PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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A buried valley system in the Strait of Dover

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with an appendix on pollen analysis
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A series of buried valleys situated south of the submerged Chalk outcrop of the Strait of Dover and eroded down to −170 m N.G.F.|| are recognized as infilled tunnel-valleys excavated subglacially during the Warthe Phase of the Saalian glaciation beneath an ice sheet that advanced up the English Channel from the west. Before the Saalian a Chalk ridge joined England and France. Later in the Warthe, ice withdrew from the English Channel and an ice lobe from the North Sea overrode the Chalk ridge to extend some distance down-Channel, eroding some deep NNE–SSW hollows associated with the tunnel-valleys and scouring out the present deep-water channel; this being probably the first physical opening of the Strait of Dover. The tunnel-valleys were infilled during the Eemian interglacial and finally during the Brørup interstadial as evidenced by palynological study of borehole V 050 cores.

The authors propose to name the major northern buried valley described in this paper 'Fosse Dangeard', to honour the doyen of English Channel geology, Professeur Louis Dangeard. We are happy to have received his gracious acceptance of this proposal.

1. Introduction

The buried valley system now described, was carefully studied during 'Sparker' surveys carried out as part of the Channel Tunnel site investigations in 1964–5 (Destombes & Shephard-Thorn 1972). At that time it was a potential hazard to the several routes under consideration for bored or 'immersed tube' tunnels. Now, happily, it is well clear of the proposed bored tunnel alinement.

During these investigations the major buried valley (now named Fosse Dangeard) and some subsidiary features to the south were delimited and a clear three-dimensional picture of its form emerged. Its sedimentary fill was investigated by a single completely cored borehole, V 050, situated towards its western extremity.

A brief mention of the buried valley was made in the account of the Channel Tunnel studies given at the 1971 colloquium in Paris (Destombes & Shephard-Thorn 1972). Since then more information has come to hand from the academic researches of one of the present authors

† We have to note with regret that Monsieurs Destombes died on 29 November 1974.
|| N.G.F., Nivelle générale de la France; O.D. (Newlyn) is about 11 cm below N.G.F.

(J.H.R.) in the Eastern Channel, which have extended the study area to the south and allowed a wider understanding of the buried valley and its related features. Samples of the V 050 cores have been made available for palynological studies, which have yielded interesting environmental and stratigraphical results, described in the Appendix.

The relation of the buried valley to basement-controlled structures in the Mesozoic rocks of the Channel floor has been discussed by Shephard-Thorn, Lake & Atitullah (1972). The researches of C.N.E.X.O. on the sea-bed of the Channel have also contributed to the knowledge of the buried valleys (Robert 1969) in the Varne area. Similarly seismic profiling figured by Sargent (1966) and van Overeem (1968), has covered parts of the buried valley system.

We attempt in this paper to give a more detailed description of the morphology of the buried valley in relation to geological structure, to consider possible modes of origin and to fit their excavation and infilling into the Quaternary history of the English Channel from the palynological and regional evidence now available.

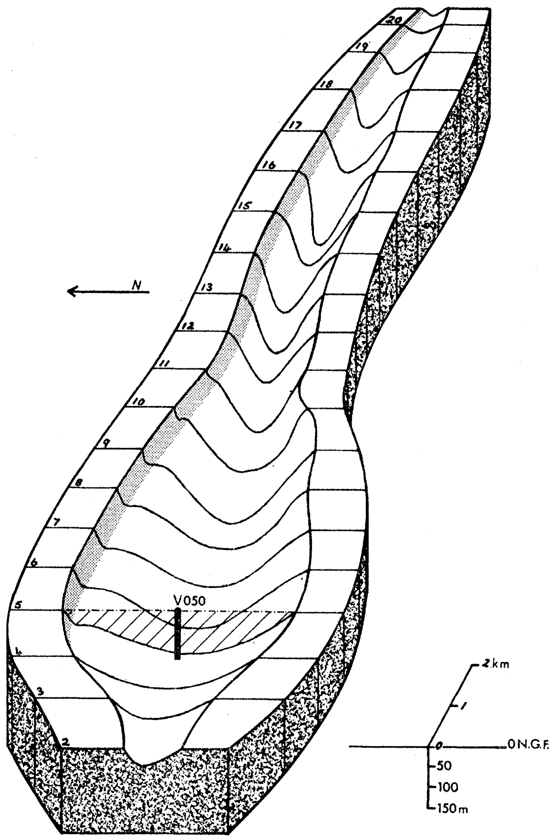


FIGURE 1. Simplified block diagram illustrating the form of Fosse Dangeard as viewed from its western extremity. The numbers refer to Sparker profiles of the Channel Tunnel investigations 1964–5.

2. THE MORPHOLOGY OF THE BURIED VALLEY SYSTEM

(a) *Interpretation of 'Sparker' profiles*

As with all seismic interpretations, the results of Sparker surveys are largely dependent on accurate knowledge of sonic velocity in the rocks or sediments involved. Regrettably *in situ* measurements of velocity in borehole V 050 could not be made, but it is possible to make

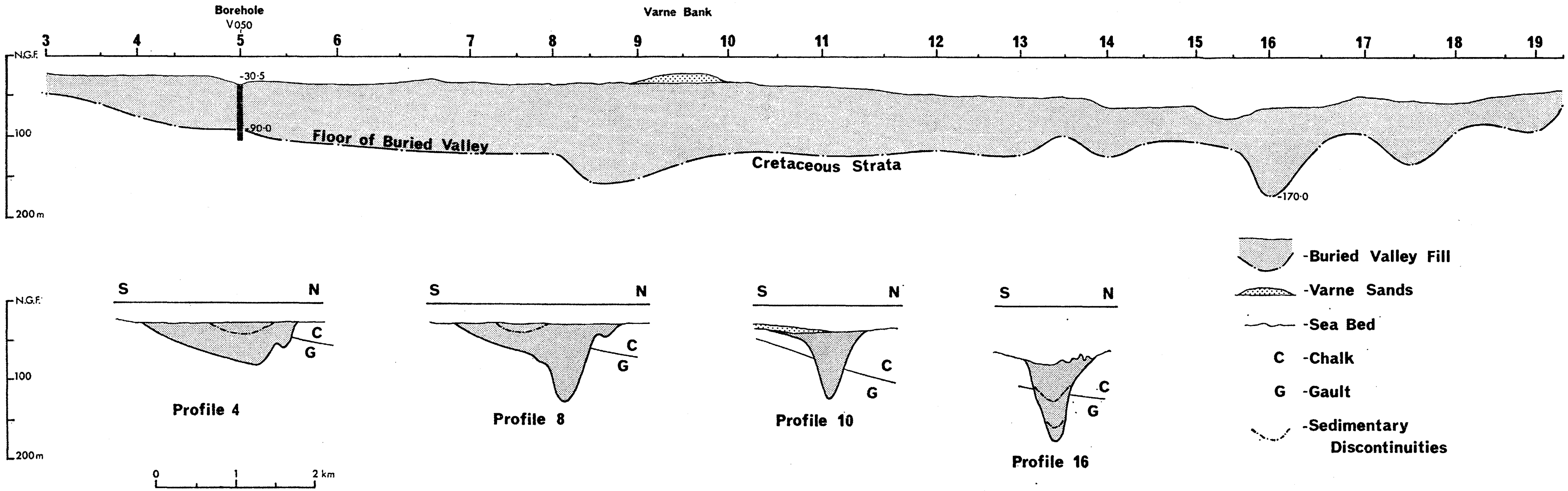


FIGURE 2. Sections along and across Fosse Dangeard based on Sparker surveys. Numbering as in figure 1.

back-calculations from the proven thickness of the buried valley sediments in the borehole in comparison with the profile on which it is sited. While this is not totally satisfactory, it is possible to deduce that the mean sonic velocity in these complex sediments varies between 1600 and 2000 m/s. In constructing the sections that illustrate this paper a mean velocity of 1800 m/s has been assumed, and has yielded Sparker interpretations in general compatibility with the geological evidence: these must however still be read with some reserve.

(*b*) *Morphology of the buried valleys in relation to sea-bed geology and topography*

The geological map of the Channel Tunnel investigation area presented at the previous Colloquium in Paris (Destombes & Shephard-Thorn 1972) indicated the sea-bed outcrops of the sediments infilling the buried valley (Fosse Dangeard) and its associated features to the south, as then known. The map also showed the major structural features of the area and the locations of the Sparker profiles on which the map is based. The block diagram (figure 1) and sections (figure 2) of the major buried valley, included herein, are based on these Channel Tunnel surveys, which had the benefit of very accurate position fixing.

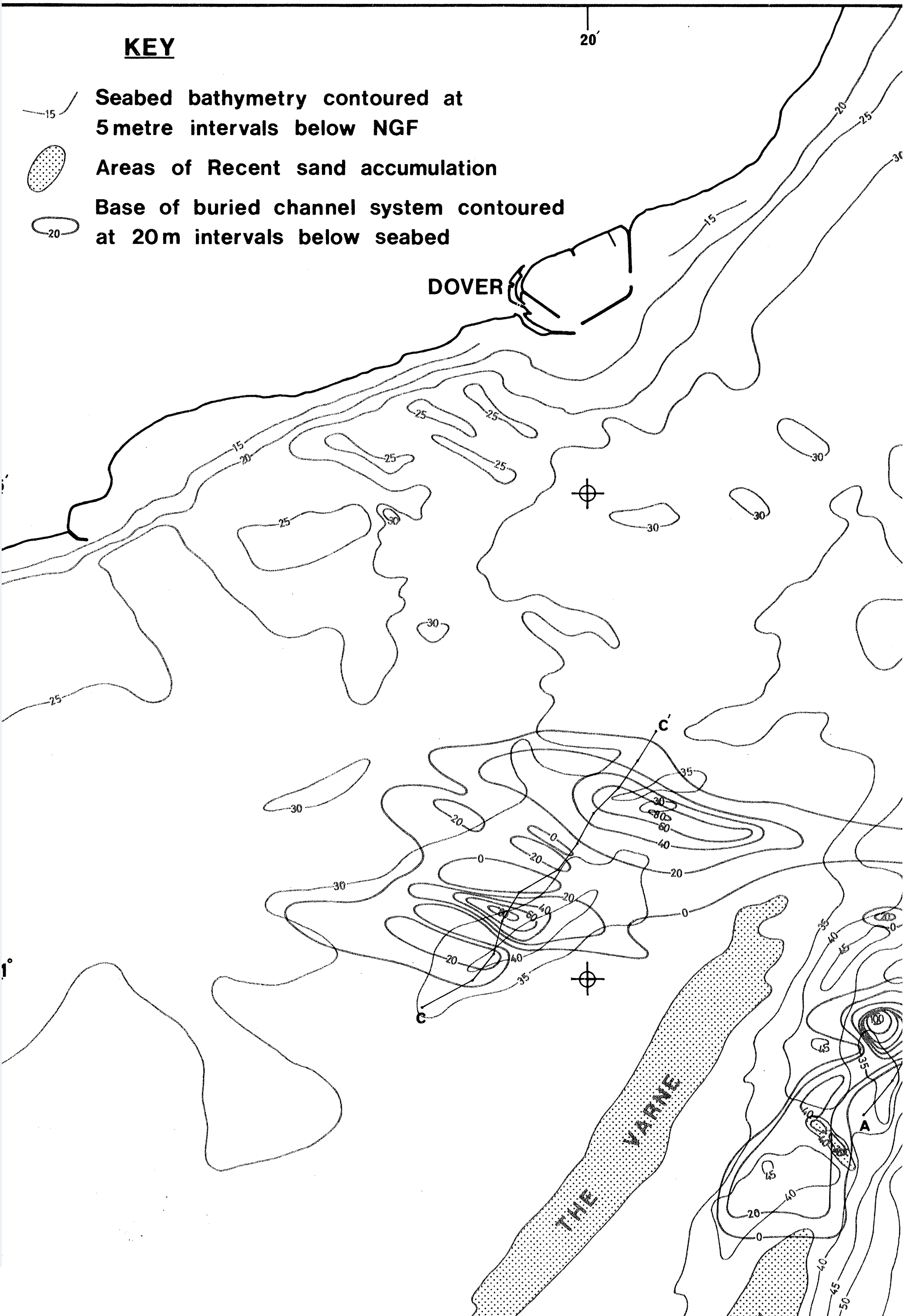
Subsequently additional Sparker surveys were carried out by one of us (J.H.R.) as part of a research programme organized by University College, London. This work extended our knowledge of the buried valley system, in particular of the more southerly portion, and has enabled the contour diagram (figure 3*a*) to be constructed.On this occasion the position fixing system did not allow the same degree of accuracy.

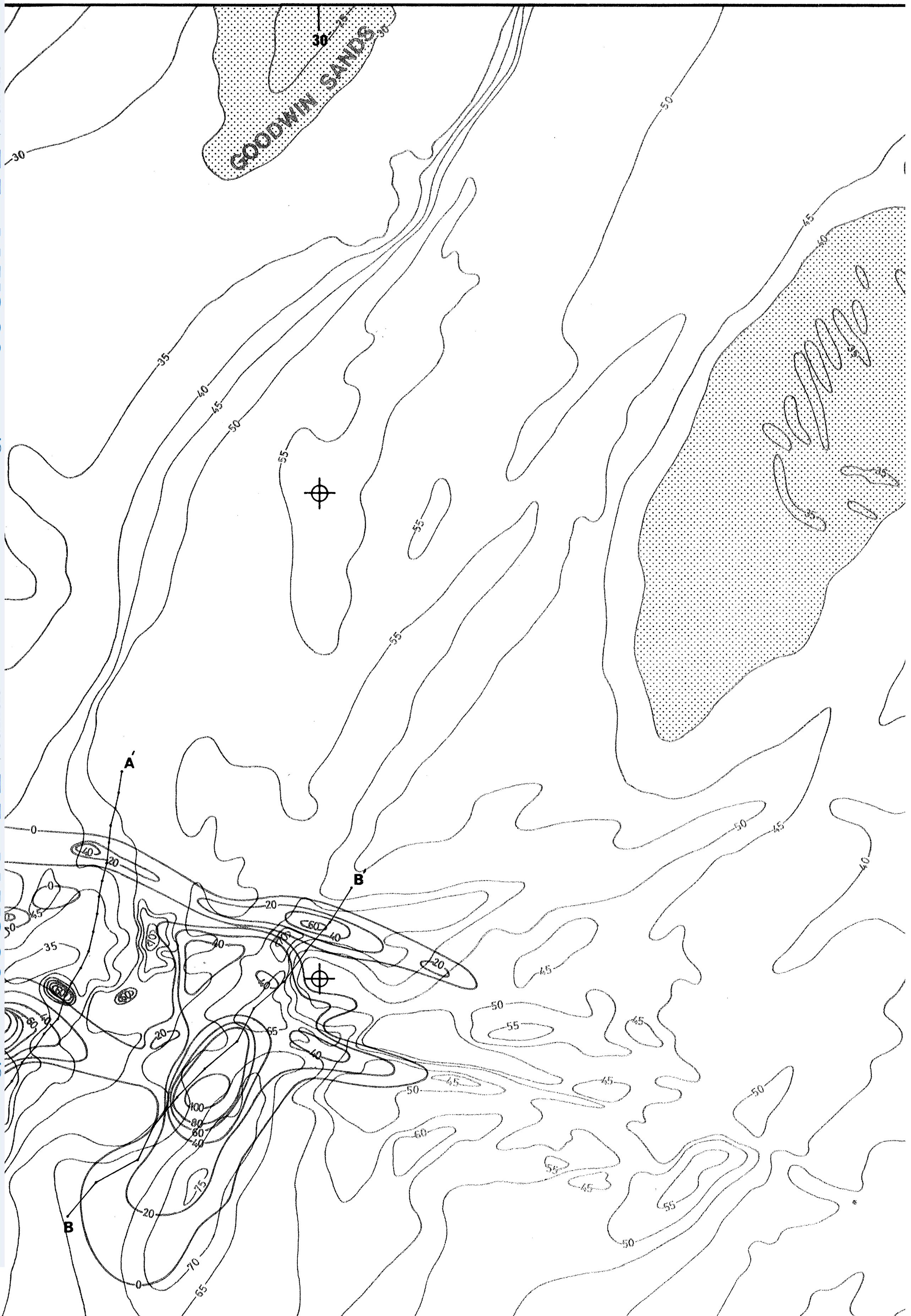
Fosse Dangeard is strongly linear in character and extends over 18 km in a W 10° N to E 10° S direction from a location approximately 10 km south of Dover. In position and width it closely parallels the submarine outcrop of the Gault Clay, being widest (over 2 km) and least deep in the west where the dip is lowest, and becoming narrow (as little as 0.25 km) and deeper as the dip increases eastwards. One could almost say that the position of Gault outcrop, itself determined by the geological structure, has determined the location and form of the buried valley. For some kilometres east of the Varne a flexure marks the contact of the Gault and Lower Greensand. A case has been argued elsewhere (Shephard-Thorn *et al.* 1972) for the influence of structures in the Palaeozoic basement on those affecting the Mesozoic rocks in this area, with some evidence for late movements. The results of the Sparker surveys, however, rule out a directly tectonic origin for the buried valley system, which is clearly revealed to be a group of erosional features.

In longitudinal profile (figure 2) the major buried valley is markedly irregular; there is no semblance of a graded river thalweg. The valley is in fact a closed depression cut down to a general level approximately 120 m below N.G.F., below a sea-bed which drops from about −30 m N.G.F. off Dover to more than −70 m in mid-Channel. Deeper hollows are excavated to −150 m between Sparker profiles 8 and 9, a possible maximum depth of −170 m near profile 16, and another deep of −130 m between profiles 17 and 18.

The same W 10° N to E 10° S trend is picked out by several of the subsidiary buried valleys to the south (figure 3*a*), but two, more ovoid, examples in mid-Channel are alined NNE–SSW. The more southerly group of valleys are cut into soft Jurassic and Lower Cretaceous strata, showing some relation to geological structure: for example figure 3*b* based on Sparker profiles, reveals that the position of one of the features is fault-controlled.

The relationship of the buried valley system to present day sea-bed relief is illustrated in figure 3*a*. West of the Varne Bank the valleys are incised into a generally flat lying area, at


KEY
Seabed bathymetry contoured at 5 metre intervals below NGF
Areas of Recent sand accumulation
Base of buried channel system contoured at 20 m intervals below seabed
20′
DOVER
C′
C
A
THE VARNE



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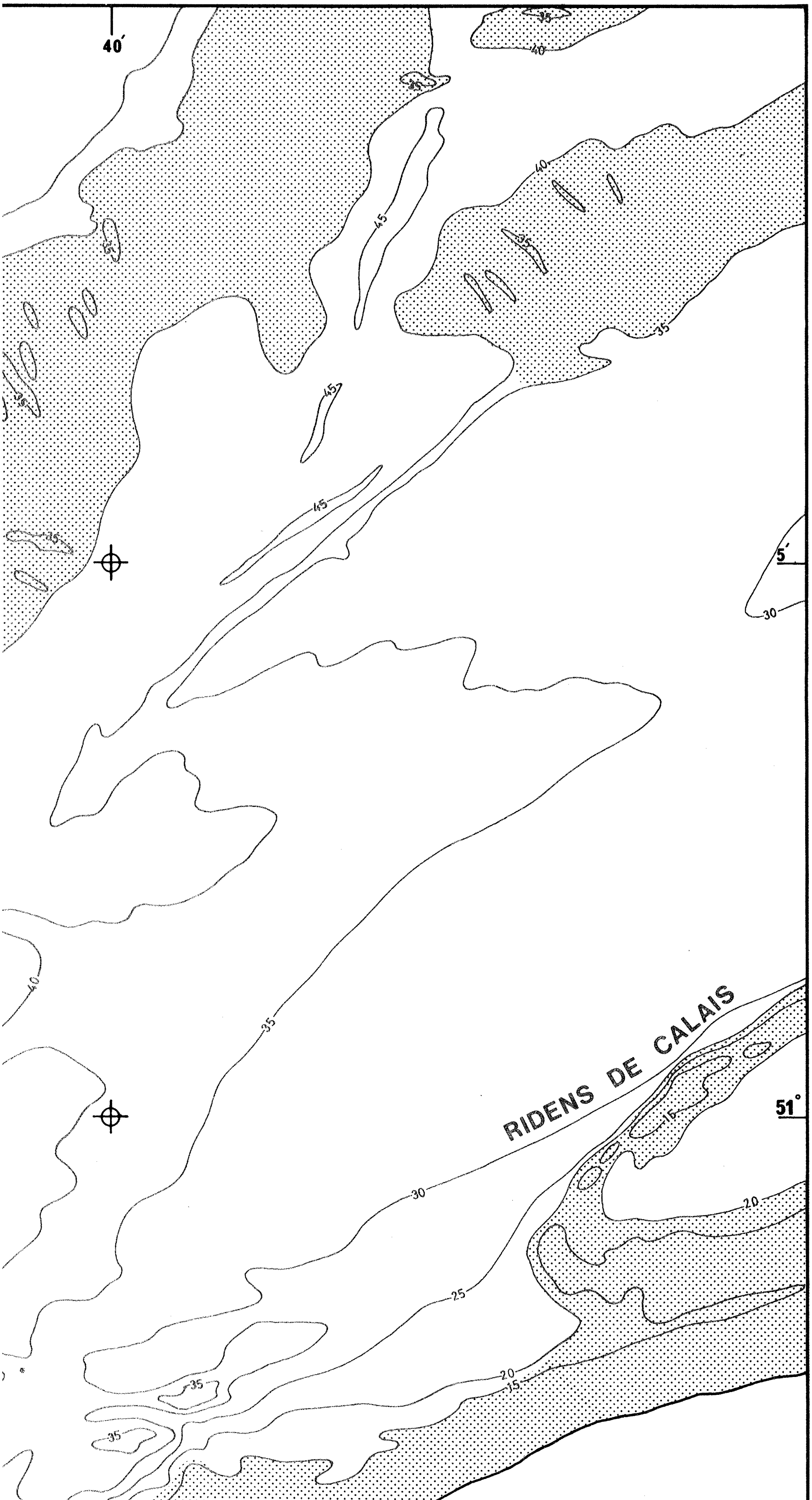

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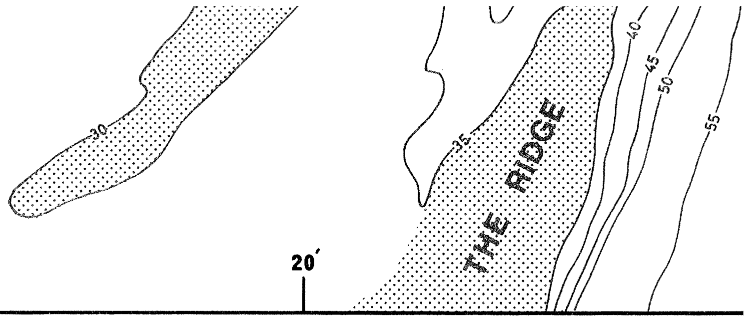

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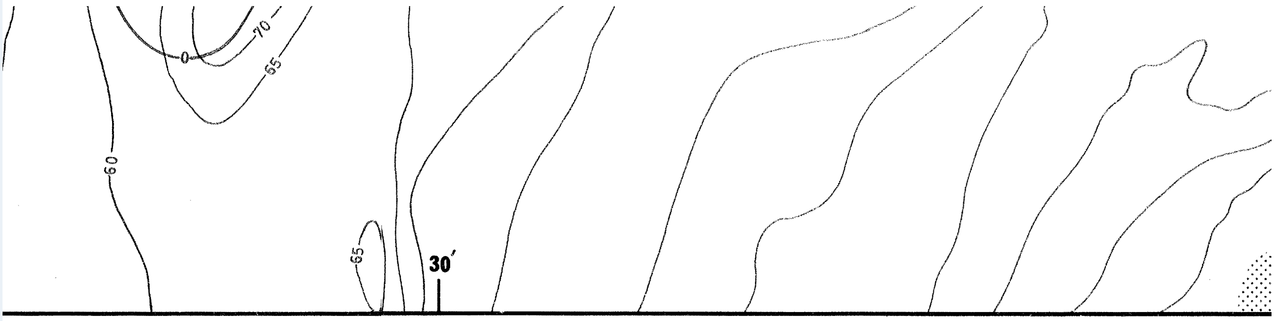

Bathymetry of the Strait of Dover with sub-drift contours of the buried valley.

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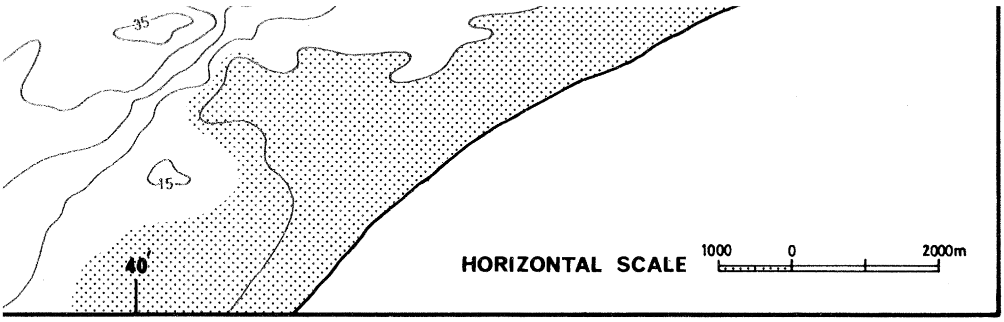

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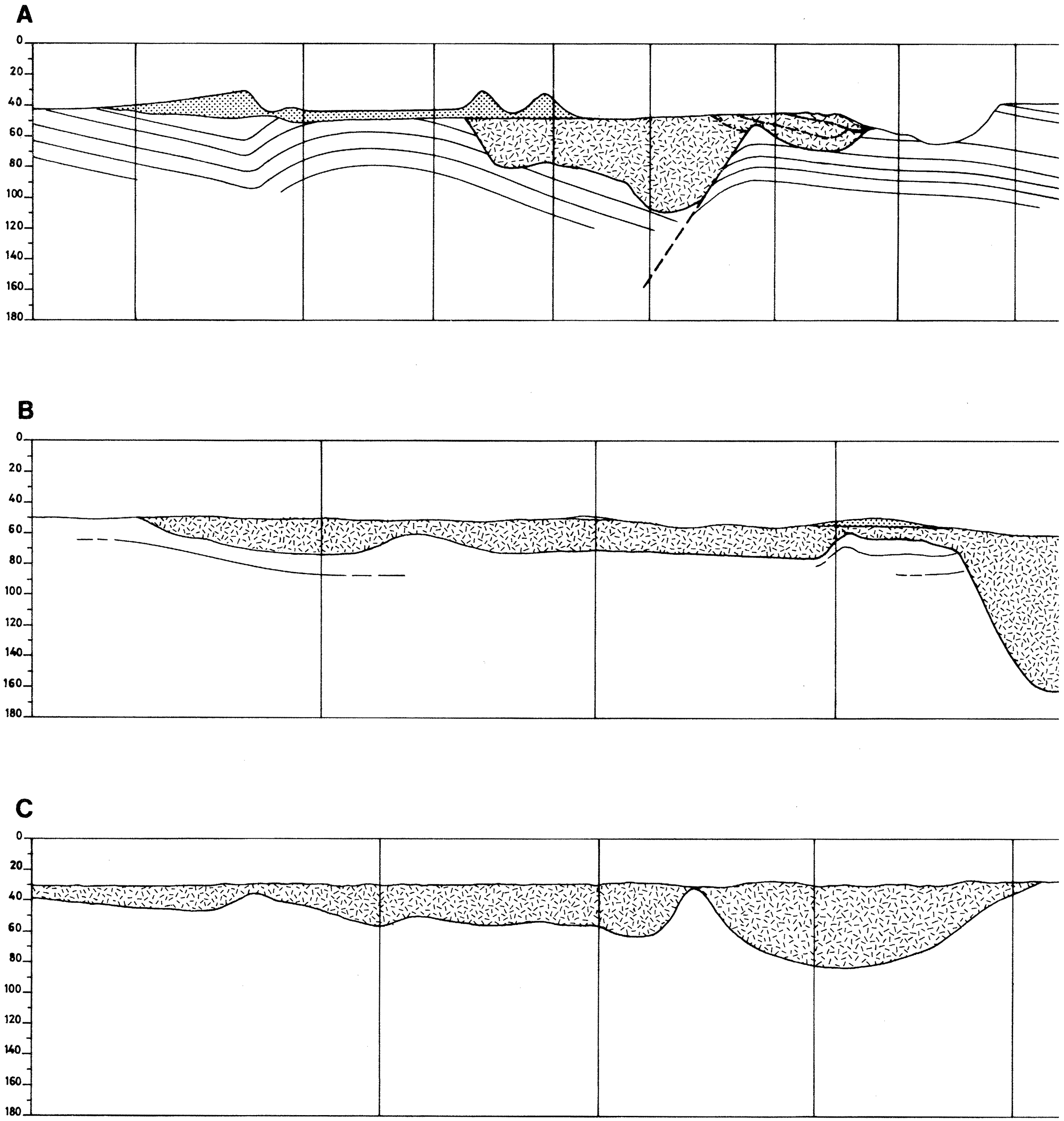
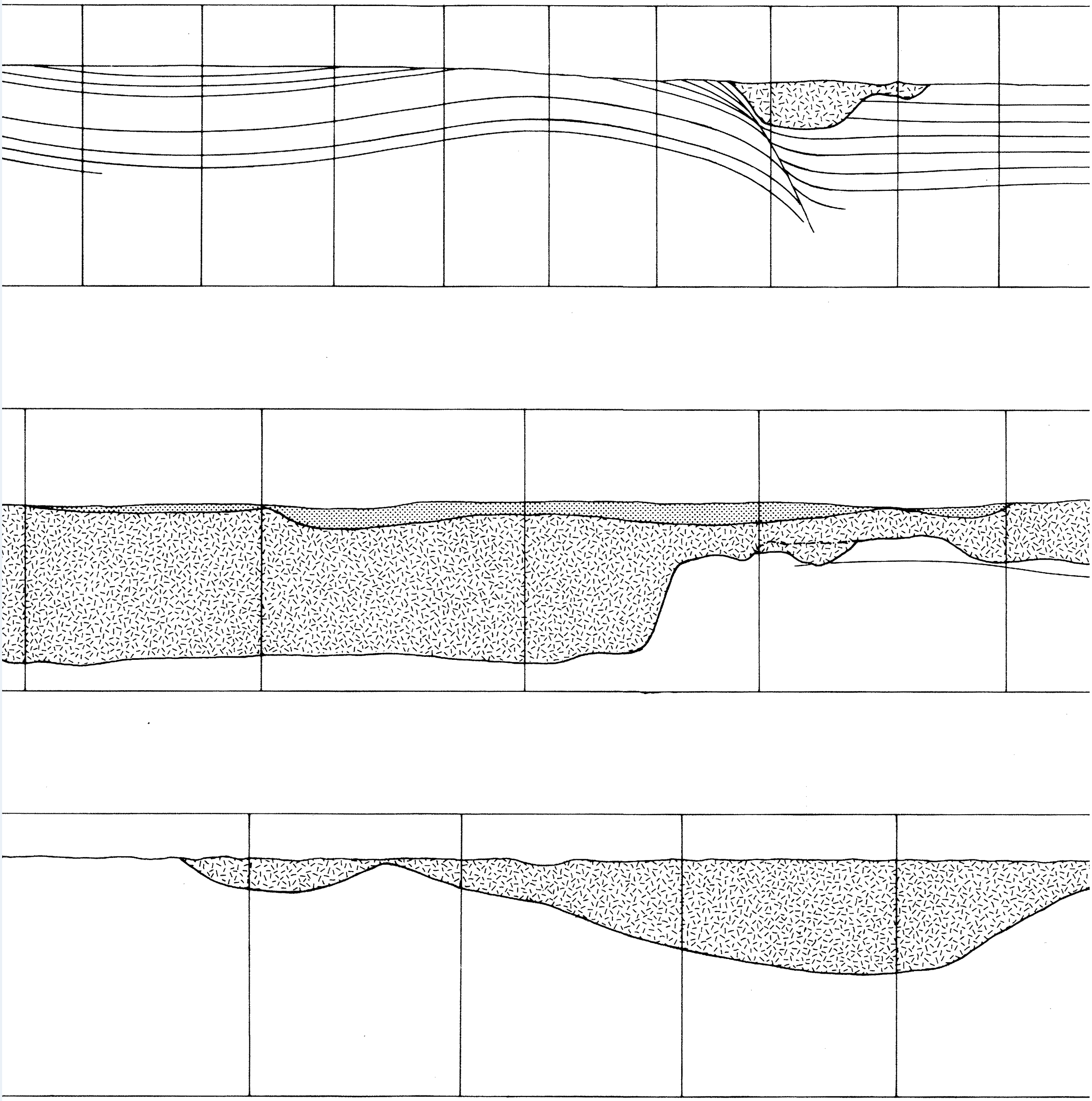
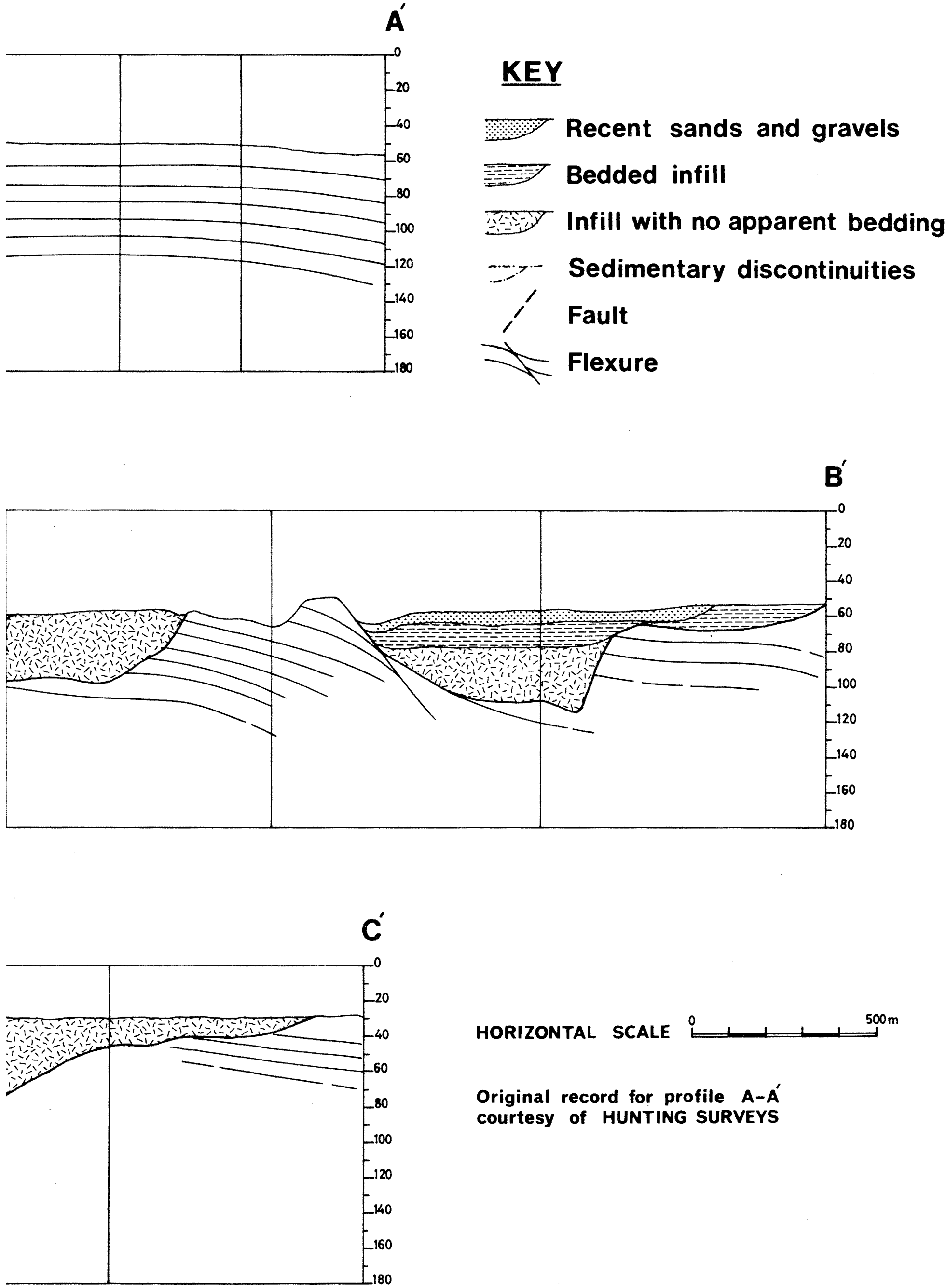

A
0
20
40
60
80
100
120
140
160
180
B
0
20
40
60
80
100
120
140
160
180
C
0
20
40
60
80
100
120
140
160
180

FIGURE 3*b*.



URE 3*b*. Geological interpretations of ‘Sparker’ profiles across the buried valley system.


A′
0
20
40
60
80
100
120
140
160
180
KEY
Recent sands and gravels
Bedded infill
Infill with no apparent bedding
Sedimentary discontinuities
Fault
Flexure
B′
C′
HORIZONTAL SCALE
0
500 m
Original record for profile A–A′
courtesy of HUNTING SURVEYS

about −30 m N.G.F. A sharp break of slope marks the eastern edge of the flat area, following the −60 m isobath in a NNE–SSW direction. This trend which is also followed by the ovoid depressions referred to above and the present deep-water channel (of complex sea-bed relief) is strongly discordant with that of most of the buried valleys and may thus reflect a different mode of origin.

(*c*) *Possible modes of origin of the buried valley system*

Here, our aim is to consider the possible mechanisms, by which the valleys could have been excavated to such great depths below the sea bed of the area, and to select the most probable with regard to the sequence of Quaternary events proposed later.

A directly tectonic origin, implying a graben-like structure to the buried valleys has been excluded in the preceding section of the negative evidence of the Sparker profiles. It is thus necessary to consider possible erosional mechanisms for the primary excavation of the valleys.

Normal sub-aerial erosion at a time of lowered sea-level is ruled out by the closed form and abnormal thalwegs of the valleys.

Tidal scour has been invoked by other authors to account for the formation or modification of some of the closed depressions of the English Channel floor. It is difficult, however, to conceive this as a possible mechanism in this case. The present tidal regime in the Strait of Dover is complex, being influenced by water movements in the English Channel and the southern North Sea. However, the main ebb and flood directions are NE–SW (i.e. transverse to the alinement of the buried valleys) with a net residual drift to the northeast which is capable of carrying only a fine suspended load (Van Veen 1936). The situation would have differed markedly when the valleys were excavated, with the implied low sea-level of a glacial maximum and a land barrier across the Strait. Even in these circumstances, however, one cannot envisage tidal currents capable of excavating closed valleys to depths of over 100 m below the sea-bed. Furthermore the valley system is totally unrelated to the present land drainage of East Kent so that it is not possible to argue a case for tidal modification of a drowned topography during an interglacial.

Hitherto, glacially linked explanations of the formation of the valleys would have been countered by the generally held view that Quaternary ice-sheets never extended south of the latitude of London in southern England, although floating ice had been invoked to explain the distribution of some far-travelled erratics around the coasts and bed of the English Channel (Dangeard 1929). Recent work by our colleague Dr Kellaway (1971, 1972), has, however, opened up the possibility of major ice-sheet glaciations of much of this area in epochs preceding the Last Glaciation (Devensian), (Hawkins & Kellaway 1971). A review of evidence supporting such glaciation has been presented in this volume (Kellaway *et al.* 1974, p. 189).

Recent work on subdrift features in East Anglia (Woodland 1970) and South Lancashire and North Cheshire (Howell 1973) has established the widespread existence of infilled 'tunnel-valley' systems akin to those of Denmark and elsewhere in Northern Europe formerly overridden by major ice-sheets. Tunnel-valleys are characterized by their overdeepened and irregular longitudinal profiles and their abrupt termination at the former position of an ice front. In competent strata their cross-profiles are typically narrow and gorge-like, but tend to be broad and shallow in softer rocks. The inferred method of erosion of these features is by debris-charged subglacial streams under high hydrostatic pressure, which enables erosion to extend well below the normal local base level. Most examples described from land areas are related to earlier valley systems of the pre-glacial landscape. Submarine examples are less well-documented but Valentin (1957) and Donovan (1973) have considered such a mechanism possible for the origin of the Silver Pit and related features in the North Sea. Likewise, in this report, Kellaway and others have suggested a subglacial origin for some of the closed deep depressions of the English Channel floor.

Glacial scouring by ice moving down-Channel from the north is considered a likely mechanism for the sculpture of the NNE–SSW orientated deep buried valleys in mid-Channel.

Our overall consideration of the local and regional evidence leads us to accept the reality of a pre-Eemian glaciation of the English Channel by ice moving from the west, with some later scouring by North Sea ice in the vicinity of the Strait of Dover. This theme will be further developed in the review of Quaternary events that concludes this paper.

(*d*) *The sedimentary infill of the buried valleys*

While the extensive Sparker surveys have adequately established the location and morphology of the buried valleys, with the suggestion on some profiles of several phases of infilling, samples of the sediments are available only from the continuously cored borehole V 050 and a single gravity core from Fosse Dangeard. Thus it is by no means possible to give a complete description of the infill at this time.

Borehole V 050 (lat. 51° 02′ 09″ N, long. 01° 19′ 57″ E, sea-bed depth −30.5 m N.G.F.) was sunk to determine the nature of the infilling in relation to proposed routes for a Channel Tunnel. It was continuously cored from 15.4 m below sea-bed, but recovery of the soft sediments which extend to a depth of 58.8 m (−89.3 m N.G.F.) averaged only 33 %. In drawing up the section that accompanies the pollen diagram (see Appendix, figure 5) the core losses have been presumed to have occurred at the base of each separate run.

To a depth of 10 m below sea-bed, marine sand with flint, greensand and limestone pebbles occur above the valley fill sediments. These latter, which are remarkably homogenous throughout, comprise more or less laminated or varved alternations of pale brown silty clay and pale, fine to medium, well-rounded quartz sand with appreciable amounts of glauconite. Most of this material has probably been derived from reworking of the local outcrops of Gault and Lower Greensand. A few angular fragments of flint and chalk noted just below 15.4 m are probably due to contamination from the overlying marine deposits. Traces of argillaceous travertine in the form of minute tubules, such as might form around plant roots, have been noted between 16.4 and 18.3 m. The valley-fill deposits rest sharply on basal Gault at 58.8 m without an intervening coarse lag deposit or basal conglomerate. The Gault rests on Lower Greensand at 61.2 m below sea bed.

Macrofossils and other visible organic remains are absent from the cores but microfossils appear to be present throughout. Foraminiferal faunas from samples taken at depths of 29.8, 39.8 and 58.8 m have been identified by D. J. Carter (personal communication) whose results for the two lower samples are tabulated below. The sample numbers refer to the Channel Tunnel Site Investigations Collection currently housed in the Department of Geology, Imperial College, London.

The upper sample (21605) contains a rather sparse fauna similar in composition to that found below. All the samples contain minute fragments of lignite, ostracods, a few sponge spicules, large circular diatom frustules, and derived material from the Chalk. The preservation of one or two indeterminate *Nonion* suggest a Pliocene derivation.

The assemblages found in these samples are dominated by *Ammonia batava*, *Pateoris hauerinoides*, *Miliolinella subrotunda* and species of *Protelphidium* and *Elphidium*, which indicate shallow marine or possibly estuarine cold-water conditions. The present depth of the enclosing sediments indicates that they cannot be younger than very early post-Glacial, although they could well be older.

Table 1. Microfaunas from the Quaternary of borehole V 050 (identified by D. J. Carter)

(R, rare; C, common; VR, very rare; VC, very common; X, present; S, one specimen.)

	58.8 m (21604)	39.8 m (21606)
Ammonia batava (Hofker)	VC	VC
Bolivina pseudoplicata Heron-Allen and Earland	X	X
B. pseudopunctata (Högland)	X	X
Brizalina variabilis (Williamson)	X	X
Buccella frigida (Cushman)	VC	VC
Buliminella elegantissima (D'Orbigny)		VR
Cibicides lobatulus (Walker and Jacob)	X	X
Colina sp.		VR
Elphidiella hannai (Cushman and Grant)	R	VR
Elphidium articulatum (D'Orbigny)	X	X
E. asklundi Brotzen	X	C
E. excavatum (Terquem)	C	C
E. gerthi van Voorthuysen	X	X
E. hallandense Brotzen	X	
E. oceanensis (D'Orbigny)		S
Fissurina lucida (Williamson)	VR	
F. marginata (Montagu)		VR
Gavelinopsis praegeri (Heron-Allen and Earland)		VR
Globigerina sp.	S	VR
Lagena semistriata Williamson	VR	VR
L. striata (D'Orbigny) forma *substriata* Williamson		VR
Miliolinella subrotunda (Montagu)	C	C
Parafissurina sp.	VR	VR
Patellina corrugata Williamson	VR	X
Pateoris hauerinoides (Rhumbler)	C	X
Protelphidium anglicum Murray	C	C
Quinqueloculina lata Terquem	VR	
'*Rotalia*' *perlucida* Heron-Allen and Earland	X	
Sigmomorphina sp.	VR	
Trifarina angulosa Williamson		VR

3. Quaternary history

Starting from our acceptance of the origin of the buried valley system as subglacial tunnel-valleys, with a possible additional role played by the scouring action of ice from the north, it is arguable that the excavation of such features must have occurred during a major glacial episode. Furthermore it is improbable that such steep-sided features could have survived for long, unfilled, during the extreme climatic and sea-level oscillations of the Quaternary. We thus maintain that they were infilled within a comparatively short time of their excavation.

We are limited in terms of reliable dating evidence to the Brørup interstadial age established for the V 050 sediments by palynology (Appendix). It seems, however, that the 50 m or so of sediments proved in this borehole represent only the last phase of infilling of Fosse Dangeard, there being elsewhere a further 80 m of fill extending down to the maximum depth of –170 N.G.F.

which has not been investigated by boring. In looking for a major glacial period before the Brørup, in which the buried valleys could have been cut, the early Weichselian (Devensian) seems too brief in duration, and possibly not cold enough, to produce an English Channel glaciation. We therefore consider the Saalian glaciation as the more probable. In view of the argument advanced above against the valleys being able to remain open for long between excavation and infilling, we suggest that the final Warthe Phase of the Saalian, immediately preceding the Eemian (Ipswichian) interglacial, is that in which the primary excavation was accomplished. Fluvioglacial materials deposited by the subglacial stream responsible for the excavation, more-or-less contemporaneously, probably represent the earliest stage of infilling of the deeper and narrower eastern end of the valley. There may then have been a lacustrine interval before sea-level rose to overtop the margin of the closed depression, in the ensuing Eemian interglacial, and deposit marine or estuarine sediments. The early Weichselian may be similarly represented, possibly with some erosion of the earlier sediments and exposed valley sides before the final Brørup stage of infill. The large proportion of reworked Cretaceous sediments and fossils present in the V 050 cores support this suggestion and may also in part explain the wider cross-profile of the western end of the valley, the last to be infilled. The Sparker surveys have also provided evidence of multi-phase infilling of the buried valley system, but as yet we cannot interpret these records stratigraphically.

An interesting demonstration of the very short interval between Eemian and Brørup periods has been provided by the archaeological researches of Lefebre on the Sangatte raised beach (personal communication), where he has found artefacts attributable to the Brørup resting on the very thin lowest marine sediments that overlie the rock-cut platform of the raised beach (see also Lefebre 1968, 1969).

In conclusion we now offer a brief outline of events in the Strait of Dover region from Saalian times to the present day illustrated by simple sketch maps. We recognize the imperfections of these chronological and geographical reconstructions but hope that they will help to provide a framework for future more detailed studies.

(i) *Pre-Saalian Coastline* (figure 4 (i))

This is necessarily somewhat speculative, but the major point, that the Strait of Dover was bridged by a Chalk ridge, is well supported by the distribution of glacial erratics (Kellaway *et al.* 1974). The coastlines of East Kent and the Pas-de-Calais would no doubt have been somewhat to seaward of their present positions.

(ii) *Saalian* (*Warthe*) *glaciation of the English Channel* (figure 4 (ii))

During the Warthe Phase an ice sheet spread eastward up the English Channel from the western edge of the continental shelf (Kellaway *et al.* 1975) halting eventually at the physical barrier presented by the Chalk ridge. At this ice margin subglacial streams excavated the W 10° N to E 10° S series of tunnel-valleys, especially in the soft Gault beneath the Chalk ridge, but also choosing other soft strata or lines of structural weakness. A possible secondary retreat position of the ice sheet may be marked by the abrupt termination of an anastomosing series of shallow closed valleys detected on the sea bed between Dungeness and Cap Gris-nez. Some melt water may have escaped northward via low gaps in the Chalk ridge.

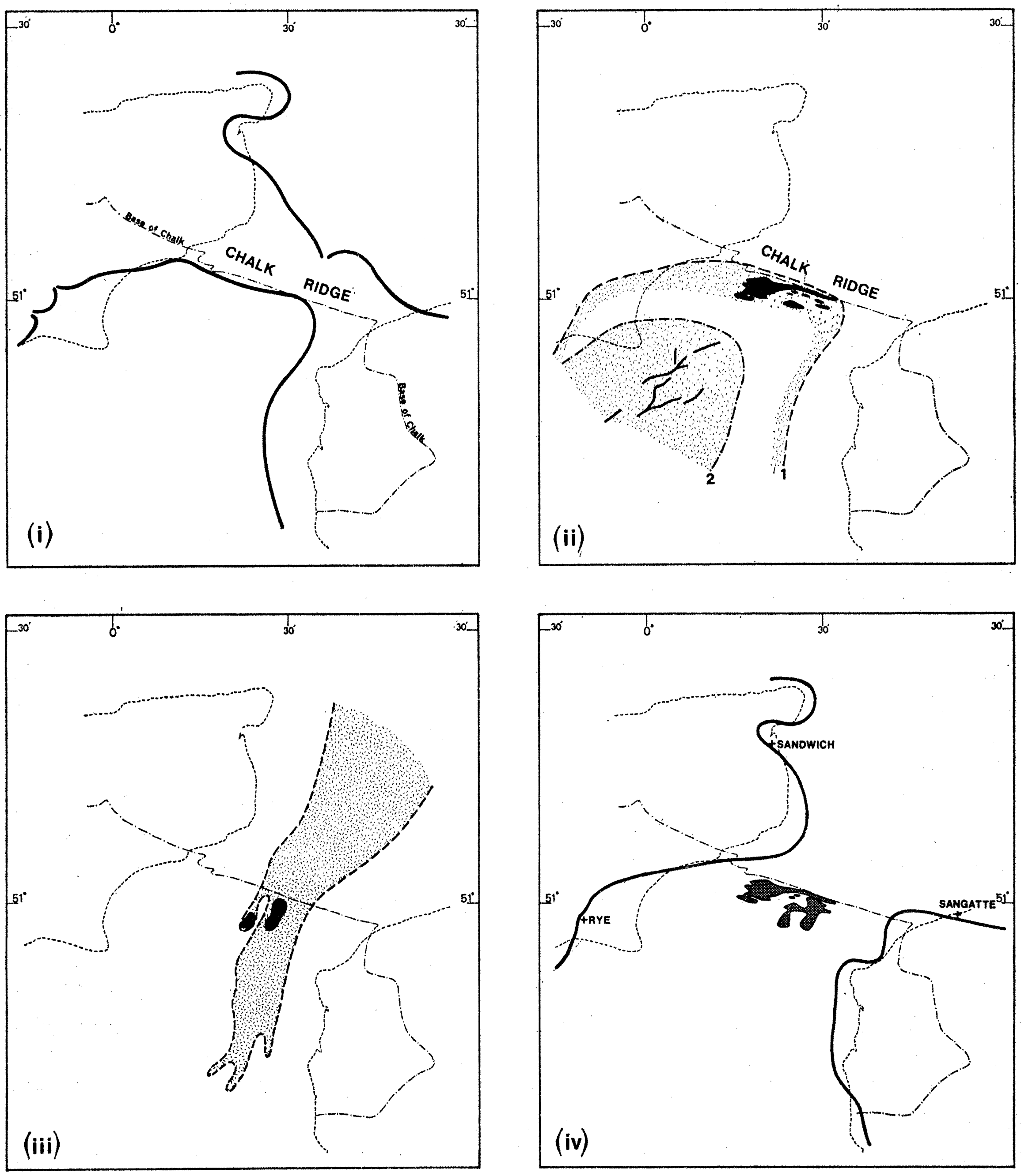


FIGURE 4. Suggested stages in the late-Quaternary evolution of the Strait of Dover. (i) Possible pre-Saalian coastline. (ii) Saalian glaciation of the English Channel, with two possible icefront positions and associated tunnel valleys. (iii) Later Saalian glaciation fiom the north overriding chalk ridge and scouring NNE–SSW hollows and deep water channel of the present day. (iv) High sea-level of the Eemian; raised beaches, tunnel valleys largely infilled; Strait of Dover open.

(iii) *Saalian glaciation from the North Sea* (figure 4 (iii))

On the evidence of the alinement of sea-bed features it is necessary to postulate that a broad tongue of ice overrode the Chalk ridge from the North Sea and proceeded some distance down-Channel. The evidence suggests that this took place in the Warthe Phase after and

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penecontemporaneously with the retreat of the English Channel ice. This Northern ice was responsible for the scouring out of the deep NNE–SSW hollows associated with the tunnel-valleys and also, more importantly, carved out the present deep-water channel that lies in the eastern half of the Channel, south of the Chalk ridge. It seems probable that the Chalk ridge was breached by this ice – perhaps the first opening of the Strait of Dover.

(iv) *High sea-level of the Eemian interglacial* (figure 4 (iv))

Sea-level rose gradually during this interglacial to the height some 5–8 m above present day represented by the raised beaches of Black Rock and Sangatte. Recent Geological Survey mapping has found traces of similar beaches near Rye and Sandwich, which have been indicated in figure 4 (iv). Lacustrine sediments probably accumulated in the closed valleys until they were overtopped by rising sea-level, whereafter marine or estuarine deposits were laid down. A narrow central strait was open.

(v) *Post-Eemian periods*

At the end of the Eemian and the return to glacial conditions, sea-level fell once more. There may have been some reworking of the earlier buried valley deposits and erosion of the valley sides still exposed, before a further brief rapid rise of sea-level in the Brørup interstadial, during which infilling by shallow marine or estuarine deposits was completed. (For simplicity we make no mention of possible effects of the Amersfoort interstadial here.)

Sea-level was again lowered during the main glacial phases of the Weichselian but ice sheets did not return to the Strait of Dover. The exposed land areas experienced severe periglacial weathering which reduced the terrain to virtually its present state, considerably widening the Strait.

Sea-level stood at −35 m, or more, below that of the present day at the end of late-Glacial times 10000 years ago. Since then the Flandrian or Holocene transgression has seen sea-level rise rapidly with minor oscillations. The coastline has been modified by marine erosion and the accumulation of coastal sediments, e.g. as at Dungeness and Wissant.

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Appendix. Palynology of the Quaternary sediments in borehole V050

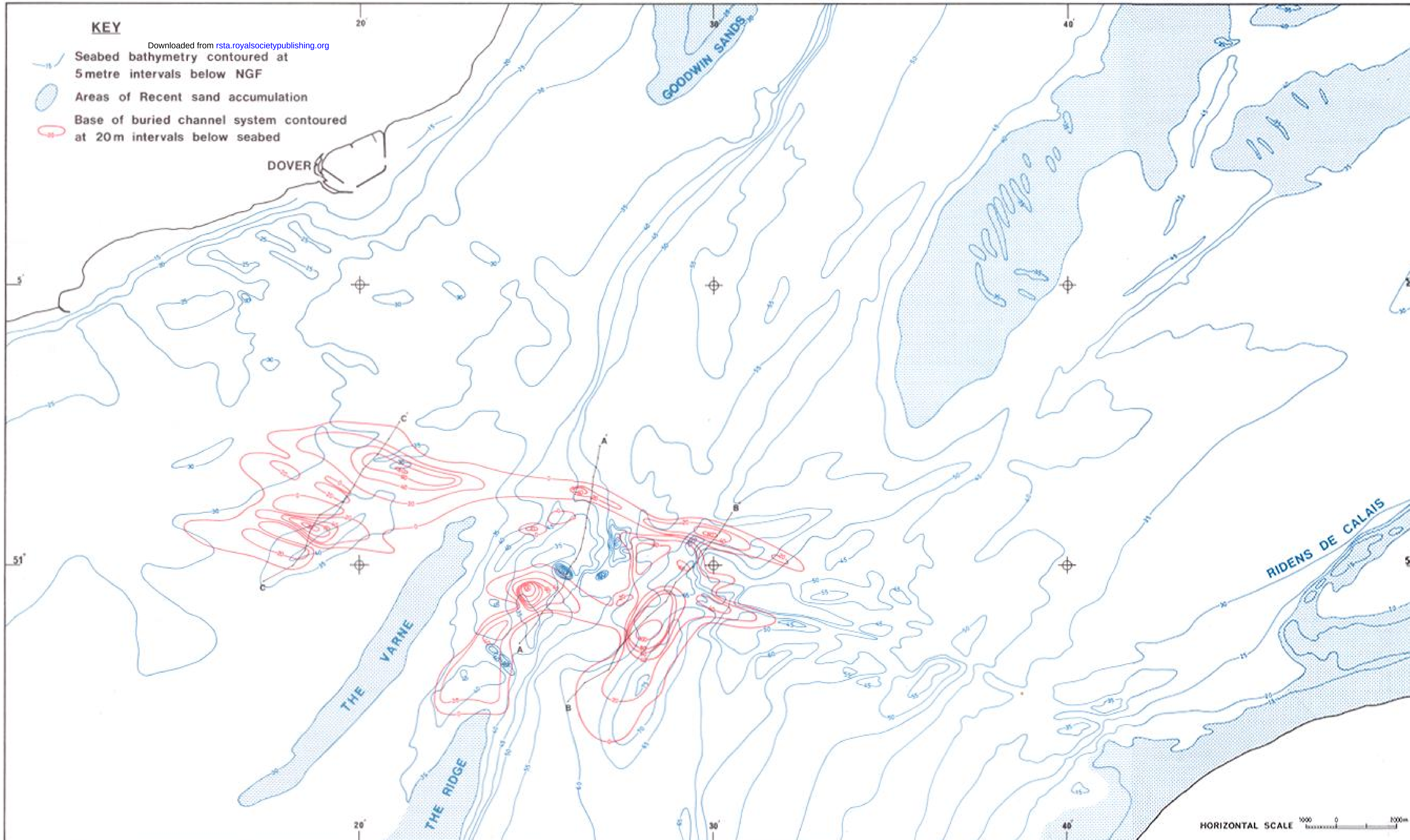
By M. T. Morzadec-Kerfourn

(*a*) *Methods of study*

Samples taken at representative levels from the cores of borehole V 050 have been treated for pollen analysis. Standard methods of removing organic and inorganic material have been employed, followed by concentration of the spores and pollen using a heavy liquid (bromoform-ethanol, D 2.1). The pollen and spores were determined at each level, the results being shown in the accompanying diagram as percentages of total tree pollen, rather than as absolute percentages.

(*b*) *Conditions of sedimentation*

The presence at all the levels studied of Chenopodiacean pollen grains, reflecting saltmarsh communities, and the occurrence of Dinoflagellate cysts confirms the estuarine character of the deposits (D. J. Carter, personal communication; Destombes & Shephard-Thorn 1972). On the basis of the above conclusion it may be relevant to consider here the origin and dispersal of pollen in estuarine environments. In estuaries, wind is the most important agent for transporting pollen. Thus anemophilous pollen of trees and shrubs, in particular the winged pollen of conifers, tends to be favourably represented at the expense of herbaceous pollen. Water transport is also important, though here the pollen is chiefly from plants of aquatic or stream-bank habitats with fern spores and freshwater algae (e.g. *Pediastrum*). Finally, the presence of

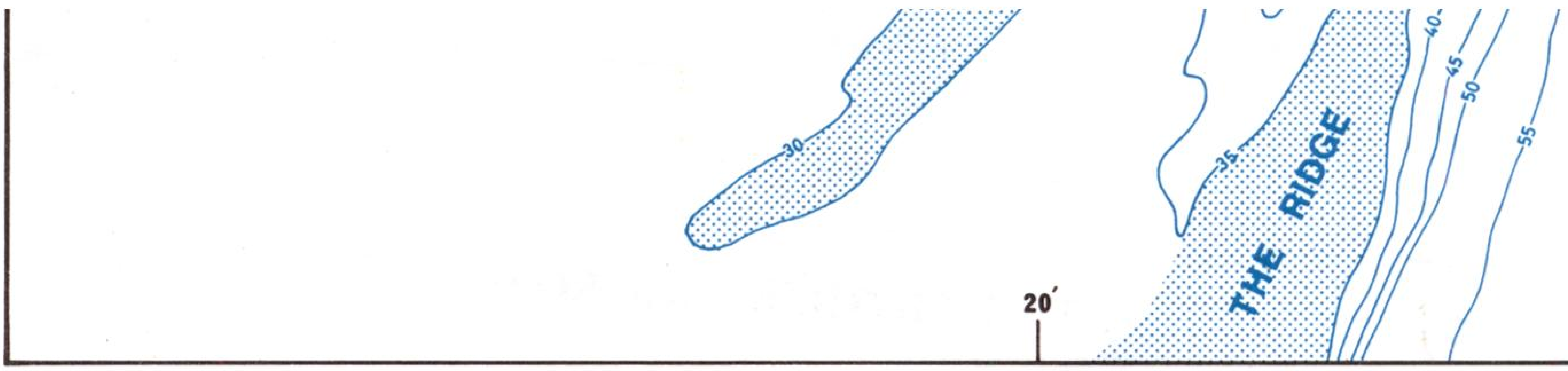


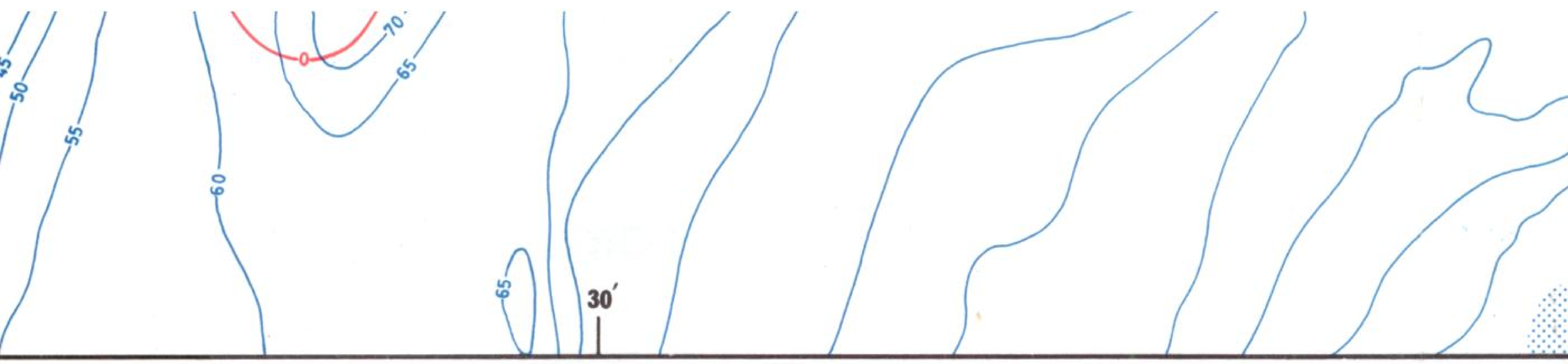
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES


KEY
Seabed bathymetry contoured at 5 metre intervals below NGF
Areas of Recent sand accumulation
Base of buried channel system contoured at 20 m intervals below seabed
DOVER
THE VARNE
20′
5′
51°
C
C′
A

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES


30
35
40
45
50
55
THE RIDGE
20′



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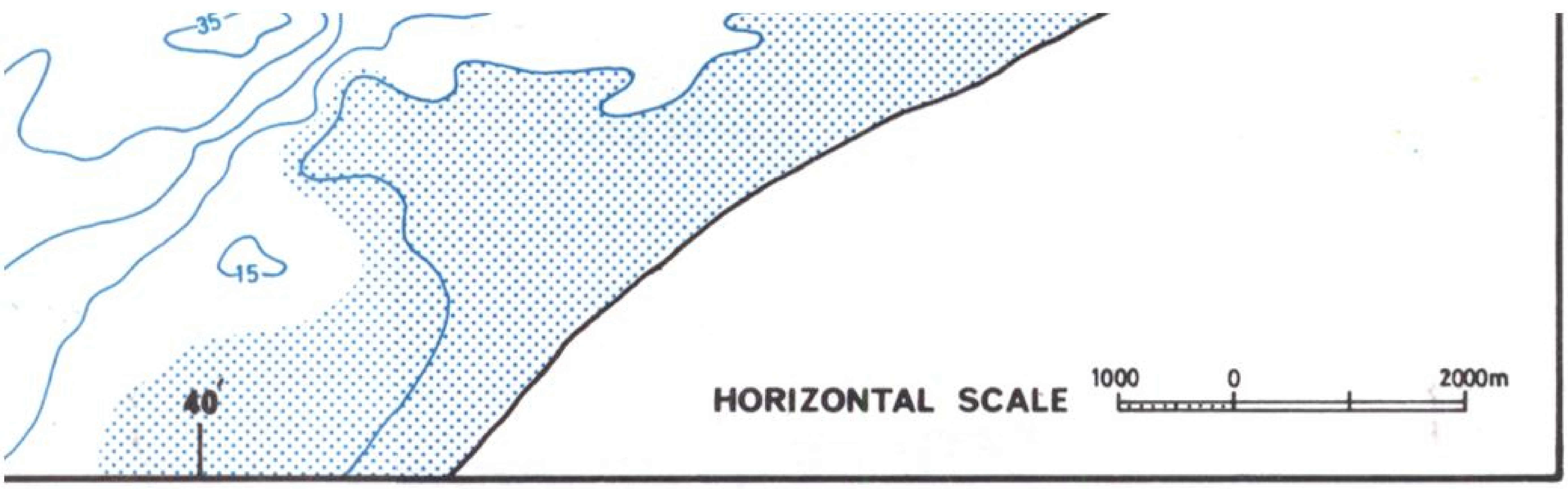

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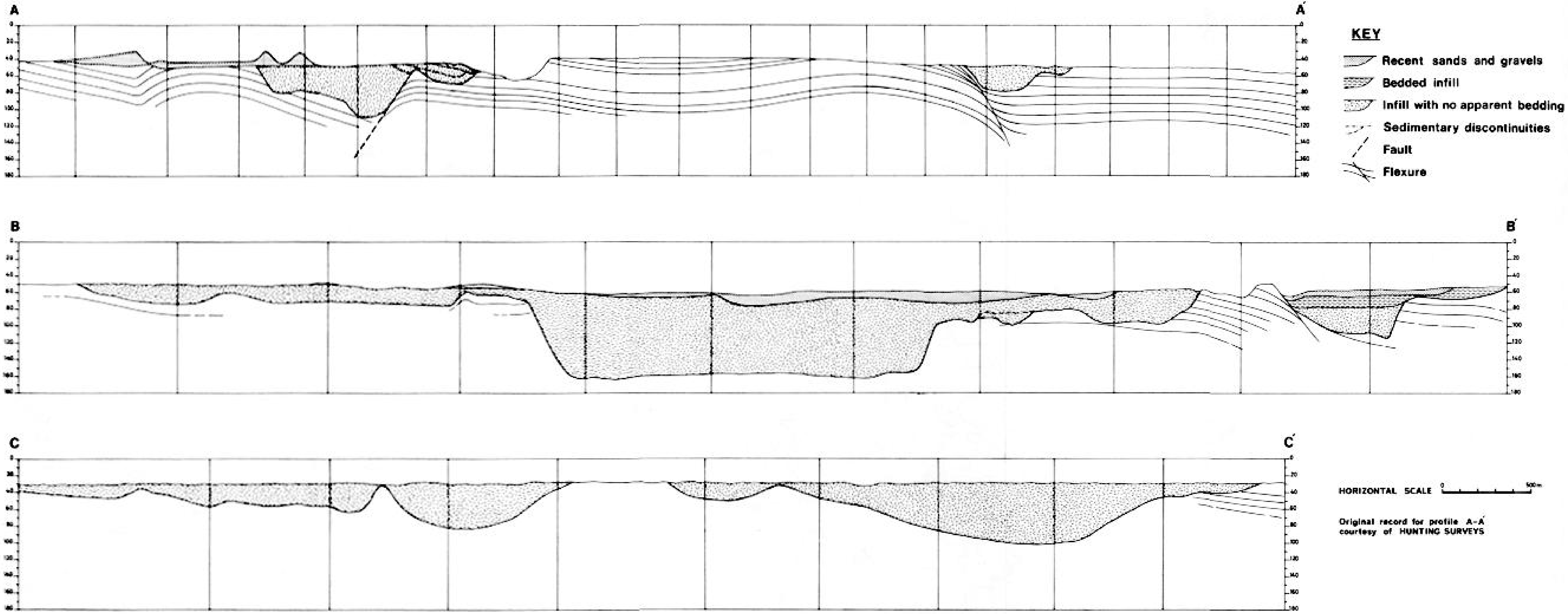

FIGURE 3*b*. Geological interpretations of 'Sparker' profiles across the buried valley system.