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THE DISTRIBUTION OF SUBMARINE PHOSPHORITE DEPOSITS ON CENTRAL CHATHAM RISE, EAST OF NEW ZEALAND

2. SUB-SURFACE DISTRIBUTION FROM CORES

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David J. Cullen

INTRODUCTION

The reasons that prompted the present investigation of the submarine phosphorite deposits on Chatham Rise have been briefly explained in *NZOI Oceanographic Field Report No. 10* (Cullen and Singleton 1977), which deals specifically with the surface distribution of the phosphorite as revealed by underwater photography. These photographs showed the surface distribution of phosphorite to be patchy, with areas of high nodule density (approximately 150–300 m across) being separated by broad expanses of relatively barren, unconsolidated muddy "ooze". Scattered particles of phosphorite were sometimes enclosed in the ooze suggesting the presence of an underlying phosphorite nodule layer just beneath the sediment surface.

In an attempt to trace the extent of the sub-surface phosphorite, and to gauge the thickness of the deposit, cores were collected from 53 stations on central Chatham Rise. They comprised 21 piston cores, 4 gravity cores, and 28 box cores, the locations of which are shown in Fig. 1, with details listed in Tables 1 and 2. Satellite navigation was used for accurate location of the sampling sites. The early cores (e.g., Stns H634-H638) tend to be widely spaced across the crest of the Rise, as they were sited during the reconnaissance phase of the investigation. The box cores, collected on the last cruise (December 1976) are mostly close-spaced in areas of supposed maximum phosphorite concentration (e.g., Stns N822-N830, N860-N864).

The two distinct types of core, the piston/gravity cores and the box cores, were collected for different reasons. The former with their narrow diameter but greater penetration, were intended to elucidate the superficial stratigraphy of sediments in the phosphorite belt. The box cores, conversely, provide large undisturbed samples suitable for statistically reliable analysis of phosphorite particle-size distributions, and the interpretation of sedimentary structures and sediment boundaries, especially of the phosphorite layer. The relatively large upper-surface area of individual box cores also allows comparisons to be made with the bottom photographs, leading to a preliminary attempt at quantitative evaluation of the phosphorite deposit.

This report presents the results of the coring programme, and discusses the implications as they relate to the sub-surface distribution of the phosphorite.

PISTON AND GRAVITY CORES

Gear used and penetration achieved

Only four gravity cores were taken (Stns H934, H936, H938, H941). Penetration and recovery of the bottom sediment were very unsatisfactory, and nowhere exceeded 0.25 m. Thus the gravity corer, comprising a barrel 2 ft (0.6 m) long with internal diameter 3 in. (76 mm), and weighted with 200 lb (91 kg) of lead, was reserved for use only in adverse weather conditions.

The piston cores recorded sea-floor penetrations ranging from 0.32 m in partly indurated ooze and phosphorite on the crest of Chatham Rise (Stn H642) to a maximum of 4.67 m in unconsolidated muddy sediments on the southern flank of the Rise (Stn H653). The early piston cores (Stns H634-H677) were recovered with an 18 ft (5.5 m) x 3 in. (76 mm) barrel carrying 750 lb (340 kg) of lead weights. For later coring (Stn H920 *et seq.*), the barrel was reduced to 6 ft (1.8 m) and the weights increased to 1500 lb (681 kg) in an attempt to improve penetration of the phosphorite nodule layer and the associated chalk (*see* Cullen and Singleton 1977 : 19). Both deposits are extremely difficult to core with a narrow-diameter barrel and, in practice, the changes in weight and barrel length made no discernible difference to the depth of penetration of the corer.

Core stratigraphy

A number of distinctive sediment units , occurring in a more or less regular sequence, are recognised in the cores from central Chatham Rise. In individual cores, however, one or more of the units may be missing. A composite reconstruction of the sedimentary sequence, from several cores, is as follows :-

1. *Chalk*. The lowest unit is the compact whitish chalk, mentioned above, which seems to be virtually impenetrable to both piston and gravity corers, and appears only sporadically as fragments intermingled with phosphorite nodules at the base of some cores (Fig. 2, Stns H638, H642), or retained in the cutter and catcher of others (Stns H661, H677). It also occurs fairly frequently in dredge samples from the region.

Micropaleontologically, the chalk is assigned to the Lower Whaingaroan Stage at the base of the Oligocene (N. de B. Hornibrook, pers. comm.), and, like the contemporary Amberley Limestone of North Canterbury, the Oxford Chalk, and the MacDonald Limestone of North Otago, it is an oceanic, globigerina-ooze chalk. It clearly forms the Tertiary basement in the

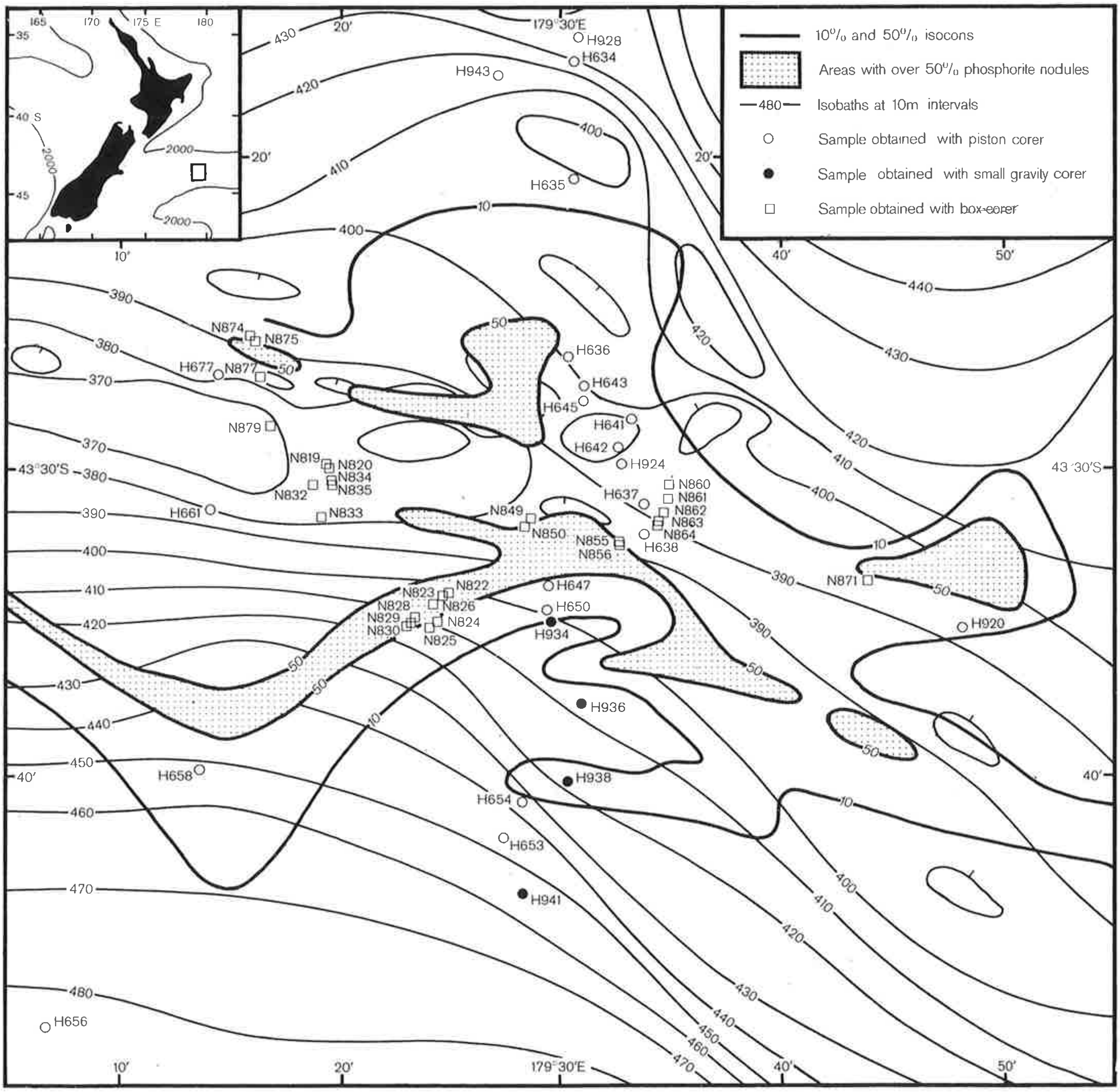


Fig. 1. Map of central Chatham Rise, showing location of coring stations in relation to the local bathymetry and to areas of phosphorite concentration delineated by JBL Minerals.

area under discussion, and lies at shallow depth beneath superficial sediments along the crest of this section of Chatham Rise.

2. *Basal phosphorite layer.* Resting upon the surface of the chalk is a phosphorite layer of variable thickness, comprising typical black, glauconite-coated phosphorite nodules, unsorted as to size, sometimes intermingled with angular chalk fragments and brachiopod shells (Fig. 2, Stns H638, H642).

Penetration of the phosphorite layer by the piston corer is usually incomplete, attaining a maximum of 0.15 m in core H638. At the very bottom of some cores (e.g., Fig. 2, Stn H643) only a few small phosphorite particles were recovered, indicating either lateral petering-out of the phosphorite or failure of the corer to reach the basal phosphorite layer.

3. *Foraminiferal ooze.* In a number of cores, the basal phosphorite is immediately overlain by up to 0.3 m of

Table 1. Piston and gravity core data - central Chatham Rise.

NZOI Stn No.	Latitude °S	Longitude °E	Water Depth (metres)	Core Length (metres)
Piston Cores				
H634	43°16.7'	179°30.4'	435	0.41
H635	43°20.6'	179°30.4'	396	0.87
H636	43°26.4'	179°30.2'	395	0.19
H637	43°31.1'	179°33.6'	430	*
H638	43°32.1'	179°33.6'	415-422	0.65
H641	43°28.4'	179°33.1'	408	*
H642	43°29.3'	179°32.6'	403	0.32
H643	43°27.3'	179°31.0'	410	0.35
H645	43°27.7'	179°31.0'	415	2.27
H647	43°33.8'	179°29.4'	398	*
H650	43°34.6'	179°29.4'	400	0.72
H653	43°42.0'	179°27.4'	470	4.70
H654	43°40.8'	179°28.2'	470	3.50
H656	43°48.25'	179°06.8'	462	2.50
H658	43°39.8'	179°13.7'	450	2.07
H661	43°31.3'	179°14.2'	410	*
H677	43°27.0'	179°14.5'	380	0.93
H920	43°35.1'	179°48.2'	402	0.32
H924	43°29.9'	179°32.6'	397	0.37
H928	43°15.9'	179°30.6'	436	0.48
H943	43°17.3'	179°27.1'	418	0.14
Gravity Cores				
H934	43°34.8'	179°29.5'	405	0.19
H936	43°37.7'	179°30.8'	416	0.27
H938	43°40.2'	179°30.2'	428	*
H941	43°43.8'	179°28.2'	460	*

* Small samples retained in cutter or catcher, or in pilot corer.

Table 2. Box core data - central Chatham Rise.

NZOI Stn No.	Latitude °S	Longitude °E	Water Depth (m)	Maximum pene-tration (m)	Percentage by weight of phosphorite
N819	43°29.8'	179°19.4'	385	*	Present
N820	43°30.0'	179°19.5'	382	*	Present
N822	43°34.0'	179°24.9'	420	0.08	14.7
N823	43°34.0'	179°24.8'	414	0.04	Present
N824	43°34.9'	179°24.5'	419	0.05	17.2
N825	43°35.1'	179°24.1'	419	*	Present
N826	43°34.4'	179°24.3'	423	0.08	19.5
N828	43°34.8'	179°23.4'	425	0.11	22.2
N829	43°34.9'	179°23.3'	428	0.06	6.8
N830	43°35.0'	179°23.2'	427	0.04	1.5
N832	43°30.5'	179°18.8'	387	-	-
N833	43°31.6'	179°19.2'	380	*	Present
N834	43°30.4'	179°19.6'	380	0.09	48.6
N835	43°30.5'	179°19.6'	373	0.20	69.9
N849	43°31.6'	179°28.6'	405	0.15	0.9
N850	43°31.9'	179°28.3'	402	0.06	14.1
N855	43°32.35'	179°32.6'	392	0.01	Present
N856	43°32.4'	179°32.6'	396	0.05	6.3
N860	43°30.5'	179°34.8'	406	*	Present
N861	43°30.9'	179°34.7'	402	-	-
N862	43°31.4'	179°34.5'	392	0.14	7.6
N863	43°31.7'	179°34.3'	392	0.18	Present
N864	43°31.8'	179°34.3'	390	0.19	4.5
N871	43°33.6'	179°43.9'	392	0.22	1.1
N874	43°25.7'	179°16.0'	395	0.05	5.3
N875	43°25.9'	179°16.1'	391	0.03	25.7
N877	43°27.1'	179°16.4'	378	0.11	52.2
N879	43°28.7'	179°16.9'	375	0.15	34.2

* Small samples only

soft, smooth, off-white foraminiferal ooze having the appearance and consistency, when fresh, of processed cream cheese (Fig. 2, Stns H638, H642, H643, H920, H924). This deposit probably represents a mixture of contemporary foraminiferal tests and derived microfossils and nannofossils from the basement Tertiary chalk.

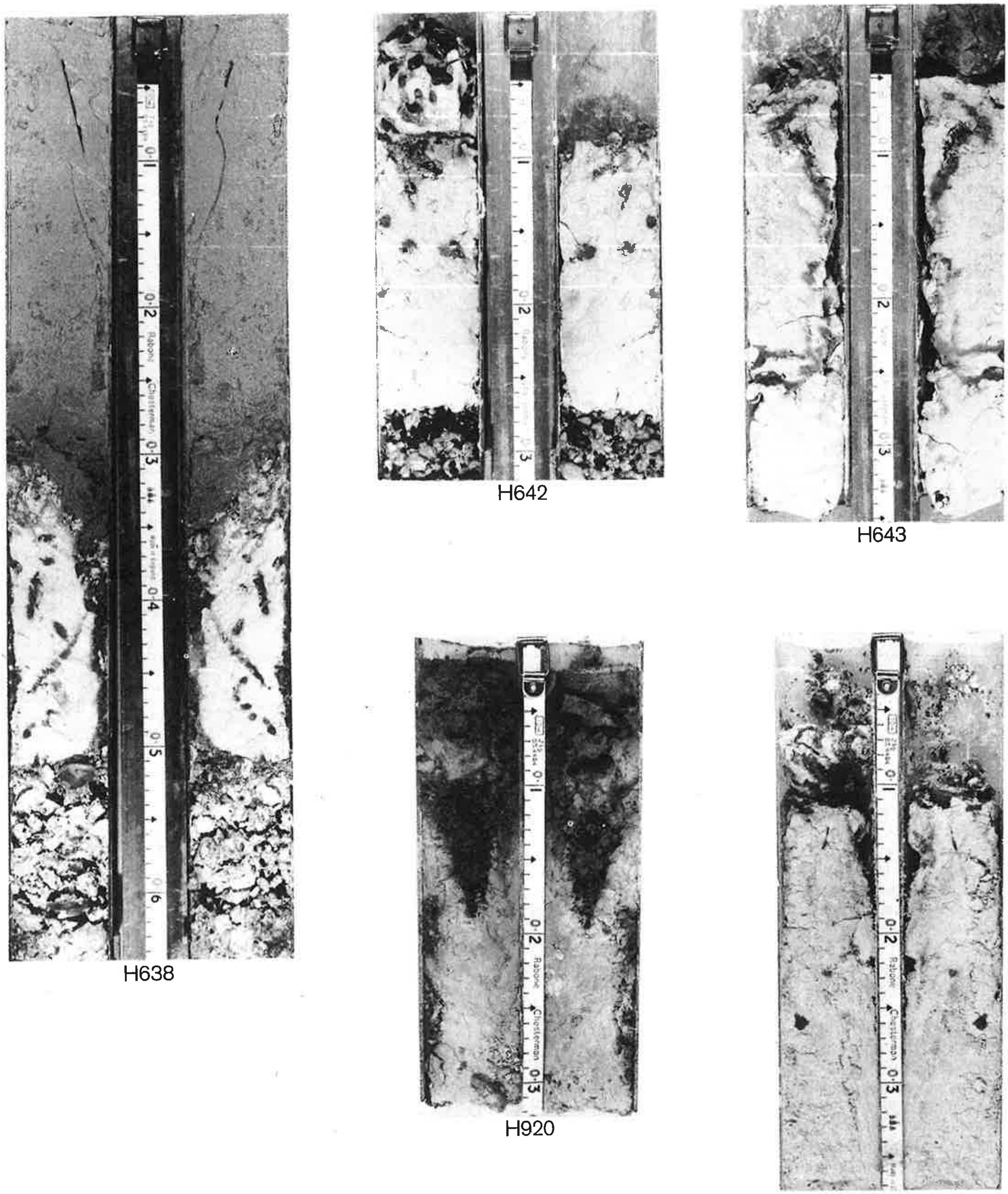
Burrows filled with a darker muddy sand, comparable with, and presumably derived from the overlying sediment layer, are a common feature of the foraminiferal ooze. In core H642 (Fig. 2), the topmost 80-90 mm of ooze have been preferentially indurated and intensively bored, apparently as a consequence of prolonged exposure on the sea floor.

4. *Upper phosphorite layer.* Unequivocal evidence of a second phosphorite layer - above the foraminiferal ooze - is provided by core H642 (Fig. 2), the indurated top of which is capped by a thin layer of small phosphorite nodules.

An equivalent layer, some 150 mm thick, of black-coated phosphorite nodules and large uncoated fragments of brownish phosphatised limestone occurs at the top of core H920 (Fig. 2), above whitish ooze. Similar deposits occupy the bases of cores H634 and H943 (Fig. 3), but in these instances the relationship to the foraminiferal ooze layer is not evident. Possibly the ooze lay at greater depth beneath the phosphorite layer in these cores, or, the ooze itself may have petered-out in the area from which the cores were recovered.

The upper phosphorite layer is represented in core H924 (Fig. 2) by a few, very small, black-coated particles of phosphorite in a sandy deposit resting on the upper surface of the white ooze. Similar tiny phosphorite particles, and associated "streaks" of white ooze occurring at the base of core H650 (Fig. 3) may represent this layer. As with the basal phosphorite layer, the upper phosphorite layer seems to be laterally impersistent, and may either thicken or peter out in an (as yet) unpredictable manner.

The significance of the uncoated lumps of brownish phosphatic limestone in the upper phosphorite layer is obscure. They are quite distinct from the fragmental Oligocene chalk described earlier; neither do they appear to be eroded nodules, although lithologically similar to the limestone that forms the nodules. They possibly consist of material derived from relict outcrops of Miocene limestone on central Chatham Rise. They would have been formed after the true nodules had been coated, but before final burial of the limestone outcrops.



H638

H642

H643

H920

H924

Fig. 2. Piston cores H638, H642, H643, H920, H924, showing predominantly the lower sediment units discussed in the text.

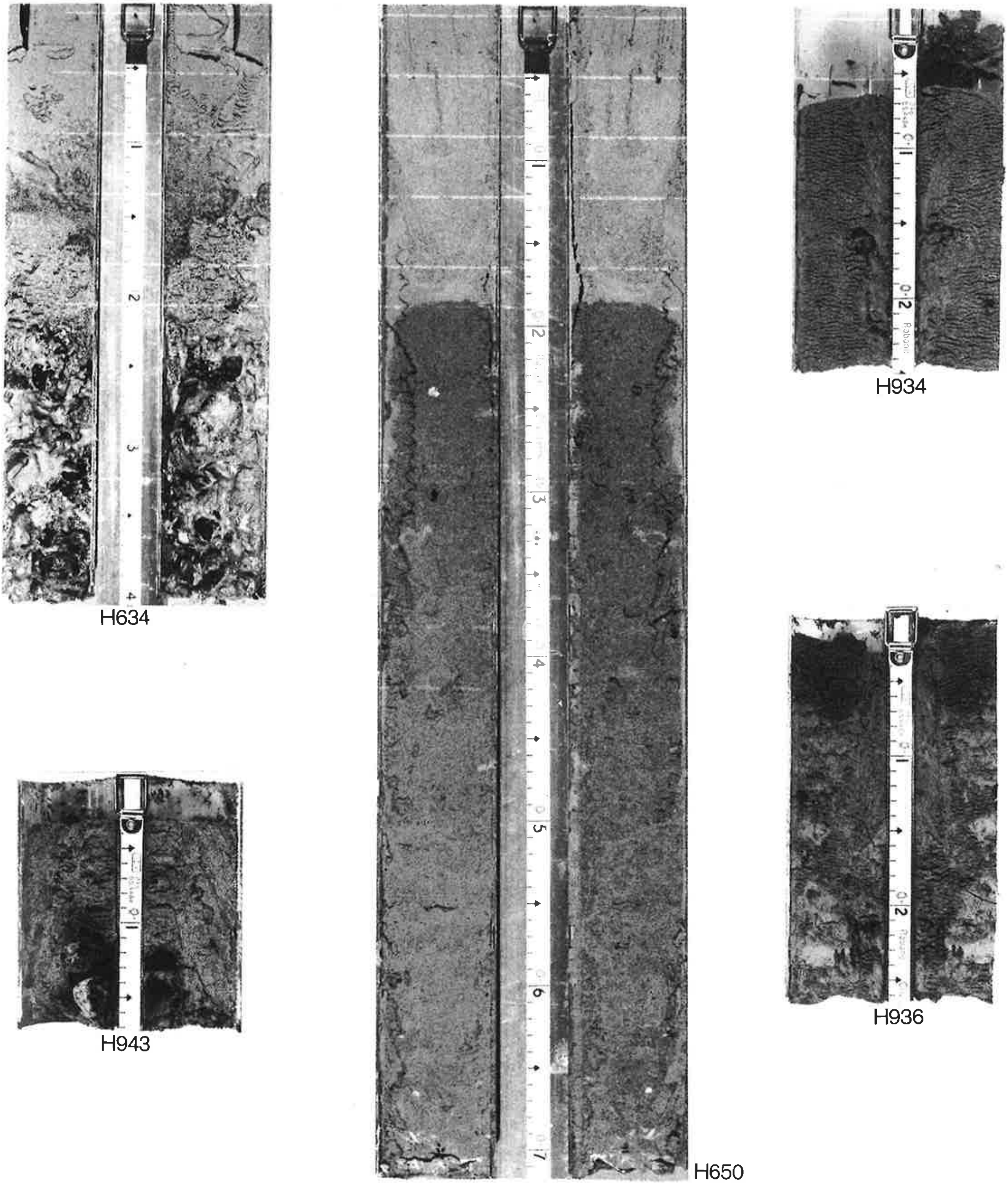
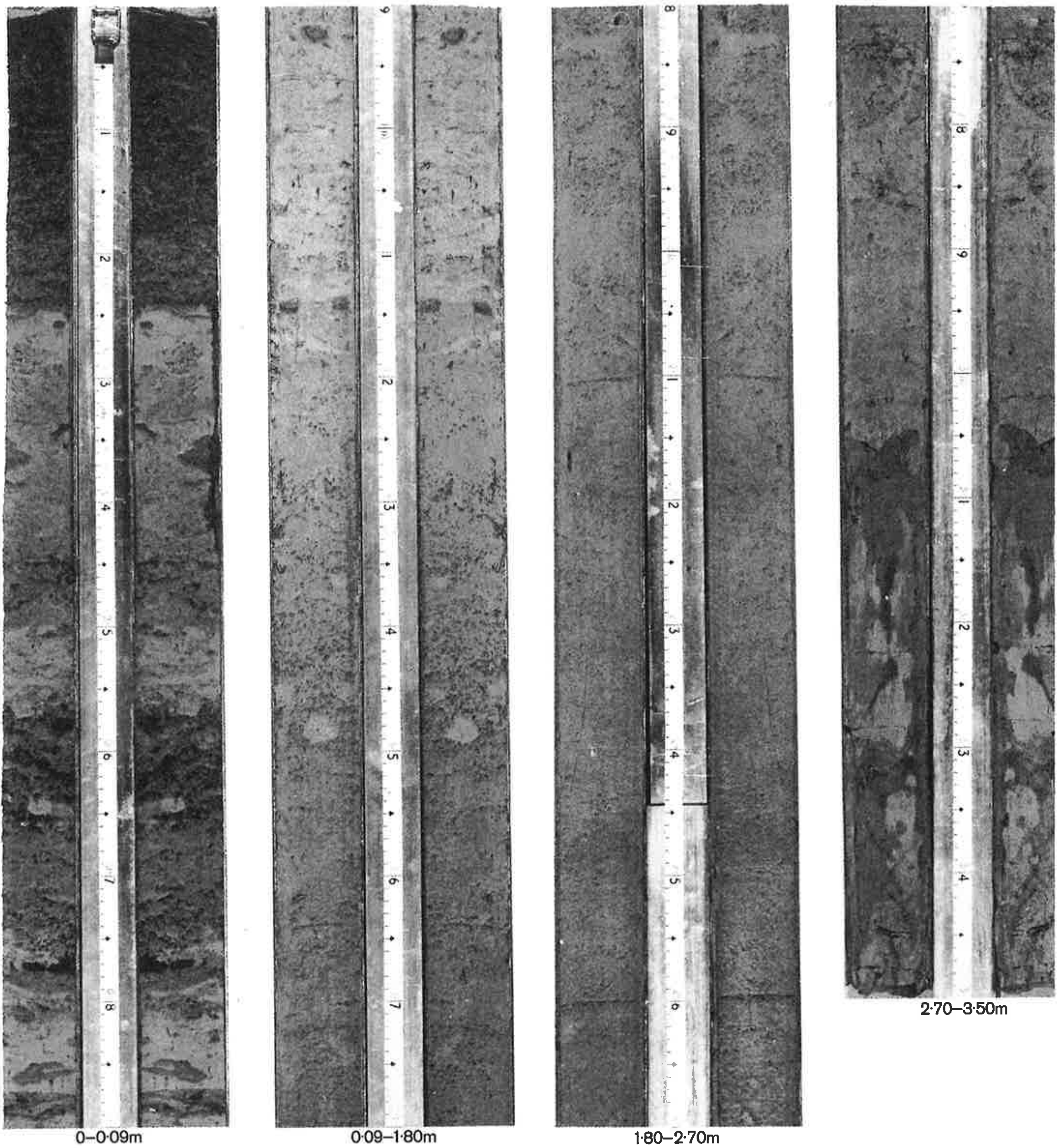


Fig. 3. Piston cores H634, H650, H943 and gravity cores H934, H936, showing the glauconitic muddy sand - sandy mud layer and the upper phosphorite layer.



0–0·09m

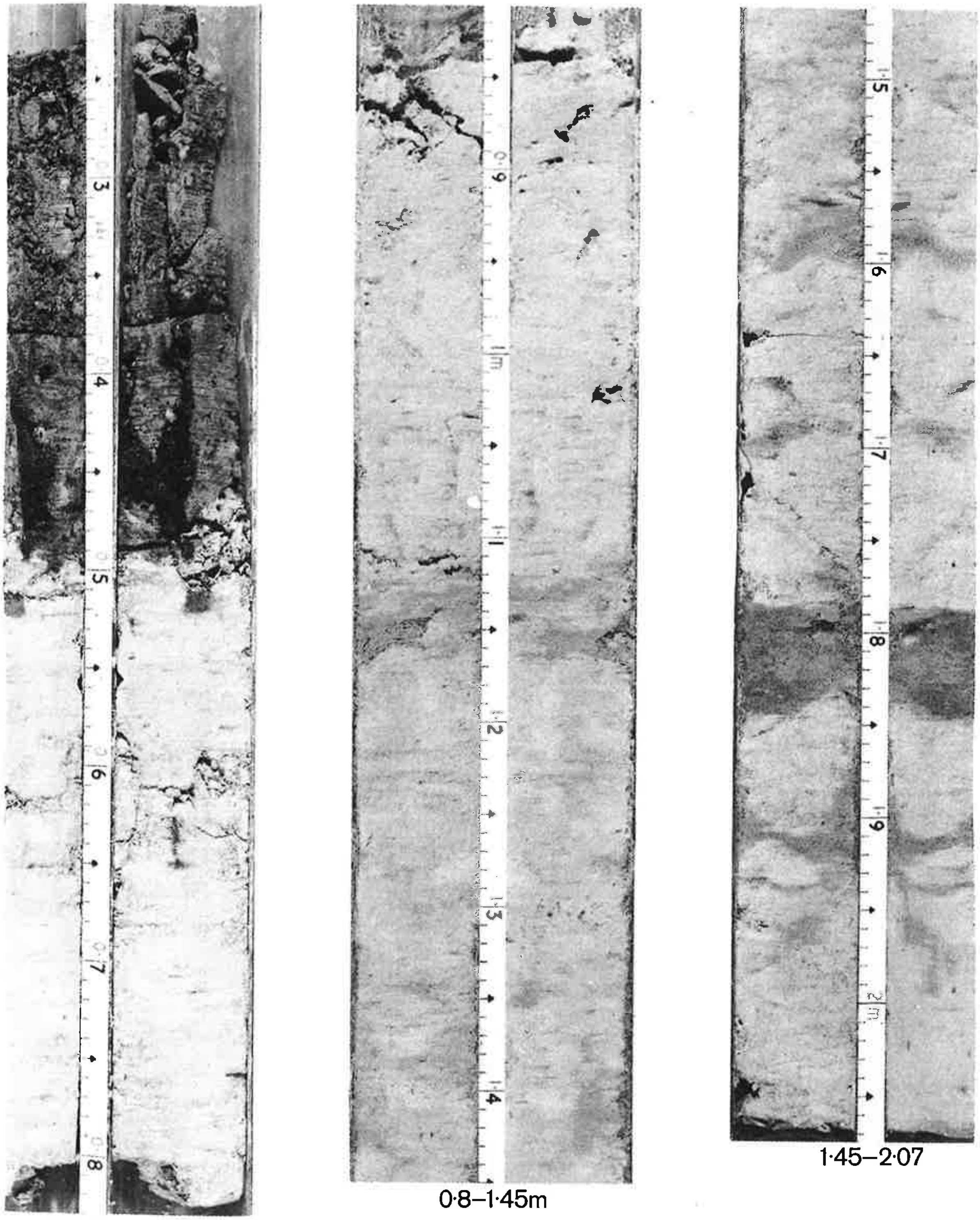
0·09–1·80m

1·80–2·70m

2·70–3·50m

H654

Fig. 4. Piston core H654, from the southern flank of Chatham Rise, showing bedding emphasised by glauconitic bands in the top part of the core.



H658

Fig. 5. Piston core H658, from the southern flank of Chatham Rise, showing highly glauconitic sediment at the top of the core overlying pale laminated ooze. Topmost sediment (removed) was badly distorted by implosion of the plastic liner.

0–0·75m

0·75–1·50m

1·50–2·27m

H645

Fig. 6. Piston core H645, from subsidiary basin on the crest of Chatham Rise, showing glauconitic, poorly-bedded muddy sand and sandy mud passing down into uniform pale ooze.

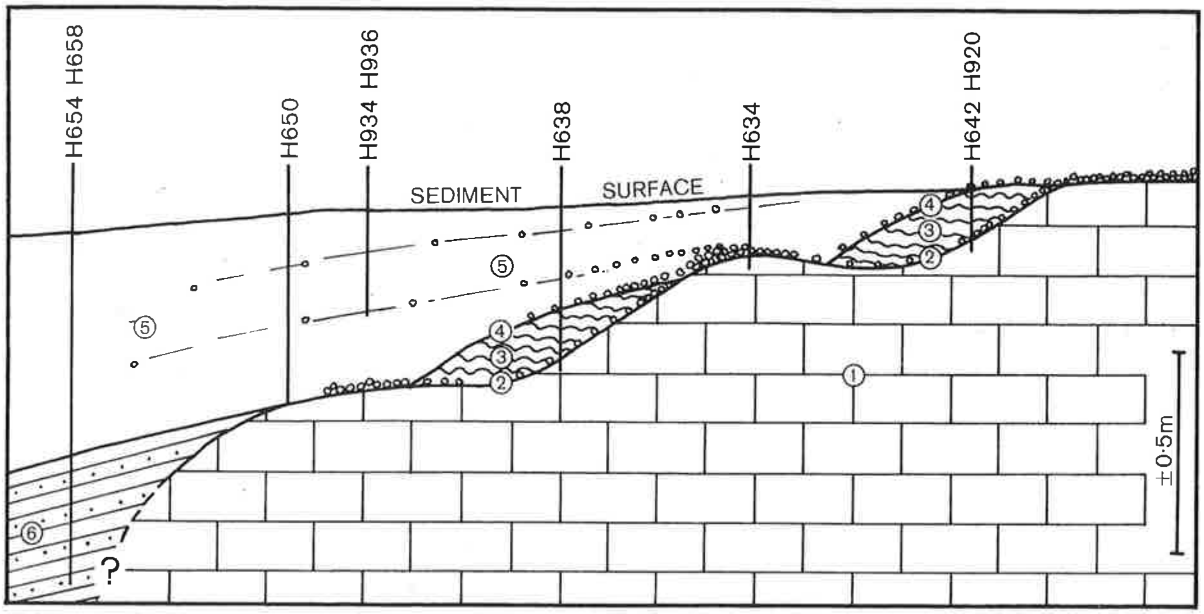


Fig. 7. Schematic section to demonstrate the supposed inter-relationships of the sediment units described in the text.

1. Oligocene chalk basement.
2. Basal phosphorite layer.
3. Foraminiferal ooze.
4. Upper phosphorite layer.
5. Glauconitic muddy sand - sandy mud (reworked).
6. Laminated sandy mud with ash layers.

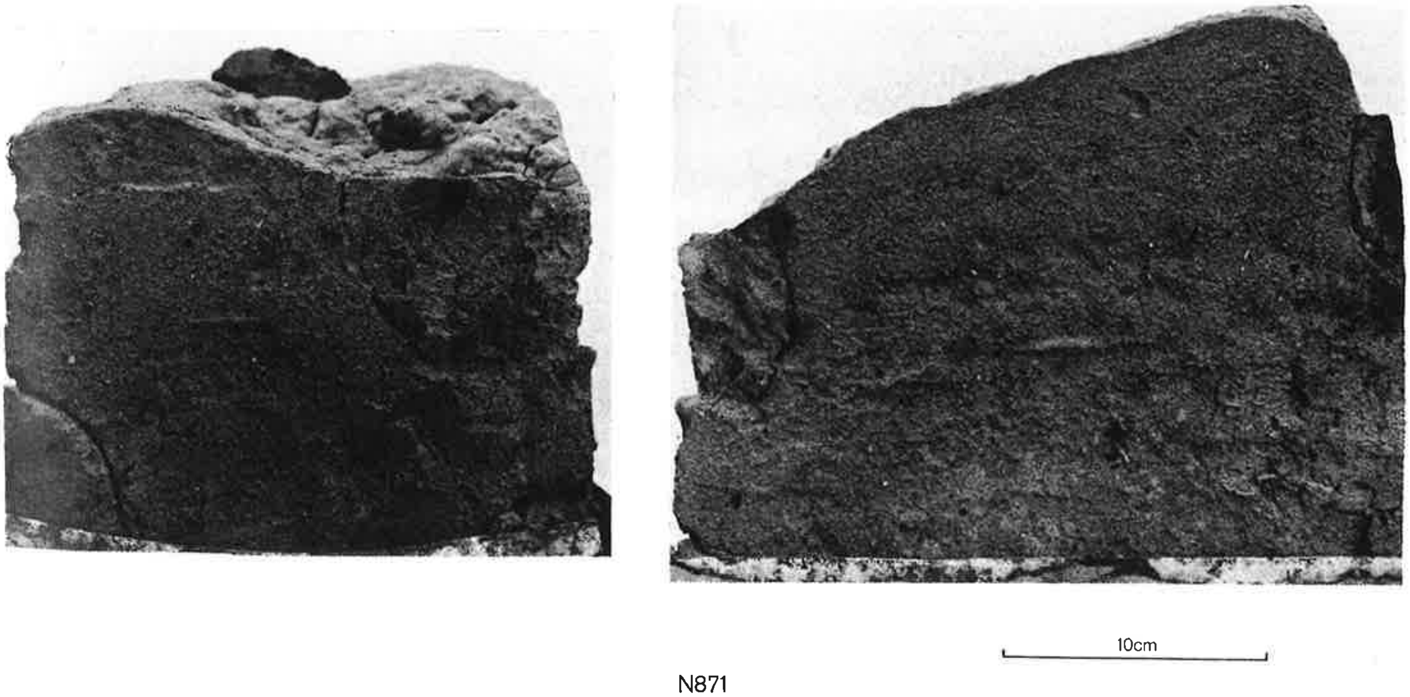


Fig. 8. Box core N871, comprising glauconitic muddy sand - sandy mud with few scattered phosphorite particles. Represents the deepest penetration by the box corer. Side view (left) and front view (right).

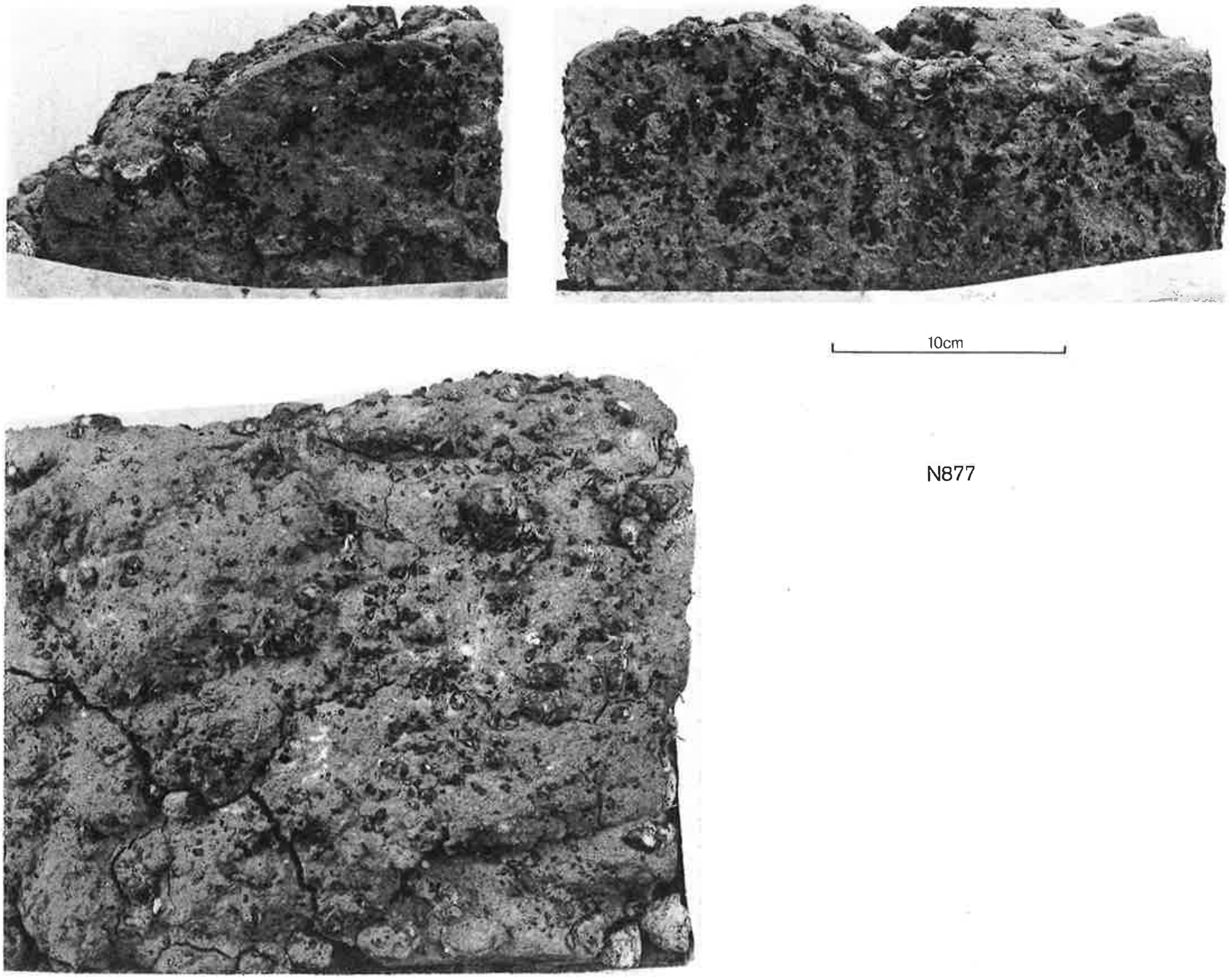


Fig. 9. Box core N877 : side (top left), front (top right) and surface views, showing abundant phosphorite nodules, mostly of small size, within and on surface of the core.

5. *Glauconitic sandy mud-muddy sand.* The topmost section of many cores from the crest of Chatham Rise is yellow-grey to olive-grey sandy muds and muddy sands with variable quantities of sand-sized glauconite grains. Minute shards of volcanic glass are visible under the microscope. The lithology of individual cores tends to be fairly uniform, except perhaps for a slight upward increase in mud content, and the sediment seems to be thoroughly reworked and mixed (Fig. 2, Stn H638; Fig. 3, Stns H634, H650, H934, H936, H943). Primary sedimentary structures are conspicuously absent, which is hardly surprising in view of the intense bioturbation of the sea floor in the area, demonstrated by the bottom photography (Cullen and Singleton 1977).

This topmost sedimentary unit on the crest of Chatham Rise seems to be the condensed equivalent of a thick sequence of sandy muds and muddy sands, containing volcanic glass and some glauconite, that has been cored to a maximum depth of 4.67 m on the southern flank of the Rise (Fig. 4, Stn H654; Fig. 5, Stn H658) and in a prominent basin on its crest (Fig. 6, Stn H645). Precise inter-relationships between these two sets of deposits are obscure, but reworking has clearly been less severe on the flanks of the Rise and in the protected basin, and in these areas traces of bedding are preserved together with some distinct layers of volcanic ash. Fission-track dating of the latter is in progress, and will be reported elsewhere.

Penetration by the corer was not sufficient to indicate whether, or to what extent, these lower sediment units continue beneath the younger deposits down the flanks of Chatham Rise. This could probably only be decided by high-resolution profiling, but, as

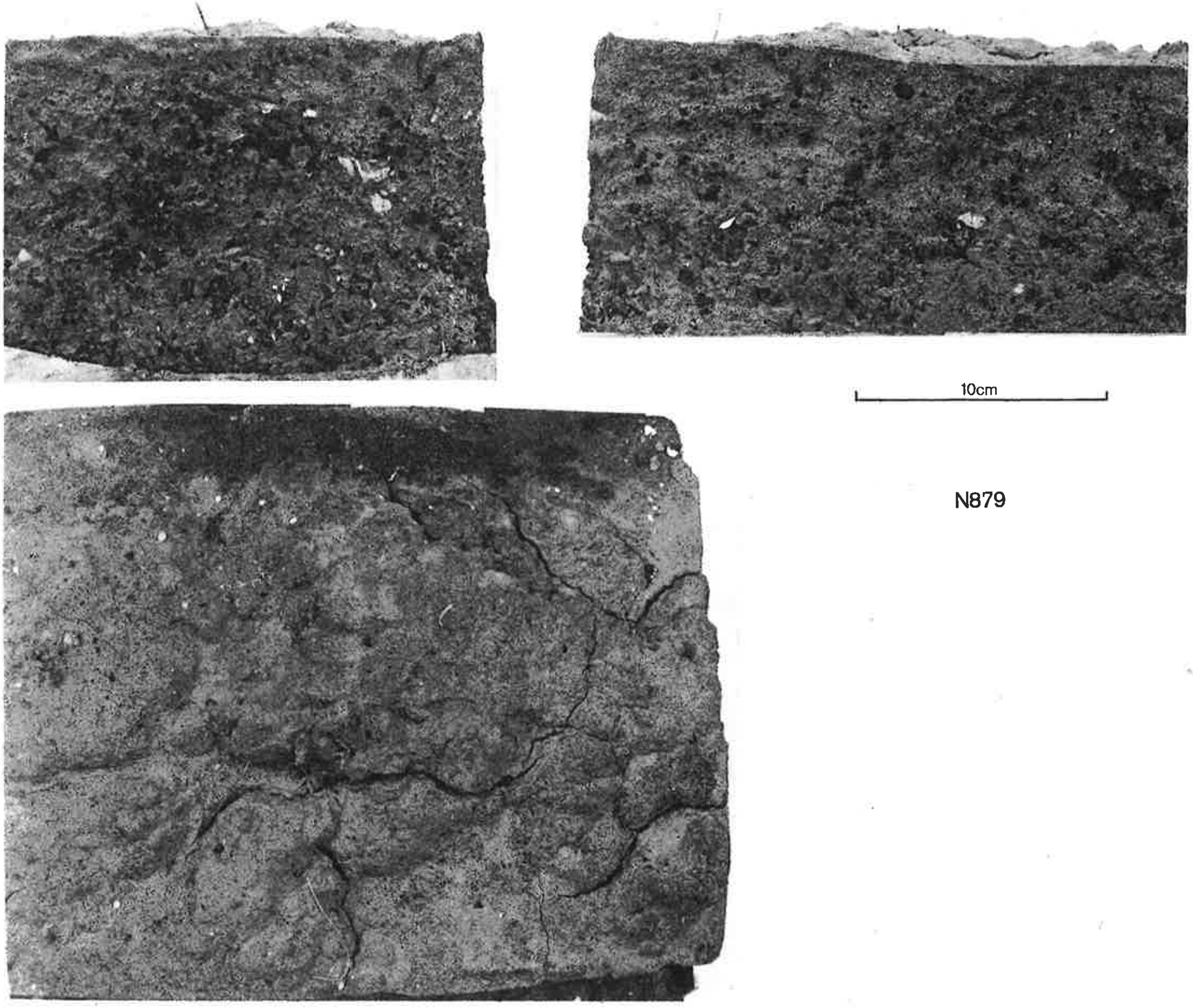


Fig. 10. Box core N879 : side (top left), front (top right) and surface views, showing abundant small phosphorite particles within the core despite paucity on surface.

the superficial sediments beyond the 450 m isobath are too thick for economic mining, the possible downslope continuity of the phosphorite is of purely academic interest.

A tentative interpretation of the inter-relationships of these five sedimentary units is attempted in Fig. 7. Lithologic details of the piston cores are presented schematically in Appendix I.

BOX CORES

The box corer used during the investigation was based on the model designed by Reineck, and manufactured by Friedrich Leutert of West Germany. Internal cross-sectional dimensions of the boxes are 0.225 m x 0.295 m, with an overall box height of 0.47 m and effective height of approximately 0.3 m. Some initial re-adjustments and modifications were necessary before optimum penetration was achieved, and good penetrations, approaching the maximum obtained (0.22 m at Stn N871, Fig. 8), were effected mostly during the later stages of the box-coring programme.

Penetration of the nodular phosphorites was surprisingly good, and highly phosphoritic deposits, 0.14 m and 0.15 m thick, were cored at Stns N877 and N879 respectively (Figs 9, 10). Sometimes, as at Stns N826, N828, N834 and N862 (Figs 11, 12), the corer reached the foraminiferal ooze layer beneath phos-

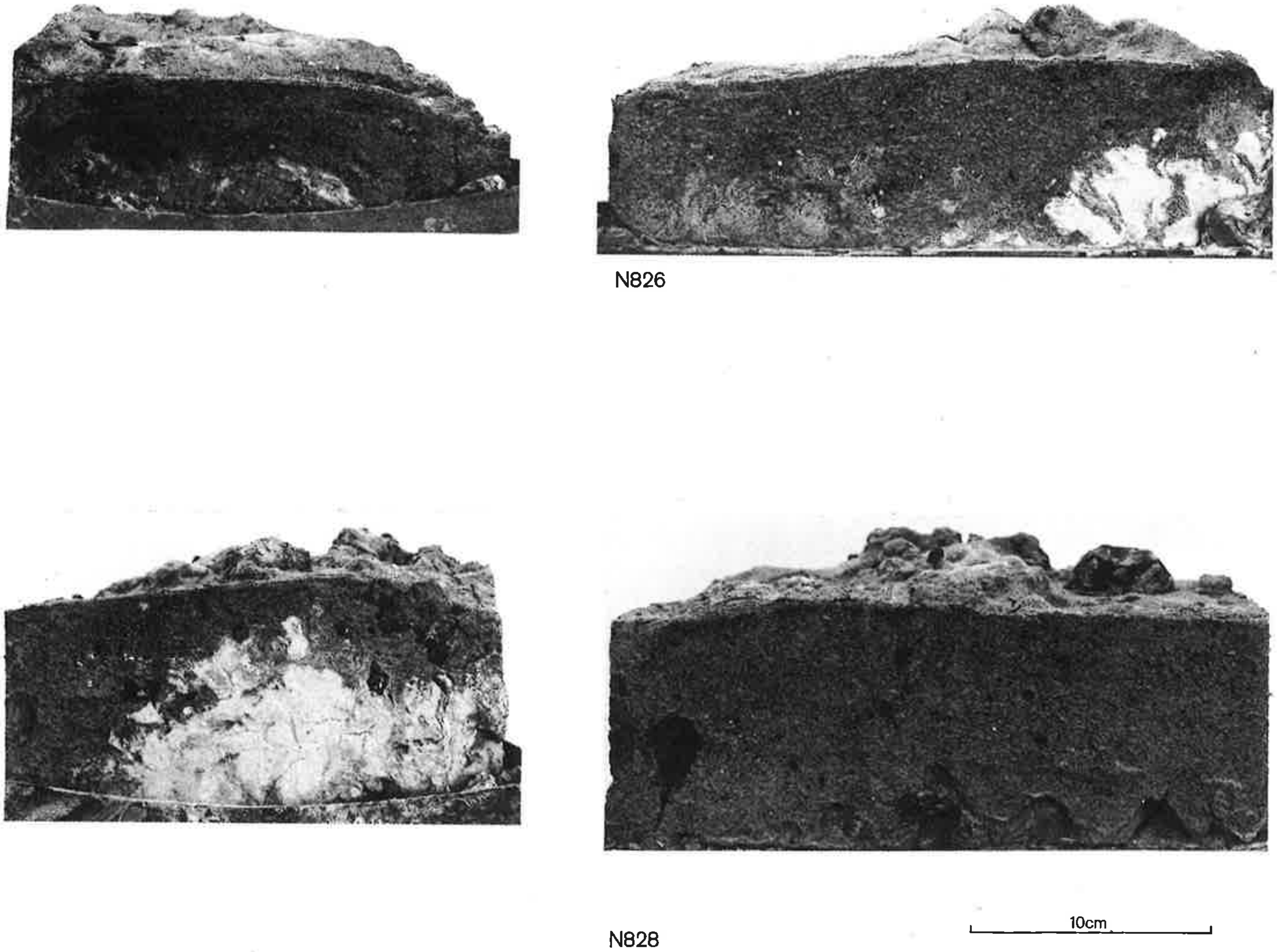
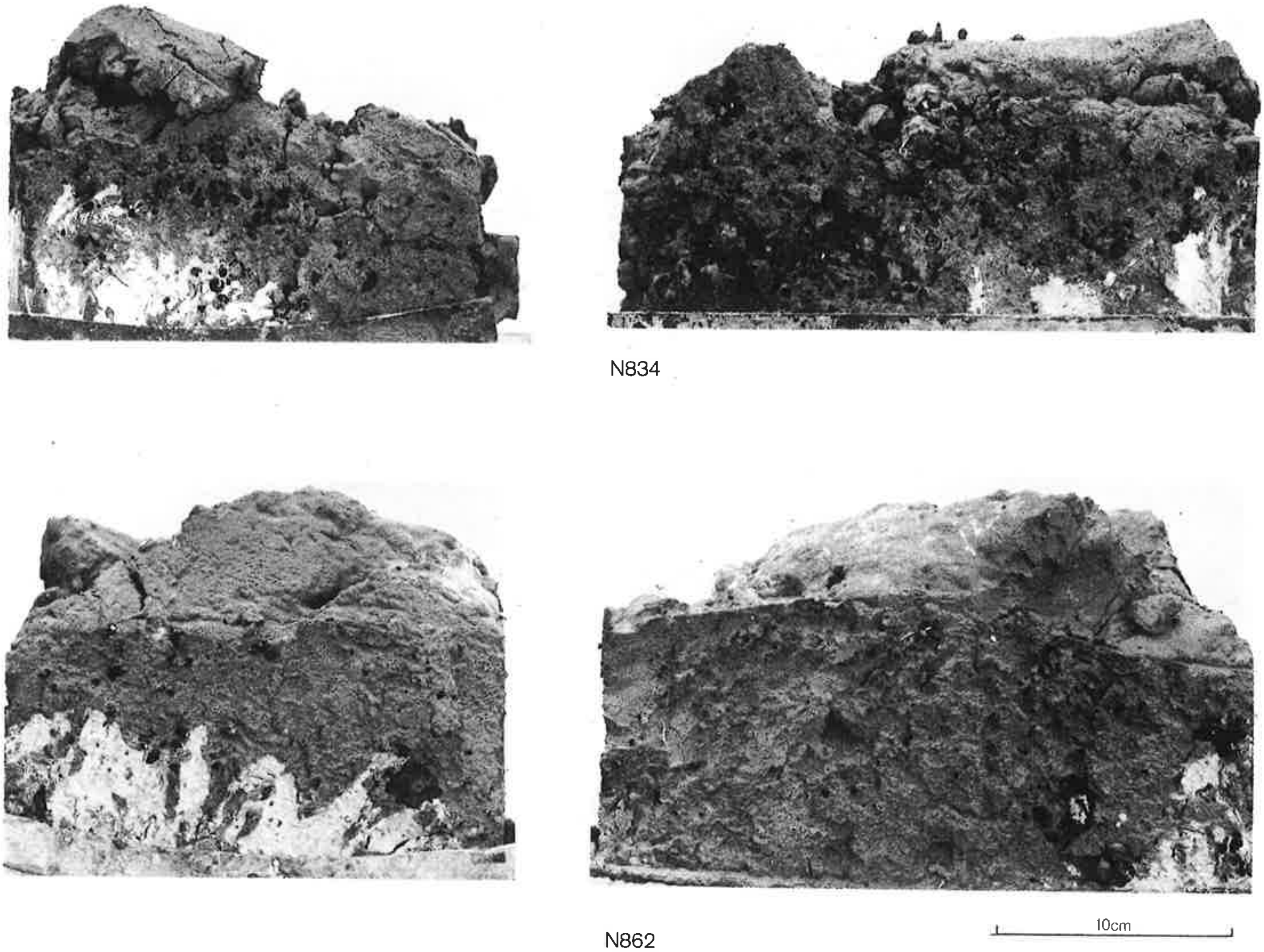


Fig. 11. Box cores N826, N828 : side (left) and front (right) views, showing foraminiferal ooze overlain by glauconitic muddy sand - sandy mud, with (N828) and without (N826) phosphorite nodules.

phorite and/or glauconitic muddy sand. The interface between the foraminiferal ooze and overlying sediments is invariably quite irregular, reflecting intense boring and bioturbation of the ooze surface before or at the onset of subsequent deposition (Fig. 13). Unlike the smaller piston cores, the box cores show small phosphorite particles, in the size range 5.00 mm or less, as a frequent, if minor, constituent of the superficial glauconite muddy sand layer (Fig. 8, Stn N871; Fig. 11, Stn N828; Fig. 14, Stns N864, N822).

QUANTITATIVE ASSESSMENT OF THE PHOSPHORITE

The box cores provide a sufficiently large area of sediment surface for visual comparisons to be made with the bottom photographs already published (Cullen and Singleton 1977). Measurement of the amount of phosphorite occurring in the various types of box-core samples then enables tentative quantitative estimates to be made of the phosphorite on Chatham Rise. For instance, the upper surface of core N877 (Fig. 9) is very similar to the area photographed at Stn H956 (Cullen and Singleton 1977, Fig. 4). The total weight of phosphorite in core N877 is 5.4 kg (12.0 lb), which by extrapolation from the surface area of the core, indicates a nodule distribution of 82.3 kg/m^2 (16.8 lb/ft^2). The linear distance represented by the three photographs that show nodules at Stn H956 is estimated at 80 m. If it is assumed that this nodule "patch" is equi-dimensional and compositionally uniform, the three photographs portray a surface deposit of phosphorite in the order of 414 tonnes (404 tons). The photographs were taken along a north-south traverse, however, and the phosphorite patches may be elongate in an east-west direction, parallel to the regional and morphological trends of the area. Thus, this figure may have to be increased by a substantial (but as yet unknown) factor to obtain a realistic evaluation of the quantities of phosphorite represented photographically at Stn H956.



N834

N862

Fig. 12. Box cores N834, N862 : side (left) and front (right) views, showing foraminiferal ooze overlain by glauconitic muddy sand - sandy mud, with abundant (N834) and relatively little (N862) phosphorite.

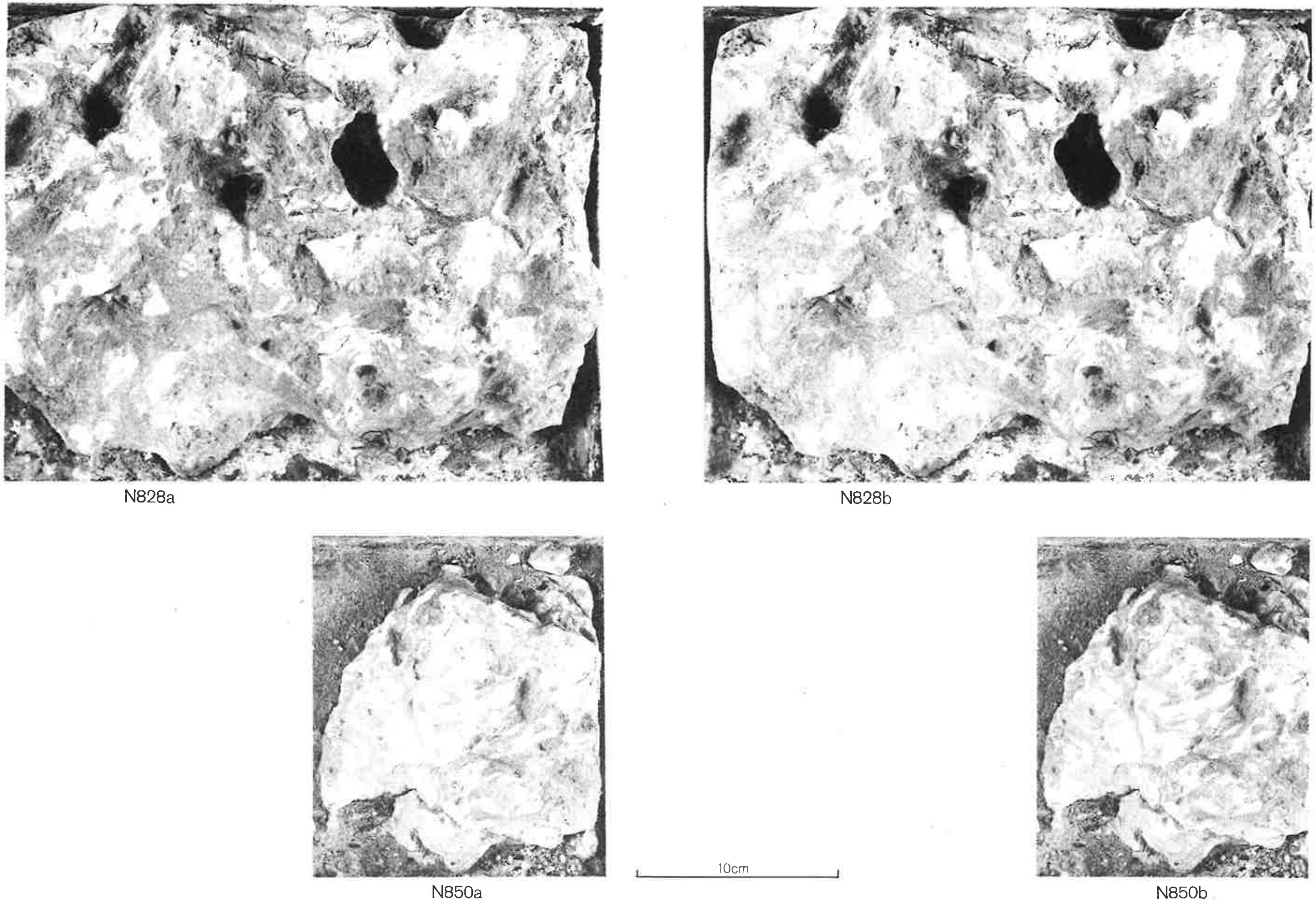
Of equal interest is core N879, which contains 5.2 kg (11.4 lb) of phosphorite and represents a distribution of 77.7 kg/m^2 (15.8 lb/ft^2). There are no surface indications of the presence of this subjacent phosphorite deposit, and this type of deposit could well underlie such unpromising stretches of sea floor as those photographed at Stns H929, H931 and H951 (Cullen and Singleton 1977, Figs 9-11). In neither of the box-core samples cited is there evidence that the base of the phosphorite layer was reached, and the quantities of phosphorite recovered in these instances can thus be regarded as minimum values. Size frequency analyses of the box-core samples are summarised in histogram form in Appendix II.

With the information provided by the bottom photographs and the piston and box cores, it is now possible to outline tentatively some of the more promising areas for phosphorite on central Chatham Rise (Fig. 15), but for an assessment of this type, the sample coverage is very incomplete, and apparent gaps in the phosphorite deposit may represent lack of data.

RECOMMENDATIONS

Extension of bottom photography, preferably using a more rapid camera system, and both piston and box coring are obvious requisites for a thorough evaluation of the Chatham Rise phosphorite deposits.

From the results to date however, it seems that a complete understanding of the distribution of the phosphorite cannot be achieved without the application of more sophisticated techniques to elucidate the micro-relief of the area and the sub-surface continuity of the phosphorite. In the case of the two box cores described above (Stns N877, N879), for instance, it is not known whether the greater abundance of nodules on the surface of N877 (Fig. 9) reflects concentration



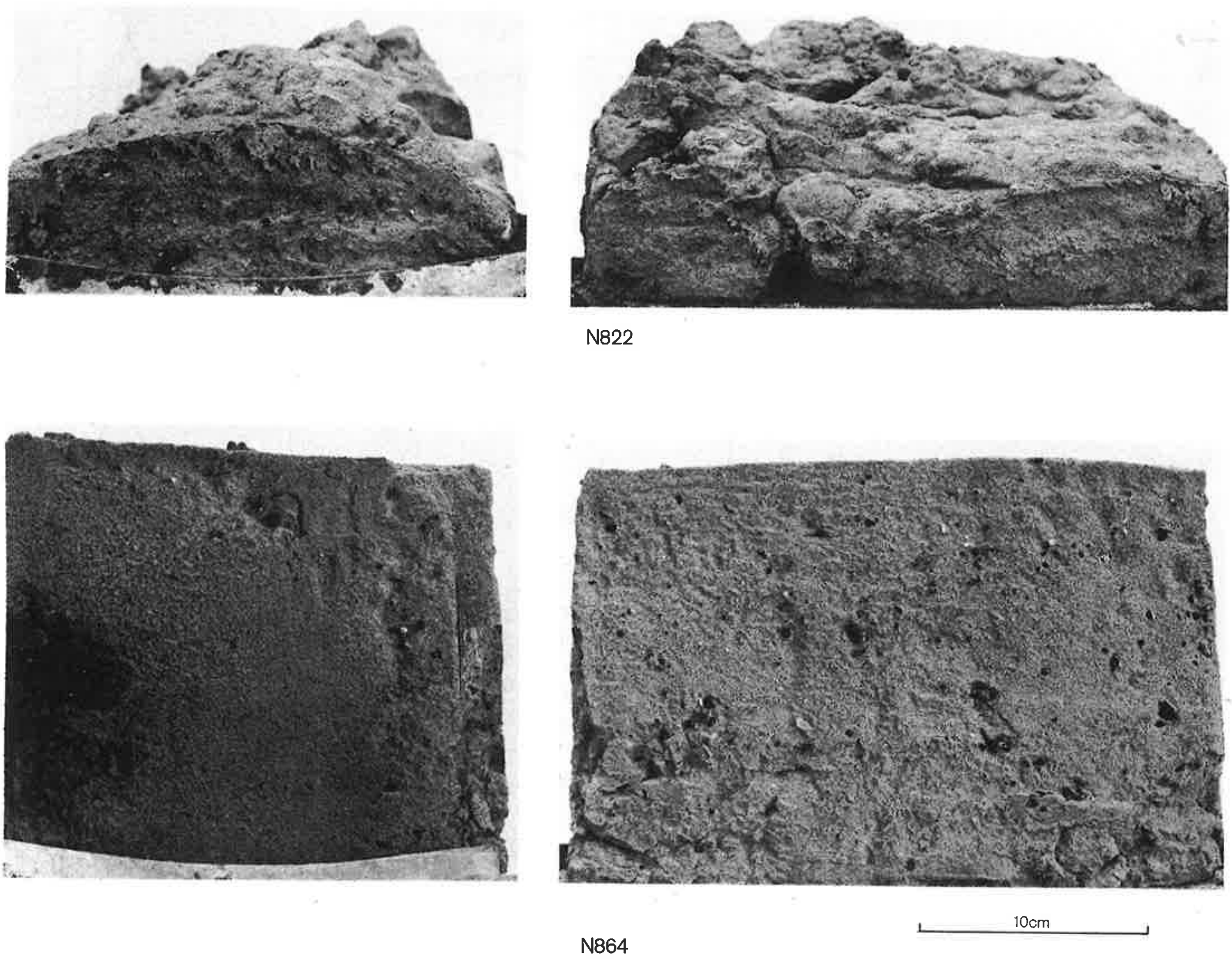
N828a

N828b

N850a

N850b

Fig. 13. Box cores N828, N850: stereo-pairs of cleaned surfaces of foraminiferal ooze layer, after removal of overlying muddy sand – sandy mud. Shows irregularity of the surfaces, and intensity of boring and burrowing at this sediment interface.


N822

N864

Fig. 14. Box cores N822, N864: side (left) and front (right) views, showing occurrence of small phosphorite particles dispersed throughout the glauconitic muddy sand - sandy mud layer.

by winnowing on a slight topographic elevation or in an intervening scoured depression (*see* Fig. 16). Both alternatives are feasible, although the first may seem the more probable and is here the preferred interpretation.

Such problems could perhaps be resolved most effectively by a combination of side-scan sonar and shallow-penetration high-resolution profiling. New Zealand Oceanographic Institute possesses side-scan sonar equipment, but its depth capacity (limited by cable length) is inadequate for use on Chatham Rise. The length of armoured multi-channel cable required to rectify this would be costly. The Institute has no high-resolution profiler, but at least one such profiling system, capable of operating in water depths down to 500 m is produced commercially. Again, this is a very expensive item which is unlikely to become available in New Zealand within the foreseeable future.

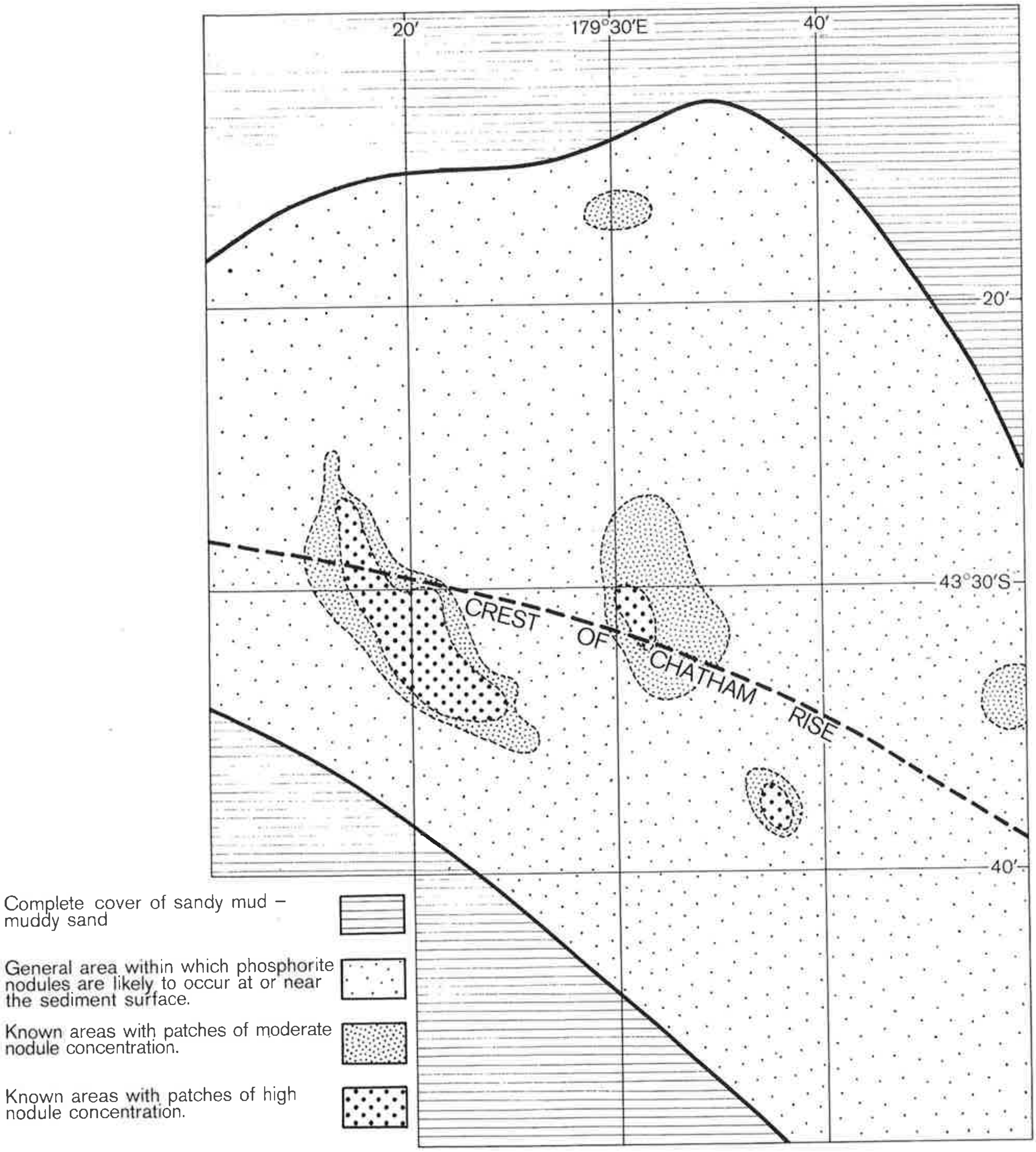


Fig. 15. Map showing areas in which some of the more promising phosphorite deposits on Chatham Rise have been found, both by coring and underwater photography. Compare with the JBL Minerals' interpretation of the phosphorite distribution in Fig. 1.

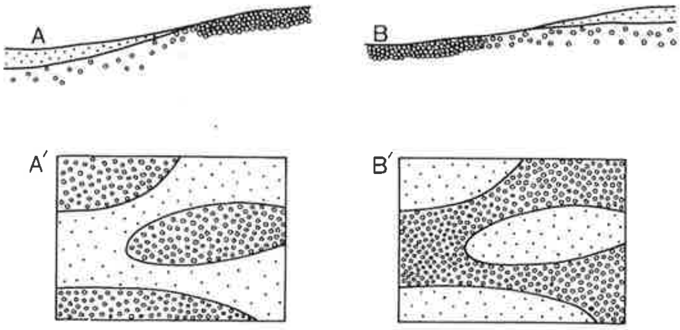


Fig. 16. Alternative interpretations of the relative distributions of phosphorite and the overlying muddy sands - sandy muds.
A–A′ : phosphorite concentrated by winnowing on slight elevations.
B–B′ : phosphorite concentrated by winnowing and perhaps lateral transportation into shallow depressions.

ACKNOWLEDGMENTS

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J.S. Harris, J.S. Mitchell and R.F. Grasse completed the sediment analyses, and helped to prepare the data for publication.

J.J. Whalan and M.J. Lankow photographed the cores.

The maps and diagrams were drawn by T.J. Savage.

REFERENCE

CULLEN, D.J.; SINGLETON, R.J. 1977: The distribution of phosphorite deposits on central Chatham Rise, east of New Zealand. 1. Surface distribution from underwater photographs. *NZOI oceanogr. Fld Rep. 10* : 24 pp.

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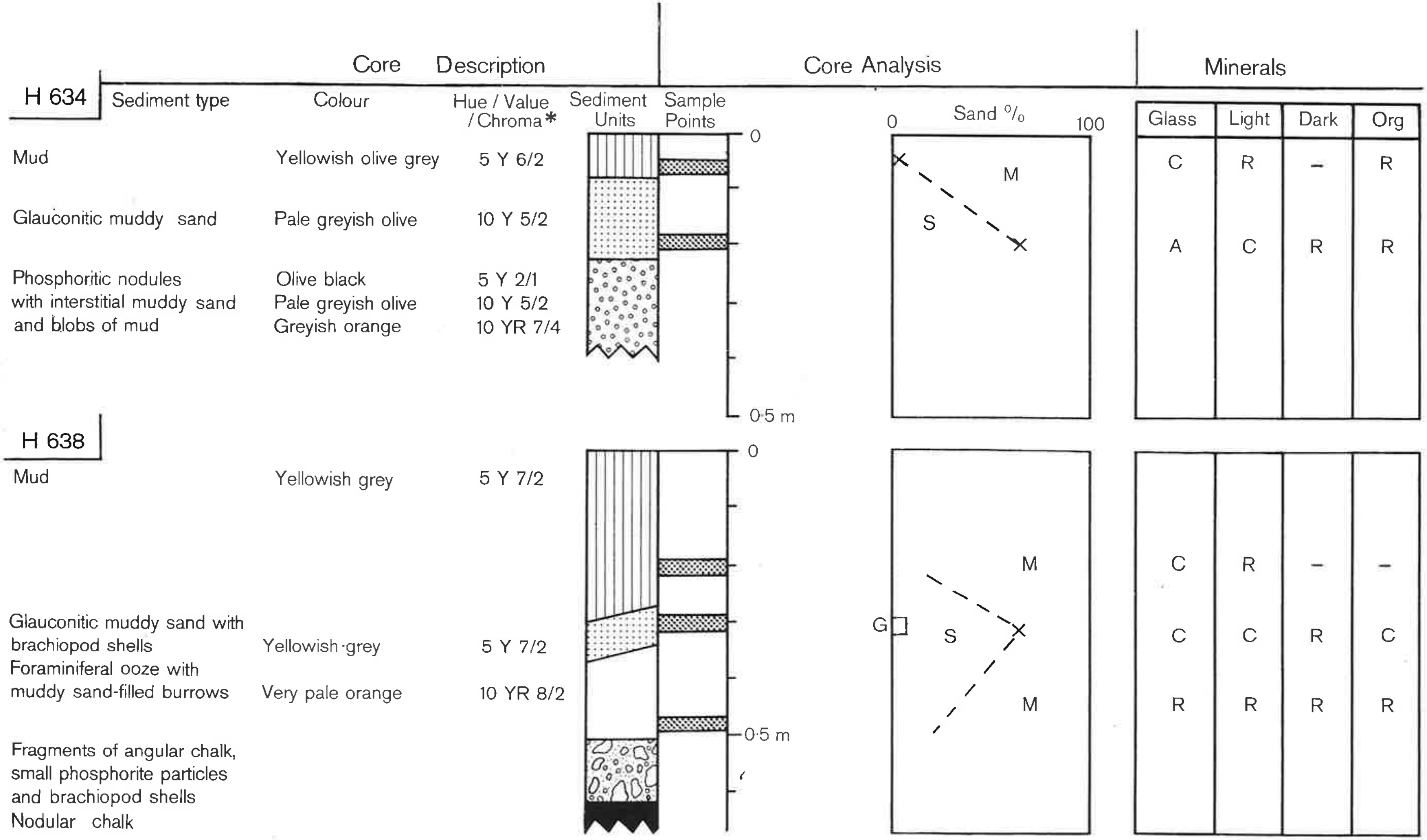
APPENDIX I

Schematic representation of piston-core lithologies from central Chatham Rise.



H 634

Sediment type	Colour	Hue / Value / Chroma*
Mud	Yellowish olive grey	5 Y 6/2
Glauconitic muddy sand	Pale greyish olive	10 Y 5/2
Phosphoritic nodules with interstitial muddy sand and blobs of mud	Olive black Pale greyish olive Greyish orange	5 Y 2/1 10 Y 5/2 10 YR 7/4

Glass	Light	Dark	Org
C	R	–	R
A	C	R	R

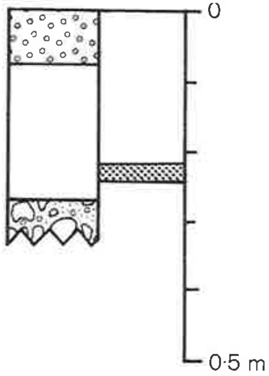
H 638

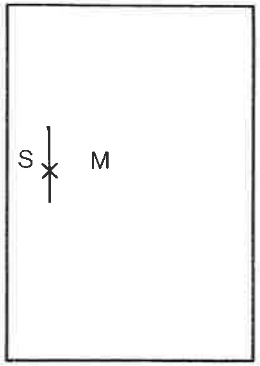
Sediment type	Colour	Hue / Value / Chroma*
Mud	Yellowish grey	5 Y 7/2
Glauconitic muddy sand with brachiopod shells	Yellowish-grey	5 Y 7/2
Foraminiferal ooze with muddy sand-filled burrows	Very pale orange	10 YR 8/2
Fragments of angular chalk, small phosphorite particles and brachiopod shells		
Nodular chalk		

Glass	Light	Dark	Org
C	R	–	–
C	C	R	C
R	R	R	R

H 642

Bored, indurated foraminiferal ooze with phosphorite nodules on surface		
Soft foraminiferal ooze with burrows	Very pale orange	10 YR 8/2
Phosphorite nodules and chalk fragments		

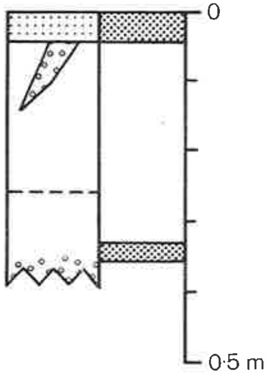


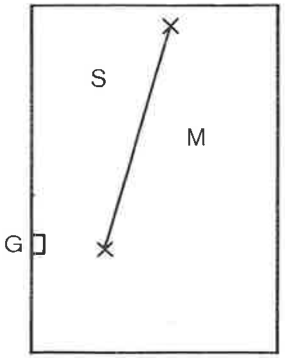


–	–	–	R

H 643

Glauconitic muddy sand	Light olive grey	5 Y 5/2
Firm foraminiferal ooze "Streak" with phosphorite particles	Greyish orange	10 YR 7/4
Foraminiferal ooze Small phosphorite particles at base	Very pale orange	10 YR 8/2





A	R	–	R
R	R	–	–

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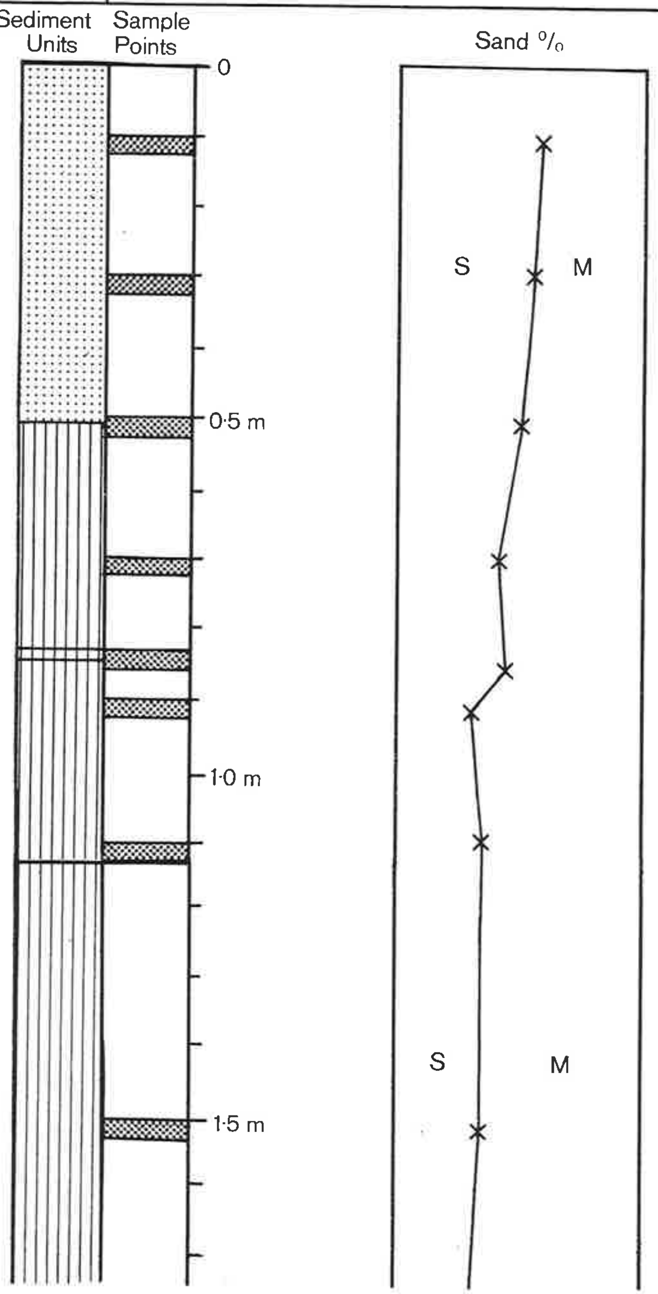
* Goddard, E.N. *et al.* 1975. "Rock-Color Chart".
The Geological Society of America, Boulder, Colorado.

H 645

Core Description

Sediment type	Colour	Hue / Value / Chroma
Glauconitic muddy sand	Light olive grey	5 Y 5/2
Glauconitic sandy mud	Yellowish grey	5 Y 7/2
Dark layer	Dark greenish grey	5 GY 4/1
Sandy mud	Yellowish grey	5 Y 7/2

Core Analysis



Minerals

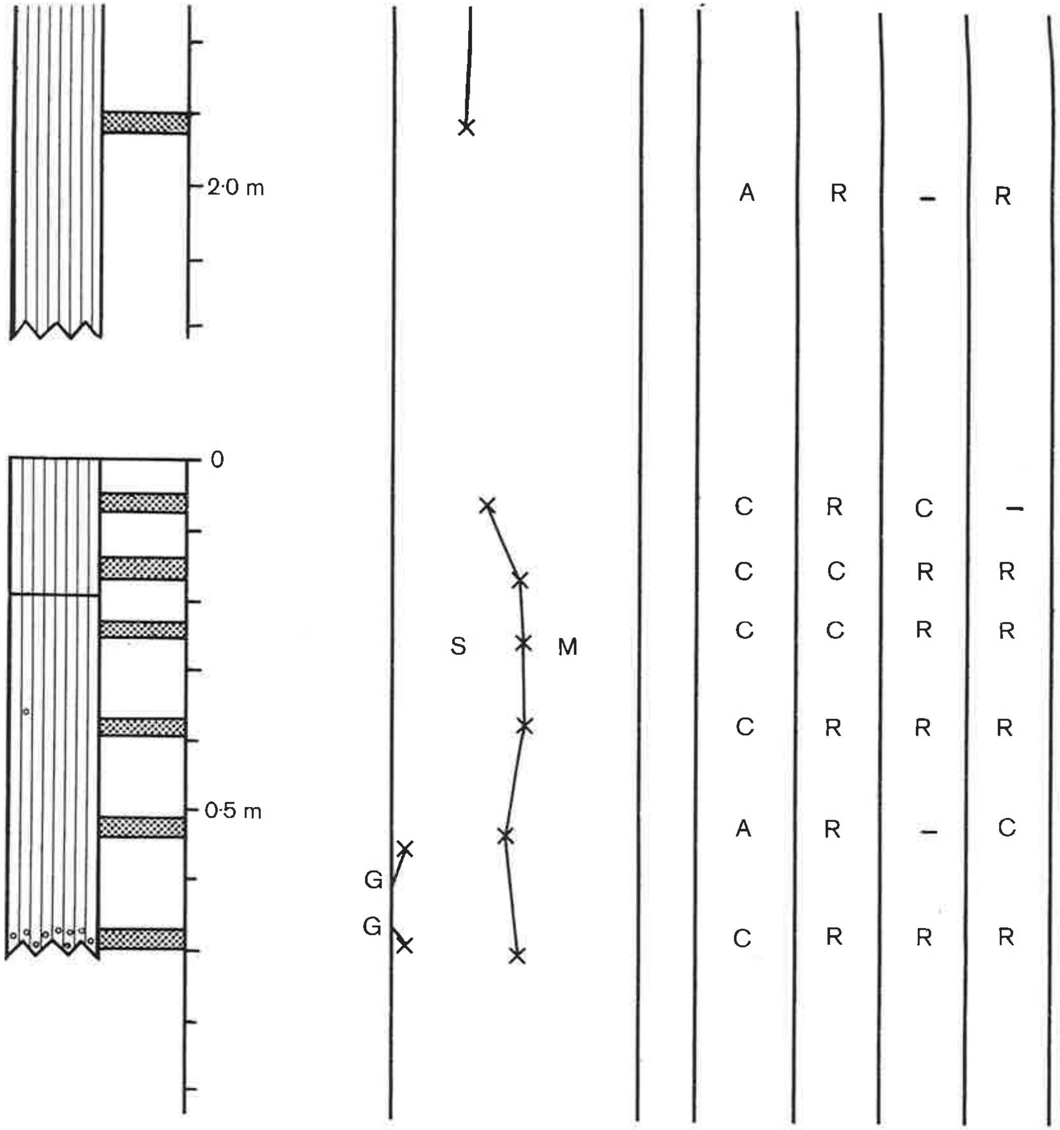
Glass	Light	Dark	Org
C	C	–	–
C	C	R	C
C	R	–	R
A	C	–	C
C	–	–	R
A	R	–	–
A	R	–	–
A	–	–	R

H 650

Sandy mud — Light olive grey — 5 Y 5/2

Sandy mud with
phosphorite nodule at 0·39 m

Streaks of foraminiferal ooze
with small phosphorite particles

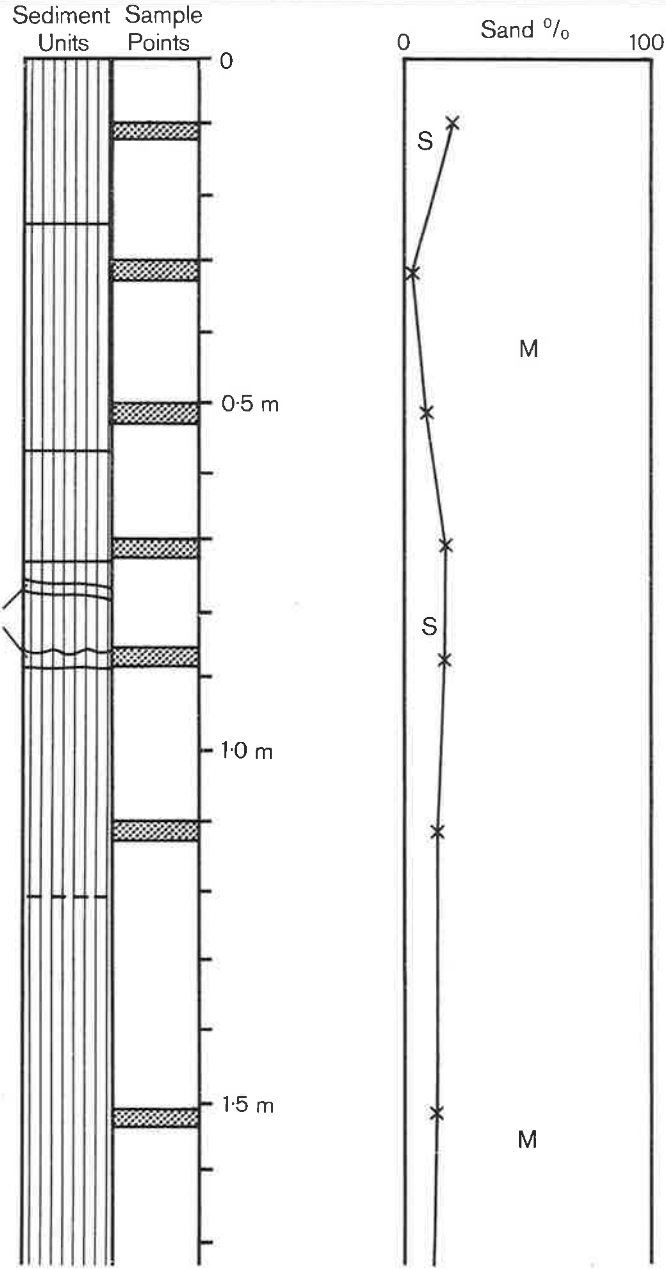


H 654

Core Description

Sediment type	Colour	Hue / Value / Chroma
Sandy mud	Greyish olive	10 Y 4/2
Mud	Light olive grey	5 Y 5/2
Sandy mud	Greyish olive	10 Y 4/2
Sandy mud with layers and lenses of darker mud...	Light olive grey Olive grey Greyish olive	5 Y 5/2 5 Y 3/2 10 Y 4/2
Sandy mud	Light olive grey	5 Y 5/2

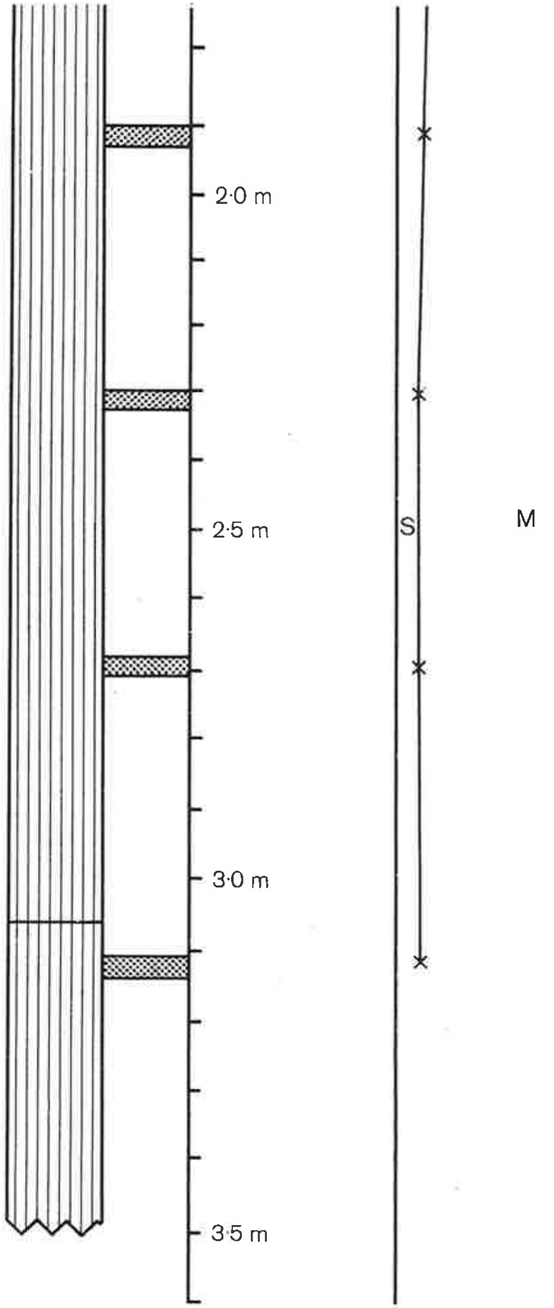
Core Analysis



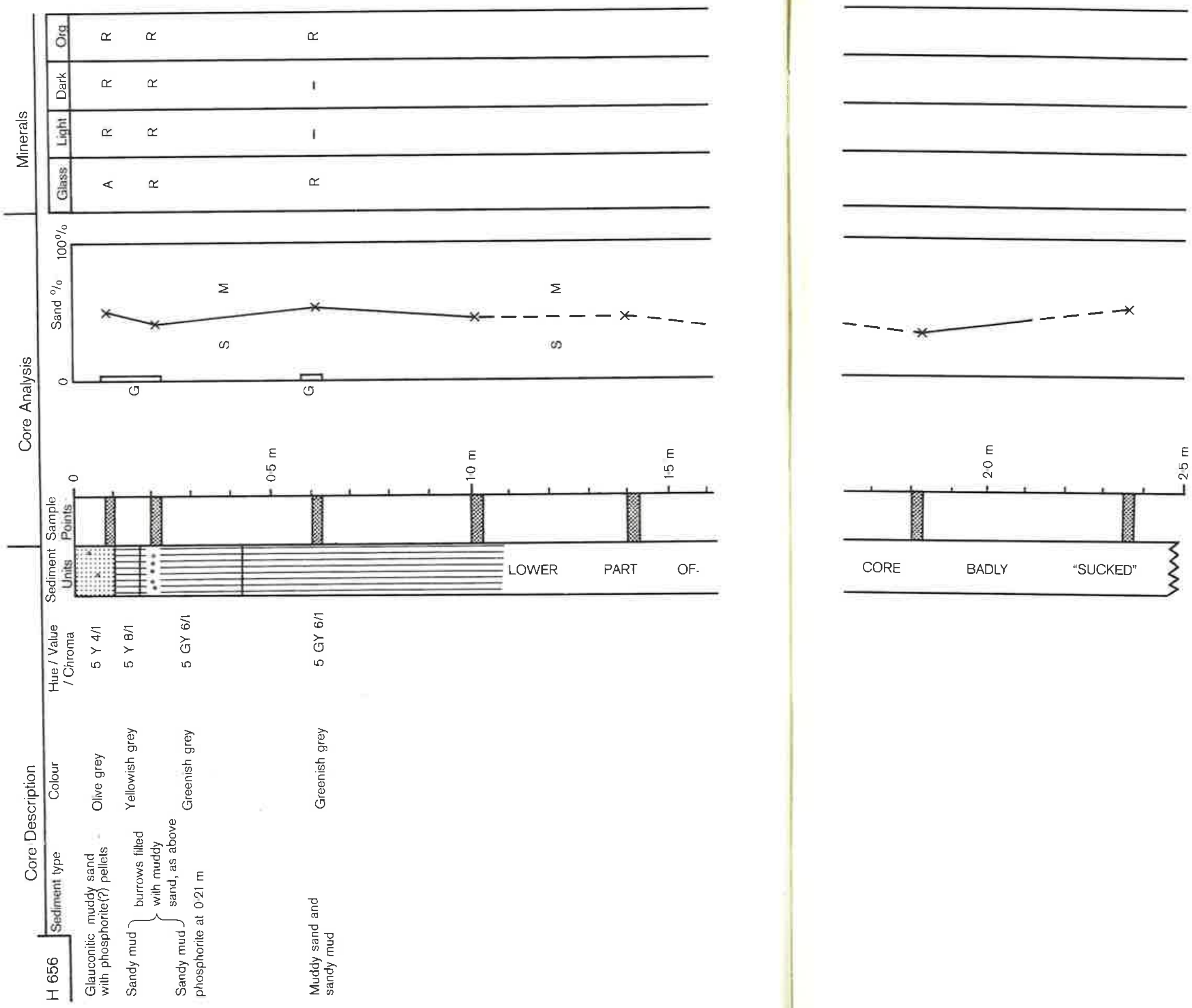
Minerals

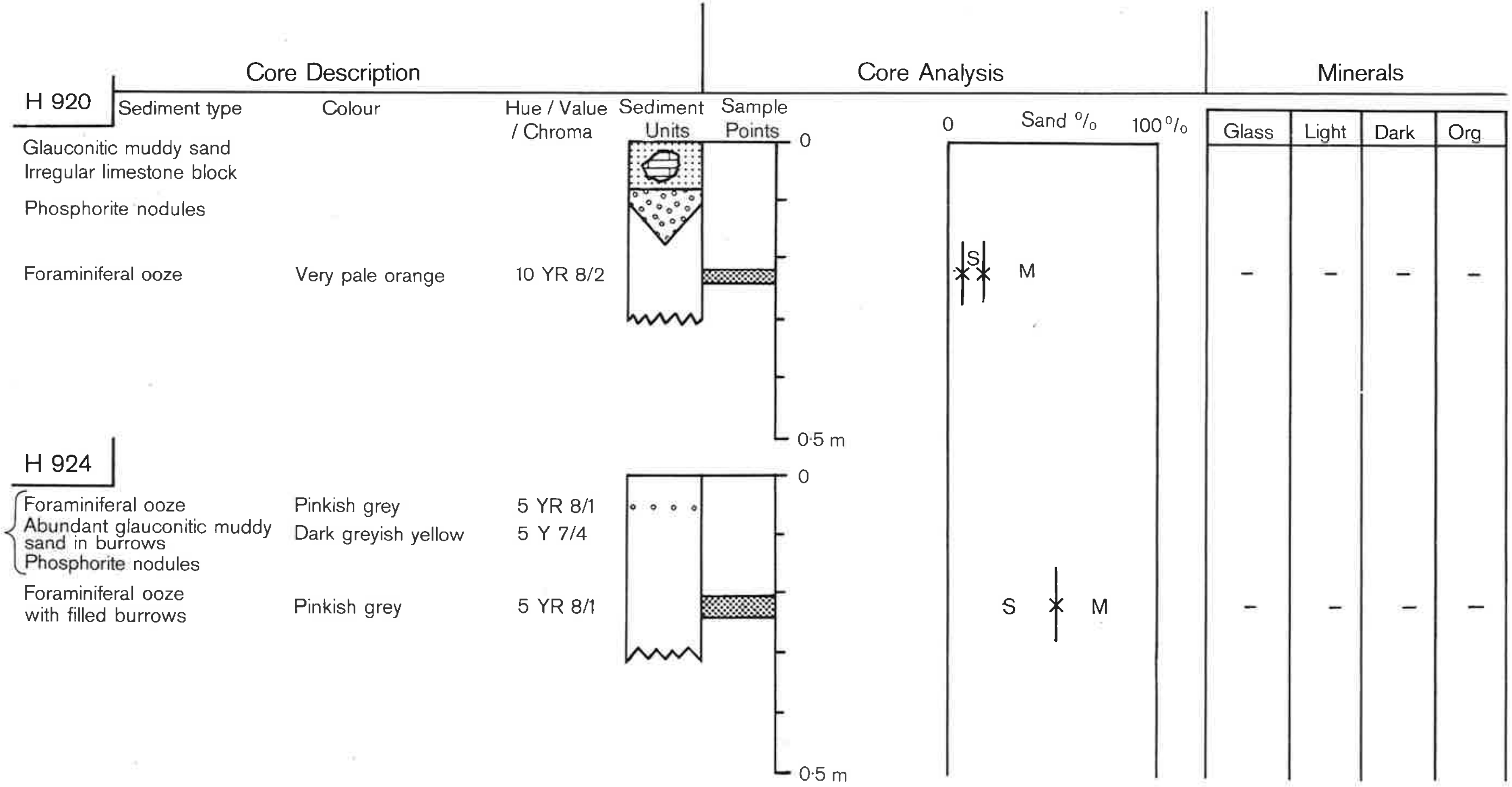
Glass	Light	Dark	Org
A	R	C	C
A	C	R	C
C	C	C	C
C	C	R	–
C	C	R	–
C	C	C	–
C	R	–	–

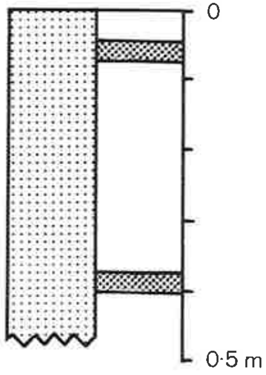
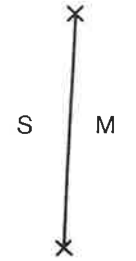
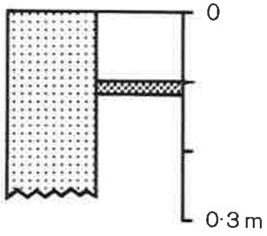
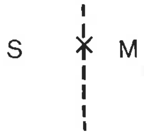
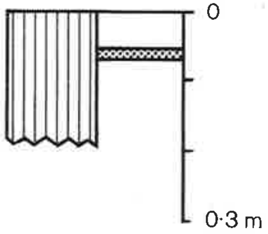
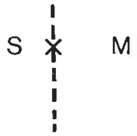
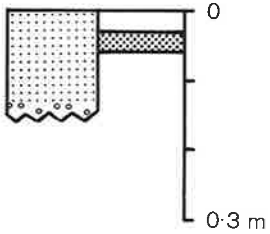
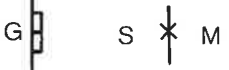
Sandy mud	Moderate olive grey	5 Y 4/2
Mottled sandy mud	Light olive grey Greyish olive	5 Y 5/2 10 Y 4/2



C	R	R	–
C	R	R	R
C	R	R	R
A	C	–	–


H 656
Core Description
Sediment type
Colour
Hue / Value / Chroma
Sediment Units
Sample Points
Core Analysis
Sand %
0
100%
Minerals
Glass
Light
Dark
Org
Glauconitic muddy sand with phosphorite(?) pellets
Olive grey
5 Y 4/1
Sandy mud
burrows filled with muddy sand, as above
Sandy mud
phosphorite at 0·21 m
Yellowish grey
5 Y 8/1
Greenish grey
5 GY 6/1
Muddy sand and sandy mud
Greenish grey
5 GY 6/1
0
0·5 m
1·0 m
1·5 m
2·0 m
2·5 m
LOWER
PART
OF
CORE
BADLY
"SUCKED"
G
G
M
S
M
S
A
R
R
R
R
R
R
R
R
R
–
–
R

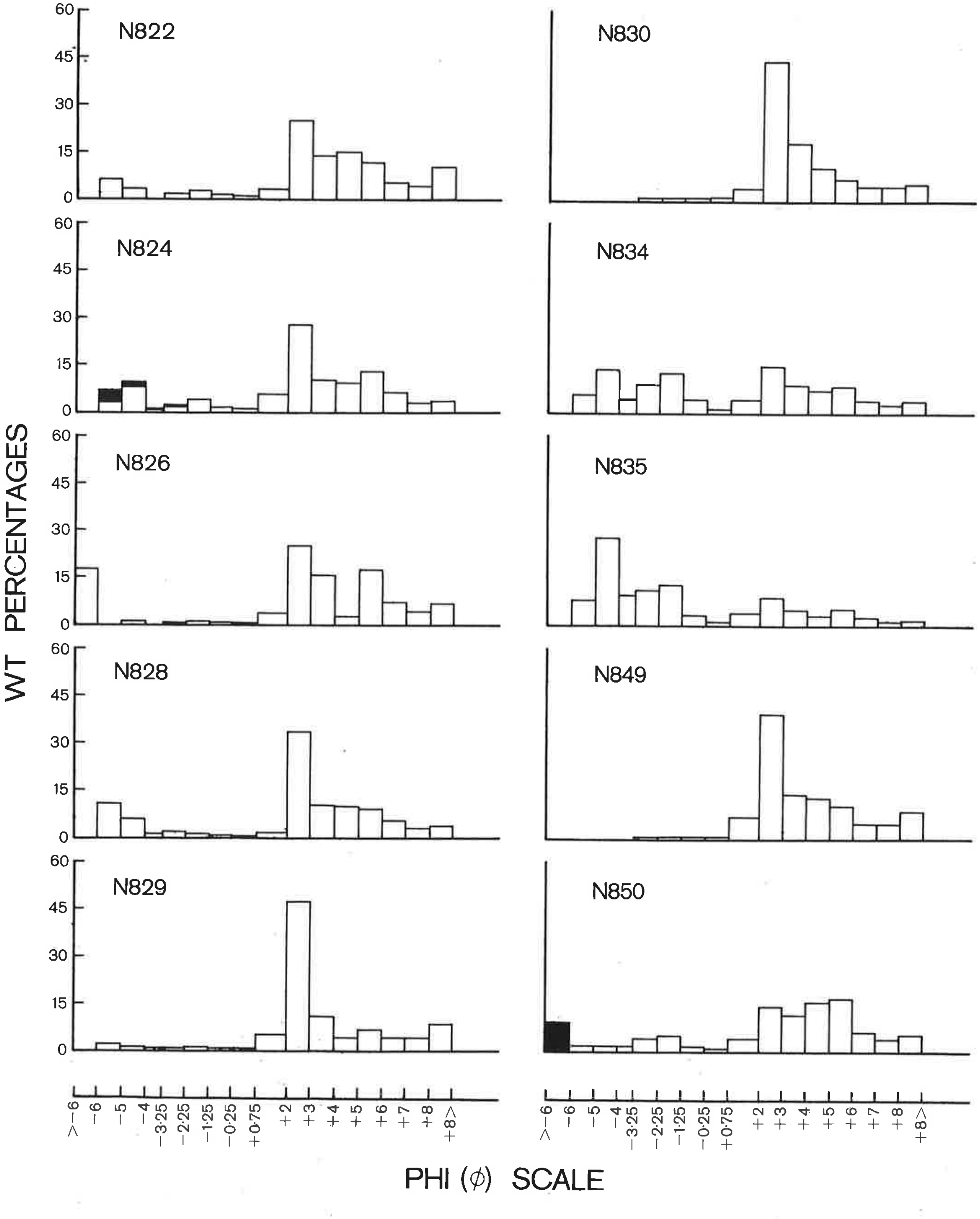

Core Description
Core Analysis
Minerals
H 920
Sediment type
Colour
Hue / Value / Chroma
Sediment Units
Sample Points
0
Sand %
100 %
Glass
Light
Dark
Org
Glauconitic muddy sand
Irregular limestone block
Phosphorite nodules
Foraminiferal ooze
Very pale orange
10 YR 8/2
S
M
–
0·5 m
H 924
Foraminiferal ooze
Abundant glauconitic muddy sand in burrows
Phosphorite nodules
Pinkish grey
5 YR 8/1
Dark greyish yellow
5 Y 7/4
Foraminiferal ooze with filled burrows
Pinkish grey
5 YR 8/1
S
M
0
0·5 m

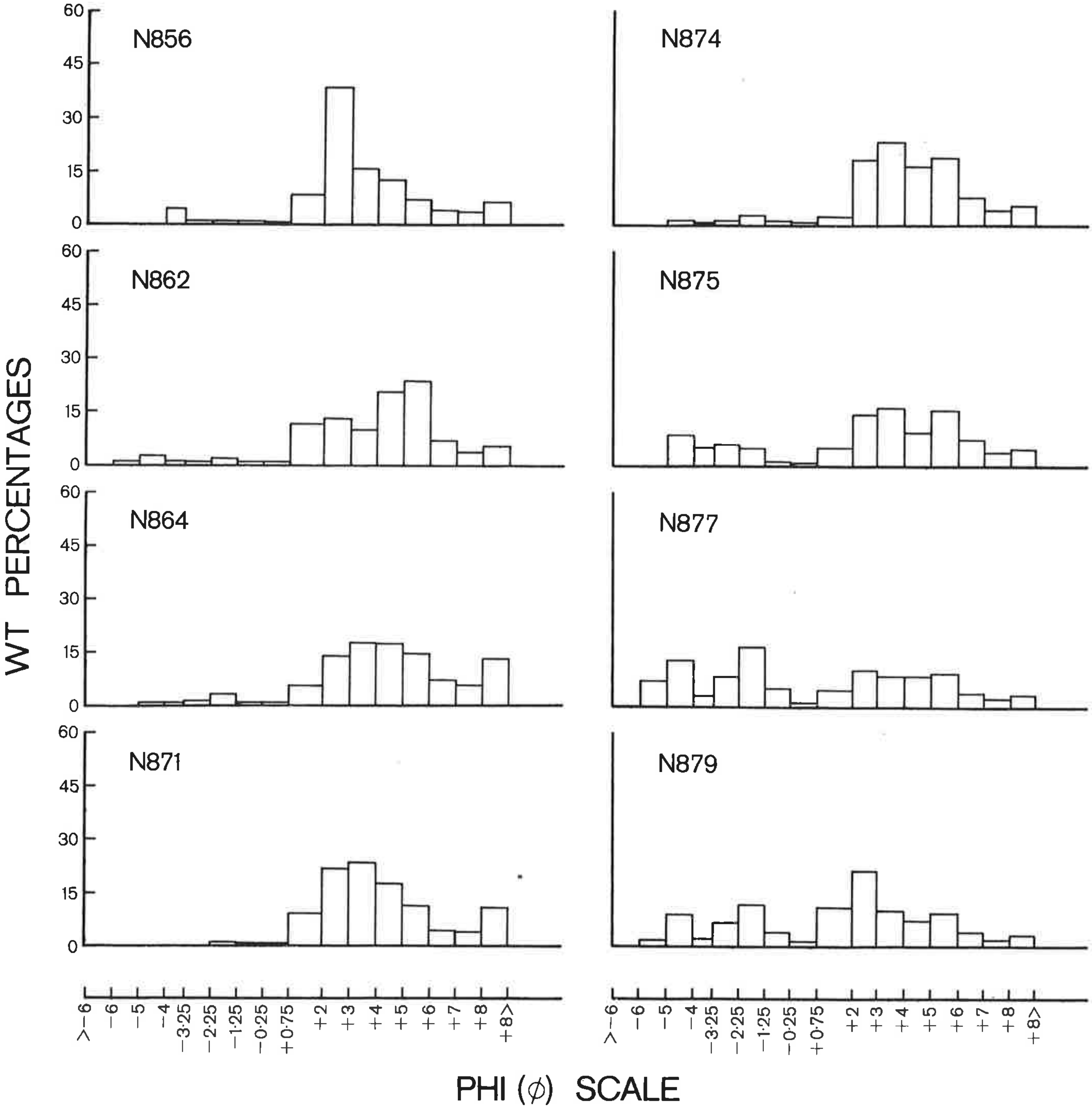
H 928	Glauconitic muddy sand	Olive grey	5 Y 5/4			C C	R R	R R	R R
H 934	Muddy sand	Yellowish grey	5 Y 7/2			A	R	R	–
H 936	Sandy mud	Yellowish grey	5 Y 7/2			A	R	R	–
H 943	Glauconitic muddy sand with phosphorite nodules at base	Dark greyish yellow	5 Y 7/4			C	R	R	R

APPENDIX II

Size frequency analyses of box cores from central Chatham Rise, presented in histogram form.

All fractions larger than +0.75 ϕ consist of phosphorite, except for glacial erratic material which is represented by solid black areas in cores N824, N850.





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