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Resistivity Investigation of an Infilled Kettle Hole

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An electrical resistivity survey of a lacustrine infilled basin in drift (Abbot Moss, N. England) clearly revealed the morphometry and internal structure of the basin. The technique also delimited extensions to the basin, which are buried beneath colluvium outside the present area of peat accumulation. Resistivity drilling has definite advantages over hand boring particularly for deposits formed between deglaciation and the onset of limnic sedimentation, or for sequences containing inpenetrable sand horizons. Geophysical techniques can provide an overall framework and gross stratigraphy of limnic deposits within which more detailed conventional Quaternary studies can be assessed.

INTRODUCTION

Abbot Moss lies on the west bank of the River Eden, 12 km north of Penrith, N. England. The bog (~0.1 km^2) occupies a basin in drift on a northeast–southwest-trending valley cut through Penrith sandstone. The 1976 1:50,000 drift edition of the Ordnance Survey Geological Map marks peat (enclosed by dotted line in Fig. 1) with river terrace to the east (covering area of Drill 14) and glacial sand and gravel around the other margins. The deposits underlying the bog, particularly their pollen content, have been investigated in detail by Walker (1966).

Hand coring techniques in such basins are normally limited to the finest-grained, wettest, or most organic late-glacial and postglacial facies. Resistivity investigations can provide information about the deeper deposits which are too deep or impenetrable for hand boring. Electricity is conducted through sediments by the process of electrolysis. Most mineral grains act as insulators and conduction occurs through the interstitial water. Hence resistivity variations depend to a large extent on water content. The relative advantages of resistivity probing over hand boring naturally become greater in even thicker deposits. At this site resistivity variations also lead to a fuller picture of basin morphometry and gross stratigraphy than is available from the hand borings of Walker (1966). Resistivity measurements at Abbot Moss were carried out as a teaching/research exercise as part of a joint undergraduate field course involving Cambridge and Edinburgh Universities. The total effort expended on field work was equivalent to about 150-man hours but could have been substantially reduced if the project had been planned solely as a research investigation.

EQUIPMENT AND FIELD PROCEDURE

A low-frequency alternating current was generated by a portable ABEM Terrameter. Resistances in the range 10^{-2}–10^4 ohm could be detected. Penetration to over 500 m would be possible at Abbot Moss with the equipment used. The standard Wenner electrode configuration (four equally spaced probes) was used for all measurements. Twenty drills (or expansions) of increasing electrode spacing were used to investigate the variation of resistivity with depth. Also five profiles (or traverses) of constant electrode separation were made in order to determine the change in thickness of the uppermost layer along the lines of the profiles. For further general discussion of field work techniques and interpretation,

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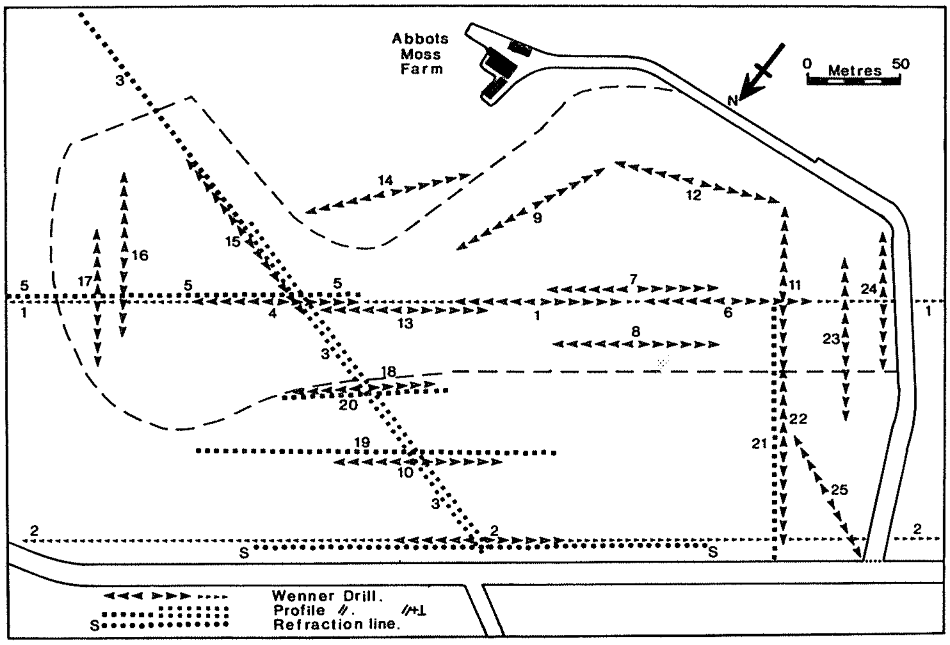

FIG. 1. Location and classification of resistivity drills (Wenner α configuration, large arrows; Wenner α, β, and γ configurations, small arrows), profiles (parallel, squares; both parallel and transverse, double squares), and seismic refraction line (circles and S). Present edge of Abbot Moss (dashed line).

see Chapters II and III in Griffiths and King (1965).

On Drills (or expansions 1 and 2, α, β, and γ measurements were made as described by Habberjam and Watkins (1967) in order to help determine the lateral homogeneity of the deposits in addition to the distribution of resistivity with depth. Drills 1 and 2 were extended to a total expansion of 576 m (192-m electrode spacing) to ensure good penetration of the bedrock. Later drills extended to an electrode spacing of 32 m to give reliable estimates of the depth and resistivity contrast at the uppermost boundary. Constant electrode separation profiles (3, 5, 19, 20, and 21) were made with an electrode spacing of 10 m to determine the change in resistivity interface depth along the profile. The western half of the profile 3 was repeated with electrodes arranged perpendicular to the profile direction to demonstrate the applicability of the assumption of lateral homogeneity (Fig. 5). Repeat measurements were carried out in ground conditions which varied from dry or frozen to flooded on different days, but the conditions did not significantly alter the resistivities under consideration.

REDUCTION TECHNIQUES

The investigations were initially concentrated on the central axis of the present day basin and the west–east traverse of Walker (1966) and then extended to complete the coverage of the Moss and finally pursued in the field to the northwest of the Moss (Fig. 1). Apparent resistivity determinations were made in the three configurations, α, β, and γ of Habberjam and Watkins (1967) at each electrode spacing of Drills 1 and 2 in order to determine the lateral inhomogeneity index (LII). For the complete 576-m spread of Drill 2 the LII was 0.4, but for the central 96 m (electrode spacing, 32 m) the LII was 0.2. Similarly for Drill 1 the LII out to the 192-m spacing was 0.3, but for the central part out to the is readily found from the electrode spacings over which the transition from high to low apparent resistivity takes place. Drill 1 (Fig. 3) is a more complicated case in which a high resistivity layer lies between two lower resistivity horizons, producing the characteristic humped K-type curve. Drill 10 (Fig. 3) represents the only example of an H-type three-layer curve. The uppermost layer is of higher resistivity than the middle layer.

Good modeling was possible using only a few layers in all drills except 16 (Fig. 3) and 18. Simple modeling breaks down in these two cases because lateral homogeneity cannot be inferred for the deeper layers. Estimates of the uppermost resistivities are, however, reliable.

Interpretation of the 20 drills was made first by the partial matching approach using double logarithmic master curves of Roman (1934) and the auxiliary curve approach based on Hummel parameters (e.g., Bhattacharya and Patra, 1968). The fitting was then improved using a computer modeling program based on Gosh (1971) which calculated apparent resistivities for theoretical resistivity-depth distributions. Modeling was usually improved until the apparent resistivity values agreed to within 5% of the field reading over the whole range of electrode spacings.

A basal layer of resistivity 100 ohm-m was chosen to provide continuity. Modeling essentially involved varying the resistivity of the middle (or high resistivity) layer and adjusting the depth of the upper interface. Additional layers to the basic K-type were necessary near the edge of the basin where there were thin marginal deposits (e.g., Drill 11) or difficulties stemming from lateral inhomogeneity (e.g., Drills 16 and 18). Resistivity-depth models for the 20 drills are listed in Table 1.

The constant separation resistivity profile data have been converted into thick-

TABLE 1

RESISTIVITY DEPTH PROFILES FOR DRILLS BETWEEN 1 AND 25[a]

1	2	4	6	7	8	9	10	11	12
82	585	105	80	88	97	85	180	90	88
(3.3)	(1.5)	(1.7)	(1.5)	(3.6)	(3.3)	(5.3)	(2.0)	(1.0)	(3.7)
600	515	180	120	490	350	600	110	440	800
(23.0)	(27.5)	(30.0)	(13.0)	(26.0)	(30.0)	(23.0)	(12.5)	(1.6)	(30.0)
100	70	100	740	100	100	100	600	85	100
			(30.0)				(30.0)	(11.5)	
			100				100	1000	
								(30.0)	
								100	
13	14	15	16	17	18	22	23	24	25
105	88	80	100	390	320	75	103	450	70
(3.3)	(6.0)	(1.6)	(1.0)	(2.6)	(1.5)	(5.3)	(8.5)	(1.8)	(4.3)
340	480	350	800	240	150	60	170	200	220
(30.0)	(27.0)	(11.0)	(5.0)	(9.0)	(3.2)	(18.0)	(30.0)	(30.0)	(30.0)
100	100	250	200	370	800	300	100	100	100
		(40.0)	(40.0)	(40.0)	(5.5)	(28.0)			
		100	100	100	240	100			
					(40.0)				
					100				

[a] Resistivity in ohm-meters; depth of interface, in parentheses, in meters below surface.

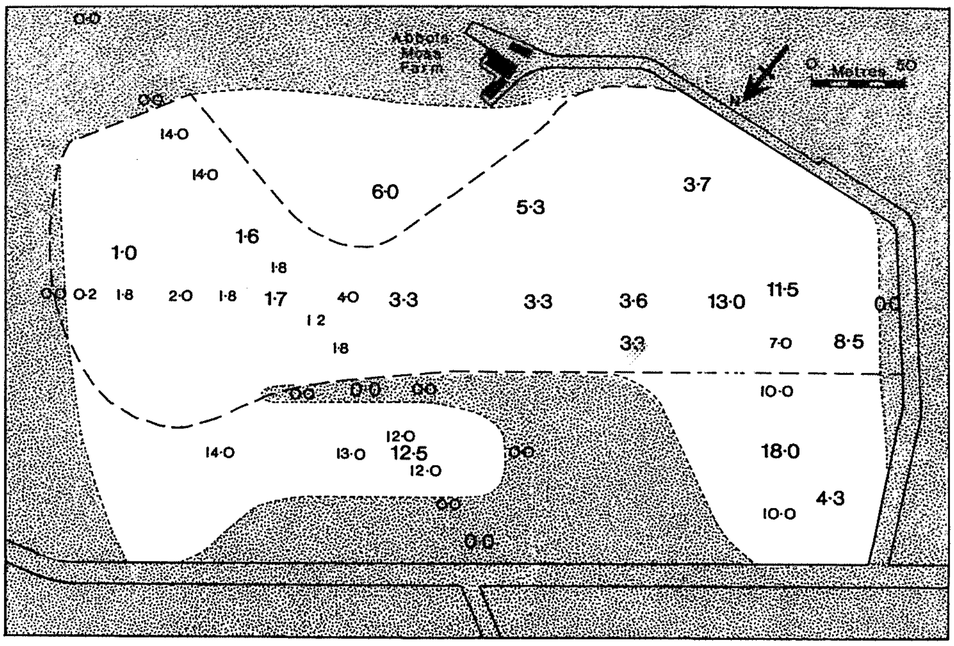

FIG. 2. Depth in meters of mud plus clay. Large figures derived from resistivity drills, small numbers from profiles. Present edge of Abbot Moss, dashed line; former extent of lake basin, unshaded. Note deep parts of basin outside present limit.

32-m spacing the LII fell below 0.1. So in general the apparent resistivity drill curves can be interpreted satisfactorily in terms of horizontally stratified ground.

Representative profiles of the Wenner expansions and drills are shown in Fig. 3 which includes the two long expansions. Drill 2 is a good example of an essentially two-layer situation. At close electrode spacings the current flows in the upper layer of high resistivity (515 ohm-m), whereas at large spacings the current flows mainly in the deeper layer of low resistivity (70 ohm-m). The depth to the second layer

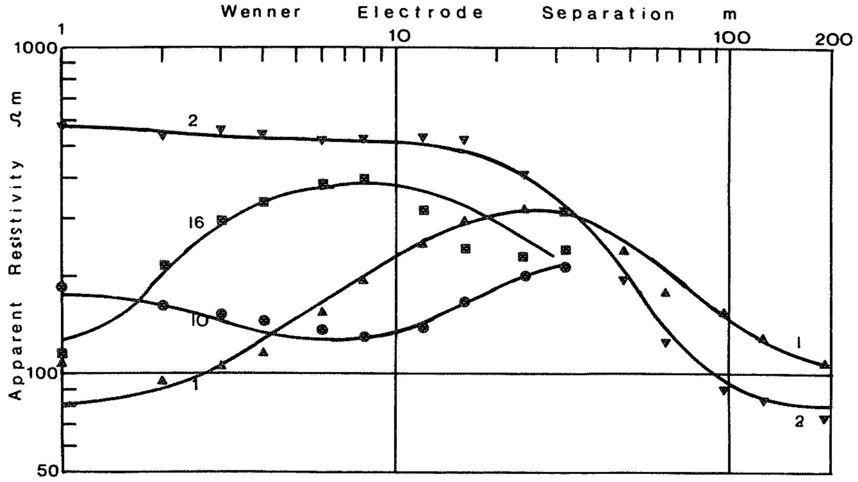

FIG. 3. Four examples of resistivity drills: 2, two-layer type ($\rho_1 > \rho_2$); 1, three-layer K-type ($\rho_1 < \rho_2 > \rho_3$); 10, three-layer H-type ($\rho_1 > \rho_2 < \rho_3$); 16, three layer K-type shallow ρ_1–ρ_2 interface. Curves computed from models in Table 1.

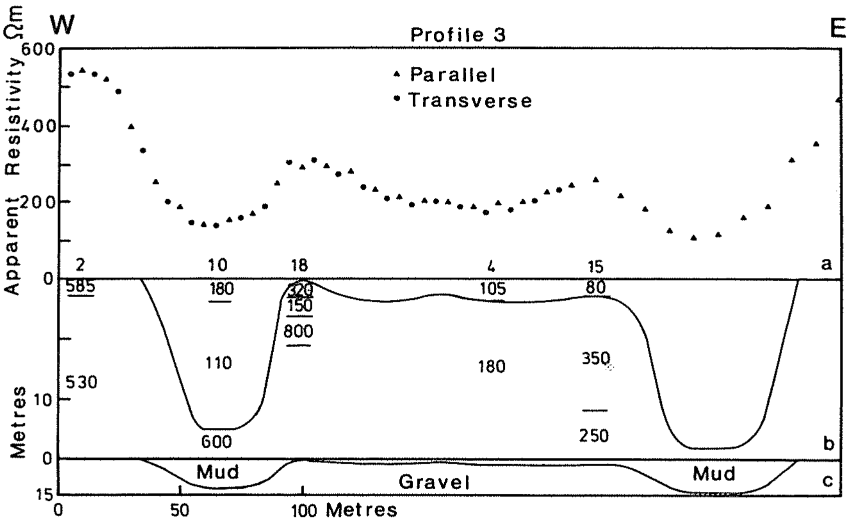

FIG. 5. West–east cross section along profile 3. (a) Resistivity profiles with a constant electrode spacing of 10 m. (b) Resistivity-depth distribution on ×5 vertical exaggeration. Numbers as in Fig. 4. (c) True scale section and interpretation.

was designed to determine the distribution and thickness of limnic sediments. These results are summarized in Fig. 2. Large numbers indicate the thickness deduced from the resistivity drills, and small numbers relate to the profile information. The resistivity data suggest that the lake basin previously had an outline quite different from that of the present edge of the Moss (Fig. 2). Furthermore, a complicated morphometry of the basin is apparent in contrast to the simple pattern derived from coring by Walker (1966 (Fig. 5).

DISCUSSION

The resistivity results suggest that the most promising site for investigation of an extended late-glacial profile would be in the southwestern basin, possibly even in the ploughing field by Drill 22 rather than in the present day basin, provided superficial colluvium could be penetrated. They also suggest that if a core were required of postglacial sediments deposited in deep water in an open area of the lake, again the southern part of the lake would be the most appropriate.

Electrical resistivity surveying is seen to be complementary to hand-boring techniques in infilled limnic basins by (i) delimiting deposits inaccessible to hand boring and (ii) providing a general distribution pattern and identifying the total stratigraphic context of the uppermost deposits. With an increasing trend in Quaternary studies toward absolute pollen counting and quantitative calculations of influx per unit area per year of both vegetational remains and chemical substances, it is becoming increasingly important to know the total morphometry of the basin as well as the spatial characteristics of limnic sediments within it. Resistivity surveys can help to obtain better estimates of total influx so that within-core variations can be quantitatively related to environmental changes in the surrounding drainage basin. Several geophysical methods in addition to resistivity surveying [e.g., magnetic parameters (Thompson *et al.*, 1975)] can quickly provide an overall spatial and temporal pattern within which to interpret detailed studies from specific cores; they also can be used as reconnaissance tools for selecting the most representative or interesting

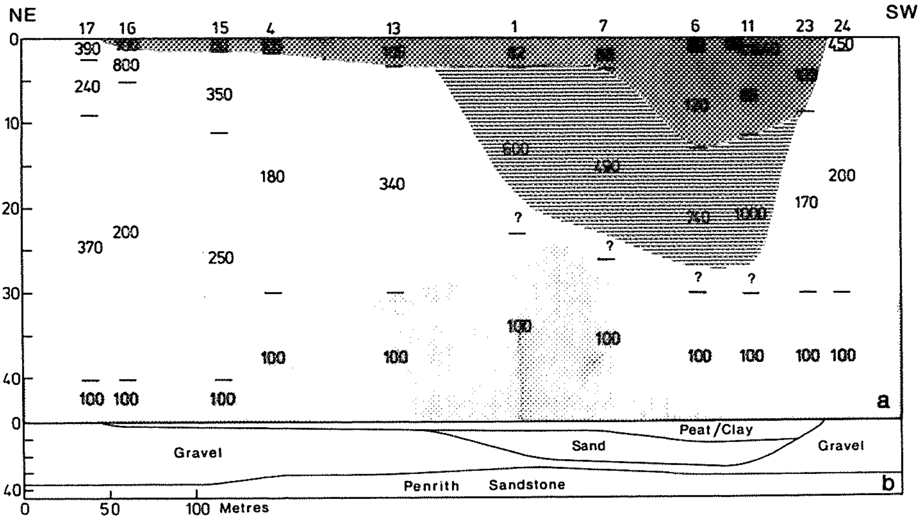

FIG. 4. Northeast–southwest cross section along line of Drill 1. (a) Resistivity-depth distribution on ×5 vertical exaggeration. (b) True scale section and interpretation. Drill numbers indicated at top of diagram. Apparent resistivities in ohm-meters. Boundaries in profiles (from Table 1) shown by short horizontal lines.

ness of the upper low resistivity layer from the associated drill models, assuming that the major variations in apparent resistivity are due to changes in interface depth rather than resistivity of the upper layers.

INTERPRETATION

A resistivity cross section of Abbot Moss along the northeast–southwest line of Drill 1 is shown in Fig. 4. The upper layer varies in resistivity from 80 to 120 ohm-m and is interpreted to include the peat, mud, clay, and silt of Walker (1966). We carried out a limited number of hand borings using a Jowsey peat sampler. Our coring in the center of Drill 1 stopped at clay at 2.5 m, in Drill 15 at 1.5 m, and in Drill 11 in wood peat at 5.0 m, all in good agreement with the above interpretation. Resistivities between 170 and 350 ohm-m are taken to represent the gravel/boulder clay drift under the lake basin. Reliable resistivity estimates between 500 and 1000 ohm-m are only found beneath the southern part of the basin except up the valley sides, e.g., Drill 2. As these deposits terminate to the southwest close to the edge of the Holocene limnic deposits, they are thought to postdate the formation of the lake basin rather than simply being lateral changes in the drift deposits, as shown in Fig. 4.

The basal low-resistivity layer found in the deep Drills 1 and 2 is interpreted as Penrith sandstone. A short (220 m) reversed seismic refraction line shot along Drill 2 is consistent with this interpretation. An upper layer of velocity about 0.8 km/sec and about 22 m thick overlies a layer of velocity 1.8 km/sec. This compares well with a longer reversed line 500 m to the north along which an additional deep resistivity drill was made. Here drift of variable thickness and velocity about 0.9 km/sec overlies weathered Penrith sandstone (velocity, 1.8 km/sec). The Penrith sandstone extends between at least 20 and 70 m and has a resistivity of 70 ohm-m. The shallow drills (maximum expansion, 32-m electrode spacing) were arranged to investigate the upper layers and consequently provide little information about the Penrith sandstone. However, a general deepening to the northeast is detectable.

The major part of the field exercises

sites before time-consuming studies are initiated.

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