PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
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# The Geological History of the Sandettie-Fairy Bank Area, Southern North Sea

R. Kirby and E. Oele

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# The geological history of the Sandettie–Fairy Bank area, southern North Sea

By R. Kirby
*Institute of Oceanographic Sciences, Taunton, Somerset*

and E. Oele
*Netherlands Geological Survey*

[Plates 5 and 6]

Tertiary strata with a low northeasterly dip, truncated by an erosion surface with low westerly dip, form the basement in the Sandettie–Fairy Bank gap except in the northwest part of the area where a basin is cut into the Tertiary strata. This basin is filled with a sequence of late Pleistocene sands overlain by Holocene sands which form the major topographic features of the Sandettie and Fairy Banks and the low sea-floor col linking them. The surface of the banks and col are moulded into transverse ridges up to 10 m in amplitude and 200 m in wavelength. Three types of ridges are present: at the north end of the col, linear transverse ridges of irregular amplitude and wavelength occur with a flint gravel base grading up into medium sand; these ridges are fossil features of Preboreal–Subboreal age. At the south end of the col there are symmetrical sandwaves of regular amplitude and wavelength which, from geological evidence, appear to be stable. To the west of Sandettie Bank and the col there are south-facing asymmetrical sandwaves which on geological evidence, are potentially mobile and which later sedimentological investigations revealed to be moving southwards in one area.

## Introduction

The Sandettie–Fairy Bank gap is a shoal water area which straddles one of the main northbound navigation routes into the southern North Sea (figure 1). These shoals are the site of rapid spatial variations in seabed relief caused chiefly by the existence of sandwaves and therefore present problems to hydrographic surveying. In 1970 the Institute of Oceanographic Sciences, the Netherlands Rijkswaterstaat and the Netherlands Geological Survey established a programme to investigate sediment transport in the area at the request of the British and the Netherlands Navies.

A geophysical reconnaissance in 1970 using Cesco Sonia was followed by a more detailed survey with Hi-fix navigation and using the Huntec IIB Boomer, a pinger and an E.G. & G. sidescan sonar. Geophysical lines were orientated chiefly NE–SW parallel to the Hi-fix lanes and perpendicular to the sandwave crests (figure 2). The geophysics provided a basis for a vibrocore sampling programme. Limited drilling in 1970, 1971 and the major investigation in 1972, was carried out using the Geodoff vibrocorer to obtain disturbed samples down to 10 m below the seabed, and the Zenkovich and U.C.S./I.G.S. vibrocorer to obtain undisturbed samples up to 5 m in length.

These detailed geophysical and geological investigations were undertaken to determine the areal extent of the various seabed features and in the search for evidence which would differentiate any stable and potentially mobile features and demonstrate the ages and relationships of the various sediment bodies. Eighty-six vibrocore samples were obtained and analyses of grain-

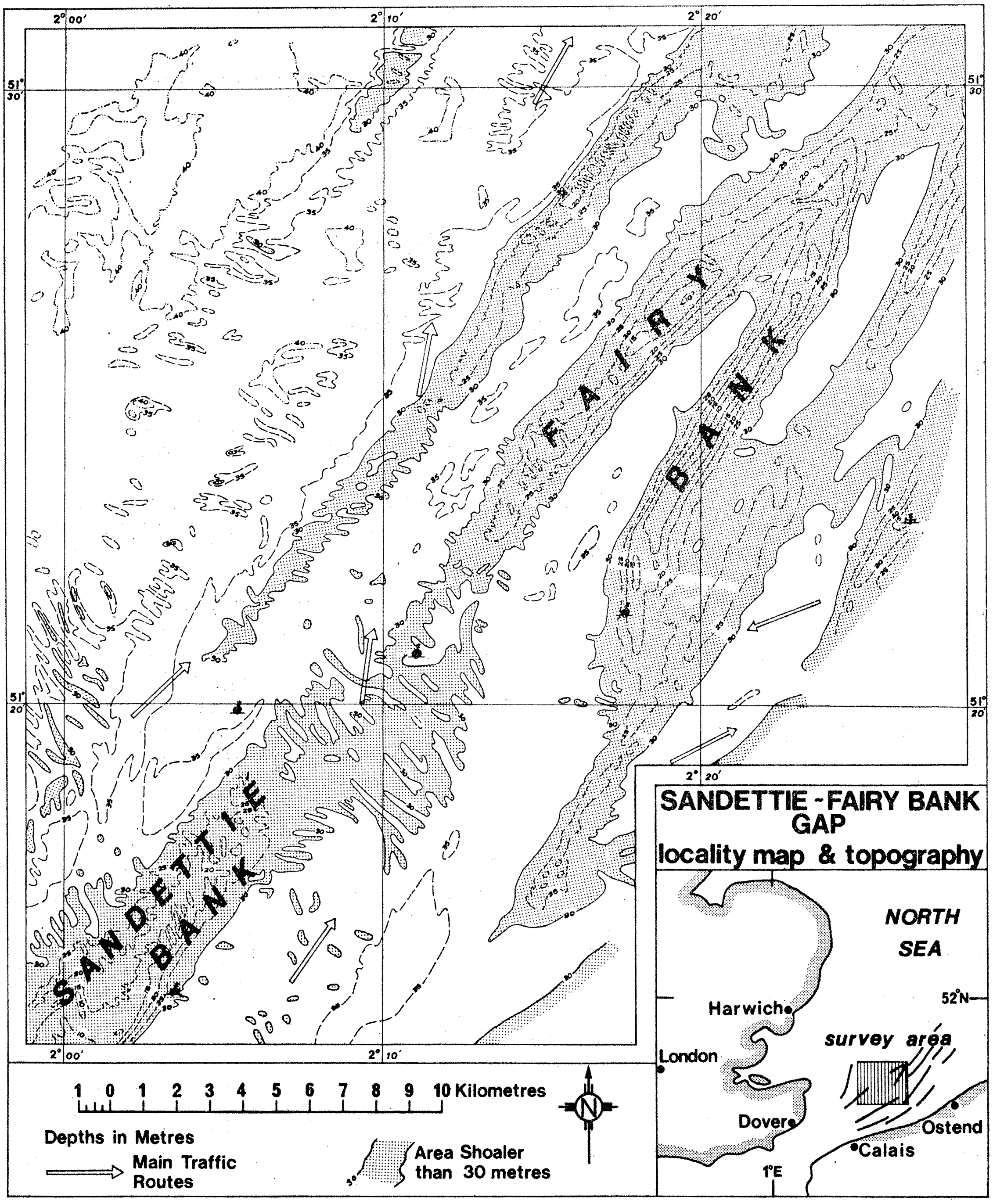


Figure 1. Bathymetric contour map of the Sandettie–Fairy Bank gap (taken from British Admiralty surveys).

size, carbonate content, gravel lithology, macrofauna, microfauna, pollen and radiocarbon age have been undertaken. This geological information has guided the later sedimentological experiments.

## Geophysical interpretation

The structure of the area is simple, consisting of Tertiary sediments overlain in part by various Quaternary deposits. The Tertiary sediments are locally folded and faulted but otherwise have a regional northeast dip of $\frac{1}{4}$°. In the east the top of the Tertiary is a level erosion surface at −34 to −35 m L.A.T. while in the northwest segment an asymmetrical basin with its steep slope to the southeast is cut into the Tertiary strata (figure 3). Similar smaller enclosed basins occur beneath the eastern flank of Sandettie Bank and near the north end of Fairy Bank.

The sediments infilling the basin outcrop at the sea-bed in many areas. Near the edge of the basin and beneath the col these sediments reach 13–14 m in thickness. They show level and inclined bedding with occasional local unconformities and are consequently of Quaternary age (figure 4). Westwards, the basin sediments thin progressively to a feather edge.

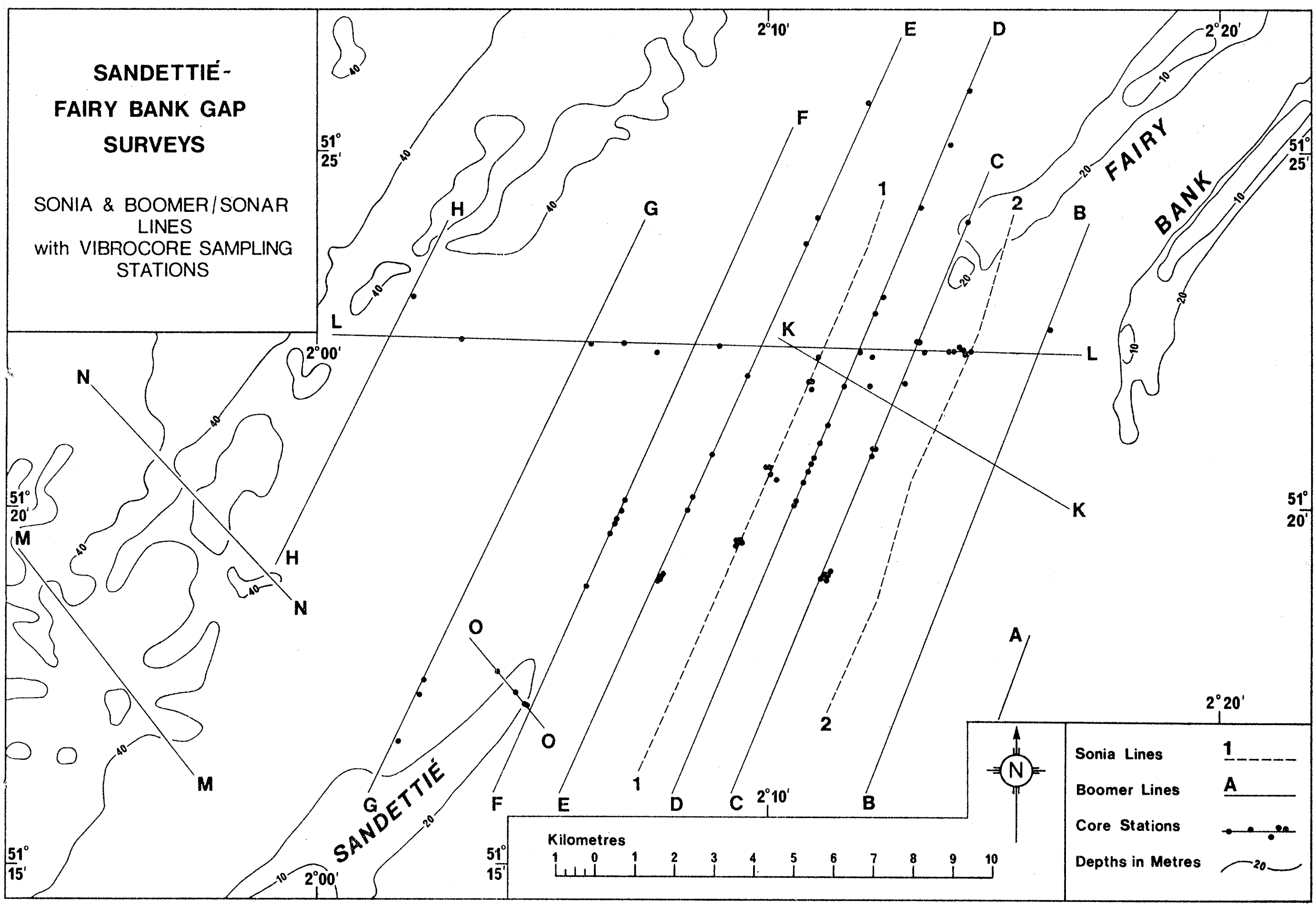


FIGURE 2. Geophysical lines and vibrocore sample positions in the Sandettie–Fairy Bank gap.

The thickness of sediments overlying the Tertiary strata and the Quaternary basin-infill is very variable. On Sandettie Bank itself the overlying deposits reach 16 m in thickness. A low sea-floor col links Sandettie Bank to Fairy Bank and a subsidiary bank extends southwestwards into the area from the north to either side of these banks (figure 1). To either side of these features Tertiary strata are exposed at the sea-bed or lie beneath a thin lag gravel veneer.

Sidescan sonar shows that the major part of the sea-bed throughout the area is covered by sand which is moulded into elongate sandwaves and a smaller superimposed pattern of sand dunes (figure 5). The sandwaves have sinuous crests with a general WNW–ESE orientation.




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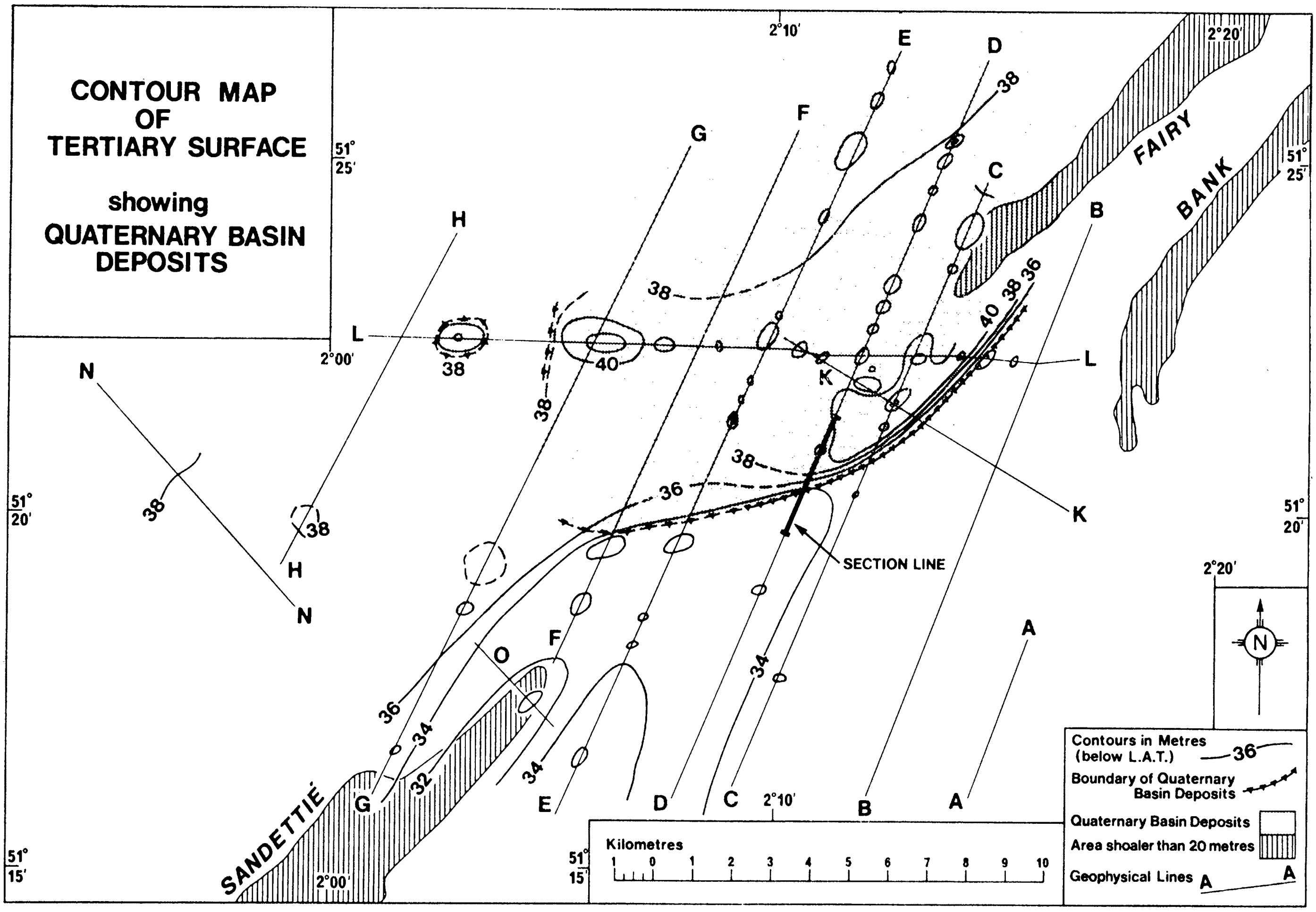


FIGURE 3. Map of contours of the Tertiary surface and position of the Quaternary basin.

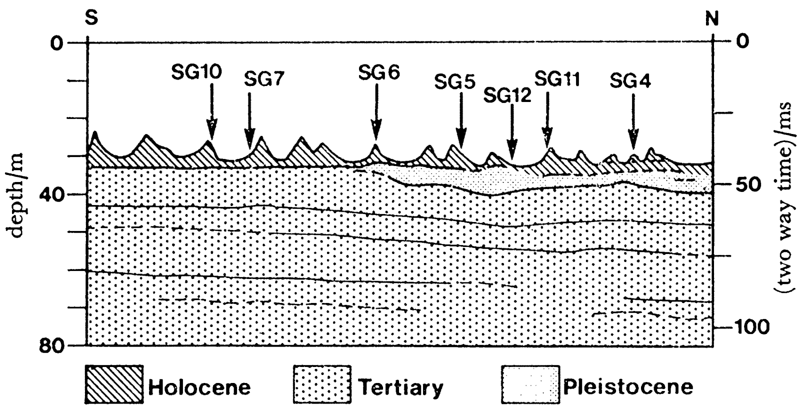


FIGURE 4. Geological section across the southeast edge of the Quaternary basin (line of section is indicated on figure 3). Horizontal:vertical scale = 25:1. ↓, drilling positions.

To the east of the col occasional isolated sandwaves, some of which are asymmetrical with a steep slope facing northeast, rest on the Tertiary erosion surface.

Sandwaves to the west of the col, however, together with those covering the subsidiary bank paralleling the col forming isolated features on the Tertiary erosion surface and on the west side of Sandettie Bank, are all asymmetrical with a steep slope facing towards the south.

The sedimentological situation on the col linking Sandettie and Fairy Banks is more complex. Northwards from Sandettie Bank along the col the surface is formed by a series of regular symmetrical sandwaves of 10 m amplitude and 250 m wavelength (figure 6, plate 5). At the

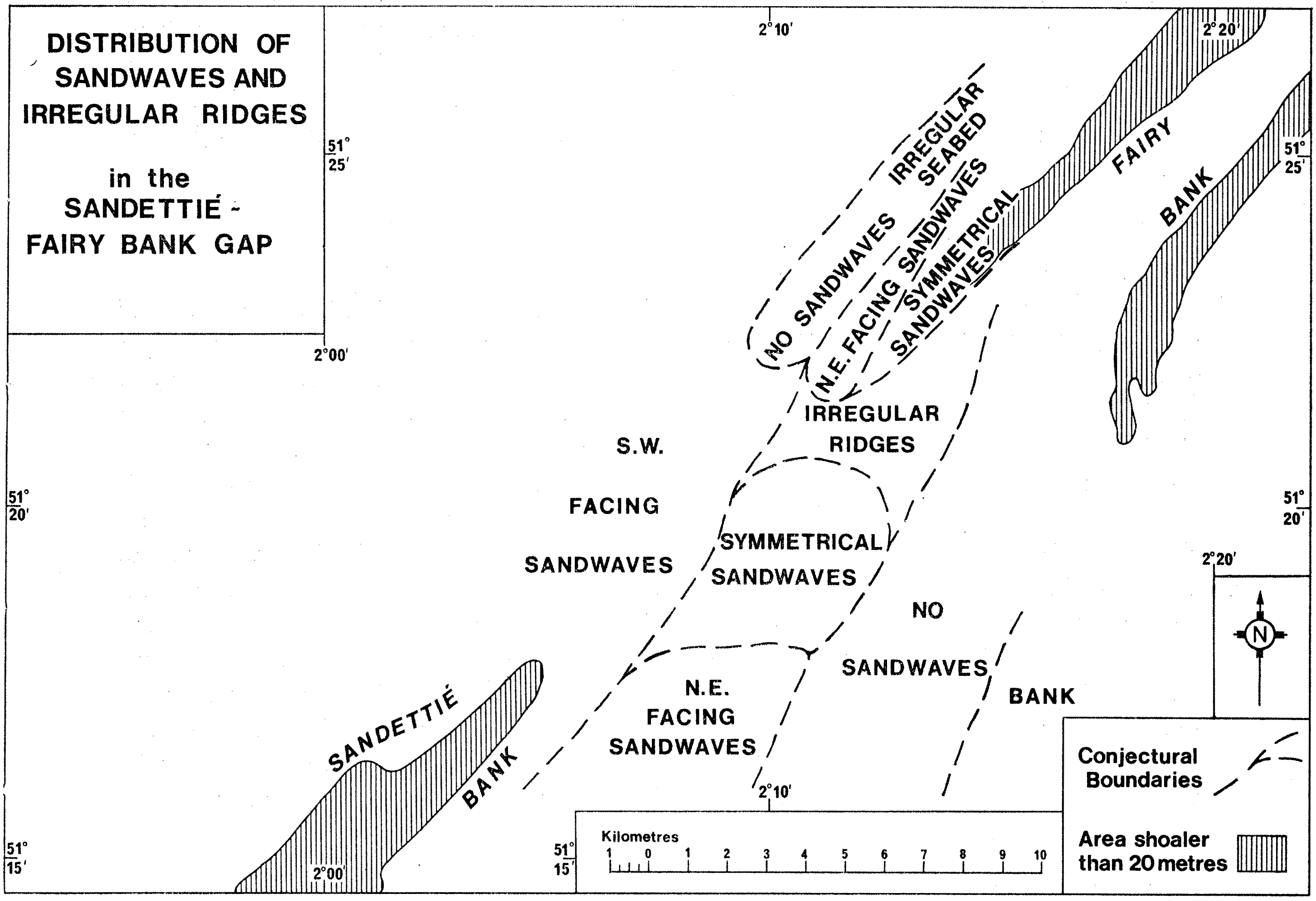


FIGURE 5. Distribution of sandwaves and irregular ridges in the Sandettie–Fairy Bank gap.

junction between these features and the Quaternary basin sediments a marked change in the surface features occurs (figure 4). The surface of the basin deposits shows smaller features (2–4 m) of less regular amplitude and wavelength, here termed ‘irregular ridges’, though the WNW–ESE trend of the ridges is maintained (figure 7, plate 5). Northward along the col, the character of the sea-bed features changes again as the irregular ridges are overlain by sands of the western limb of Fairy Bank.



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## Geological interpretation

### (a) Tertiary sediments

Tertiary sediments, chiefly grey clays, have been sampled at 5–6 localities. The fauna of the clays is pyritized but in two instances examination of the macrofauna revealed an Eocene faunal assemblage. Pollen analysis also indicated an early Tertiary age.

### (b) Quaternary sediments

Three 10 m cores taken with the Geodoff corer reached the basal part of the basin fill. In one of these a sedimentary succession showing early Holocene deposits with a basal peat layer was underlain by a fluviatile layer of Weichselian age resting on cold-water marine Eemian sediments at the base. The sediments chiefly consist of medium-coarse sands with, locally, finer-grained material. Since pollen is rarely found in such sediments, precise dating has depended upon faunal analysis alone.

#### (i) *Eemian*

These deposits reach 9 m in thickness and extend across the whole of the outcrop of the Quaternary basin sediments. Microfauna samples from the cores included large numbers of the foraminifer *Bucella frigida*, indicating the Eemian age of the deposits. Other information supports this evidence for the infilling of the basin during the last interglacial. Paepe (1971) and Paepe & Vanhoorne (1972) describe similar closed asymmetrical depressions cut into the Tertiary and infilled by Eemian sediments in Belgium. The origin of the basins is not known but their morphology would appear to exclude a fluviatile origin. Evidence from the Dutch continental shelf shows that the southern margin of areas inundated during pre-Eemian interglacials are situated much farther north (Oele 1971). In addition, the Rhine has been shown to have flowed northward from the Dutch coast during pre-Eemian interglacials indicating that the Strait of Dover was still closed. Such a barrier would also prevent any marine inundation from the south. The sediments contain a cold water bivalve fauna which includes *Astarte montagui*, *Leda minuta*, *Macoma calcarea* and large and thick-walled specimens of *Hiatella arctica* and *Modiolus modiolus*. In other cores reaching the Eemian, the macrofauna shows less evidence of a cold climate. An extensive marine microfauna was identified, in one of the cores 44 species of ostracods were present, five of which are only known to occur today off Scandinavia. This may support the macrofaunal evidence for a cold climate.

#### (ii) *Weichselian*

At some sites the Eemian was locally reworked during the Weichselian. Weichselian deposits are up to 4 m in thickness and form an incomplete cover over the underlying Eemian deposits. The Weichselian succession found beneath the Preboreal peat consists of a clay, pollen-dated as late Weichselian, followed by reworked sands containing a freshwater molluscan fauna. An early Weichselian clay was found in another core.

#### (iii) *Holocene deposits in relation to sediment mobility*

The Tertiary, Eemian and Weichselian deposits are overlain by Holocene sediments which form the upper part of the Quaternary basin fill, the major sand banks and the sandwaves. The basal layer of the Holocene is a transgressive peat which has been sampled *in situ* on top of the Weichselian basin sediments. Loose blocks of peat sampled at two stations $2\frac{1}{2}$ miles apart are believed to be from the same horizon and have been radiocarbon dated at $9374 \pm 90$ B.P. and $9949 \pm 125$ B.P. The Holocene basin sediments are graded but only in the area of the col between the Sandettie and Fairy Banks are they known to form ridges (Kirby & Kelland 1972). The geology of the Holocene deposits is discussed in terms of the major types of bedform since this was the information required for later sedimentological research.

(1) *Irregular ridges*. Profiles of four to five vibrocore samples were obtained from each of two irregular ridges (figure 8, plate 6). In all cases the cores have a well-developed graded succession from flint and shell gravel at the base through shelly quartz sands to a thin clay cap. The clay cap is an artefact of drilling. Since the thickness of the unit was approximately the same on the crest and in the trough of the feature, it appears that the succession is a drape over an originally irregular sea-bed. Cores showing a similar graded succession have been obtained at 16 other sites in the area of outcrop of the Quaternary basin sediments which could not be located relative to the irregular ridges. Similar successions have not been recorded on the Dutch continental shelf or from other areas investigated by I.O.S., Taunton.

The cores are almost invariably grey in colour due to the presence of a small proportion of clay. Grain-size analysis shows that the grading occurs both in the skeletal carbonate and in the inorganic sand fraction (see table 1).

Table 1. Sample SG4

| | mean grain size in $\phi$ units* | | |
|---|---|---|---|
| depth/cm | untreated sample | insoluble residue | size |
| 30–40 | 1.7 | 2.0 | medium sand |
| 130–140 | 1.2 | 1.7 | medium sand |
| 230–240 | 1.2 | 1.7 | medium sand |
| 330–340 | 0.2 | 0.5 | coarse sand |

* $\phi = -\log_2 \{\text{diameter/mm}\}$.

Examination of the molluscan fauna of five cores from the area of outcrop of the Quaternary basin sediments, including three showing good grading, showed the universal presence of the bivalve *Angulus pygmeus* which identifies the ridges as being of Holocene age. The graded and other Holocene basin sediments also contain a greater variety of mollusc species than the surrounding sandwave sediments. Variations in the faunal assemblages at different levels reveals a decreasing abundance of the gastropods *Gibbula tumida*, *Gibbula cinararia*, *Epitonium clathraculus*, *Nassarius incrassatus* and various species of *Odostomia* and the bivalves *Venerupis rhomboides*, *Divaricella divaricata*, *Lepton nitidum* and *Lepton squamosum* from the base upwards. G. Spaink (Netherlands Geological Survey, personal communication) believes these molluscs to be particularly indicative of the fauna of the English Channel and thus to indicate a decreasing influence of Channel sediments in the cores. Fragments of large adult *Modiolus modiolus* and *Hiatella arctica* valves occur in the lower parts of the cores. Adult individuals of these bivalves appear to attain progressively larger size with decreasing water temperature. One brackish-water gastropod, *Hydrobia ulvae*, is occasionally present in the graded sediments.

The microfauna of the cores was also examined. Ostracods and foraminifers were present in much of the sand fraction. Cores from the graded irregular ridges had a moderate to abundant quantity of microfauna in contrast to the cores from the sandwave areas in which a microfauna was generally sparse or absent. There is also a large variety of foraminifer and ostracod species in the graded sediments. Ostracod samples from the graded sediments all have more than 20 species and, in one case, 37 different species were isolated in one core.

The ostracod species of the graded sediments include both phytal and benthonic, littoral and sublittoral, in addition to arctic and brackish groups. The shallow phytal species are a large group and include *Aurila convexa*, *Hemicythere villosa*, *Microcytherura fulva* and also eight species of thin-walled ostracods. The latter are all members of the Paradoxostomatidae and include *Paradoxostoma abbreviatum*, *P. normani*, *P. variabile* and *Schlerochilus contortus*. A group of five shallow benthonic species are dominantly present in the graded sediments (*Leptocythere confusa*, *L. ?macallana*, *L. porcellanea*, *Semicytherurua cornuta*, *S. sella*).

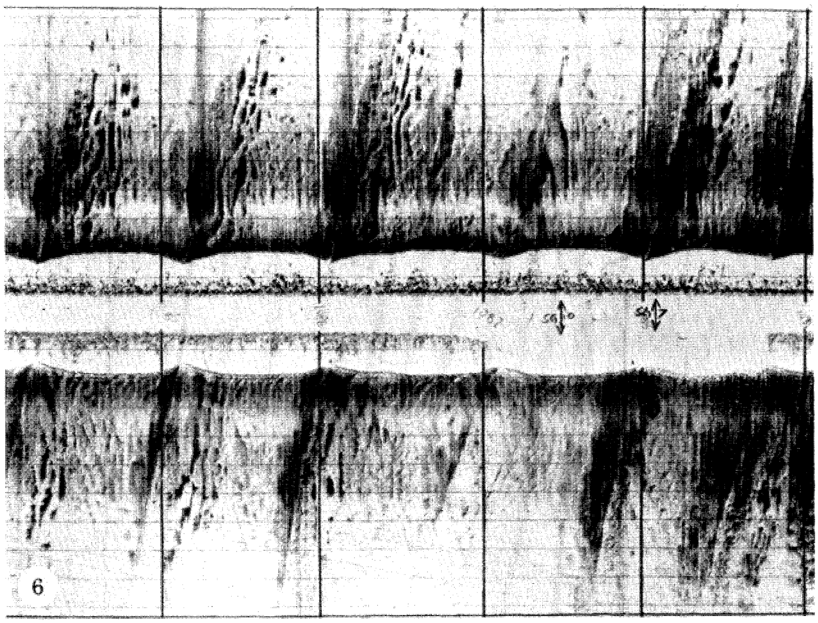
Fourteen species of 'deep' water benthonic ostracods, certain of which have been found on stable sediment from a few fathoms downward, occur in all the cores examined. Four of these species – *Elofsonella concinna*, *Finmarchinella angulata*, *F. finmarchica* and *Robertsonites tuberculata* – are not known to live in British waters today and all are boreal forms found in Scandinavian waters and northwards. These four species are dominantly found in the graded sediments, but bearing in mind the uncertainties of the ecological history and the scarce knowledge of the distribution of these ostracods today it is not possible to infer directly that they are remnants of a colder water fauna. However, *Hemicytherura clathrata*, although of doubtful ecological niche, has also been found living at shallow depths from Scandinavia and is dominantly present in the graded sediments.

Five brackish species confined in life to salinities less than 25 % have been isolated. They occur in small numbers predominantly in the graded and Weichselian sediments and are apparently introduced species.

Pollen is present in the graded sediments which could not have been derived from the underlying Pleistocene sediments. The pollen occurs in thin clay concentrates at the top of the graded cores and varies in date from Preboreal, Zone I, to Boreal, IIa, and Atlantic or Subboreal, Zone III or IV (zones and sub-zones used by the Netherlands Geological Survey).

The individual items of evidence are tenuous in themselves but each points to the graded irregular ridges being both stable and old. The graded sediments forming the upper part of the Quaternary Basin deposits and in the irregular ridges were deposited in a shallow littoral to sublittoral environment in relatively stable sediment where benthonic species could live without great danger of burial by mobile sediment. Houbolt (1968) believes that large quantities of sand would be available at this time however. There is speculative evidence for a colder climate. Palaeogeographical reconstructions of the eastern English Channel and southern North Sea according to Pratje (1931), Valentin (1957), Jelgersma (1961), Brinkman (1966) and de Jong (1967) suggest that such conditions would exist in the area during the Preboreal when the landbridge between Britain and France was breached.

The graded succession in the irregular ridges indicates a decrease in energy conditions at the bed during the period of deposition. This decrease may be associated with the slow regional rise in sea-level during the Flandrian. The ridges arose *in situ* by processes unlike those believed to be responsible for the creation of asymmetrical sandwaves since they have not been reworked or transported across the seabed. Additional evidence for their stability is found in the presence of fragile species of microfauna and the progressive decrease in Channel faunal influences up the cores. This, together with the range of pollen dates, may support the inferred slow development of the features.



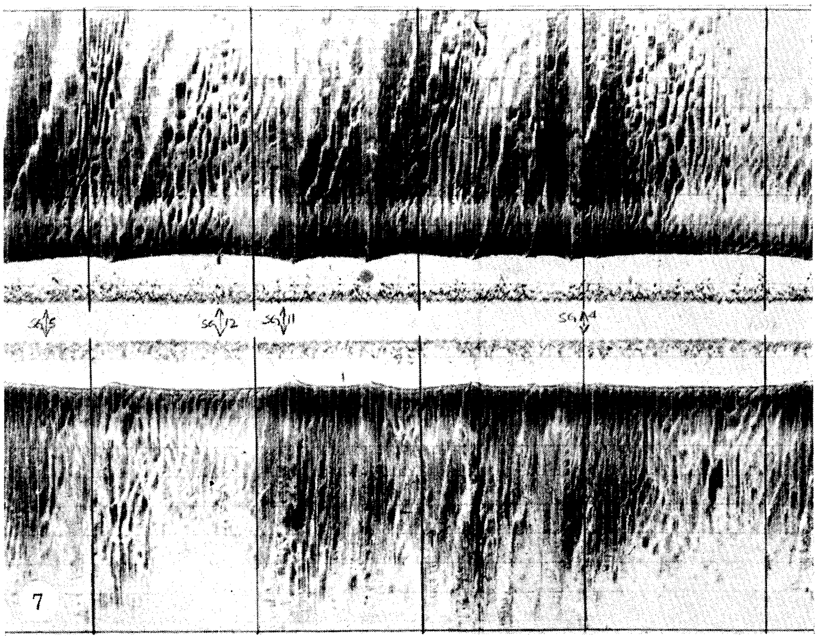


FIGURE 6. Side scan sonar record of symmetrical sandwaves on the col between the Sandettie and Fairy Banks.
FIGURE 7. Side scan sonar record of irregular ridges on the col between the Sandettie and Fairy Banks.

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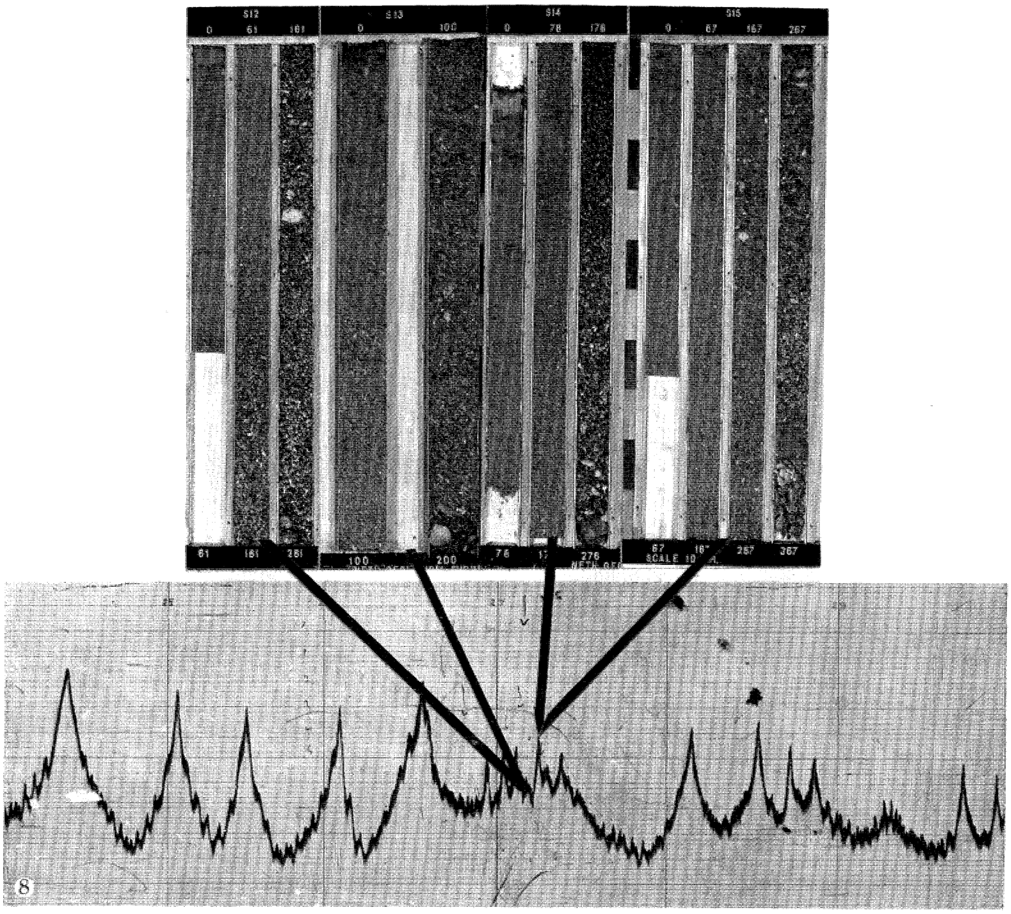

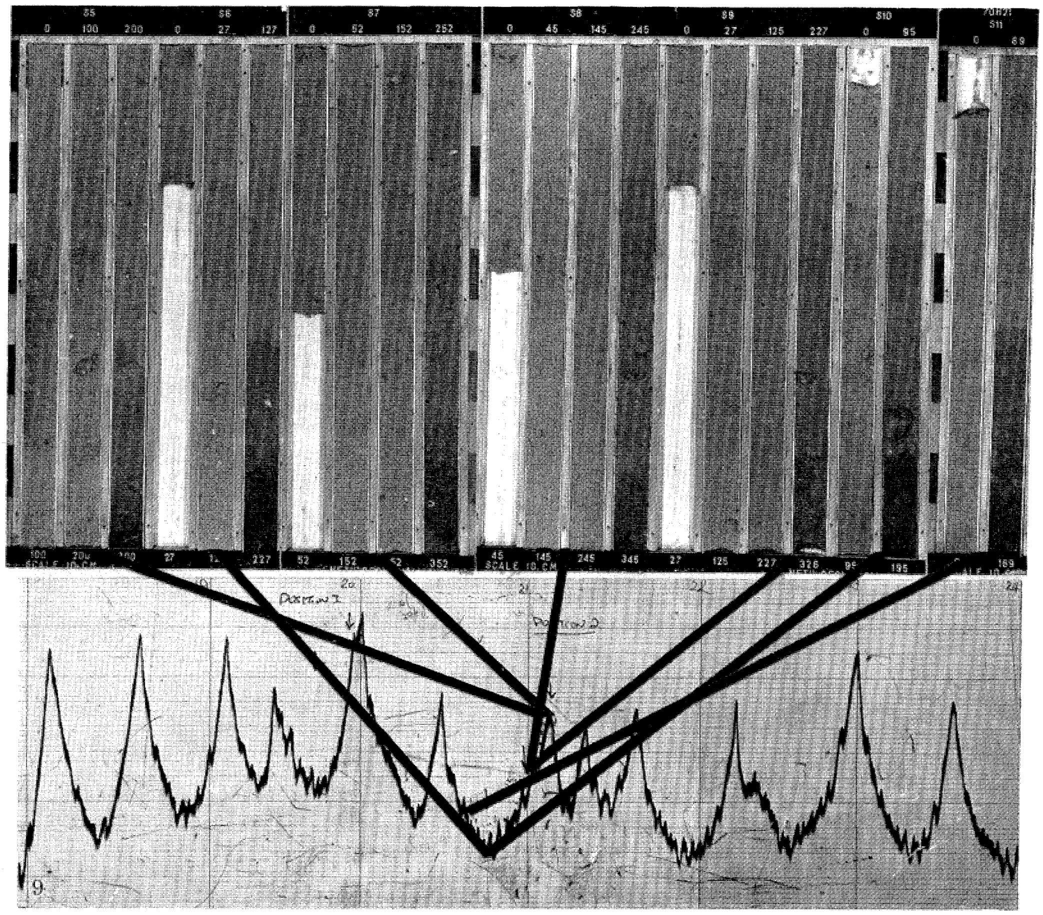



FIGURE 8. Profile of vibrocore samples over irregular ridge on the col between the Sandettie and Fairy Banks.
FIGURE 9. Profile of vibrocore samples over symmetrical sandwave on the col between the Sandettie and Fairy Banks.

(2) *Symmetrical sandwaves.* Cores were obtained from six symmetrical sandwaves on the col linking the Sandettie and Fairy Banks and in two of these cases a profile of five to six cores was taken over the feature to show the internal structure (figure 9, plate 6). These two profiles reveal the symmetrical sandwaves to consist of a yellow quartz sand succession overlying a thin lag gravel and Tertiary strata with no sign of grading. However, several cores taken near the outcrop of the Quaternary basin sediments are graded (see table 2).

Table 2. Sample SG7

| depth/cm | mean grain size in $\phi$ units: untreated sample | mean grain size in $\phi$ units: insoluble residue | size |
|---|---|---|---|
| 0–33 | 1.9 | 2.0 | medium sand |
| 150–160 | 1.5 | 1.7 | medium sand |
| 250–260 | 1.0 | 1.4 | medium sand |
| 330–340 | 1.8 | 1.8 | medium sand |

Examination of the macrofauna from the profiles taken over the sandwaves reveals a Holocene *Angulus pygmeus* fauna with slight evidence for an upwards decrease in English Channel influences in the fauna. Occasional examples of the freshwater bivalve and gastropod *Limnaea* sp. and *Corbicula fluminalis* respectively occur. Both the Channel and freshwater species could have been reworked from older sediments nearby.

Unlike the graded early Holocene sediments the symmetrical sandwaves have a sparse microfauna or are barren. Where present at all, the ostracod fauna is restricted to a few species. In contrast to the irregular ridge graded sediments and the asymmetrical sandwave samples examined, the microfauna vary in abundance along the core. Several cores were barren at the base with moderate-sparse numbers of individuals in the upper 30 cm (e.g. SG7).

Thus, the few cores analysed provided some tentative evidence suggesting only limited mobility and reworking. Unfortunately no conclusive evidence was forthcoming but repeated hydrographic surveys using Hi-fix navigation shows that the features in one small area were stable over the three-year time-scale of the investigation.

(3) *Asymmetrical sandwaves.* Cores were taken in five asymmetrical sandwaves, and in one case a profile of five samples over one sandwave was obtained. The samples are yellow fine/medium quartz sands with occasional shelly horizons and show occasional well-developed bedding with inclined laminations both within and between lithological units. None of the cores show well developed grading (see table 3).

Table 3. Sample SG16

| depth/cm | mean grain size in $\phi$ units untreated sample | size |
|---|---|---|
| 17–30 | 0.6 | coarse sand |
| 65–75 | 0.8 | coarse sand |
| 181–190 | 1.2 | medium sand |
| 275–285 | 1.1 | medium sand |

*Angulus pygmeus* was universally present through the succession in all the cores examined. Certain cores have a poor and juvenile macrofauna which was possibly indigenous to the mobile sands. The microfauna was sparse or absent, and that which was present was fairly evenly distributed throughout the samples examined. From the limited analyses undertaken none of the lithological, macro- or microfaunal evidence precludes mobility of the features and later research has demonstrated that the asymmetrical sandwaves in one area are mobile being transported towards the south at an average rate of 40 m in three years.

## Provenance of sediments in the Sandettie–Fairy Bank gap

The gravel fraction of 60 samples has been examined by Hey (Cambridge University) and Zandstra (Netherlands Geological Survey) and others. The gravels grade in size from granules to cobbles and include a large proportion of well-rounded material frequently having percussion marks on the surface. These gravels, which have apparently suffered fluviatile and polycyclic marine abrasion, include chalk and a large proportion of flints. The well-rounded material is associated with a small proportion of pebbles of fresh looking, angular, exotic rock types. The latter are most common in the Pleistocene gravels of the Quaternary basin sediments where angular granites of two varieties, green-veined jasper, cleaved volcanic ash, grey phyllite, red lavas and green micaceous quartzites occur.

Veenstra (1969) reports that the parent rocks for gravel deposits in the extreme southern North Sea are situated in Belgium, southeast England and northeast France. Examination of the material from the Sandettie area supports this. No material of Scandinavian origin, from the British drifts or from the Rhine, Meuse or Scheldt has been identified. The exotic material appears to be largely of French origin.

Specimens of a macroscopic foraminifer provisionally identified as *Nummulites orbignyi*, in various states of preservation, are present all through the Holocene. One present-day source of these Upper Eocene foraminifers is the Wemmel Sands of Belgium (Murray, Bristol, personal communication). One worn individual which could be *Fabularia bella* has been found. This foraminifer occurs in the Eocene Lede Sands, Wemmel Sands and Asse Clays of Belgium. Modern sediments rich in Nummulites and presumably derived from the Palaeogene basin off the Isle of Wight occur in the Strait of Dover. They have not been recorded off the Dutch coast and are not known to occur in the Tertiary sediments of the North Sea. Thus a significant fraction of the gravels, the Nummulites and a proportion of the macrofauna, particularly in early Holocene deposits, have apparently been introduced from southerly source areas. Further work on provenance is required since the unabraded exotic gravels, tentatively attributed to a southerly provenance, occur in the Eemian sediments to the north of the suggested Pleistocene landbridge.

## Conclusions

Drilling revealed that graded deposits, in addition to the expected sand successions, occur in an area where morphological evidence of acoustic records indicated only the presence of features undistinguishable from sandwaves. Geological methods reveal that the various types of feature contain evidence of their stability and potential mobility. A southerly provenance of particular fractions of the sediment is particularly marked in the early Holocene sediments.

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R. W. Hey (Cambridge University), Dr J. Murray (Bristol University), Dr J. D. Taylor and Dr J. E. Whittaker (British Museum (Natural History) London), Mr N. C. Kelland, Mr J. O. Malcolm and Mrs B. Lees (Institute of Oceanographic Sciences 'Taunton), Mr G. G. Zandstra, Mr A. du Saar, Mr G. Spaink and Dr W. H. Zagwijn (Netherlands Geological Survey). The opinions expressed in the paper are those of the authors and not necessarily those of individuals acknowledged above.

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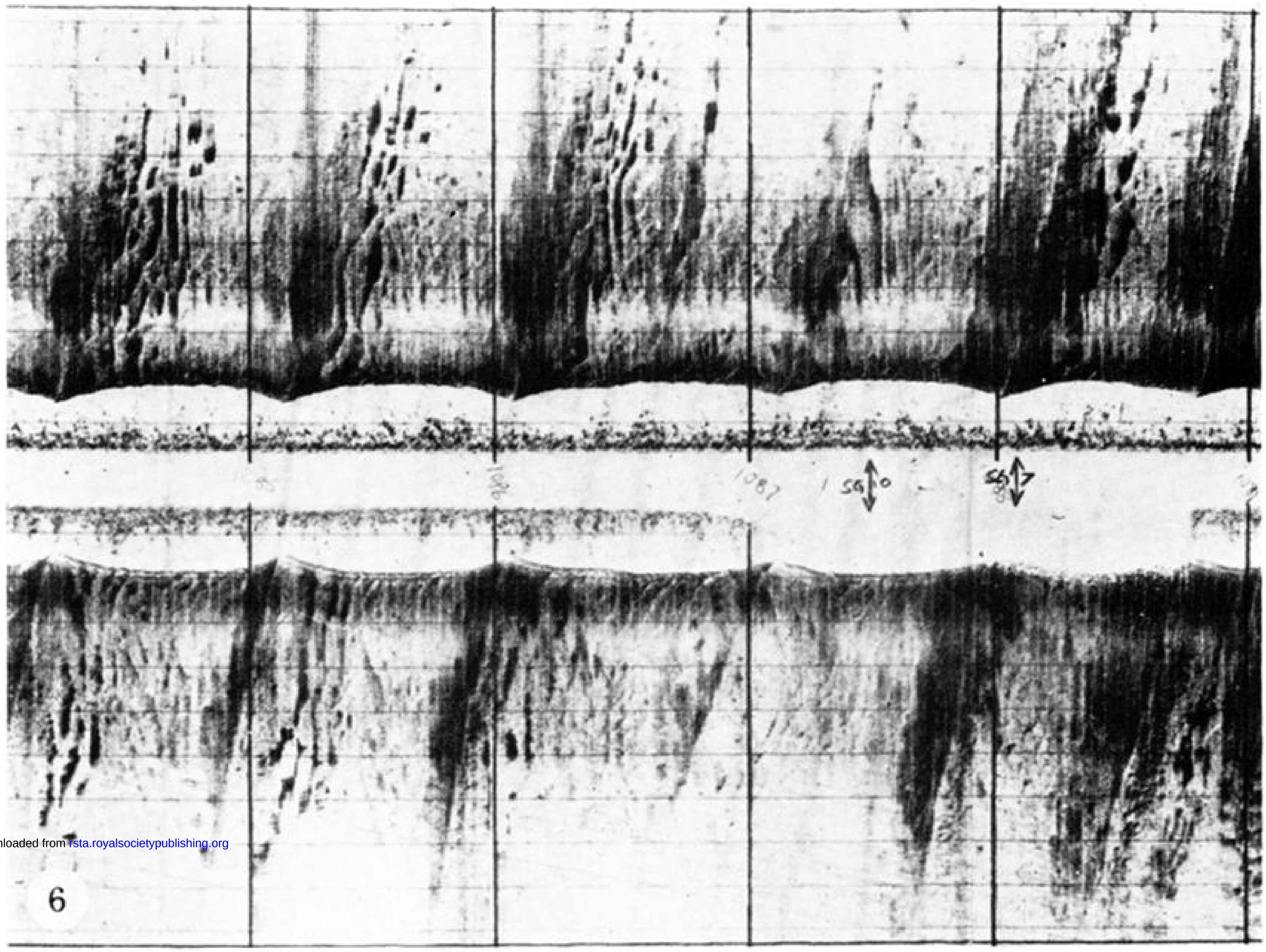

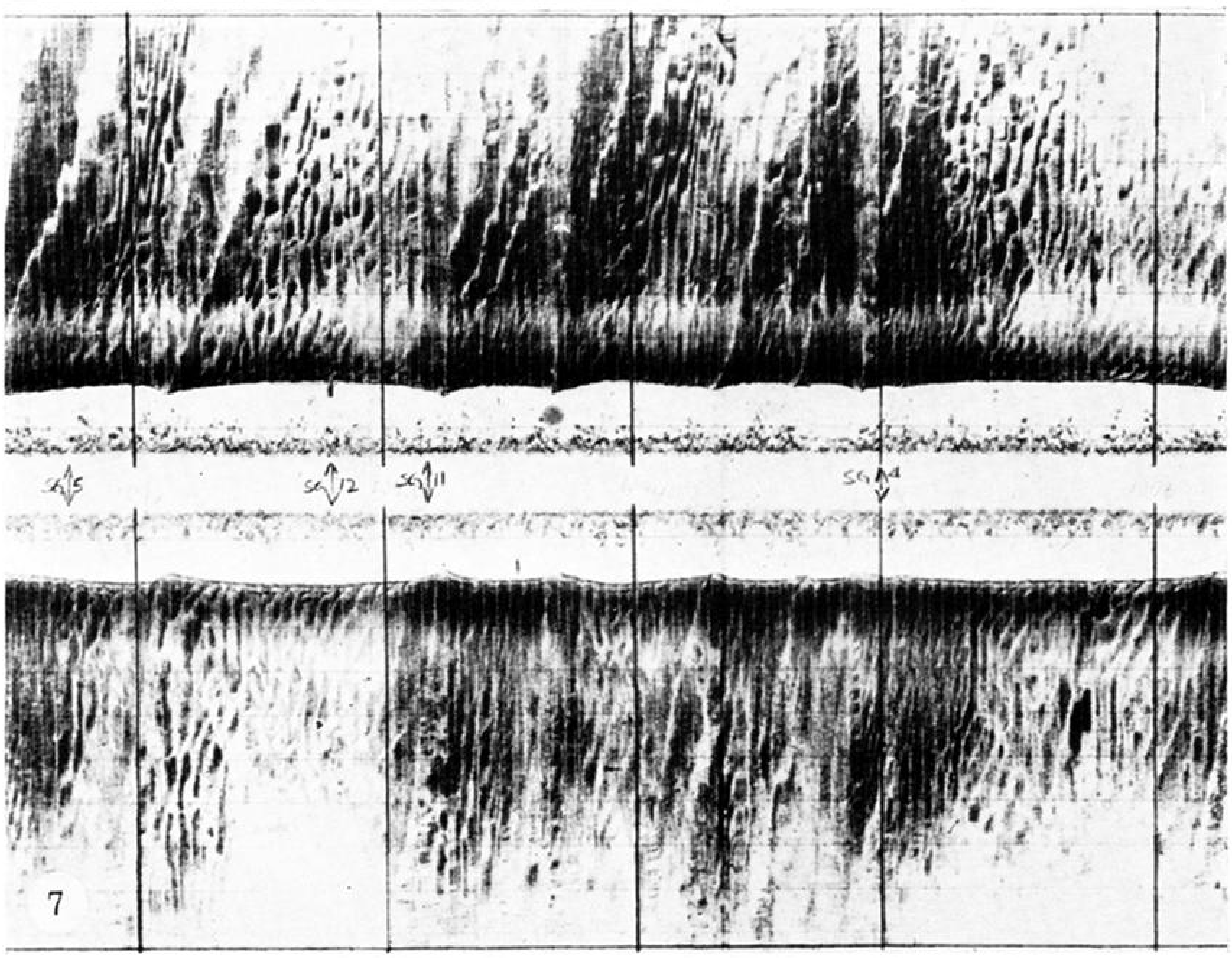

FIGURE 6. Side scan sonar record of symmetrical sandwaves on the col between the Sandettie and Fairy Banks.

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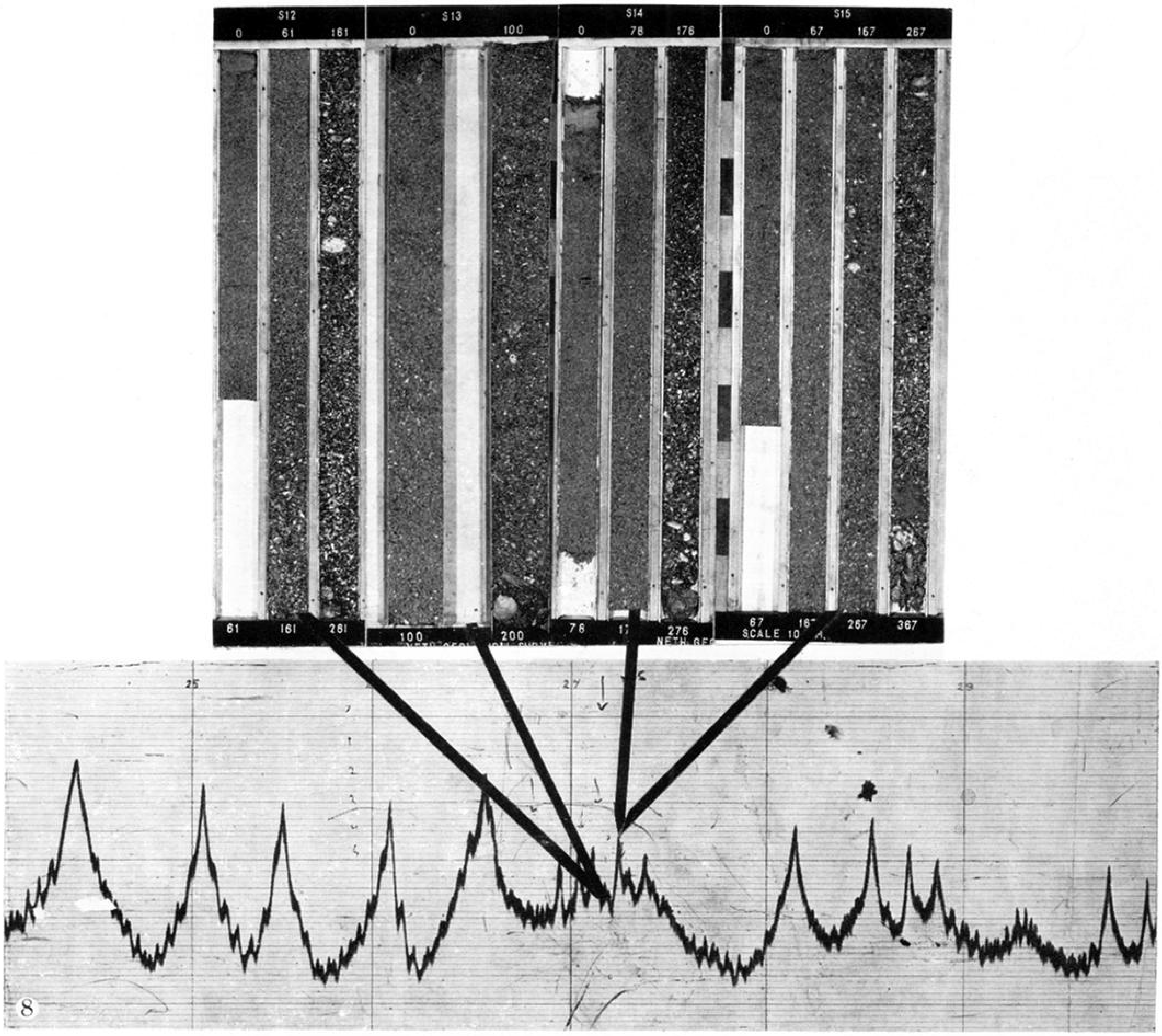


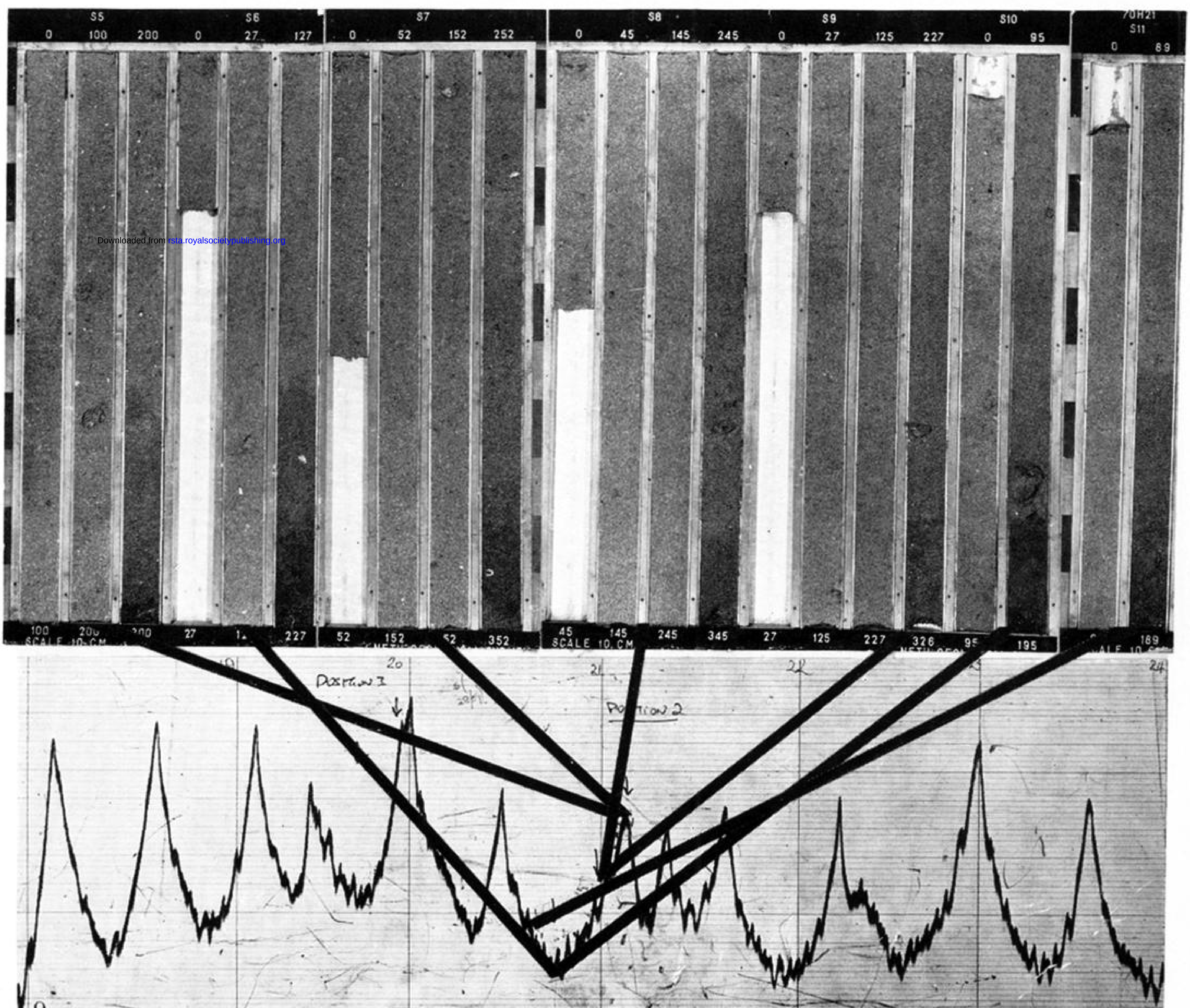




FIGURE 8. Profile of vibrocore samples over irregular ridge on the col between the Sandettie and Fairy Banks.

FIGURE 9. Profile of vibrocore samples over symmetrical sandwave on the col between the Sandettie and Fairy Banks.