Deep Earth Academy
CONSORTIUM FOR OCEAN LEADERSHIP

Paleocene-Eocene Thermal Maximum (PETM)
Part 1 – Shipboard Data and Analysis

Coring in the Deep Sea and the Role of the Shipboard Scientist

Two Co-Chief Scientists, one Staff Scientist, and 22-25 scientists representing a diverse range of expertise staff each scientific ocean drilling leg, or expedition aboard the *JOIDES Resolution*. The Shipboard Scientific Party may include geophysicists, geochemists, sedimentologists, micropaleontologists, paleomagnetists, physical properties specialists, petrologists, and microbiologists. In addition to the scientists, there are marine technicians, the ship's crew, accommodations staff, and drilling crew on board the drillship.

Once the ship has arrived on-site and coring operations have begun, the Shipboard Scientific Party swings into full gear. With coring operations occurring 24 hours a day, 7 days a week, the ship is a continuous buzz of activity. The scientific party is divided into two 12-hour shifts, with shifts typically on-duty from noon to midnight, and midnight to noon. Which shift would you prefer? There are pros and cons to both!

Coring into the seafloor occurs in 9.5-m intervals corresponding to the length of the core barrel that lies within the hollow drill pipe and locks into a position above the drill bit. Inside the core barrel is a clear plastic core liner containing the cylinder of sediment or rock cut by the drill bit or other coring device (e.g., hydraulic piston corer, advanced piston corer). After a 9.5-m core has been cut, a wire-line is run down the inside of the drill pipe. The wire-line latches on to the top of the core barrel, which is then pulled up to the drill floor and extracted from the drill pipe by the drilling crew. The core barrel is laid on its side and the core-catcher is removed from the bottom of the core barrel (the core-catcher prevents the sediment or rock from slipping out of the core liner as the core barrel is lifted up through the drill pipe). The drilling crew pulls the core liner out of the core barrel. A group of marine technicians then carry the nearly 10-m long core liner filled with sediment (hopefully filled with something other than seawater!) and lay it out on a special rack on the catwalk, which is located outside the core laboratory. The techs then measure the core from the top and mark it off in 1.5 m (150 cm) sections. As each section is cut, it is labeled and an end-cap is affixed to both ends (a blue end-cap for the top and a clear for the bottom).

The 1.5-m sections are brought into the lab and placed in racks for at least 4 hours so that they can thermally equilibrate with surface temperatures. After 4 hours, the cores are run through the multisensor track (MST) to collect an array of data (described below). Now the cores are ready to be split longitudinally into two halves: the working half, which is used to collect discrete samples (e.g., physical properties, paleomagnetics, inorganic and organic geochemistry, micropaleontology), and the archive half, which is used for core description, color reflectance, color scanning, paleomagnetics, and core photography.

Core Description

Describing the geology of the cores collected from beneath the seafloor is one of the most important tasks to be completed as coring proceeds. For sediment expeditions, this task is shouldered principally by the sedimentologists. The sedimentologists prepare visual core descriptions of all cores containing sediments and sedimentary rocks. On the ship they use a software program called AppleCORE to compile their descriptions and other data. Other types of data, including physical properties, magnetic properties,

micropaleontology (age), and interstitial water and sediment geochemistry, are also used to characterize the sedimentary section.

Core description might include the following types of observations:

1. Sediment color
2. Composition (type of sediment = lithology)
3. Induration (soft, firm, hard)
4. Bedding contacts (sharp, gradational, scoured)
5. Sedimentary structures (e.g., graded bedding, laminated, cross bedding, bioturbation, microfaults)
6. Accessory components (e.g., macrofossils, concretions, pebbles)
7. Drilling disturbance

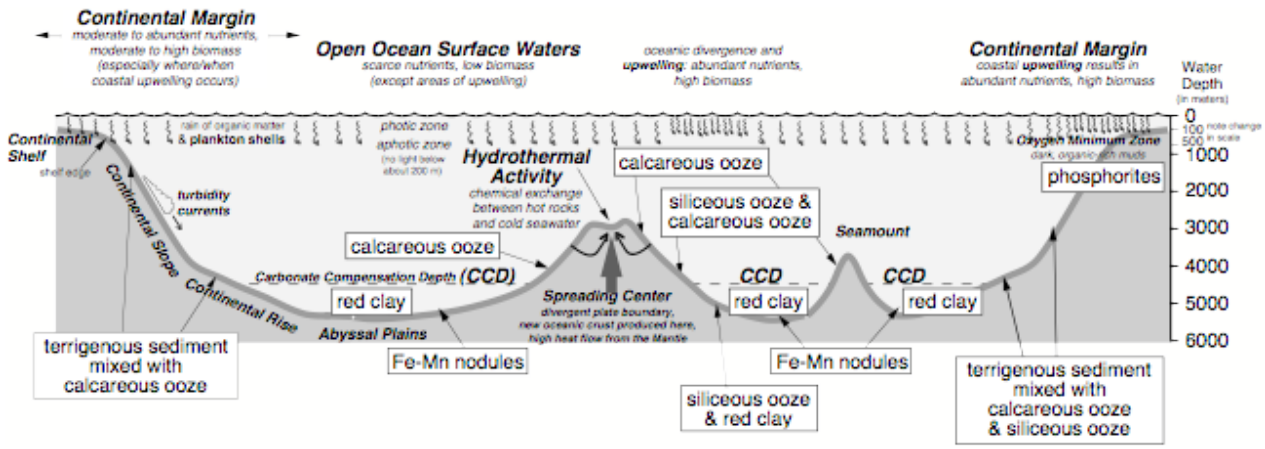
Color is a very important visual property of sediments. It can be indicative of sediment composition, or the oxidation state of iron present in sedimentary minerals. For example, sediment consisting primarily of plankton shells (e.g., calcareous ooze, siliceous ooze; see below) ranges in color from light gray or tan to pure white, while sediment rich in mud is typically much darker in color. Sediments that accumulated under well-oxygenated conditions are typically red to brown due to the presence of oxidized iron, whereas sediments that accumulated under oxygen-poor or anoxic conditions are typically green to black due to the presence of reduced iron and/or organic matter.

Coarse-grained sediments are examined with a hand-lens in order to determine the composition. For fine-grained sediments, smear slides are prepared by taking a small amount of sediment (e.g., sampled from the split core with a toothpick) and mixing it with a couple of drops of water to make a slurry, which is spread thinly on a glass slide and then covered with a glass cover slip. The smear slides are examined under a petrographic microscope to determine the composition of the sediment (Figure 1). You will be considering actual smear slide data in the core description exercise that follows. If the sediment has been indurated to rock, then a thin-section can be cut and polished in order to determine to composition. A brief summary of the major types of deep-sea sediments is presented below.

Marine Sediments – A primer adapted from Leckie and Yuretich, *Investigating the Ocean-An Interactive Guide to the Science of Oceanography*, 3rd Edition, McGraw-Hill, 2003.

Sediments on the floor of the deep-sea are classified according to the texture (e.g., grain size) and the composition of the materials. Their distribution in the world ocean is related to a number of factors including proximity to source, processes of distribution (gravity, deep and shallow ocean currents, and wind), and ocean chemistry. Mixtures of sediment types are common.

Terrigenous sediment or lithogenic sediment is composed of sand, silt, or clay-sized particles derived from the physical and chemical weathering of rocks and soil on land. These sediments form an apron of debris around the continents, consisting mostly of sand and mud. Specific varieties of lithogenic sediment include red clay (wind-blown silt and clay deposited on the abyssal plains), neritic sediment (terrigenous sediment of the continental shelves), glacial marine sediment (deposited by glacial ice or transported out to sea by icebergs as ice-rafted debris and deposited in an apron around land areas in the high latitudes), and volcaniclastic sediment (eroded or ejected volcanic debris and ash deposited around volcanic islands and seamounts).



Biogenic sediment is composed of the microscopic shells of marine plankton (single-celled protists). Plankton live in the sunlit surface waters where they passively drift with the ocean currents. The groups of plankton with mineralized shells are important contributors to deep-sea sediments; *in many places in the deep-sea these microfossils are the sediment*. Plankton with shells of calcium carbonate ($CaCO_3$), including calcareous nannoplankton and planktic foraminifera, produce a type of sediment called calcareous ooze. Nearly 50% of the ocean floor beyond the continental margins is today covered by calcareous ooze. The White Cliffs of Dover are composed of chalk, which is lithified calcareous ooze (i.e., nearly 100% biogenic sediment!). Plankton with shells of opaline silica ($SiO_2 \cdot H_2O$), including diatoms and radiolarians, produce siliceous ooze. Two examples of lithified siliceous ooze are diatomite and chert. Siliceous ooze accumulates beneath areas of high biological productivity, including the zone of equatorial divergence and the cool surface waters of the high latitudes.

Plankton are grazed and preyed upon by many types of small and large animals, ranging from the flea-sized copepods (an abundant type of zooplankton) to the largest baleen whales. As a result, their microscopic shells are packaged into fecal pellets. Fecal pellets are an important mode of transport of the tiny shells from the surface waters where the plankton live to the seafloor where the shells accumulate. Passive settling through the water column is another mode of deposition.

The Carbonate Compensation Depth (CCD) represents a chemical boundary in the deep ocean (~4000-5000 m water depth). Calcareous ooze does not accumulate on the seafloor at depths greater than the CCD because of intense chemical dissolution caused by low temperature, high pressure, and relatively high concentration of dissolved CO_2. Red clay is the most common lithology found on the abyssal plains beneath the CCD where sedimentation rates are very low.

Authigenic sediment precipitates directly from seawater. Precipitation may be mediated by microbial activity. Authigenic sediments are most common in areas below the CCD, or in areas of very slow pelagic or terrigenous accumulation rates (e.g., iron-manganese nodules), or along continental margins with high biological productivity (phosphorites). Gas hydrates (also called methane clathrates) also form along productive continental margins due to the decomposition of organic matter by methanogenic bacteria in the sediments. Zeolites (a group of hydrous alumino-silicate minerals with microperforate crystalline structure) and zeolitic clay accumulate in parts of the deep-sea due to the alteration of volcanic glass or by hydrothermal alteration of volcanic alumino-silicate minerals.

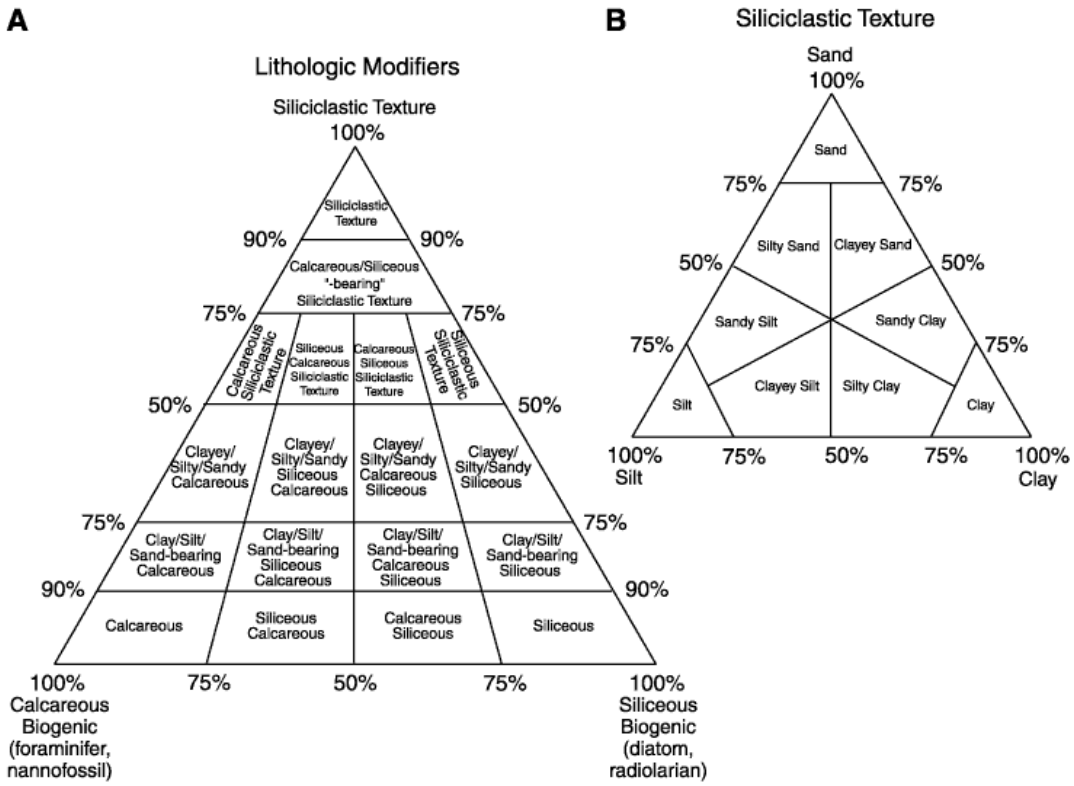


Figure 1. Sediment classification *used for ODP Leg 208.* ***A.*** *Ternary diagram for calcareous, siliceous, and siliclastic end-member lithologies.* ***B.*** *Ternary diagram for siliclastic lithologies. http://www-odp.tamu.edu/publications/208_IR/chap_02/c2_f1.htm#535817*

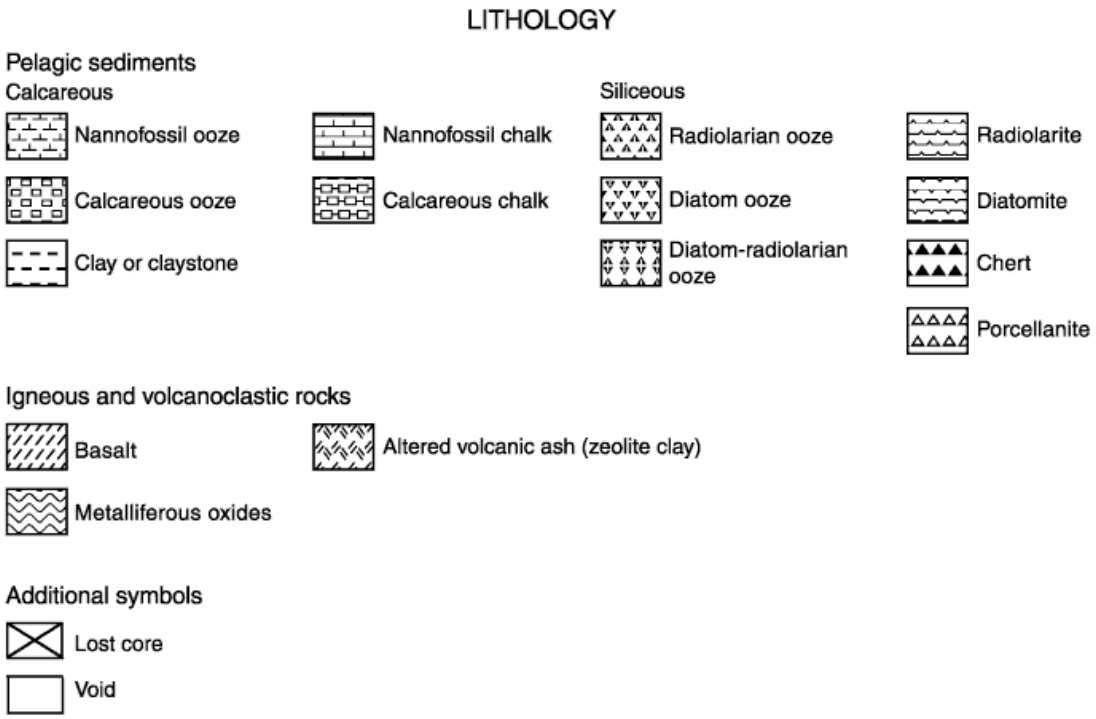


Figure 2. *Key to symbols used for graphic lithologies on the AppleCORE summary barrel sheets. http://www-odp.tamu.edu/publications/199_IR/chap_02/c2_f3.htm#547431*

Non-Destructive Shipboard Measurements

Shipboard measurements of physical properties can be used to provide an initial look at variations in the recovered core material, which may be used to characterize lithologic units, correlate with downhole geophysical logging data, and interpret seismic reflection data. After the cores have attained room temperature, non-destructive tests of the whole-round (unsplit) core sections are made with the multisensor track (MST). The MST consists of four physical property sensors on an automated track that measures magnetic susceptibility, bulk density, compressional wave velocity, and natural gamma ray emissions. After splitting the cores, additional measurements are made of P-wave velocity on cores of soft sediments and on discrete samples of hard rock. Bulk density, grain density, porosity, and water content are calculated from moisture and density measurements on discrete samples. Thermal conductivity measurements are also made on whole sediment cores and split hard rock cores (for more detail see *http://www-odp.tamu.edu/publications/200_IR/chap_02/c2_6.htm*).

Two measurements that are frequently used on sediment cores to characterize sediment composition and detect cyclic trends are magnetic susceptibility and color reflectance. Magnetic susceptibility is the degree of magnetization of the sediment and is measured on the whole-round core before it is split. Magnetic susceptibility data aid in detecting variations in magnetic properties caused by lithologic changes or alteration. The core is passed through a magnetic loop that is mounted on the MST and measurements are collected at 1 to 3-cm spacing.

Once the cores are split into a working half and an archive half, color reflectance is measured on the archive halves after the cores are described and before they are measured for magnetic intensity, inclination, and declination in the cryogenic magnetometer. In addition to visual estimates of the color, reflectance of visible light from soft sediment cores is routinely measured using a Minolta spectrophotometer mounted on the archive multisensor track (AMST). The AMST provides a high-resolution stratigraphic record of color variations for visible wavelengths (400-700 nm). Freshly split cores are covered with clear plastic wrap and placed on the AMST. Measurements are taken at 1 to 3-cm spacing.

Figure 3 shows a visual core description and associated gamma ray attenuation, magnetic susceptibility, and color reflectance data.

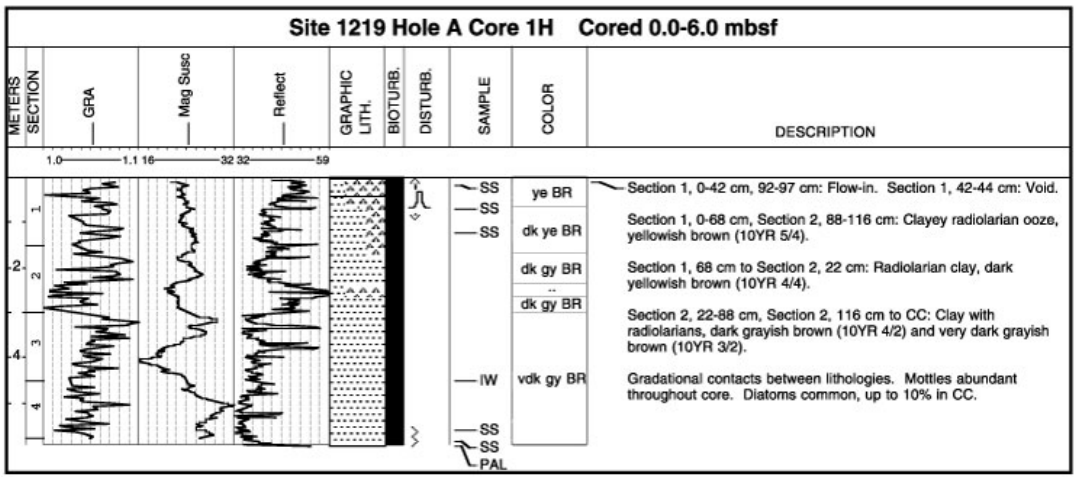


Figure 3. *Example of an AppleCORE* ***summary barrel sheet showing MST and AMST data (GRA, MS, and color reflectance) alongside a simplified graphical summary of the visual core description****. MST = multisensor track, GRA = gamma ray attenuation, SS = smear slide, IW = interstitial water samples, PAL = micropaleontology samples, ye BR = yellowish brown, dk ye BR = dark yellowish brown, dk gy BR = dark grayish brown, vdk gy BR = very dark grayish brown. From the ODP Leg 199 Initial Report volume (http://www-odp.tamu.edu/publications/199_IR/chap_02/c2_f2.htm).*

Sample Data and Exercises

The purpose of this exercise is to become familiar with a rapid perturbation to the ocean-climate system about 55 million years ago referred to as the Paleocene-Eocene Thermal Maximum, or PETM. In the first part of our exploration of the PETM, we want to consider the view of the event from the perspective of a shipboard scientist. We will examine select cores from the deep-sea that are known to contain the PETM. Our first priority is to describe the cores. We will use core photographs, smear slide data (qualitative estimates of sediment composition), magnetic susceptibility, and color reflectance. Data from nine deep-sea sites representing four regions of the world ocean will be considered (Table 1).

1. Prepare a description of one of the ODP sites using the core photograph and available smear slide, magnetic susceptibility, and color reflectance data.
2. Can you find physical evidence in this core for an abrupt change in the nature of the sediment? What section and interval? Describe the characteristics of this interval (i.e., how does it differ from sediments above and below)?
3. How does your core compare with nearby sites?
4. How is your core similar, and how does it differ from the more distal cores?
5. How might these observations be formulated into a series of hypotheses to describe the cause or effects of the PETM?

Table 1. *Select ODP cores containing the PETM*

ODP Leg	Hole-Core	Core Depth	Location	Latitude	Longitude	Water Depth
113	690B-19H	166.9-174.3	Maud Rise, Southern Ocean	65°9.63'S	1°12.30'E	2914 m
198	1209B-22H	195.1-204.6	Shatsky Rise, NW Pacific	32°39.11´N	158°30.36´E	2387 m
198	1210B-20H	180.2-189.7	Shatsky Rise, NW Pacific	32°13.42´N	158°15.56´E	2573 m
198	1211C-13H	111.8-121.3	Shatsky Rise, NW Pacific	32°0.12´N	157°51.00´E	2907 m
199	1220B-20X	197.4-202.0	Equatorial Pacific	10°10.60´N	142°45.50´W	5218 m
199	1221C-11X	150.4-155.4	Equatorial Pacific	12°01.99´N	143°41.65´W	5174 m
208	1262A-13H	114.0-123.5	Walvis Ridge, SE Atlantic	27°11.16´S	1°34.62´E	4759 m
208	1263C-14H	282.4-285.6	Walvis Ridge, SE Atlantic	28°31.98´S	2°46.78´E	2717 m
208	1266C-17H	264.0-273.5	Walvis Ridge, SE Atlantic	28°32.54´S	2°20.61´E	3797 m

We will work in teams, just like a shipboard scientific party, and then share our findings with others, just like we were publishing our preliminary results in the Initial Reports volume of the Ocean Drilling Program.

Notice that multiple drill sites (holes) are represented for three of the regions (northwest Pacific, equatorial Pacific, and southeast Atlantic), while a single drill site represents the Southern Ocean. You will each focus on a single site, but it will be useful to compare your findings with other results from nearby sites so that we may investigate similarities and differences among the sites. For example, might latitude (climatic zone) or water depth account for some of the differences within regions or between regions? Let's find out.

Table 2. Smear slide data from each of the 9 select drill sites. These are qualitative data based on visual estimates. Please note that no smear slide data are available for Holes 1209B, 1210B, and 1211C; therefore, smear slide data from Holes 1209A, 1210A, and 1211A, which also contain the PETM, are provided to represent the composition of the sediment adjacent to the PETM interval.

In addition to core photographs, magnetic susceptibility and/or color reflectance data are provided for all the sites with the exception of Site 690.

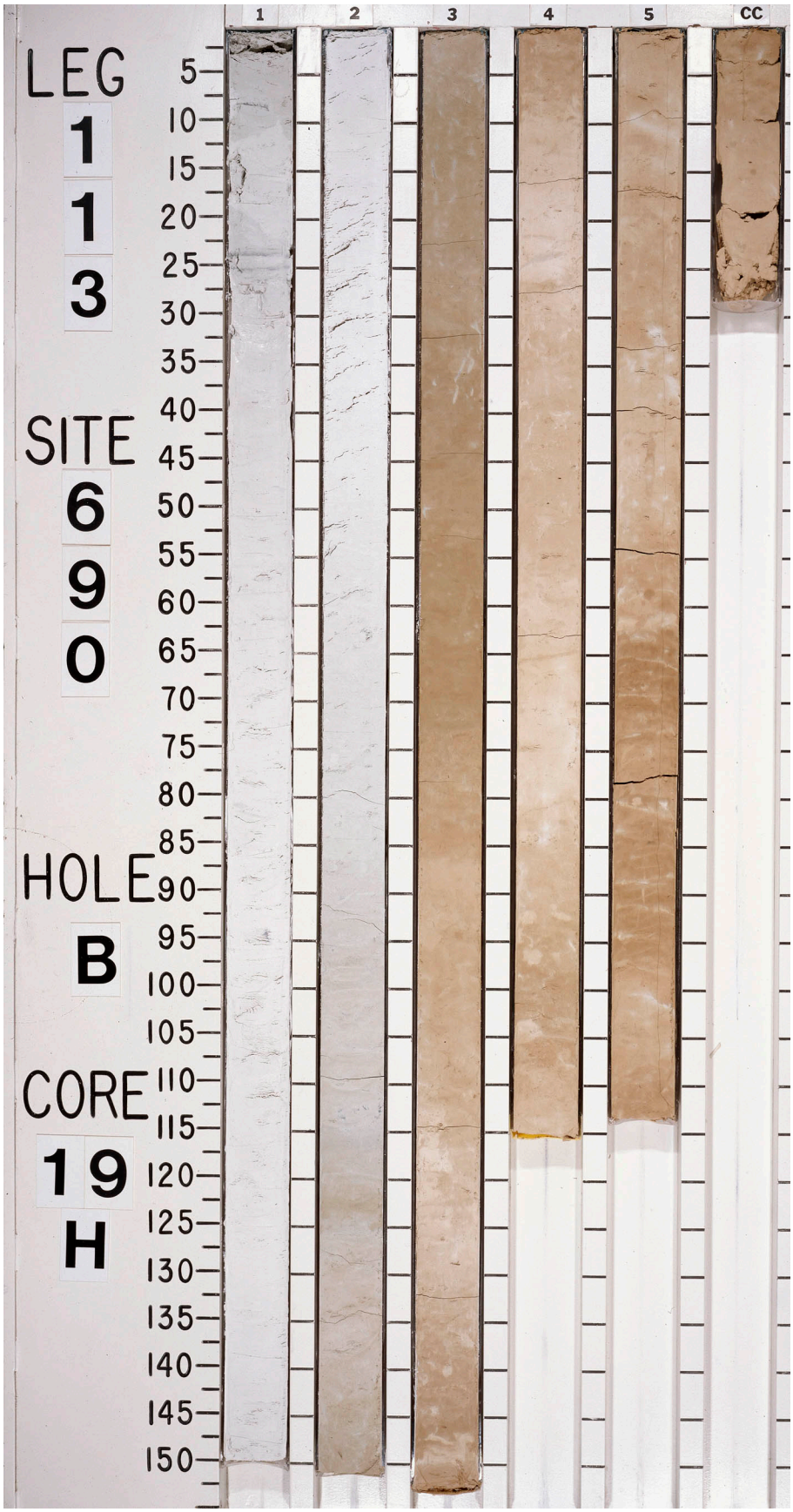
Developed by: Mark Leckie (mleckie@geo.umass.edu) and Debbie Thomas (dthomas@ocean.tamu.edu), 3/2007

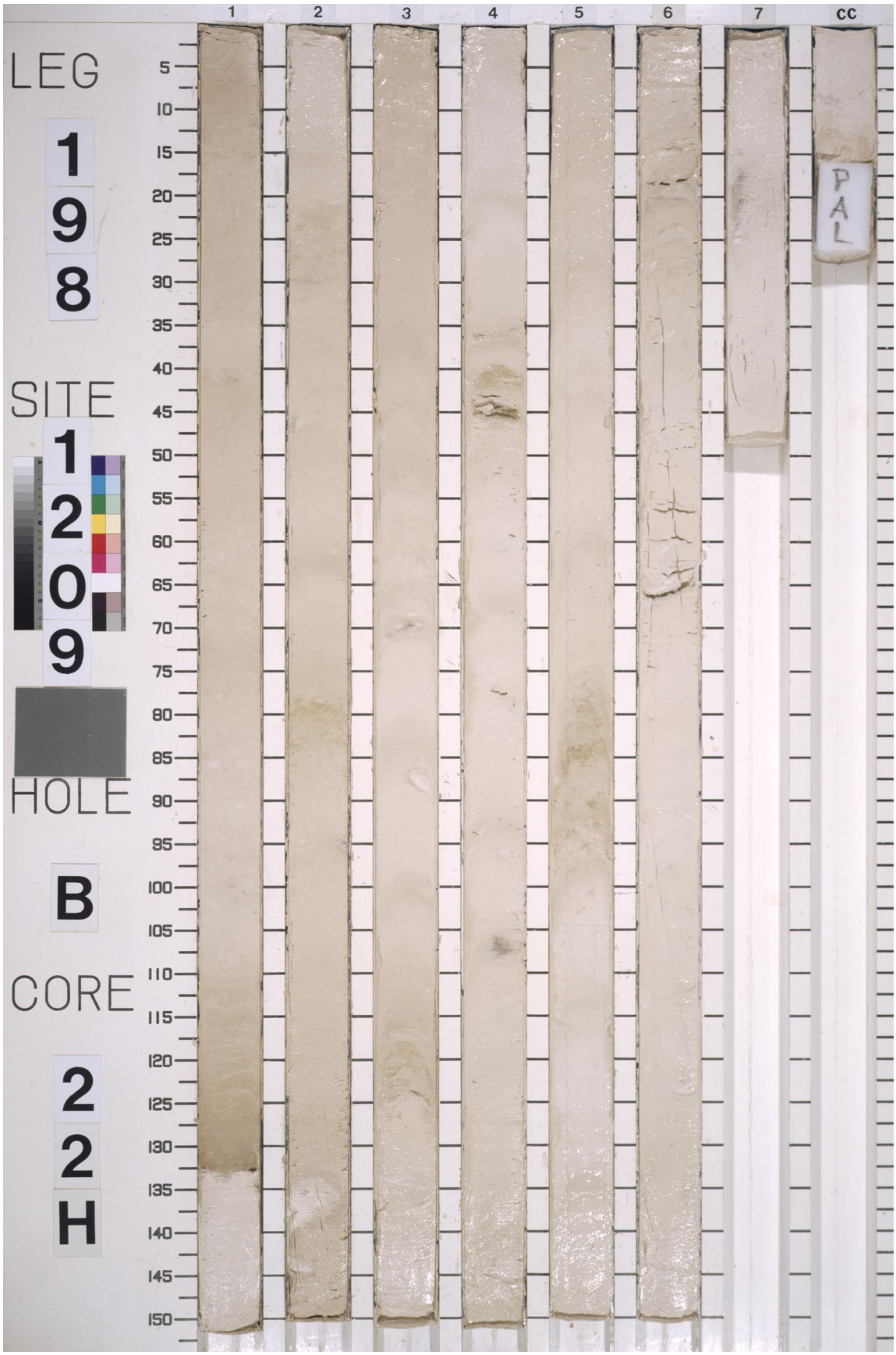
Table 2. Smear slide data.

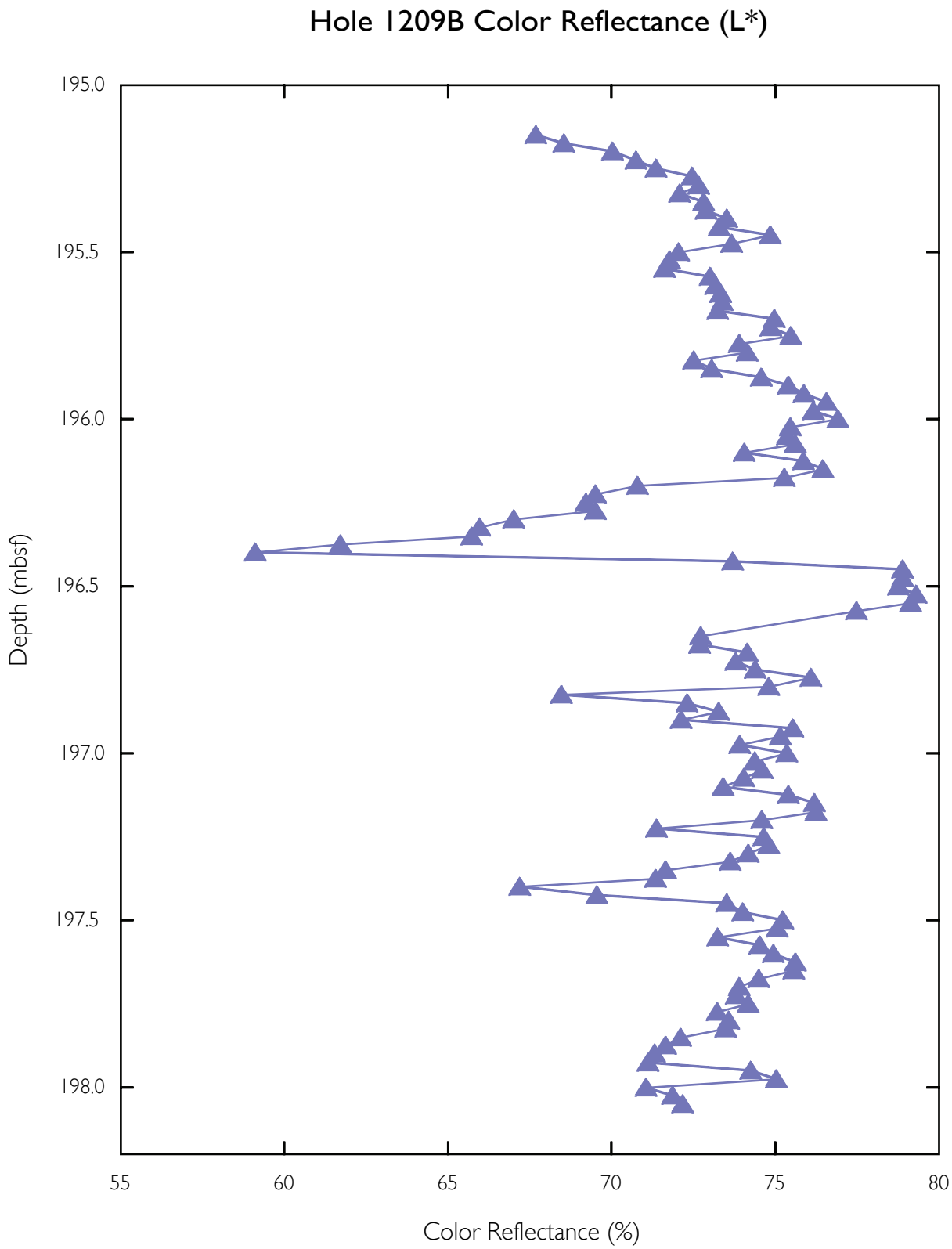
Smear Slide Analyses - Qualitative Estimates							Mineral Component										Biogenic Component							
ODP Leg	Hole	Core	Core Type	Section	Top (cm)	Depth (mbsf)	Clay Minerals	Fe oxides	Quartz	Mica	Feldspar	Volcanic Glass	Apatite	Opaque Minerals	Inorganic Calcite	Dolomite	Zeolite	Calcispheres	Calcareous Nannofossils	Planktic Foraminifers	Dinoflagellates or Pollen	Organic Debris	Diatoms	Radiolarians	Comments
113	690B	19	H	1	50	167.40	15		tr	15		tr							69	1					
113	690B	19	H	2	50	168.90	5		1	10									84	tr			tr		
113	690B	19	H	3	50	170.40	15		1	10									71	3					tr = trace (<1%)
113	690B	19	H	4	50	171.90	7		1	10									67	15					
113	690B	19	H	5	50	173.40	10		tr	7					tr				73	10					
198	1209A	21	H	1	72	189.42	8	tr						1	5				80	6					no smear slide data available for Hole 1209B
198	1209A	21	H	3	60	192.30		tr						tr	5				80	7					PETM is in Section **1209A-21H-7**
198	1209A	21	H	7	25	197.95	5	tr						tr	15				75	5					
198	1209A	21	H	7	26	197.96	5	10						tr	5				75	5					
198	1209A	21	H	7	31	198.01	5	tr						tr	5				85	5					
198	1210A	20	H	1	71	177.61	12												87	1					no smear slide data available for Hole 1210B
198	1210A	20	H	2	25	178.65	30					5							59	6					PETM is in Section **1210A-20H-6**
198	1210A	20	H	3	71	180.61	6												93	1					
198	1210A	20	H	6	50	184.90	31	1							10				38	8	12				
198	1210A	20	H	6	115	185.55	5								5				88	2					
198	1211A	13	H	1	60	107.90	tr								7				90	3					no smear slide data available for Hole 1211C
198	1211A	13	H	1	90	108.20	25				tr				2				73	tr					PETM is in Section **1211A-13H-5**
198	1211A	13	H	6	11	114.76	13				5				2				75	2	3				
199	1220B	20	X	1	30	197.70	30	5				tr			20	35			10						
199	1220B	20	X	1	57	197.97	15					tr			2	15			68						
199	1220B	20	X	1	93	198.33	10								5	15			70						
199	1220B	20	X	1	128	198.68	5								2	10			83						
199	1220B	20	X	2	4	198.94		tr				tr			10	5			85						
199	1220B	20	X	2	8	198.98	5								5	2		1	87						
199	1220B	20	X	2	25	199.15		tr							60	5		tr	20	15					
199	1220B	20	X	2	32	199.22	10	tr							60	5		tr	5	20					
199	1220B	20	X	2	33	199.23	10								45	5			10	30					
199	1220B	20	X	2	44	199.34									78	2		5	10	5					
199	1220B	20	X	2	47	199.37	10								82	5		3		tr					
199	1220B	20	X	2	48	199.38	25	1							61	10		1		2					
199	1220B	20	X	2	54	199.44	35	3						5	47	10									
199	1220B	20	X	2	59	199.49	35	5				tr		30	20	10			tr						
199	1220B	20	X	2	63	199.53	50	18				2		25		5									
199	1220B	20	X	2	65	199.55	35	4				1		5	45	5			5						
199	1220B	20	X	2	66	199.56	20	2				3		5	35	20			15	tr					
199	1220B	20	X	2	68	199.58	15	2				2			68	10			3						
199	1220B	20	X	2	70	199.60	35					5		20	10	15	15								
199	1220B	20	X	2	76	199.66	25								58	10	2		5						
199	1220B	20	X	2	85	199.75	5	tr				tr			25				70						
199	1221C	11	X	1	121	151.61	10								50	18		1	20	1					
199	1221C	11	X	1	139	151.79	15								30	30			25	tr					
199	1221C	11	X	3	30	153.70	10								55	15		5	15						
199	1221C	11	X	3	45	153.85	10								60	7		3	20						
199	1221C	11	X	3	48	153.88	10	tr							68	5		2	15	tr					
199	1221C	11	X	3	51	153.91	15								72	3	5	tr	5	tr					
199	1221C	11	X	3	54	153.94	15	2						3	65	tr			15						
199	1221C	11	X	3	55	153.95	20	10						20	25		10		15						
199	1221C	11	X	3	56	153.96	10	tr						1	69			tr	20						
199	1221C	11	X	3	57	153.97	15							1	59	5		tr	20						
199	1221C	11	X	3	60	154.00	15						3	5	5		70		2						
199	1221C	11	X	3	62	154.02	15	1					5	4	3		70		2						
199	1221C	11	X	3	64	154.04	10	3					5	12	tr		70		tr						
199	1221C	11	X	3	66	154.06	10					tr	5	3		3	79								
199	1221C	11	X	3	68	154.08	20	10					3	15	2		50								
199	1221C	11	X	3	69	154.09	50	3					2	6	15	4	10		10						

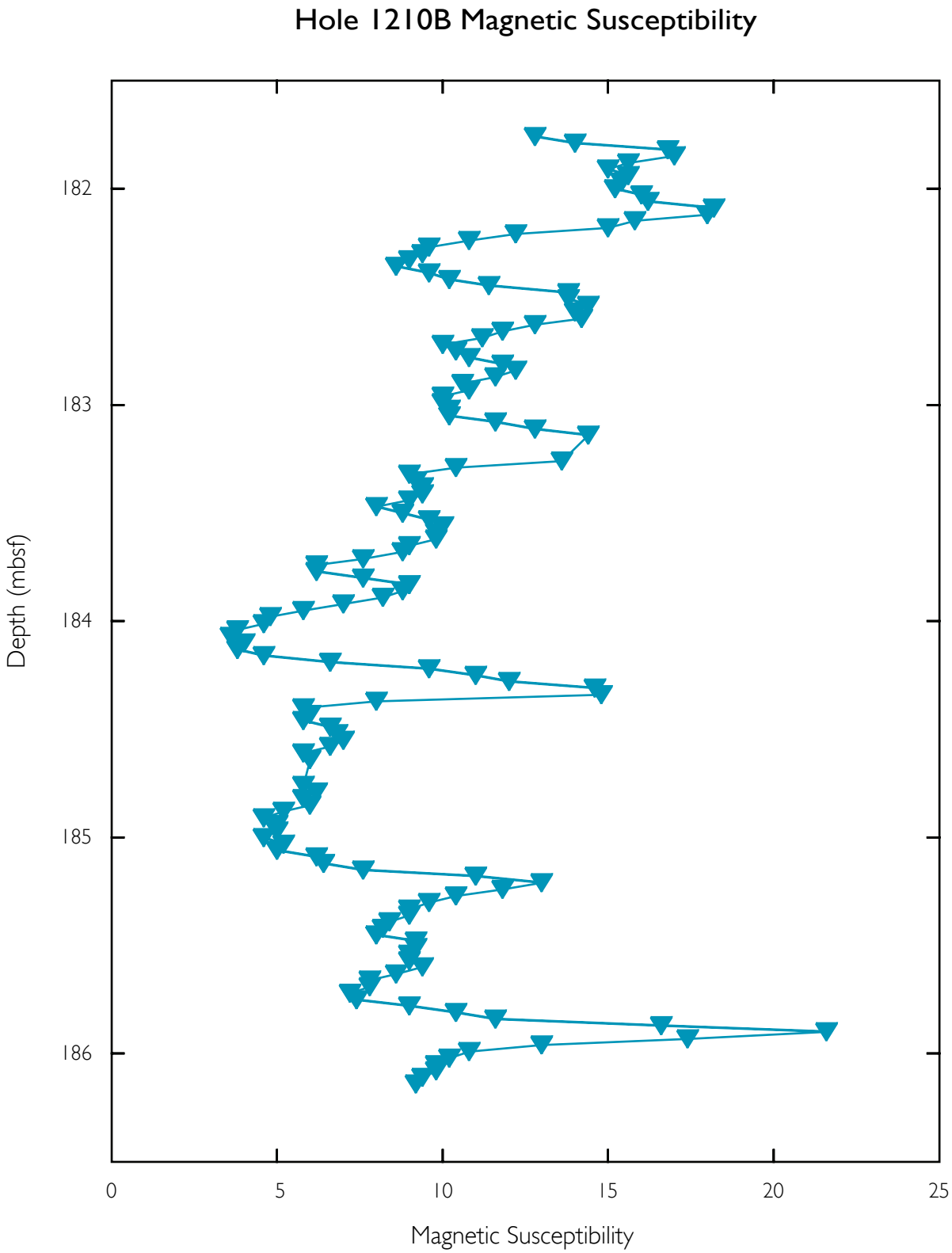
Smear Slide Analyses - Qualitative Estimates							Mineral Component											Biogenic Component							
ODP Leg	Hole	Core	Core Type	Section	Top (cm)	Depth (mbsf)	Clay Minerals	Fe oxides	Quartz	Mica	Feldspar	Volcanic Glass	Apatite	Opaque Minerals	Inorganic Calcite	Dolomite	Zeolite	Calcispheres	Calcareous Nannofossils	Planktic Foraminifers	Dinoflagellates or Pollen	Organic Debris	Diatoms	Radiolarians	Comments
199	1221C	11	X	3	70	154.10	25	3					2	15	5		45		5						
199	1221C	11	X	3	71	154.11	45	15						35			5		tr						
199	1221C	11	X	3	73	154.13	27	3						25			45		tr						
199	1221C	11	X	3	75	154.15	25				tr	5				tr	70								
199	1221C	11	X	3	77	154.17	63	1			tr			35	1	tr	tr		tr						
199	1221C	11	X	3	78	154.18	44	1				5			tr		50		tr						
199	1221C	11	X	3	79	154.19	10	1				tr		2	tr		87		tr						
199	1221C	11	X	3	84	154.24	55					tr		10			35								
199	1221C	11	X	3	94	154.34	5								65	15	5		10						
199	1221C	11	X	3	102	154.42	10	1						1	48		35		5						
199	1221C	11	X	3	119	154.59		3				tr		2	80	5			10						
199	1221C	11	X	3	127	154.67	5	tr							75	5			15						
199	1221C	11	X	CC	9	154.91	10	2						1	52	5	15		15						
208	1262A	13	H	1	34	132.45		tr							3				97						
208	1262A	13	H	3	5	135.16									2				98						
208	1262A	13	H	3	60	135.71									3				97						
208	1262A	13	H	5	36	138.47		1							1				98						
208	1262A	13	H	5	47	138.58		1				tr			tr				99						
208	1262A	13	H	5	51	138.62	95			1					tr		1		3						
208	1262A	13	H	6	5	139.66	2	1											95	1	1				
208	1262A	13	H	6	17	139.78	5	1							1				92			1			
208	1262A	13	H	6	25	139.86	35	1	2	tr					1				60			1			
208	1262A	13	H	6	38	139.99	40	5				30			2		1		22						
208	1262A	13	H	6	47	140.08	76	3		1		10			2		2		6						
208	1262A	13	H	6	49	140.10	84	2		tr		2			2		8		2						
208	1262A	13	H	6	52	140.13		1		tr					tr		1		98						
208	1262A	13	H	6	70	140.31	tr	tr							2				98						
208	1263C	14	H	1	141	283.81	2												94	4					
208	1263C	14	H	2	30	284.20	8	1				1							88	2					
208	1263C	14	H	2	70	284.60	10	tr				2							81	6		1			
208	1263C	14	H	2	100	284.90	60	1				2							35	2					
208	1263C	14	H	2	110	285.00	54	1				10							35						
208	1263C	14	H	2	148	285.38	25	1				70							4						
208	1263C	14	H	2	149	285.39	20	1			5	60		1					13						
208	1266C	17	H	2	98	266.48	10	tr											88	2					
208	1266C	17	H	3	75	267.75	13	1									1		85						
208	1266C	17	H	3	98	267.98	25	1				1							73						
208	1266C	17	H	3	111	268.11	78	2											20						
208	1266C	17	H	4	56	269.06	2					tr		tr	tr				91	7					
208	1266C	17	H	5	10	270.10	5	tr											85	10					
208	1266C	17	H	6	118	272.68	2	tr											93	5					
208	1266C	17	H	7	74	273.74	1	tr											97	2					

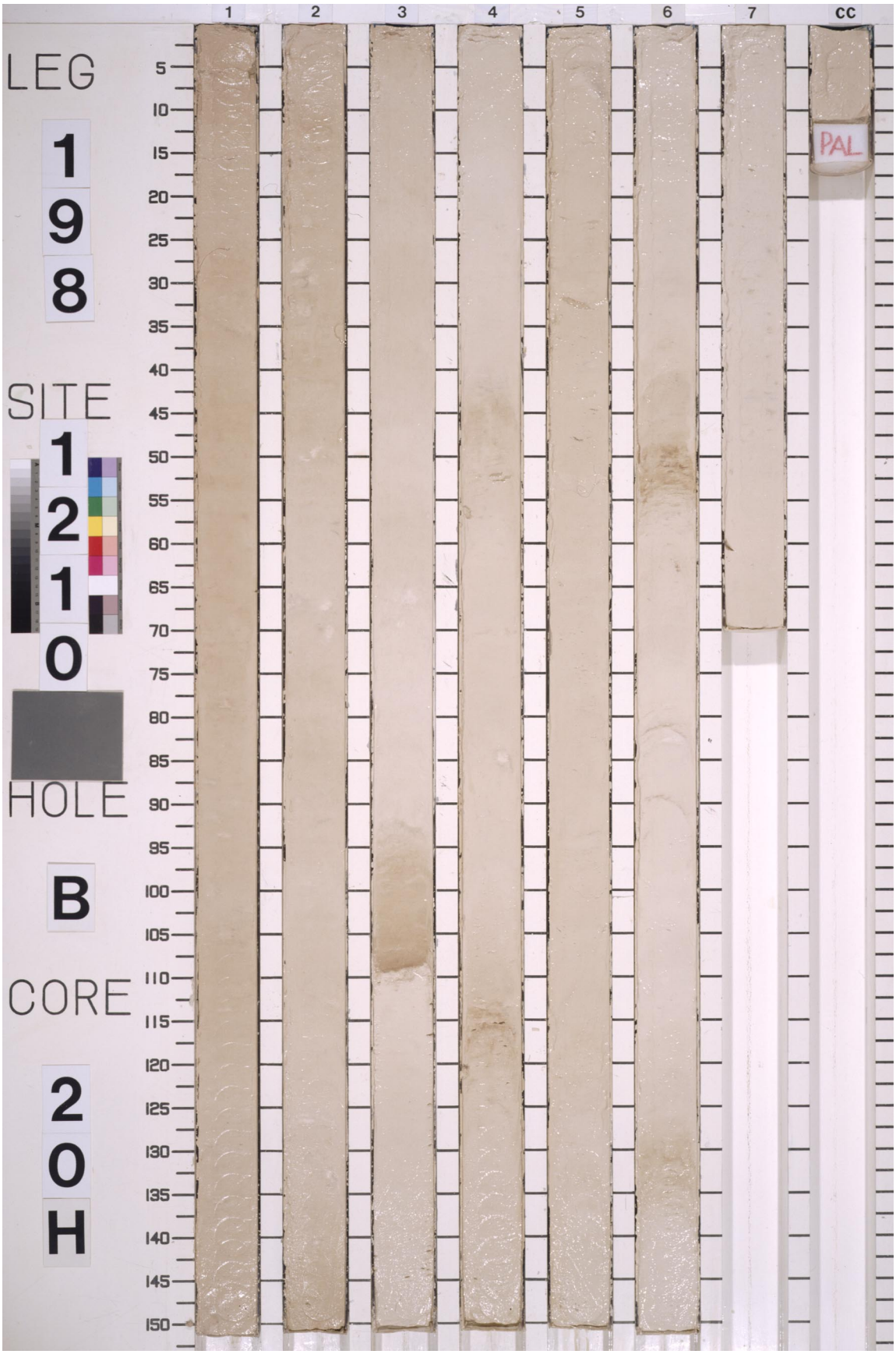
H = hydraulic piston corer
X = extended core barrel

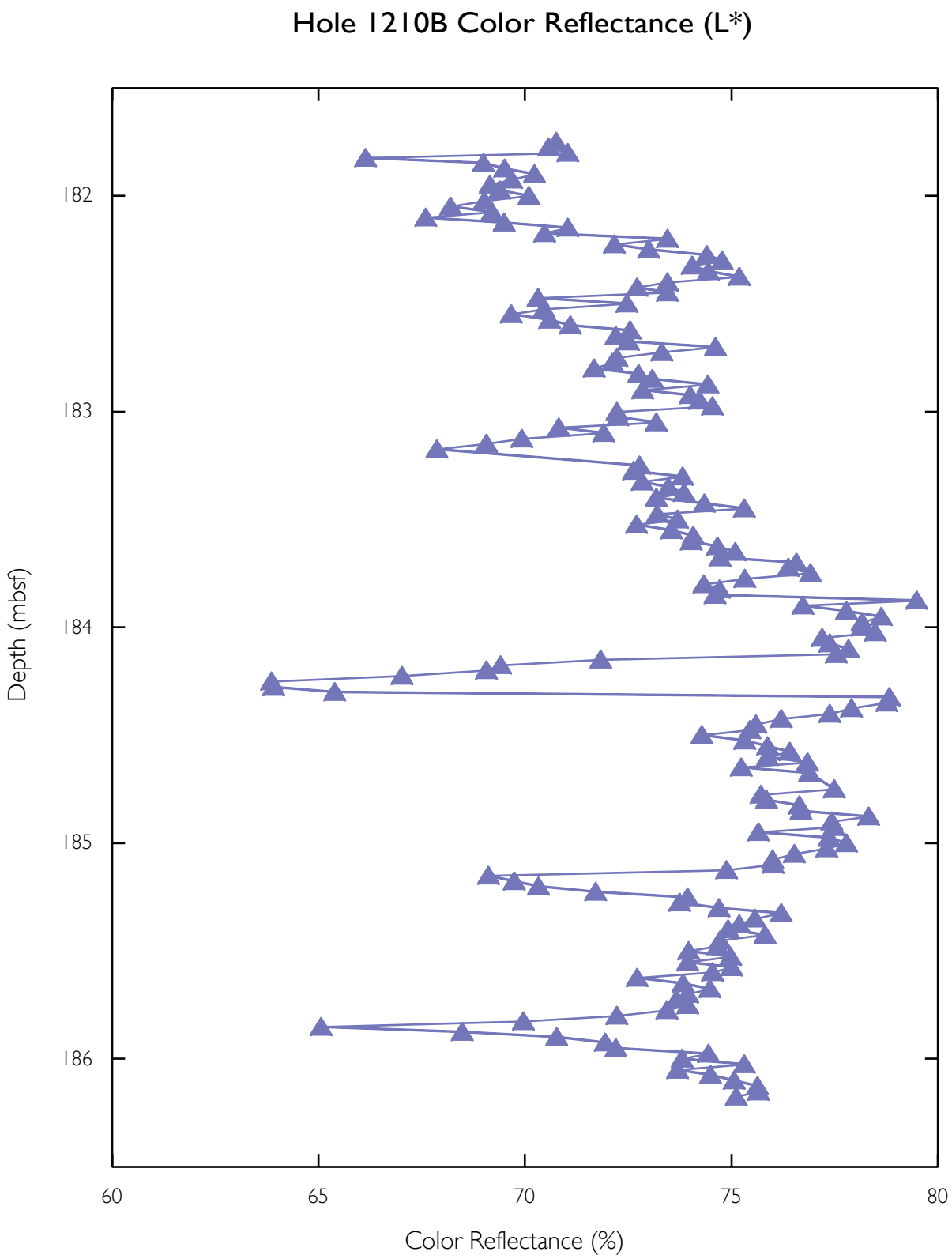

LEG
113
SITE
690
HOLE
B
CORE
19
H
1
2
3
4
5
CC
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150

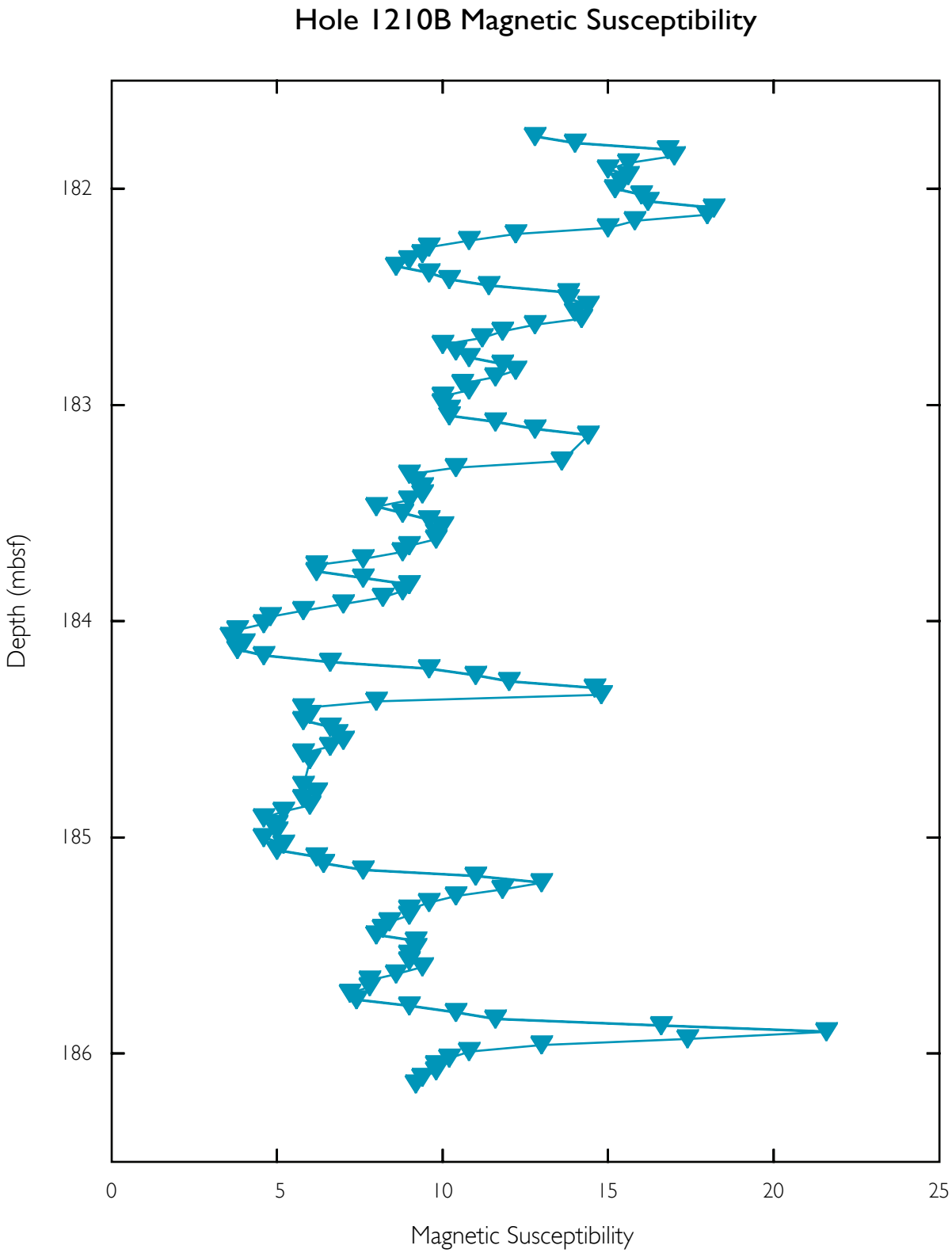

1
2
3
4
5
6
7
CC
LEG
198
SITE
1209
HOLE
B
CORE
22H
PAL

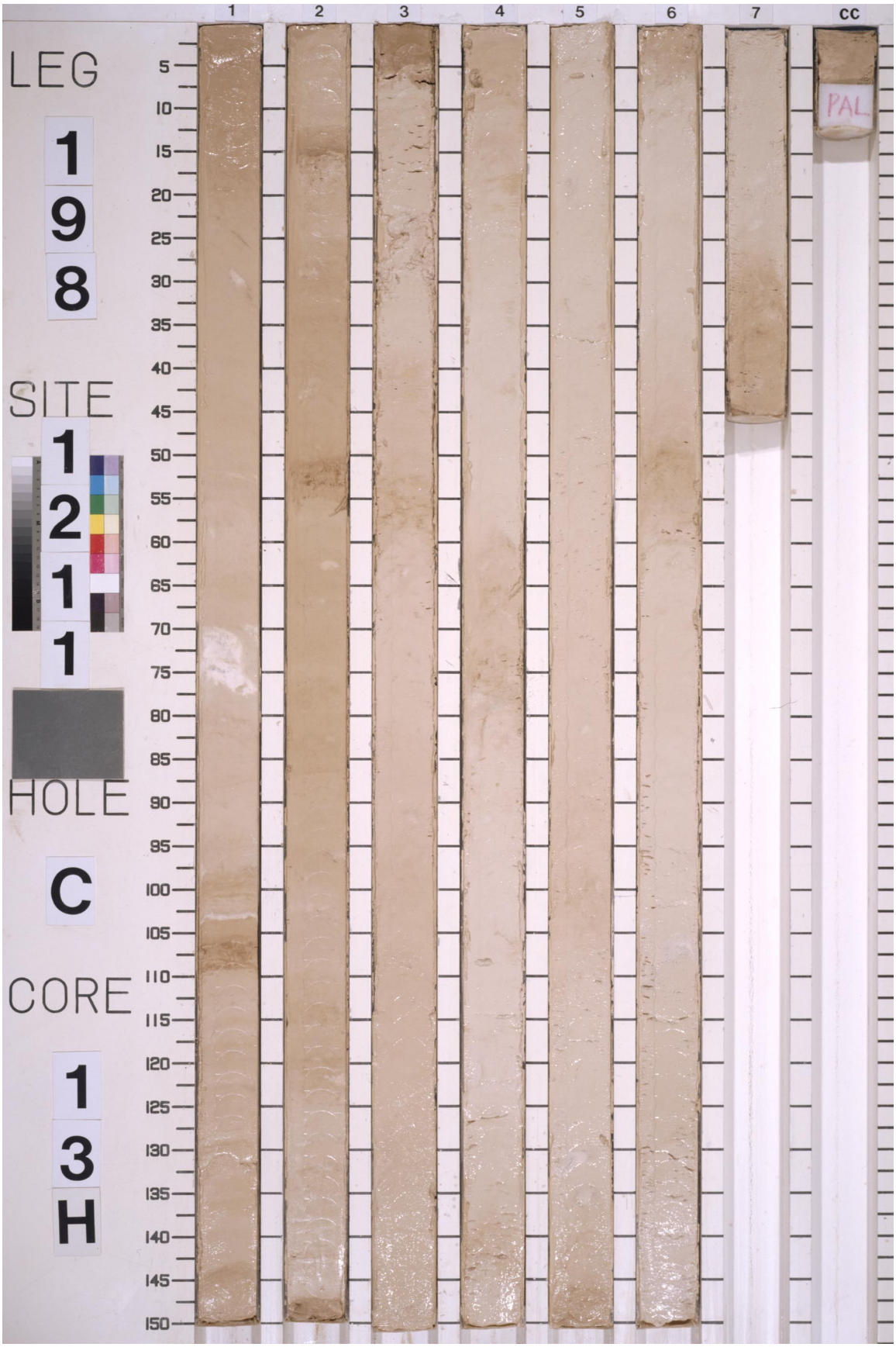

Hole 1209B Color Reflectance (L*)
195.0
195.5
196.0
196.5
197.0
197.5
198.0
Depth (mbsf)
55
60
65
70
75
80
Color Reflectance (%)

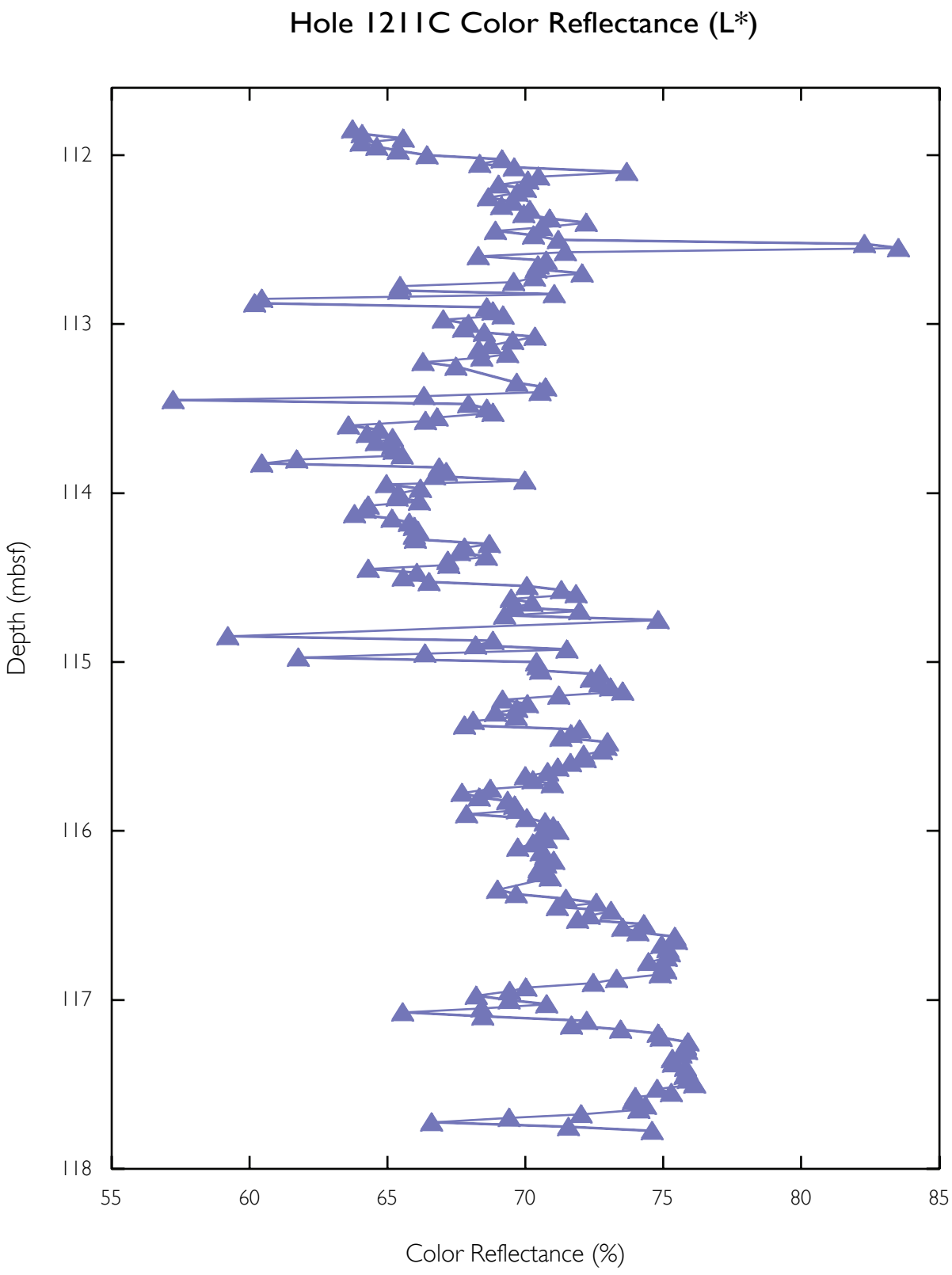

Hole 1210B Magnetic Susceptibility
Depth (mbsf)
182
183
184
185
186
0
5
10
15
20
25
Magnetic Susceptibility

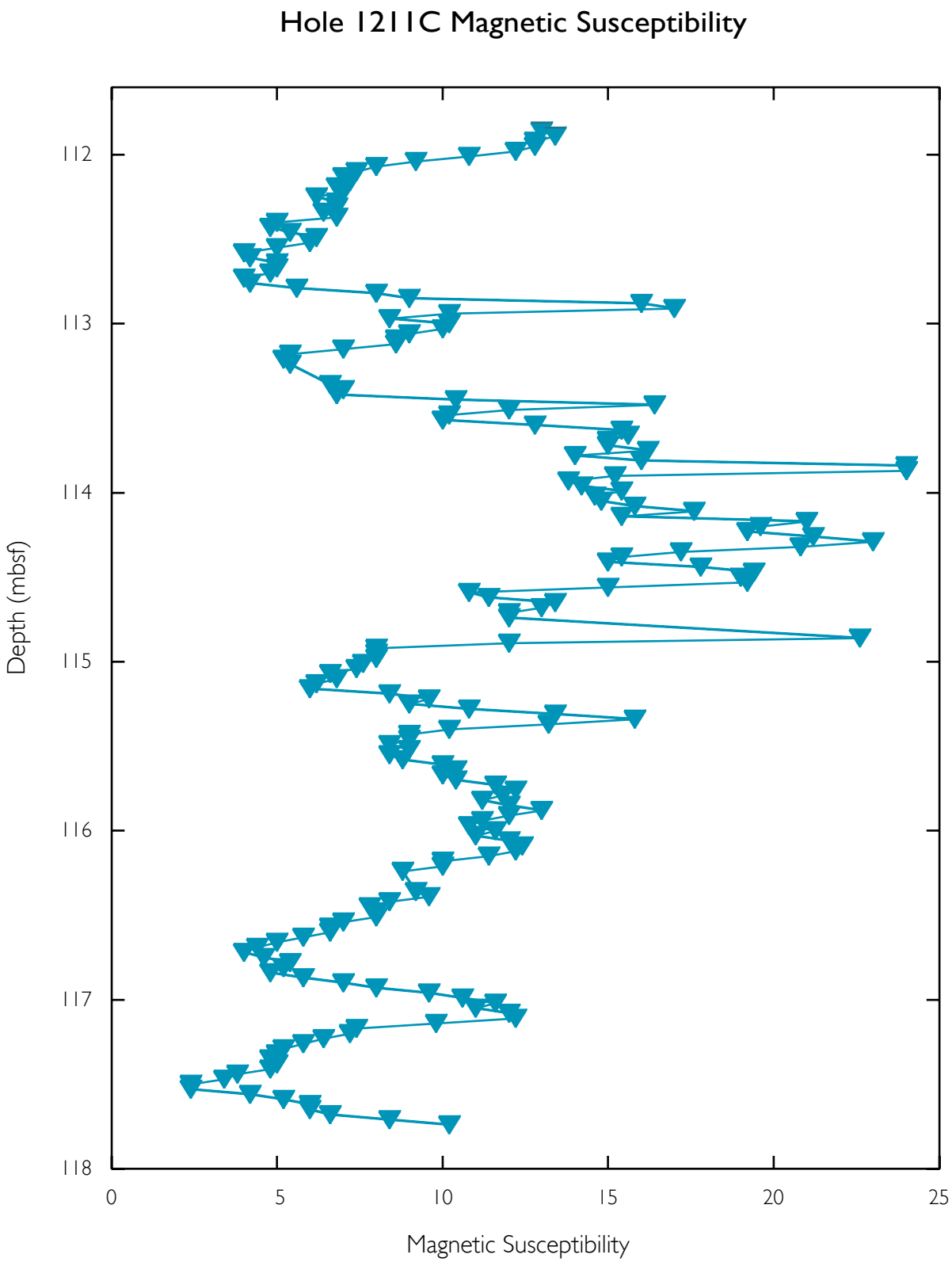

LEG
198
SITE
1210
HOLE
B
CORE
20H
1
2
3
4
5
6
7
CC
PAL

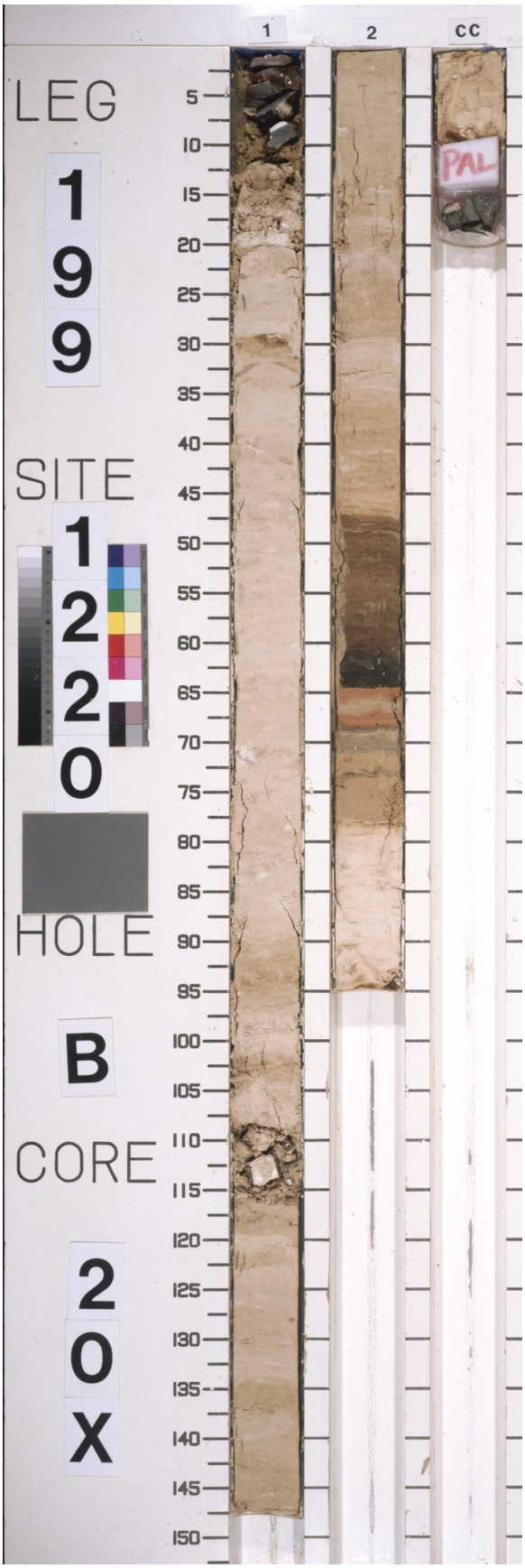

Hole 1210B Color Reflectance (L*)
Depth (mbsf)
182
183
184
185
186
60
65
70
75
80
Color Reflectance (%)

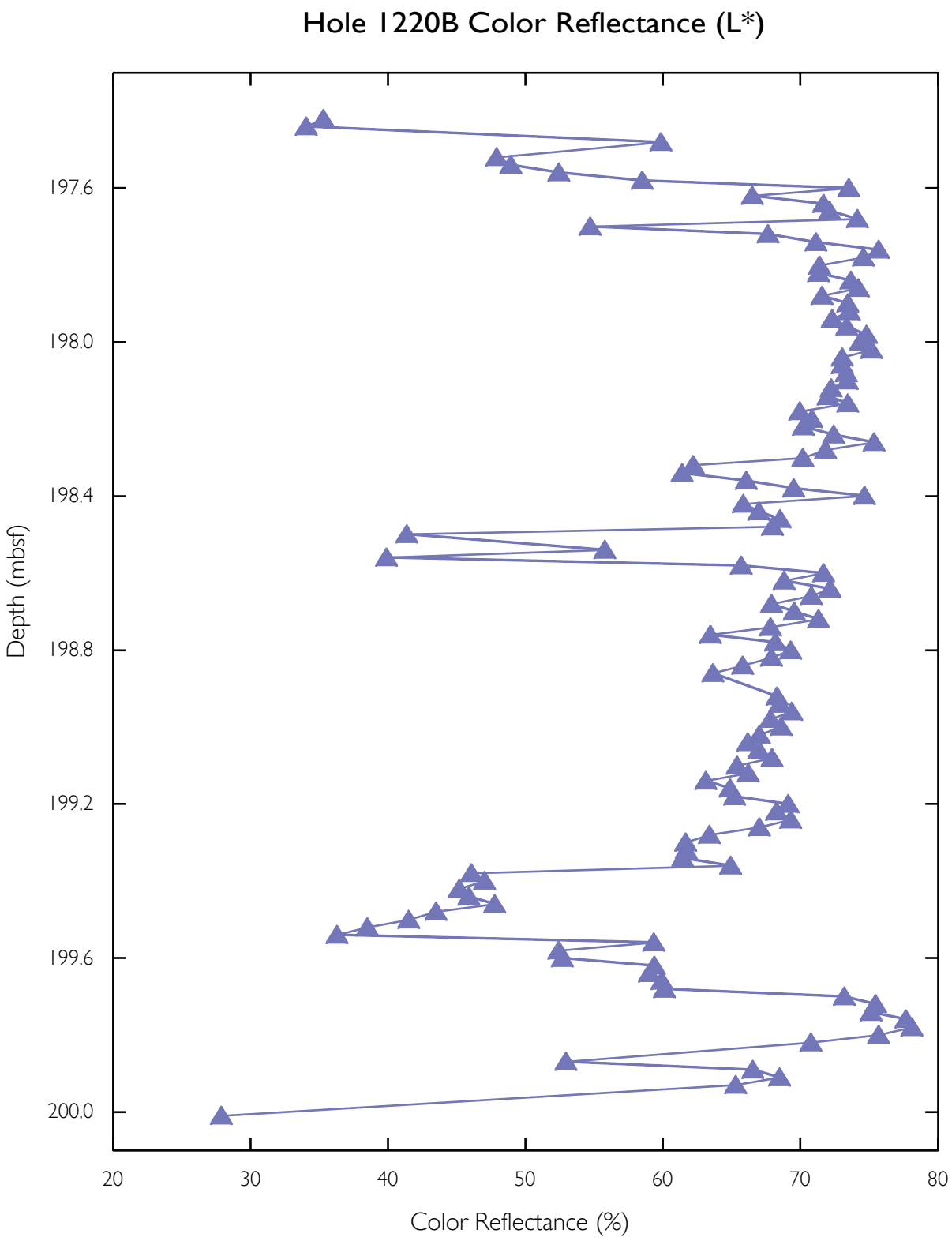

Hole 1210B Magnetic Susceptibility
Depth (mbsf)
182
183
184
185
186
0
5
10
15
20
25
Magnetic Susceptibility

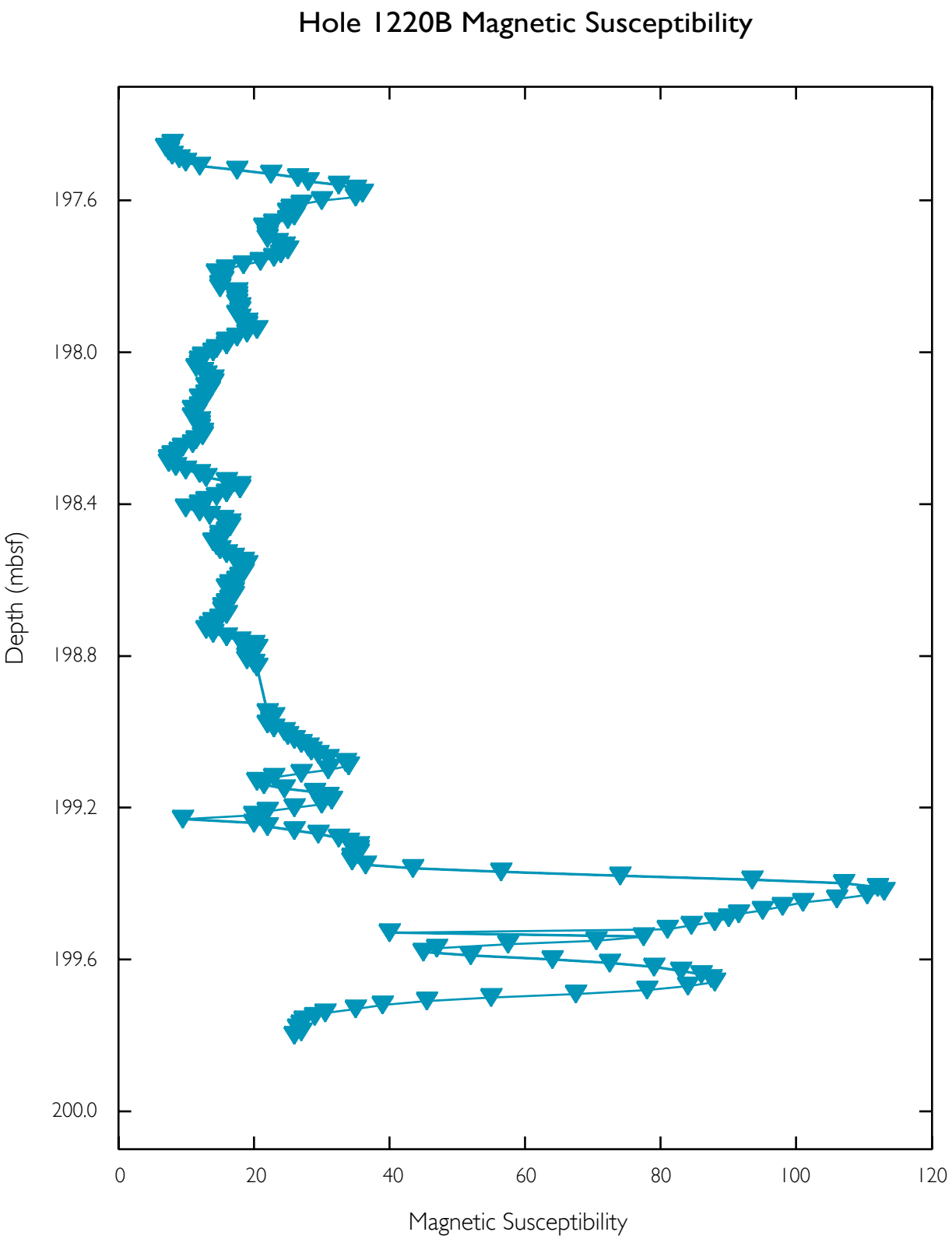

LEG
198
SITE
1211
HOLE
C
CORE
13H
1
2
3
4
5
6
7
CC
PAL

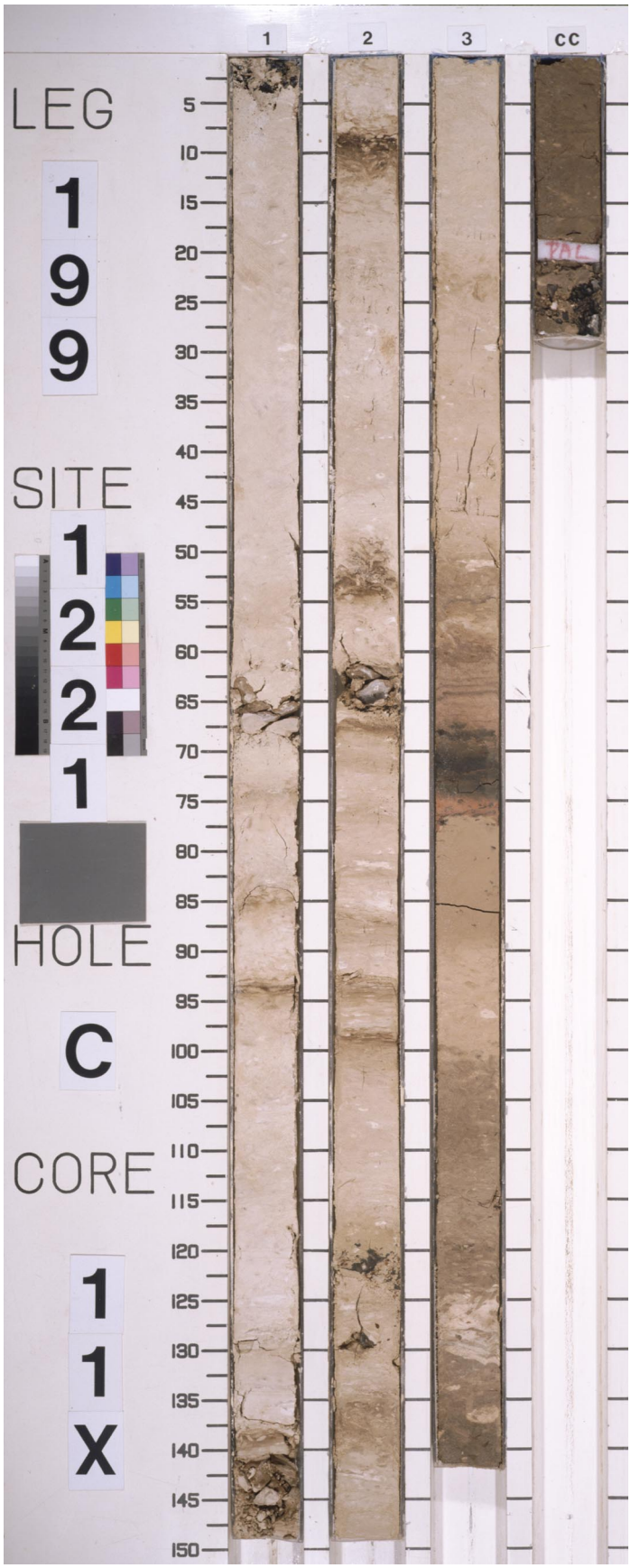

Hole 1211C Color Reflectance (L*)
Depth (mbsf)
112
113
114
115
116
117
118
55
60
65
70
75
80
85
Color Reflectance (%)

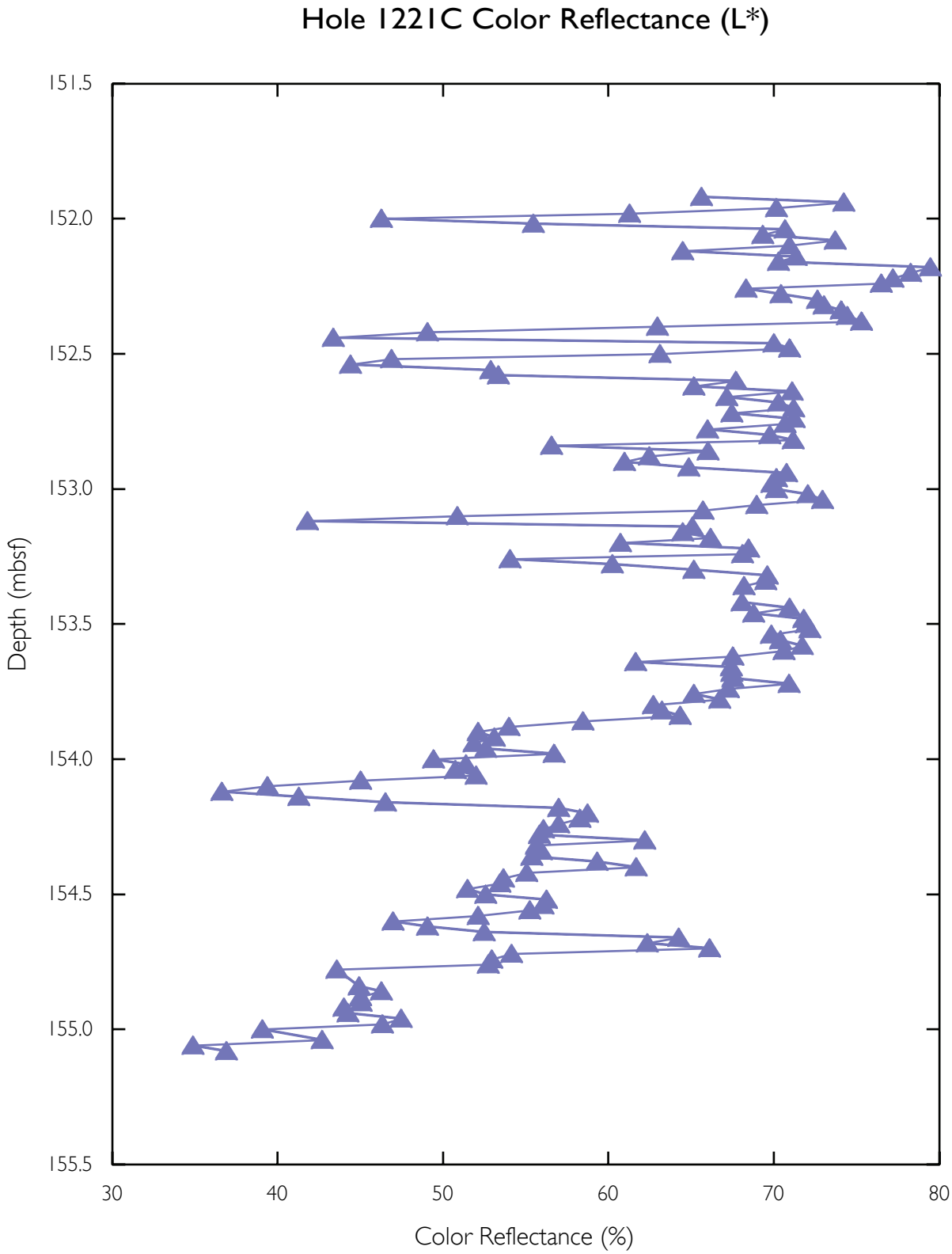

Hole 1211C Magnetic Susceptibility
Depth (mbsf)
112
113
114
115
116
117
118
0
5
10
15
20
25
Magnetic Susceptibility

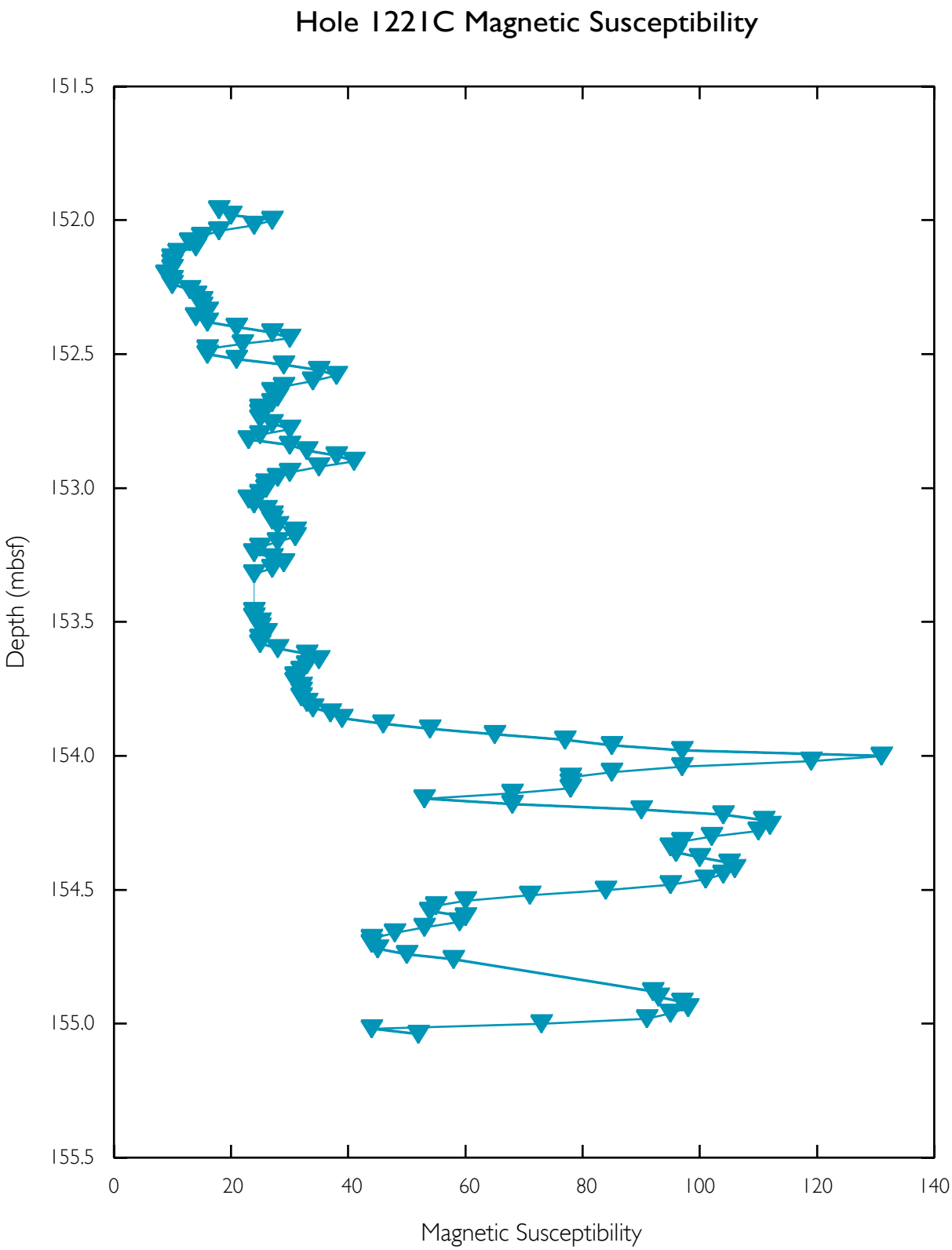

1
2
CC
LEG
199
SITE
1220
HOLE
B
CORE
20X
PAL

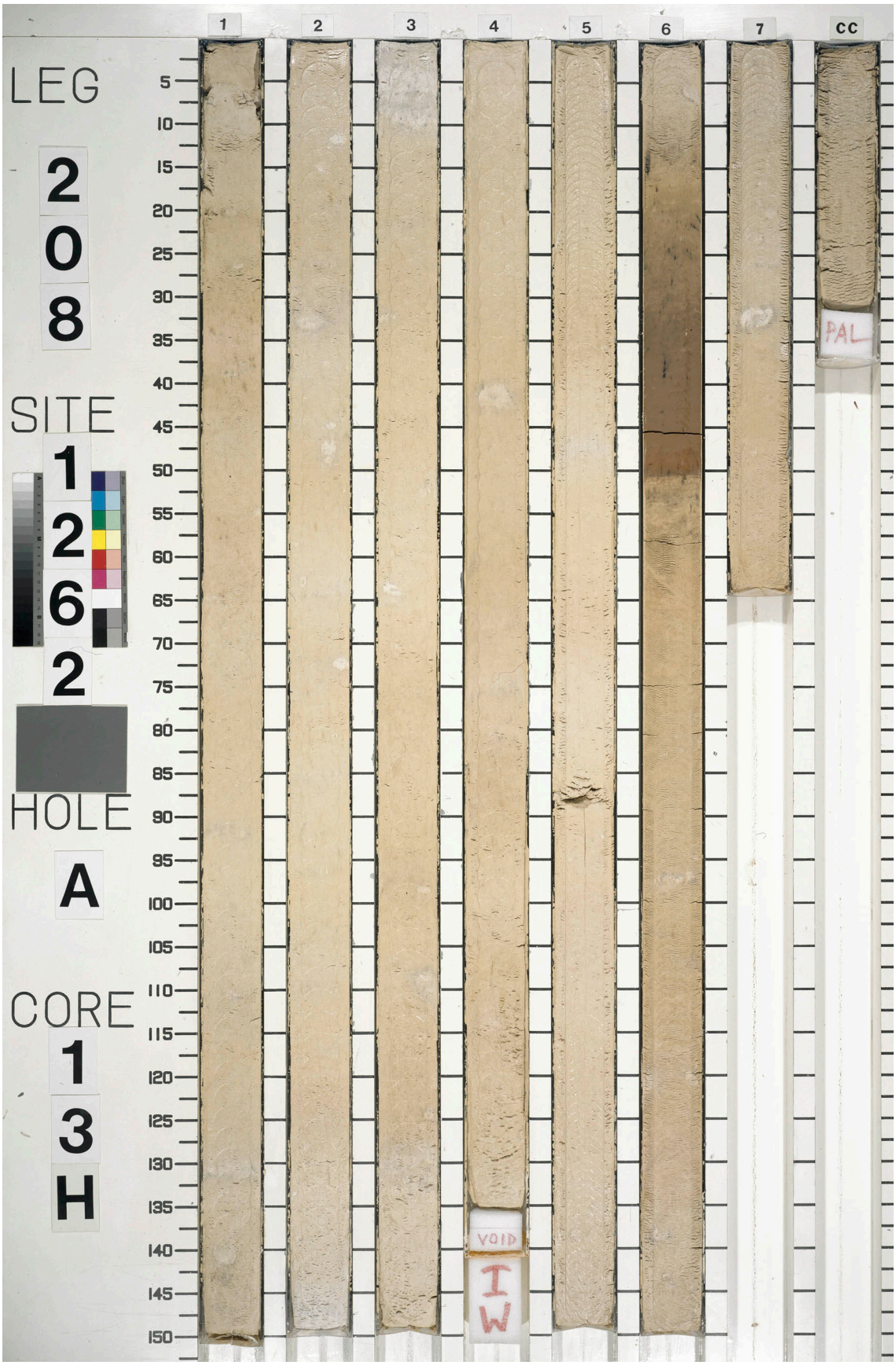

Hole 1220B Color Reflectance (L*)
Depth (mbsf)
197.6
198.0
198.4
198.8
199.2
199.6
200.0
20
30
40
50
60
70
80
Color Reflectance (%)

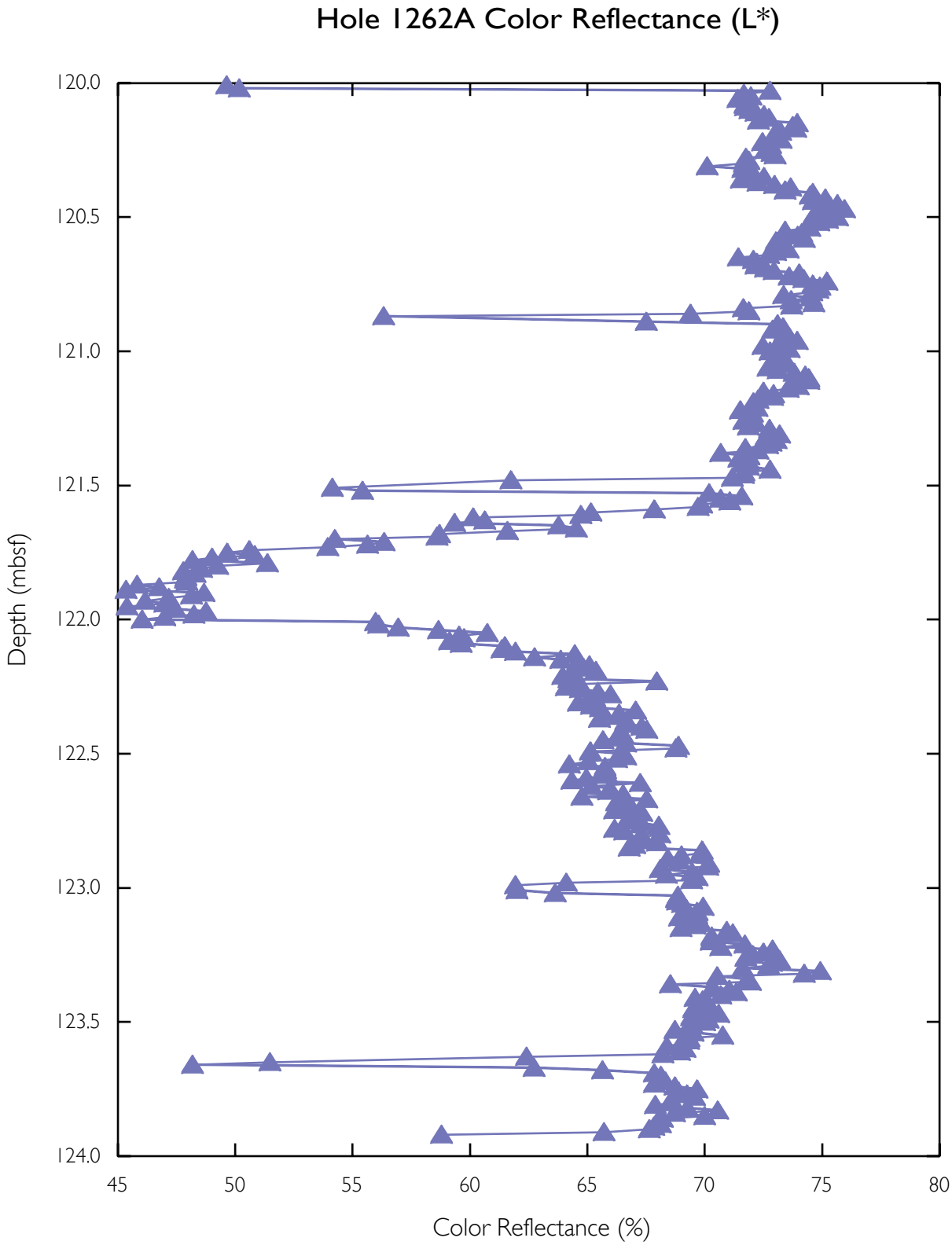

Hole 1220B Magnetic Susceptibility
Depth (mbsf)
197.6
198.0
198.4
198.8
199.2
199.6
200.0
0
20
40
60
80
100
120
Magnetic Susceptibility

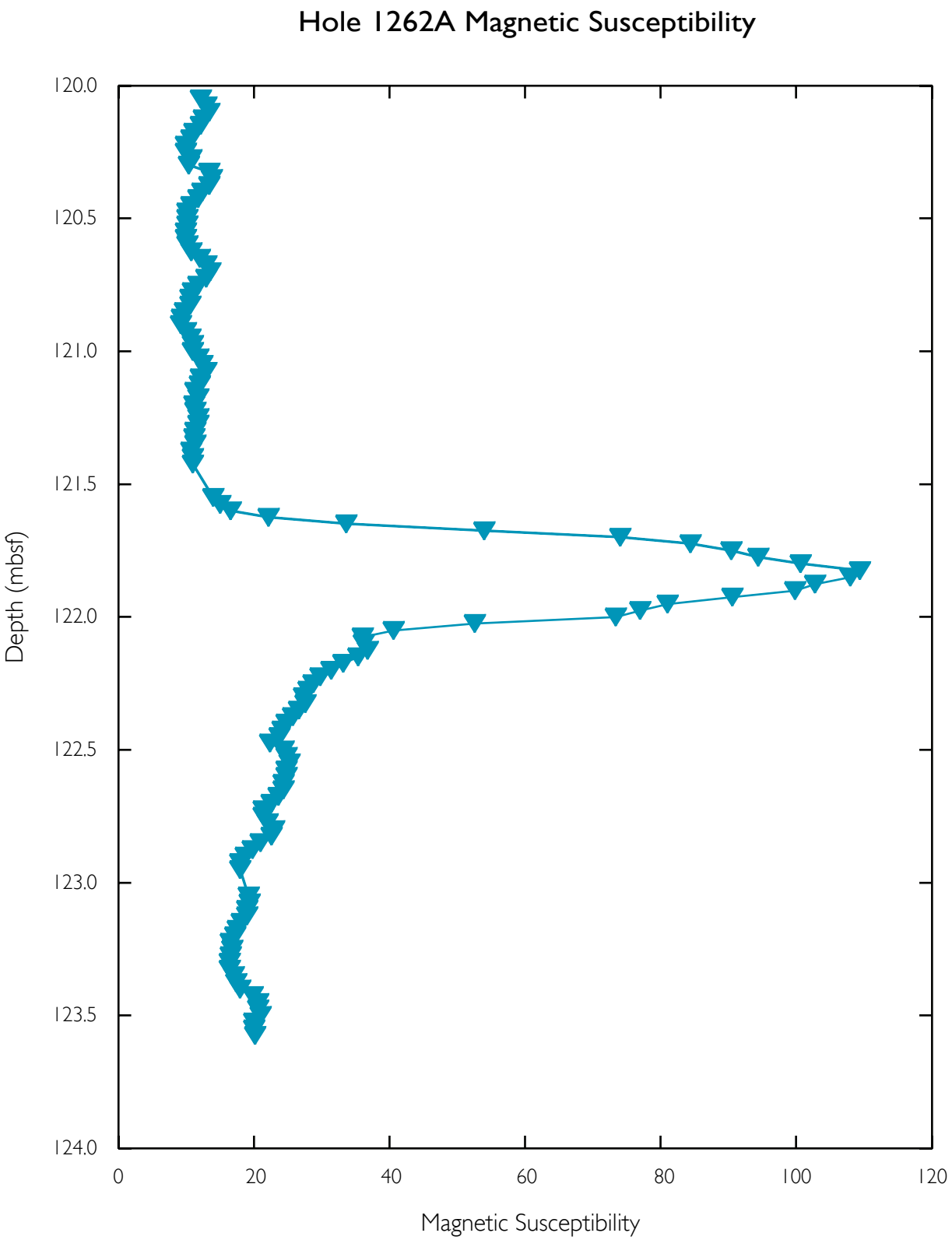

1
2
3
CC
LEG
199
SITE
1212
HOLE
C
CORE
11X

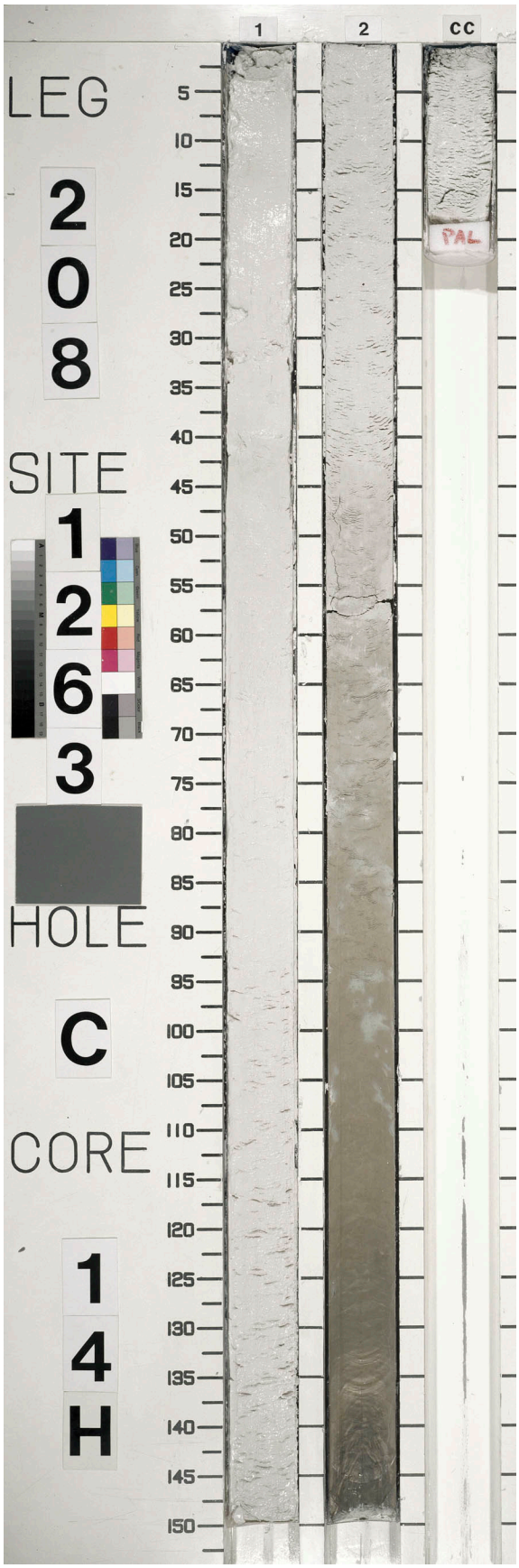

Hole 1221C Color Reflectance (L*)
Depth (mbsf)
151.5
152.0
152.5
153.0
153.5
154.0
154.5
155.0
155.5
30
40
50
60
70
80
Color Reflectance (%)

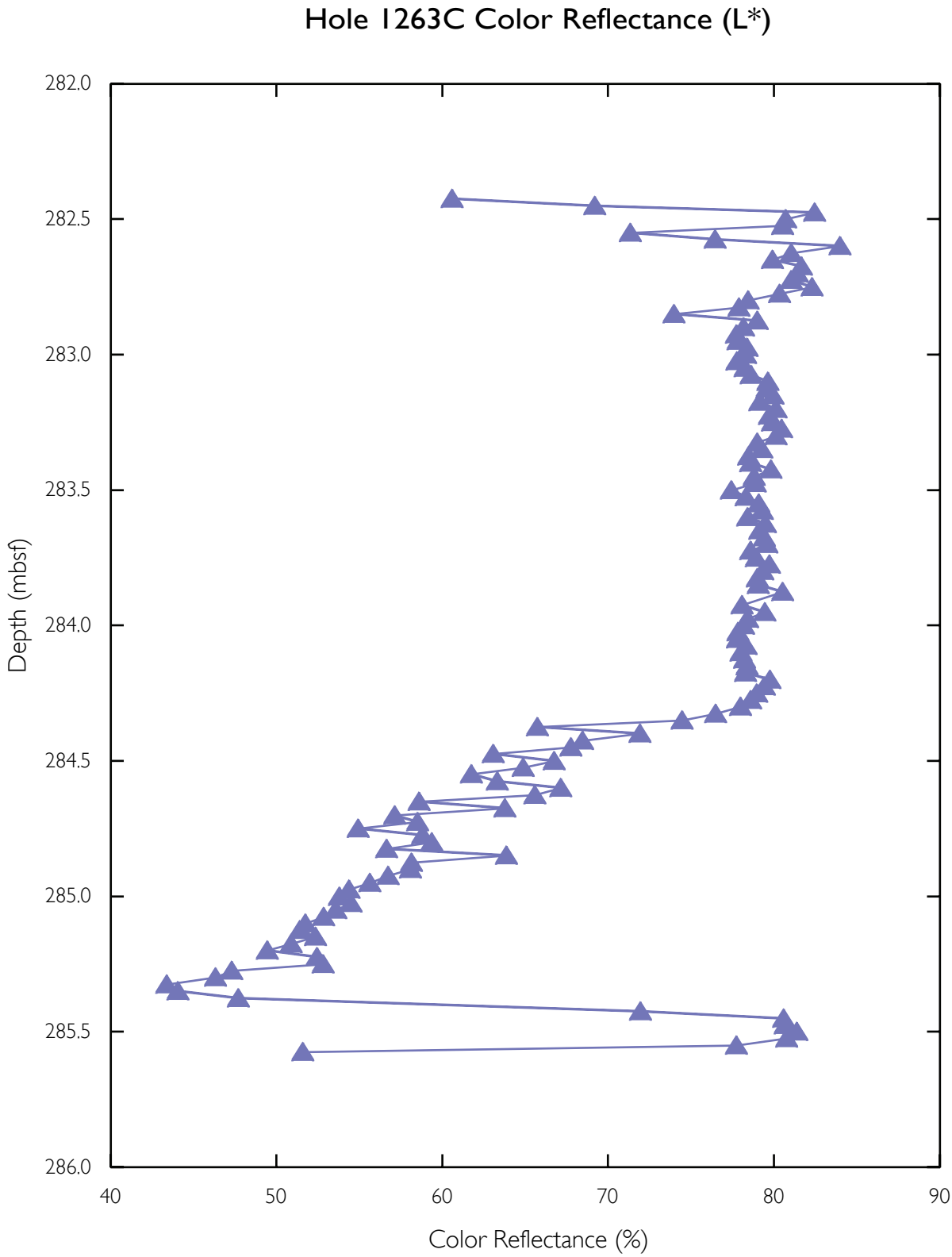

Hole 1221C Magnetic Susceptibility
Depth (mbsf)
151.5
152.0
152.5
153.0
153.5
154.0
154.5
155.0
155.5
0
20
40
60
80
100
120
140
Magnetic Susceptibility

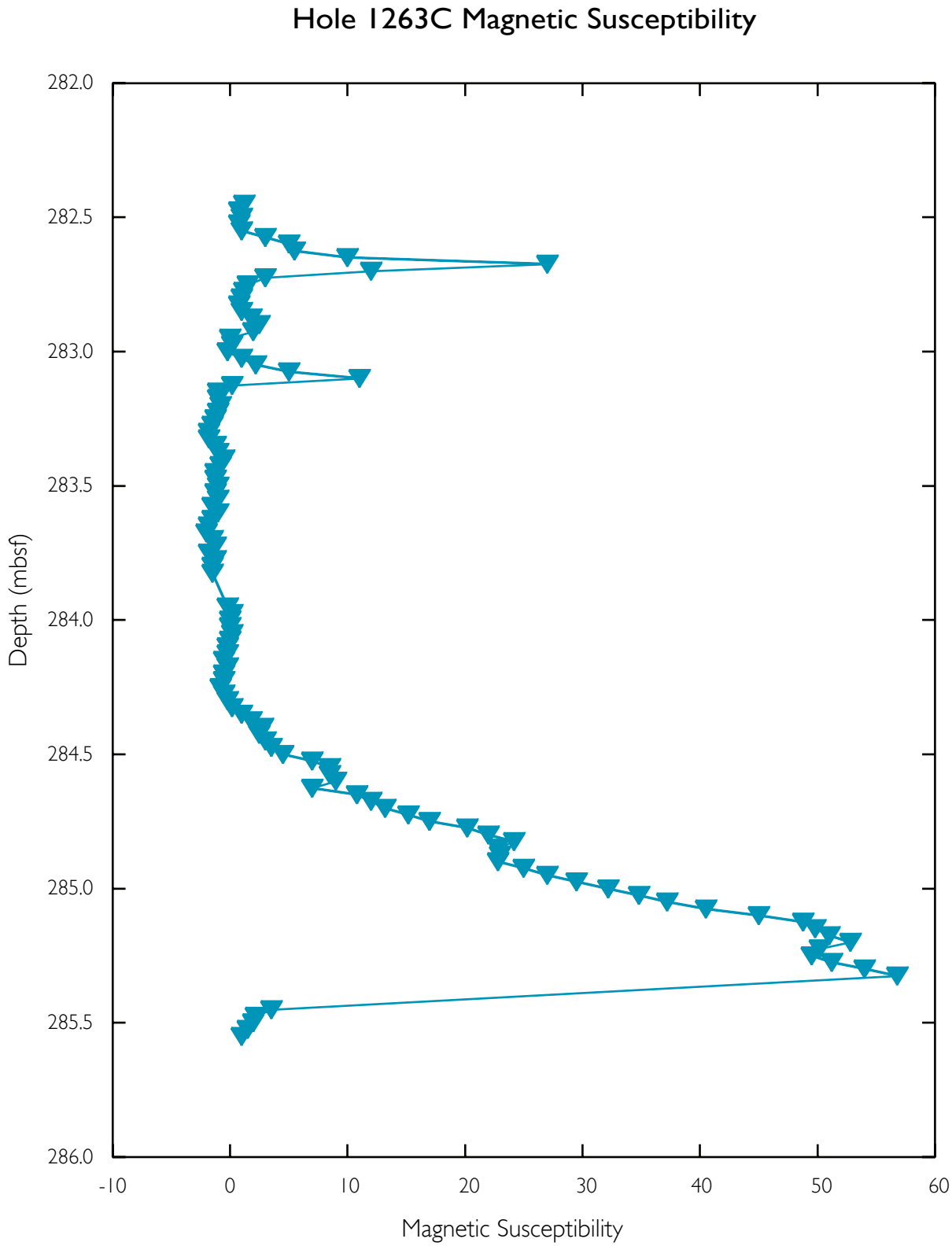

LEG
208
SITE
1262
HOLE
A
CORE
13H
1
2
3
4
5
6
7
CC
PAL
VOID
IW

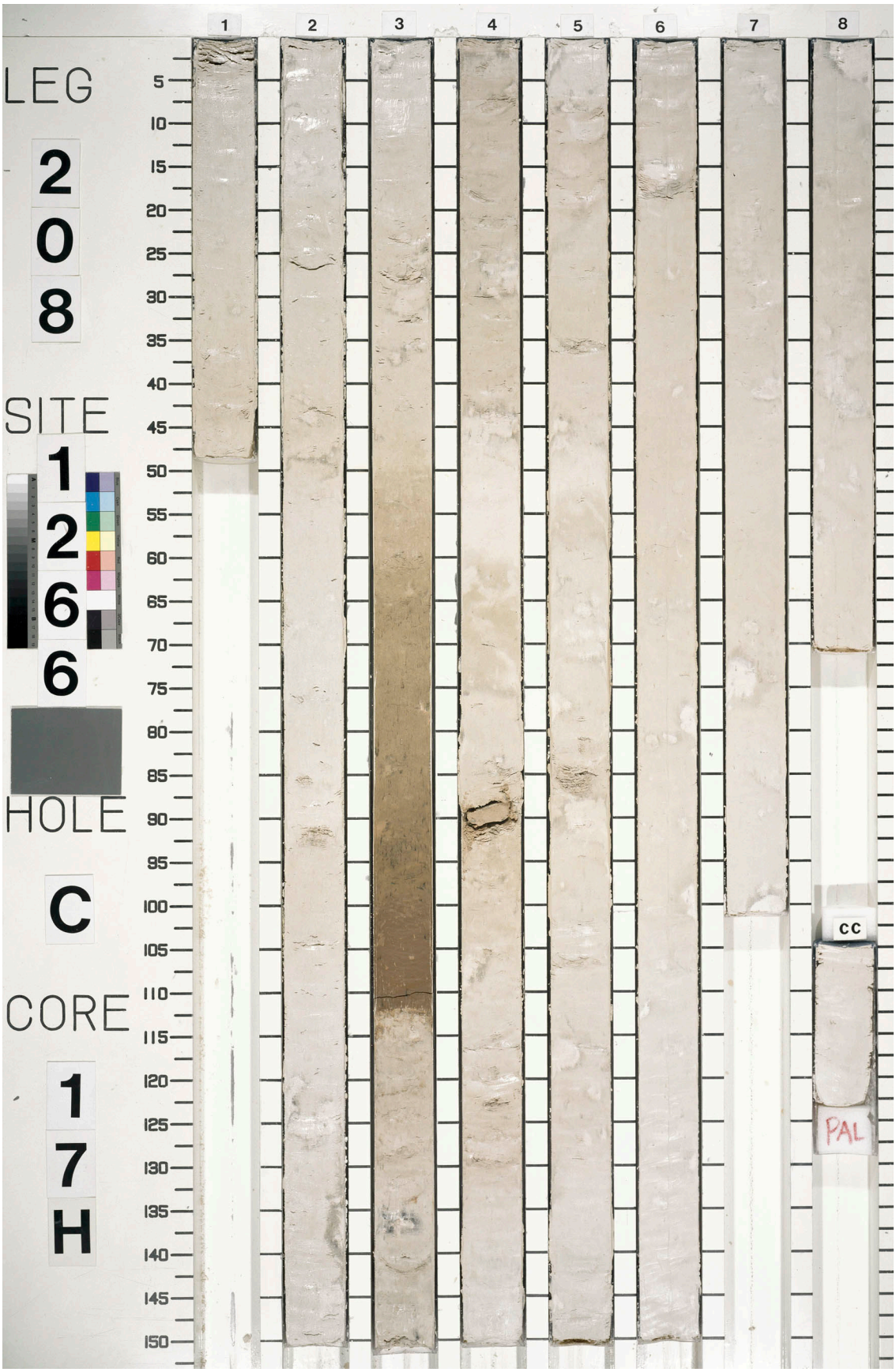

Hole 1262A Color Reflectance (L*)
Depth (mbsf)
120.0
120.5
121.0
121.5
122.0
122.5
123.0
123.5
124.0
45
50
55
60
65
70
75
80
Color Reflectance (%)

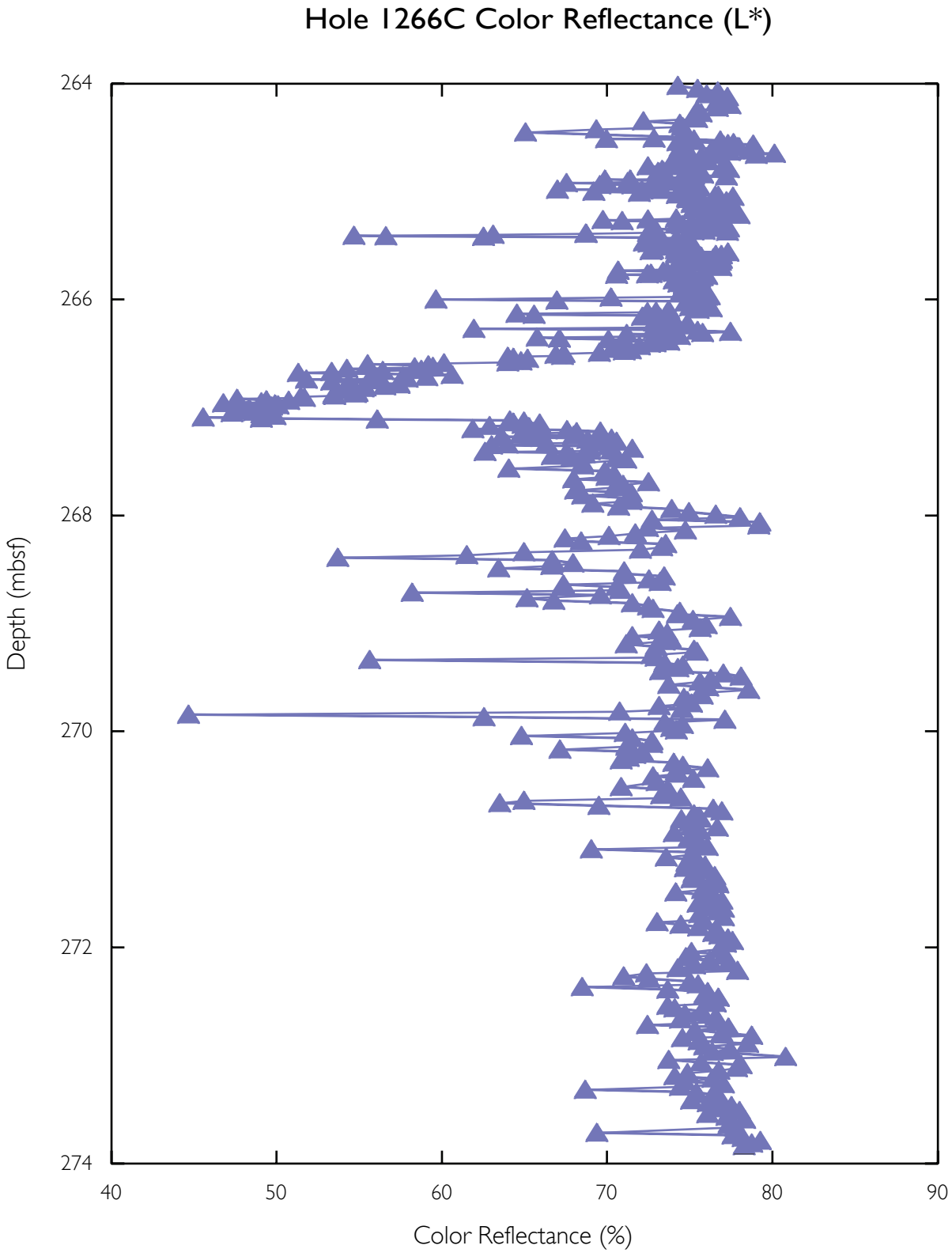

Hole 1262A Magnetic Susceptibility
Depth (mbsf)
120.0
120.5
121.0
121.5
122.0
122.5
123.0
123.5
124.0
0
20
40
60
80
100
120
Magnetic Susceptibility

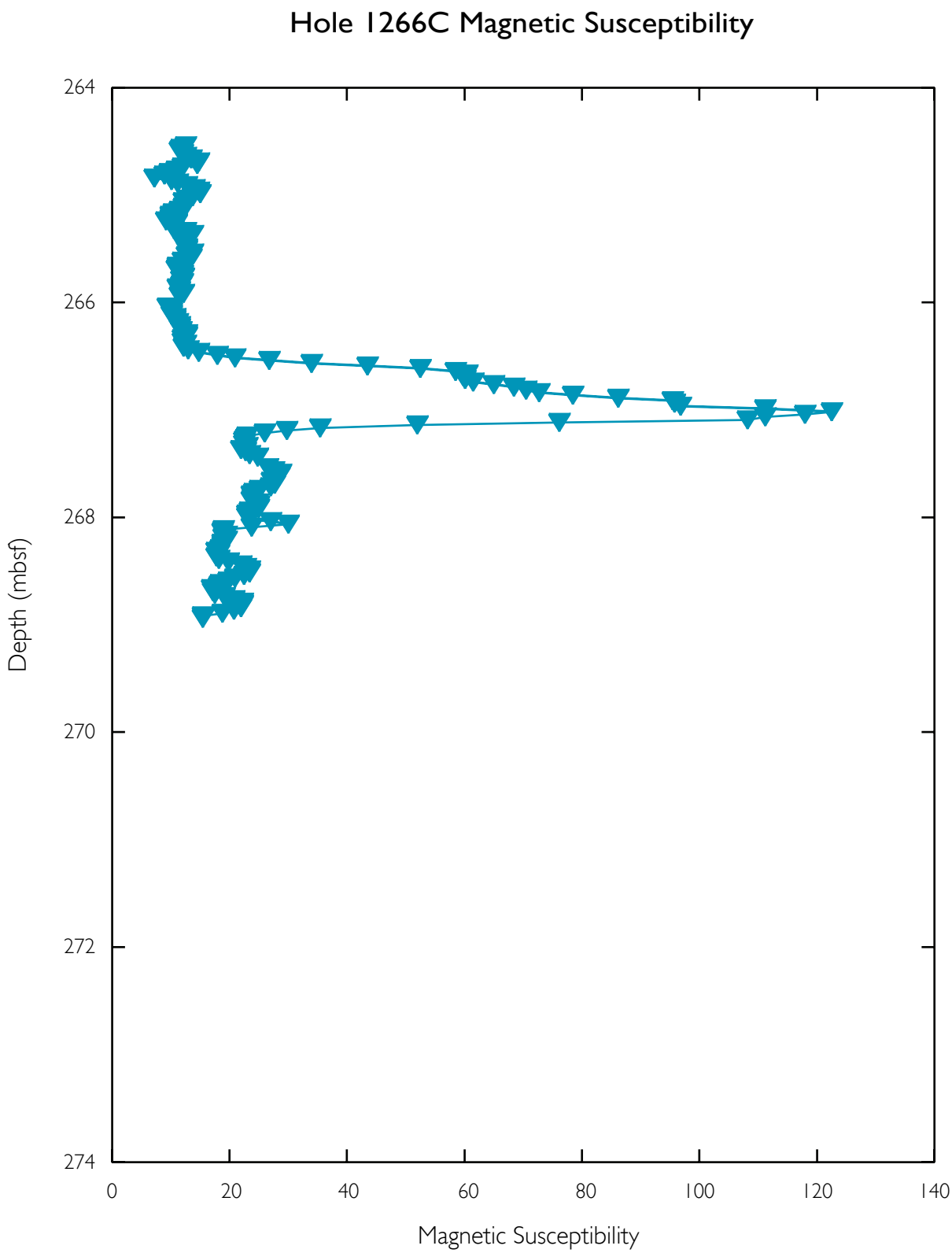

1
2
CC
LEG
2
0
8
SITE
1
2
6
3
HOLE
C
CORE
1
4
H
PAL
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150


Hole 1263C Color Reflectance (L*)
Depth (mbsf)
282.0
282.5
283.0
283.5
284.0
284.5
285.0
285.5
286.0
40
50
60
70
80
90
Color Reflectance (%)


Hole 1263C Magnetic Susceptibility
Depth (mbsf)
282.0
282.5
283.0
283.5
284.0
284.5
285.0
285.5
286.0
-10
0
10
20
30
40
50
60
Magnetic Susceptibility


LEG
208
SITE
1266
HOLE
C
CORE
17H
1
2
3
4
5
6
7
8
CC
PAL


Hole 1266C Color Reflectance (L*)
264
266
268
270
272
274
Depth (mbsf)
40
50
60
70
80
90
Color Reflectance (%)


Hole 1266C Magnetic Susceptibility
264
266
268
270
272
274
Depth (mbsf)
0
20
40
60
80
100
120
140
Magnetic Susceptibility