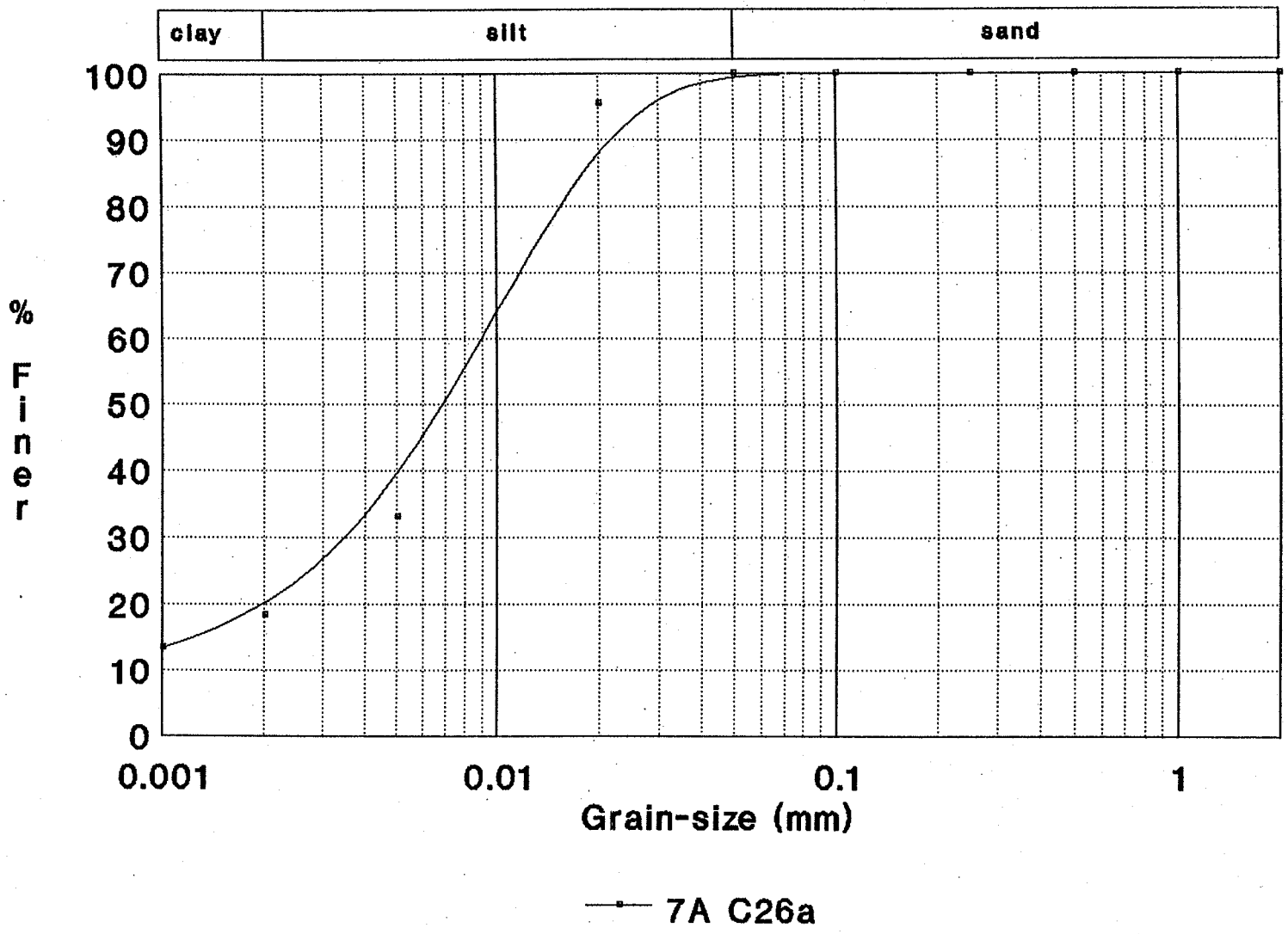


Grain-size Analysis



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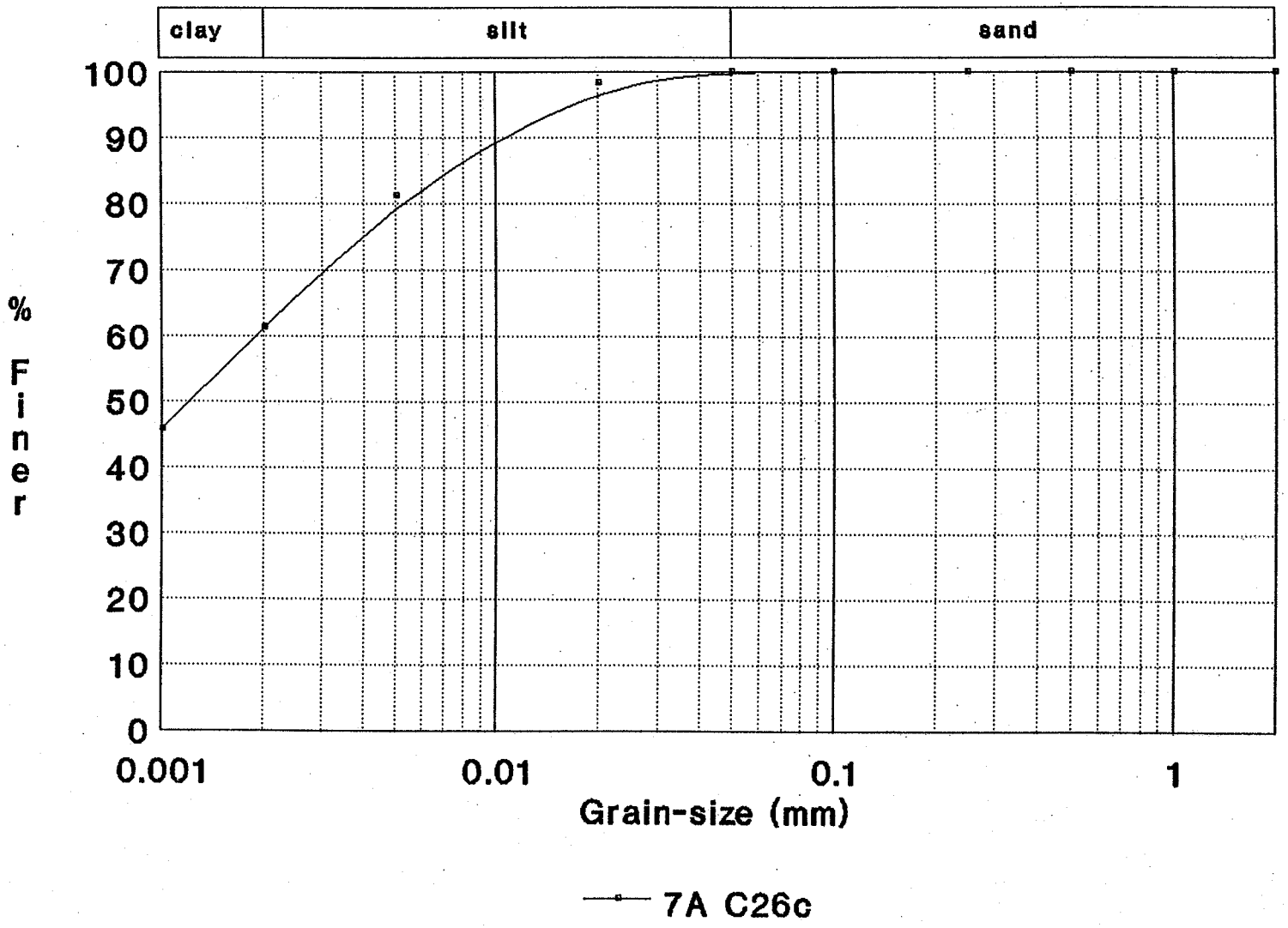

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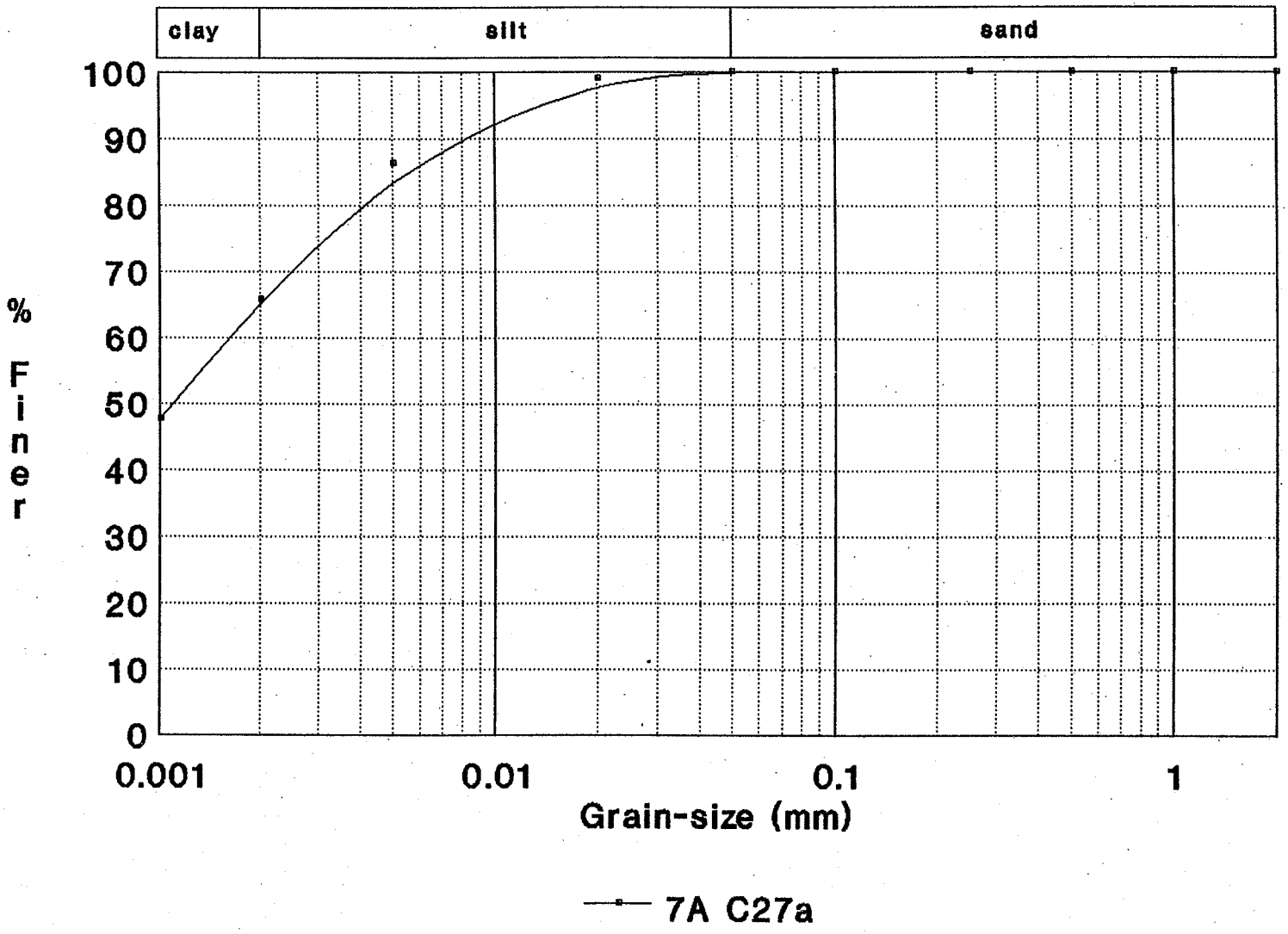

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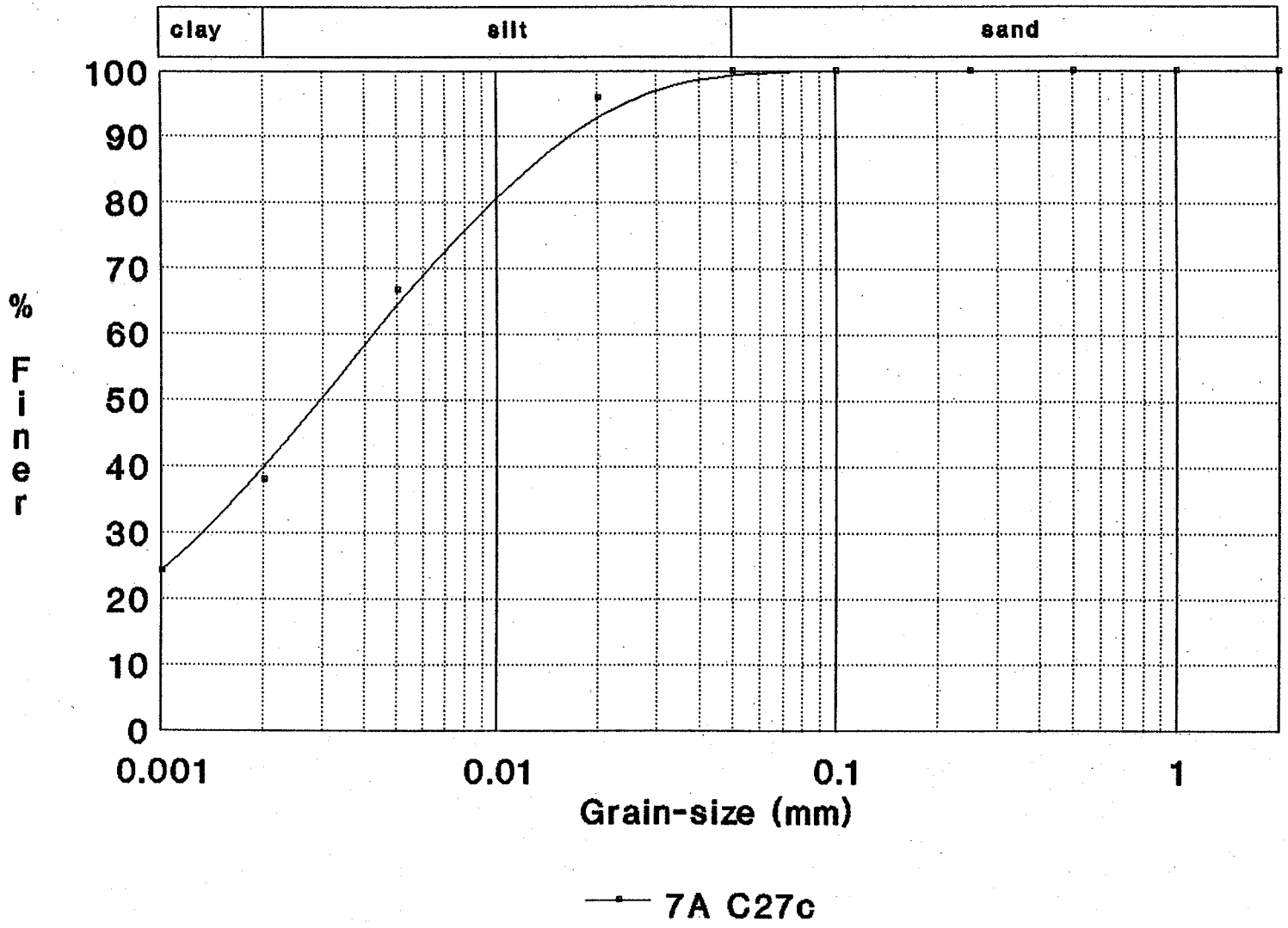

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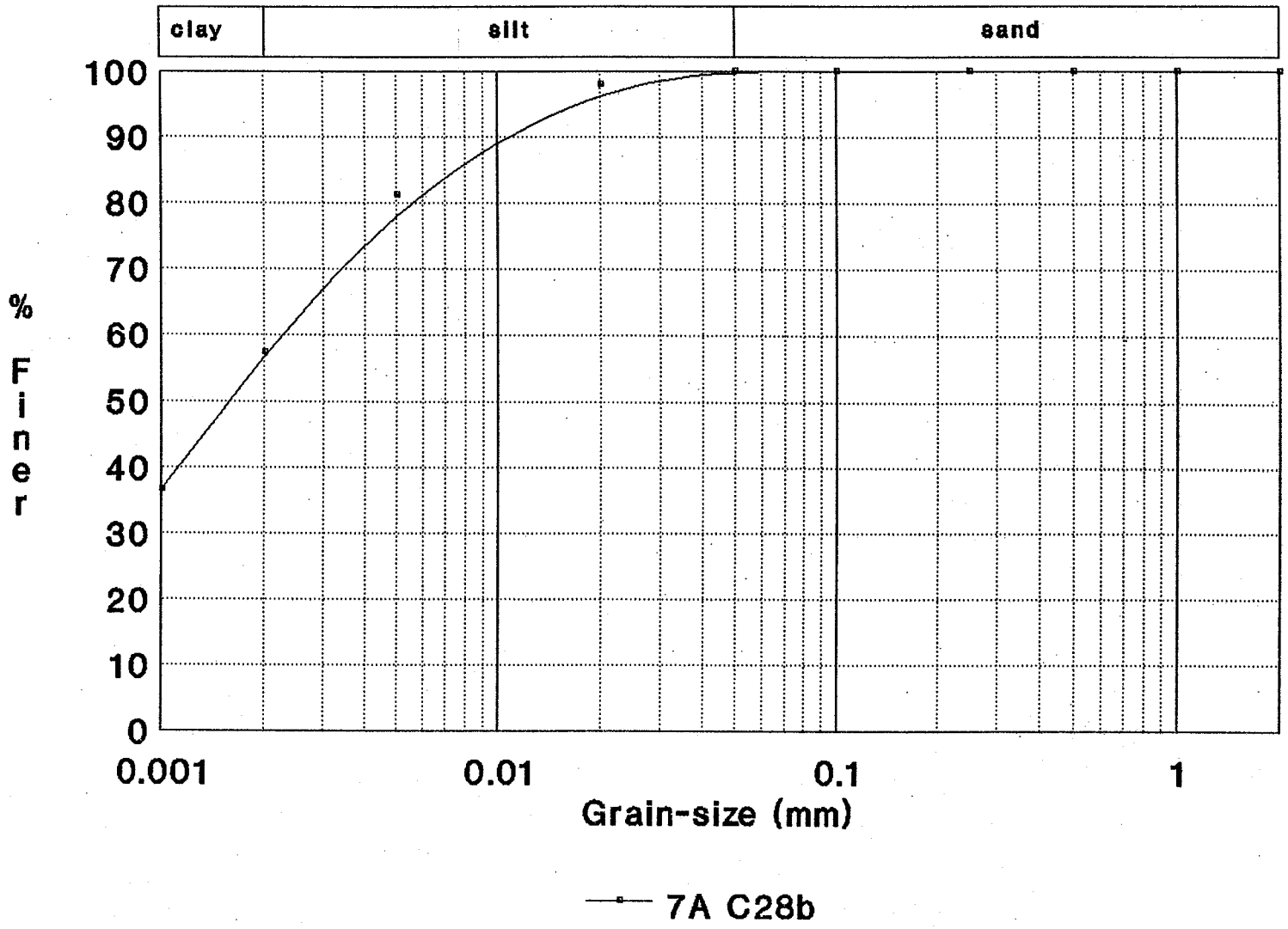

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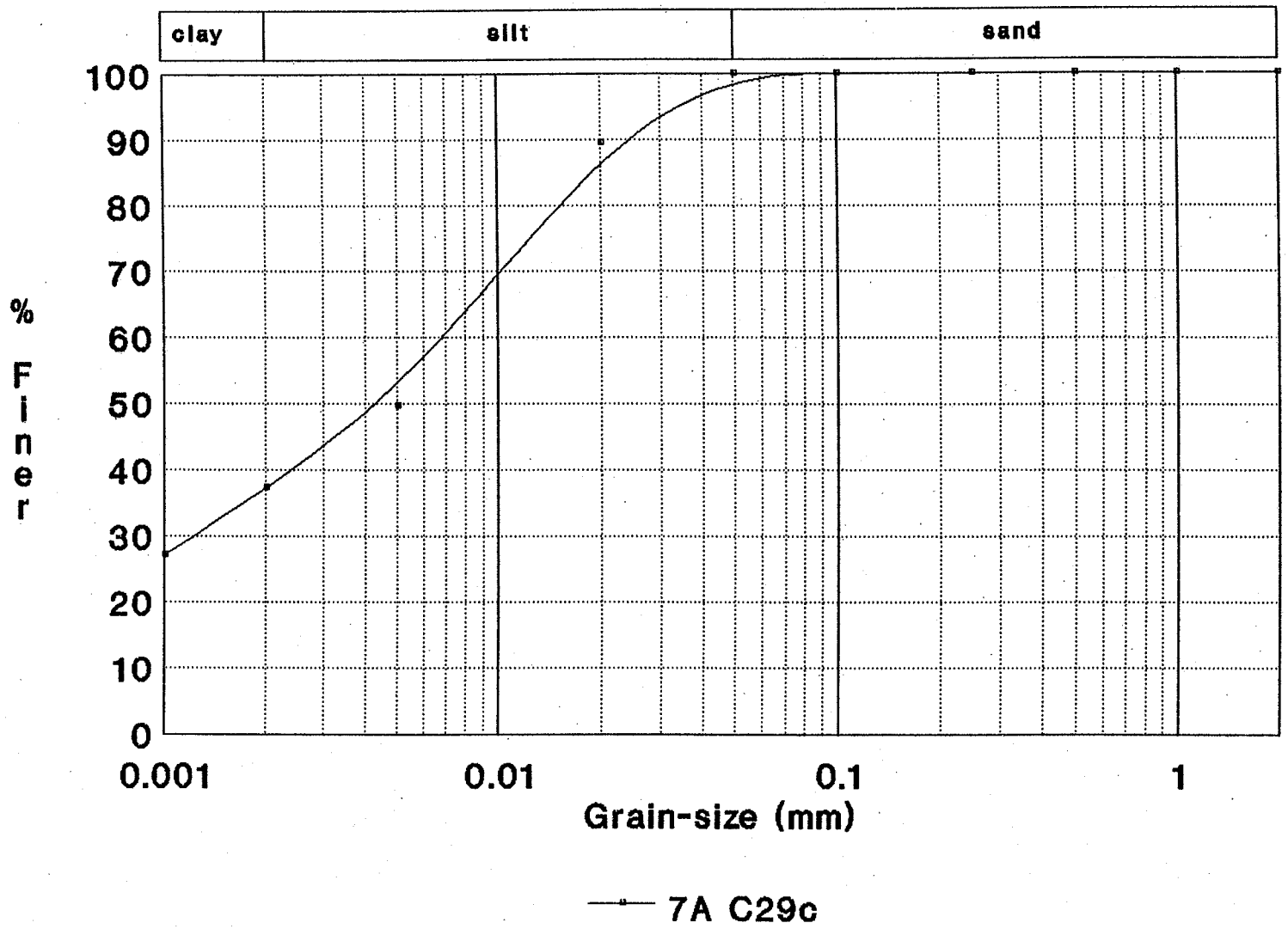

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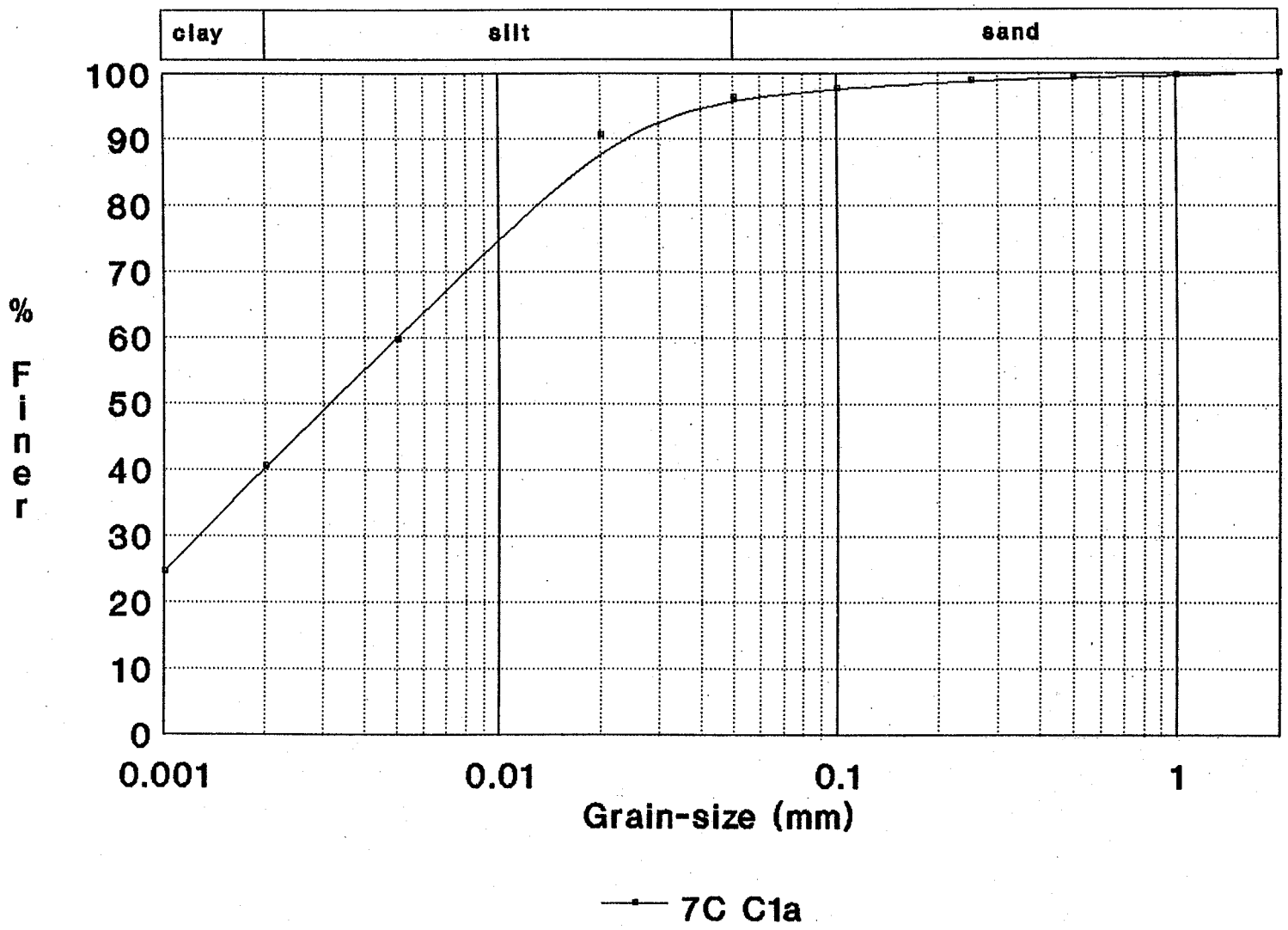

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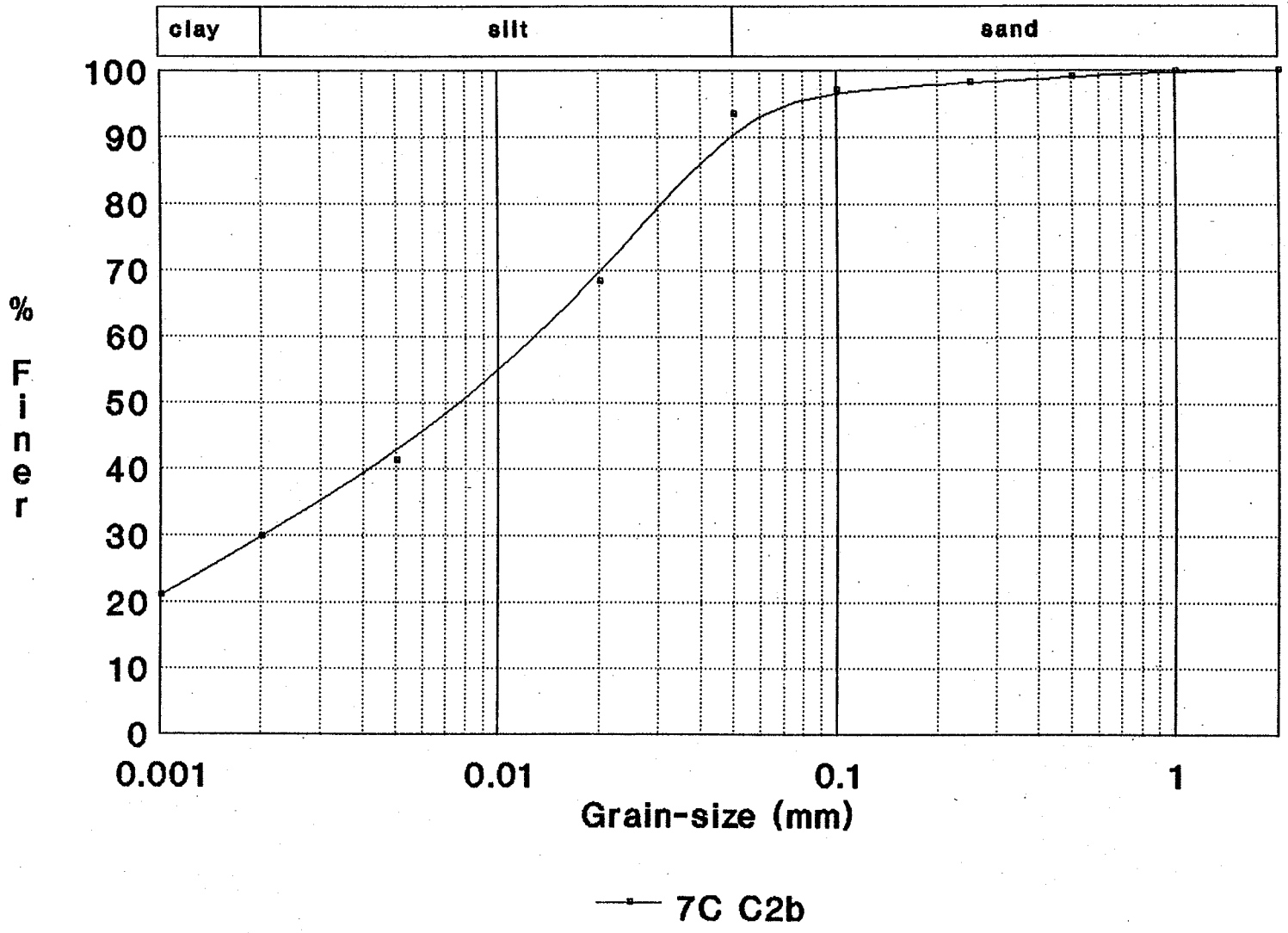

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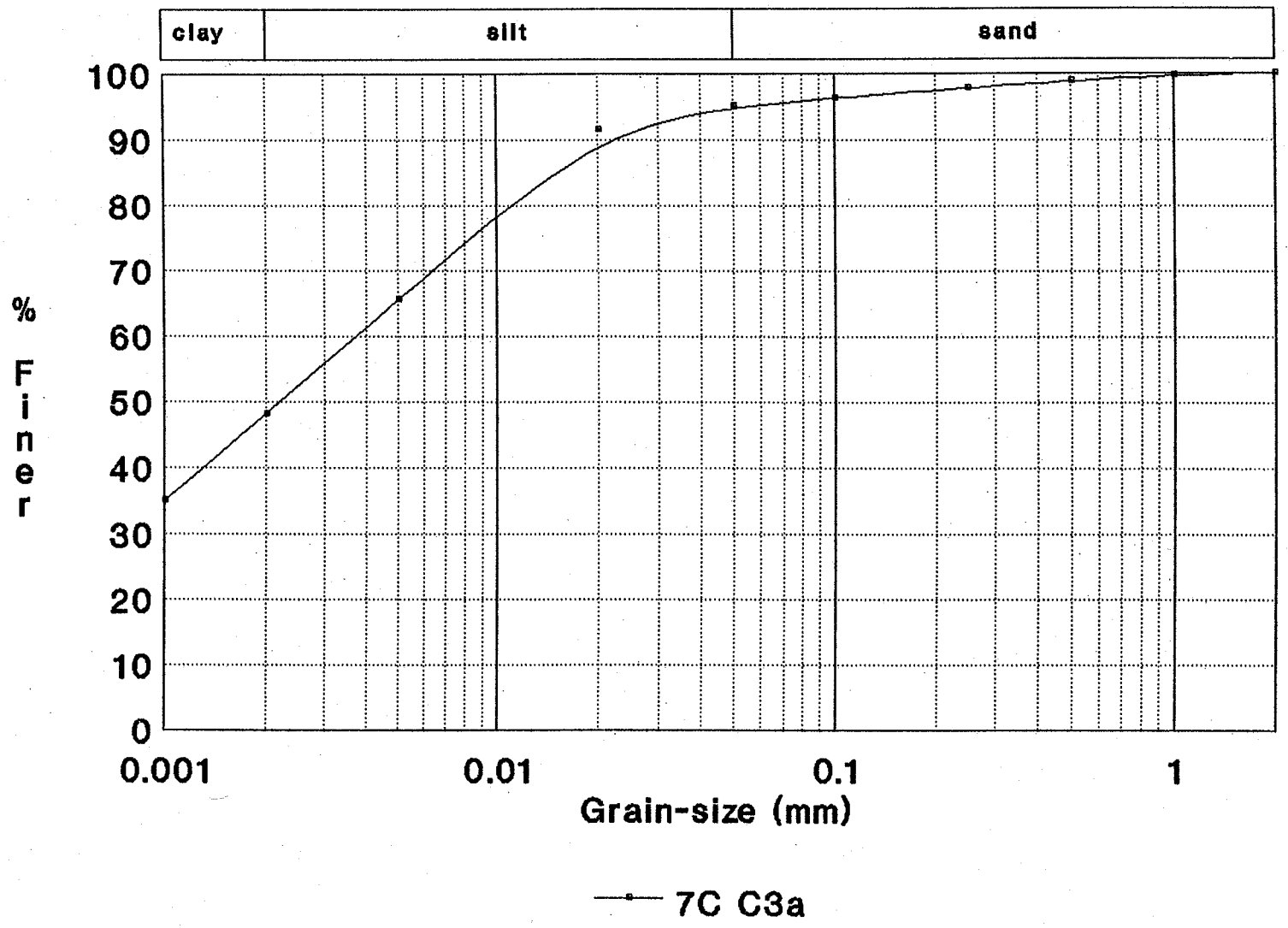

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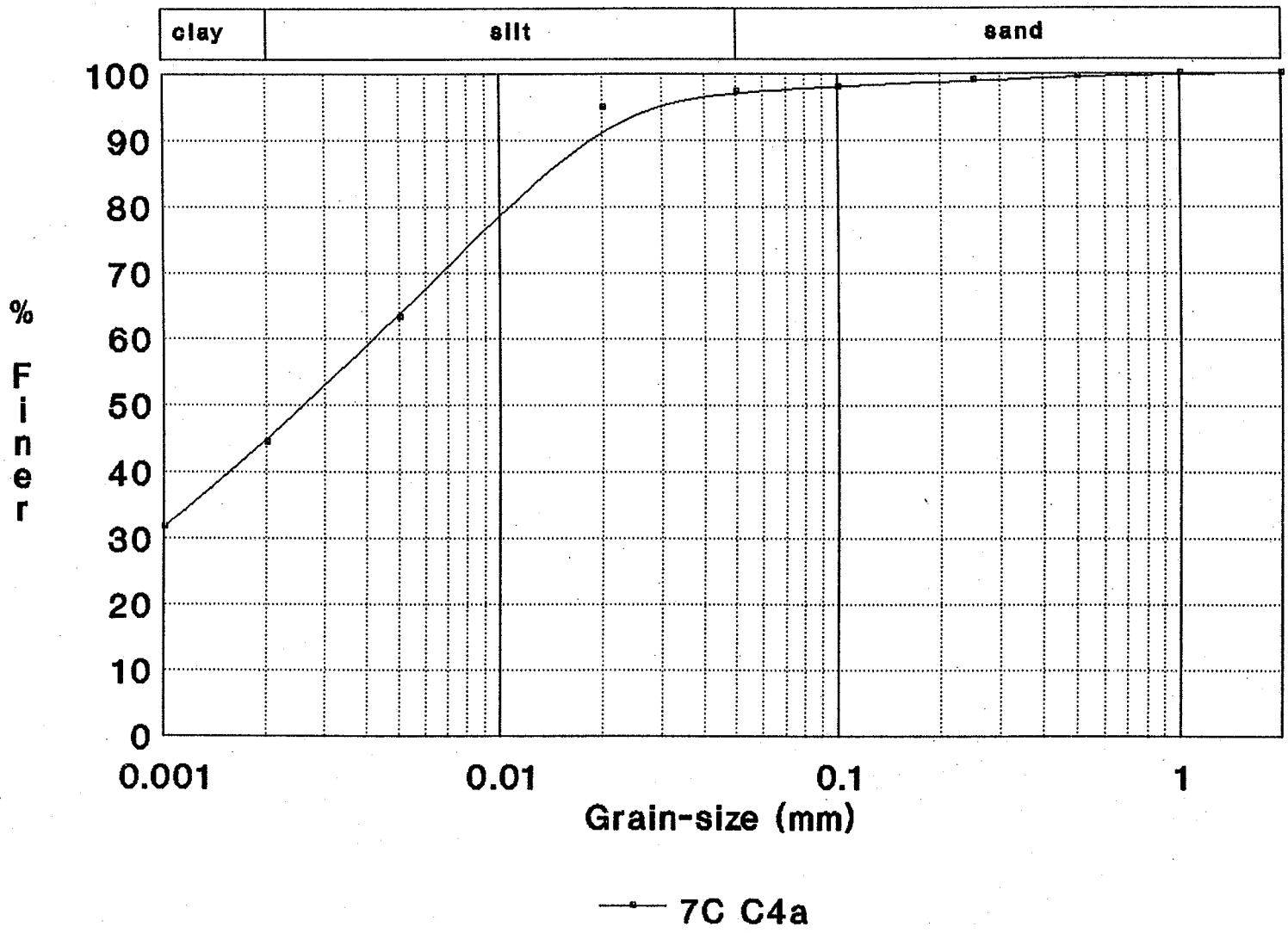

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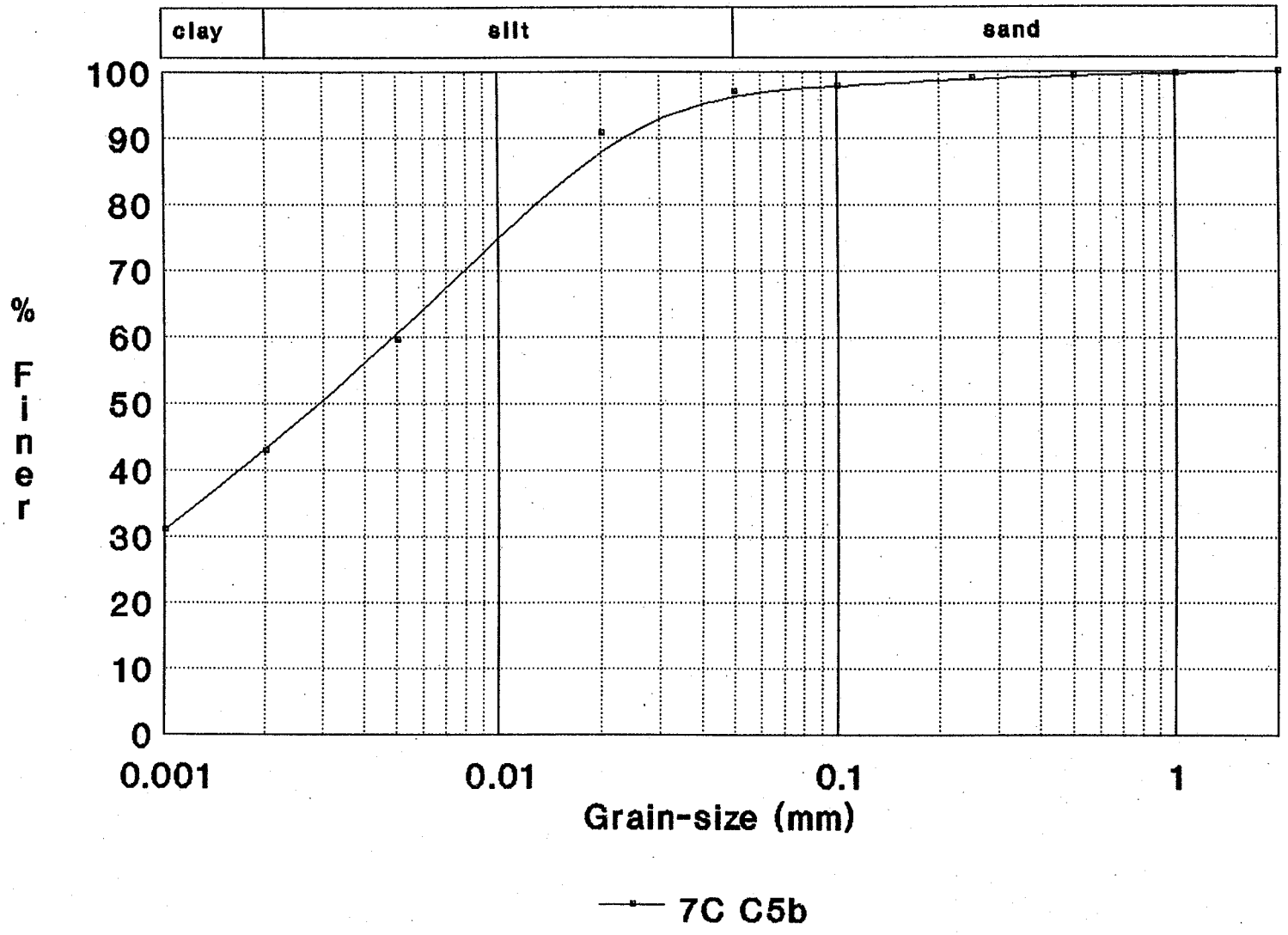

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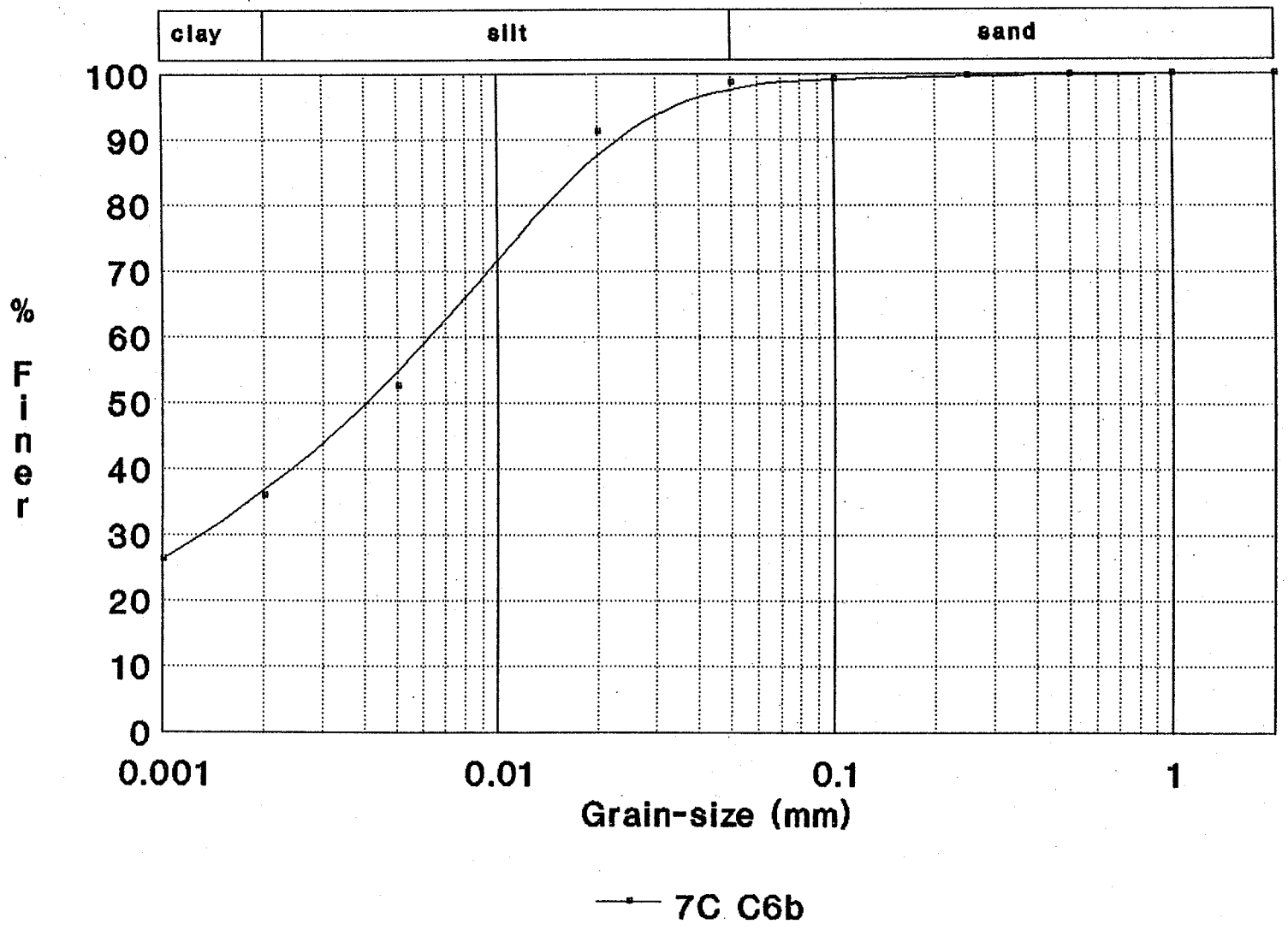

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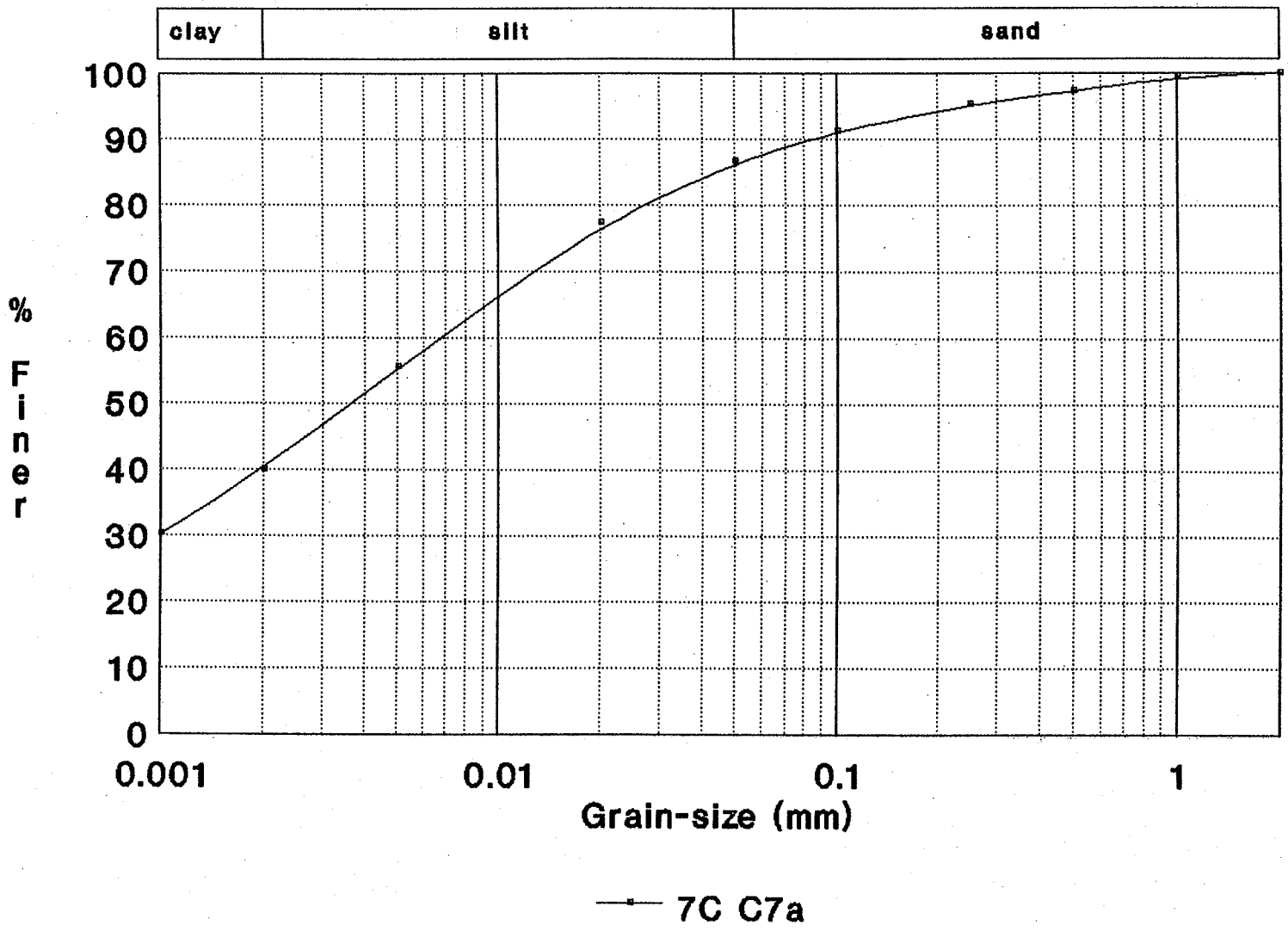

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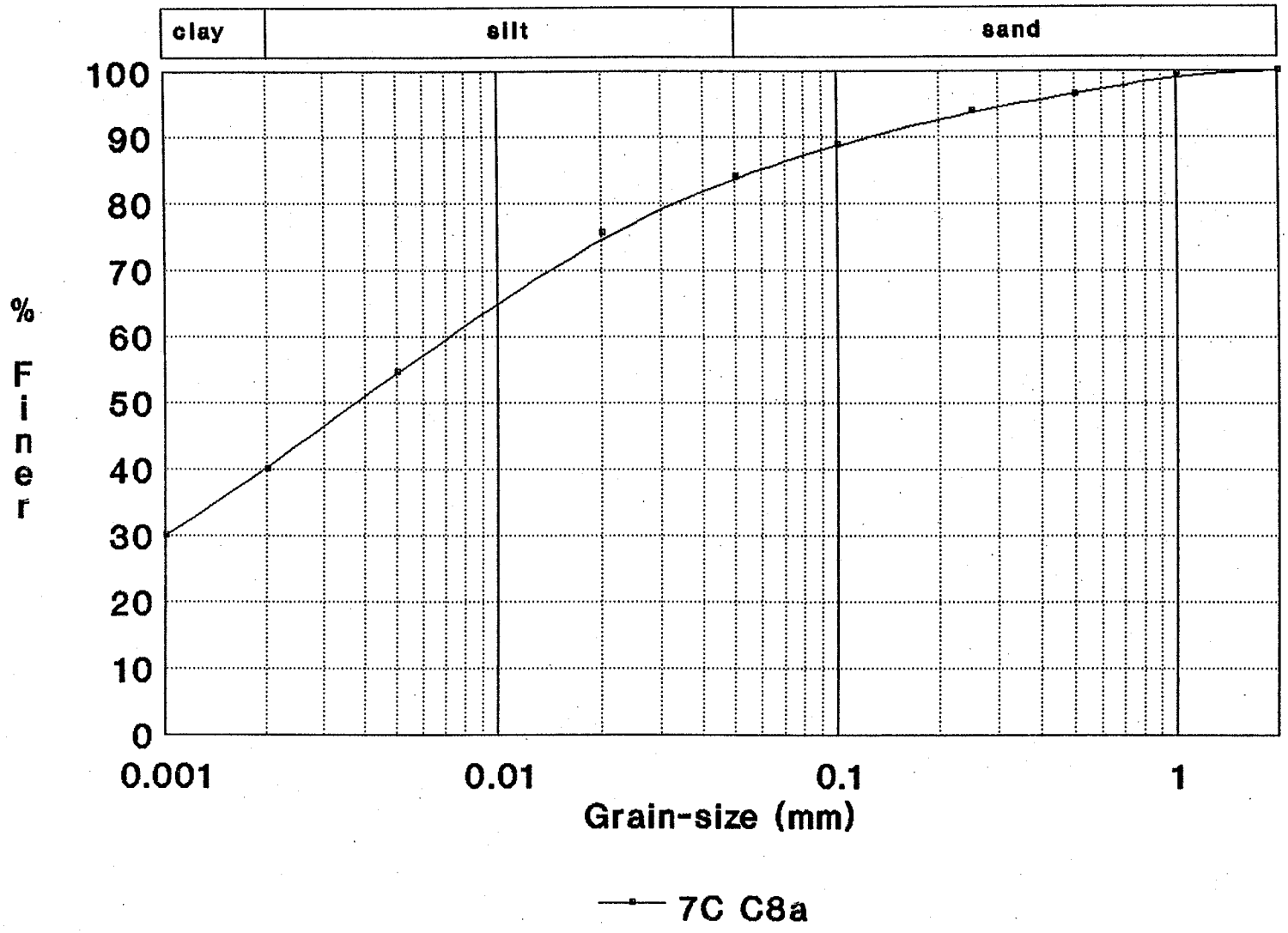

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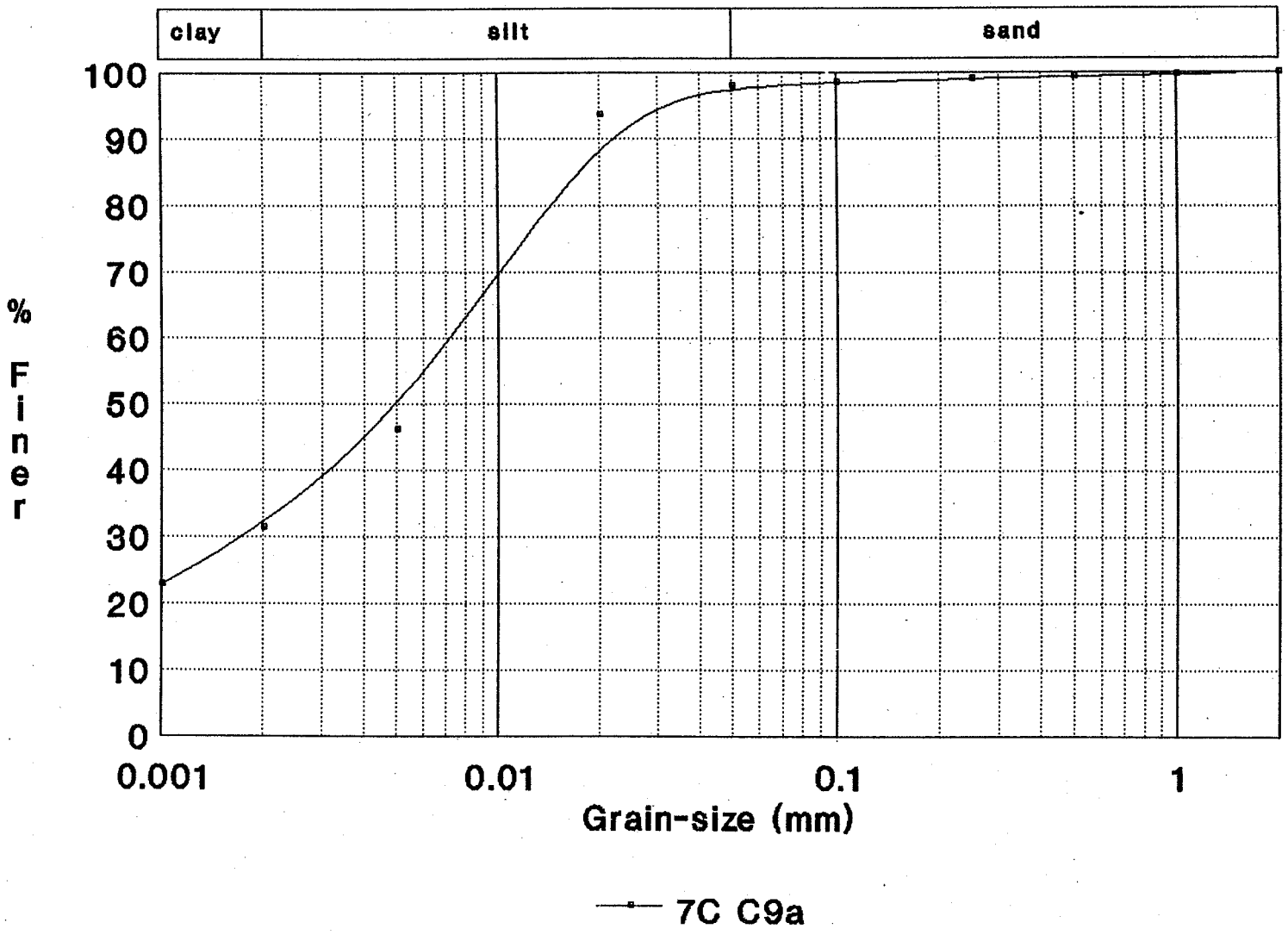

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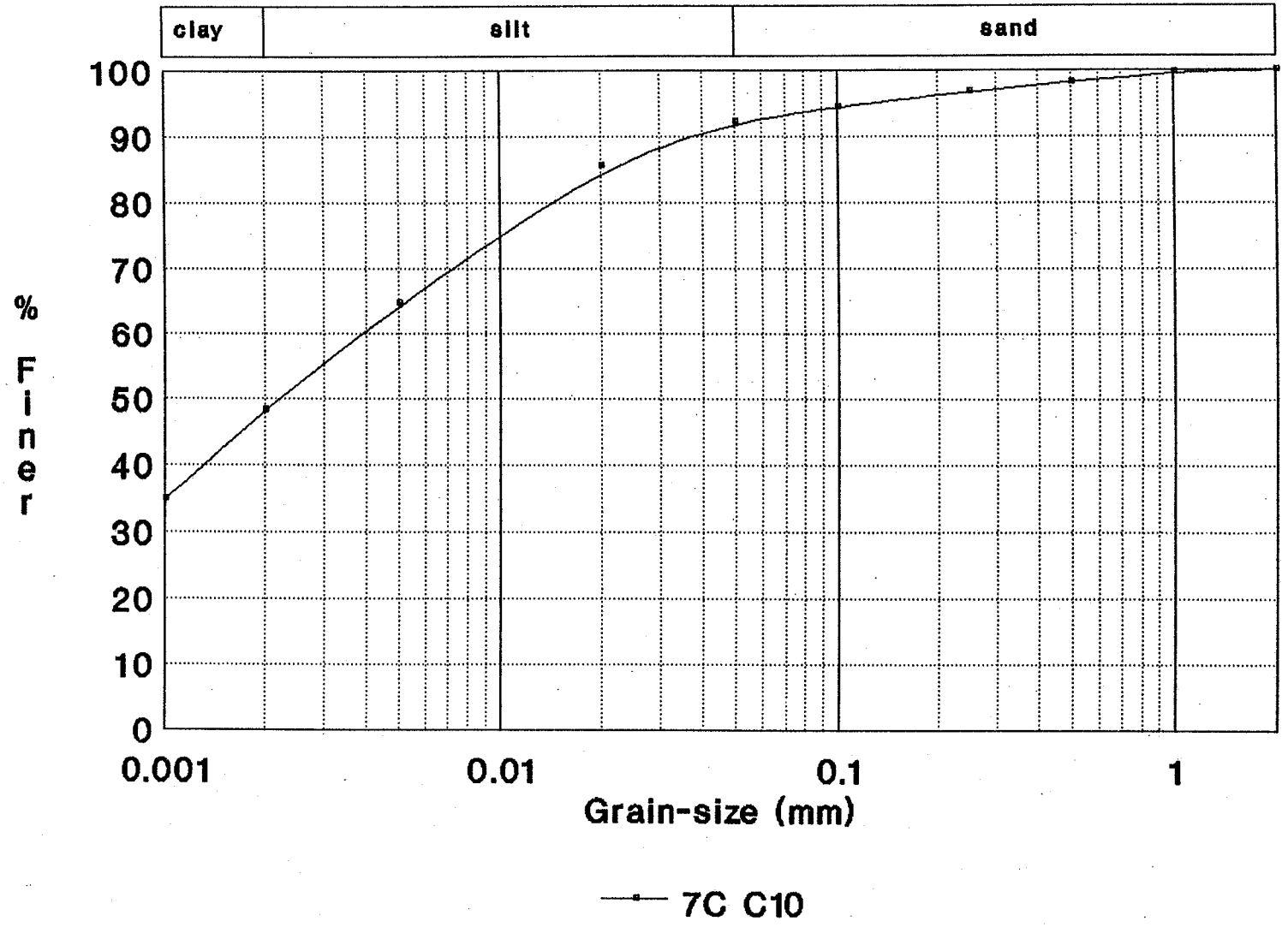

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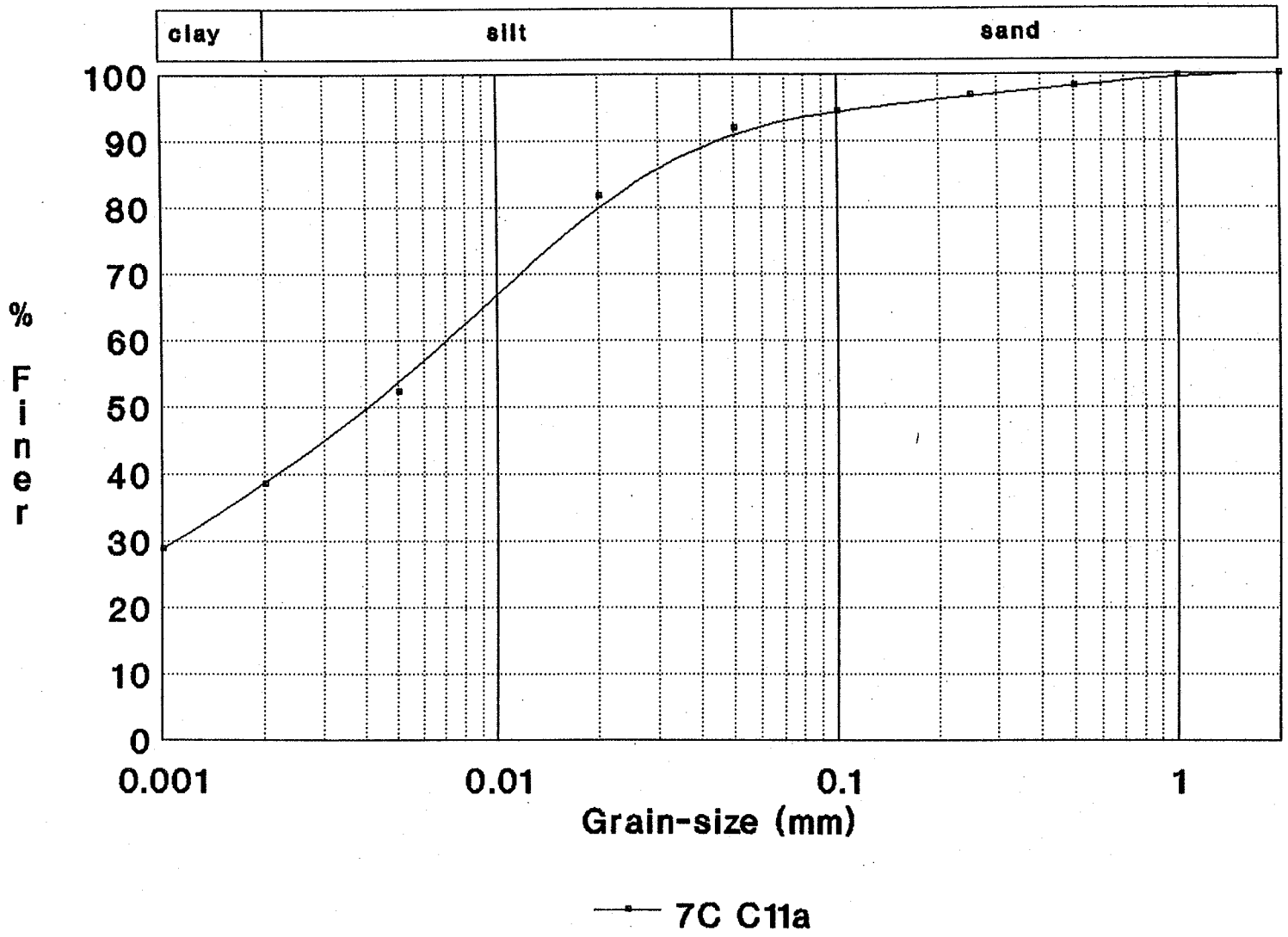

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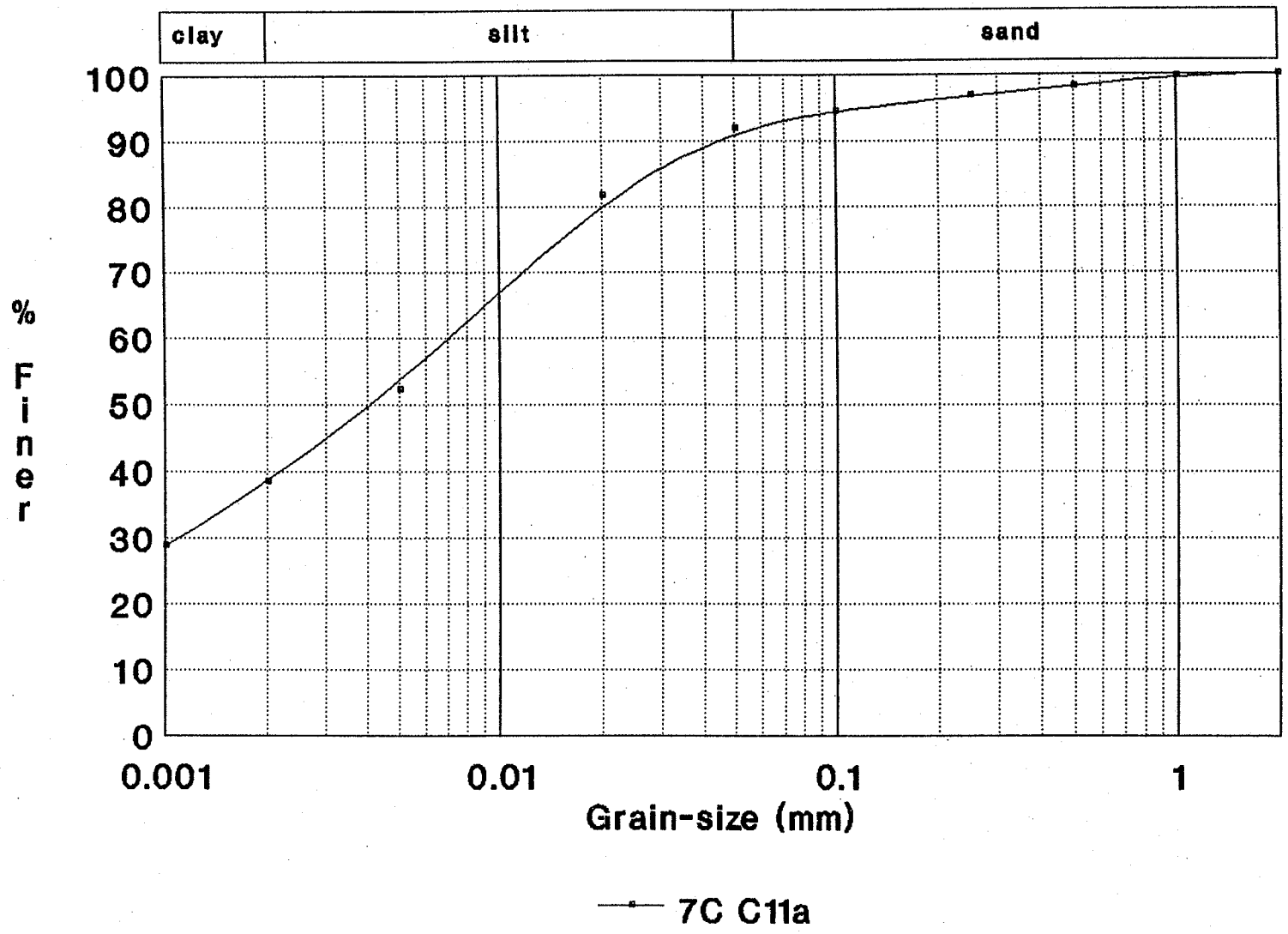

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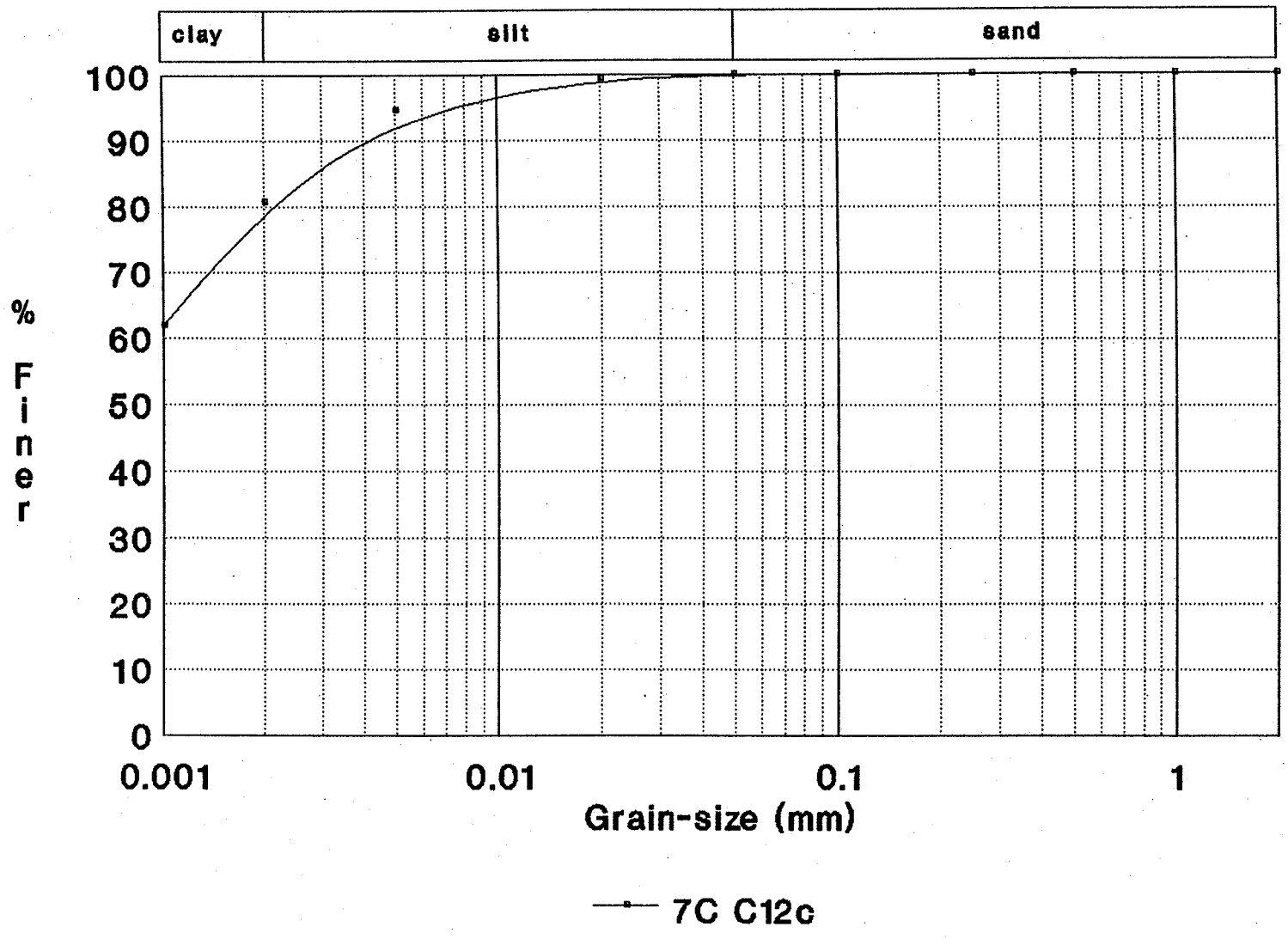

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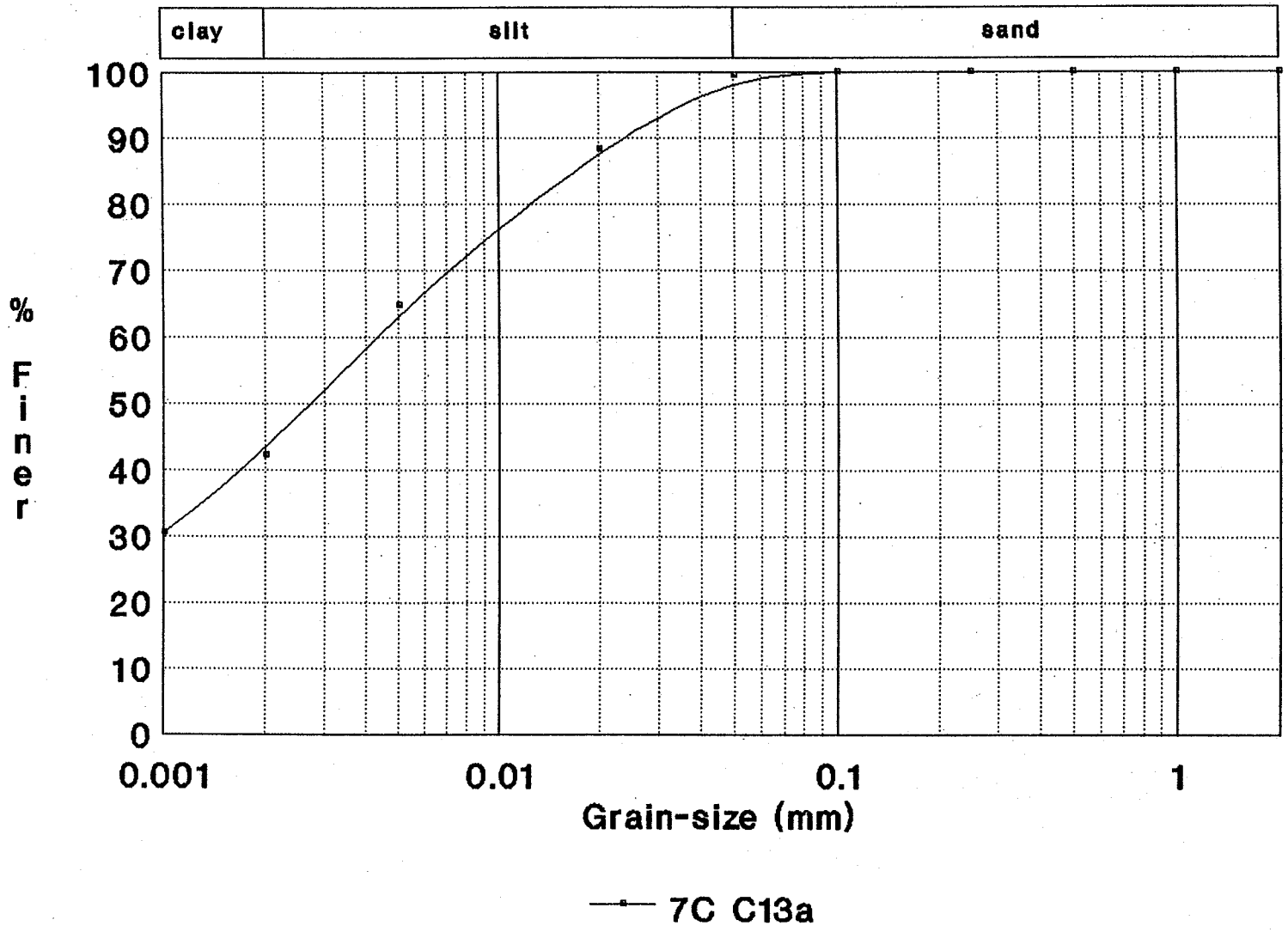

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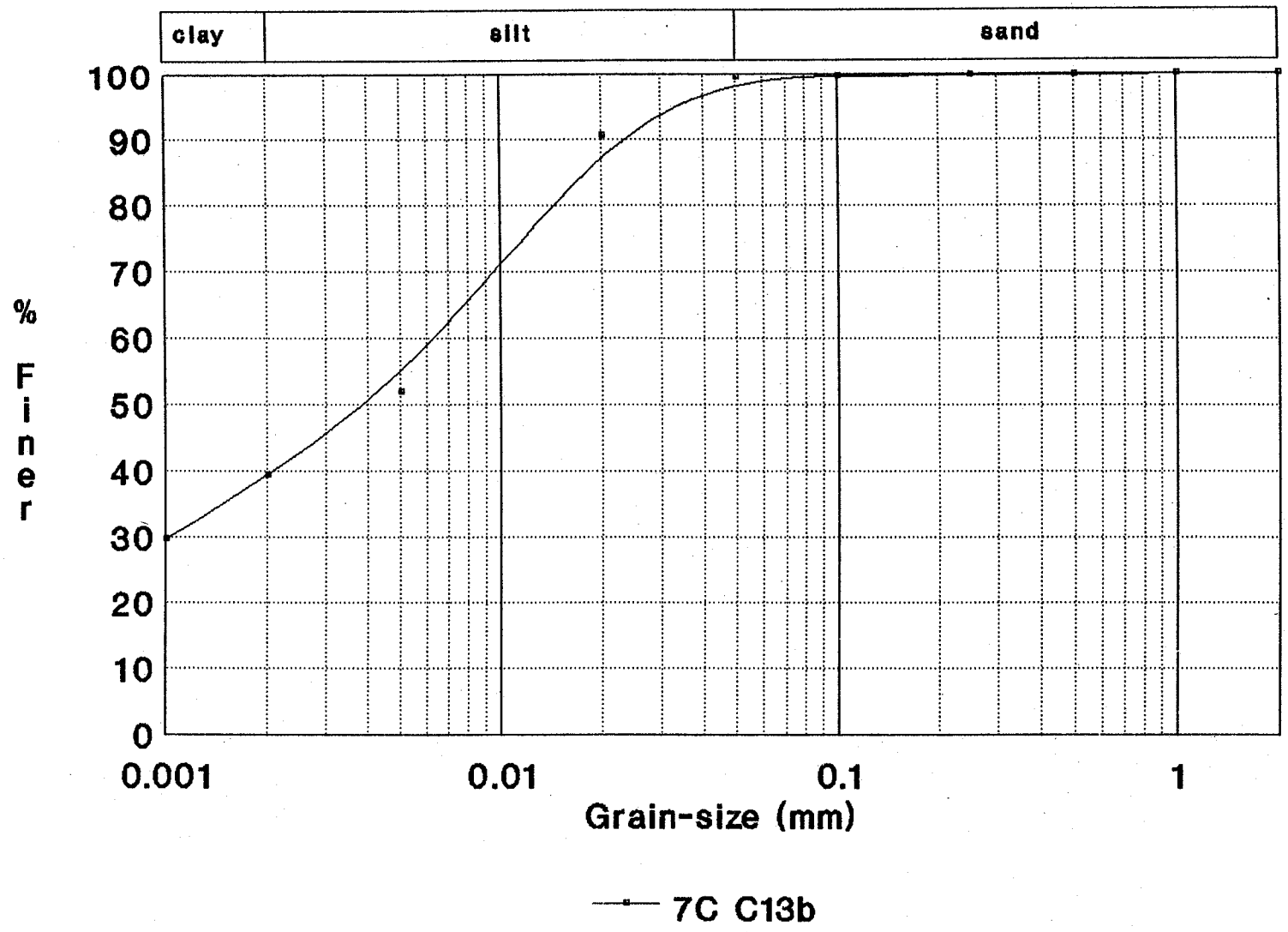

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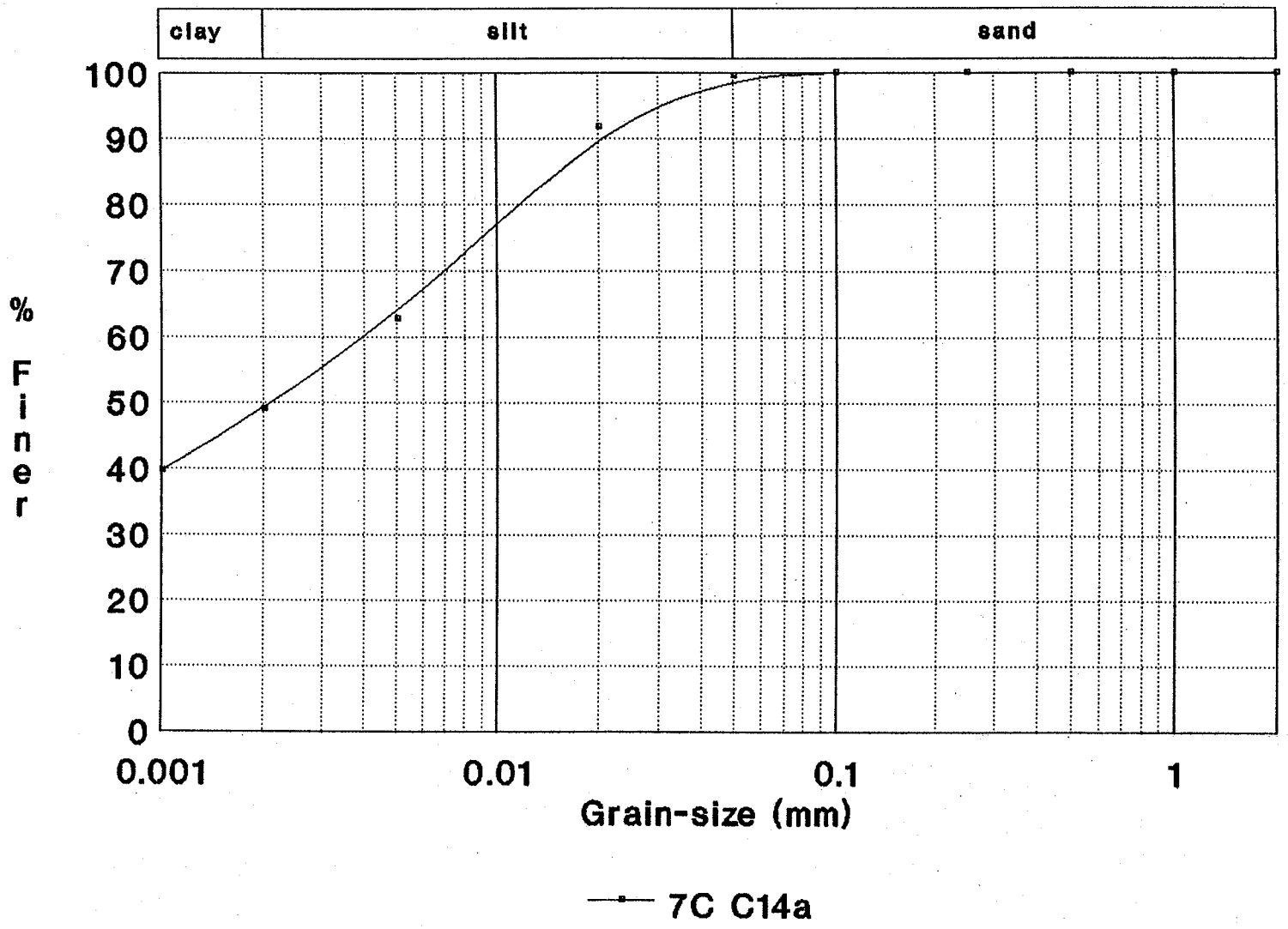

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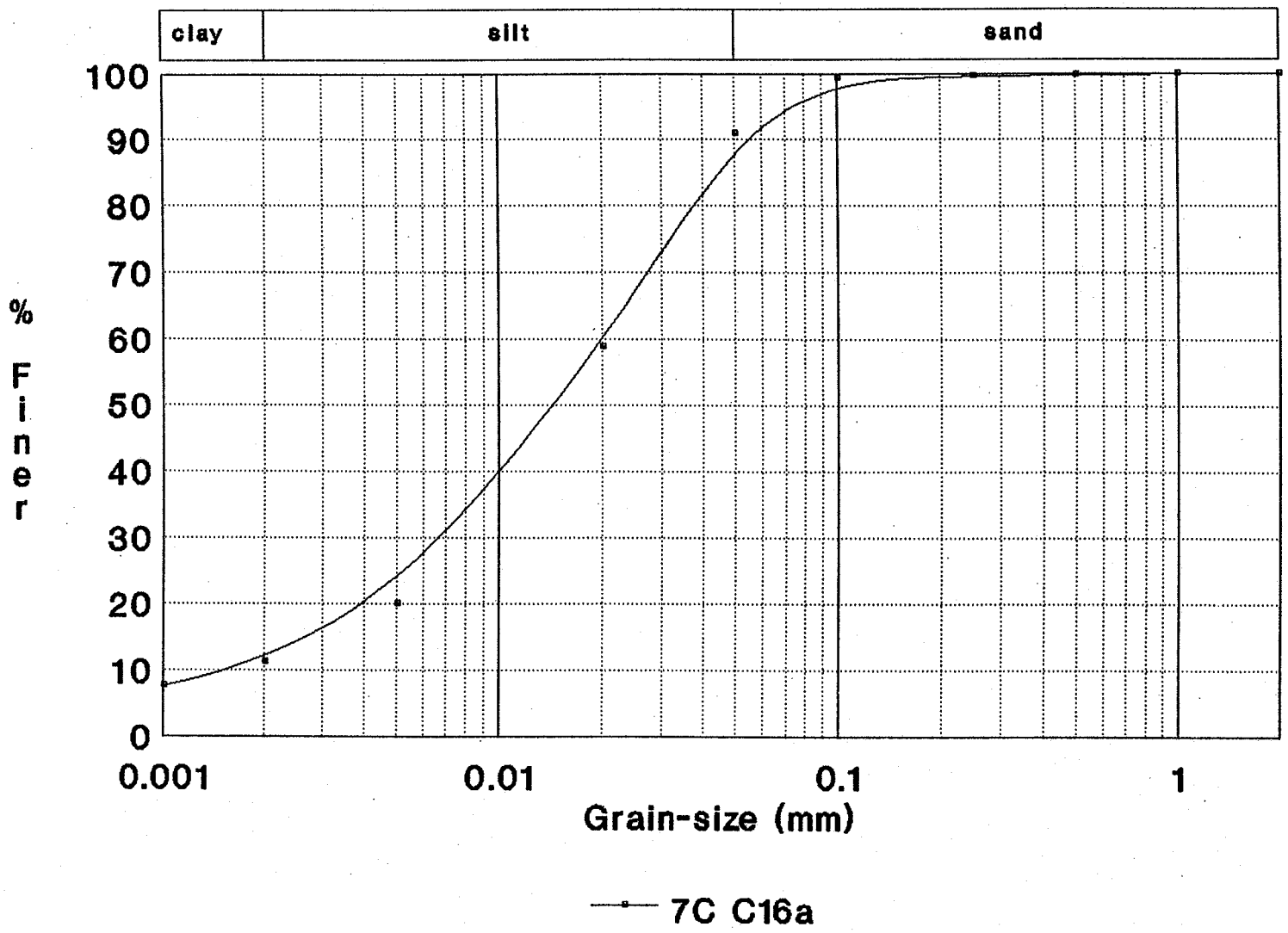

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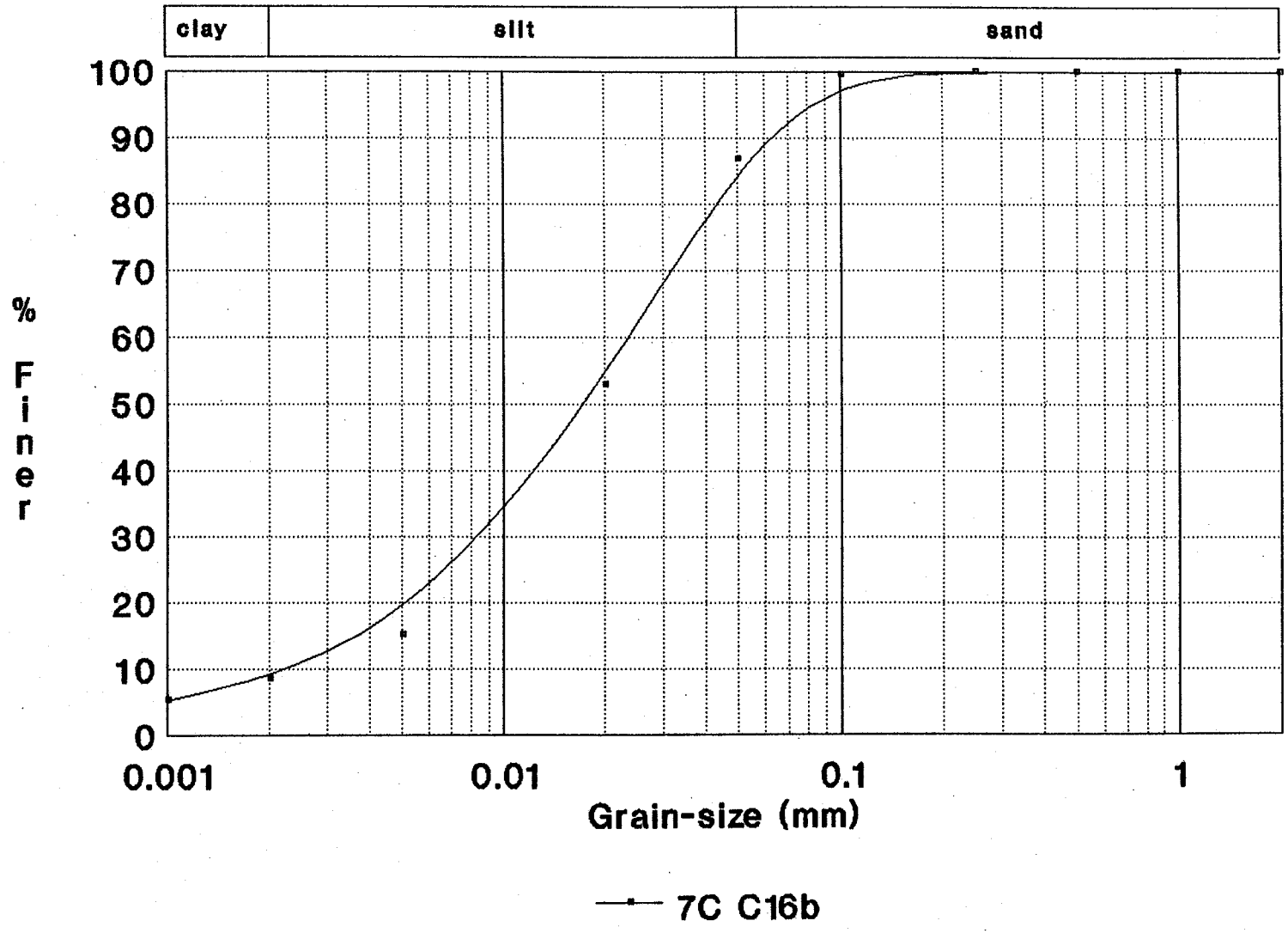

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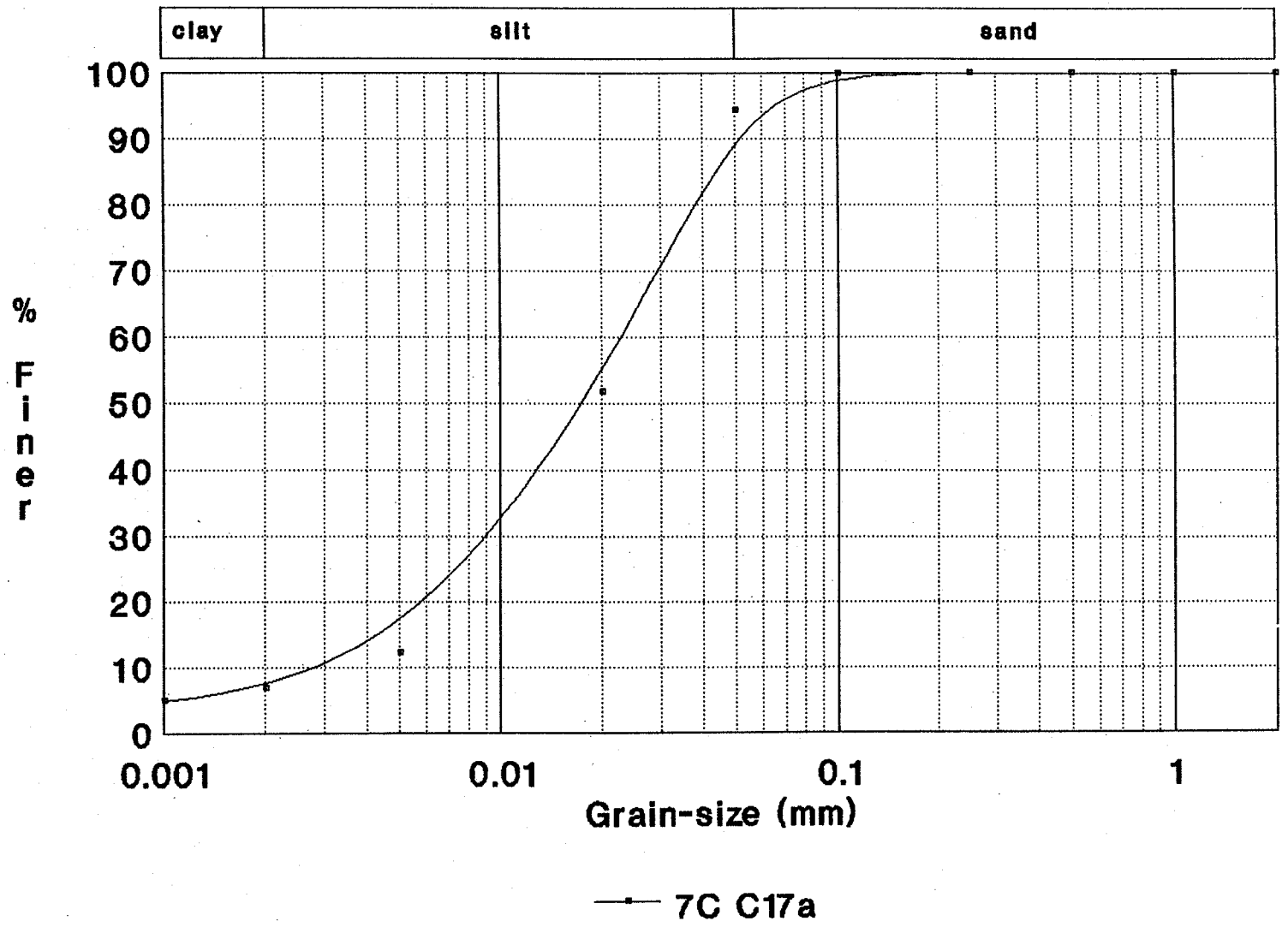

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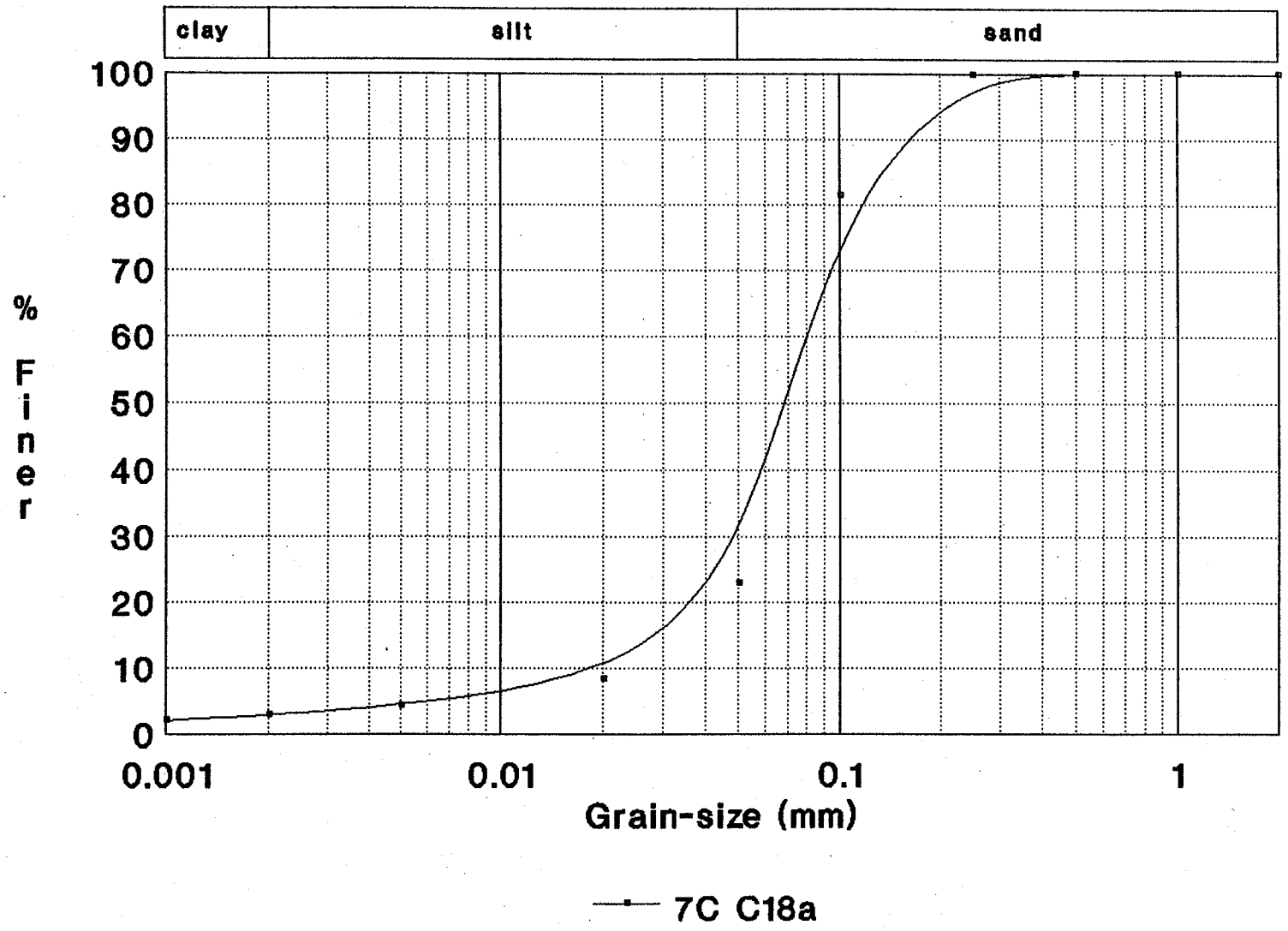

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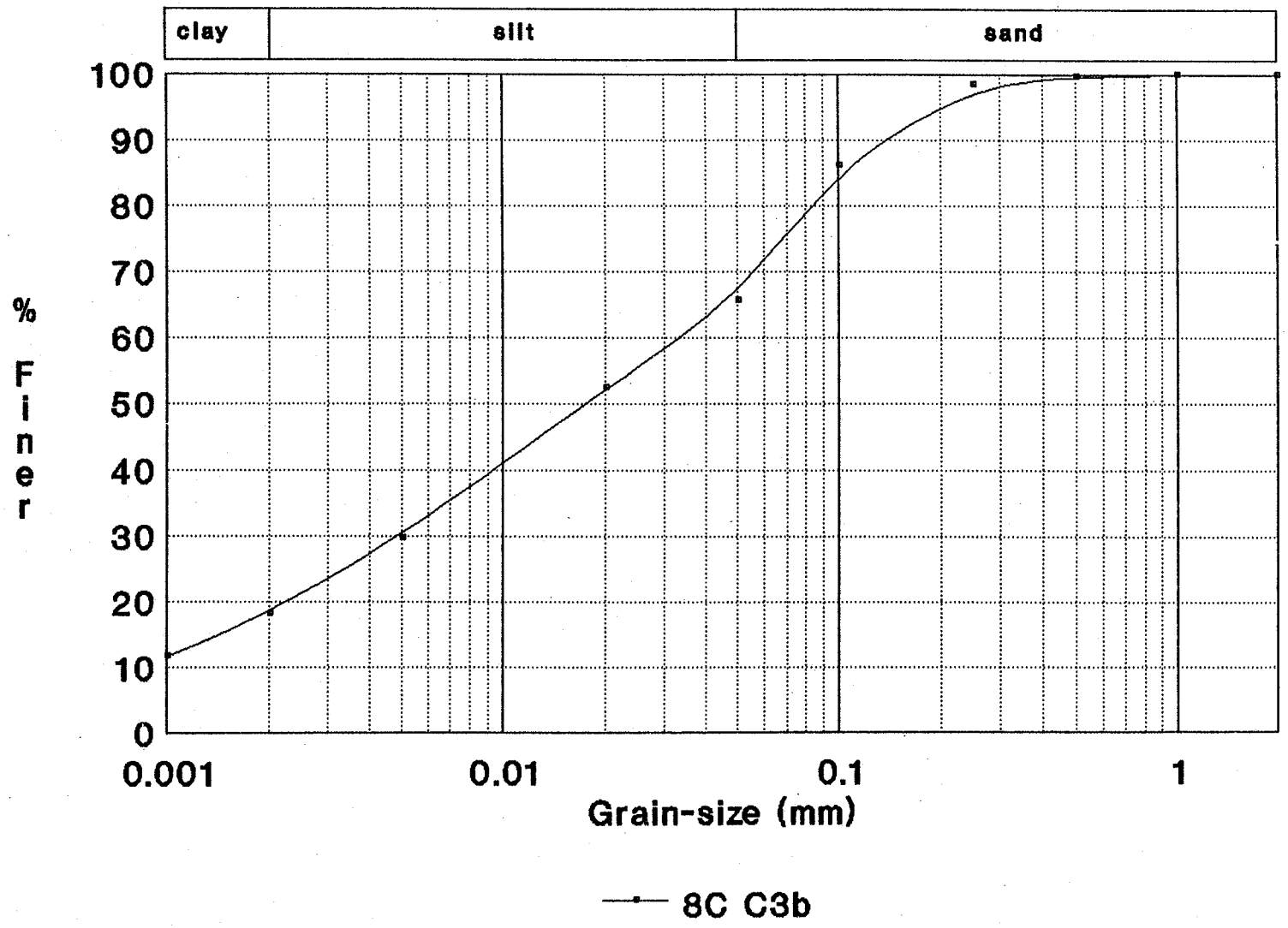

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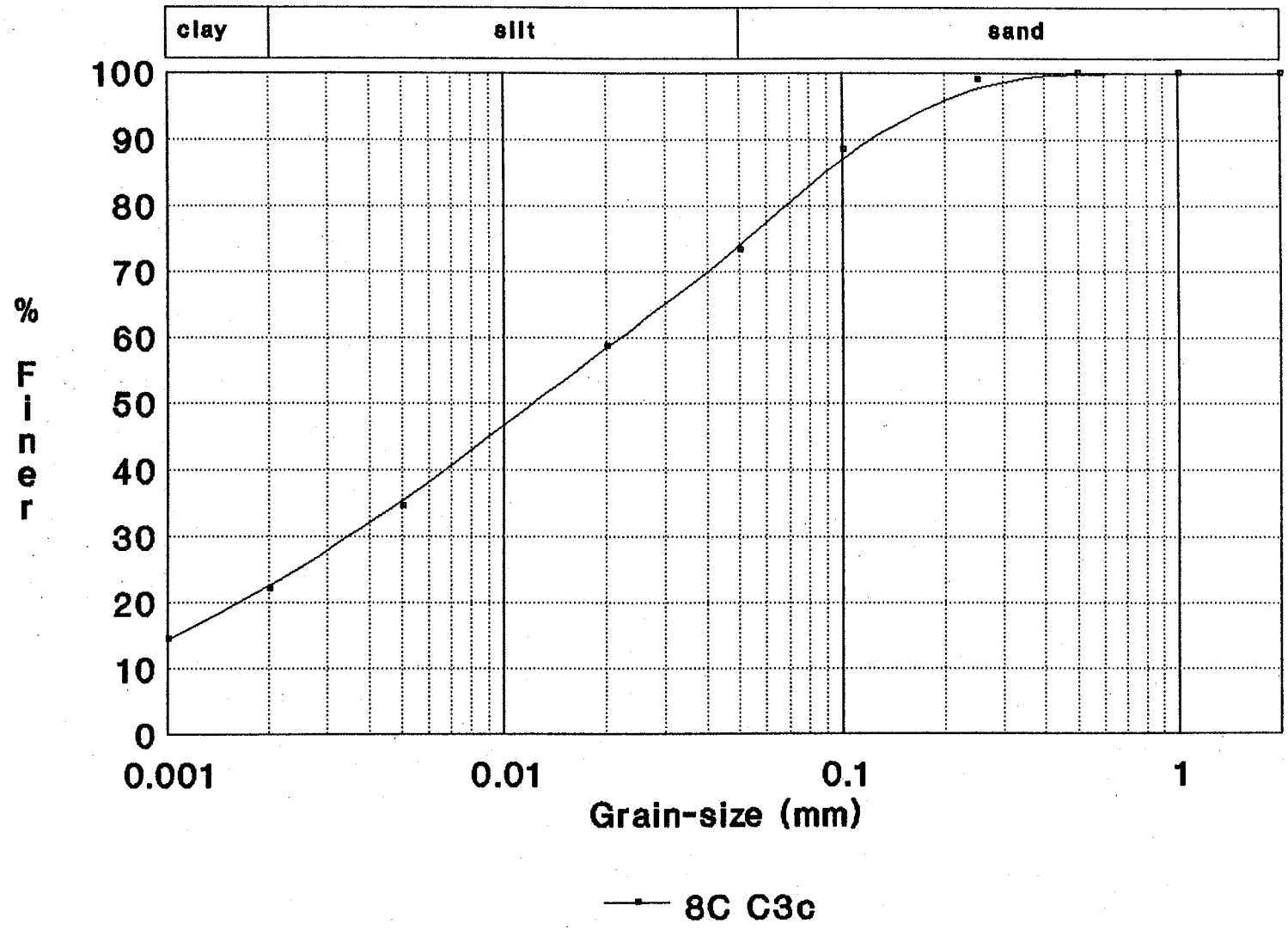

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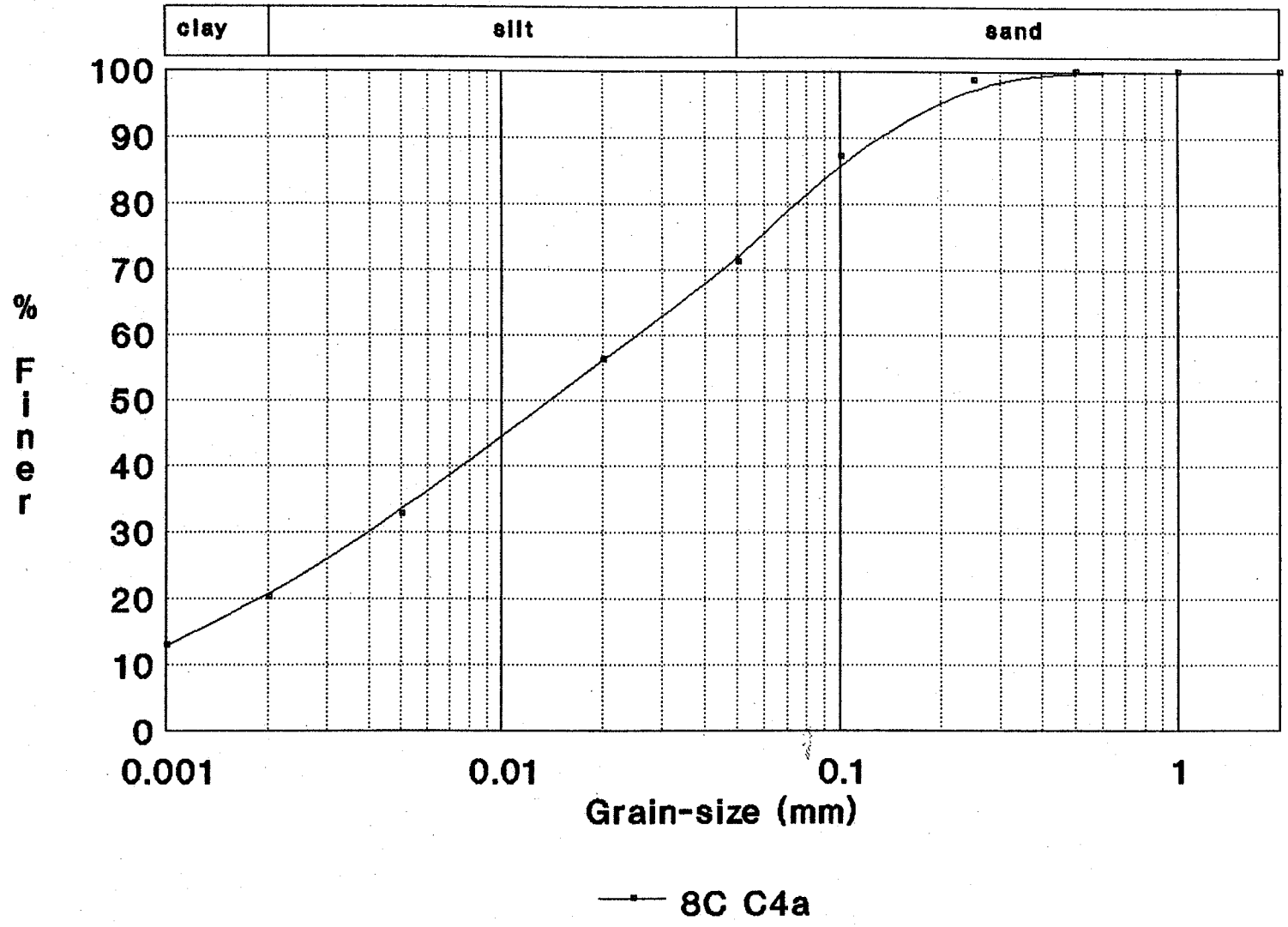

Grain-size Analysis