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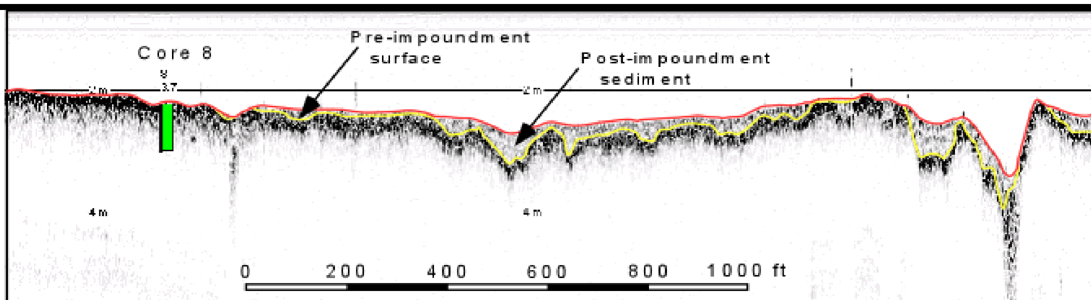
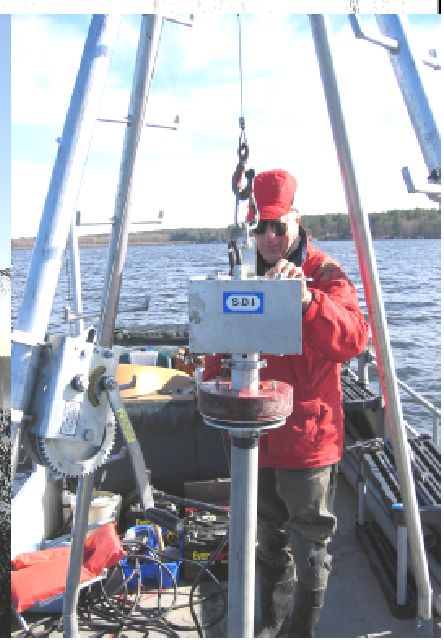
Sediment Thickness from Coring and Acoustic, Lake Cherokee, Rusk County, TX





By John A. Dunbar and Peter M. Allen

TWDB Contract No. 2003-483-499 August, 2004

EXECUTIVE SUMMARY

In November, 2003 the Texas Water Development Board (TWDB) conducted an acoustic survey of Lake Cherokee, in Rusk County, Texas to determine the volume of sediment in the reservoir. The goal of the study described in this report was to validate the TWDB's results by collecting core samples through the sediment at a number of locations along TWDB transects. We collected sediment cores at 8 locations in the reservoir using the vibracore technique, which produces continuous, undisturbed sediment samples. The cores ranged in length from 35 cm to 170 cm. The pre-impoundment surface was reached and sampled at all eight locations. Post-impoundment sediment at the core locations ranged in thickness from 0 to 25 cm. The cores were sub-sampled at 5 cm increments. The sub-samples were visually examined for evidence of the pre-impoundment surface and described. The sub-samples were also analyzed for water content and sediment shear strength. We found that the pre-impoundment surface was distinct and easily identified in all the cores. The post-impoundment sediment is a silty-clay, with high organic content and unusually high water continent (70-85%). Pre-impoundment materials range from nearly pure sand to clayey-sand. These sands are highly compacted, with shear strengths ranging up to 15 kg/cm^2 and have relatively low water content (20-30%). In all cases the pre-impoundment material contained intact terrestrial plant roots.

The correlation between the cores and the acoustic data was achieved in two ways. First, the core samples were collected at positions along acoustic profiles previously surveyed by the TWDB, so that the coring results could be directly compared with the TWDB data. Second, short acoustic records were collected at each core site, using an acoustic profiling system of the same make as that used by the TWDB. This system collects sub-bottom acoustic images at three discrete acoustic frequencies (200, 48, and 24 kilohertz (kHz)). The 200 kHz data show no visible distinction between the pre- and post-impoundment material. However, in the 48 and 24 kHz data, the post-impoundment layer appears light gray and the underlying pre-impoundment material is dark gray to black. The clearest image of the pre-impoundment surface is given by the 48 kHz data. Thicknesses estimated from the acoustic data agree with the core results to within 1 cm, assuming a sediment velocity of 1480 m/s (4,854 ft/s). The profiling results show that the post-impoundment layer produces a distinct acoustic response that is easily traced on acoustic profiles.

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1. INTRODUCTION

In the November, 2003 the Texas Water Development Board (TWDB) conducted a survey of Lake Cherokee, Rusk County, Texas. The goal of this survey was to determine the volume of sediments that have accumulated in the reservoir since its impoundment in 1948 and to update the Area and Volume Tables for the reservoir. The approach used by the TWDB was to determine the sediment thickness by acoustic sub-bottom profiling along profiles spaced 500 ft apart throughout the lake. On these profiles the water bottom and the original lake bottom or pre-impoundment surface are identified and traced throughout. In the study described in this report we corroborate the TWDB's acoustic results by physical measurement of sediment thickness using the vibracoring method. The core samples were collected at points along selected TWDB acoustic profiles to validate the identification of the pre-impoundment surface and the speed of sound used to convert from acoustic transit time to sediment thickness.

2. PROCEDURES

The measurement of sediment thickness was done by collecting continuous, undisturbed cores using a vibracore device. The correlation between the cores and the acoustic data was achieved in two ways. First, the cores were collected along selected TWDB profiles, by positioning the coring vessel using differential GPS navigation. Because errors in vessel positioning during the original TWDB survey compound with errors in our positioning of the coring vessel along the same profile, the core locations may differ from the actual profile track line by 10 to 30 ft. Hence, to insure accurate co-location of acoustic and core data, short acoustic records were collected using the same model SDI profiling system as that used by the TWDB, at each core site at the time the cores were collected. Because the survey boat remained anchored at the core site, these short records image the bottom at points only a few feet away from where the core tube penetrated the bottom.

2.1 Sediment Coring

A vibracoring system commercially available from SDI was used to core sediments within Lake Cherokee. Vibracoring is a common approach for obtaining undisturbed cores of unconsolidated sediment in saturated or nearly saturated conditions (Lanesky et al., 1979; Smith, 1984). The SDI vibracore uses a 1-HP motor that drives a pair of weights that are eccentrically mounted on two counter rotating shafts. The motor and vibrator mechanism are housed within a watertight aluminum chamber so it can be immersed in water. The chamber is connected to the top of a 76 cm (3 in.) diameter aluminum core tube. The vibracore driver is powered by two 12-volt batteries connected in series through a 125-ft power cord, thus limiting the depth of operation. Lengths of core tube 4 to 12 ft (1.2 to 3.7 m) long were used. The gantry is mounted on a 24 ft pontoon boat that has a 4 ft square “moon pool” cut into its deck (Figures 2-1).

Cores were collected by lowering the vibrator with core tube attached to the bottom by hand winch, switching on the vibrator, and allowing the tube to slowly vibrate into the bottom. The vibration causes the sediment to liquefy in a region a few millimeters thick near the tube wall, allowing the tube to slide into the sediment with little drag. This method results in less disturbance and compaction of the sediment cores than occurs with gravity-driven drop coring devices. Core catchers made of thin sheet aluminum are attached inside of the leading end of the core tube. They allow the core to slide into the tube, but prevent it from sliding back out of the tube during retrieval. When the core had reached the point of refusal, the vibrator was turned off and the core was winched out of the bottom. On deck, the retrieved cores were capped top and bottom with rubber end-caps and stored upright during transport.

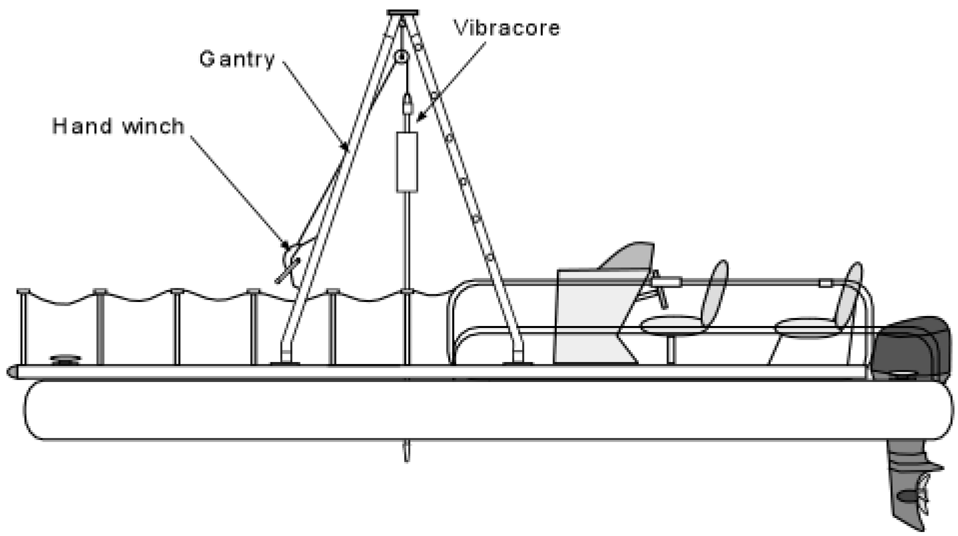


Figure 2-1. Coring boat with gantry. Schematic diagram of 24 ft coring boat and vibracoring system.

2.2 Core analysis:

The main goal of our core analysis was to determine the thickness of the post-impoundment sediment present in each core. In this analysis, we relied on visual examination of the sampled material, and measurements of the sediment water content and sediment shear strength versus depth in the cores. After the cores were brought back from the field, they were sub-sampled by cutting the core tube and sediment into 5-cm long slices using a pipe cutter. The sediment within each 5-cm slice was placed into pre-weighed containers, dried for 48 hours at 106º F, reweighed and stored for further analysis. The wet and dry weights of the samples were used to compute water content profiles along the cores. During the sub-sampling operation the strength of the sediment was determined using a pocket penetrometer that measures the force required to drive a 2.5 cm diameter disk into the sediment. These tests were performed on the top of each 5 cm sample, while the sample was confined in the core tube.

2.3 Discriminating Between Pre- and Post-impoundment materials

We determined the depth to the pre-impoundment surface in each core based on the following evidence: (1) a visual examination of the core for in-place terrestrial materials, such as leaf litter, tree bark, twigs, intact roots, etc., concentrations of which would be expected on or just below the pre-impoundment surface, but not in the post-impoundment sediment and (2) variations in the physical properties of the sediment, particularly sediment water content and shear strength. Sediments deposited in reservoirs typically have water contents that range from 50 to 80% at the water bottom and decrease with burial to 30 to 40% at depths of several meters. Soils, in contrast, typically have water contents of 20 to 30% when saturated. The shear strength of reservoir sediments (as measured with penetration devices) typically ranges from 0 to 2 kg/cm^2. The shear strength of saturated clay-rich soils typically ranges from 3 to over 10 kg/cm^2.

2.4 Acoustic Profiling

The acoustic profiling system used in this study is the same SDI profiler model as that used by the TWDB in its sediment surveys. The system images the bottom and sub-bottom sediments with acoustic transducers with central frequencies of 200, 48, and 24 kHz. During acquisition, the system collects traces using each transducer independently in a rapid, round-robin succession. The high-frequency signals provide a sharp image of low-density mud at the water bottom, whereas the low-frequency signals penetrate many meters into the bottom to image the base of sediment fill, even in areas of high sediment accumulation. For the present study, the sound source was suspended over the side of the coring boat, adjacent to the coring gantry. Short acoustic records were collected at each core site. During post survey processing of the acoustic data, the core locations, and depths to the pre-impoundment surface were read into the acoustic processing program. The program posts core diagrams that show the interpreted post-impoundment sediment thickness on the acoustic data at the point of closest approach of the profile to the core location.

3. Results

Eight cores were collected in Lake Cherokee at locations spaced along its length (Figure 3-1). A summary of core locations, core lengths, and the interpreted depth to the pre-impoundment surface are given in Table 3-1. Tables describing the results of the physical analysis of cores from each site are given in Appendix A. Water content and shear strength versus depth in the cores are shown along side the visual description of the core material in Figures 3-2 to 3-9. The interpreted tops to the pre- and post-impoundment intervals on co-located acoustic profiles are also shown in Figures 3-2 to 3-9.

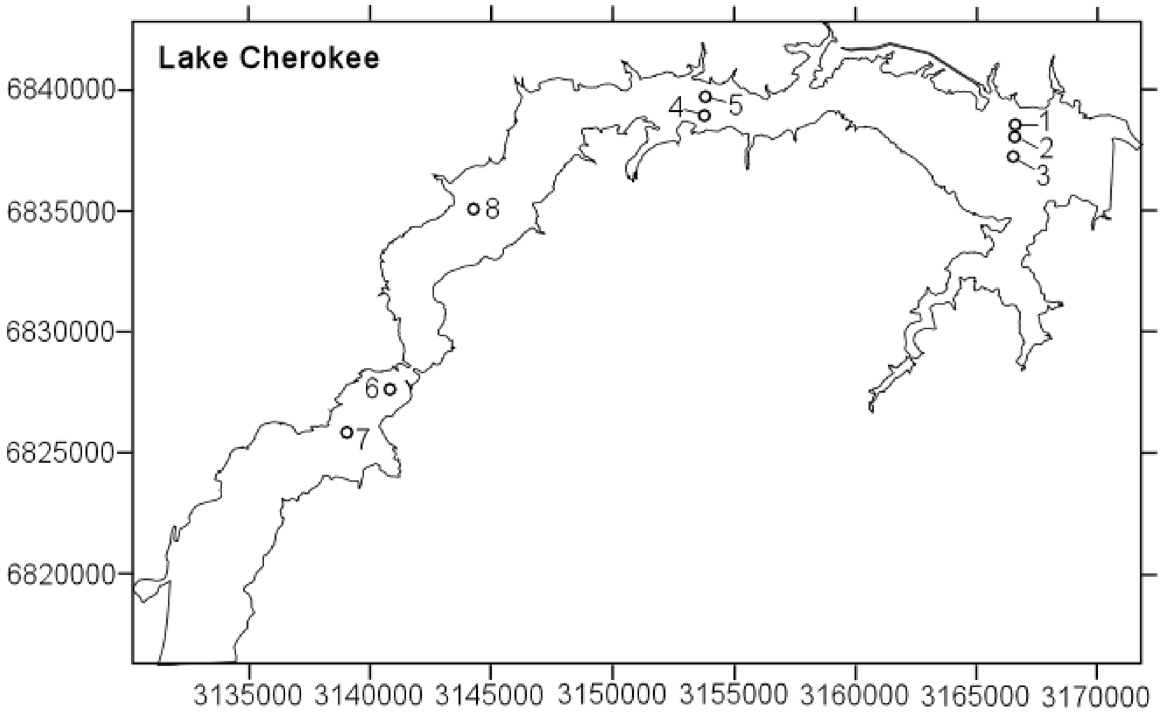


Figure 3-1. Map showing core locations in Lake Cherokee (circles). Map coordinates are Texas State Plane, North Central Zone, NAD 83, feet.

Table 3-1. Summary of sediment cores collected in Lake Cherokee. The core locations are given in Texas State Plane, North Central Zone, NAD 83, feet. Survey line numbers refer to acoustic profiles collected during the November, 2003 TWDB survey of Lake Cherokee that are closest to each core location.

Core ID	Easting (ft)	Northing (ft)	Length (cm)	Depth to pre-impoundment (cm)	TWDB Survey Line No.
CKE1	3166610.9	6838535.7	42	20	10
CKE2	3166598.6	6838031.6	170	25	10
CKE3	3166539.2	6837238.1	35	15	10
CKE4	3153784.0	6838936.0	38	15	62
CKE5	3153831.8	6839686.9	145	10	62
CKE6	3140811.8	6827655.5	82	10	111
CKE7	3139029.0	6825896.2	59	15	116
CKE8	3144277.2	6835057.9	78	0	92

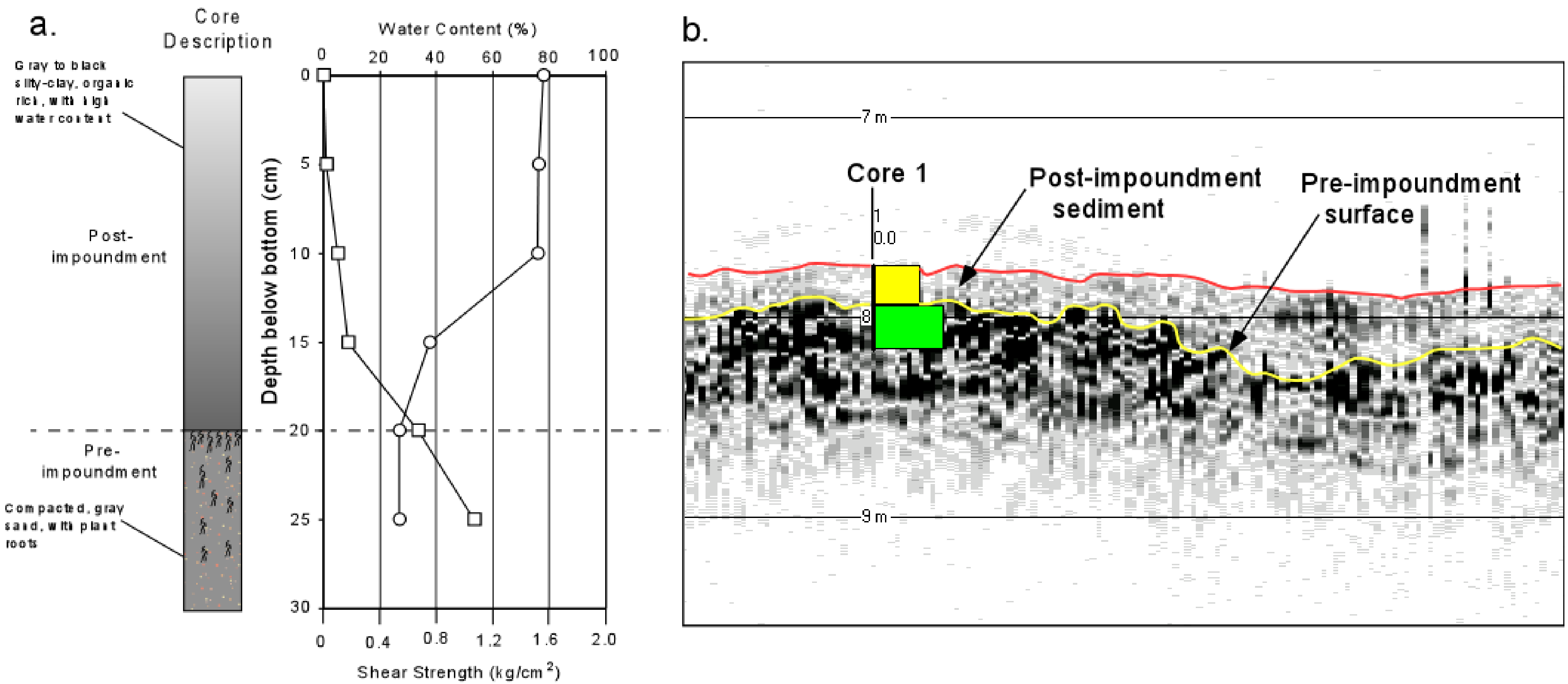


Figure 3-2. Core and acoustic results for site CKE1. (a) Physical analysis of Core 1, showing 20 cm of post-impoundment sediment over pre-impoundment. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface. In the core diagrams yellow represents post-impoundment fill and green represents cored interval of pre-impoundment material. The location of core CKE1 is shown in Figure 3-1.

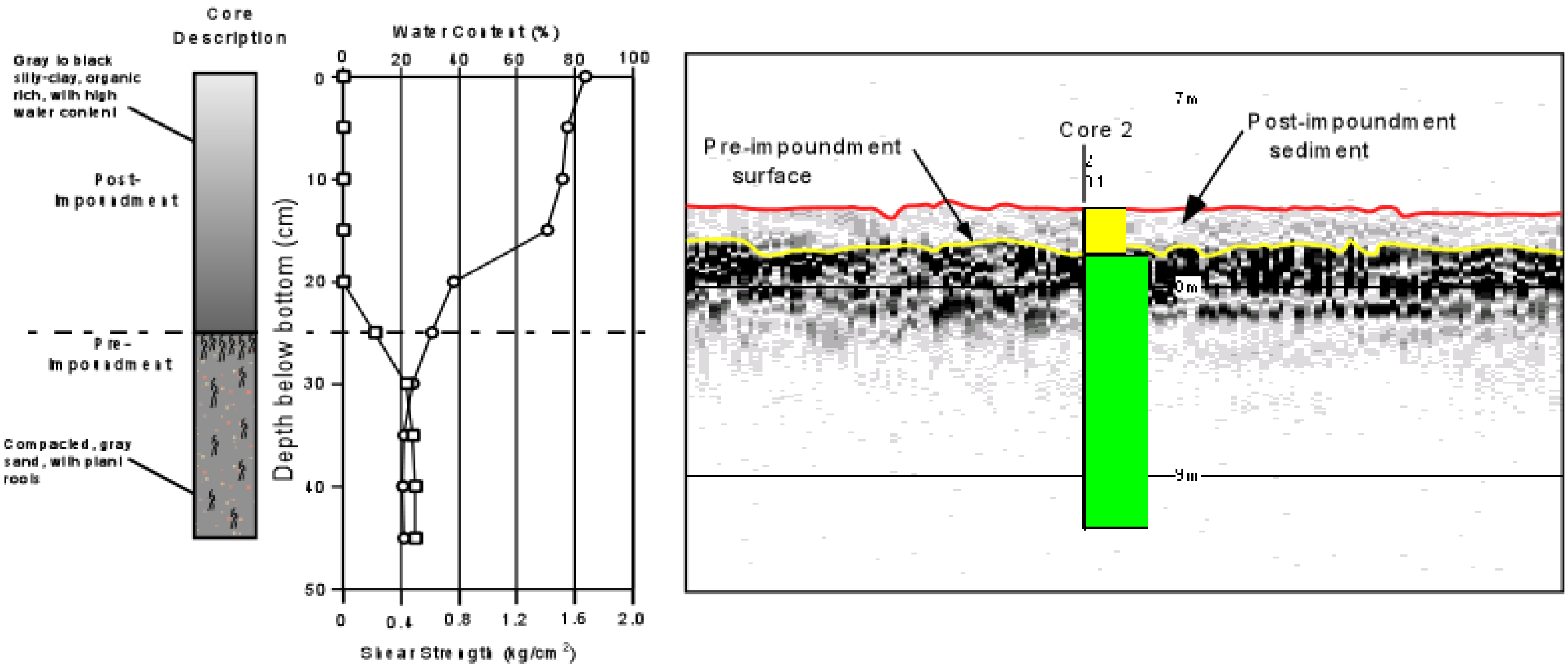


Figure 3-3. Core and acoustic results for site CKE2. (a) Physical analysis of Core 2, showing 25 cm of post-impoundment sediment over pre-impoundment. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface.

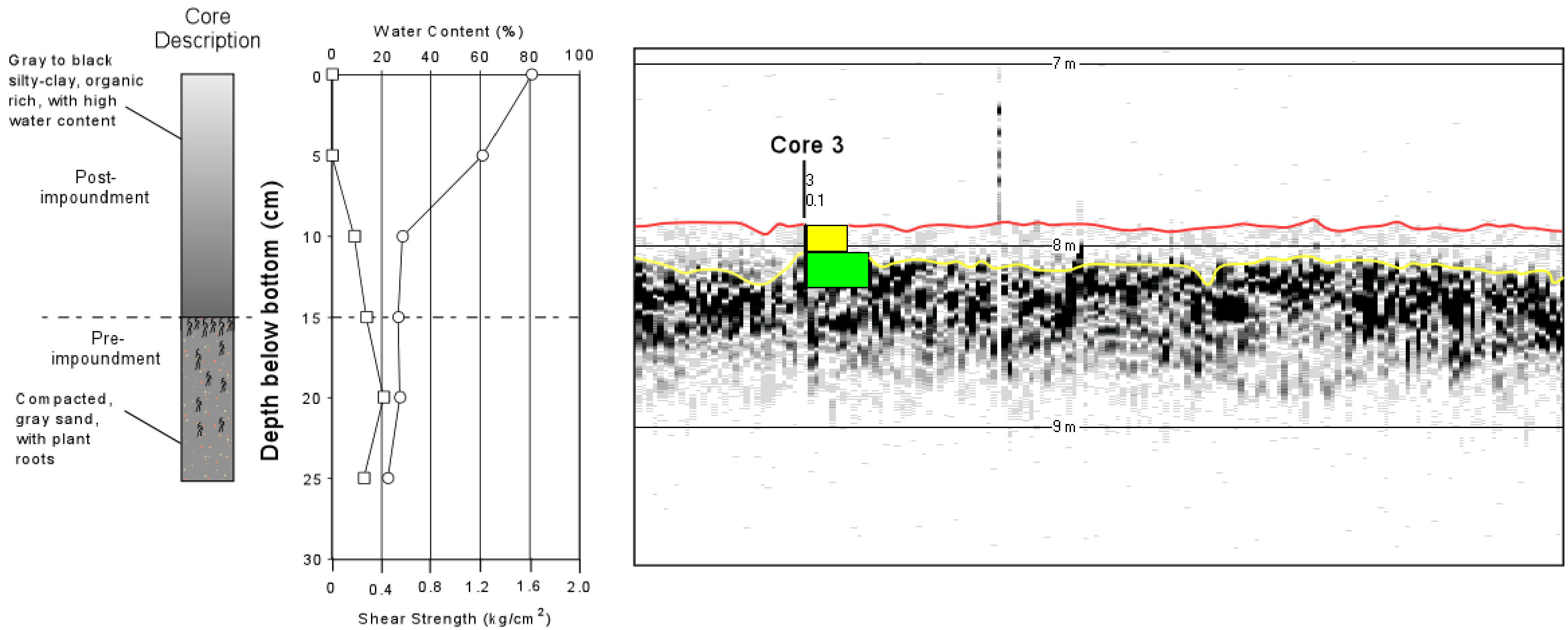
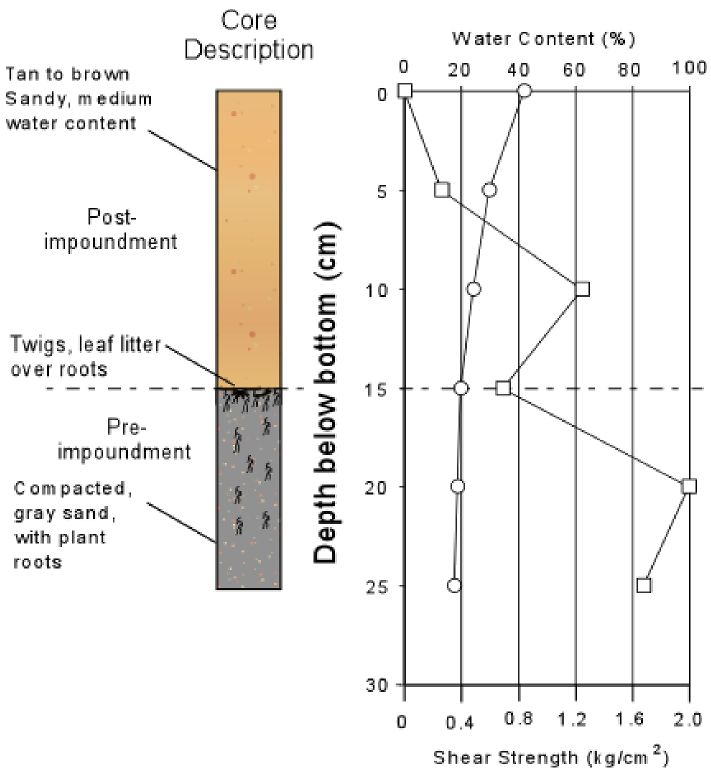


Figure 3-4. Core and acoustic results for site CKE3. (a) Physical analysis of Core 3, showing 15 cm of post-impoundment sediment over pre-impoundment. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface.



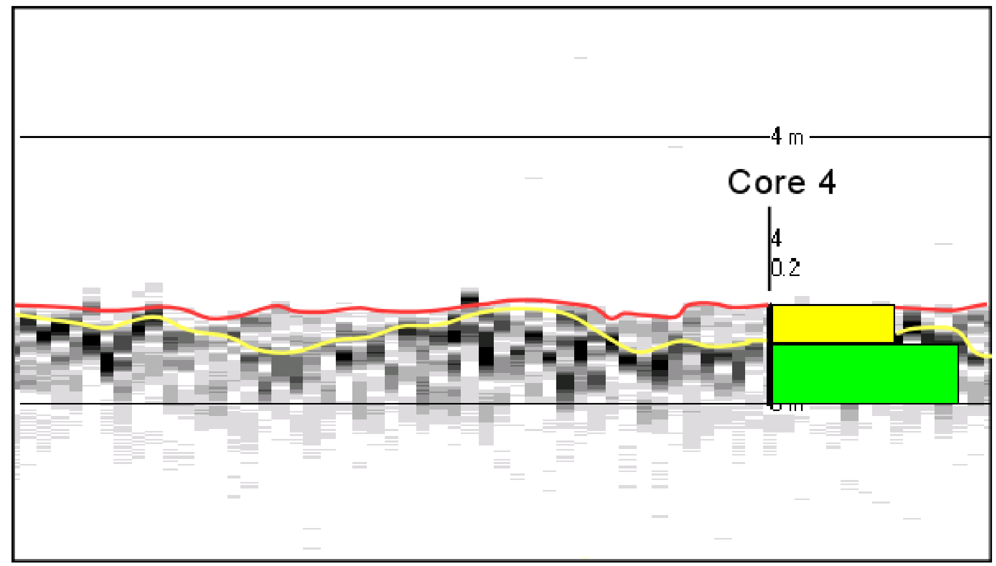


Figure 3-5. Core and acoustic results for site CKE4. (a) Physical analysis of Core 4, showing 15 cm of post-impoundment sediment over pre-impoundment. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface.

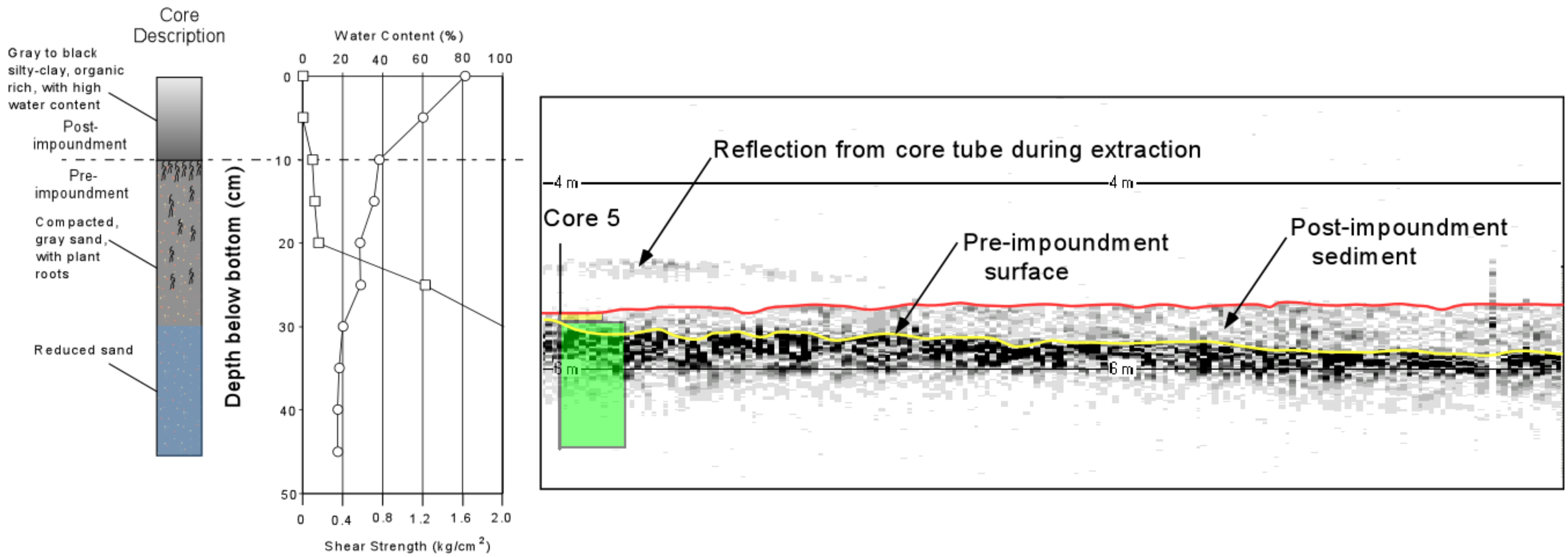


Figure 3-6. Core and acoustic results for site CKE5. (a) Physical analysis of Core 5, showing 10 cm of post-impoundment sediment over pre-impoundment. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface.

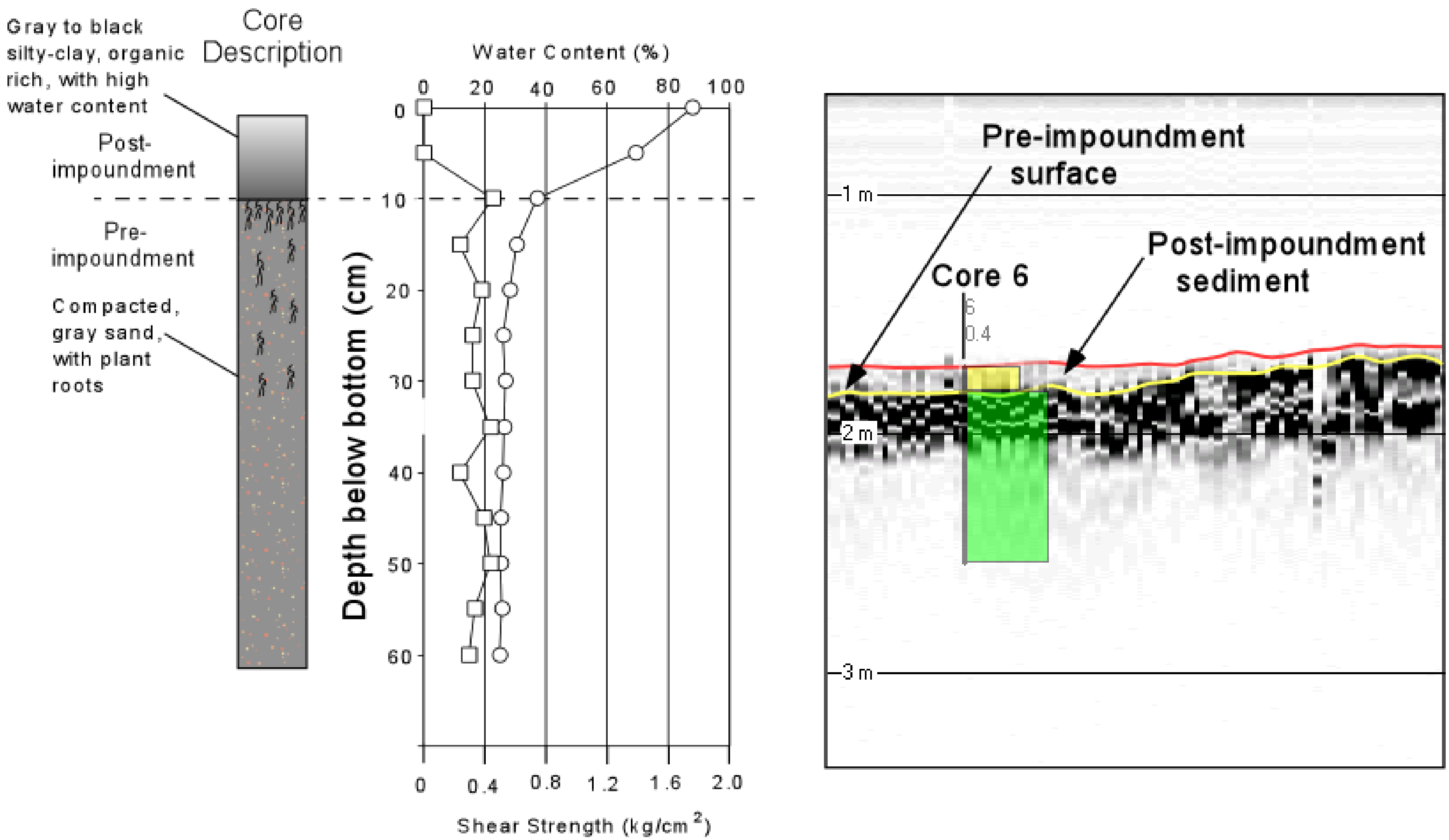


Figure 3-7. Core and acoustic results for site CKE6. (a) Physical analysis of Core 6, showing 10 cm of post-impoundment sediment over pre-impoundment. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface.

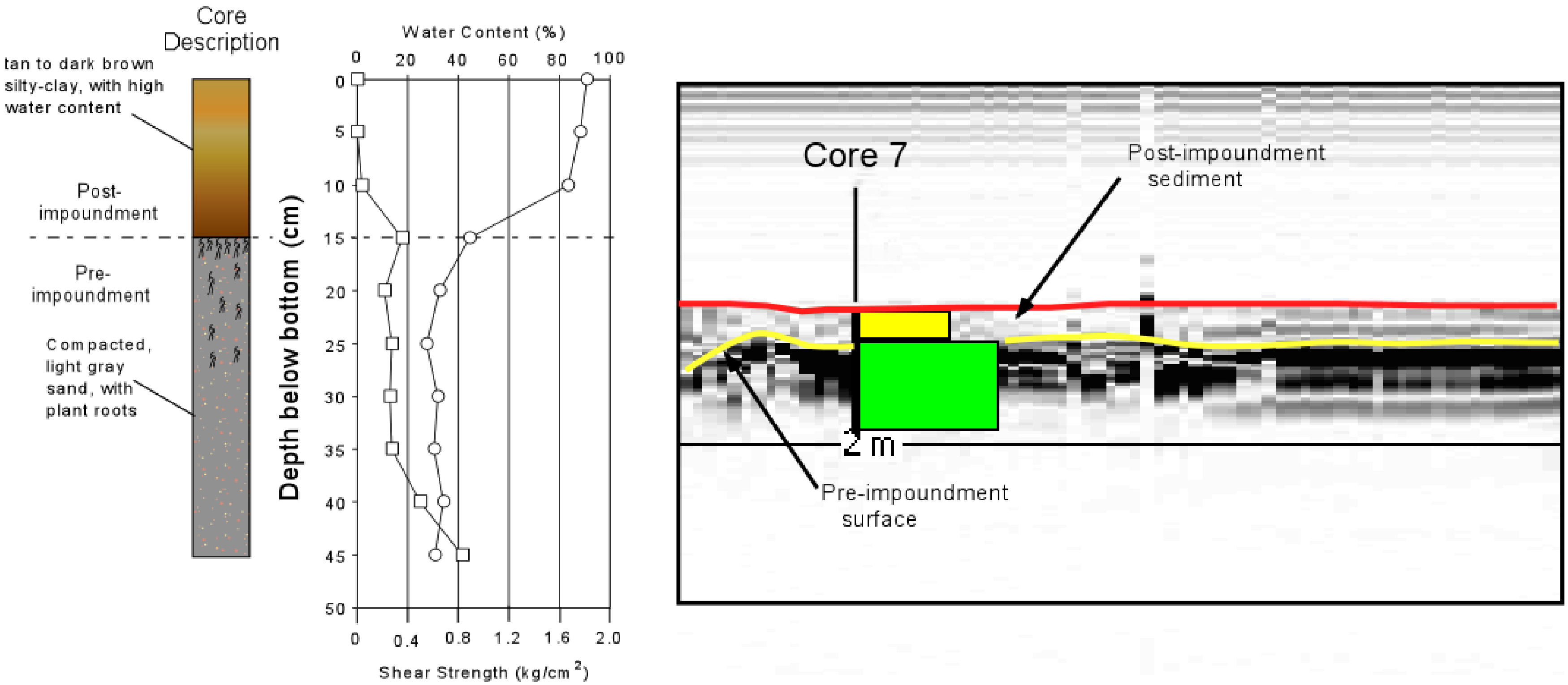


Figure 3-8. Core and acoustic results for site CKE7. (a) Physical analysis of Core 7, showing 15 cm of post-impoundment sediment over pre-impoundment. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface.

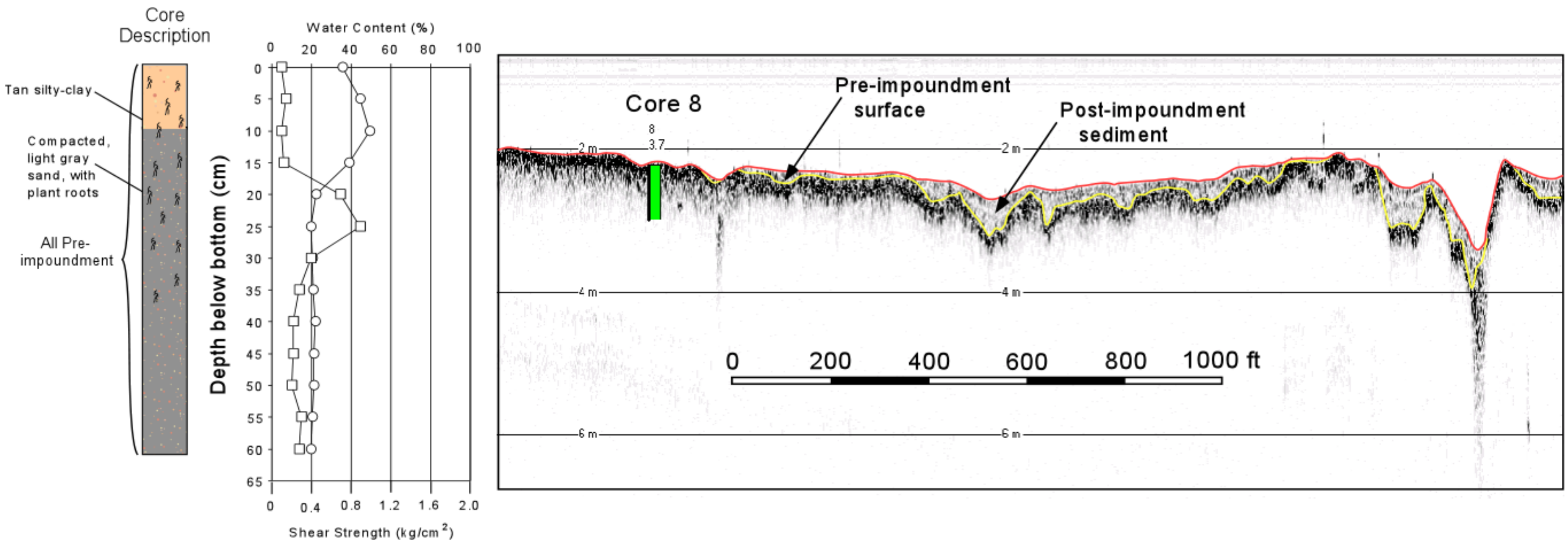


Figure 3-9. Core and acoustic results for site CKE8. (a) Physical analysis of Core 8, showing essentially no post-impoundment sediment over pre-impoundment at the core site. Water content versus depth is marked with circles. Shear strength versus depth is marked with squares. (b) Short acoustic profile showing only the 48 kHz acoustic signal. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface. Extended profile through Lake Cherokee Core site CKE8. Only the 48 kHz acoustic data are shown. On the acoustic data, the red line marks the water bottom and the yellow line marks the interpreted pre-impoundment surface. In the core diagrams yellow represents post-impoundment fill and green represents cored interval of pre-impoundment material. At the site of the core there is no post-impoundment sediment. Elsewhere along the profile the post-impoundment interval reaches a thickness of 60 cm.

4. Discussion

The goal of this study was to identify the pre-impoundment surface in a series of cores and on co-located acoustic data in support of the November, 2003 TWDB survey of Lake Cherokee. Two aspects of our results stand out as noteworthy. First, in the cores the layer of post-impoundment sediment fill is unusually thin (0 to 25 cm) for reservoirs of this age. This is partly an artifact of where the cores were collected. In many cases the sites that were pre-selected for coring from the TWDB's acoustic data could not be reached with the coring boat because of stumps and other obstructions. Alternate core locations were selected based on access to the site, rather than specific sediment targets. Somewhat thicker sediment accumulations (50 to 60 cm) with the same acoustic character are seen on the profiles at other points (see for example Figure 3-9). Still, the amount of sedimentation is lower than is found in reservoirs of comparable age in the Blackland Prairie, for example. We attribute this to the relatively small contributing watershed surface area (170 mi^2) for a reservoir of this size and the sandy soils that dominate the watershed.

The second noteworthy finding is that the pre-impoundment surface and the post-impoundment sediment column is best imaged on the 48 kHz data. The 200 kHz signal scatters efficiently in both the post- and pre-impoundment material to the extent that the two material types are not distinguishable on the 200 kHz records. In contrast, the post-impoundment sediment scatters the 48 and 24 kHz signals much less efficiently than the pre-impoundment material. Hence, the two materials are distinct on both the 48 and 24 kHz records, but the pre-impoundment surface is more sharply imaged on the 48 kHz data.

5. CONCLUSIONS

The main conclusions of our study are listed below.

1. The post impoundment fill in Lake Cherokee has high water continent (70-85%) and low shear strength throughout. At the core sites the post-impoundment layer is relatively thin, ranging in thickness from 0 to 25 cm thick.

2. The post-impoundment layer is acoustically distinct from the pre-impoundment material, appearing light gray on the 48 kHz single frequency acoustic displays. The underlying pre-impoundment materials appear dark gray to black on the same displays.

6. REFERENCES

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Smith, D.G., 1984. Vibracoring fluvial and deltaic sediments: Tips on improving penetration and recovery. Journal of Sedimentary Petrology, 54, 660-663.

Appendix A

Cherokee Core 1

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg)	Comment 1
1	0	5	0.44	5.63	1.59	77.8	0	Dark gray to black
2	5	10	0.44	6.83	1.97	76.1	0.1	mud
3	10	15	0.44	4.97	1.54	75.7	0.5	
4	15	20	0.45	8.44	5.43	37.7	0.9	Pre-impoudment
5	20	25	0.45	6.71	5.03	26.8	3.4	Dark brown, roots
6	25	30	0.43	9.23	6.87	26.8	5.4	

Cherokee Core 2

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg)	Comment 1
1	0	5	8.5	218.5	43.36	83.4	0	Soupy, silty-clay,
2	5	10	8.42	247.95	62.45	77.4	0	gray to black
3	10	15	8.27	220.59	60.09	75.6	0	
4	15	20	8.18	204.29	66.53	70.2	0	
5	20	25	8.58	280.17	177.26	37.9	0	twigs, leaf fragments
6	25	30	8.12	298.65	209.6	30.7	1.1	pre-impoundment
7	30	35	8.32	339.05	260	23.9	2.2	gray sand, plant roots
8	35	40	8.33	297.26	236.51	21.0	2.4	
9	40	45	8.48	281.7	225.2	20.7	2.5	
10	45	50	8.15	283.84	226.59	20.8	2.5	

Cherokee Core 3

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg)	Comment 1
1	0	5	0.65	7.54	1.99	80.6	0	black mud
2	5	10	0.43	13.31	5.49	60.7	0	mass of twigs
3	10	15	0.44	9.48	6.9	28.5	0.9	Pre-impoundment
4	15	20	0.45	8.18	6.12	26.6	1.4	brown, roots
5	20	25	0.44	11.82	8.71	27.3	2.1	
6	25	30	0.43	13.72	10.74	22.4	1.3	

Cherokee Core 4

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg)	Comment 1
1	0	5	0.44	8.24	4.98	41.8	0	tan, sandy-clay
2	5	10	0.44	13.98	9.95	29.8	1.3	
3	10	15	0.44	15.09	11.58	24.0	6.3	
4	15	20	0.43	23.2	18.75	19.5	3.5	twigs, leaf fragments
5	20	25	0.45	22.15	18.16	18.4	10.1	pre-impoundment
6	25	30	0.45	20.04	16.65	17.3	8.5	roots

Cherokee Core 5

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg)	Comment 1
1	0	5	8.48	163.3	37.98	80.9	0	Dark brown to black
2	5	10	8.07	222.62	93.6	60.1	0	organic material
3	10	15	8.28	340.69	214.17	38.1	0.5	pre-impoundment
4	15	20	8.59	358.28	233.58	35.7	0.6	Dark gray to black
5	20	25	8.77	364.74	262.76	28.6	0.8	sand with roots
6	25	30	8.09	341.01	244.36	29.0	6.2	
7	30	35	8.4	394.95	317.25	20.1	10.2	
8	35	40	8.06	217.61	179.46	18.2	15	
9	40	45	8.46	226.74	189.07	17.3	10.5	
10	45	50	8.46	224.78	186.89	17.5	15	

Cherokee Core 6

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg)	Comment 1
1	0	5	7.97	145.54	24.86	87.7	0	Dark brown-Black
2	5	10	8.12	205.37	68.81	69.2	0	Mud
3	10	15	8.54	379.43	242.55	36.9	2.3	pre-impoundment
4	15	20	8.46	357.74	252.1	30.2	1.2	Gray pure sand with
5	20	25	8.42	373.44	270.67	28.2	1.9	no roots
6	25	30	8.45	338.4	253.39	25.8	1.6	
7	30	35	8.07	386.9	285.86	26.7	1.6	
8	35	40	8.29	384.25	285.02	26.4	2.2	
9	40	45	8.01	388.38	289.96	25.9	1.2	
10	45	50	8.33	318.74	240.57	25.2	2	
11	50	55	8.2	394.61	297.95	25.0	2.2	
12	55	60	8.21	346.06	260	25.5	1.7	
13	60	65	8.59	279.07	212.22	24.7	1.5	

Cherokee Core 7

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg/25)	Comment 1
1	0	5	0.44	7.87	1.13	90.7	0	Dark brown-Black
2	5	10	0.44	10.59	1.66	88.0	0	Mud
3	10	15	0.44	13.79	2.66	83.4	0.2	twigs, leaf fragments
4	15	20	0.64	25.31	14.39	44.3	1.8	Pre-impoundment
5	20	25	0.43	15	10.23	32.7	1.1	Gray pure sand with
6	25	30	0.43	20.51	15.01	27.4	1.4	plant roots
7	30	35	0.45	13.66	9.44	31.9	1.3	
8	35	40	0.44	16.43	11.58	30.3	1.4	
9	40	45	0.43	18.83	12.53	34.2	2.5	
10	45	50	0.44	16.14	11.31	30.8	4.2	

Cherokee Core 8

Sample	Top (cm)	Bot (cm)	Cont. wt (gr)	Wet wt. (gr)	Dry wt. (gr)	Wat Cont. (%)	Pen. At Top (kg/25)	Comment 1
1	0	5	8.66	373.73	244.11	35.5	0.5	Pre-impoundment
2	5	10	8.56	327.37	186.13	44.3	0.7	Pebble-size lithic
3	10	15	8.51	321.75	166.99	49.4	0.5	fragments
4	15	20	8.64	387.61	240.5	38.8	0.6	Uniform gray sand
5	20	25	8.66	354.29	277.78	22.1	3.5	plant roots
6	25	30	8.43	358.02	289.26	19.7	4.5	
7	30	35	8.59	330.81	264.85	20.5	2	
8	35	40	8.81	382.48	304.91	20.8	1.4	
9	40	45	8.55	345.56	272.39	21.7	1.1	
10	45	50	8.76	350.08	278.58	20.9	1.1	
11	50	55	8.56	352.56	280.3	21.0	1	
12	55	60	8.58	390.6	312.18	20.5	1.5	
13	60	65	8.01	284.79	230.59	19.6	1.4	