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COMPARISON OF RESULTS OBTAINED FROM THE FRENCH RUTTING TESTER WITH PAVEMENTS OF KNOWN FIELD PERFOMANCE

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16. Abstract

The French rutting tester has been used successfully in France to eliminate the occurrence of rutting. The Colorado Department of Transportation (CDOT) and the Turner-Fairbank Highway Research Center (TFHRC) were selected to demonstrate this equipment.

Thirty-three sites across Colorado with good and poor performance and a variety of temperature and traffic conditions were selected. Test results indicated that the French rutting tester, using the French specifications, was overly severe for many of the temperature and environmental conditions encountered in Colorado. However, by adjusting the testing temperature to match the highest temperature at a site location, the French rutting tester did an excellent job of predicting pavement performance. The results from the French rutting tester also had good correlation with actual rutting depths when temperature and traffic levels were considered.

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I. INTRODUCTION

In September 1990, a group of individuals representing AASHTO, FHWA, NAPA, SHRP, AI, and TRB participated in a two-week tour of six European countries. Information on this tour has been published in a "Report on the 1990 European Asphalt Study Tour" (1). Several areas for potential improvement of asphalt pavements were identified, including the use of performance-related testing equipment used in several European countries. Since the French equipment was commercially distributed and marketed, it was a natural choice for demonstration in the United States. The Colorado Department of Transportation (CDOT) and the FHWA Turner-Fairbank Highway Research Center (TFHRC) were selected to demonstrate this equipment.

The first priority was to verify the predictive capabilities of this equipment by performing tests on mixtures of known field performance. Since the French rutting tester arrived in February of 1992, rutting was the initial focus of the testing. Samples of hot mix asphalt pavements with a history of rutting and of good performance were identified and tested in the French rutting tester. The purpose of this report is to present the results of the correlation of the French rutting tester and pavements with known performance.

II. EQUIPMENT DESCRIPTION

A full description of the French hot mix asphalt (HMA) design methodology and equipment operation, as followed by the Laboratoire Central des Ponts et Chaussees (LCPC), is provided by Bonnot (2). A brief description of the testing device, operation and results is provided here.

Testing Equipment and Procedure. To evaluate resistance to permanent deformation, the French rutting tester (Photo 1, Appendix A) is used on a confined slab. The slab is 50 by 18 cm (19.7 by 7.1 in) and can be 20 to 100 mm (0.8 to 3.9 in) thick. A 100 mm thick slab weighs approximately 15 kg (33 lbs).

Two slabs can be tested simultaneously. The slabs are loaded with 5000 N (1124 lbs) by a pneumatic tire inflated to 0.6 MPa (87 psi). The tire loads the sample at 1 cycle per second; one cycle is two passes. The loading time on any given point on the slab is approximately 0.1 second. The chamber is typically heated to 60^{o}C (140^{o}F) but can be set to any temperature between 35^{o} and 60^{o}C (95^{o} and 140^{o}F).

When a test is performed on a laboratory compacted slab, it is aged at room temperature for as long as seven days. It then is placed in the French rutting tester and loaded with 1000 cycles at room temperature. The deformations recorded after the initial loading are the "zero" readings. The sample is then heated to the test temperature for 12 hours before the test begins. Rutting depths are measured after 100, 300, 1,000, 3,000, 10,000, 30,000 and possibly 100,000 cycles (Photo 1, Appendix A). The rutting depth is reported as a percentage of the slab thickness. After a given number of cycles, the percentage is calculated as the average of 15 measurements (five locations along the length and three along the width) divided by the original slab thickness. A pair of slabs can be tested in about nine hours.

Test Results. A successful test typically will have a rutting depth that is less than or equal to 10% of the slab thickness after 30,000 cycles. The shape of the percent rutting depth versus cycles curve and the sensitivity of the curve to void content also should be considered.

The results are plotted on log-log graph paper. The slope and intercept (at 1000 cycles) are calculated using linear regression. The equation is:

$$Y = A \left[\frac{X}{1000} \right]^{B} \qquad \text{(Equation 1)}$$

where:

- Y = rutting depth in percent,
- X = cycles,
- A = intercept of rutting depth at 1000 cycles, and
- B = slope of curve.

French Specifications. The French specifications for hot mix asphalt samples tested in the rutting tester (3) are shown in Table 1. The test always is performed at 60°C. The thickness of the slab tested is controlled by the thickness of the overlay. If the overlay thickness is greater than 5 cm (2.0 in.), the 10 cm (3.9 in.) slab should be tested. If the overlay thickness is less than or equal to 5 cm, the 5 cm slab should be tested. In some instances the design engineer may set more stringent criteria. For example, if there is very heavy traffic loads and a grade of 3% to 4%, the rutting depth should be less than 5%.

Stress Conditions. The French rutting tester applies a 5000 N (1124 lb) force onto a pneumatic tire inflated to 0.6 MPa (87 psi). CHEVPC is a pavement analysis program adopted for personal computers from CHEVNL, a program originally developed by the Chevron Research Company to run on mainframe computers. As calculated by CHEVPC, throughout the thickness of the slab the average compressive stress in a 100 mm thick slab below the tire is 0.41 MPa (60 psi), and in a 50 mm thick slab is 0.55 MPa (80 psi). The French rutting tester can apply average compressive stresses ranging from 0.28 to 0.62 MPa (40 to 90 psi) to a slab.

Table 1. Specifications for the French Rutting Tester

Pavement Thickness	Pavement Type	Number of Cycles	Maximum % Rutting
	Subbase Base	10,000	≤ 10
6-8 cm (2.4-3.1 in.)	Base Course Wearing Course	30,000	≤ 10
3-4 cm (1.2-1.6 in.)	Wearing Course	1,000 3,000	≤ 10 ≤ 20
8-10 cm (3.1-3.9 in.)	Base Course (High modulus for rut resistance)	30,000	≤ 8

III. STUDY APPROACH

Three possible approaches were considered for comparing the French rutting tester results to pavements of known field performance. The first option involved developing mixes that pass the testing specification and then placing the mix on a project. The project would be monitored over time. This option will be performed, but results may not be available for 5 years.

The second and third options involved testing mixes that were placed in the past, whose history already has been determined. The second option involved obtaining field cores and slabs and testing the original materials from the pavements of known performance. The flaws in this option include: the asphalt has aged, air voids have changed with time, etc.

The third option involved obtaining the original raw materials from projects of known performance. The original material would be blended in the laboratory and tested. The test results would be compared to the field performance. The flaws in this approach are readily identified; the aggregates and asphalts will not be the same as those used when the project was constructed. For example: the crushing operations at the aggregate sources change; the location and material used at the aggregate sources change over time; some of the aggregate sources have been reclaimed; the asphalts (even though from the same refinery) may be from a different crude source; and construction will be difficult to take into consideration (4) (the mixing efficiency of the plant, the introduction of baghouse fines, the wasting of fines from a wet scrubber, construction variability of gradation and asphalt content, etc.)

The first option will be performed and will be the primary method for validating the French rutting tester. Since results from this option would not be available for approximately 5 years, the second option was selected to provide initial field performance validation.

IV. SITE SELECTION

Sites were selected based upon performance, temperature, and traffic. The SHRP classifications were used to categorize temperature and traffic.

Temperature. SHRP has developed recommendations for four levels of high temperature environment, three of which exist in Colorado. The high temperature environment is defined as the highest monthly mean maximum temperature (HMMMT), i.e. the average of the daily high temperatures in the hottest month of the year. The temperatures used in this report were determined from data recorded at approximately 240 weather stations in Colorado and reported by the National Oceanic and Atmospheric Administration's National Climatic Data Center.

Traffic. SHRP has developed recommendations for seven traffic levels, six of which exist in Colorado. The levels are defined according to the number of equivalent 18-kip single axle loads (ESAL's) during the design life of the pavement. The traffic levels used in this report were determined from the network level pavement management reports. The equivalent daily 18-kip load applications (EDLAs) were reported.

It is desirable to know the total traffic that has traveled on each highway. The Average Daily Traffic (ADT) was not considered appropriate because rutting is related more to the load applied to the pavement rather than the number of vehicles. EDLA was selected over total ESALs. Considering observations of rutting in Colorado and the administrative decision process, EDLA is believed to be a more appropriate unit of measure than ESALs for designing against rutting.

In Colorado's experience a pavement will appear to be performing acceptably and in a very short period (usually 1 month in a hot summer) the rutting becomes very dramatic. This rutting generally occurs when the pavement is 3 to 5 years old; however, in some instances rutting does occur before and after that time range. After the rut develops, the depth does not increase much with additional traffic and time. Rutting depth does not increase linearly with cumulative ESALs.

Determining the traffic loading at the time the rut depth increases dramatically is a most desirable value, but the information is not available. Since traffic loading after the rut develops is not important because the rut depth does not increase significantly, the total cumulative ESALs is not appropriate. EDLA was selected to provide a relative comparison of traffic loading for each level of highway analyzed.

A second reason EDLA is more appropriate than cumulative ESALs is that the structural design is not tied to material design. In the design of asphalt pavements, there are engineering designs and administrative decisions based on budget limitations. When the cost of the engineering design exceeds the budget for the project, administrative decisions often are made to shorten the design life. Situations developed where interstate pavements have been designed for 2.2 years. In terms of rutting this could be disastrous, resulting in a 50-blow Marshall effort. The structural design of an asphalt pavement should be tied to the material design. Unfortunately, when the structural design is changed in an administratively acceptable manner (often unacceptable from an engineering perspective) the use of total ESALs also will affect the material properties. By using EDLA, administrative decisions that influence the structural design can be separated from engineering decisions of the required mix properties.

Based upon the rutting observations in Colorado and the nature of the unexpected implementation of administrative decisions, EDLA is considered appropriate for use in designing the rutting resistance of a mix.

<u>Performance.</u> Rutting depths, in inches, were reported by the network level pavement management report. Several sites with high levels of rutting and several sites with no rutting were identified for evaluation in this study. Each combination of traffic and temperature classifications was included.

Based on experience in Colorado, pavements typically rut in the first 3 to 5 years. There is a high probability that pavements that do not rut in the first 3 to 5 years will not rut throughout their service life. Good pavements selected for this study were over 6 years old.

Each site was visited to determine actual rutting depth and the cause of rutting. Only sites that exhibited rutting from plastic flow were used. Sites rutting because of subgrade failure or improper compaction were eliminated. Additionally, sites at intersections or with climbing lanes for trucks on steep grades were eliminated. It was attempted to accept sites that rutted from plastic flow in areas of normal highway speeds, 73 to 105 km/hr (45 to 65 mph).

<u>Final Site Selection.</u> At least one rutting and one non-rutting site from each traffic level and temperature environment in Colorado was selected and are shown on Table 2. Additional sites were selected which corresponded to a majority of Colorado's Interstate conditions. A total of 33 sites were evaluated and are listed on Table 3. The vicinity of each test site is shown on Figure 1.

Table 2. Summary of Site Conditions by Site Number

	Highest Monthly Mean Maximum Temperature		
EDLA	< 80°	80° to 90°F	90° to 100°F
< 27		19,20	25,26
27- 82	33	27,28	23,24
82- 274	31,32	5,6	21
274- 822	17,18	7,8	15,34,35
822-2740	36,37	3,4,11,12,13,14	9,10
2740-8220		29,30	

Table 3. Sites for French Rutting Tester

Site	Hwy	M.P.		Location	Rut Depth	HMMM Temp.	Traffic EDLA
3	US-85	251	(SB)	Platteville	0.0"	88	941
4	US-85	248.3	(SB)	Platteville	1.0"	88	864
5	SH-66	40	(EB)	Longmont	0.0"	88	250
6	SH-119	50	(EB)	Niwot	0.4"	88	221
7	SH-52	12	(WB)	Dacona	0.1"	88	358
8	SH-52	19	(WB)	Fort Lupton	0.7"	88	310
9	US-287	430.3	(EB)	Lamar	0.1"	96	878
10	US-287	430.5	(EB)	Lamar	1.0"	96	878
11	I-25	41	(SB)	Walsenburg	0.0"	85	1027
12	I-25	35	(SB)	Walsenburg	0.8"	85	1027
13	I-70	430	(EB)	Burlington	0.1"	89	1377
14	I-70	445	(EB)	Burlington	0.8"	89	1336
15	US-50	375	(WB)	LaJunta	0.1"	94	551
17	US-160	271	(EB)	LaVeta Pass	0.5"	75	493
18	US-160	278	(WB)	LaVeta Pass	0.1"	75	465
19	US-389	10.3	(NB)	Branson	0.0"	84	3
20	US-389	10.5	(SB)	Branson	0.4"	84	3
21	US-50	454	(WB)	Granada	0.0"	94	270
23	US-160	490	(WB)	Walsh	0.1"	91	48
24	US-160	486	(WB)	Walsh	0.4"	91	48
25	SH-55	2	(NB)	Crook	0.1"	91	20
26	SH-55	0.3	(SB)	Crook	0.5"	91	20
27	SH-71	219	(NB)	Stoneham	0.0"	87	56
28	SH-71	214.4	(NB)	Stoneham	0.7"	87	56
29	I-25	237	(SB)	Denver	0.3"	87	3127
30	I-25	242.5	(NB)	Denver	0.6"	87	3127
31	US-40	225	(EB)	Fraser	0.4"	75	169
32	US-40	216	(WB)	Granby	0.1"	75	171
33	US-34	2.3	(WB)	Granby	0.5"	75	53
34	I-70	14.9	(WB)	Fruita	1.0"	93	780
35	US-50	75	(NB)	Delta	0.5"	93	399
36	I-70	214	(EB)	Eisenhower	0.8"	72	1137
37	I-70	207	(EB)	Silverthorne	0.1"	72	1137

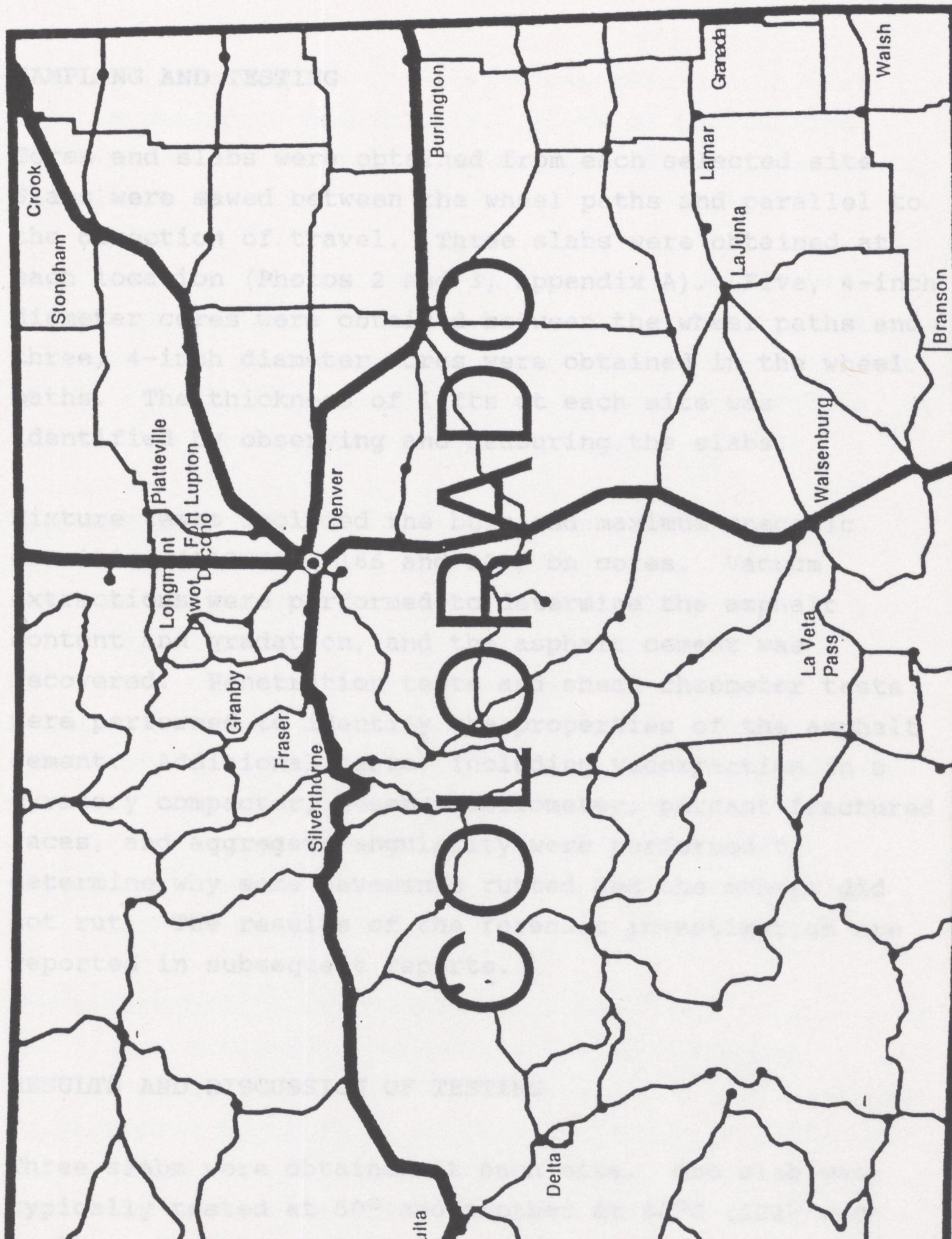

Figure 1 Test Site Locations Listed by City's Name

V. SAMPLING AND TESTING

Cores and slabs were obtained from each selected site. Slabs were sawed between the wheel paths and parallel to the direction of travel. Three slabs were obtained at each location (Photos 2 and 3, Appendix A). Five, 4-inch diameter cores were obtained between the wheel paths and three, 4-inch diameter cores were obtained in the wheel paths. The thickness of lifts at each site was identified by observing and measuring the slabs.

Mixture tests included the bulk and maximum specific gravities (AASHTO T 166 and 209) on cores. Vacuum extractions were performed to determine the asphalt content and gradation, and the asphalt cement was recovered. Penetration tests and shear rheometer tests were performed to identify the properties of the asphalt cement. Additional tests, including recompaction in a gyratory compactor, Hveem stabilometer, percent fractured faces, and aggregate angularity were performed to determine why some pavements rutted and the others did not rut. The results of the forensic investigation are reported in subsequent reports.

VI. RESULTS AND DISCUSSION OF TESTING

Three slabs were obtained at each site. One slab was typically tested at 50° and another at 60°C (122° and 140°F). The third slab was tested at either 40° or 45°C (104° or 113°F) for low temperature sites and typically at 55°C (131°F) for moderate and high temperature sites.

In some instances the third slab was tested at 50°C or 60°C to measure repeatability. Plots of the rutting depth versus cycles for all slabs tested are included in Appendix B.

Each slab that was tested typically had 2 to 4 layers. No attempt was made to separate the layers of the slabs. Each slab was tested as a multiple layer, just as it was in the field. If a lower lift contributed to rutting, it will be detected by the French rutting tester (5).

<u>Repeatability.</u> Some replicate slabs were tested at identical temperatures. Repeatability and reproducibility have been defined according to ASTM C 802. Repeatability provides an estimate of the difference that may be expected between duplicate measurements made on the same material in the same laboratory by the same operator using the same apparatus within a time span of a few days. Reproducibility provides an estimate of the difference that may be expected between measurements on the same materials in two different laboratories.

The repeatability and reproducibility of the results from the French rutting tester currently are not known, so the LCPC is performing a statistical study (3). The analysis is performed for a 2% to 8% rutting depth. A difference in the rutting depth of 1.5 mm (0.06 in) or greater is necessary to distinguish between two materials tested with 100 mm (3.9 in) thick slabs.

A full repeatability task will be performed as part of the CDOT's overall study. For the study documented in this paper, some slabs were tested twice at the same temperature to provide an indication of the repeatability. The results of replicate testing for unacceptable sites are shown on Table 4. The cycles at a 7% rutting depth are reported to be consistent with the French study (3). Since the results from the acceptable sites did not reach the 7% rutting depth, the rutting depths at 30,000 cycles are reported on Table 5.

Table 4. Results of Replicate Testing for Unacceptable Sites

	Cycles at 7% Rutting Depth	
Site	1st Replicate	2nd Replicate
4	800	4,000
6	800	3,000
8	2,000	6,000
12	1,000	3,000
20	1,000	2,000
23	4,000	5,000
24	2,000	1,000
28	2,000	600
34	2,000	3,000
35	300	500

Table 5. Results of Replicate Testing for Acceptable Sites

	Rutting Depth at 30,000 Cycles	
Site	1st Replicate	2nd Replicate
3	2.9 %	3.5 %
7	6.4	4.8
11	4.4	4.5
21	5.5	4.1

Rutting depths on replicate samples for acceptable sites were typically within 1.5%, as reported by the French. On bad sites, the difference in the cycles to failure varied by 1000 to 4000. Considering the specification is 30,000 cycles, 4000 cycles is a reasonable difference, especially on such bad samples that appear to be very sensitive.

French Specification. An acceptable mix for the pavements tested in this study using the French specification will have a rutting depth of less than or equal to 10% of the slab thickness after 30,000 cycles at 60°C. This is a "go, no-go" criteria. The shape of the rutting depth versus cycles curve and the sensitivity of the curve to void content also should be considered.

The French indicate that there are no reports of rutting on highways in which the placed mix passed the test (3). In the few cases where rutting did occur, problems were identified which included: the mix placed failed in the design, an improper test procedure was used with the French rutting tester, or the material placed on the project varied from the material used in the design.

For the 31 Colorado sites tested at 60°C, the comparison of the actual pavement performance versus the specification established by the French is shown on Table 6. Two sites (32 and 36) were not included on the Table because the slabs were not tested at 60°C.

Table 6. Comparison of French Specification to Actual Performance

		Actual Pavement Performance	
		Acceptable	Unacceptable
French Spec.	Acceptable	4	0
	Unacceptable	11	16

The French specification is very severe for conditions typically encountered in Colorado. For the sites tested, there was no rutting in the field when the slabs passed the test and sites that rutted in the field all failed the test. However, several pavements with good performance would have failed the French specification. It may be necessary to examine the testing specification for the different traffic and climatic conditions that exist in Colorado.

Temperature Adjustments. The French use one very severe temperature to perform the test. This is appropriate to create a high factor of safety against rutting. However, in order to make the test more representative of the conditions in Colorado and less severe, different test temperatures were examined. The testing temperature should simulate the actual pavement conditions. The actual field temperature was defined using the highest monthly mean maximum temperature (HMMMT).

Tests were performed using different testing temperatures. The slope, B, as defined in Equation 1 is reported along with results from the French rutting tester on Tables 7-9. The rutting depth at 30,000 cycles was reported if the sample survived; the cycles at a 10% rutting depth were reported if the test had to be terminated.

1) High Temperature. Most of the high temperature sites shown on Table 7 worked very well using the "go, no-go" criteria. A 60°C testing temperature seems appropriate. Site 23 at Walsh had very poor performance in the rutting tester despite good performance on the road. The results from Sites 23 and 24 were not distinguishable from each

other despite having different performance histories. The sites were from the same project and within four miles of each other. It was assumed that this mix was marginal and that some site specific situation during or after placement caused the difference in rutting in the field.

Site 15 in LaJunta did not meet the criteria despite good field performance. The pavement had 1.7% air voids in the wheel path and at adjacent locations there is 0.5" rutting depths. Past research had indicated that pavements with less than 3% air voids in the wheel path have a high probability of rutting (6,7,8). Even though the pavement did not rut at the location of the sample, the material would be undesirable to produce for projects statewide. Results from the French rutting tester indicated that the material was unacceptable.

Mechanical problems developed with the French rutting tester while testing Sites 25 and 26. Therefore only one result from each site was obtained. Site 25 had very low traffic. For low traffic, 10,000 or 20,000 cycles possibly could be specified.

Table 7. Sites with HMMMT from 32^{O} to $38^{O}C$ (90^{O} to $100^{O}F$).

Site	EDLA	Pvmnt Rut Depth (in.)	60°C Test Temp. Slope (B)	60°C Test Temp. Rut Depth @ 30,000 or Cycles @ 10%	55°C Test Temp. Slope (B)	55°C Test Temp. Rut Depth @ 30,000 or Cycles @ 10%	50°C Test Temp. Slope (B)	50°C Test Temp. Rut Depth @ 30,000 or Cycles @ 10%
25	20	0.1			0.40	22,000		
26	20	0.5					0.70	9,000
23	48	0.1	0.86	600			0.70	4,000
24	48	0.4	0.86	100			0.80	2,000
21	270	0.0	0.33	5.5			0.35	4.1
35	399	0.5	1.02	600			0.89	2,000
15	550	0.1	0.45	9,000			0.57	29,000
34	780	1.0	0.84	3,000			0.69	12,000
9	878	0.1	0.34	4.8			0.36	7.1
10	878	1.0	0.73	300			0.40	2,000

2) Moderate Temperature. Results from the pavements placed in moderate temperature areas shown on Table 8 were significantly affected by the testing temperature. By changing the testing temperature from 60^{O} to $50^{O}C$, six sites with good field performance (3, 5, 7, 19, 27 and 29) went from failing to passing, and no sites with poor performance went from failing to passing. The drastic change is not uncommon. By using a polymer modified asphalt, which is less temperature sensitive, the dramatic change in rutting results is reduced significantly (5). A testing temperature of $55^{O}C$ would still be very severe, and the "go, no-go" specification would have better correlation with the actual pavement performance.

Site 29 in Denver had a 0.3" rutting depth; this is considered barely unacceptable. At the $55^{O}C$ testing temperature, the slab failed at 27,000 cycles, barely short of the required 30,000 cycles. A testing temperature of 55°C would closely represent the actual performance of this pavement.

Values were estimated for many of the sites at the 55°C test temperature based upon results from 50° and 60°C because there was no test performed at this temperature. No values were estimated for Sites 3 and 5 since there was a large change in results in the 10°C difference in testing temperature.

Table 8. Sites with HMMMT from 27° to 32°C (80° to 90°F).

Site	EDLA	Pvmnt Rut Depth (in.)	60°C Test Temp. Slope (B)	60°C Test Temp. Rut Depth @ 30,000 or Cycles @ 10%	55°C Test Temp. Slope (B)	55°C Test Temp. Rut Depth @ 30,000 or Cycles @ 10%	50°C Test Temp. Slope (B)	50°C Test Temp. Rut Depth @ 30,000 or Cycles @ 10%
19	93	0.0	0.37	12,000	0.36	7.8	0.37	9.7
20	3	0.4	0.96	400	*0.93	*700	0.90	1,000
27	56	0.0	0.41	20,000	0.28	4.4	0.31	3.7
28	56	0.7	1.02	200	*1.03	*1,000	1.03	2,000
5	250	0.0	0.71	7,000	0.26	3.1	0.38	2.5
6	221	0.4	0.74	300	*0.72	*1,000	0.70	2,000
7	308	0.1	0.49	4,000			0.37	6.4
8	310	0.7	0.89	400	*0.82	*700	0.75	1,000
3	941	0.0	0.55	7,000			0.37	2.9
4	864	1.0	0.73	500	*0.73	*2,000	0.74	5,000
13	1377	0.1	0.41	7.9 -	*0.32	*5.5	0.24	3.0
14	1336	0.8	0.92	200	0.55	5,000	0.62	3,000
11	1027	0.0	0.22	5.70	*0.21	*5.1	0.21	4.4
12	1027	0.8	1.06	800	*0.95	*2,000	0.85	3,000
29	3127	0.3	0.38	15,000	0.44	27,000	0.36	3.6
30	3127	0.6	0.60	4,000	0.55	6,000	0.59	12,000

*estimated value

3) Low Temperature. The low temperature sites are shown on Table 9. Correlating results with actual pavement performance was highly variable and believed to be dependent on elevation. It was not always possible to obtain the HMMMT at the exact site location. The "standard" low temperature sites (Sites 17, 31, 32, and

33) were below 2400 meters (8,000 feet) in elevation and had good correlation at 50°C. Site 18 was at the top of LaVeta Pass at over 3,000 meters (9,000 feet). For a mix placed at this elevation the testing temperature that models field performance, possibly 40°C, appears to be much lower than the "standard" sites.

Site 36 was in the Eisenhower Tunnel at an elevation of over 3,000 meters (9,000 feet). Although the pavement rutted 0.6", it was not because of plastic flow; it likely was due to abrasion from studded tires and tire chains. The voids in the wheel path were 6.4%. Additionally, the pavement texture was very rough and potholed in the bottom of the rut in the wheel path. This site was not included in any additional analysis.

Table 9. Sites with HMMMT Less Than 27°C (80°F).

			50°C Test Temp.		45°C Test Temp.		40°C Test Temp.	
Site	EDLA	Pvmnt Rut Depth (in.)	Slope (B)	Rut Depth @ 30,000 or Cycles @ 10%	Slope (B)	Rut Depth @ 30,000 or Cycles @ 10%	Slope (B)	Rut Depth @ 30,000 or Cycles @ 10%
33	53	0.5	0.85	5,000	0.77	8,000	0.46	5.5
32	169	0.1	0.33	4.7	0.35	4.3	0.44	4.1
31	171	0.1	0.62	5,000			0.60	3.9
18	465	0.1	0.66	8,000	0.53	17,000		
17	493	0.5	0.79	3,000	0.71	9,000	0.75	9,000
37	1137	0.1	0.37	3.8			0.30	1.9
36	1137	0.8	0.29	6.1	0.29	5.3	0.30	4.3

<u>**Modified "Go, No-Go" Specification.**</u> Testing specifications should be selected to match the testing temperature with the field temperature. To select the highest testing temperature that still would provide a correlation with the results, the proposed "go, no-go" testing temperatures are 60°, 55°, and 50°C for sites

that correspond to the three different HMMMTs. Table 10 shows acceptable and unacceptable mixes as related to pavement performance based upon the "go, no-go" specification.

Table 10. Comparison of Modified Specification to Actual Performance

		Actual Pavement Performance	
		Acceptable	Unacceptable
Modified French Spec.	Acceptable	10	0
	Unacceptable	4	16

Three sites were not included on Table 10. Sites 3 and 7 did not have a sample tested at the proposed specification temperature. Site 36 did not rut because of plastic flow.

The four sites that had acceptable field performance but were not acceptable using the French specification were Sites 15, 18, 23, and 25. Sites 15 and 23 were discussed in the high temperature sites and were considered marginally acceptable. Site 18 was at a very high elevation and possibly should have been tested 10°C lower than the modified specification.

Site 25 had very low traffic and consideration should be given to establish a testing specification of 10,000 or 20,000 cycles for low volume roads. Although the 30,000 cycle criteria worked for Sites 19, 20, 23, 24, 25, 26, 27 and 28 which also had very low traffic, using the 10,000 or 20,000 cycle criteria would also have been appropriate.

Prediction of Rutting Depth. Additional analysis was performed in order to determine if the test could be extended beyond a "go, no-go" criteria and was used to forecast actual rutting depths. The results from the French rutting tester used in the analysis were the slope of the rutting curve, B, as defined in Equation 1 and the log of the cycles at failure, C. The slopes and cycles were plotted versus actual pavement rutting depths. The regression results as expressed by the coefficient of determination, r^2, are shown on Table 11. The low temperature sites were not included in these regressions since no testing was performed at 60°C.

Observation of the results indicated that there was a distinct difference between sites with high and low levels of traffic. In all cases, when traffic was divided into two categories, the coefficient of determination increased dramatically. Several entities use 1 million ESALs to differentiate between high and moderate traffic, and that is approximately an EDLA of 250 for 10 years. Regardless of test temperature, there seemed to be slightly better correlation when an EDLA of 400 was used which is approximately 1.5 million ESALs over 10 years.

Regression analysis was performed for all sites using the 60°C testing temperature specified by the French. Additional analyses were performed by varying the testing temperature to better represent the actual pavement temperatures. When the slope was used the best correlations were obtained when a testing temperature of 60°C was used for sites with a HMMMT of 32° to 38°C (90o to 100°F) and 50°C was used for 27° to 32°C (80° to 90°F). When the cycles were used, the best correlations were obtained when a testing temperature of 60°C was used for sites with a HMMMT of 32° to 38°C (90° to 100°F) and 55°C was used for 27° to 32°C (80° to 90°F).

Based on regression analysis, there was a correlation with the tests from the French rutting tester and actual rutting depths. The forecasting capability was better when traffic volume and site temperatures were considered. The plot shown on Fig. 2 is for traffic with an EDLA greater than 400 and a testing temperature of 60°C and 50°C was used for sites with a HMMMT of 32° to 38°C (90° to 100°F) and 27° to 32°C (80° to 90°F), respectively. The coefficient of determination, r^2, of 0.87 indicated good correlation. Fig. 3 is a plot for traffic with an EDLA less than 400 and the testing temperature of 60° and 50°C. The coefficient of determination, r^2, of 0.68 indicated a positive correlation.

FRENCH RUTTING TESTER VS. ACTUAL RUT DEPTH

Fig. 2

For High Traffic with 60° C or 50° C Test Temperature

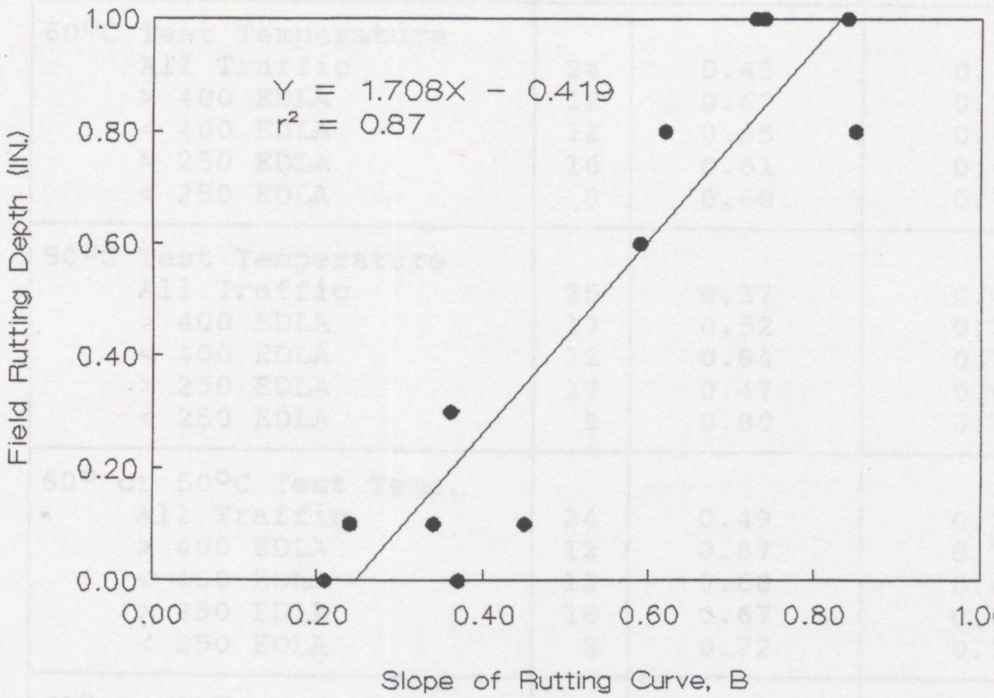

Fig. 3

For Low Traffic with 60° C or 50° C Test Temperature

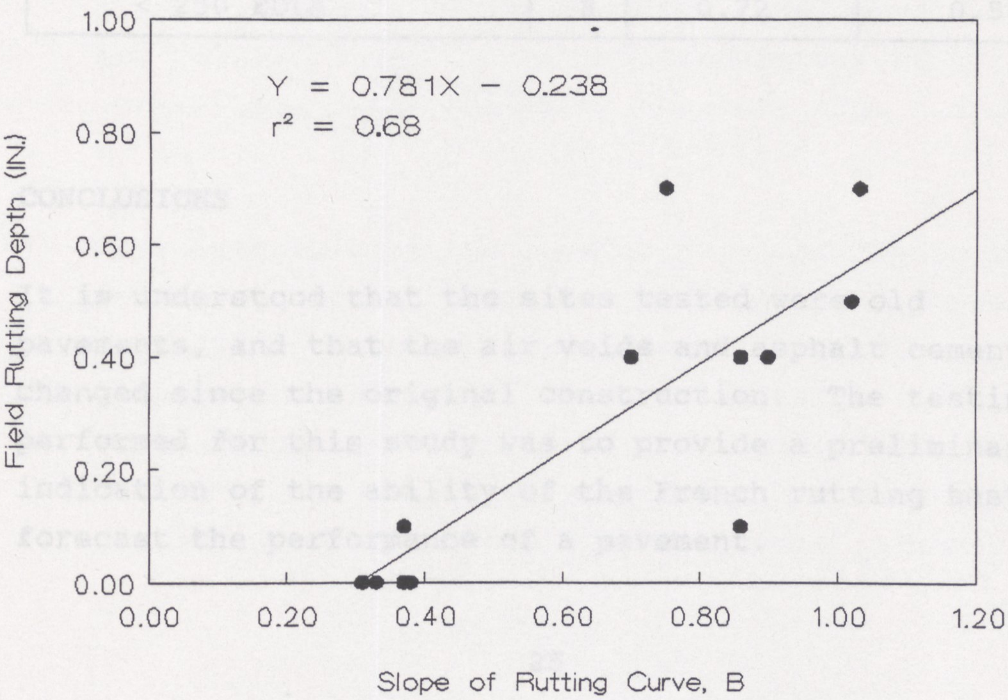

Table 11. Coefficients of Determination (r^2) for Predicting Actual Rutting Depths with French Rutting Tester Results.

	n	Slope (B)	Log(C/1000)
60°C Test Temperature			
All Traffic	24	0.45	0.47
> 400 EDLA	12	0.67	0.74
< 400 EDLA	12	0.65	0.68
> 250 EDLA	16	0.61	0.69
< 250 EDLA	8	0.60	0.72
50°C Test Temperature			
All Traffic	25	0.37	0.44
> 400 EDLA	13	0.52	0.75
< 400 EDLA	12	0.84	0.78
> 250 EDLA	17	0.47	0.61
< 250 EDLA	8	0.80	0.71
60° or 50°C Test Temp.			
All Traffic	24	0.49	0.35
> 400 EDLA	12	0.87	0.70
< 400 EDLA	12	0.68	0.48
> 250 EDLA	16	0.67	0.61
< 250 EDLA	8	0.72	0.38
60° or 55°C Test Temp.			
All Traffic	22	0.45	0.33
> 400 EDLA	11	0.78	0.76
< 400 EDLA	11	0.70	0.56
> 250 EDLA	14	0.60	0.63
< 250 EDLA	8	0.72	0.50

VII. CONCLUSIONS

It is understood that the sites tested were old pavements, and that the air voids and asphalt cement had changed since the original construction. The testing performed for this study was to provide a preliminary indication of the ability of the French rutting tester to forecast the performance of a pavement.

1) The French specification for the French rutting tester is overly severe for many sites in Colorado. It also is empirical. Eleven of 15 sites failed the criteria despite good pavement performance. However, all sites that passed the French test specification did not rut in the field, and all sites that rutted in the field failed the test specification.

2) By making slight modifications for temperature and traffic conditions to the French "go, no-go" specification, the test can be made more representative of field conditions. The use of test temperatures of 50°, 55° or 60°C (122°, 131° or 140°F) for sites in low, moderate and high temperature environments, respectively, correlated well with field performance. For pavements with good performance, 10 of 14 sites met the modified "go, no-go" criteria, and all rutting sites failed the modified "go, no-go" criteria.

   Additional adjustments might consider extremely low traffic and extremely high altitudes. Requiring 10,000 to 20,000 cycles might be considered for very low volume sites. A testing temperature of 40°C (104°F) might be considered for very high elevation sites.

3) Correlations with the results from the French rutting tester and actual pavement rutting depths showed good correlation when the temperature and traffic at the site were considered. The best correlation for forecasting actual pavement rutting depths was obtained when the slope was correlated with actual rutting depth using two traffic levels (greater and

less than an EDLA of 400) and test temperatures of 60°C and 50°C for sites with a HMMMT of 32° to 38°C (90° to 100°F) and 27° to 32°C (80° to 90°F), respectively. The best correlation with the number of cycles and actual rutting depth was obtained using test temperatures of 60°C and 55°C.

4) The French rutting tester can apply a variety of stresses into the slabs being tested. The French rutting tester could probably model field results better by considering stress levels when performing tests.

VIII. ADDITIONAL RESEARCH

A study titled "Investigation of the rutting Performance of Pavement in Colorado" which documents why the good pavements performed well and the bad pavements did not will be available for distribution in November 1992.

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Appendix A

PHOTOGRAPHS

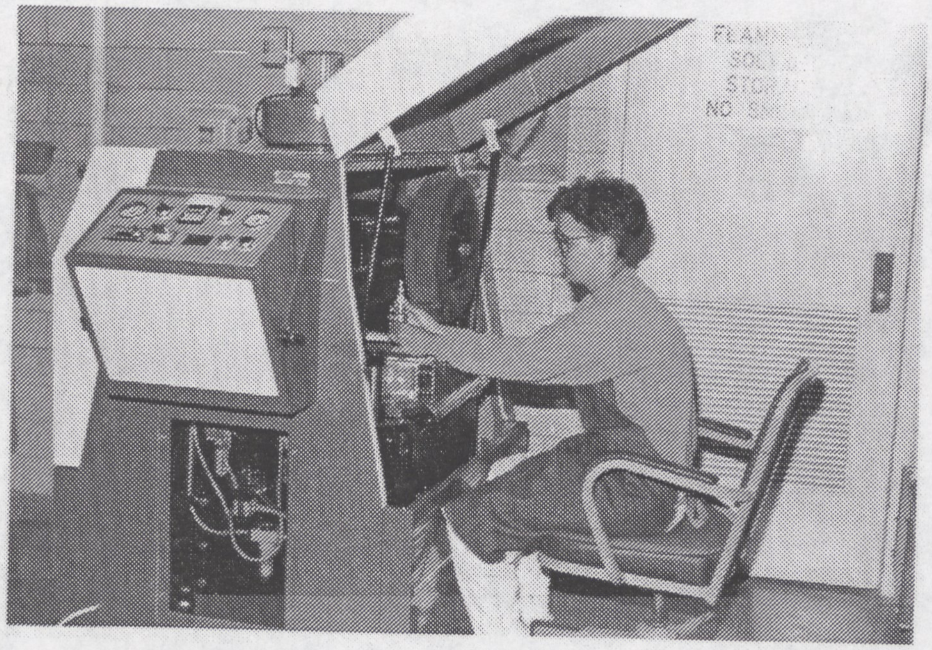


Photo 1

Measuring rutting depths on a slab in the French rutting tester.

Photo 2

Sites were sawed between the wheels paths and parallel to the direction of travel.

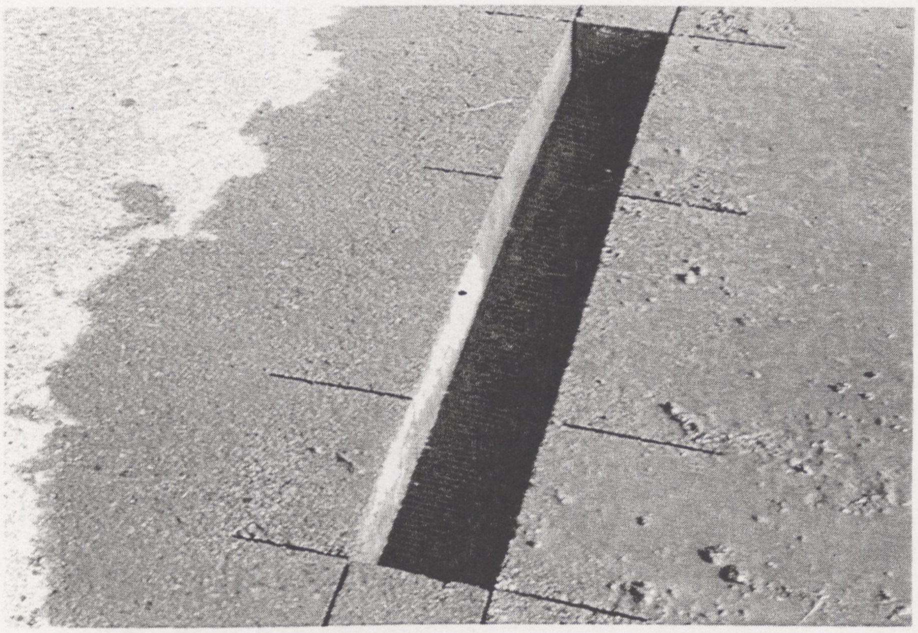
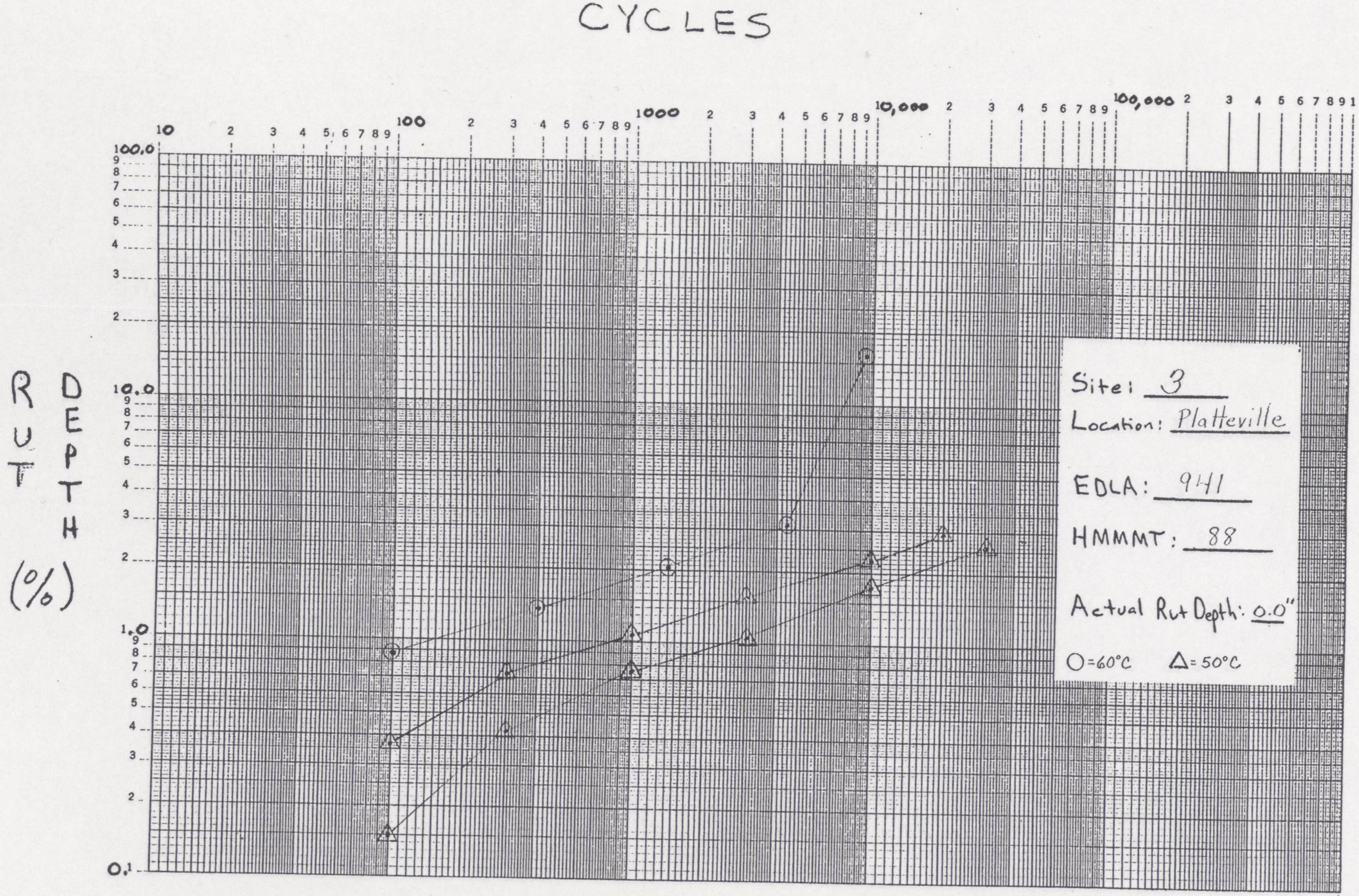


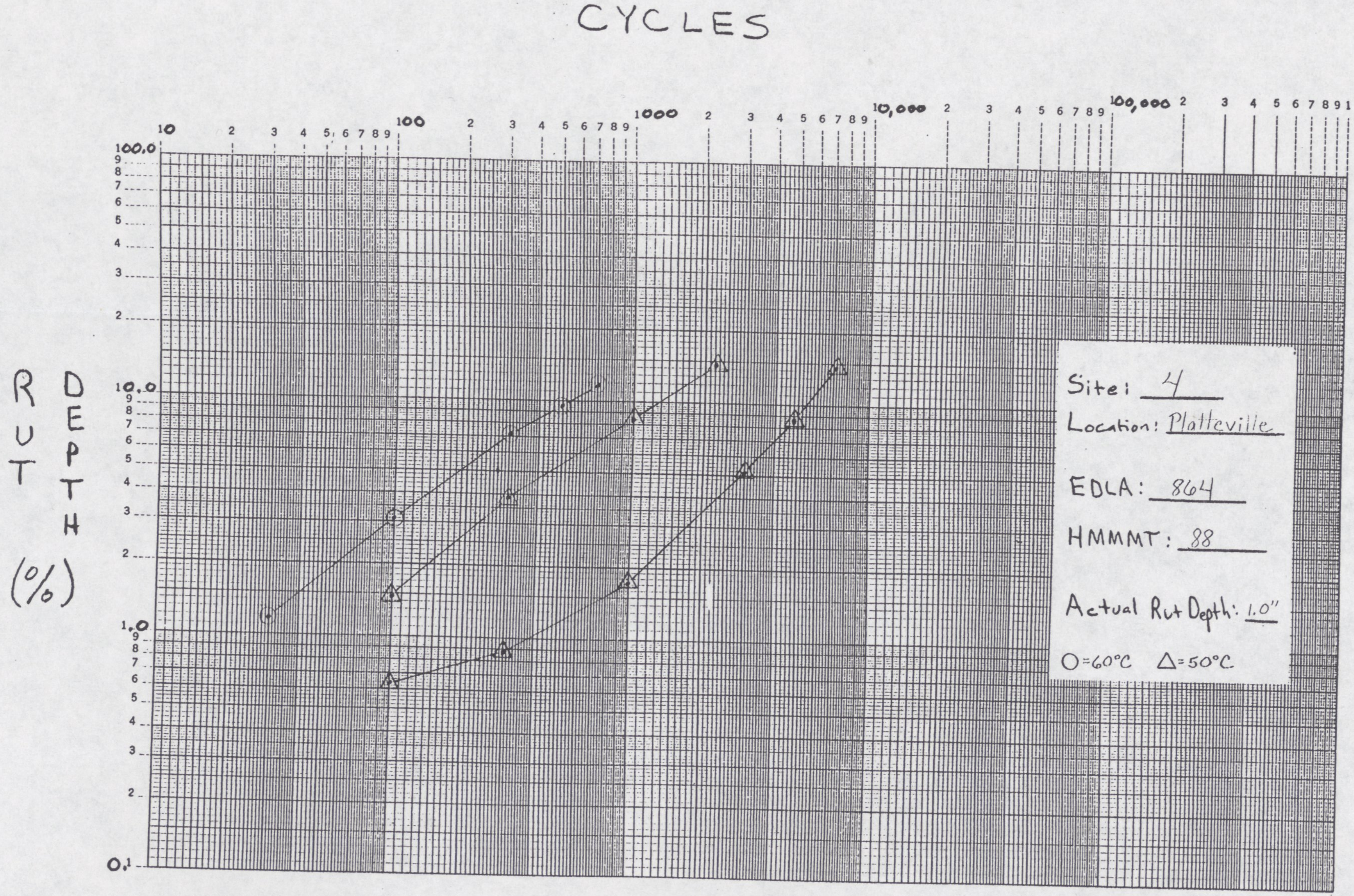
Photo 3

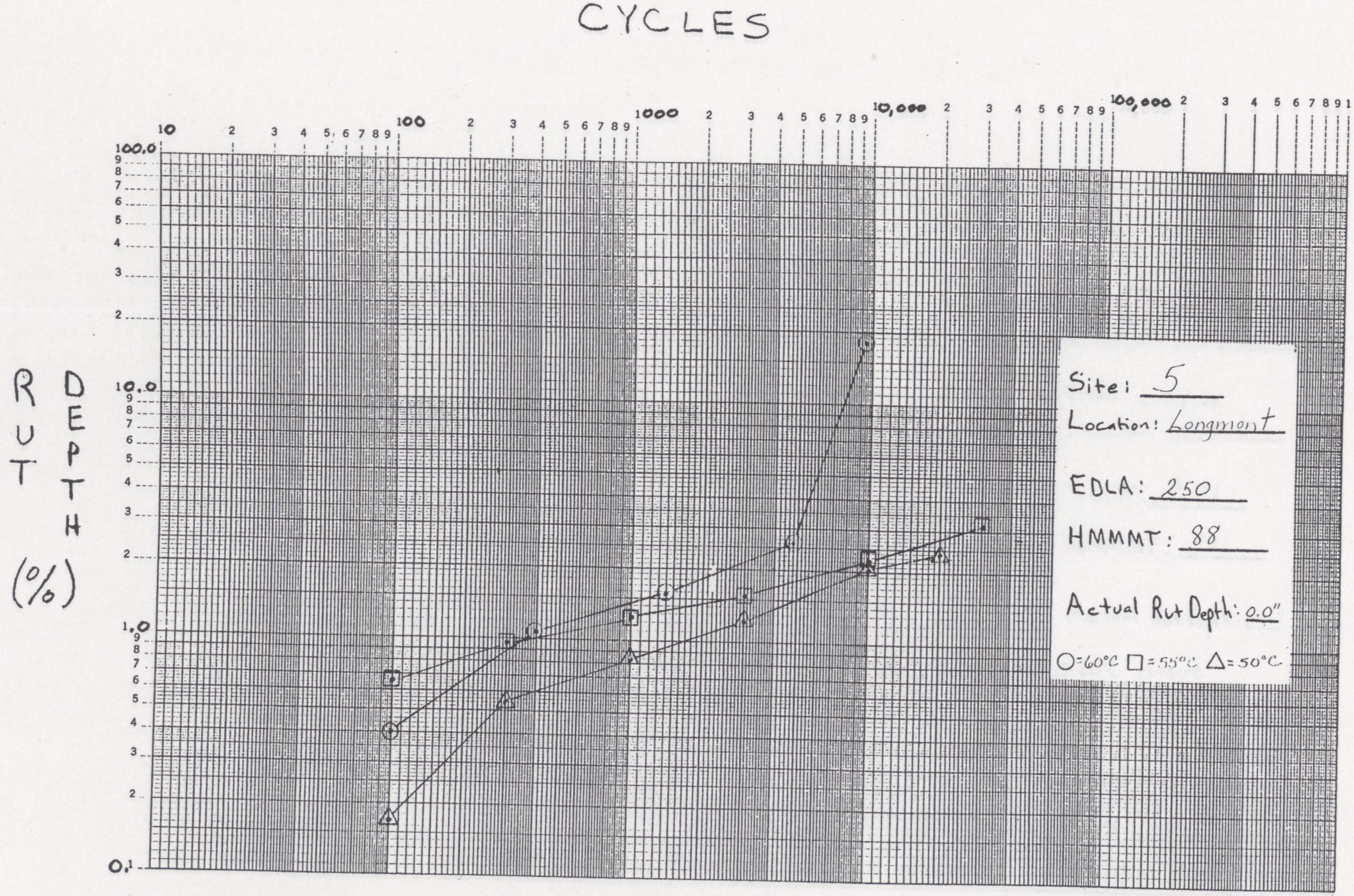
Three slabs were obtained at each location. The slabs cut in the field were 7.1" wide and 19.7" long. The depth of the slab varied depending on the thickness of the pavement.

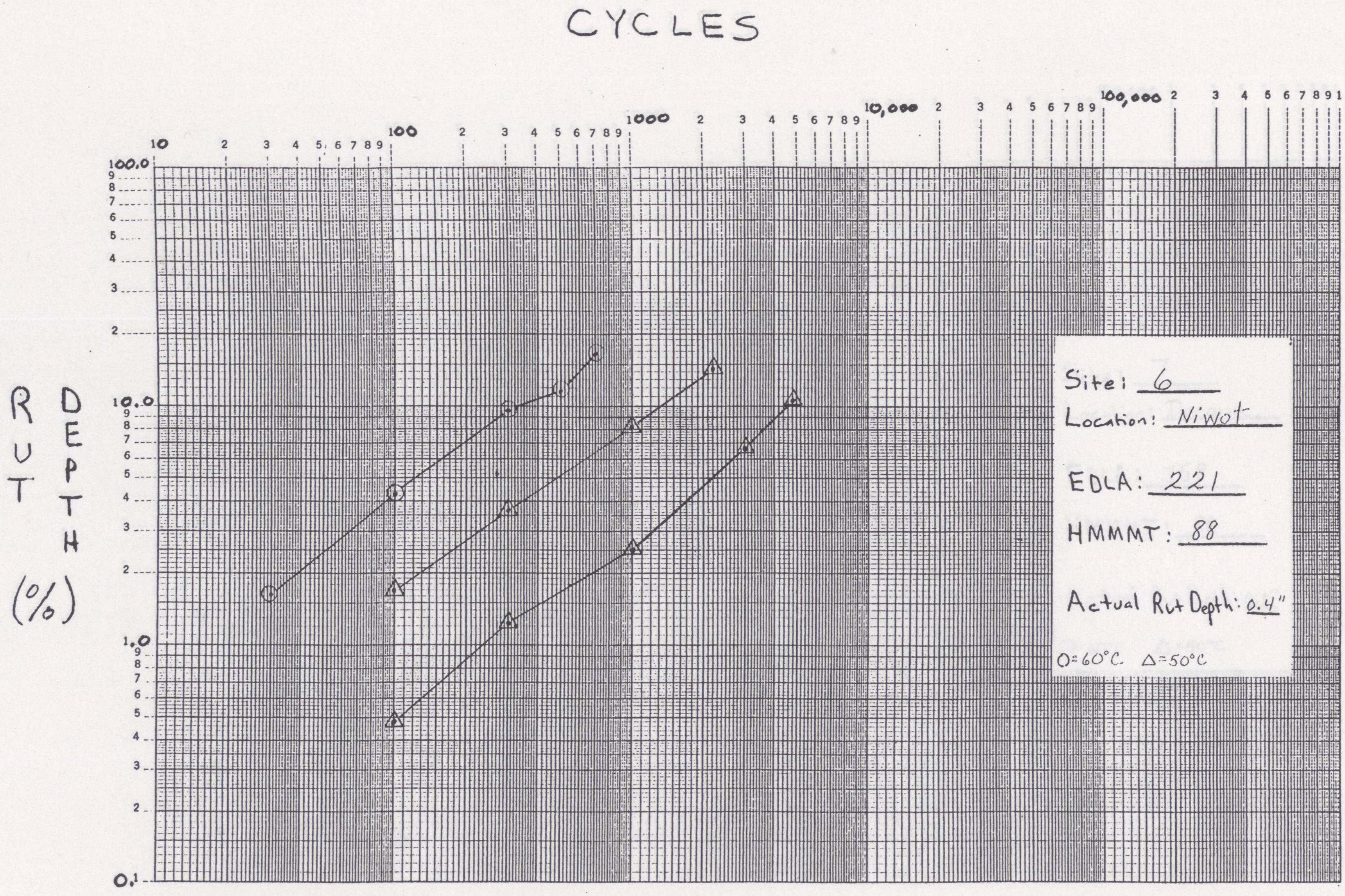
Appendix B

RUTTING DEPTHS VERSUS CYCLES

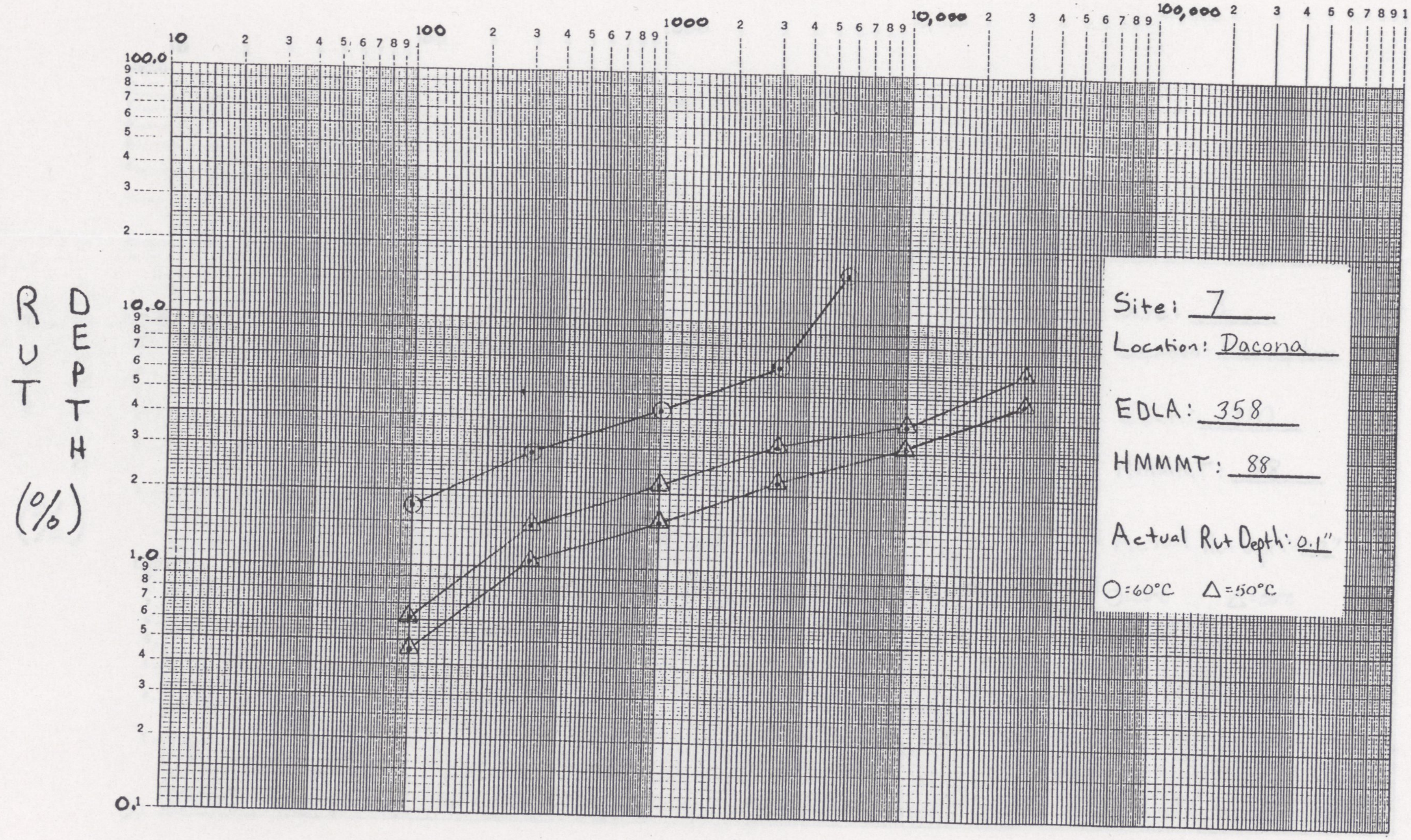

CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 3
Location: Platteville
EDLA: 941
HMMMT: 88
Actual Rut Depth: 0.0"
○=60°C
Δ=50°C


CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 4
Location: Platteville
EDLA: 864
HMMMT: 88
Actual Rut Depth: 1.0"
O=60°C Δ=50°C

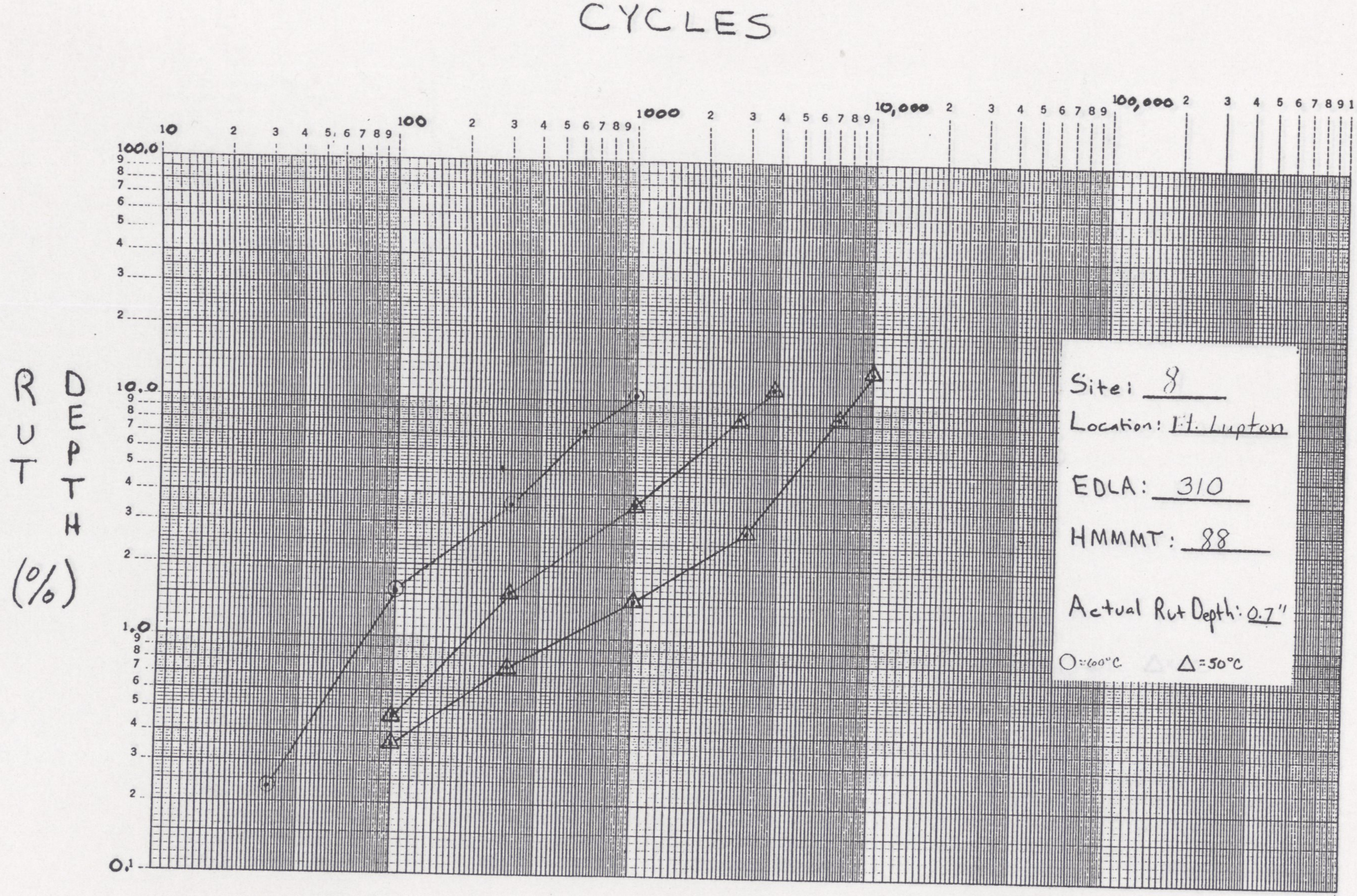

CYCLES
RUT DEPTH (%)
Site: 5
Location: Longmont
EDLA: 250
HMMMT: 88
Actual Rut Depth: 0.0"
○=60°C □=55°C △=50°C

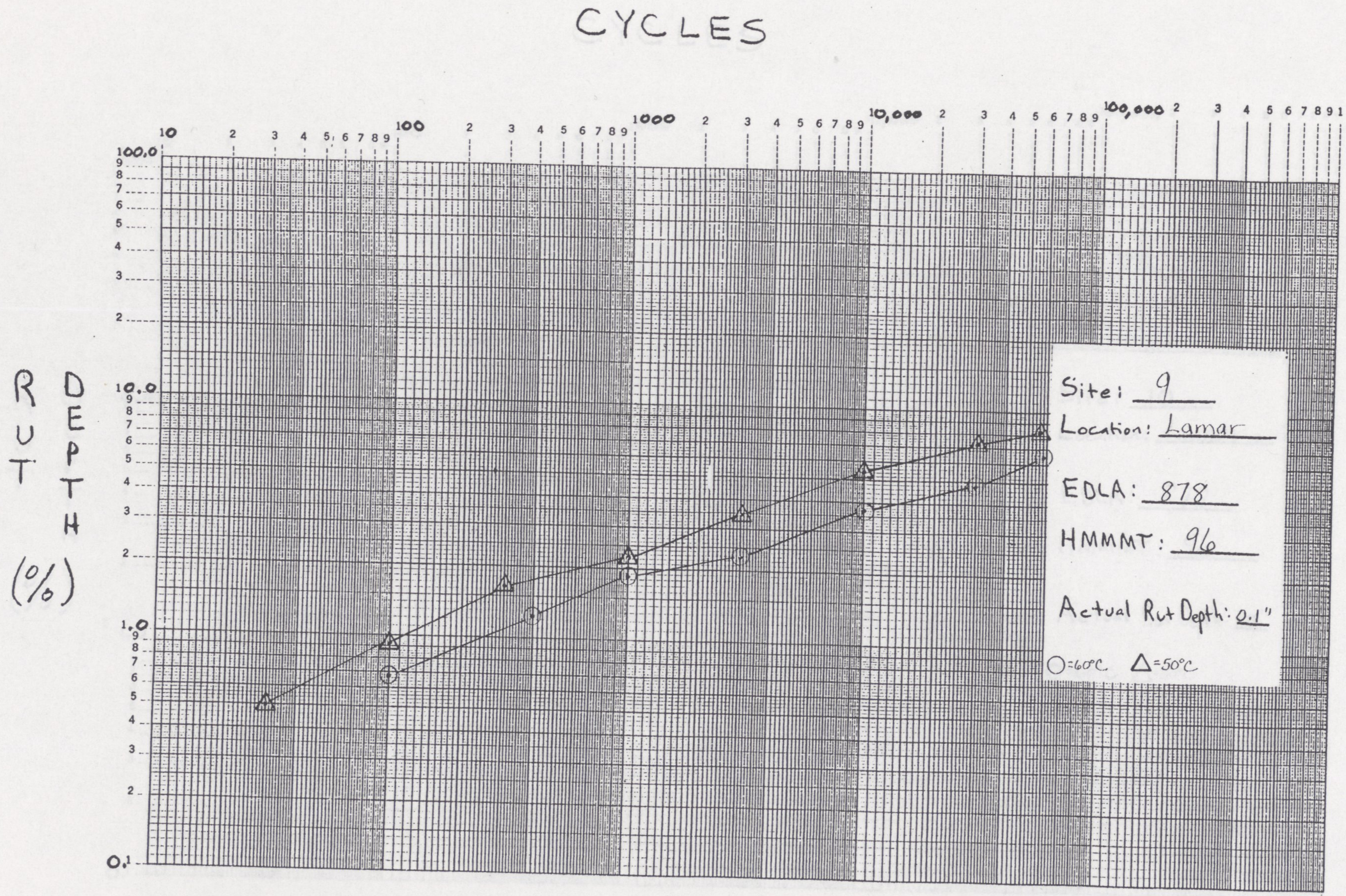

CYCLES
RUT DEPTH
(%)
Site: 6
Location: Niwot
EDLA: 221
HMMMT: 88
Actual Rut Depth: 0.4"
O=60°C Δ=50°C

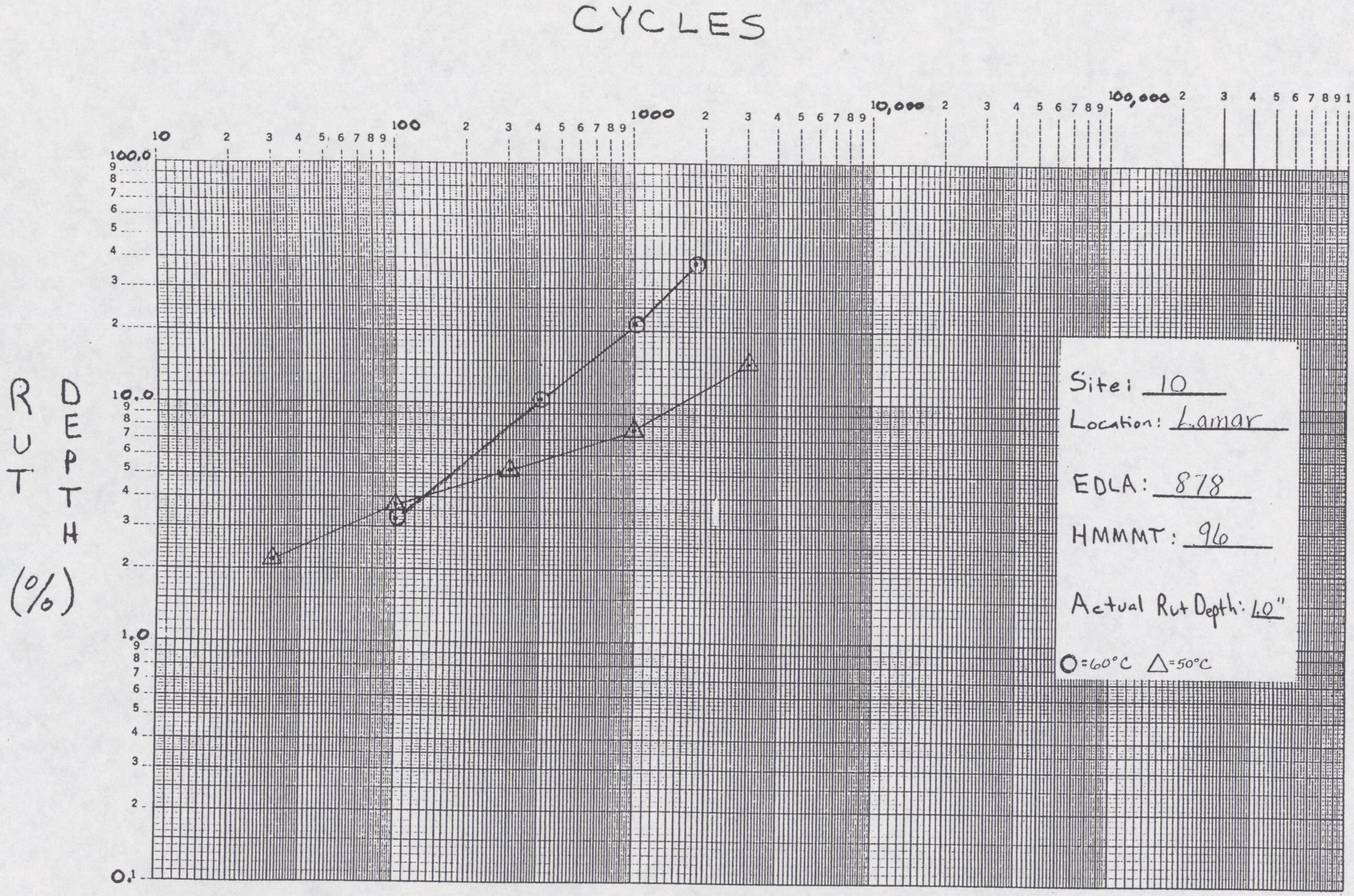
CYCLES



RUT DEPTH (%)
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
Site: 7
Location: Dacona
EDLA: 358
HMMMT: 88
Actual Rut Depth: 0.1"
○=60°C △=50°C


CYCLES
RUT DEPTH (%)
Site: 8
Location: Ft. Lupton
EDLA: 310
HMMMT: 88
Actual Rut Depth: 0.7"
○=60°C
△=50°C


CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 9
Location: Lamar
EDLA: 878
HMMMT: 96
Actual Rut Depth: 0.1"
○=60°C △=50°C


CYCLES
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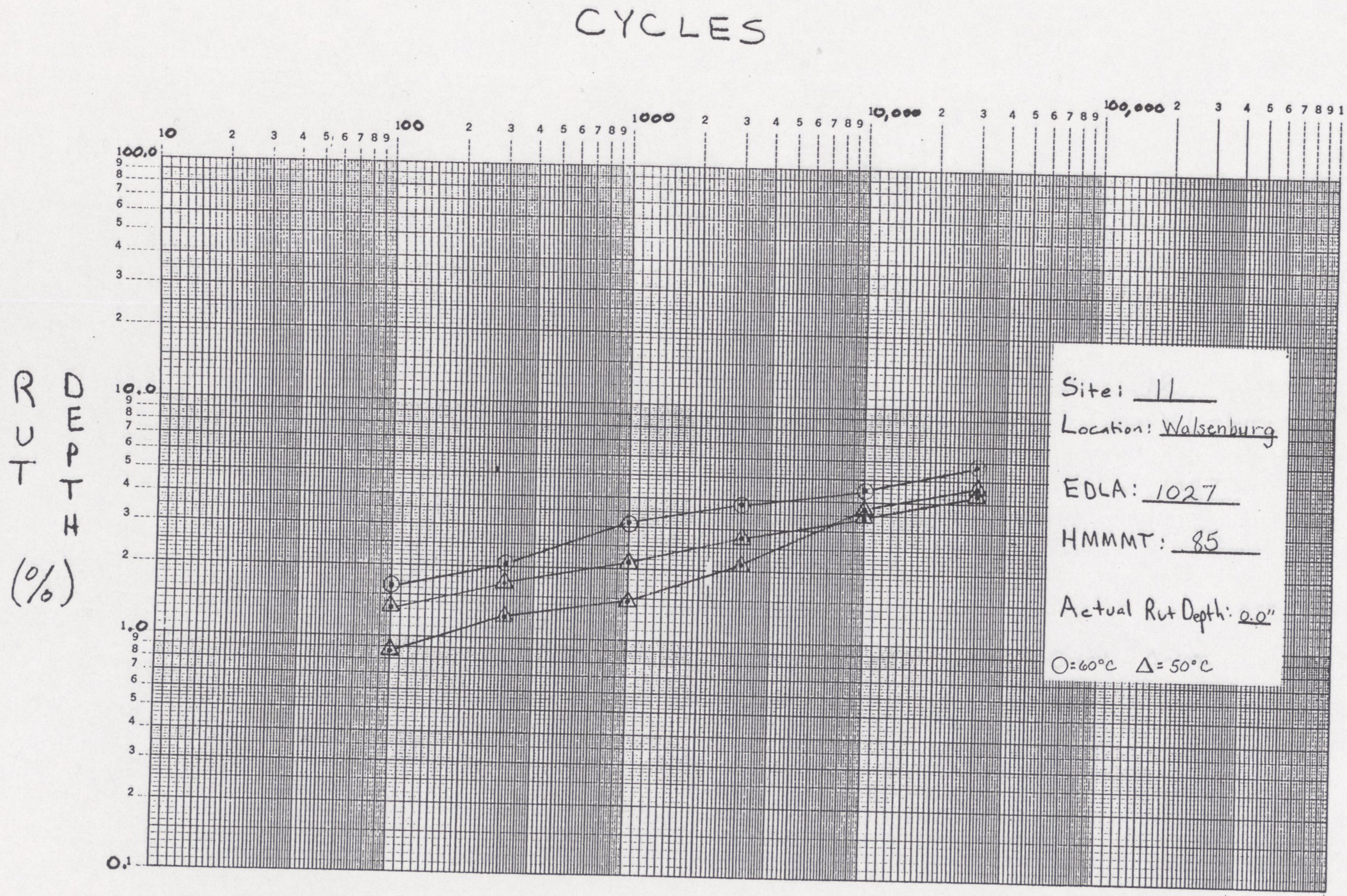
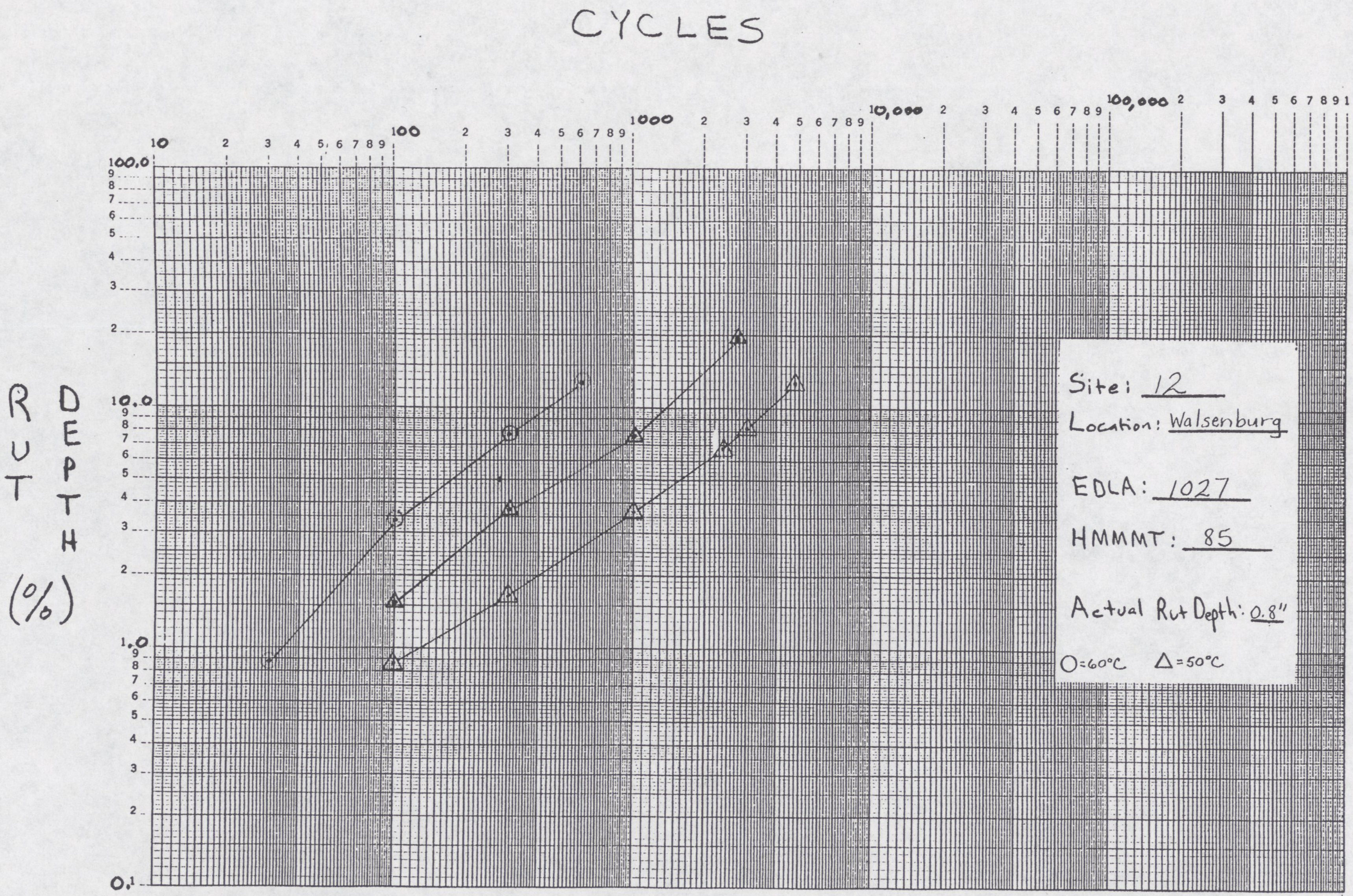
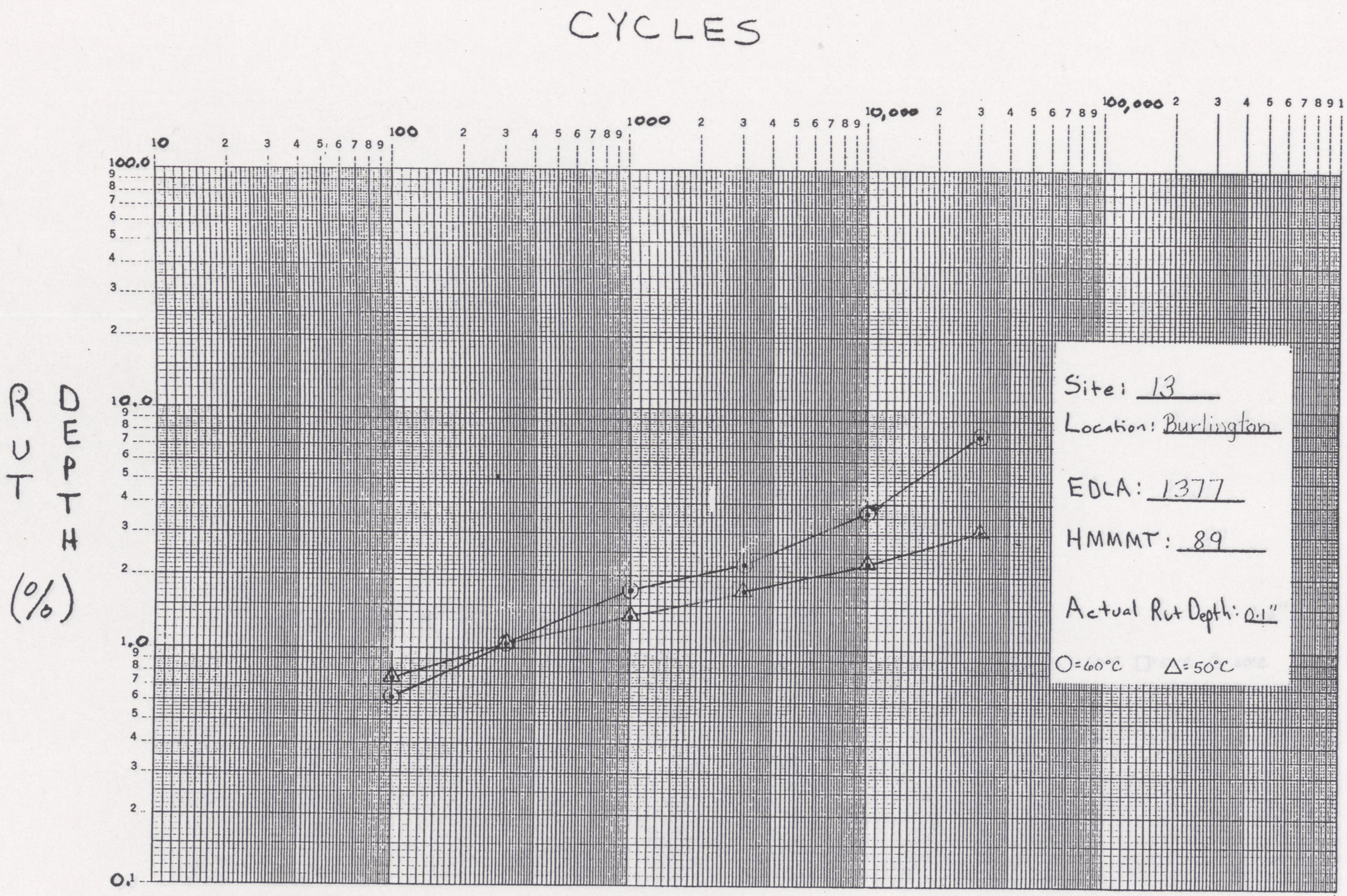
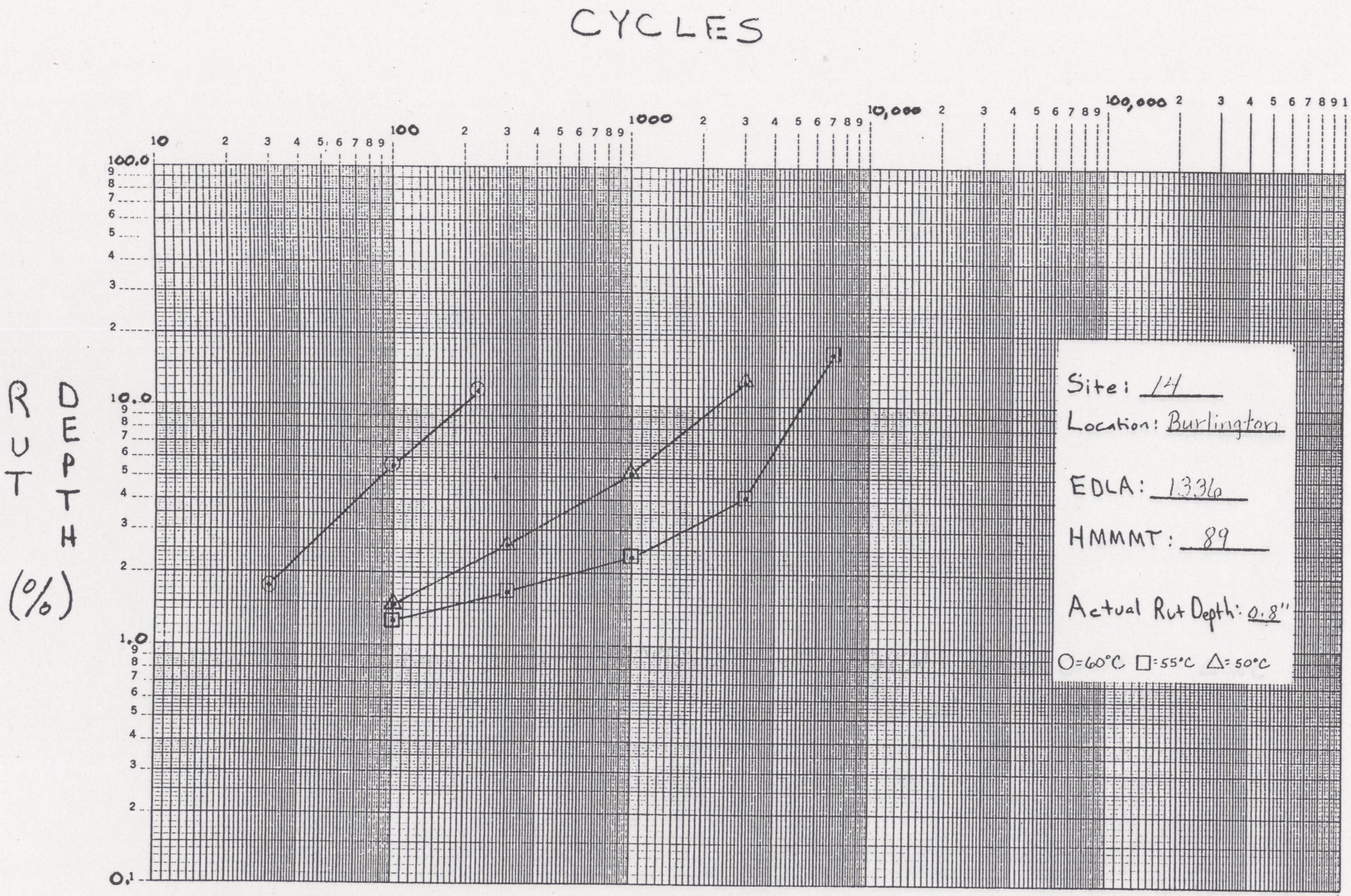
100
1000
10,000
100,000
RUT DEPTH (%)
100.0
10.0
1.0
0.1
Site: 10
Location: Lamar
EDLA: 878
HMMMT: 96
Actual Rut Depth: 1.0"
O=60°C △=50°C


CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 11
Location: Walsenburg
EDLA: 1027
HMMMT: 85
Actual Rut Depth: 0.0"
O=60°C Δ=50°C


CYCLES
RUT DEPTH (%)
Site: 12
Location: Walsenburg
EDLA: 1027
HMMMT: 85
Actual Rut Depth: 0.8"
O=60°C
Δ=50°C


CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 13
Location: Burlington
EDLA: 1377
HMMMT: 89
Actual Rut Depth: 0.1"
O=60°C
Δ=50°C


CYCLES
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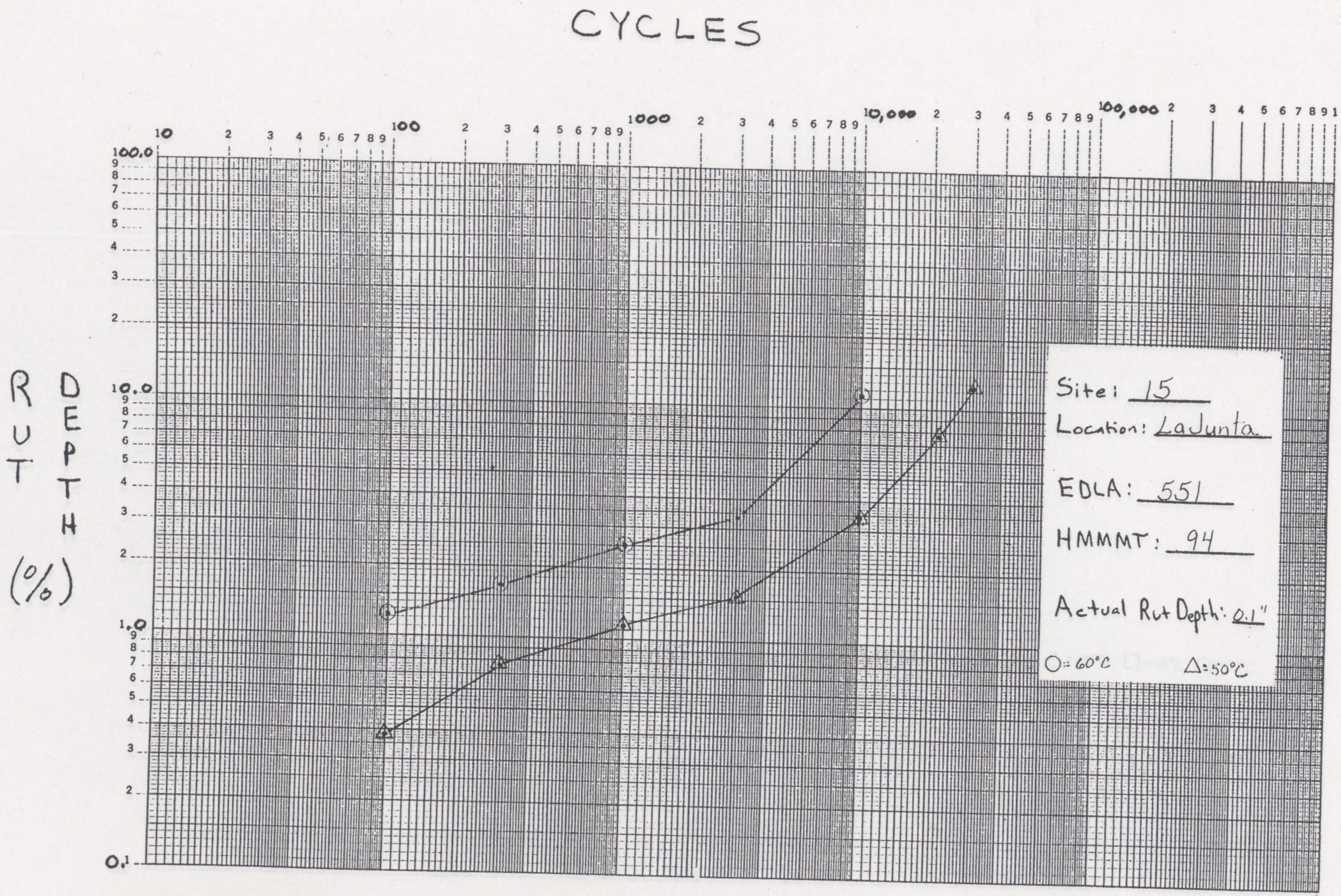
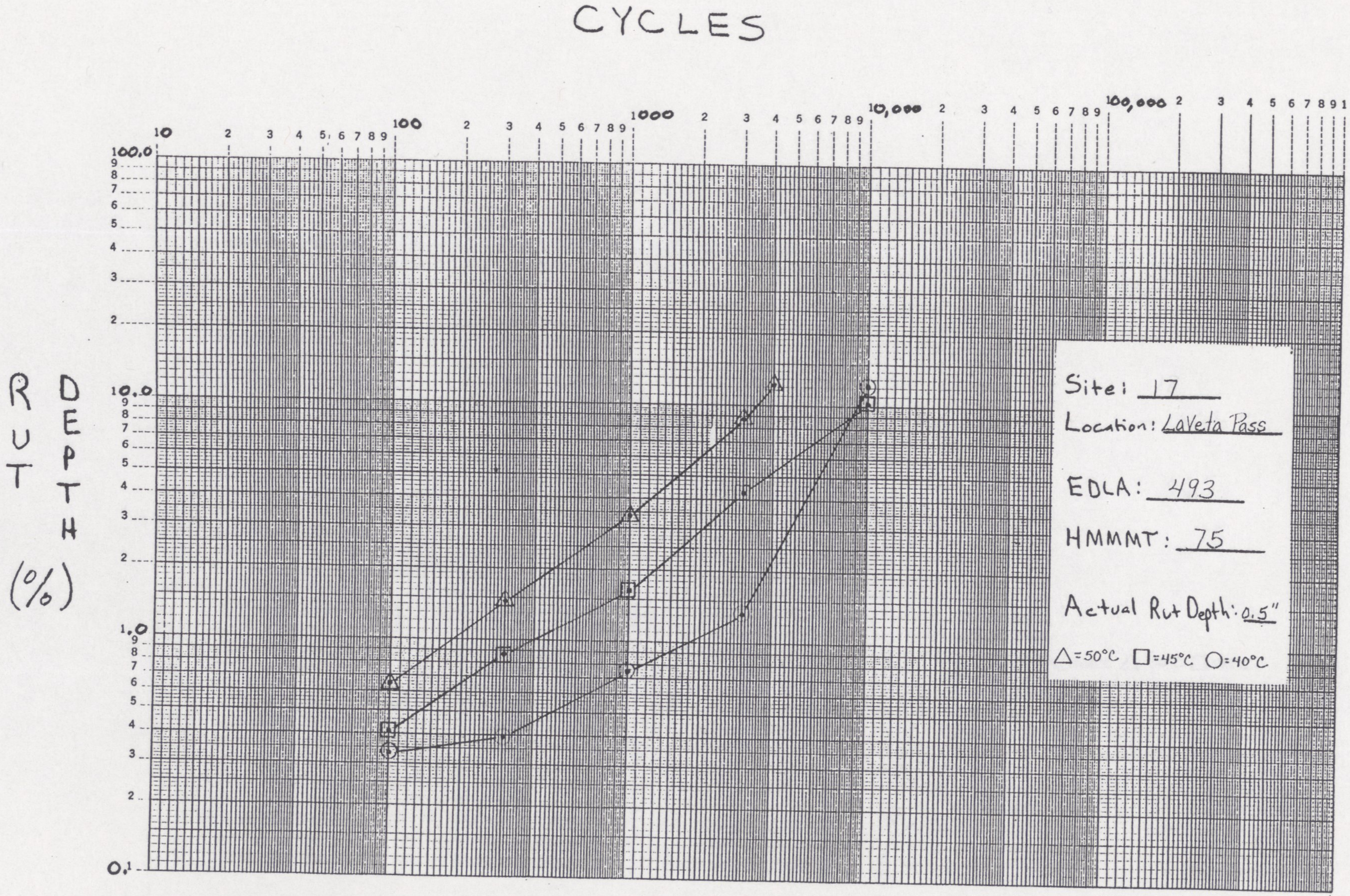
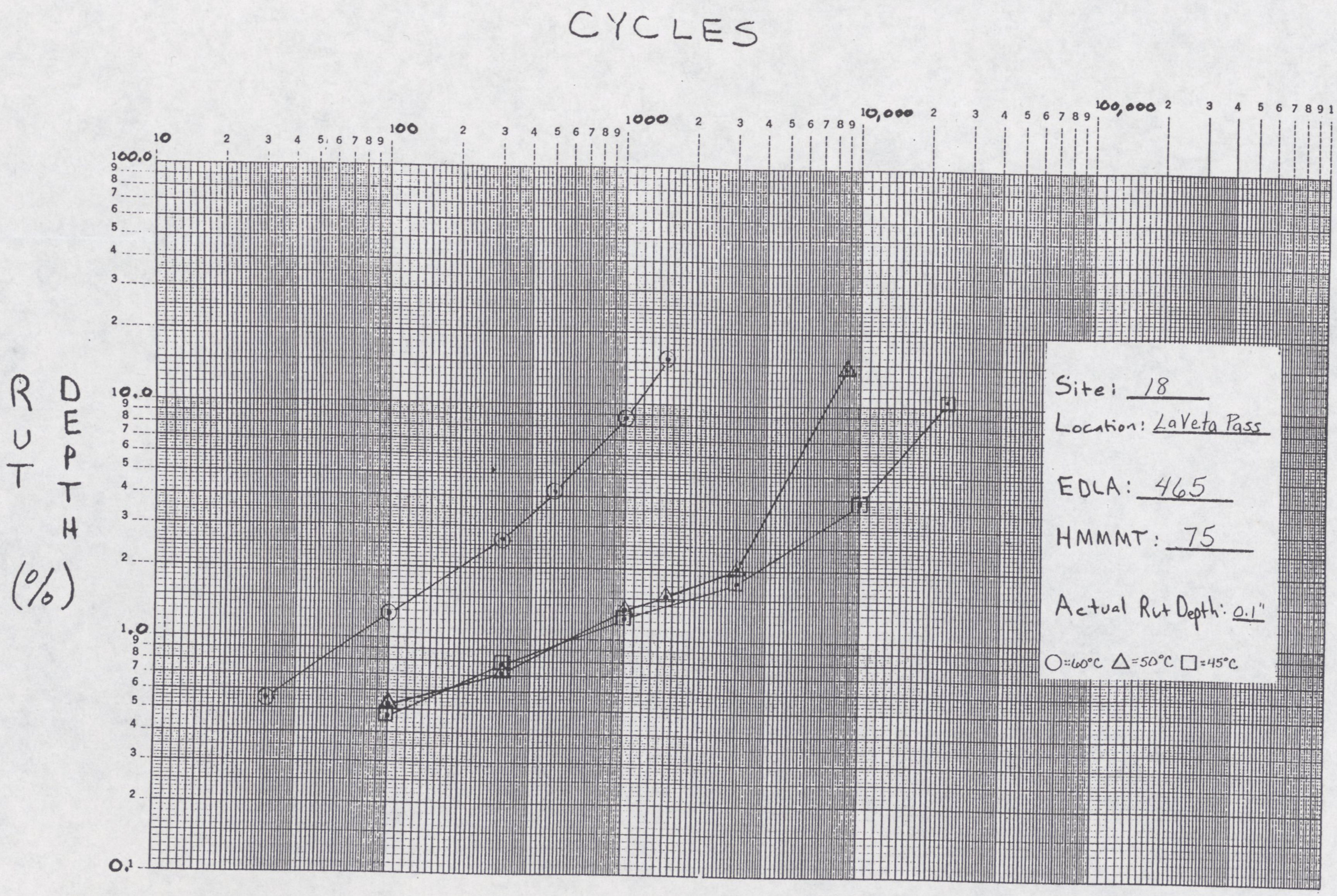
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 14
Location: Burlington
EDLA: 1336
HMMMT: 89
Actual Rut Depth: 0.8"
○=60°C □=55°C △=50°C


CYCLES
RUT DEPTH (%)
Site: 15
Location: LaJunta
EDLA: 551
HMMMT: 94
Actual Rut Depth: 0.1"
○= 60°C
△= 50°C



CYCLES
RUT DEPTH (%)
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
Site: 17
Location: LaVeta Pass
EDLA: 493
HMMMT: 75
Actual Rut Depth: 0.5"
△=50°C □=45°C ○=40°C


CYCLES
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1000
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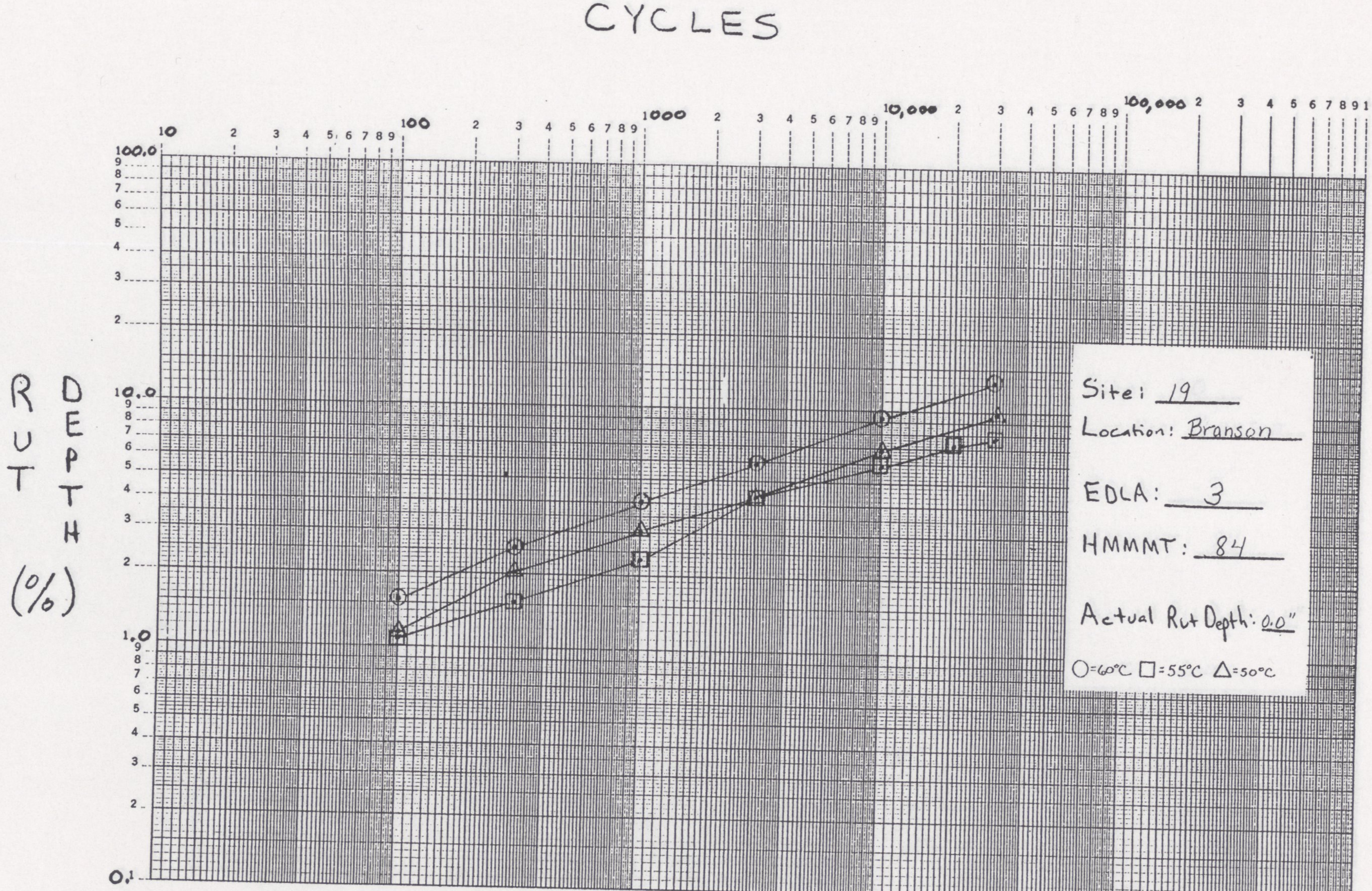
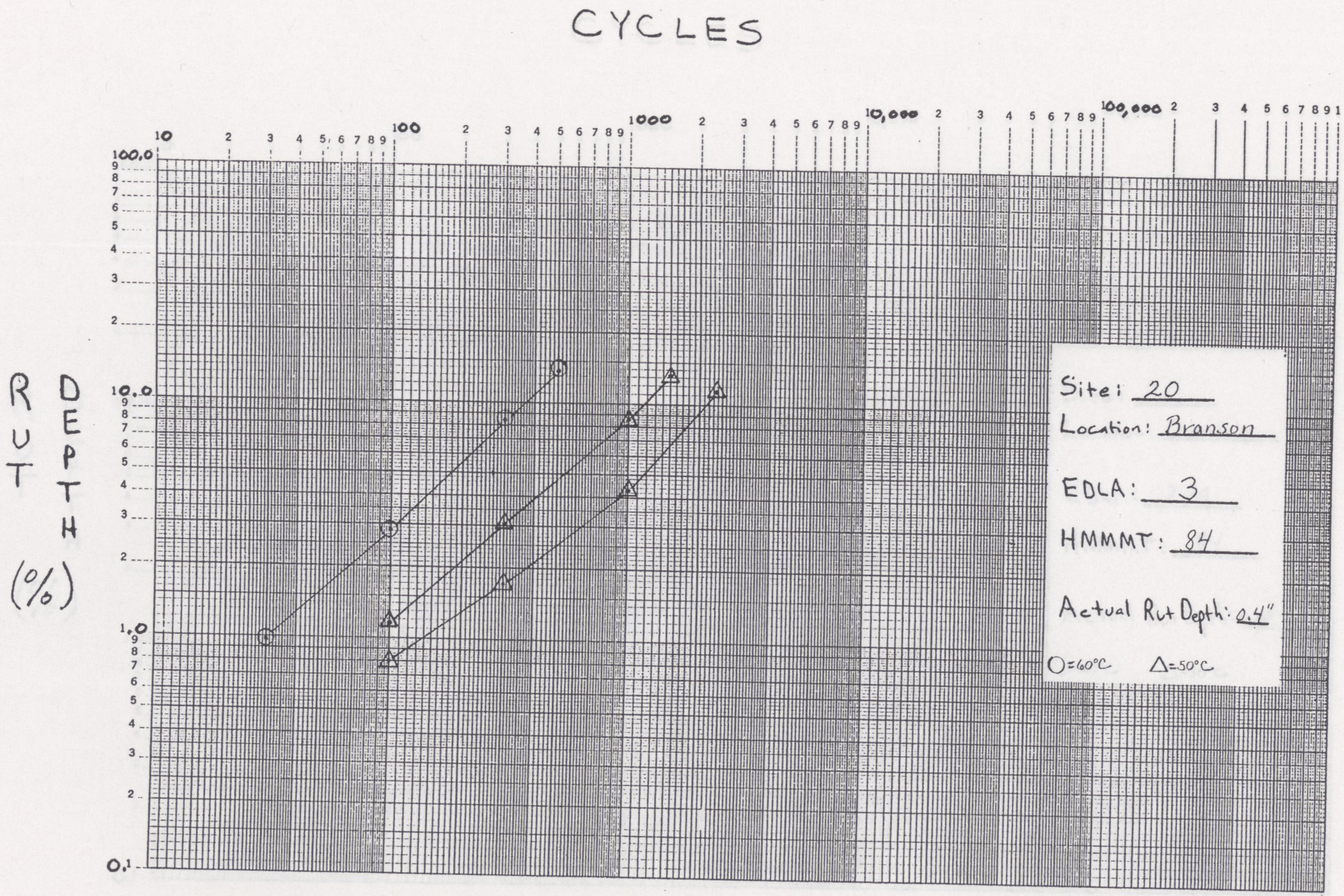
100,000
100.0
10.0
1.0
0.1
RUT DEPTH
(%)
Site: 18
Location: LaVeta Pass
EDLA: 465
HMMMT: 75
Actual Rut Depth: 0.1"
○=60°C △=50°C □=45°C


CYCLES
RUT DEPTH (%)
Site: 19
Location: Branson
EDLA: 3
HMMMT: 84
Actual Rut Depth: 0.0"
○=60°C □=55°C △=50°C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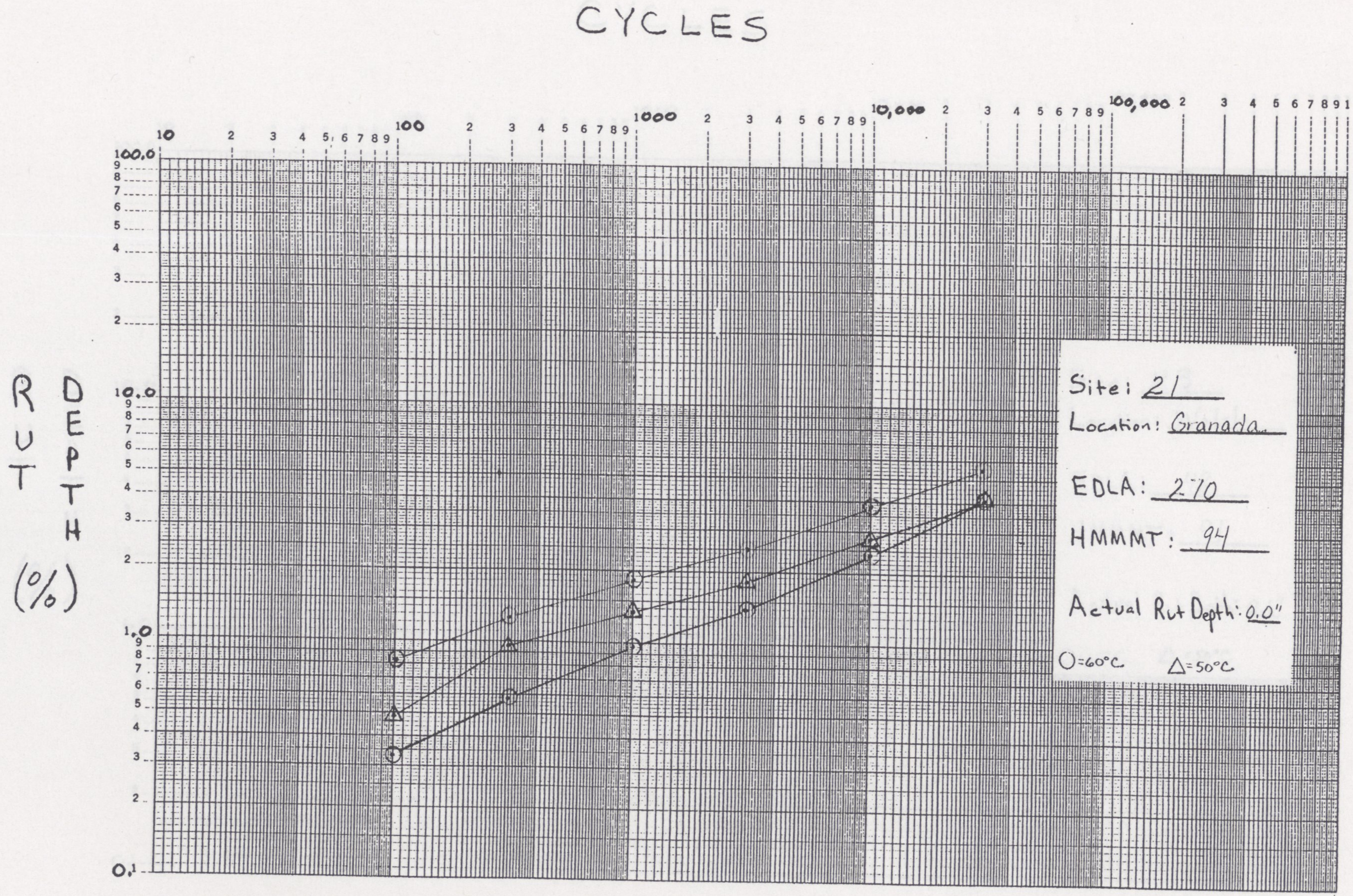
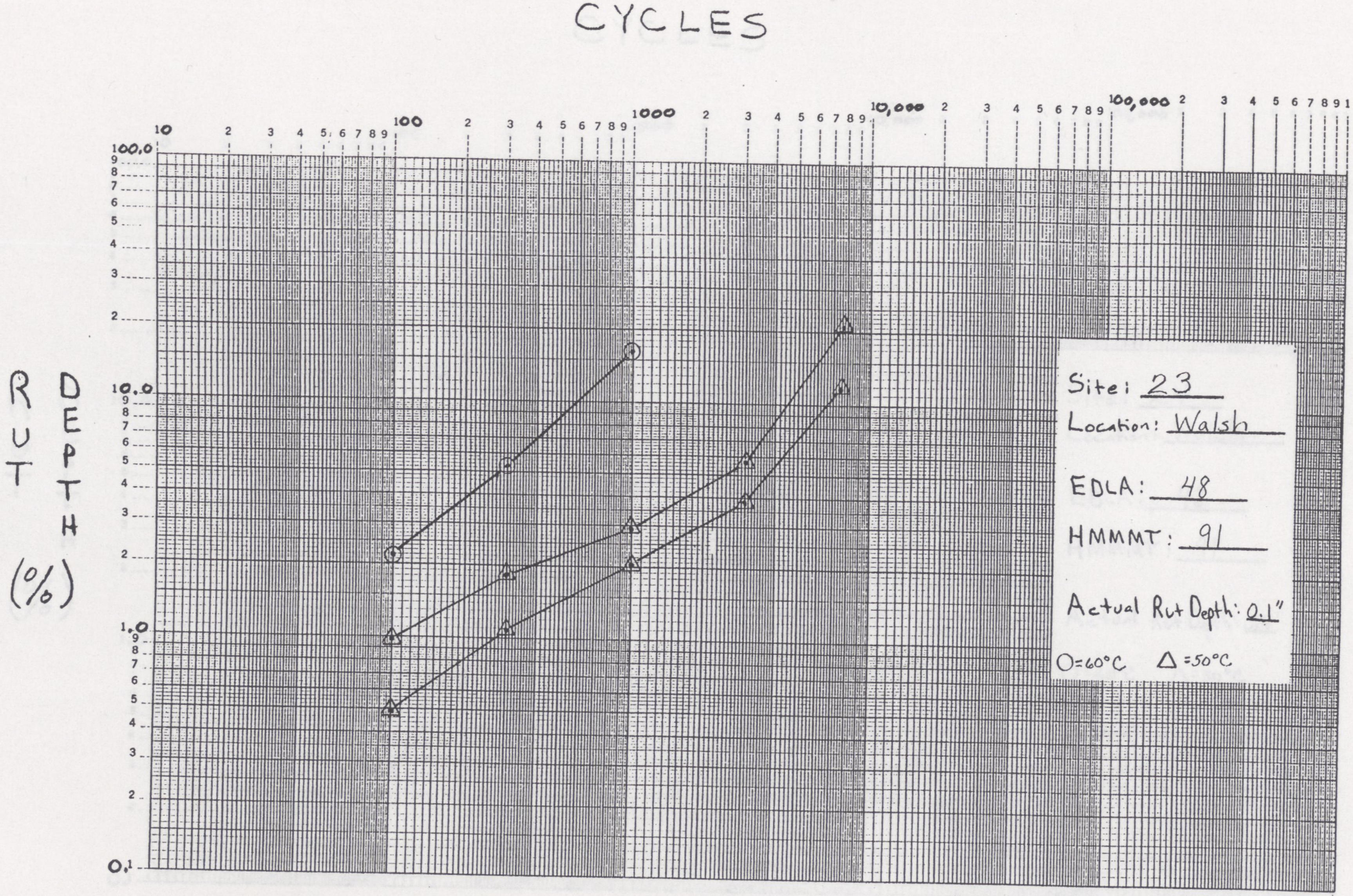
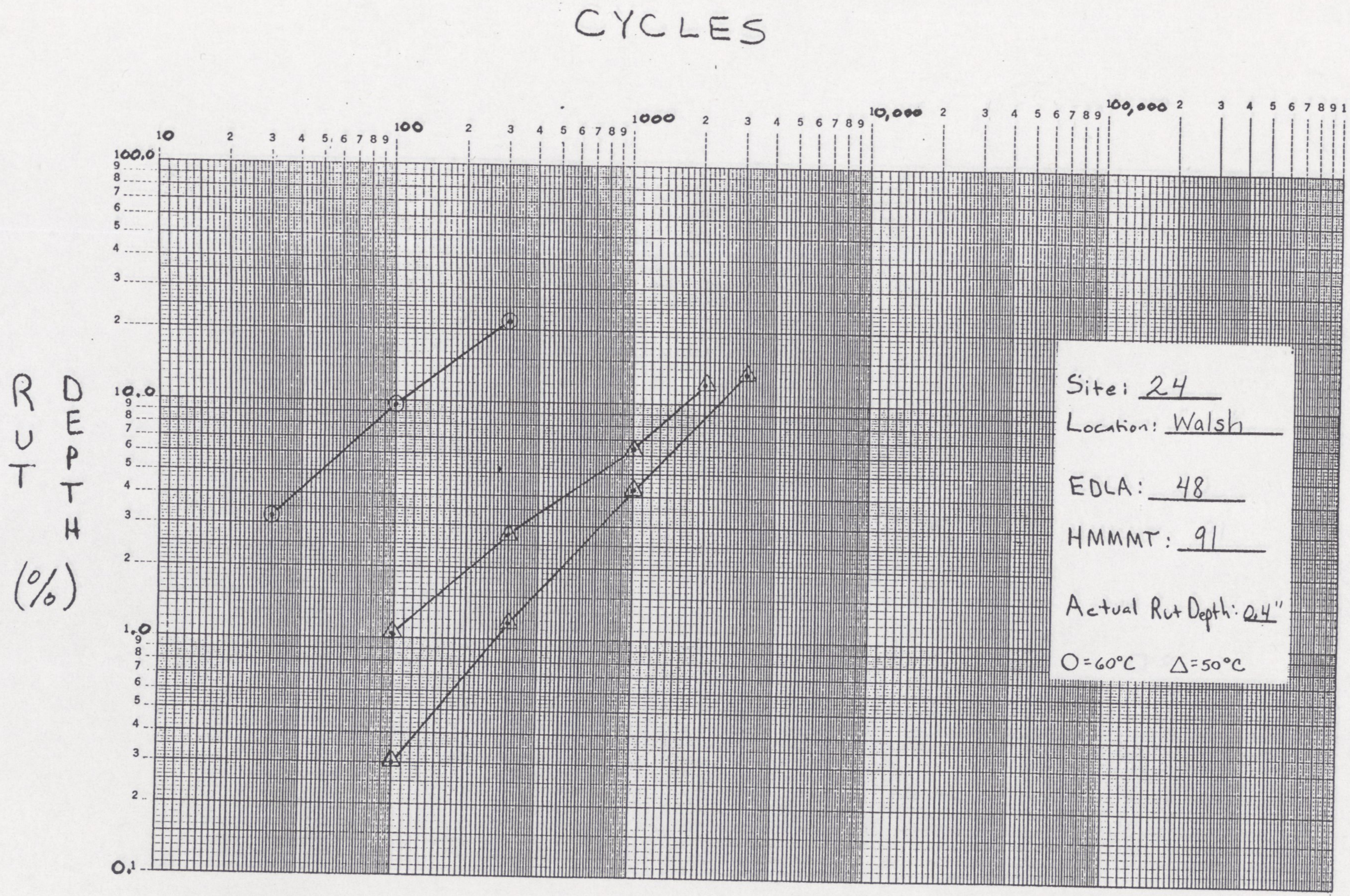
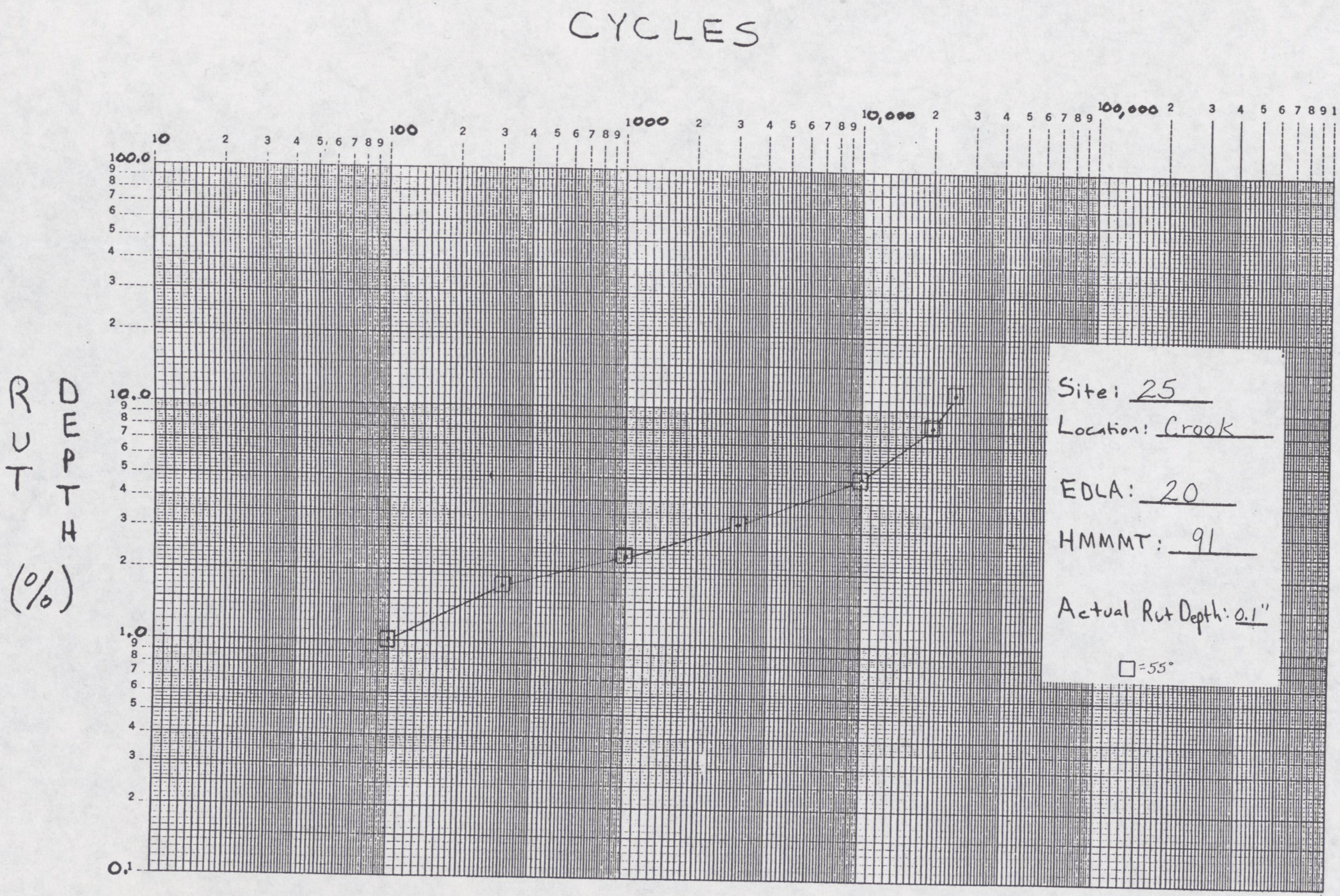
RUT DEPTH (%)
Site: 20
Location: Branson
EDLA: 3
HMMMT: 84
Actual Rut Depth: 0.4"
O=60°C
Δ=50°C

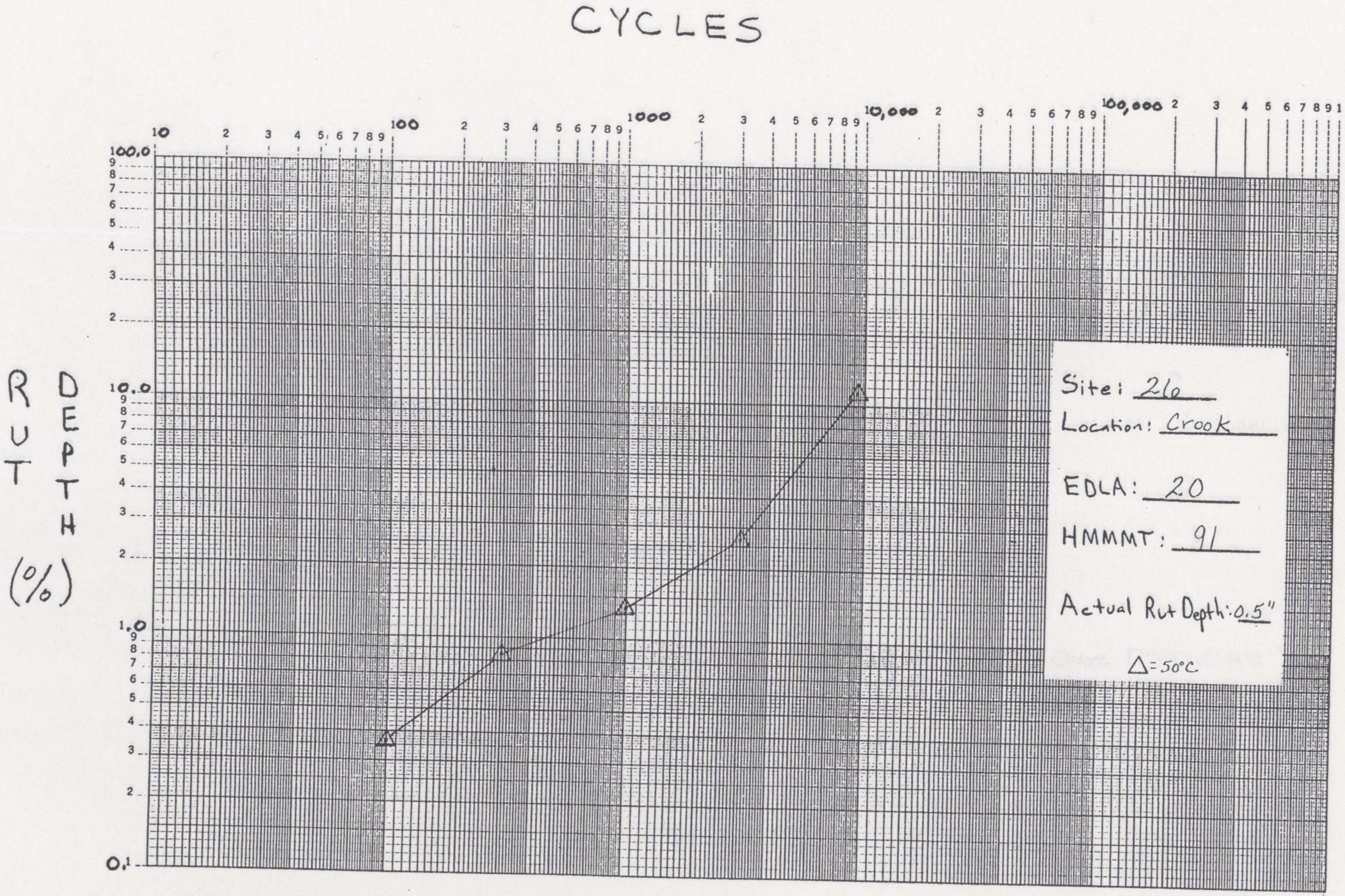

CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 21
Location: Granada
EDLA: 270
HMMMT: 94
Actual Rut Depth: 0.0"
O=60°C
△=50°C

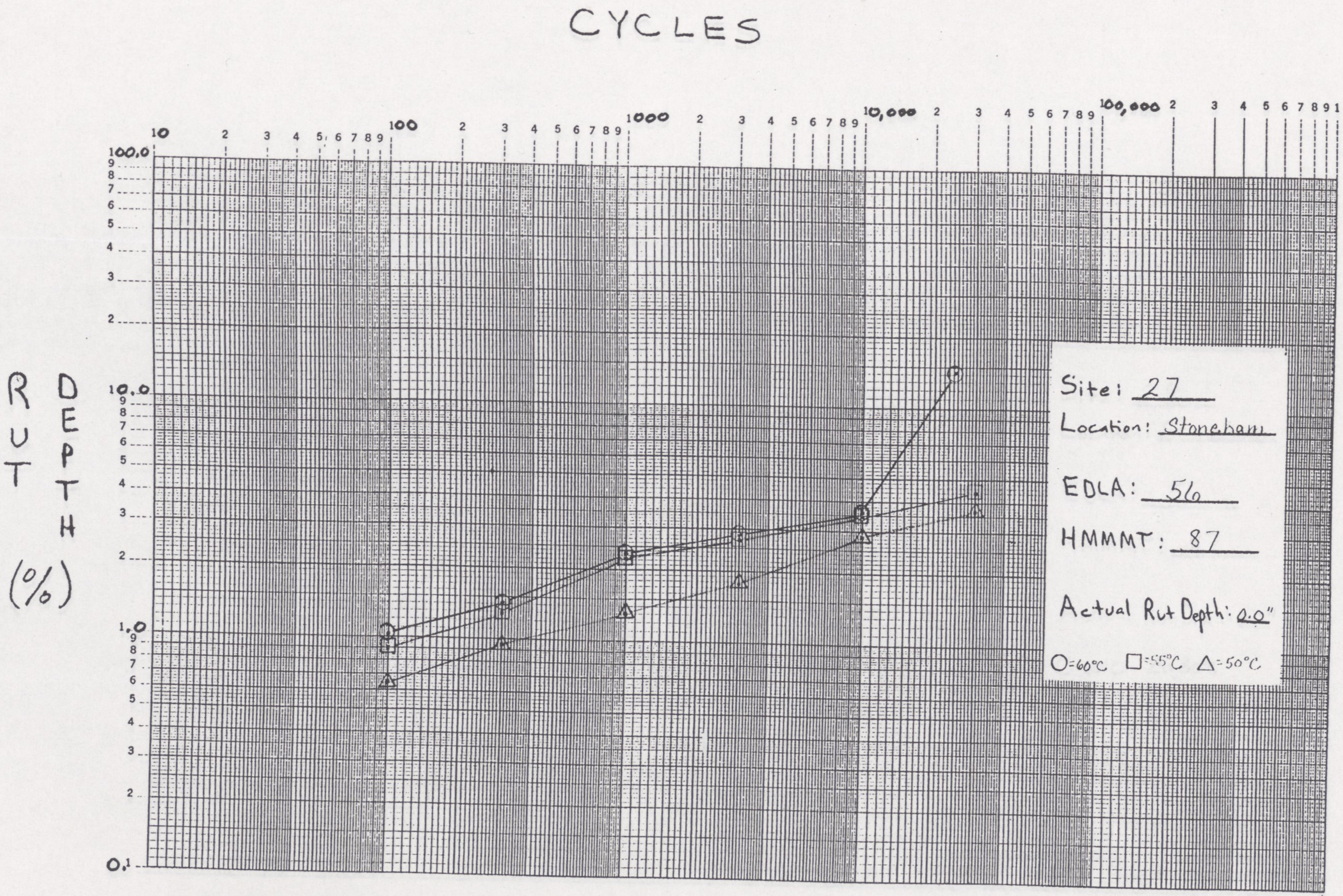


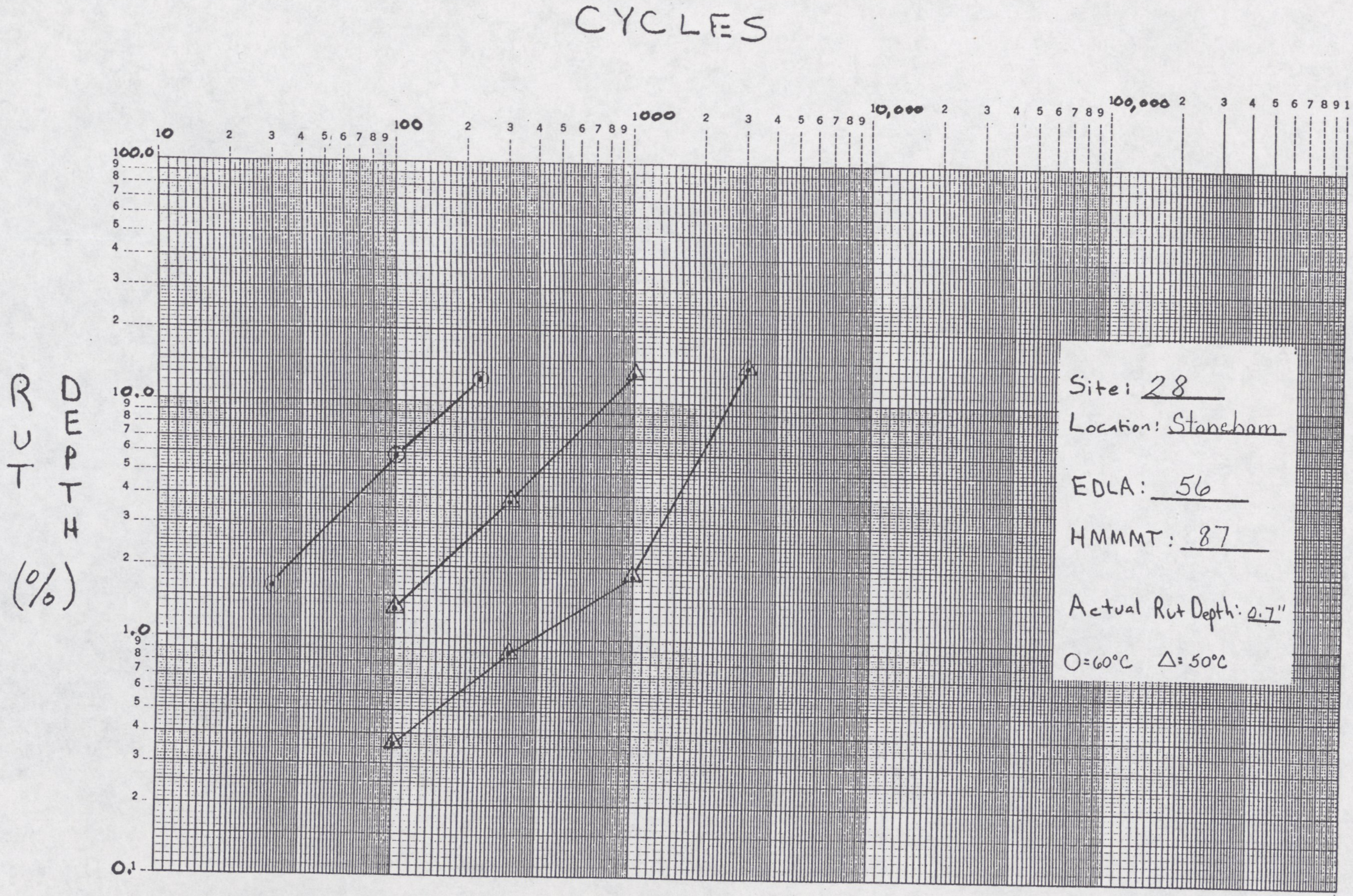
CYCLES
RUT DEPTH (%)
Site: 23
Location: Walsh
EDLA: 48
HMMMT: 91
Actual Rut Depth: 0.1"
O=60°C △=50°C

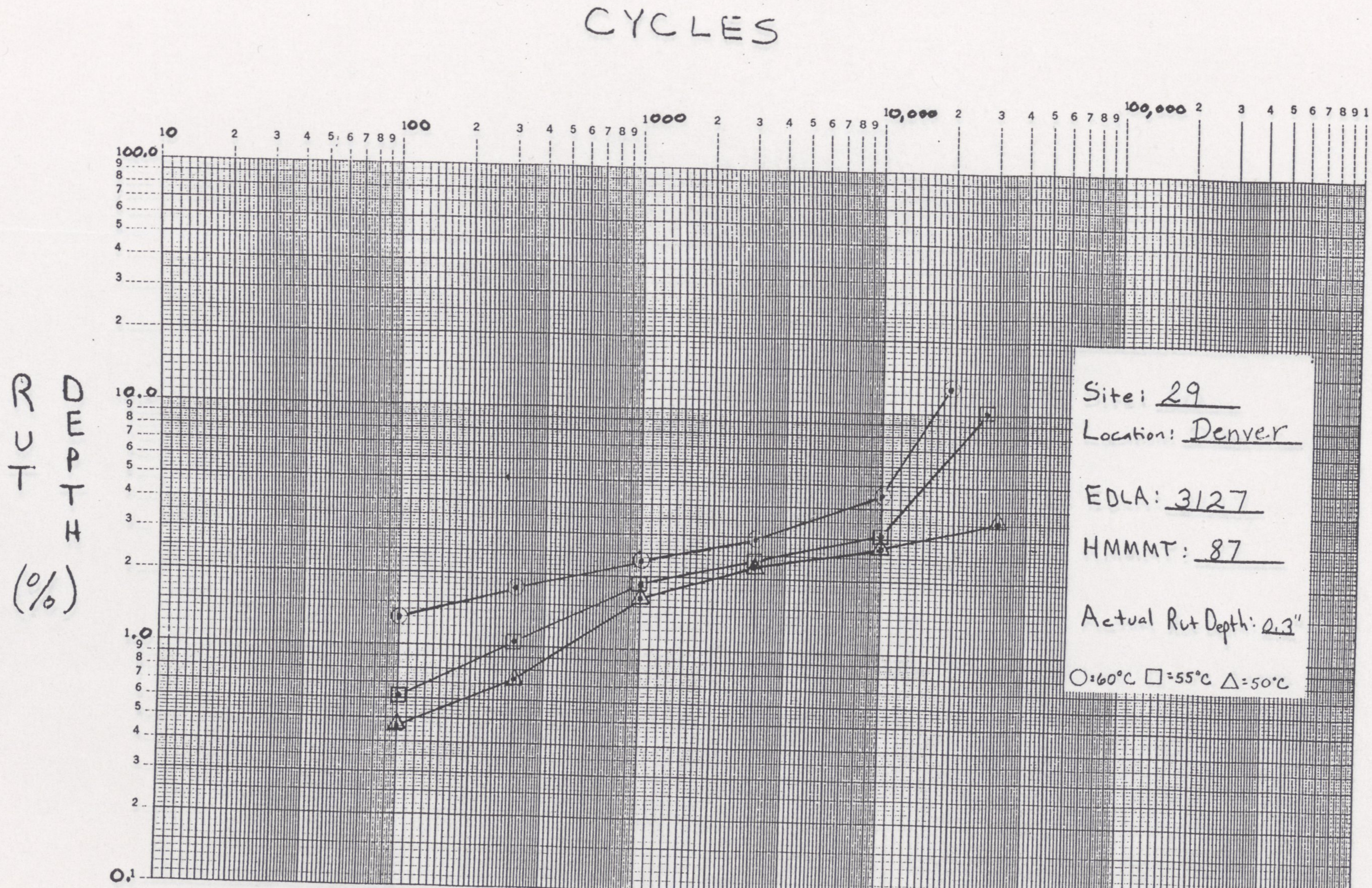

CYCLES
RUT DEPTH (%)
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
Site: 24
Location: Walsh
EDLA: 48
HMMMT: 91
Actual Rut Depth: 0.4"
O=60°C
Δ=50°C


CYCLES
RUT DEPTH (%)
Site: 25
Location: Crook
EDLA: 20
HMMMT: 91
Actual Rut Depth: 0.1"
□=55°
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1

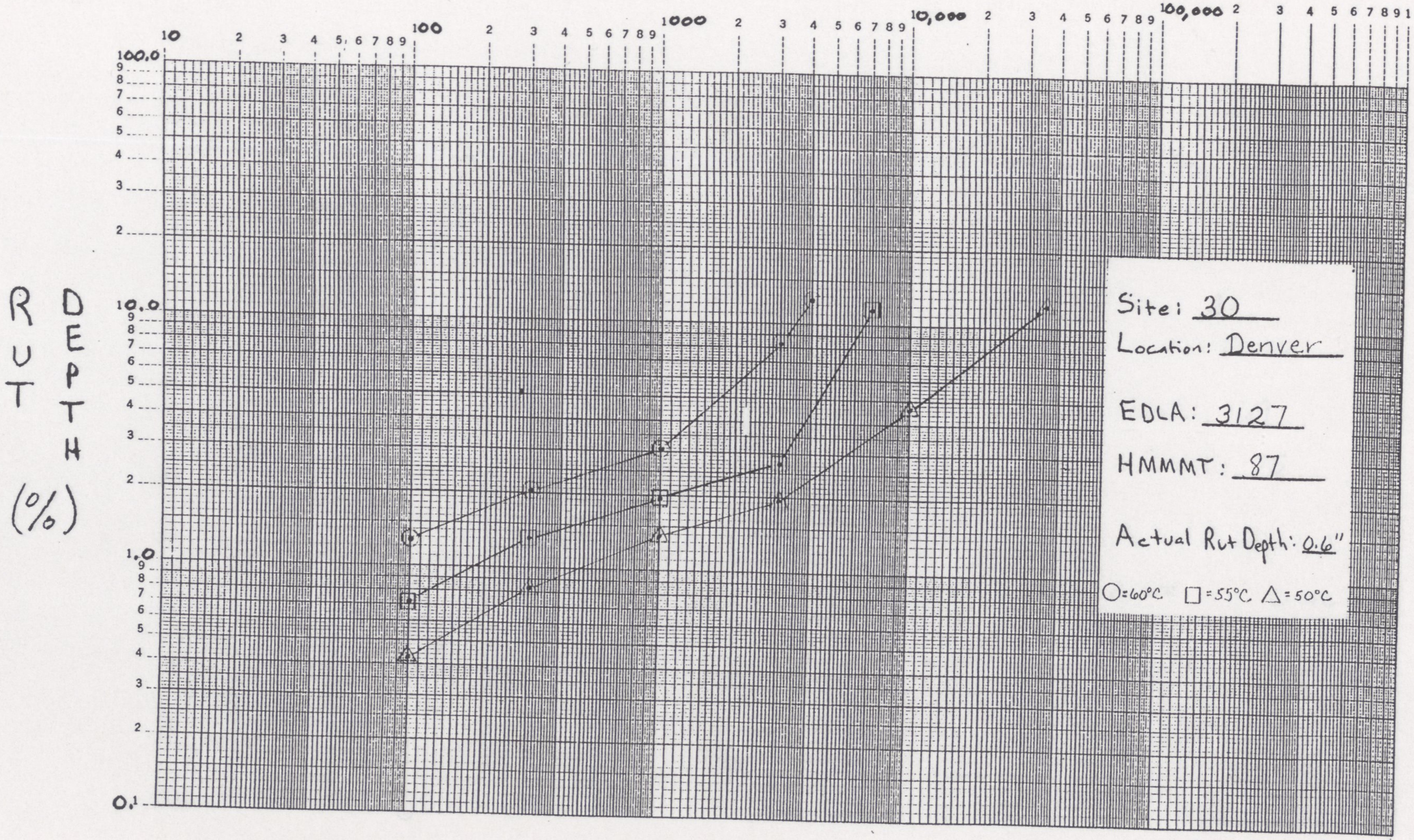

CYCLES
RUT DEPTH (%)
Site: 26
Location: Crook
EDLA: 20
HMMMT: 91
Actual Rut Depth: 0.5"
△=50°C


CYCLES
RUT DEPTH (%)
Site: 27
Location: Stoneham
EDLA: 56
HMMMT: 87
Actual Rut Depth: 0.0"
○=60°C □=55°C △=50°C

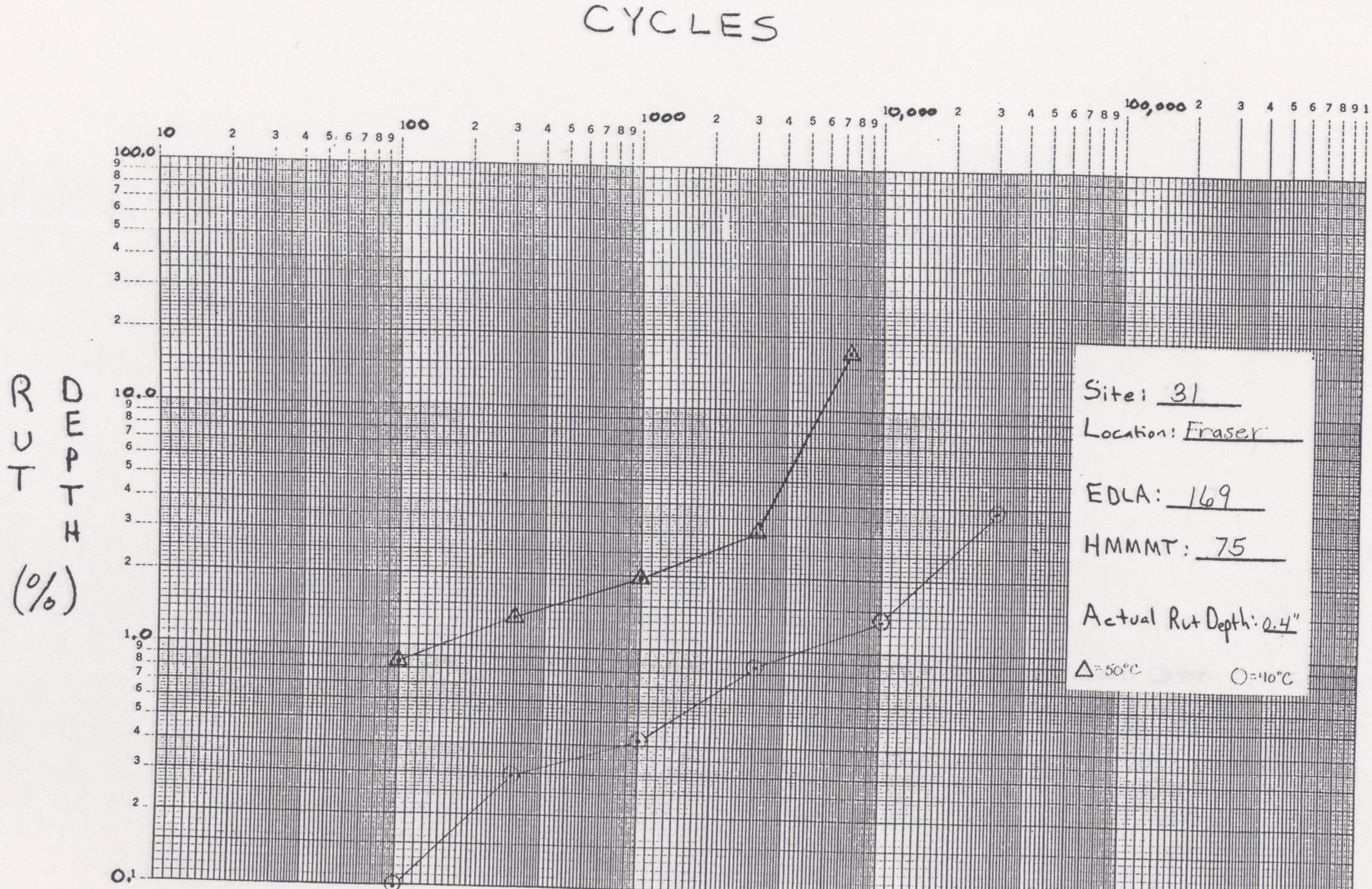

CYCLES
RUT DEPTH (%)
Site: 28
Location: Stoneham
EDLA: 56
HMMMT: 87
Actual Rut Depth: 0.7"
O=60°C △=50°C

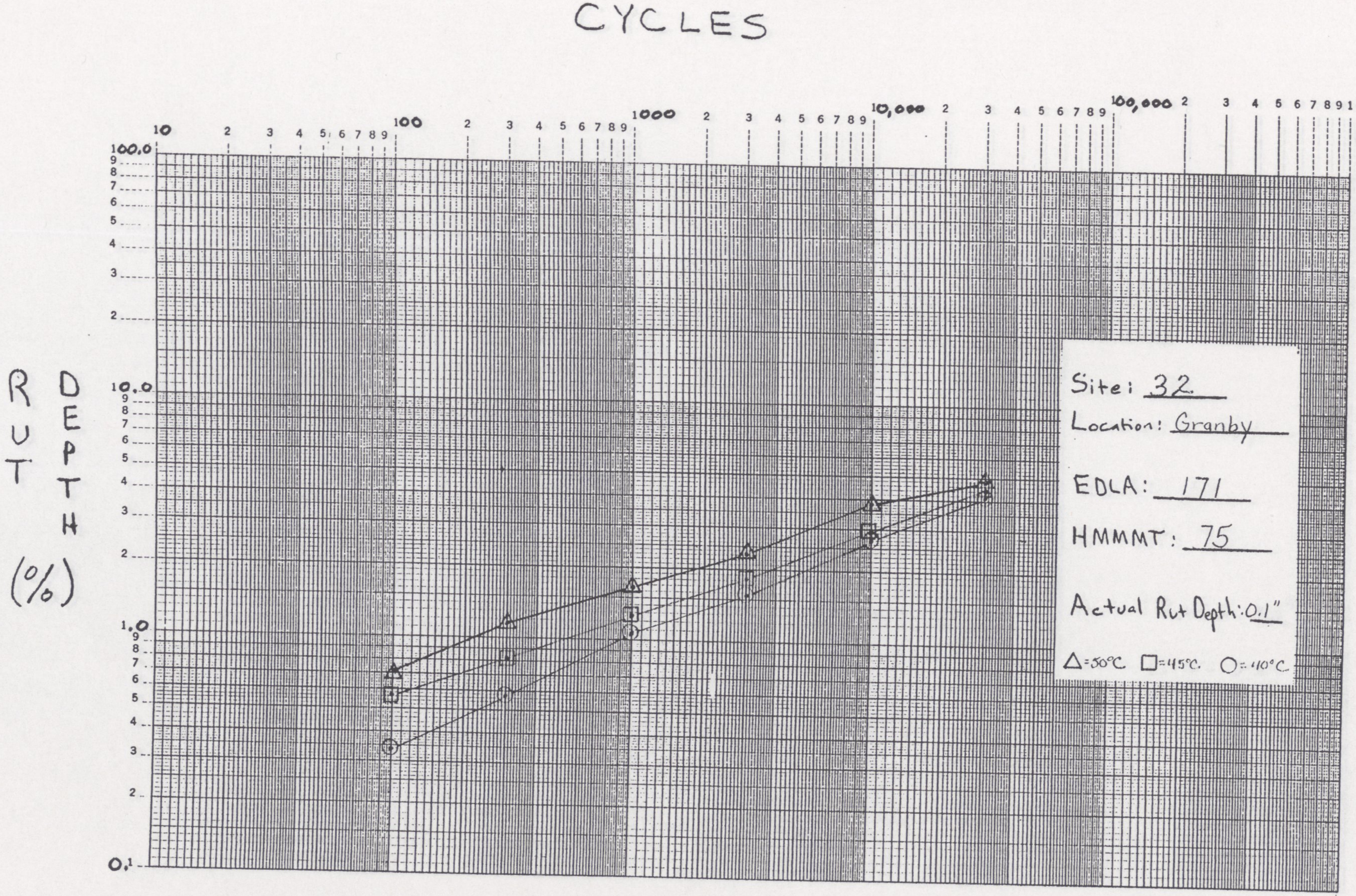

CYCLES
RUT DEPTH (%)
Site: 29
Location: Denver
EDLA: 3127
HMMMT: 87
Actual Rut Depth: 0.3"
○=60°C □=55°C △=50°C

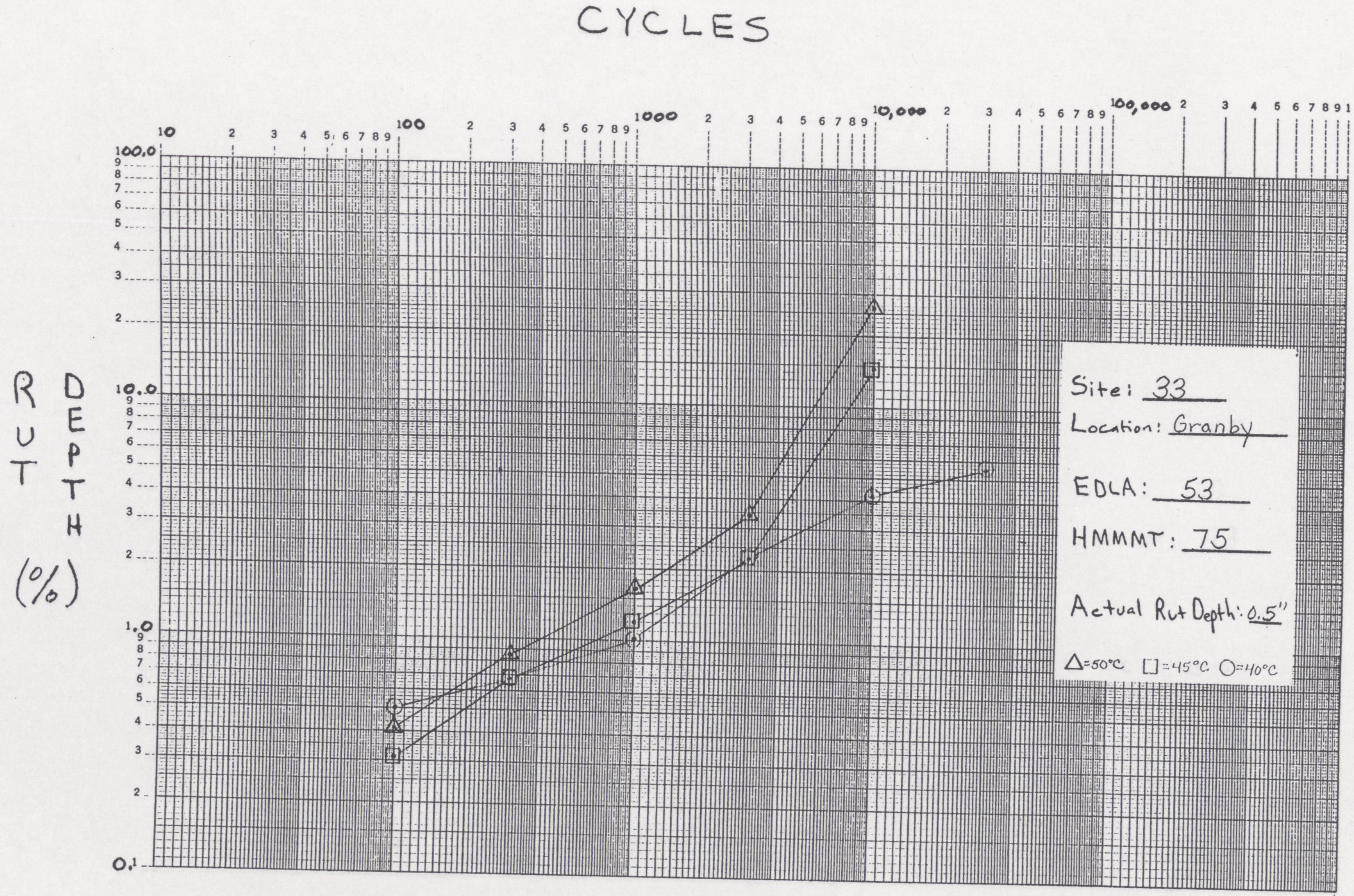
CYCLES

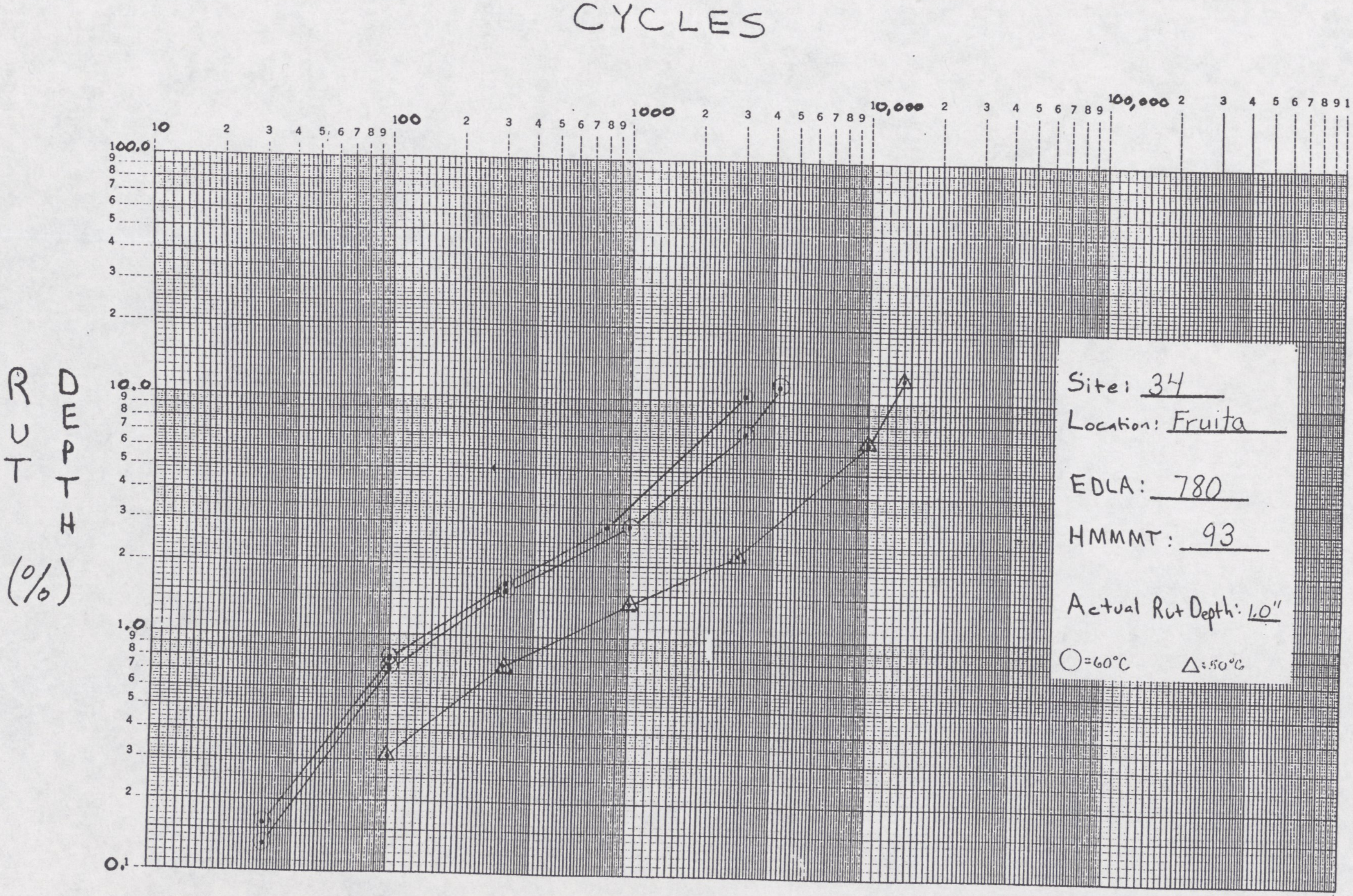


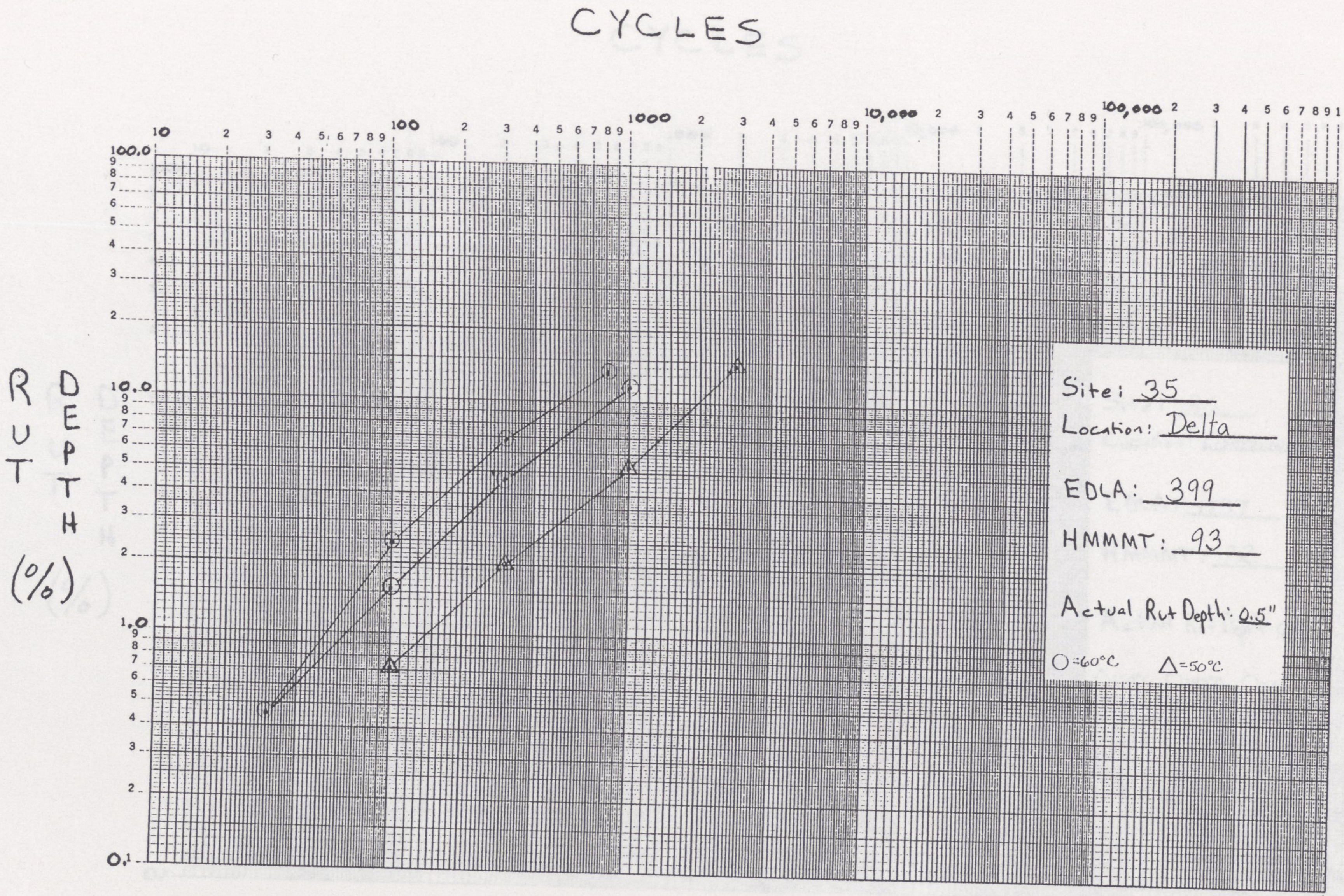
RUT DEPTH (%)
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
Site: 30
Location: Denver
EDLA: 3127
HMMMT: 87
Actual Rut Depth: 0.6"
○=60°C □=55°C △=50°C

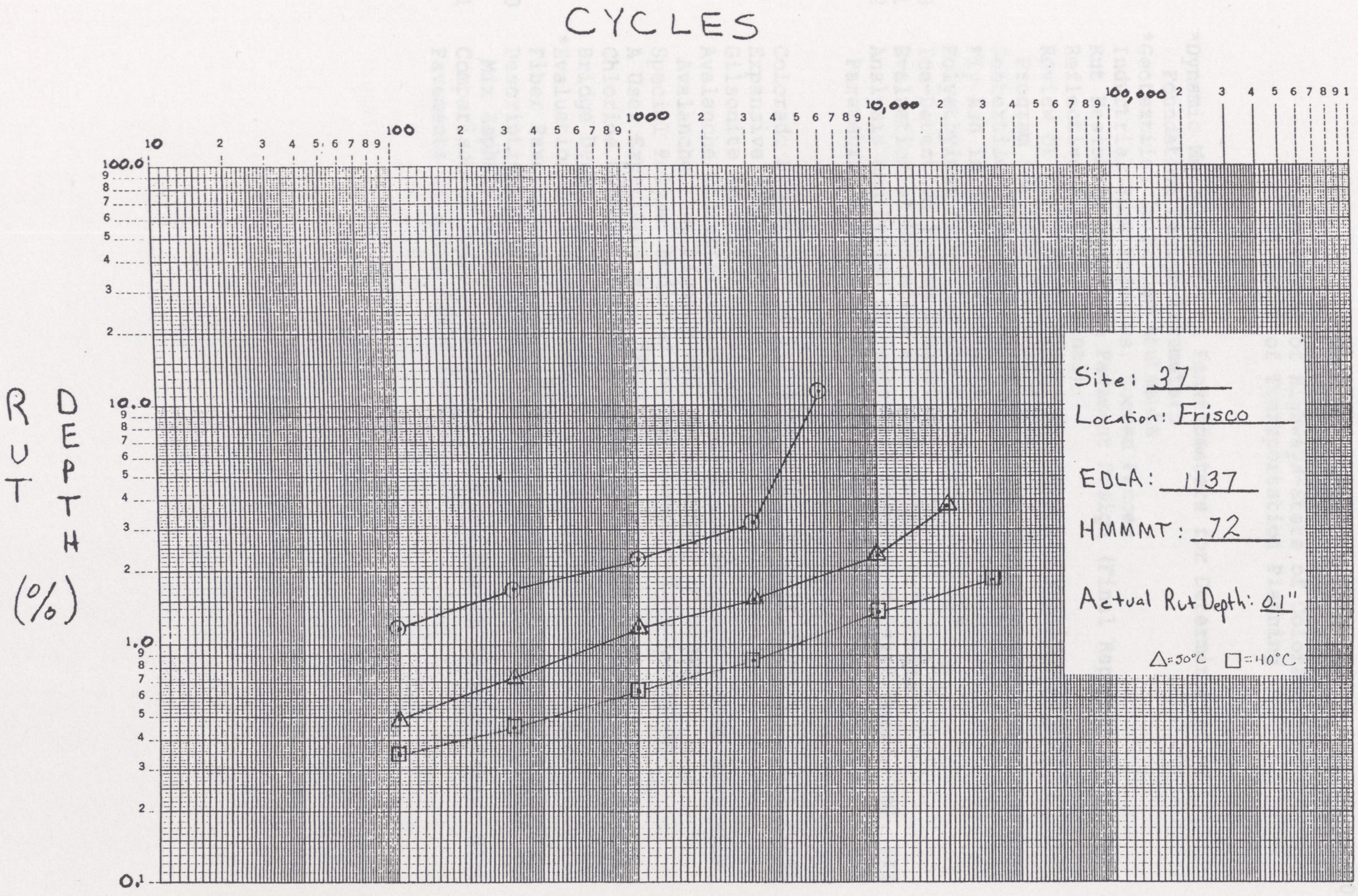

CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 31
Location: Fraser
EDLA: 169
HMMMT: 75
Actual Rut Depth: 0.4"
△=50°C
○=40°C


CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 32
Location: Granby
EDLA: 171
HMMMT: 75
Actual Rut Depth: 0.1"
△=50°C □=45°C ○=40°C


CYCLES
RUT DEPTH (%)
Site: 33
Location: Granby
EDLA: 53
HMMMT: 75
Actual Rut Depth: 0.5"
△=50°C □=45°C ○=40°C


CYCLES
RUT DEPTH (%)
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
Site: 34
Location: Fruita
EDLA: 780
HMMMT: 93
Actual Rut Depth: 1.0"
○=60°C
△=50°C


CYCLES
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
RUT DEPTH (%)
Site: 35
Location: Delta
EDLA: 399
HMMMT: 93
Actual Rut Depth: 0.5"
○=60°C
△=50°C


CYCLES
RUT DEPTH (%)
10
100
1000
10,000
100,000
100.0
10.0
1.0
0.1
Site: 37
Location: Frisco
EDLA: 1137
HMMMT: 72
Actual Rut Depth: 0.1"
△=50°C □=40°C

PUBLICATION
Department of Highways-State of Colorado
Division of Transportation Planning

91-1 *Dynamic Measurements on Penetrometers for Determination of Foundation Design Parameters
91-2 *Geotextiles in Bridge Abutments
91-3 Industrial Snow Fence vs. Wooden Fences
91-4 Rut Resistant Composite Pavement Design (Final Report)
91-5 Reflective Sheeting (Final)
91-6 Review of Field Tests and Development of Dynamic Analysis Program for CDOH Flexpost Fence
91-7 Geotextile Walls For Rockfall Control (CANCELLED)
91-8 Fly Ash in Structural Concrete
91-9 Polyethylene Pipes for Use as Highway Culverts
91-10 Ice-Detection System Evaluation
91-11 Evaluation of Swareflex Wildlife Warning Reflectors
91-12 Analysis and Design of Geotextile-Reinforced Earth Walls, Vol. III Parametric Study and Preliminary Design Method

92-1 Colorado Department of Transportation Asphalt Pavement White Paper
92-2 Expansive Soil Treatment Methods in Colorado
92-3 Gilsonite An Asphalt Modifier
92-4 Avalanche Characteristics and Structure Response - East Riverside Avalanche Shed Highway 550, Ouray County Colorado
92-5 Special Polymer Modified Asphalt Cement - Interim Report
92-6 A User Experience with Hydrain
92-7 Chloride Content Program for the Evaluation of Reinforced Concrete Bridge Decks
92-8 *Evaluation of Unbonded Concrete Overlay
92-9 Fiber Pave, Polypropylene Fiber
92-10 Description of the Demonstration of European Testing Equipment for Hot Mix Asphalt Pavement
92-11 Comparison of Results Obtained From The French Rutting Tester With Pavements of Known Field Performance

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Department of Highways-State of Colorado
Division of Transportation Planning

89-1	Truck Tire Pressures in Colorado
89-2	Rockfall Modeling and Attenuator Testing
89-2B	Colorado Rockfall Simulation Program Users Manual f Version 2.1 (Reprint 11/5/91)
89-3	Frost Heave Control With Buried Insulation
89-4	Verglimit Evaluation (Boulder)
89-5	Use of Road Oils by Maintenance
89-6	Accelerated Rigid Paving Techniques
89-7	IBC Median Barrier Demonstration
89-8	Monitoring of Nondurable Shale Fill in Semi-Arid Climate
89-9	Resilient Properties of Colorado Soils
89-10	Consolidation Testing Using Triaxial Apparatus
89-11	Reactive Aggregate in Structures
89-12	Five Inch Asphalt Overlay
89-13	Avalanche - Interim Report
89-14	Sawed Joints in AC Pavements
89-15	Mirimat Erosion Control Fabric
89-16	Use of Spirolite Plastic Pipe

90-1	Pretreatment of Aggregates
90-2	Experimental Gravel Shoulders
90-3	Cold Recycling of Asphalt Pavement, US 24, Proj. CX-04-0024-25
90-4	Pavement Marking Materials
90-5	Geotextiles in Landfills
90-6	Criblock Retaining Wall
90-7	Project Level Pavement Management
90-8	A Peak Runoff Prediction Method For Small Watersheds in Colorado
90-9	Research Status Report
90-10	Public Perception of Pavement Rideability
90-11	Bridge Deck Repair Demonstration
90-12	Highway Rockfall Research Project
90-13	In-Service Evaluation of Highway Safety Devices, Exp. Proj. No. 7
90-14	Study of Urban Interchange Performance

PUBLICATION
Department of Highways-State of Colorado
Division of Transportation Planning

87-01 Finite Element Analysis of Twin-T Test Walls in Glenwood Canyon, CO
87-02 Flow Conflict Study
87-03 Epoxy Thermoplastic Pavement Marking Demonstration Project 60
87-04 Elastometric Concrete End Dams Used in Conjunction With Bridge Deck Expansion Devices
87-05 Colorado Reactive Aggregate
87-06 Bridge Approach Settlement
87-07
87-08 Third Party Construction Engineering
87-09 Preloading of Sanitary Landfills
87-10 Frost Heave Control With Buried Insulation (Interim)
87-11 AC Gauge "Between Operator" Precision Experiment
87-12 Long-Term Creep of Geotextile in the Confinement of Soils Under Sustained Loading - Phase I
87-13 Dynaflect Benkelman Beam Correlation
87-14 Cathodic Protection
87-15 Rubber Modified Asphalt Concrete
87-16 Concrete Pavement Repair Bennett to Strasburg

88-1 Pavement Profile Measurement Seminar Proceedings, Vol. I, Seminar Overview
88-2 Pavement Profile Measurement Seminar Proceedings, Vol. II, Data Collection Equipment
88-3 Pavement Profile Measurement Seminar Proceedings, Vol. III, Workshop Summaries
88-4 Micro Computers in Project Field Offices
88-5 Development of a Risk Cost Methodology for Detour Culvert Design
88-6 Concrete Pavement Restoration Demonstration
88-7 Inservice Evaluation of Highway Safety Appurtenances, FHWA Experimental Project No. 7 -
88-8 Embankment Settlement in Glenwood Canyon
88-8 Rehabilitation of Concrete Pavements Follow-Up Study
88-10 Effectiveness of Geogrids and Geotextiles in Embankment Reinforcement
88-11 Spring Breakup Study
88-12 Plastic Pipe Use Under Highways
88-13 Geothermal Space Heating
88-14
88-15 Tapered Asphalt Shoulders
88-16 Development of a Retrievable Test Rig for Drilled Pier Bridge Foundations
88-17 Flexible Roadside Delineator Post Evaluation
88-18 Long Term Pavement Monitoring
88-19 Expandable Membrane Ground Anchors in Talus
88-20 Research Status Report