U.S. Geological Survey

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Preliminary description and interpretation of cores and radiographs from Clear Lake, Lake County, California: Core 6

by

John D. Sims and Michael J. Rymer

1975

INTRODUCTION

Clear Lake, California is located in the California Coast Ranges about 120 km north of San Francisco and is the largest freshwater lake wholly within California. The lake basin is tectonically controlled (Anderson, 1936; Brice, 1953; Sims and Rymer, 1974) and the area seismically active (Coffman and von Hake, 1973).

Interest in this lake was stimulated by hypotheses developed from a study of sediments in Van Norman Reservoir after the 1971 San Fernando earthquake (Sims, 1973). During this study three zones of deformational structures were found in the 1 m-thick sequence of sediments exposed over about 2 km^2 of the reservoir bottom. These zones were correlated with moderate earthquakes that shook the San Fernando area in 1930, 1952, and 1971. Results of this study, coupled with the experimental formation of deformational structures similar to those from Van Norman Reservoir, led to a search for similar structures in Pleistocene and Holocene lakes and lake sediments in other seismically active areas. Clear Lake, California was chosen specifically because of its location near the San Andreas fault and the San Francisco-Oakland urban complex, and the probability of obtaining an uninterrupted sediment record from the present into Pleistocene time. Eight 12 to 15 cm diameter continuous cores were taken from the lake sediments (fig. 1) as part of a study of earthquake induced structures in sediments and the tectonic framework of the Clear Lake basin. The eight cores range in length from 13.87 m to 115.21 m (Table 1).

SUMMARY OF DATA

Core 6 is from the part of Clear Lake known as the Oaks Arm, and was taken on 29-31 Oct. 1973. Depth of water at the site is 12.2 m. The core is

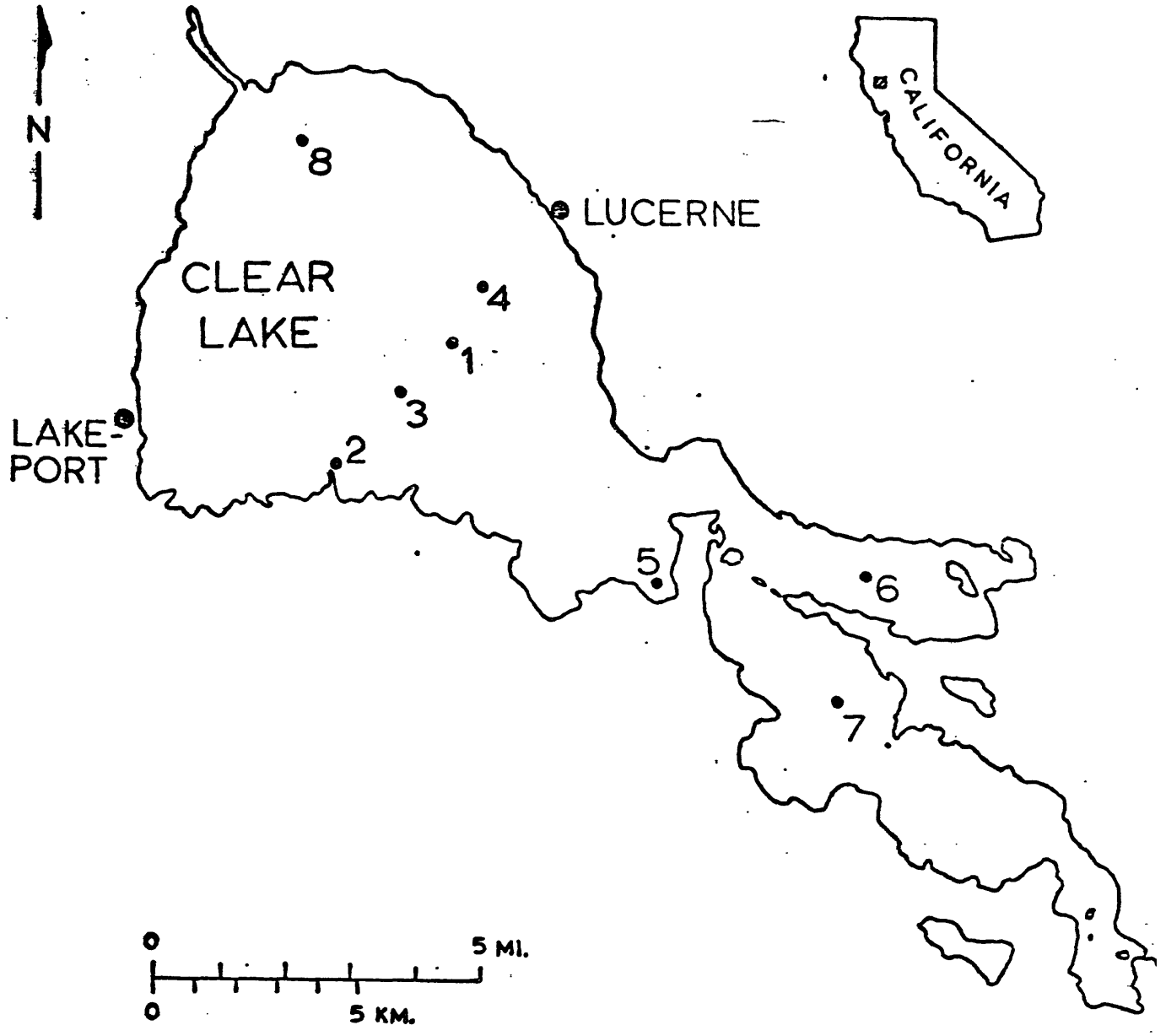


Figure 1. Map showing location of Core 6 in Clear Lake, California. Other numbered core sites in the lake are the subjects of separate reports.

Table 1. Total length and recovery percent of eight cores from Clear Lake, California.

Core	Length (m)	Recovery (%)
1	52.58	35.0
2	13.87	88.0
3	69.04	96.0
4	115.21	92.0
5	22.56	94.0
6	21.64	99.0
7	27.43	94.9
8	20.52	99.6

Table 2. Radiocarbon dates from sediments in Core 6, Clear Lake, California

Sample Number [1]	Sample depth (cm)	Material [2]	Conventional radiocarbon date (radiocarbon years B.P.)
W-3213	801-811	carbonaceous mud	13,650 ± 450
W-3221	878-888	mud with peat laminae	13,200 ± 400
W-3218	1618-1631	peat	25,890 ± 1,000
W-3199	1773-1783	peaty mud	34,070 ± 1,000
W-3226	1925-1935	carbonaceous clay	32,400 [3]
W-3225	1989-1996	carbonaceous clay	29,810 ± 1,000

[1] All ^{14}C-age determinations by Meyer Rubin, U.S. Geological Survey, Reston, Virginia.

[2] All samples were pretreated for the removal of carbonates but not for the removal of humic acids.

[3] Provisional date.

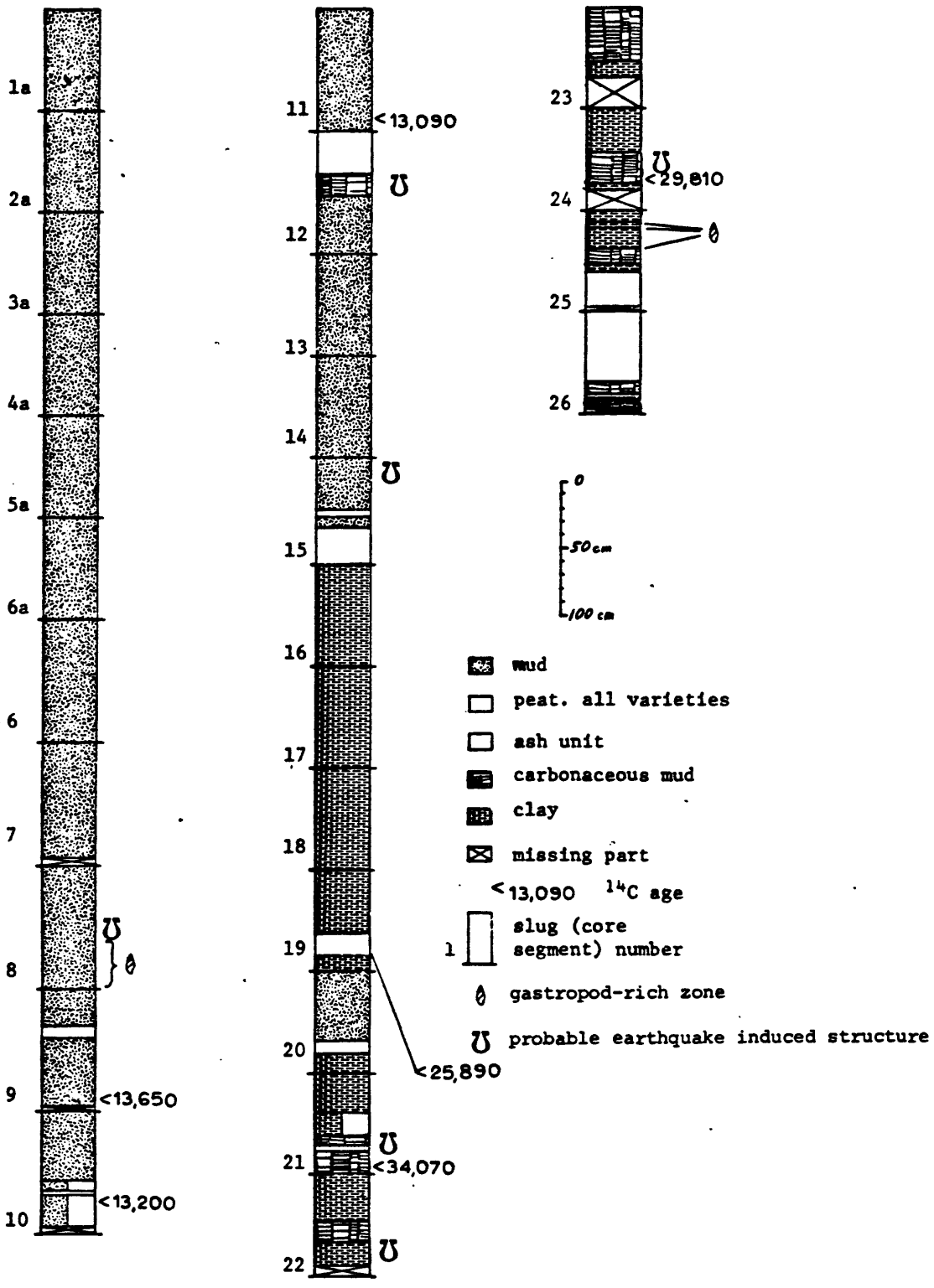


Figure 2. Generalized lithology of sediments from Core 6, Clear Lake, California. A vertical line within a slug represents interbedding of the respective lithologies.

21.64 m long and consists of 757 cm of fine, very dark greyish brown to very dark brown (10YR4/2 to 5Y3/2) sapropelic mud (gyttja) overlying a complexly interbedded sequence of peat, mud, clay, and volcanic ash (fig.2). Peat-rich mud and peaty clay comprise about 16 percent of Core 6. Mud and clay dominate the remainder of the core. The boundary between the sapropelic mud and the uppermost carbonaceous zone is a sharp, distinct contact. Thin laminae of black to dark brownish black granular peat are dispersed throughout the lower 14 m of core. Radiocarbon age determinations (table 2, fig. 2) were made on 6 samples to determine approximate timing of sedimentologic and volcanic events. In addition to the 6 ^{14}C-age dates, five ash beds were correlated with ash beds in Core 7 (fig. 3), from the Highlands Arm of Clear Lake (Sims and Rymer, 1975). Correlated ash dates are consistantly younger than would be determined from the ^{14}C-age dates on materials from Core 6. This is in part due to the types of materials dated and the radioactivity measurement error. ^{14}C-age dates for Core 7 (Sims and Rymer, 1975) are considered to be of excellent quality because they are dominantly from the analysis of peat or peaty mud. Peat is rarer in Core 6 and thus the dates are somewhat less precise (table 2).

Nine ash beds or probable ash beds are preserved in this core (fig. 2 and fig. 3). Most of the beds interpreted as ashes are clay units that have a mottled texture and are interpreted as altered basaltic, and andesitic or dacitic pyroclastic material which is common in the Clear Lake Volacanic field (Carter Hearn, personal communication). The Clear Lake pyroclastic deposits are in part late Pleistocene in age

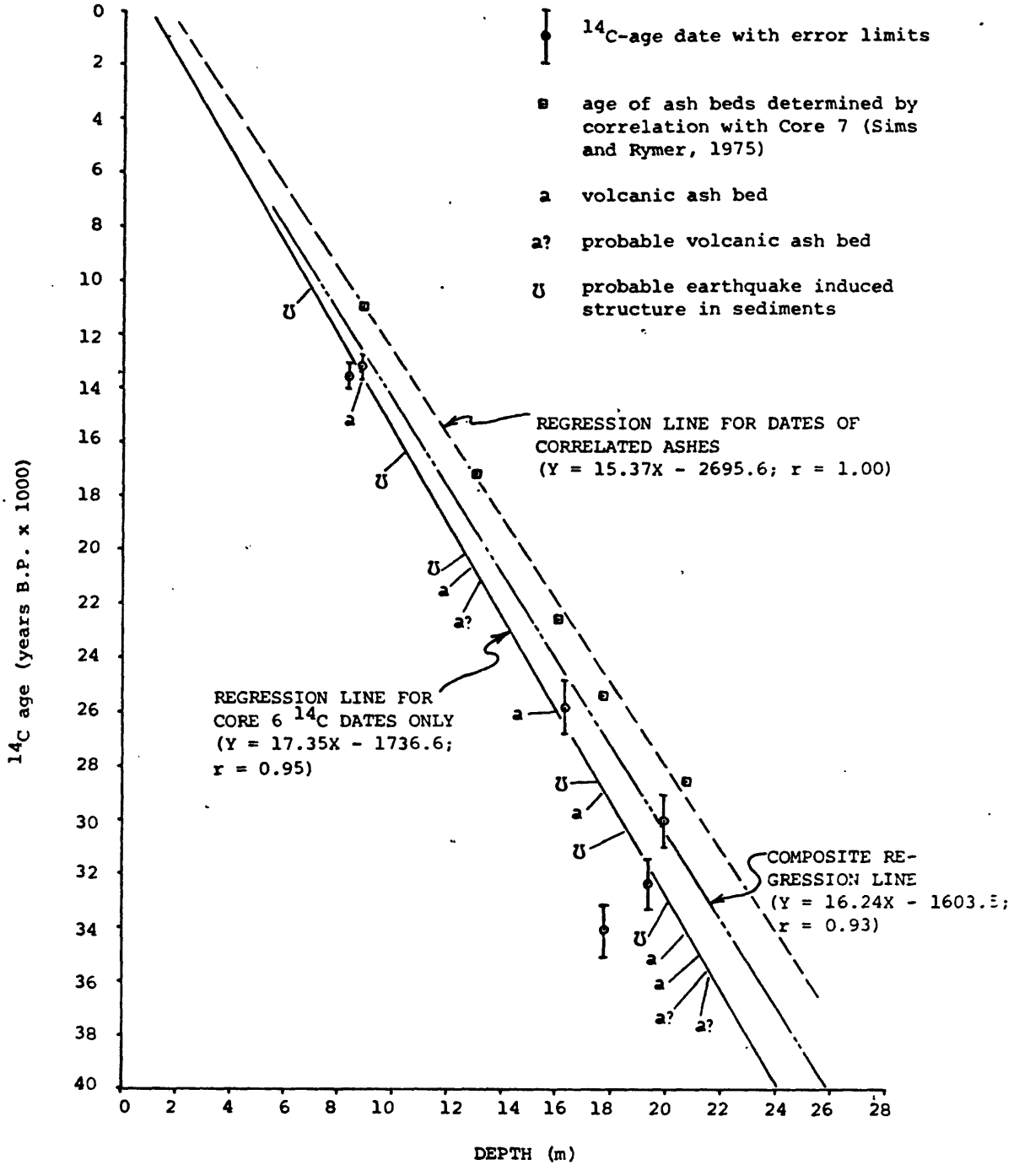


Figure 3. Plot of ^{14}C-age determinations and depths in Clear Lake Core 6. Volcanic ash beds and locations of zones of probable earthquake induced structures shown on regression line (y = 17.35x - 1736.6, fit to ^{14}C dates from material in Core 6. A regression line (y = 15.37x - 2695.6) is also fit to ash beds dated by correlation to ash beds in Core 7 (Sims and Rymer, 1975). A composite regression line (y = 16.24x - 1603.5) is also calculated using all age-depth data for this core.

Table 3. Sedimentation rates from Core 6, Clear Lake, California

From (cm)	To (cm)	Thickness (cm)	Years (B.P.)	Sedimentation Rate (mm yr^{-1})
Top	844 [1]	844	13,400	.63
844	880 [2]	36	2,900	.12 [7]
880	1294 [3]	450	4,100	1.10
1294	1605 [4]	311	5,400	.58
1294	1624	330	12,490	.26
1605	1624	19	3,290	.06 [7]
1605	1765 [5]	160	2,100	.76
1624	1765 [5]	141	[8]	-
1624	1930	306	6,510	.47
1624	1990	366	3,920	.93
1765	1778	13	150	.87
1765	1930	165	2,600	.63
1765	1990	225	3,550	.63

[1] Average of two dates, W-3213 and W-3221

[2] Ash from Core 7, slug 11 dated at 10,500 years B.P. (Sims and Rymer, 1975)

[3] Ash from Core 7, slug 17 dated at 17,200 years B.P. (Sims and Rymer, 1975)

[4] Ash from slug 19 correlated with ash from Core 7, slug 21 dated at 22,600 B.P.

[5] Ash from slug 21 correlated with ash from Core 7, slug 23 dated at 24,700 B.P.

[6] Ash from slug 25 correlated with ash from Core 7, slug 27 dated at 28,600 B.P.

[7] Exceptionally low sedimentation rate. Probably erroneous.

[8] Stratigraphic reversal of dates. Subtraction of stratigraphically higher date from stratigraphically lower one yields a negative number.

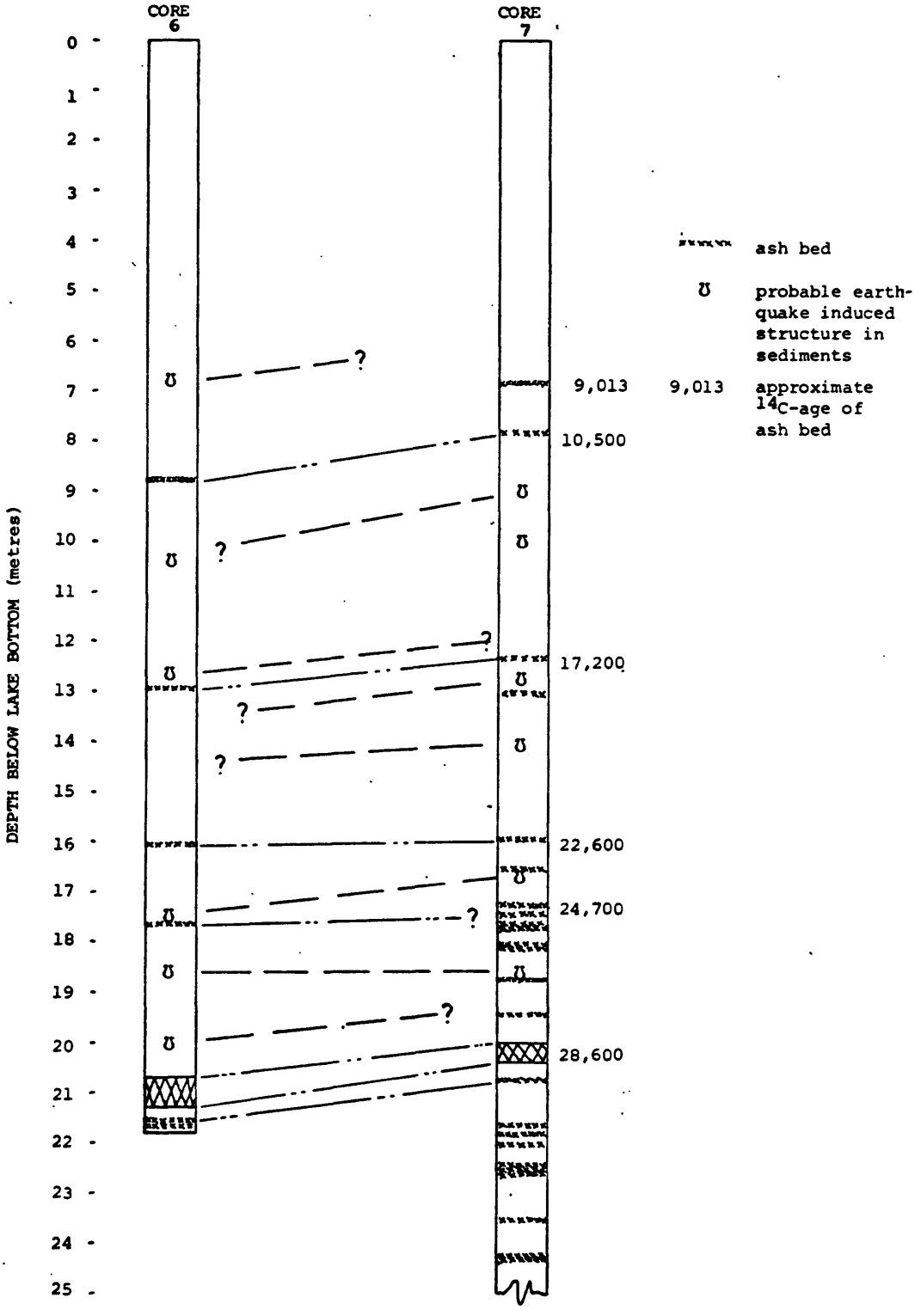


Figure 4. Correlation of ash beds and zones of probable earthquake induced structures in sediments between Cores 6 and 7.

(Julie Donnelly, personal communication). One of the ashes is easily identifiable as such because little alteration has occurred and the shards are still well preserved (fig. 2, slug 15).

Six zones of deformed sediments were found between 680 cm and 2005 cm in the core (fig. 2 and Appendix A). The age of these sediments ranges from approximately 10,500 yr. B.P. to 33,000 yr. B.P. Preliminary correlations of ash beds and zones of probable earthquake-induced structures (fig. 4) show good correlation between ash beds in cores 6 and 7. Core 7 contains a more complex record of volcanic ashes than Core 6. However, ash beds deposited at about 17,200 and 28,600 ^{14}C-years B.P. are of distinctive lithology and are easily correlated. Correlation of the zones of probable earthquake-induced structures is more difficult. This is in part due to extensive bioturbation of the sediments that may have completely obscured or rendered uninterpretable these sedimentologic features.

METHOD OF STUDY

Core 6 was obtained using Shelby and Ostenberg samplers with a barge mounted drill rig. The samples were retrieved and extruded into rigid plastic tubes which were sealed with plastic endcaps, and waxed to prevent moisture loss. For examination the plastic containers were cut open and the core cut in half lengthwise using a "cheese cutter" type instrument. Lithologic and other sedimentologic data were then recorded (see Appendix A for detailed descriptions). One-half of each core segment was photographed on color and black and white film. Then a one cm thick slice was taken from the center of the core segment and an x-ray radiograph made to study the internal structures and fine details of the visible structures.

The original x-ray radiographs were taken on 30 x 43 cm sheets of industrial x-ray film at 1:1 scale. Exposures to x-radiation ranged from 4 to 7 minutes at 45-55 KV and 3.5 ma. The prints from the radiographs in Appendix B of this paper are photographically reduced 3.7x from the originals.

After lengthwise splitting, samples were taken from one-half of the core for other sedimentologic and paleontologic studies as follows:

a) bulk mineralogy

b) cladocerae

c) diatoms

d) fine grain size analysis (<125 μ diameter)

e) macro fossils

f) pollen

g) water content/organic carbon content

The remaining core half, resting in a rigid plastic half-round, was sealed in a polyethelane bag and retained for future use and reference.

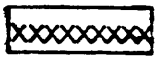
These samples and the original radiographs may be examined by contacting:

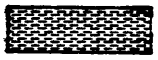
John D. Sims
U.S. Geological Survey
Earthquake Tectonics Branch
345 Middlefield Road
Menlo Park, California 94025

GRAPHIC NOTATIONS USED IN STRATIGRAPHIC DESCRIPTIONS

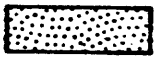
The stratigraphic descriptions of each core segment (slug) are contained on individual sheets in the format shown in fig. 5. The graphical notations used in the core descriptions and radiograph interpretations in Appendix B are modified from the methods of Bouma (1962). The conventions and symbols used follow: Those symbols marked* are also used in the column entitled Radiographic.

Lithology


ash


clay


silt

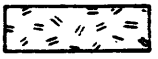

sand


gravel


peat

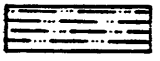

mud


silty sand


clayey silt

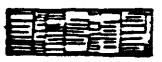

silty clay


clayey sand


sandy mud


sandy silt


sandy gravel


clayey peat


silty peat

material from sides of hole as a contaminant, generally at the top of a sample (debris).

v

vivianite, an iron phosphate present in the sediments.

interlaminated strata; dominant lithology on left (in this example clayey peat and mud)

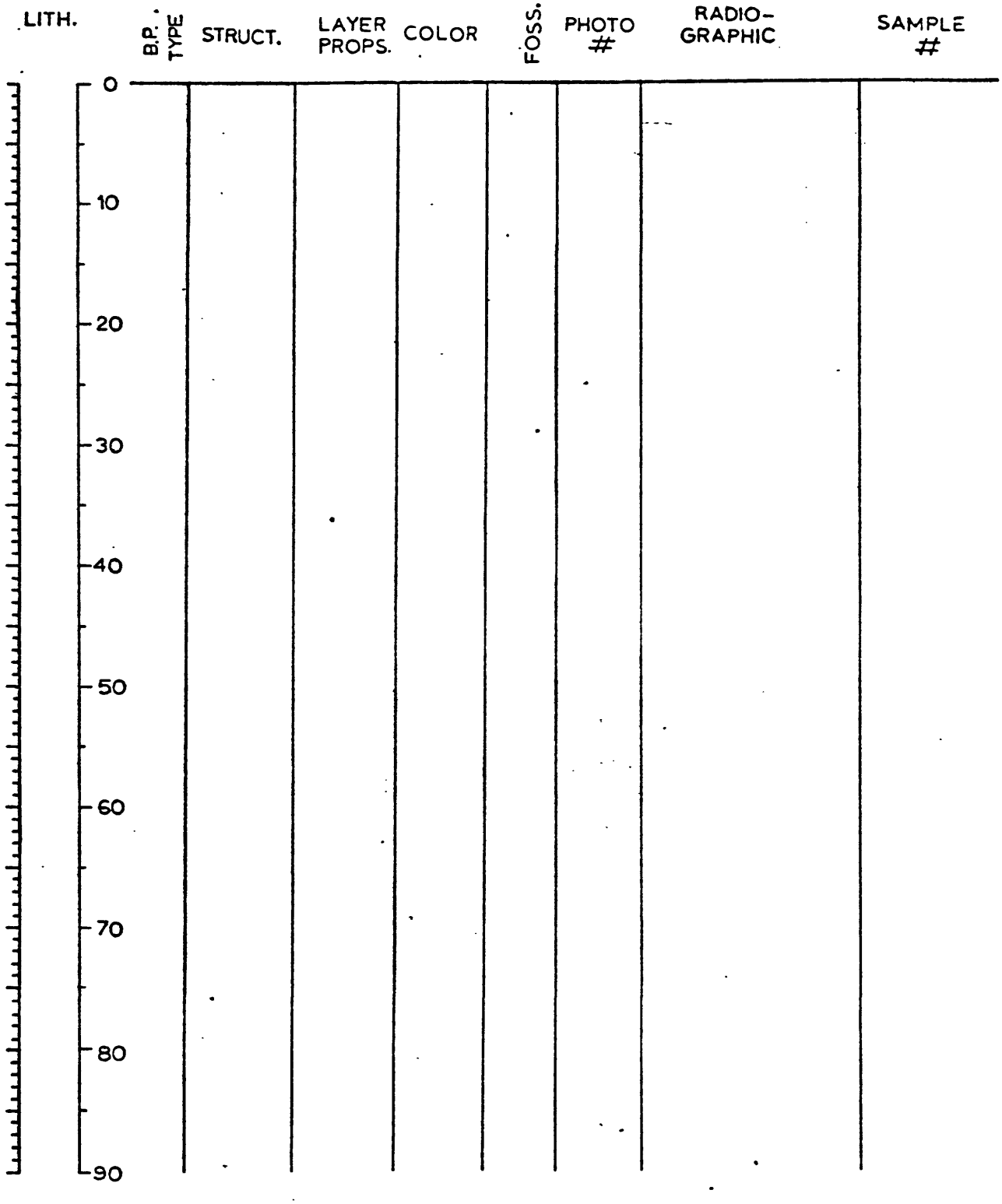
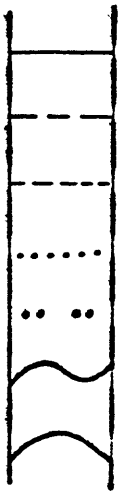


Figure 5. Form for stratigraphic descriptions of core segments (slugs) Column headings from left to right are Lithology, Bedding plane type, Bedding plane structures, Layer properties, Munsel Color designation, Fossil content, Photograph numbers, Radiographic interpretation, and Sample numbers.

Bedding Plane Type*



Sharp flat contact

distinct flat contact

transition (range of transition < 0.5 cm)

gradual transition (range of transition 0.5-1.0 cm)

transition gradual and hardly visible (range of transition > 1.0 c

undulating contact; gradations as above

irregular contact; gradations as above

Structure

graded bedding

load cast

earthquake induced structure*

fault*

Interval in which structure occurs*

indistinct structure*

structure barely visible*

Layer Properties

parallel lamination (< 0.5 cm thick)*:

coarse laminae predominate

fine laminae predominate

parallel lamination* — slightly disturbed

parallel lamination* — strongly disturbed

* Also used in column entitled Radiographic

parallel wavy lamination* 

(predominating thickness and degree of disturbance as noted above)

lenticular wavy lamination* 

(predominating thickness and degree of disturbance as noted above)

interval in which property occurs* 

indistinct property* ( )

Color

Color designations are taken from the Munsell Soil Color Chart (Munsell, 1973). Conventions used are as follows:

$\frac{10Y\ 5/4}{5YR\ 5/4}$	distinct color break between between two units.
10Y 5/4/5YR 5/4	two colors present throughout the interval noted. First color is most prevalent and the right hand color is present as clots, belbs, or patches.
10Y 5/4 | 5YR 5/4	distinct interlamination throughout the interval noted.
10Y 5/4 (5YR 5/4)	oxidized color (unoxidized color) this notation is used only where partial oxidization of the sediments has occurred and the unoxidized color is readily apparent.

Fossils

fish scale* 

fish bone*

* Also used in column entitled Radiographic

gastropod* 

clam* 

root 

root level 

wood oriented parallel to bedding plane

wood not parallel to bedding plane 

plant fragment parallel to bedding plane

plant fragment not parallel to bedding plane 

Photograph Number

Numbers refer to the index number of both the color and black and white photos taken of the cut surface of the core segment.

Example: 7-1-1 refers to Core 7, Slug 1, Photo 1.

There are 5 photos for each slug in Core 6. Each photo covers approximately 20 cm of core segment length with overlap with adjacent photos.

These photos may be examined and copies made at the requestor's expense by contacting:

John D. Sims
U.S. Geological Survey
Earthquake Tectonics Branch
345 Middlefield Road
Menlo Park, California 94025

* Also used in column entitled Radiographic

Radiographic

This column contains supplementary information derived from an analysis of information taken from x-ray radiographs. The notations used in this column are a combination of those marked by * under the headings Bedding Plane Type, Bedding Plane Structure, Layer Properties, and Fossils, plus some additional special symbols not previously used (list below):

granule - an x-ray opaque small body < 1 mm in diameter.

granule cluster - a regularly to irregularly shaped mass of granules.

pebble - a large (> 3 mm diameter) x-ray opaque body.

mottling - areas of low x-ray transparency of irregular shape and unknown origin.

bioturbation - animal burrows. The degree of sediment disturbance generally accompanies this note such as: heavy, slight, etc.

$\Delta\delta$ - a difference in x-ray transparency between stratigraphic subunits due to compositional, grain size or other physiochemical differences.

fractured - physical breaking of the indicated part of the sediment slice that usually occurred during sample preparation prior to x-ray inspection.

plastic - plastic chips derived from sawing the rigid plastic core container.

Sample Number

Three types of sample numbers are present and identify samples taken for specific tests or supplementary data. The specific use and identity of samples are as follows:

1) Four digit numbers without a prefix are reserved for bulk mineralogy, fine grain size analysis (fraction < 125 μ diameter), fossil cladocerae, palynological examination, weight loss on drying, fossil diatoms and macrofossil content.

2) Four digits prefixed by "I" (example: I-7030). A radiocarbon date performed by Mr. James Buckley in the laboratories of Isotopes, Inc., Westwood, N.J. The absolute date and all pertinent data are listed at the bottom of the page on which the sample number occurs.

3) Four digits prefixed by "W" (example: W-3030). A radiocarbon date performed by Mr. Meyer Rubin in the laboratories of the U.S. Geological Survey, Reston, VA. The absolute date and all pertinent data are listed at the bottom of the page on which the sample number occurs.

Acknowledgements;

This project was in part financed by a grant from Lake County, California. We wish also to thank D. Adam, D. Peterson, G. Reed, D. Greenwood, I. Gassoway, P. Margolin and R. Wright for their assistance during the coring operations at Clear Lake.

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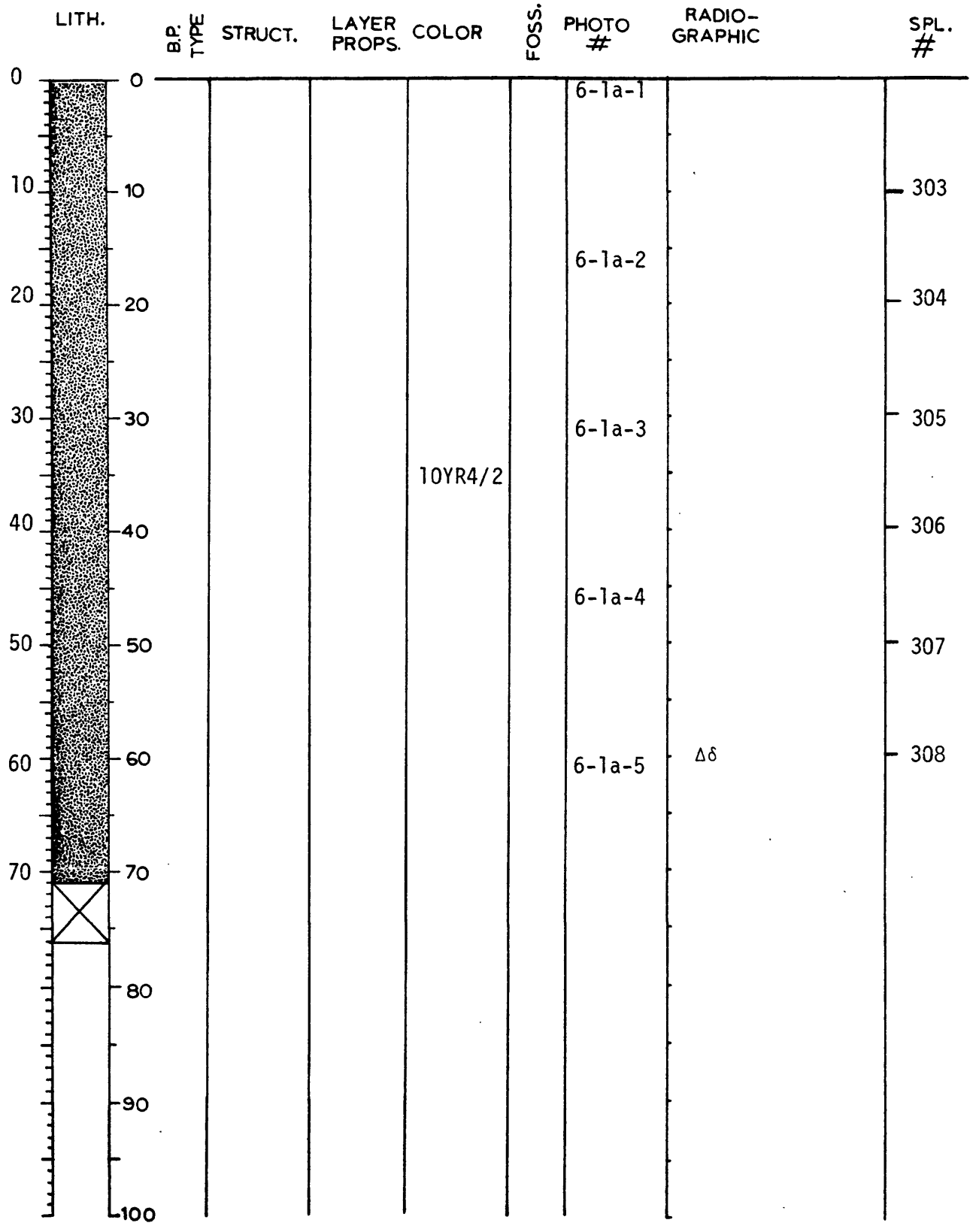
Appendix A

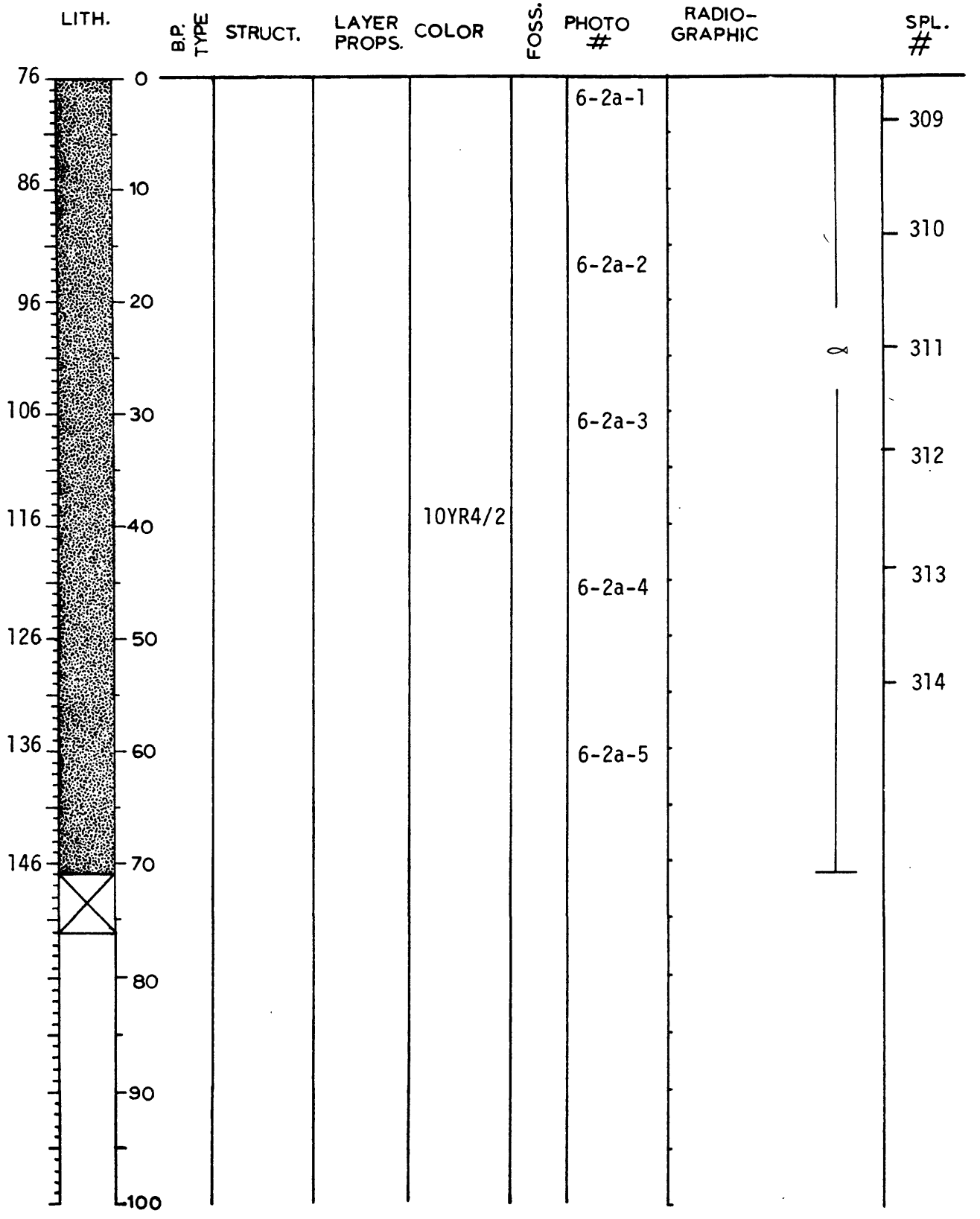
Graphical Logs

HOLE 6 SLUG 1a DEPTH 0 cm. to 76 cm.



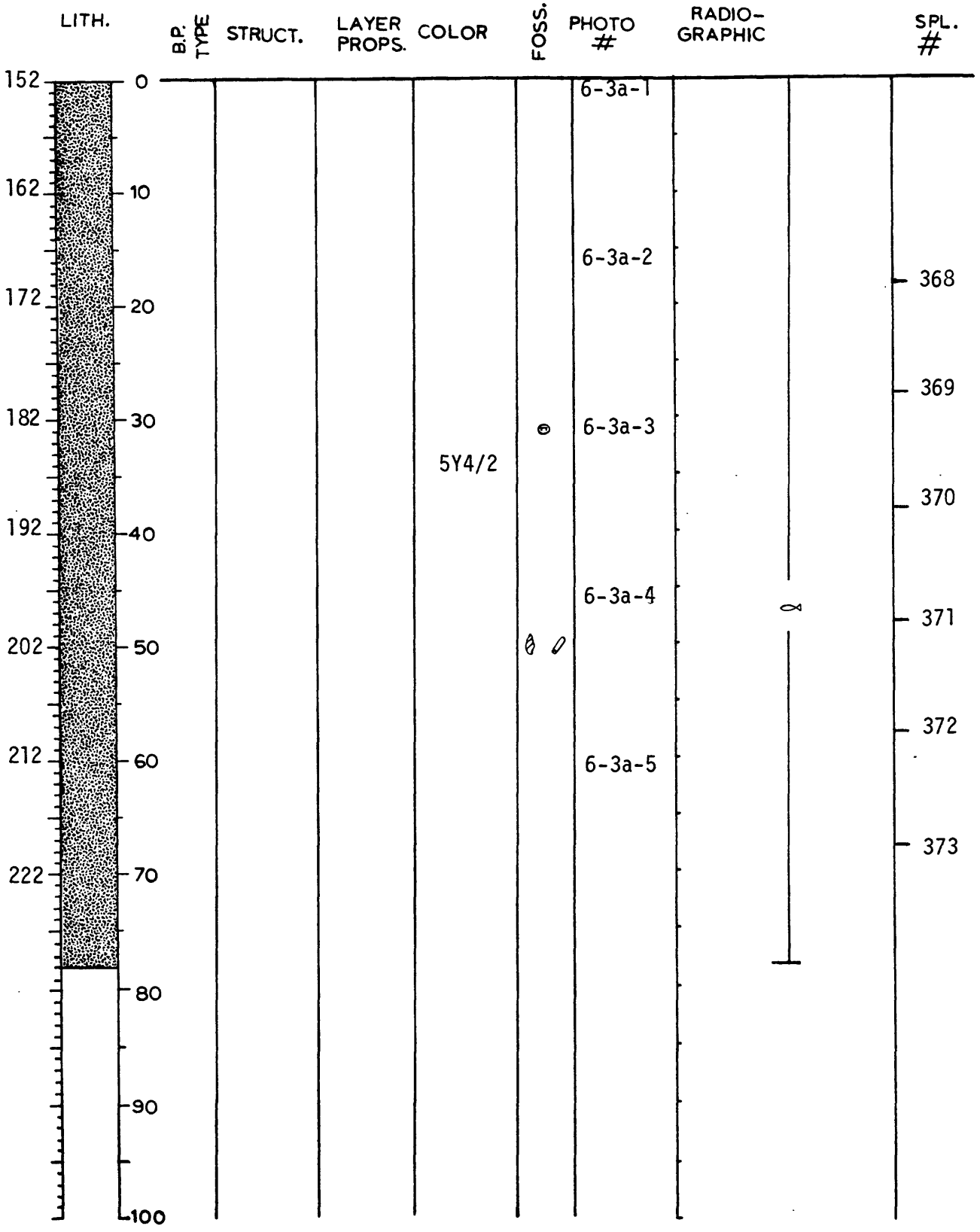
granules and bioturbation throughout

HOLE 6 SLUG 2a DEPTH 76 cm. to 152 cm.



granules and bioturbation throughout

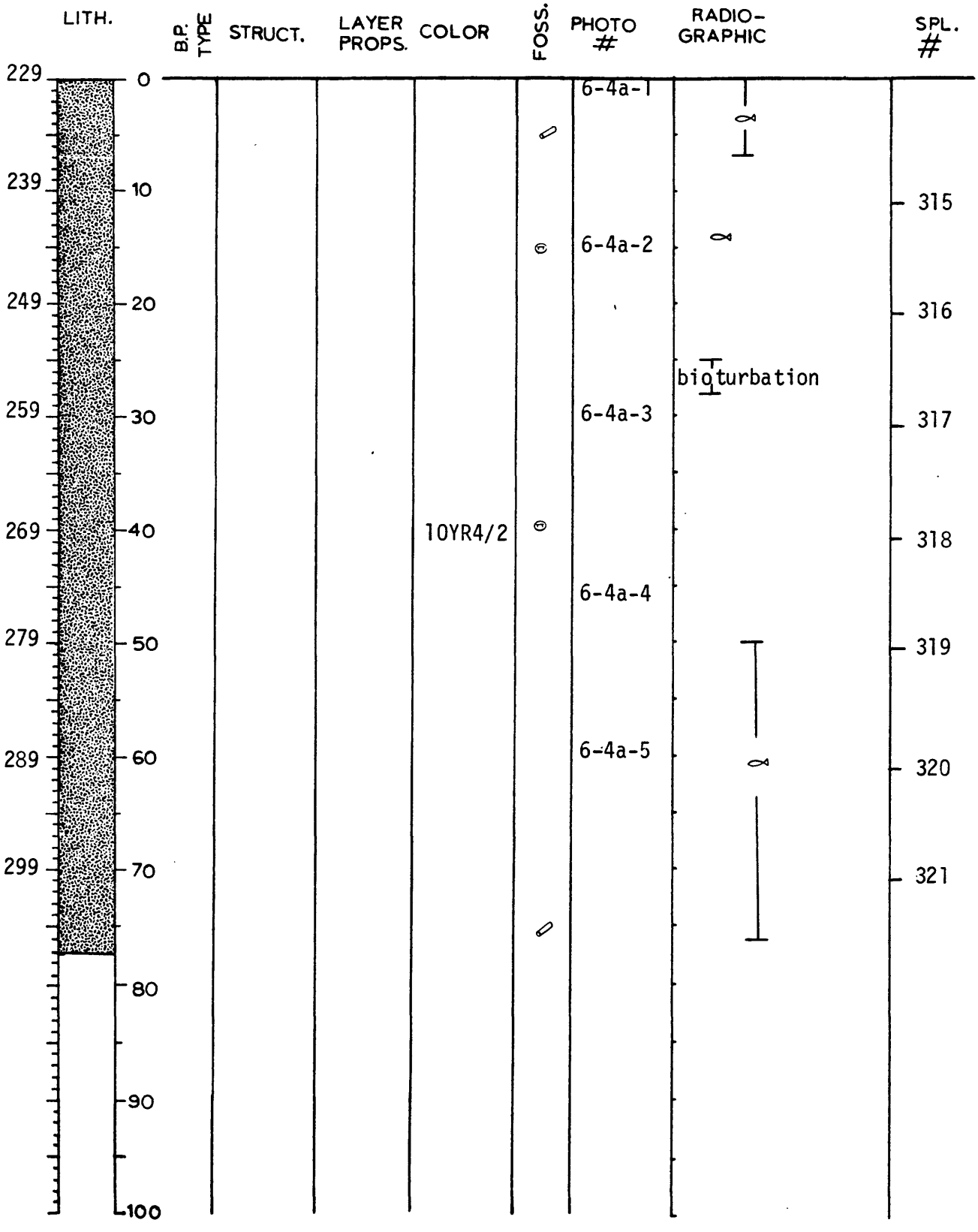
HOLE 6 SLUG 3a DEPTH 152 cm. to 229 cm.



granules and bioturbation throughout

Note: core has apparently elongated slightly during handling and storage.

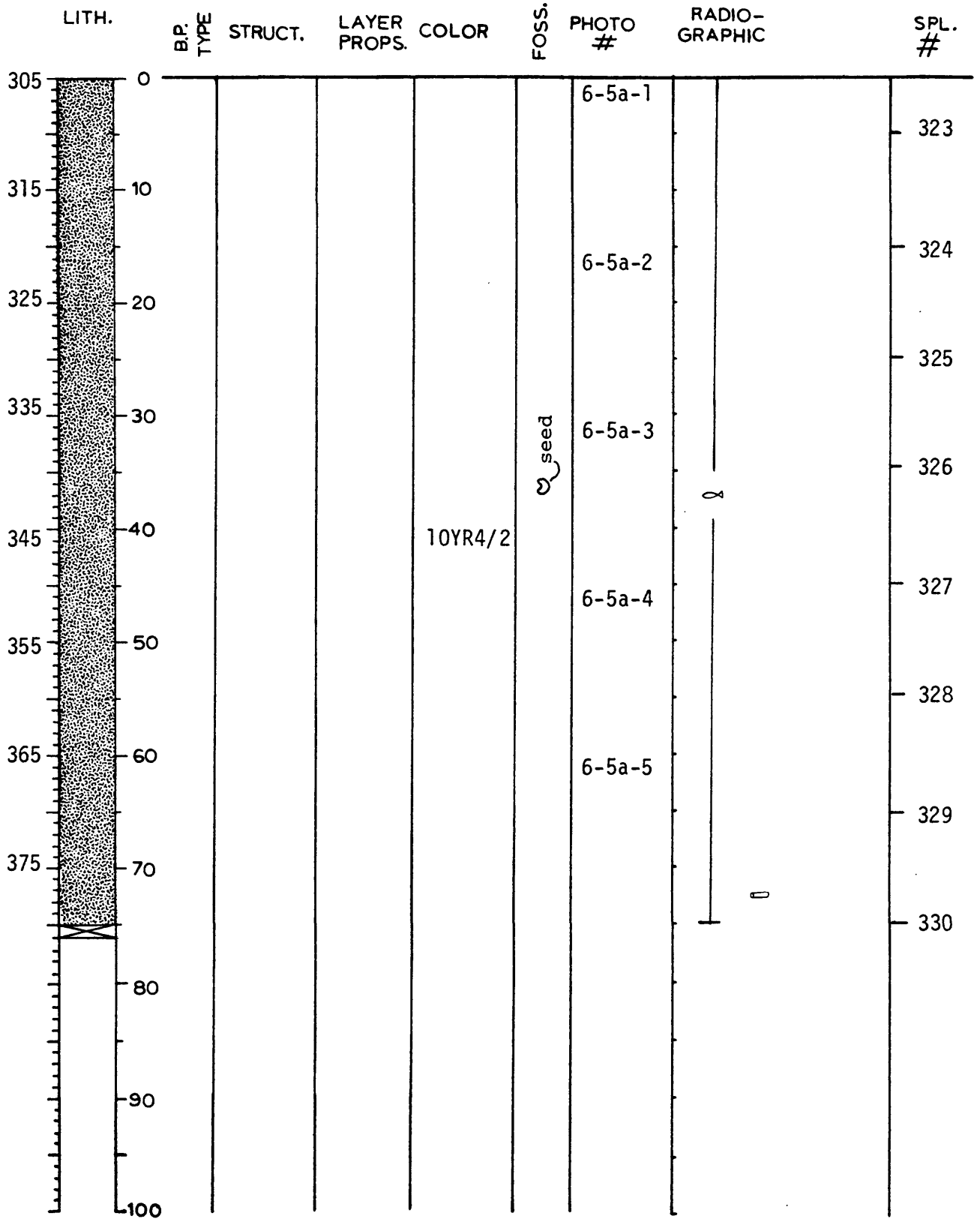
HOLE 6 SLUG 4a DEPTH 229 cm. to 305 cm.



granules throughout

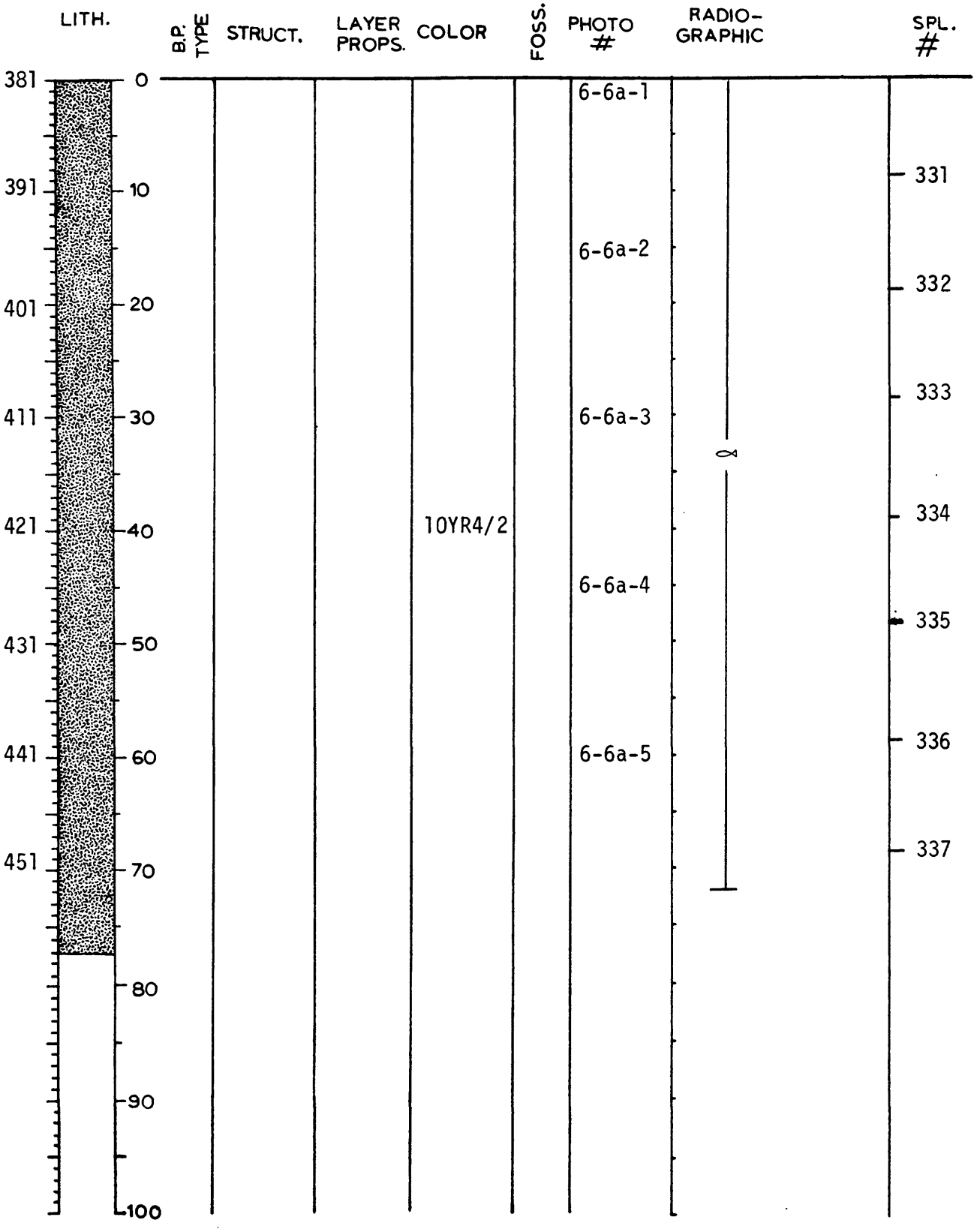
Note: core has apparently elongated slightly during handling and storage.

HOLE 6 SLUG 5a DEPTH 305 cm. to 381 cm.



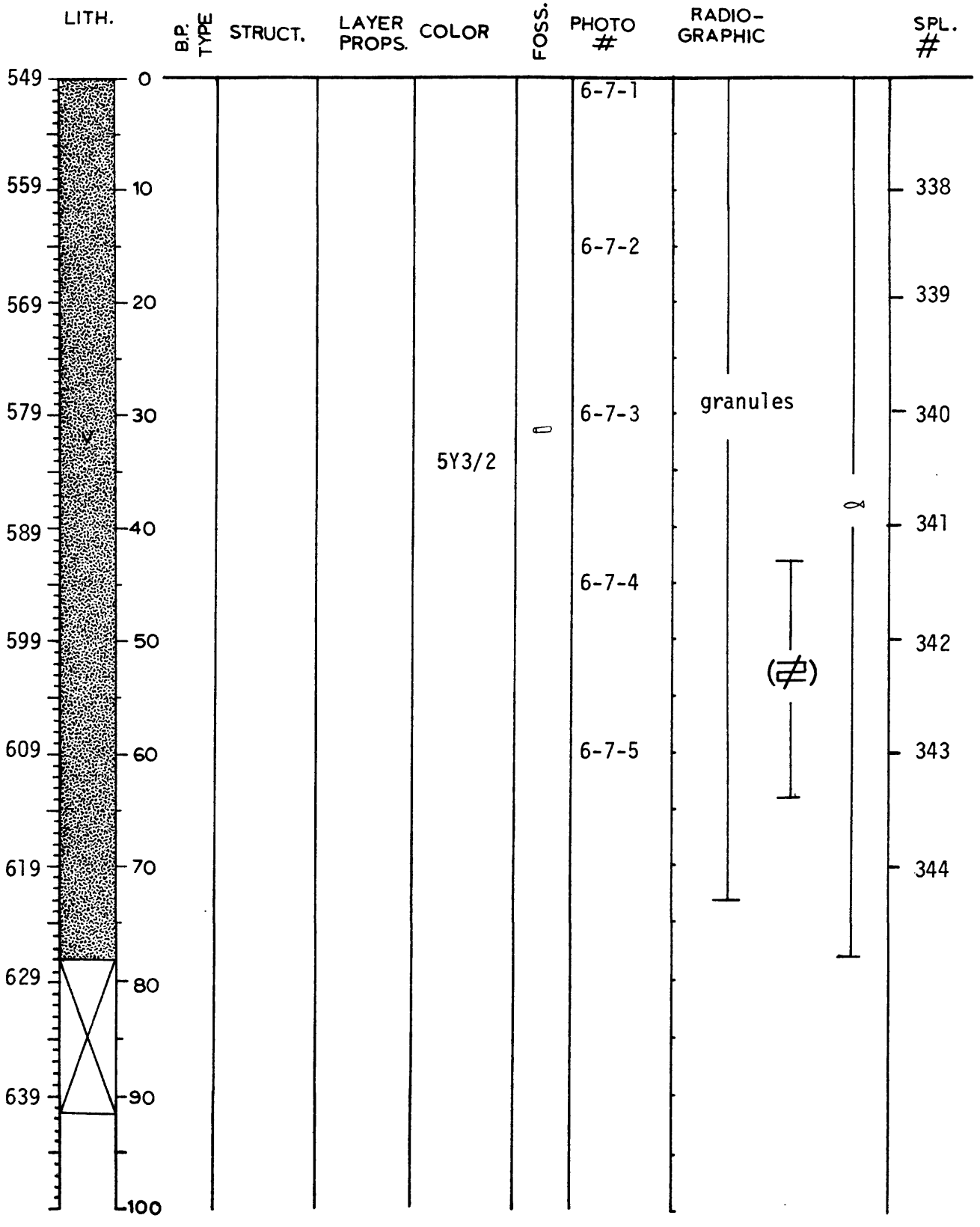
granules and bioturbation throughout

HOLE 6 SLUG 6a DEPTH 381 cm. to 457 cm.



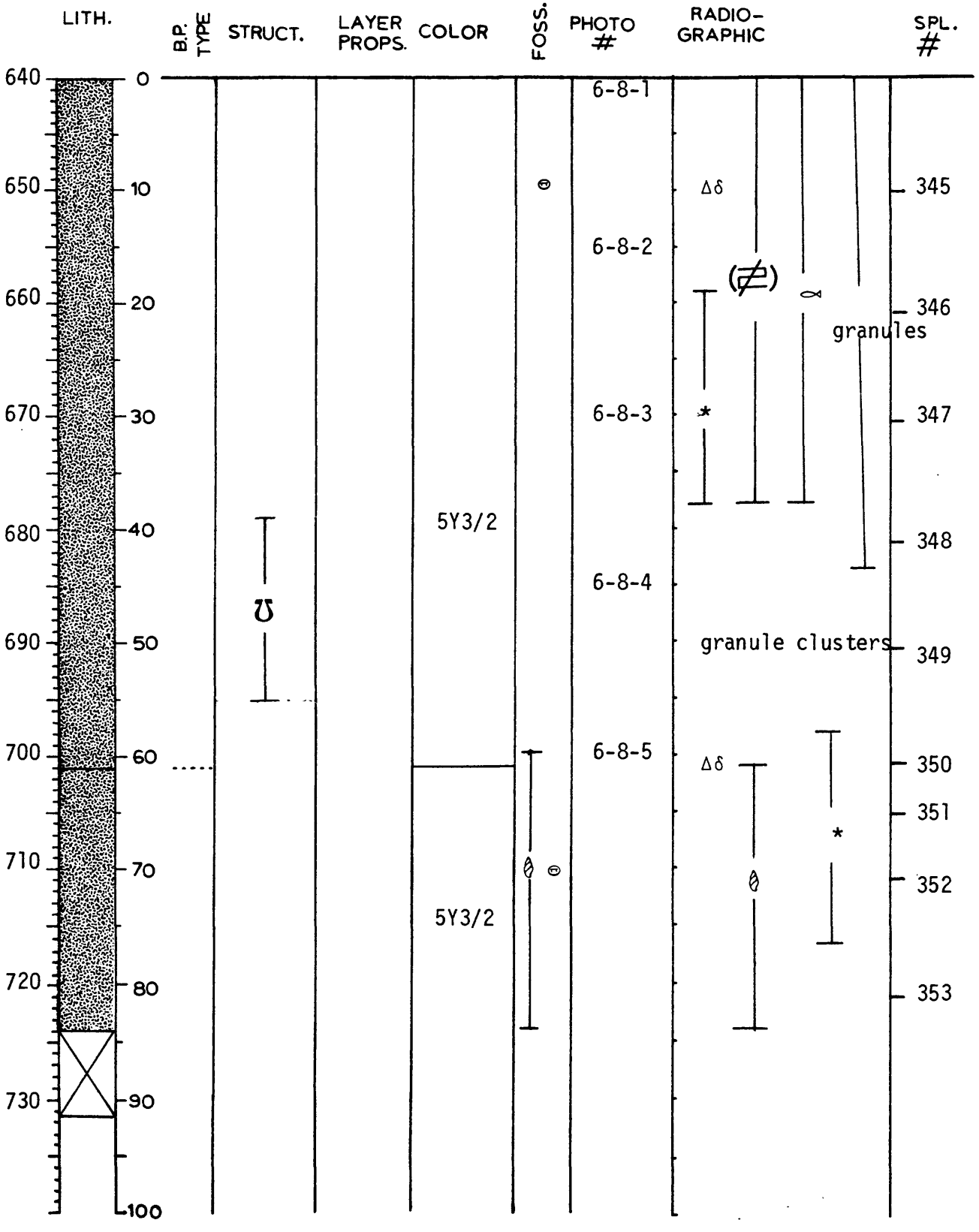
Note: core has apparently elongated slightly during handling and storage
abundant granules and intense bioturbation throughout

HOLE 6 SLUG 7 DEPTH 549 cm. to 640 cm.



extensive cracking 0-63 cm

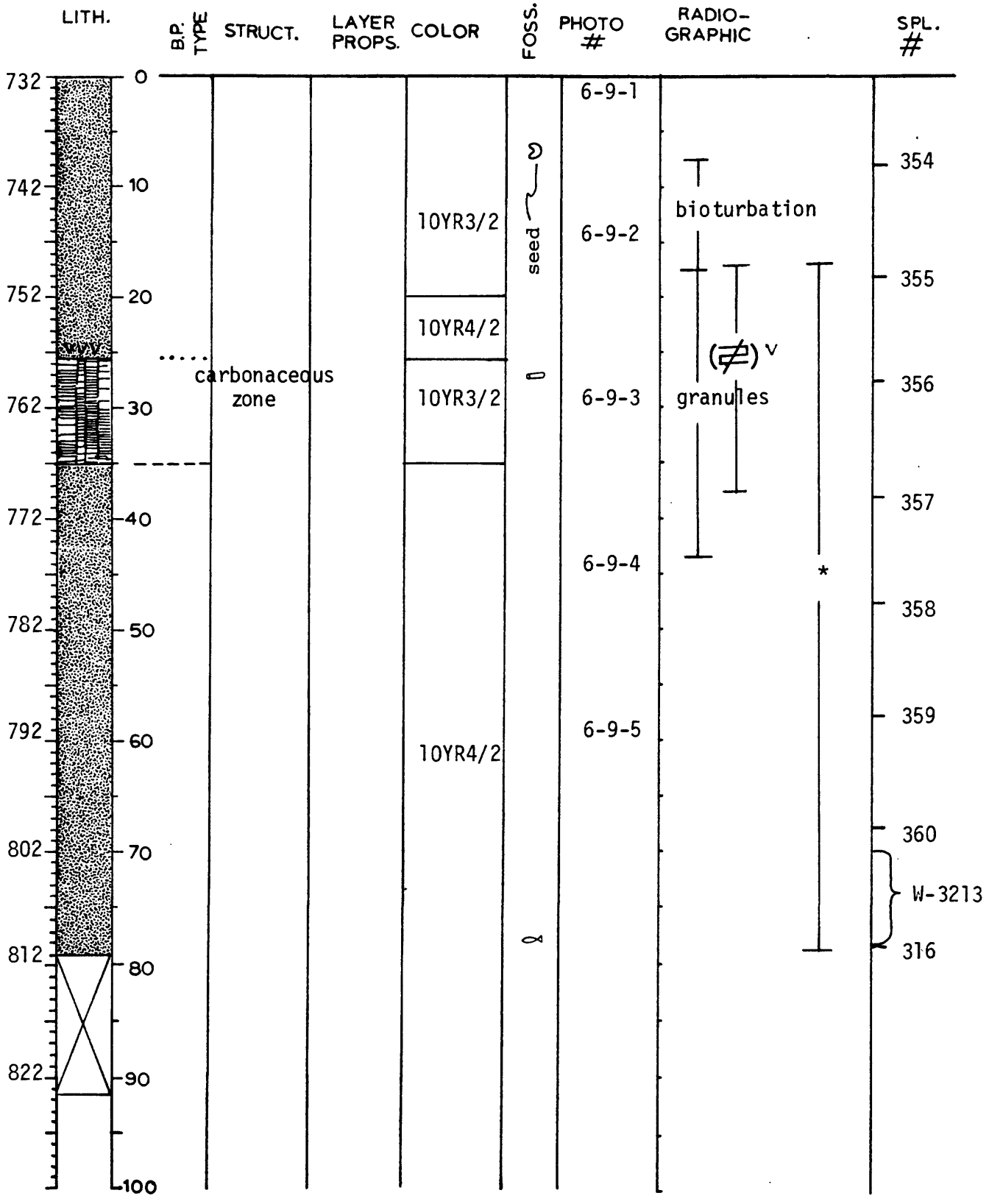
HOLE 6 SLUG 8 DEPTH 640 cm. to 732 cm.



* deformational structure appears to be a sedimentary dike

bioturbation throughout

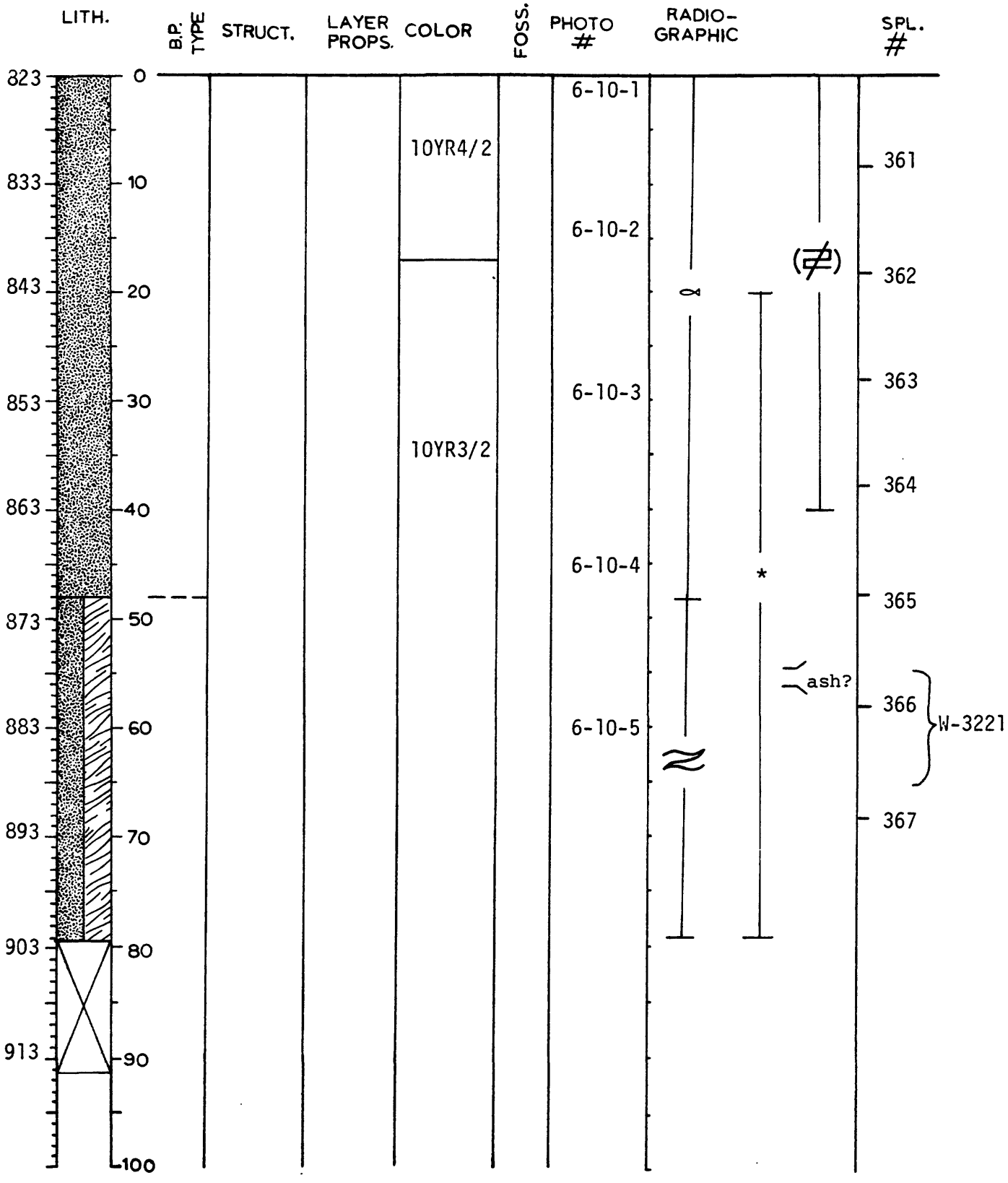
HOLE 6 SLUG 9 DEPTH 732 cm. to 823 cm.



* x-ray opaque filamentous objects

W-3213: 13,650 ± 450 yr. B.P.

HOLE 6 SLUG 10 DEPTH 823 cm. to 914 cm.

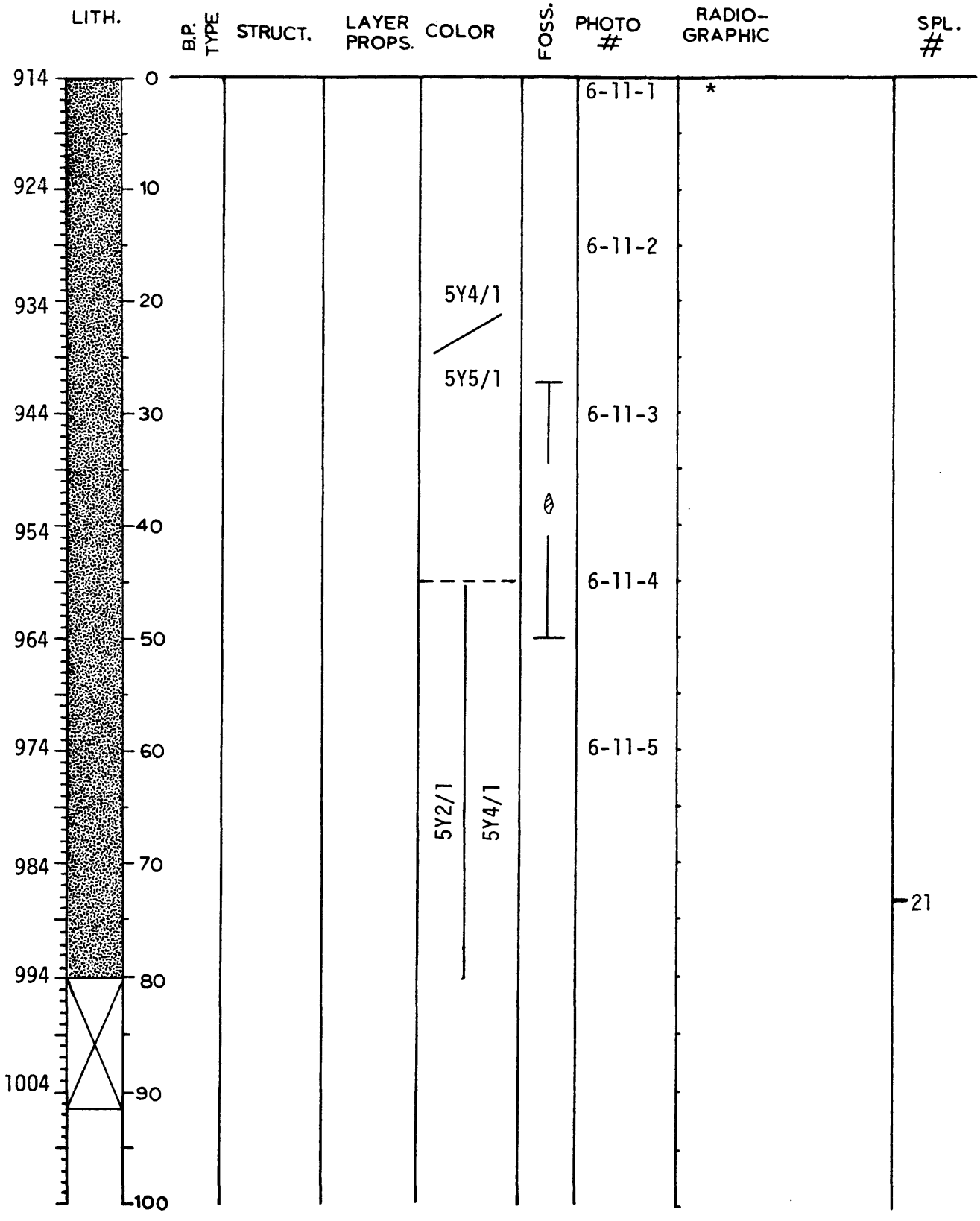


* x-ray opaque filamentous objects

granules throughout

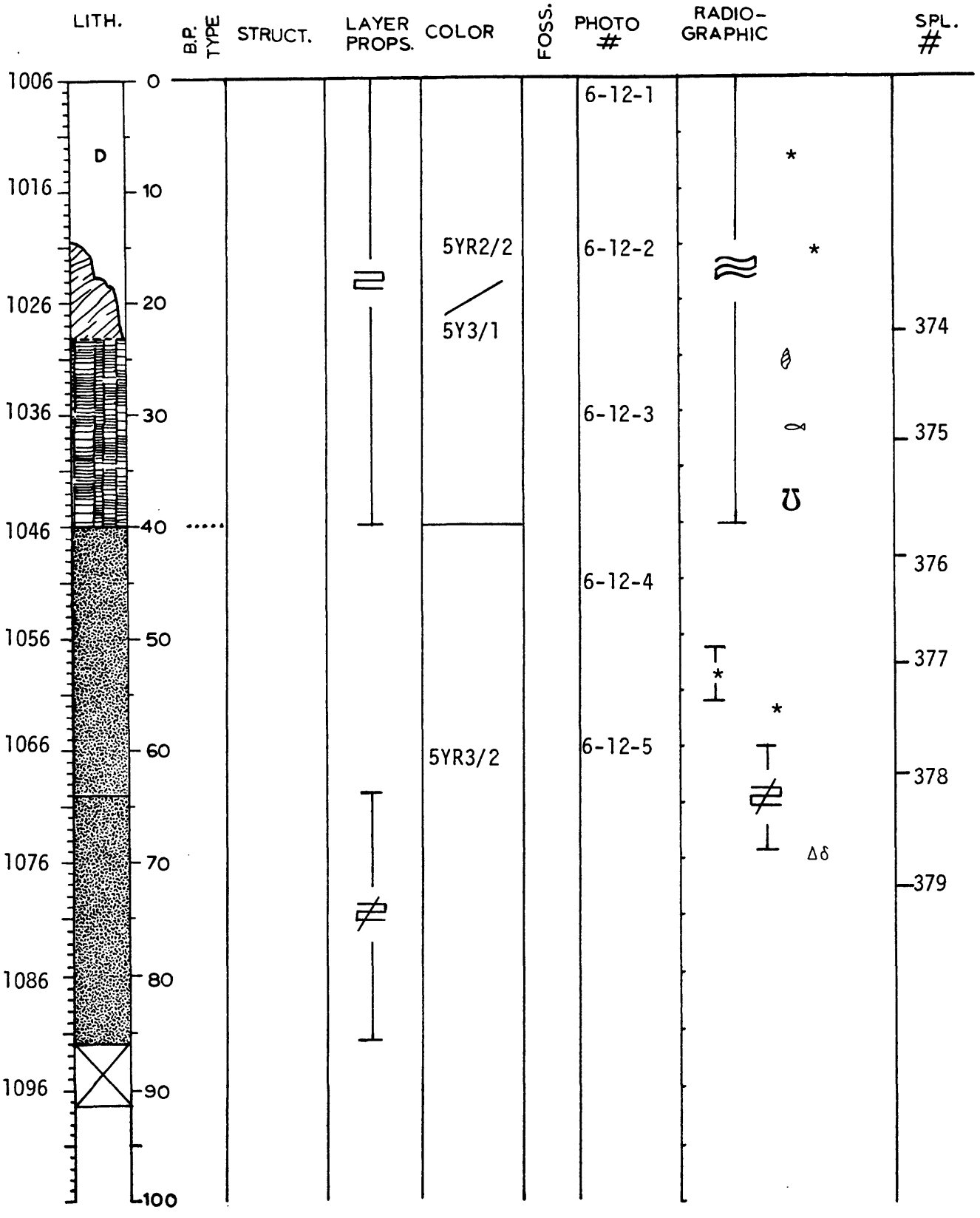
W-3221: 13,200 ± 400 yr. B.P.

HOLE 6 SLUG 11 DEPTH 914 cm. to 1006 cm.



* severely disturbed probably elongated by 4 cm

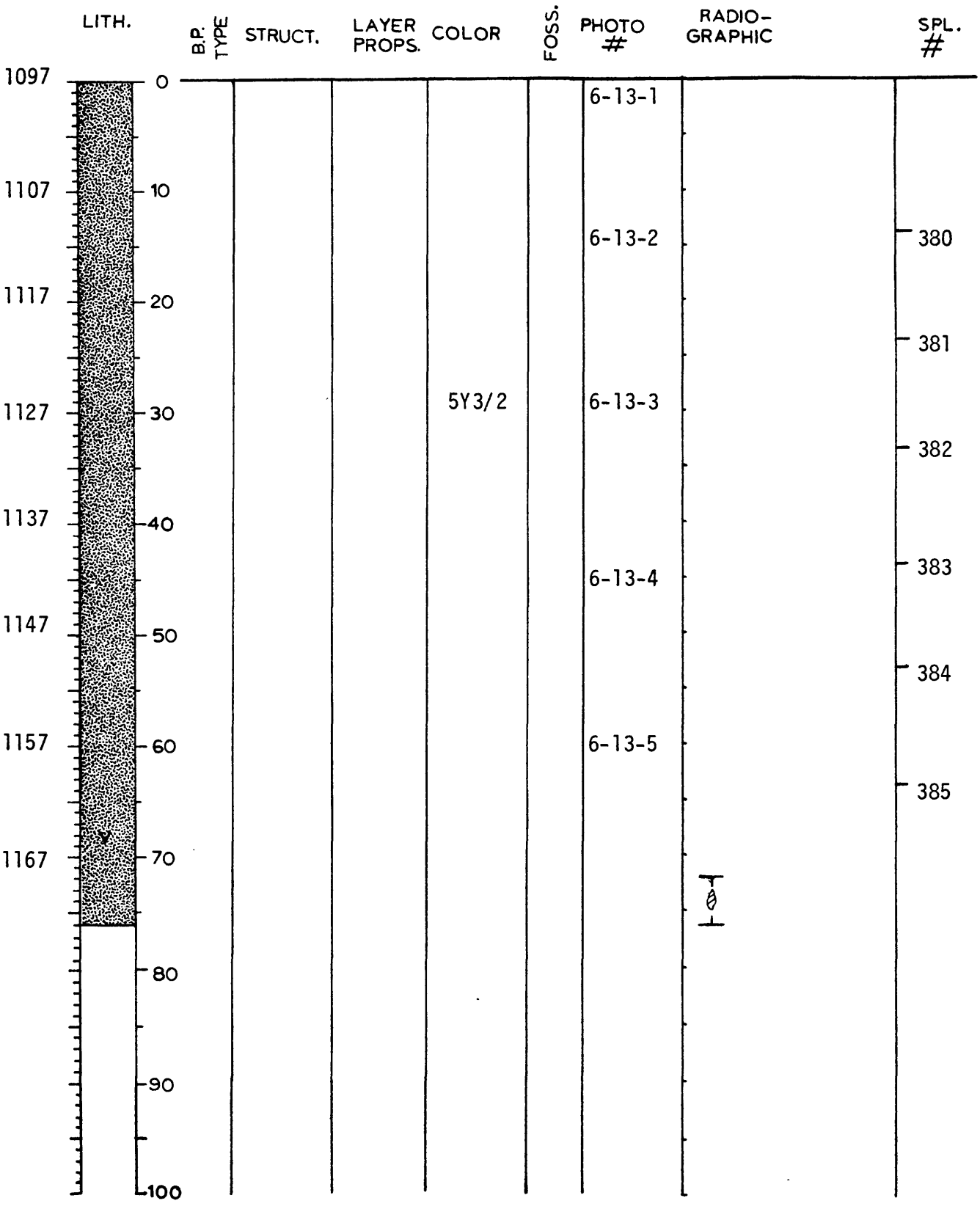
HOLE 6 SLUG 12 DEPTH 1006 cm. to 1097 cm.



disturbed upper 15 cm

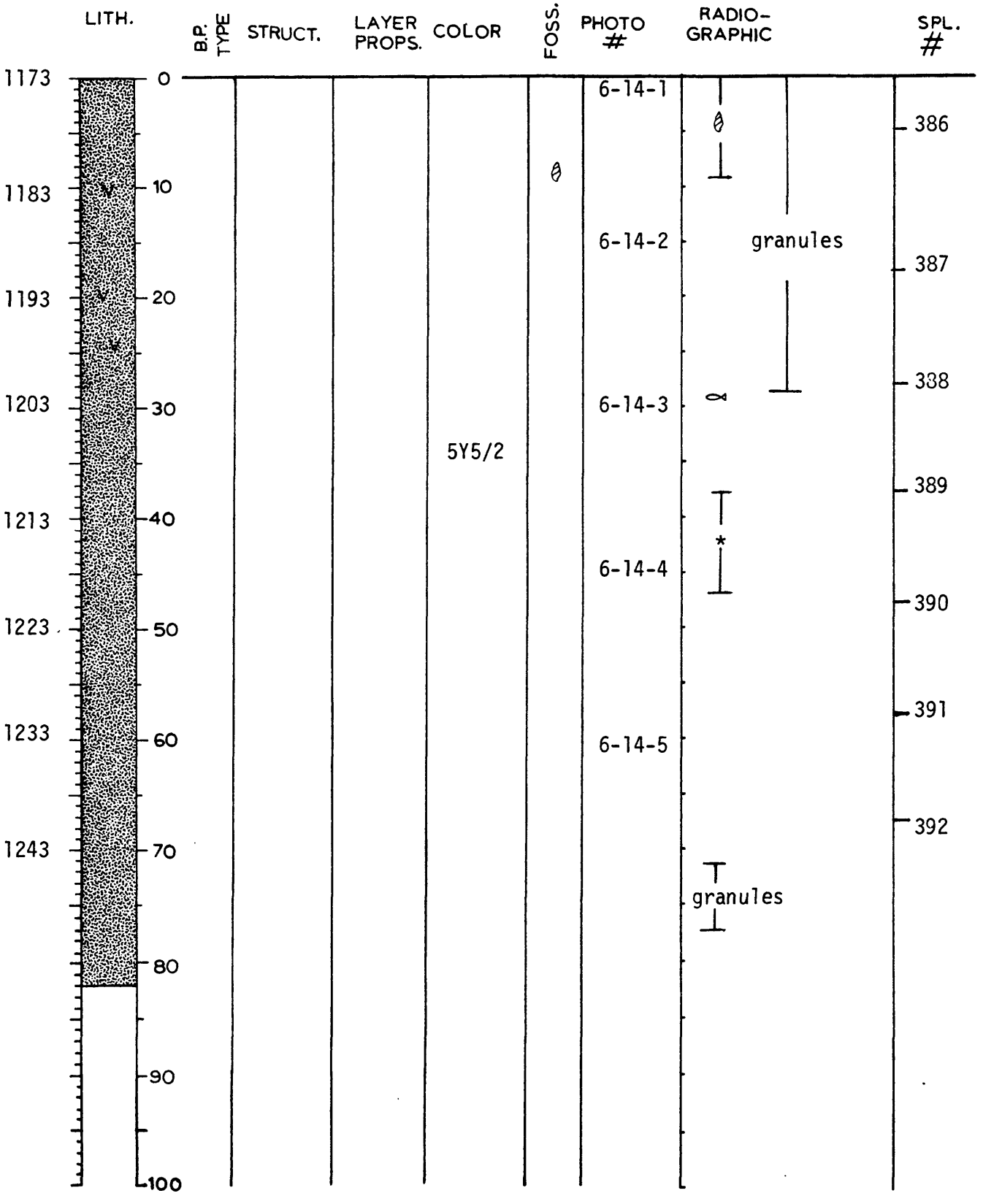
* x-ray opaque filamentous objects (vivianite veinlets probably in part in abandoned worm burrows).

HOLE 6 SLUG 13 DEPTH 1097 cm. to 1173 cm.



granules throughout

HOLE 6 SLUG 14 DEPTH 1173 cm. to 1250 cm.

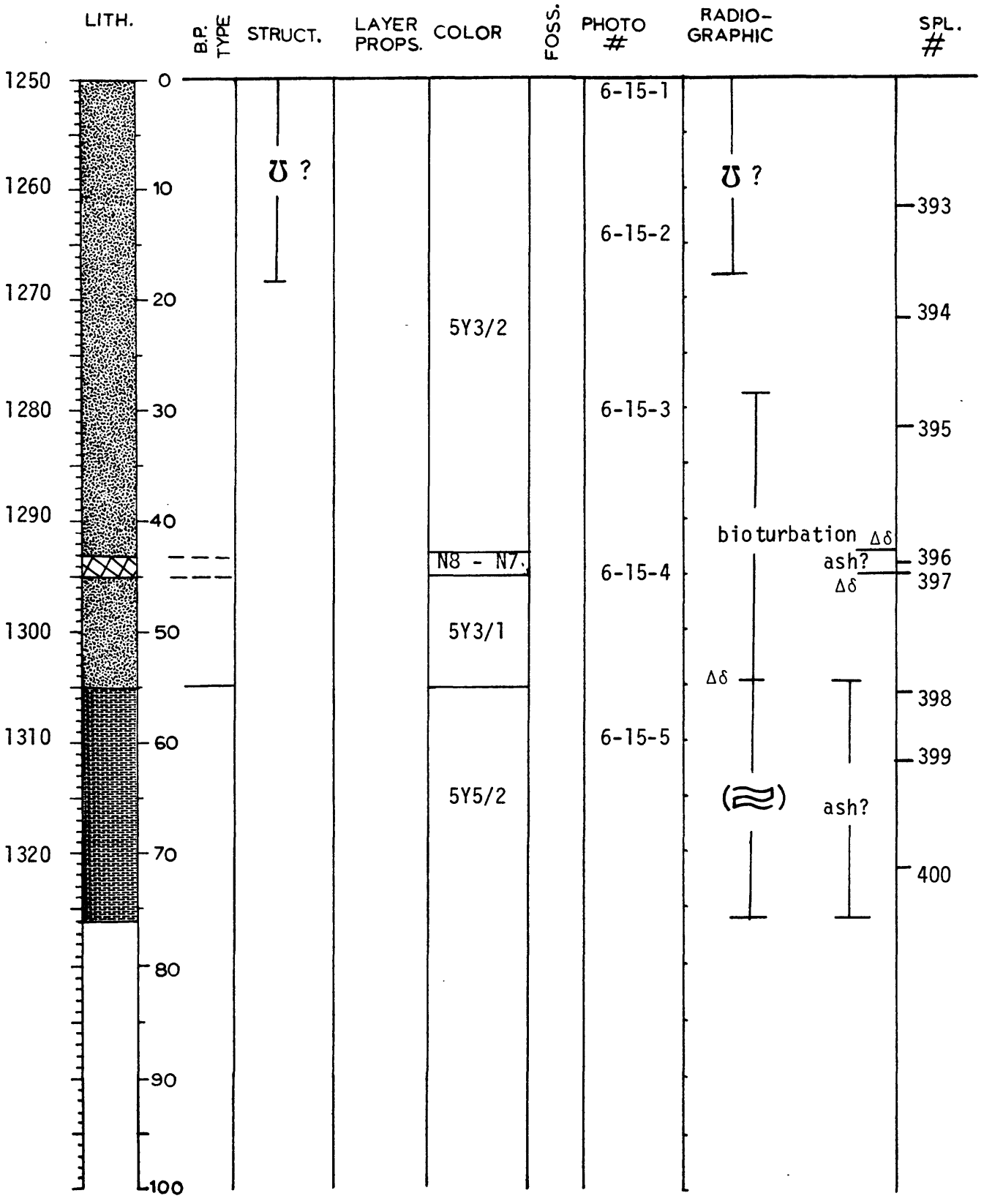


bioturbation throughout

* x-ray opaque filamentous objects (probably vivianite veinlets)

Note: core has apparently elongated slightly during handling and storage.

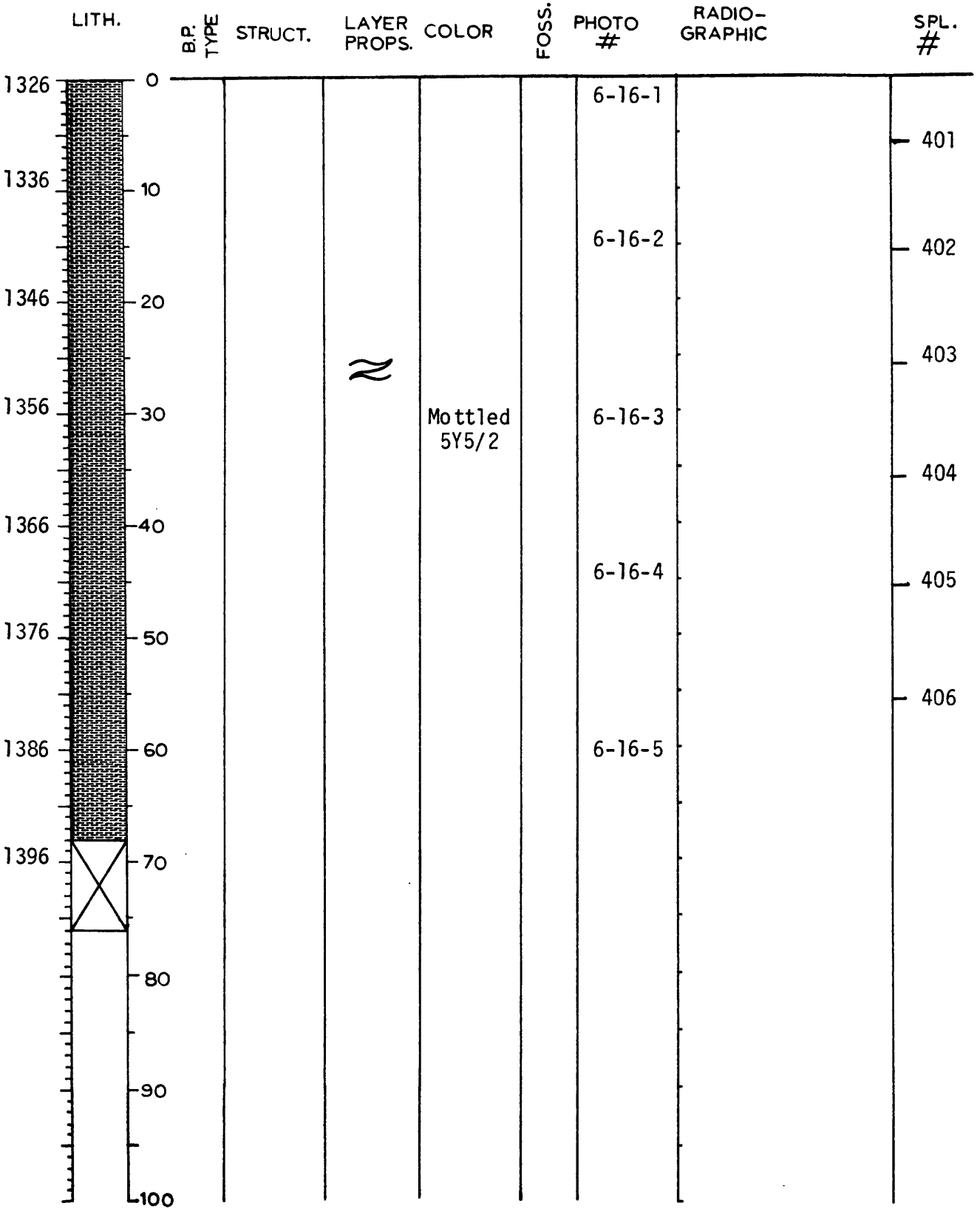
HOLE 6 SLUG 15 DEPTH 1250 cm. to 1326 cm.



ash between 43 and 45 cm is bioturbated. This ash is correlated with the ash in core 7 slug 17 (Sims and Rymer, 1975).

This latter ash is ^{14}C dated at 17,500 years B.P.

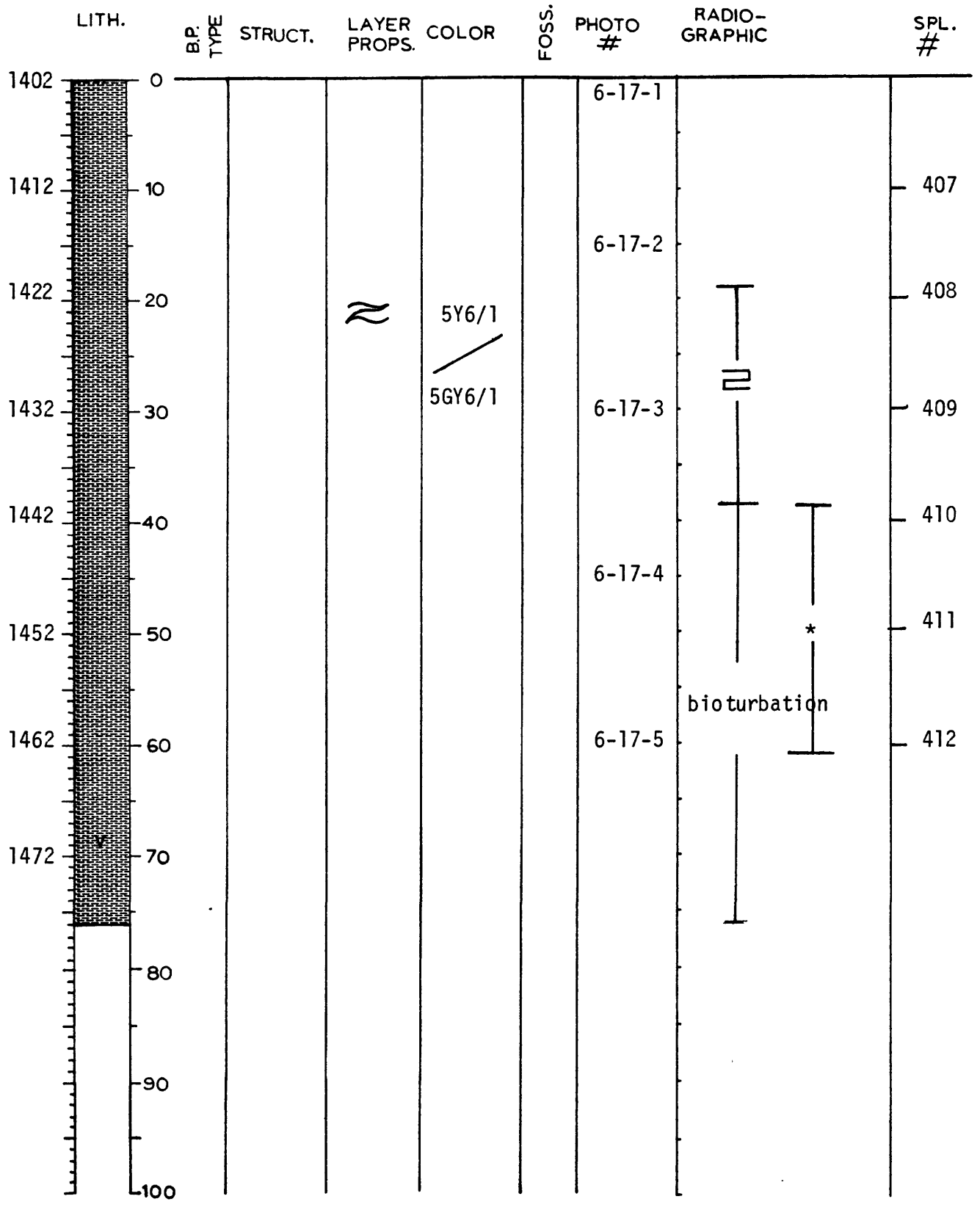
HOLE 6 SLUG 16 DEPTH 1326 cm. to 1402 cm.



material is a dense clay.

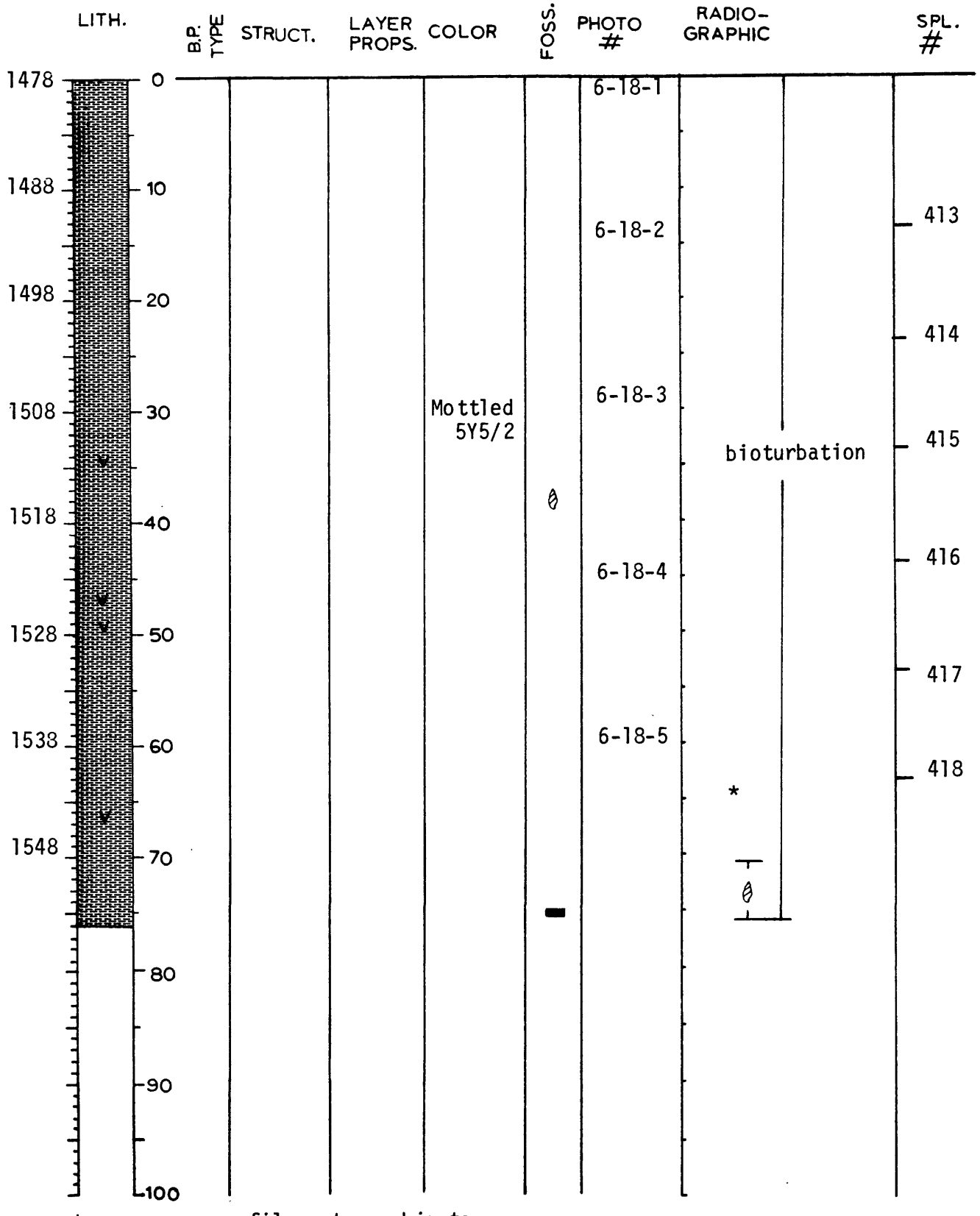
bioturbation throughout

HOLE 6 SLUG 17 DEPTH 1402 cm. to 1478 cm.



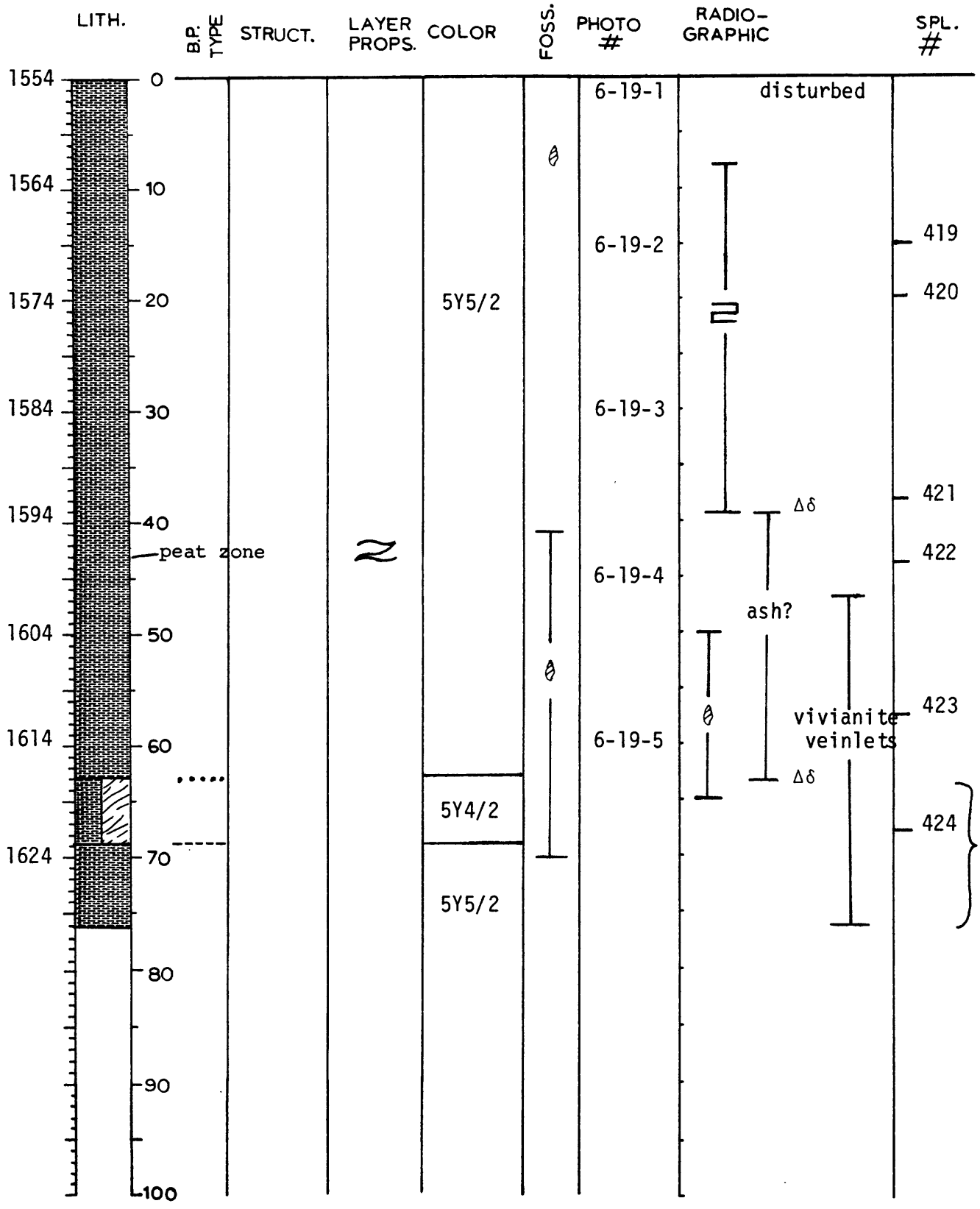
* dense patches are high concentrations of organic material

HOLE 6 SLUG 18 DEPTH 1478 cm. to 1554 cm.



* x-ray opaque filamentous objects

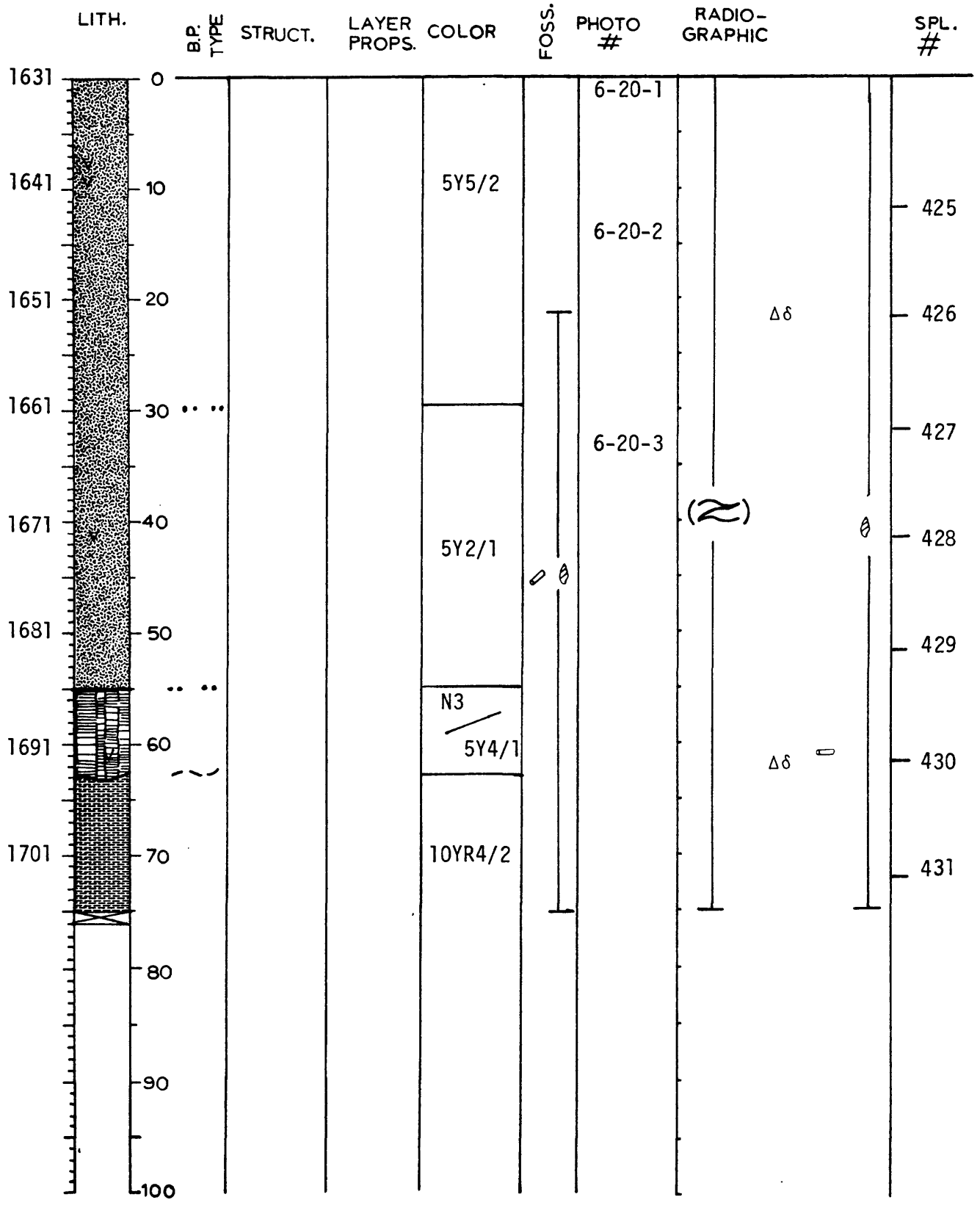
HOLE 6 SLUG 19 DEPTH 1554 cm. to 1631 cm.



mottled texture between Δδ's at 42 cm and 63 cm may represent ped-texture of a soil or altered lapilli in a volcanic ash.

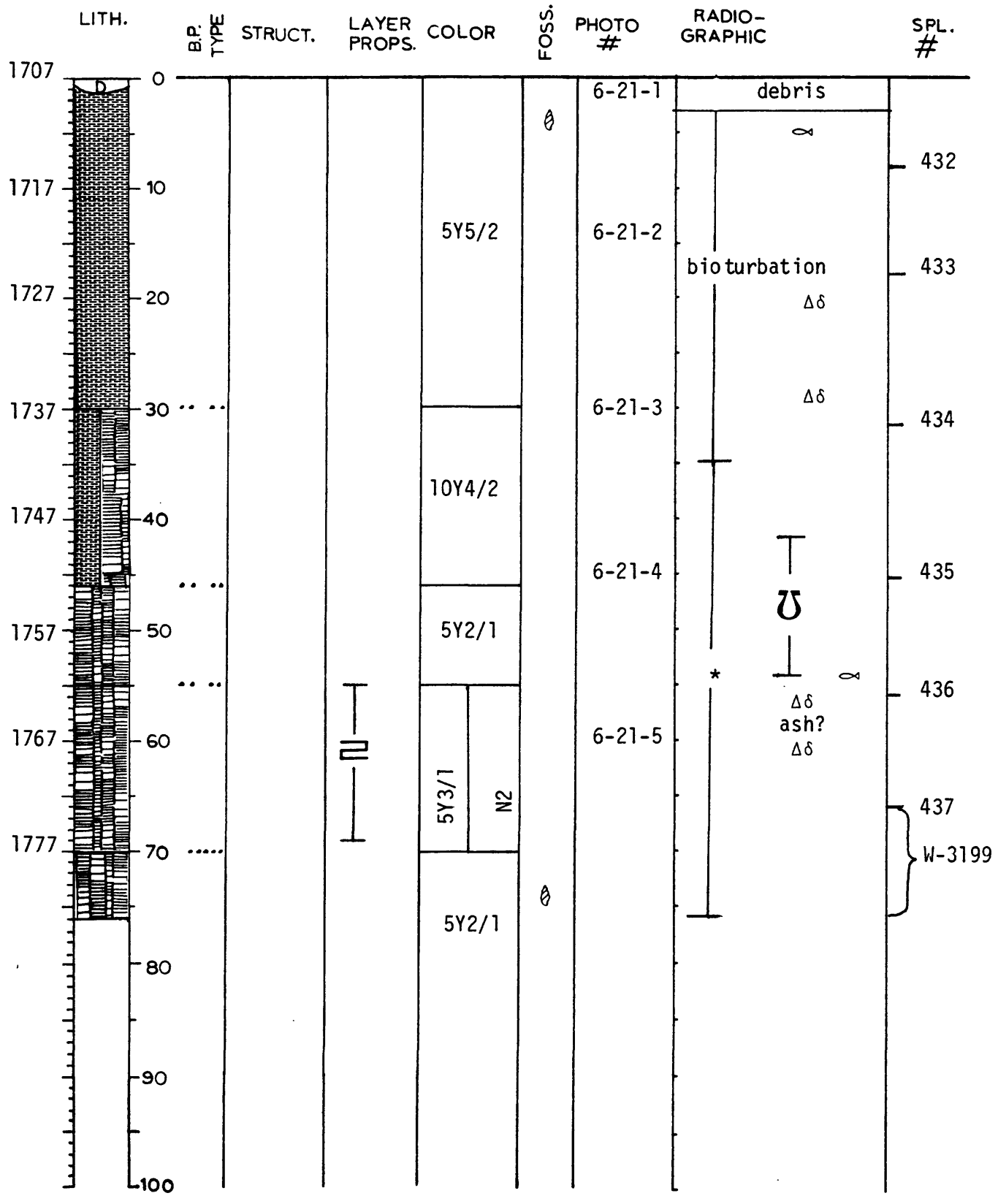
W-3218: 25,890 ± 1,000 yr. B.P.

HOLE 6 SLUG 20 DEPTH 1631 cm. to 1707 cm.



x-ray opaque filamentous objects and granules throughout

HOLE 6 SLUG 21 DEPTH 1707 cm. to 1783 cm.

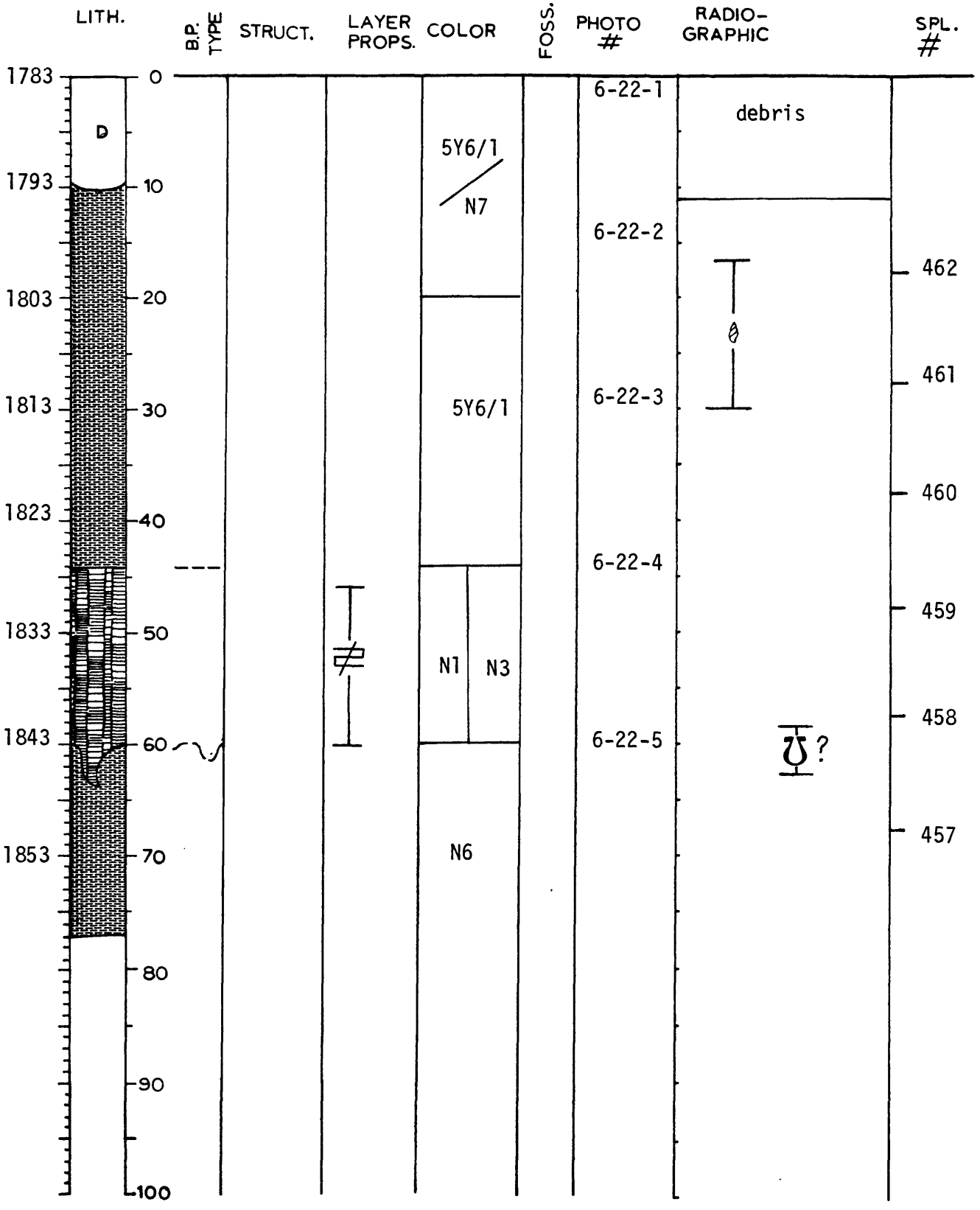


* root-like vertical structures (possibly bioturbation)

sparse granules throughout

W-3199: 34,070 ± 1,000 yr. B.P.

HOLE 6 SLUG 22 DEPTH 1783 cm. to 1859 cm.

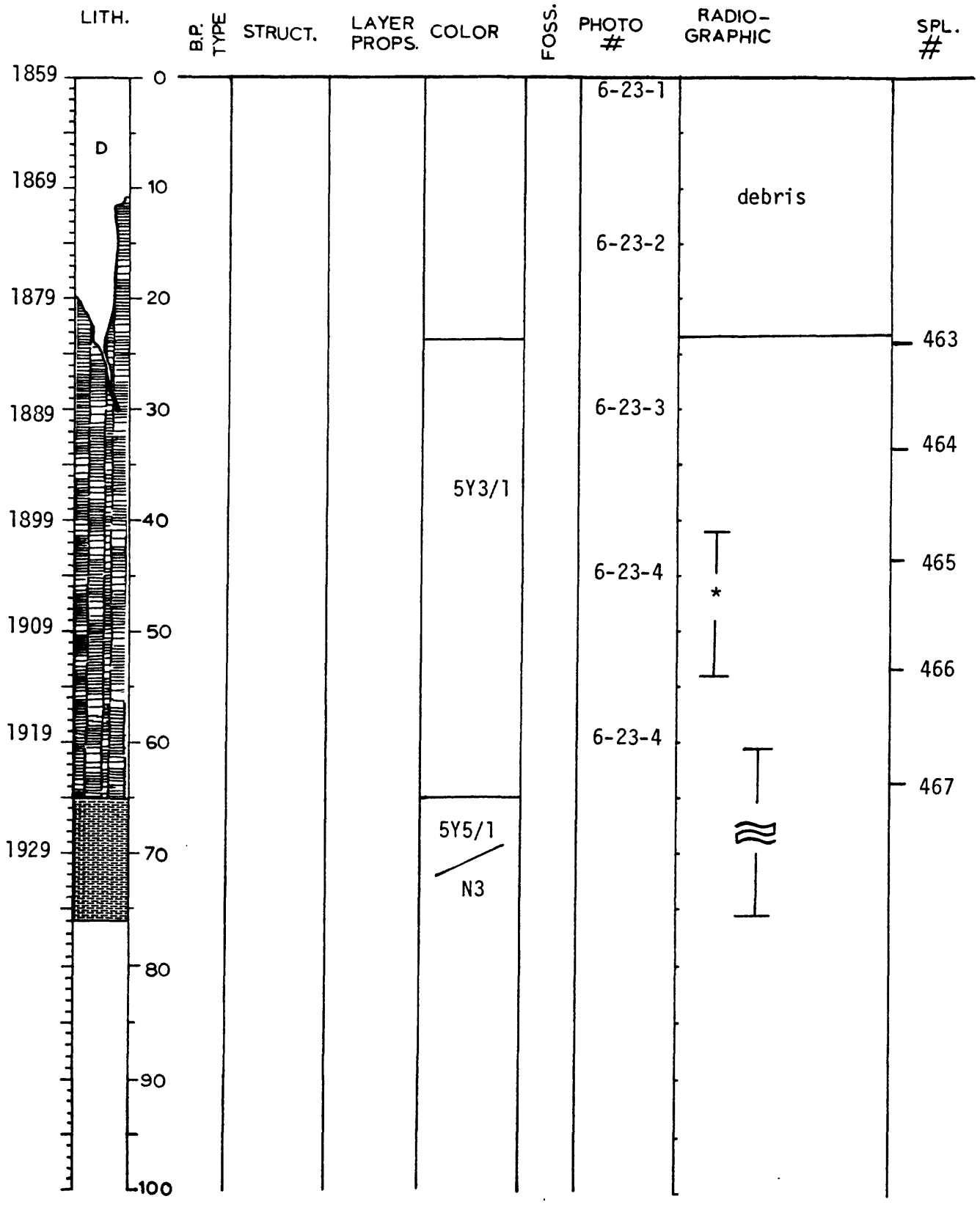


76 cm is probably the actual length of core; top debris probably expanded slightly

x-ray opaque filamentous objects throughout (probably vivianite veinlets)

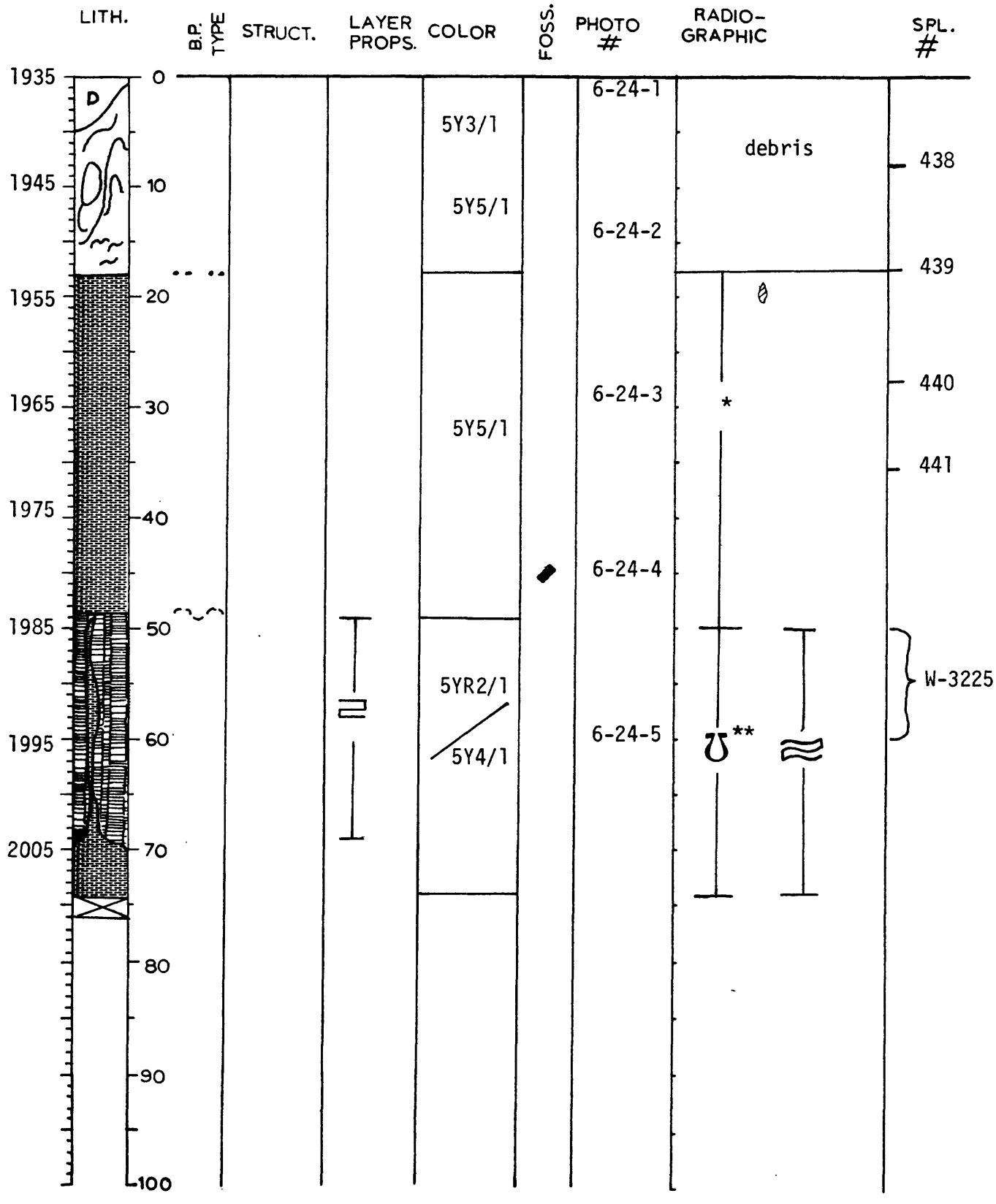
Note: some apparent elongation occurred during handling and storage

HOLE 6 SLUG 23 DEPTH 1859 cm. to 1935 cm.



* root-like vertical structures

HOLE 6 SLUG 24 DEPTH 1935 cm. to 2012 cm.

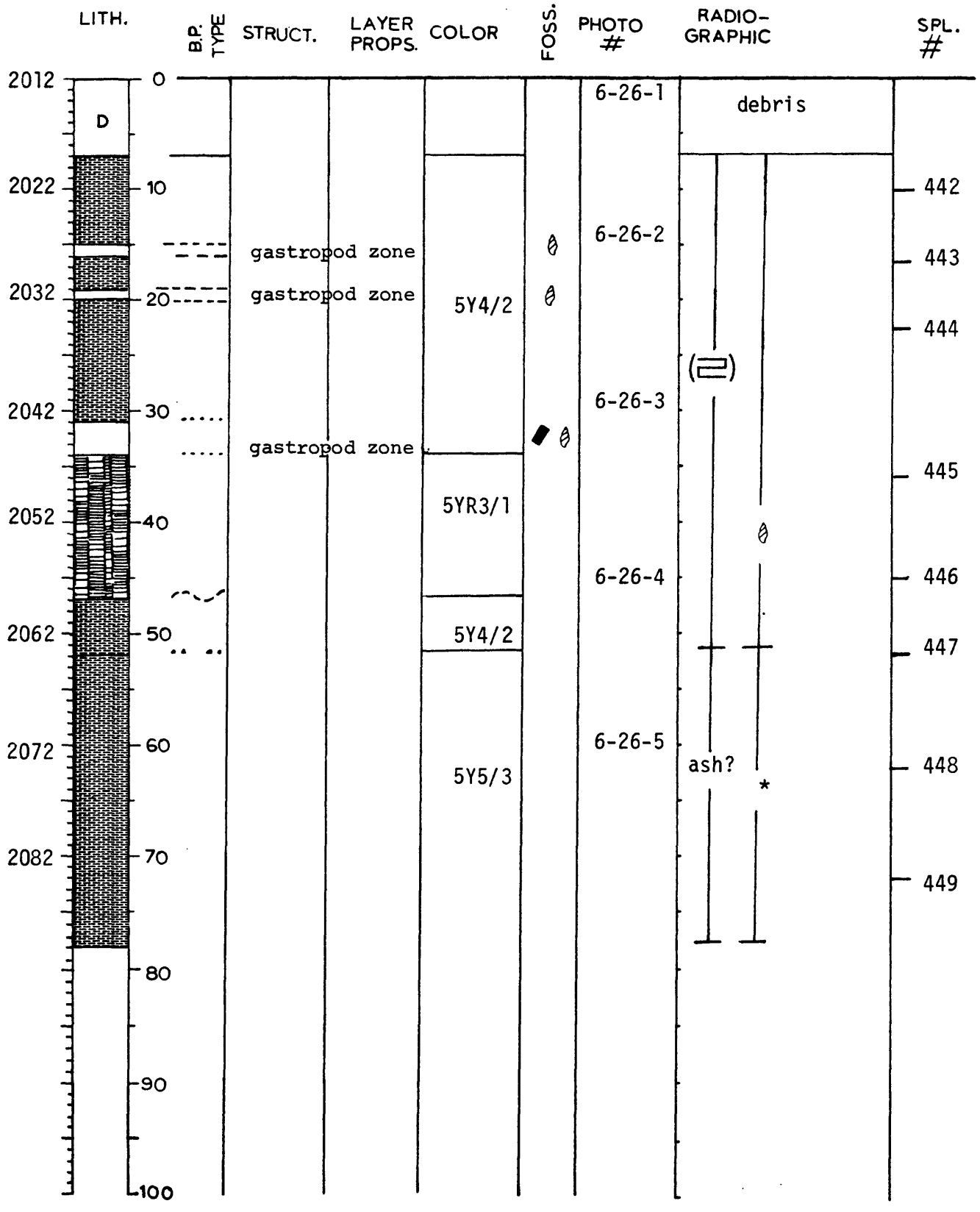


* x-ray opaque filimentous objects

** dike-like sedimentary intrusions

W-3225: 29,810 ± 1,000 yr. B.P.

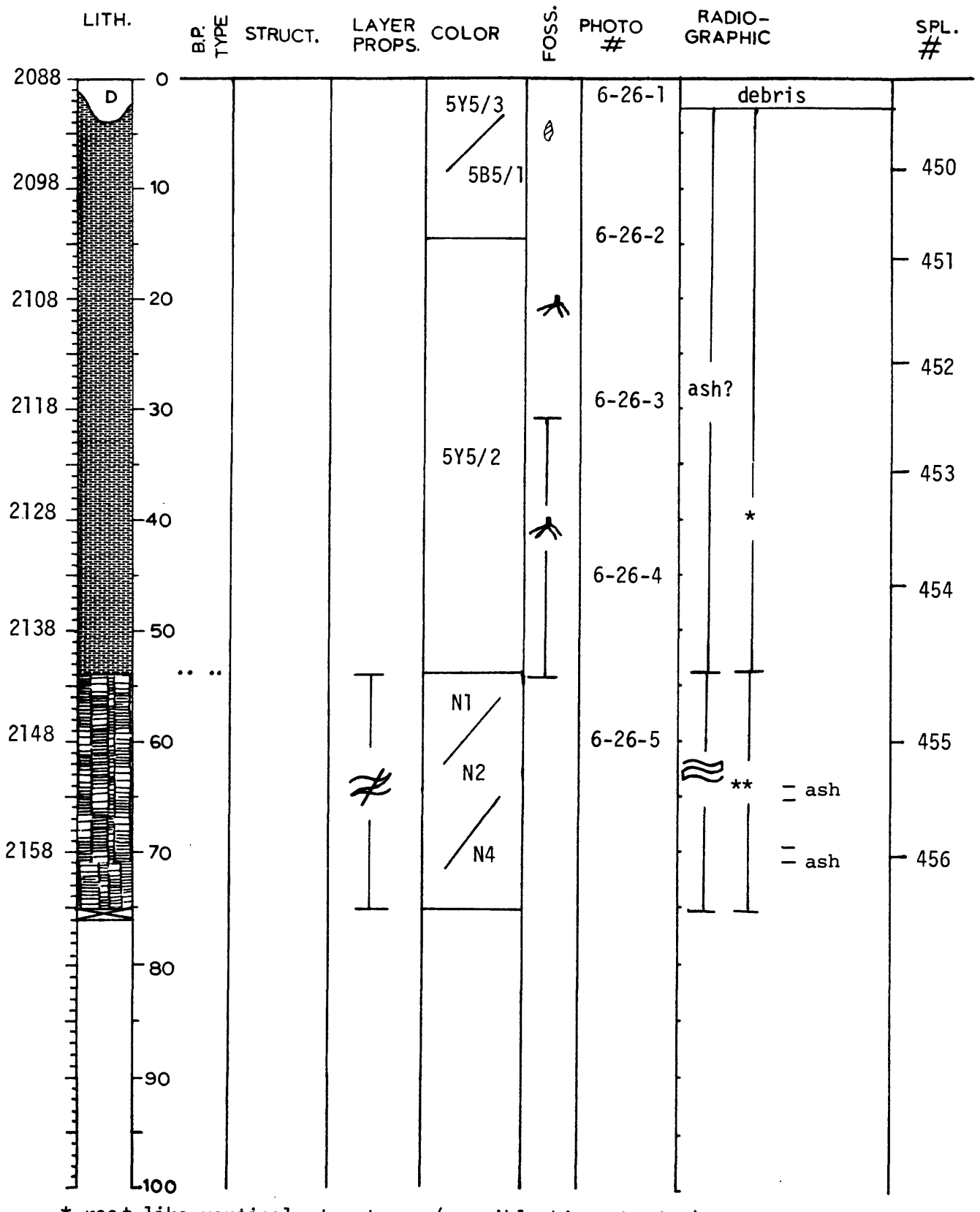
HOLE 6 SLUG 25 DEPTH 2012 cm. to 2088 cm.



* root-like vertical structures

x-ray opaque filamentous objects throughout

HOLE 6 SLUG 26 DEPTH 2088 cm. to 2164 cm.



* root-like vertical structures (possibly bioturbation)

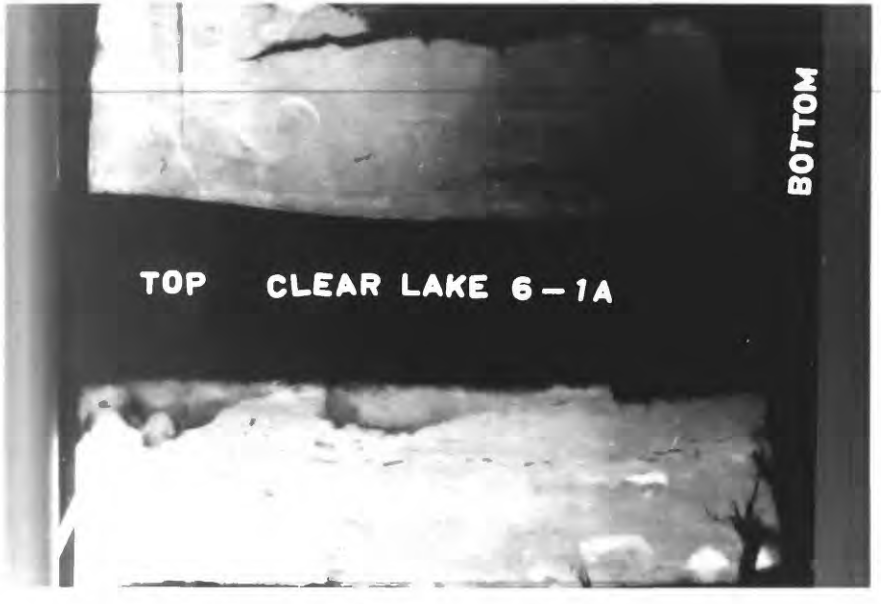
** x-ray opaque filamentous objects.

Appendix B

X-ray Radiographs


BOTTOM
TOP CLEAR LAKE 6-2A


BOTTOM
TOP CLEAR LAKE 6-04A


BOTTOM
TOP CLEAR LAKE 6-1A


TOP CLEAR LAKE 6-3A


BOTTOM
TOP CLEAR LAKE 6-06A


TOP CLEAR LAKE 6-8


BOTTOM
TOP CLEAR LAKE 6-05A


TOP CLEAR LAKE 6-7


BOTTOM
TOP CLEAR LAKE 6-10


TOP CLEAR LAKE 6-12


TOP CLEAR LAKE 6-09


TOP CLEAR LAKE 6-11


TOP CLEAR LAKE 6-15
BOTTOM


BOTTOM
TOP CLEAR LAKE 6-15

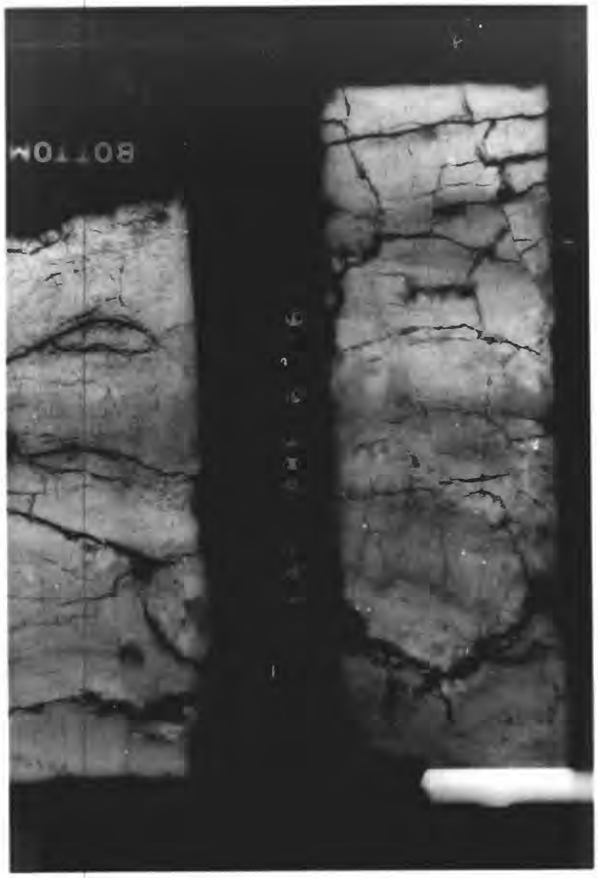

TOP CLEAR LAKE 6-14


BOTTOM
TOP CLEAR LAKE 6-13


BOTTOM
TOP CLEAR LAKE 6-19


BOTTOM
CLEAR LAKE 6-18


BOTTOM
TOP CLEAR LAKE 6-17

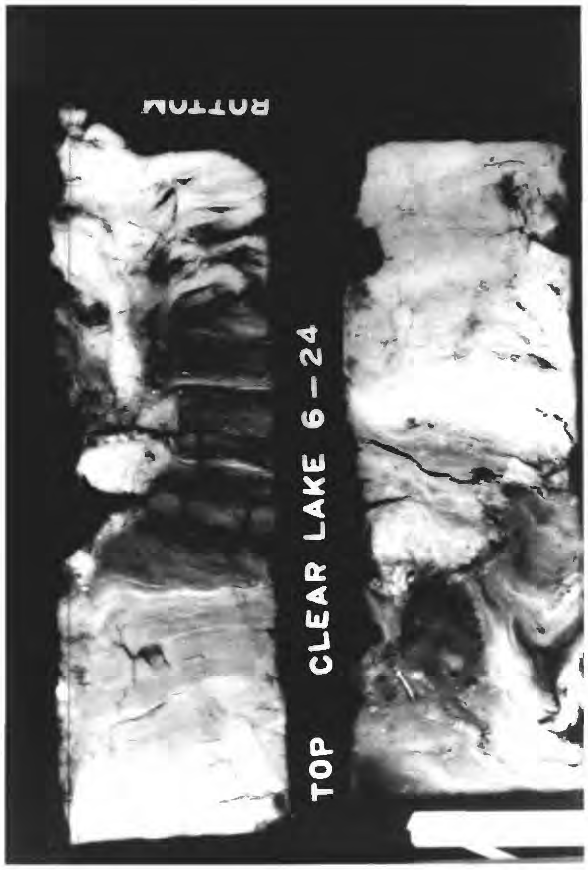

BOTTOM


TOP CLEAR LAKE 6-22


BOTTOM
TOP CLEAR LAKE 6-21


BOTTOM
TOP CLEAR LAKE 6-20


BOTTOM
TOP CLEAR LAKE 6-25


BOTTOM
TOP CLEAR LAKE 6-24


BOTTOM
TOP CLEAR LAKE 6-23


TOP CLEAR LAKE 6-26
BOTTOM