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Late Jurassic-Early Cretaceous reef trends on the Continental Margin south-west of the British Isles

D.G. Masson and D.G. Roberts

Internal Document No. 112

October 1980

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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INTRODUCTION

Within the shallow water carbonate sediments which are abundant in the Late Jurassic and Early Cretaceous strata of southern and western Europe, reefal deposits are widespread (Newell, 1972; Coates, 1973; BRGM et al., 1974; Wilson, 1975). In the lands around the Bay of Biscay, Late Jurassic reefal sediments are known from northern Spain (Del Pozo, 1971) and from the Aquitaine Basin (Delfaud et al., 1968; Carozzi et al., 1972; Winnock, 1971; BRGM et al., 1974), the northern flank of which represents the onshore continuation of the Armorican (northern) margin of the Bay of Biscay (Montadert et al., 1974). Early Cretaceous reefs, largely composed of rudistid bivalves, are also known from the Aquitaine Basin, as well as from the Iberian coastal area of the Bay of Biscay (Newell, 1972; Del Pozo, 1971). Dredging and drilling on the Armorican margin have demonstrated Late Jurassic and Early Cretaceous reefal sediments on the Meriadzek Terrace, while clasts of Early Cretaceous peri-reefal limestones have been found in Upper Cretaceous breccias from Goban Spur (Pastouret et al., 1974; Pastouret and Auffret, 1976; Auffret et al., 1979; Montadert et al., 1979).

In this paper we examine the possible wider occurrence and distribution of Late Jurassic-Early Cretaceous reefal sediments on the continental margin southwest of the British Isles using multichannel seismic reflection data (Figure 1) with stratigraphic control provided by dredging and drilling results.

REGIONAL GEOLOGY AND STRUCTURE

The structure of the continental margin southwest of the British Isles consists of a series of tilted and rotated fault blocks thinly covered by undeformed sediments of Cretaceous and Tertiary age (Montadert et al., 1979; Roberts, Masson, Montadert and de Charpal, in press).

The blocks are bounded by listric normal faults, whose throw is consistently down toward the adjoining ocean basin. The faulting occurred during the rifting of Iberia and North America from Western Europe and ceased in Early Aptian time in Biscay and possibly slightly later on Goban Spur. The principal fault trends are WNW-ESE in Biscay and NW-SE on Goban Spur (Montadert et al., 1979; Roberts, Masson, Montadert and de Charpal, in press).

Four seismic formations have been recognized above basement (Montadert et al., 1979). Formations 1 and 2 of Late Cretaceous and Tertiary age are separated from formation 3 by a hiatus or prominent regional unconformity. The underlying Formation 3 is of Aptian-Albian age and was deposited immediately after rifting. The nature of the stratigraphic break between Formation 3 and underlying formation 4 is variable. Towards the crests of the tilted blocks, a prominent erosion surface separates these formations, but within some half-graben there is no obvious stratigraphic break. The age of the erosion surface was determined at DSDP site 401 on Meriadzek Terrace (Figure 1) where Late Aptian chalks rested on latest Jurassic and earliest Cretaceous shallow water carbonates (Montadert et al., 1979). Seismic reflection profiles (e.g. Figure 3, 6) demonstrate the occurrence of formation 3 immediately above the erosion surface over much of the study area thus confirming a minimum age of lowermost Aptian for the event. However, the duration of the event and its maximum age may vary widely.

Formation 4 comprises sediment deposited contemporaneously with rifting and must be pre-Aptian in age. The age of its base is unknown but must be pre-Kimmeridgian-Portlandian assuming that the sediments of this age recovered from site 401 lie within formation 4 rather than within 'basement'. Evidence from well logging suggests that there may be several stratigraphic breaks within the Late Jurassic-Early Cretaceous at DSDP site 401.

INTERPRETATION OF SEISMIC REFLECTION PROFILES

Bubb and Hatlelid (1977) have given a detailed discussion of the various criteria that can be used to identify reefs and carbonate banks on seismic profiles. Criteria found to be of most use in this study included the outline of the carbonate build-ups, lateral changes in seismic response between reefal and contemporaneous non-reefal sediments, and drape of the overlying sediments.

Seismic parameters such as amplitude, frequency and interval velocity can also be used, the latter being especially useful. In the present study, consistently high velocities (4.0-4.5 km/sec) were observed in supposed carbonate bodies, even though the lack of velocity 'pull-ups' under such reefs appears to suggest that they are of no great thickness. The accuracy of interval velocity determinations made over such limited intervals (100-200 m.secs) and their use as lithological indicators may be questionable, but is here justified by the reasonable agreement with velocities logged down-hole in peri-reefal carbonates at DSDP site 401 (Montadert, Roberts et al., 1979). A high velocity contrast between reefal and non-reefal sediments is also indicated by the exceptionally high amplitude reflections which frequently define the tops of the carbonate bodies.

We must also consider the possibility that some of the supposed reefs may be small intrusions (e.g. Figure 5), particularly in view of recent evidence for a Mid-Jurassic igneous episode in the study area (Caston et al., 1979; Roberts, Masson, Montadert and de Charpal, in press; Robinson et al., in press). However, onlap of later reflectors onto the supposed reefs would appear to rule out an intrusive igneous origin, and comparison with known intrusive and extrusive bodies seen on seismic reflection records from the Rockall Trough (Roberts, Masson and Miles, in press) shows a radically different reflection configuration from that which defines the supposed reefs.

An example of a reef that occurs within a half-graben on Goban Spur is shown in Figures 2 and 3. The reefal body is lenticular in profile and is characterised by a lack of internal structure in an otherwise well-layered sediment sequence. The surface of the body is defined by an unusually strong reflection and the body has a high interval velocity of 5.3 km sec^{-1} (Figure 2). Adjacent reflectors onlap and wedge out against the proposed reef, while those below appear to be continuous. High interval velocities of between 4.0 and 4.5 km sec^{-1} observed in the adjacent sediments at the same stratigraphic level on the reefs may indicate peri-reefal carbonates.

DISTRIBUTION OF THE REEFS

All the reefs or reef complexes identified in this study lie within formation 4 of Montadert et al. (1979), and occur within the half-graben below the level of the pre-Aptian unconformity. Reefs are conspicuously absent from fault block crests and appear to be concentrated in the shallowest parts of the half-graben immediately behind and below the crests of tilted blocks. This suggests that reef growth was contemporaneous with the subsidence of the half-graben, and that the rate of reef growth approximately equaled the rate of subsidence in the shallower parts of the half-graben. Speculatively, reef trends may parallel those of tilted blocks.

Possible occurrences of reefs in the deeper parts of half-graben (e.g. Figure 5), which initially appear unlikely sites for reef growth, may indicate early phases of reef growth subsequently buried as a result of later or faster subsidence accompanied by contemporaneous sedimentation.

The absence of reefs from fault-block crests is best and most simply accounted for by the affects of pre-Aptian and possibly later erosion which has truncated the fault-block crests and removed much of formation 4. Confirmation of at least one phase of erosion is given by the occurrence of clasts of Lower Cretaceous peri-reefal limestones in Late Cretaceous breccias dredged from the flanks of Goban Spur (Auffret et al., 1979). Evidence of earlier erosion during development of the fault-block topography is not so strong, but may be indicated by possible hiatuses within the Kimmeridgian-Portlandian at site 401 (Montadert, Roberts et al., 1979). Alternatively, continuous erosion of some fault blocks during their development may have completely inhibited reef growth.

Estimates of the dimensions and trend of individual reef complexes cannot be easily made because of the wide spacing of the seismic profiles. On individual seismic profiles, the largest reef complexes reach 2 km in width and may have thicknesses of between 100 and 200m, although this is particularly difficult to estimate. On Goban Spur, two seismic profiles some 5 km apart show a possibly continuous reefal body that has an E-W trend parallel to the axis of the half-graben within which it occurs.

AGE OF THE REEFS

The occurrence of the reefs within formation 4 demonstrates that they are pre-Aptian in age. Dredging has established the presence of Early Cretaceous rudistid reefs, and Kimmeridgian-Portlandian reefal sediments were sampled at DSDP site 401 (Pastouret & Auffret, 1979; Montadert, Roberts et al., 1979). Newell (1972) has pointed out that reefs are largely unknown for the first 20 m.y. of the Cretaceous. These observations suggest the possibility of two phases of reef development of Late Jurassic and Hauterivian-Barremian age respectively. However, even earlier ages within the Jurassic should not be excluded although the position of reefs within the upper part of the syn-rift sequence tends to suggest development during the later stages of rifting.

PALAEOBATHYMETRY

The present day occurrence of Mesozoic reefs in water depths exceeding 200m is best understood as the result of regional subsidence of the continental margin which was initiated at the onset of sea-floor spreading at about 110 m.y. in the Bay of Biscay and possibly slightly later to the west of Goban Spur (Montadert et al., 1979; Roberts, Masson, Montadert and de Charpal, in press). The distribution of the reefs, and their close spatial relationship to the pre-Aptian erosional unconformity, is therefore pertinent to our understanding of the palaeobathymetry of the incipient margin during the later stages of rifting.

In the case of Goban Spur, the distribution of the erosion surface and the occurrence of Lower Cretaceous reefs (Figure 7) demonstrates that shallow marine conditions existed at least until the middle of the Cretaceous. In Biscay, however, both the reefs and the erosion surface are confined to the southern slope of Goban Spur, to the area of the present day shelf edge, and to an isolated fault-block underlying the Meriadzek Terrace (Figure 7), indicating that the remainder of the area had already subsided below depths favourable for reefal growth by pre-Aptian time. Indeed, the presence of Calpionellid limestones on the northern margin of the Bay of Biscay (Pastouret and Auffret, 1976) may indicate open and relatively deep water conditions as early as the Late Jurassic, although this fauna is of dubious bathymetric significance (Auffret et al., 1979). The apparent absence of reefs on the north Biscay margin is surprising but may be a consequence of later erosion or of higher clastic input and subsidence faster than possible reefal growth. The presence of a series of closely spaced tilted blocks at shallow depth on Goban Spur may have favoured entrapment of clastics and preservation of a favourable habitat for reef growth.

PETROLEUM PROSPECTIVITY

The Upper Jurassic reefal limestones drilled on Meriadzek Terrace have good primary and secondary porosity (5-30%, Montadert, Roberts et al., 1979) and are thus good potential reservoirs where they are effectively sealed by the overlying hemipelagic marls. Although no porosity data are available for the Cretaceous reefal sediments, Arthur and Schlanger (1979) have noted the worldwide importance of Cretaceous rudistid limestones as a reservoir facies.

The question of the likely maturity of any potential source beds and of hydrocarbon generation is very open. In north Biscay, the only known potential source is the Aptian-Albian black shale sequence drilled at sites 400A and 402A although there may be further potential source beds in the as yet untested formation 4 (e.g. Kimmeridgian shales). The Albian-Aptian black shales are composed of terrigenous organic matter only and thus represent a potential gas source (Tissot et al., 1974) but they are immature (Deroo et al., 1979) and covered only by 1-2 km of sediment.

The relationship between subsidence and the thermal history of rifted margins shows that the highest heat flows (and thus temperature gradients) are developed prior to and immediately after continental break-up (Sleep, 1971; Royden et al., 1980). In Biscay, the time of continental break-up and the onset of spreading is estimated at about 110 m.y. (Montadert et al., 1977, 1979). Even if temperature gradients exceeded the oil generation threshold at this time the reefs in both Biscay and on Goban Spur were probably not buried to any significant depth and were thus unlikely to have been effectively sealed. Within the adjoining Porcupine

Seabight, however, there are in excess of 5 km of Cretaceous and Tertiary sediments. In this basin, hydrocarbon generation may, in addition to the above mechanism, have proceeded according to normal depth and time of burial concepts (Dow, 1978). Provided that adequate source beds (e.g. Kimmeridgian or Aptian-Albian black shale) and migration paths are present, the hydrocarbon prospects of reef structures adjoining the Porcupine Seabight on Goban Spur should be considered promising.

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FIGURE CAPTIONS

Fig. 1. Seismic reflection data used in this paper. Also shown are the bathymetry of the study area and the location of DSDP site 401.

Fig. 2. Interpreted seismic profile from Goban Spur (Figure 1) illustrating a reefal body. Note the very high interval velocity within the reefal body.

Fig. 3a Part of a seismic profile from Goban Spur (Figure 1) illustrating a reefal body. Scale as for Figure 3b.

Fig. 3b Interpretation of profile shown in Figure 3a. Key as for Figure 2.

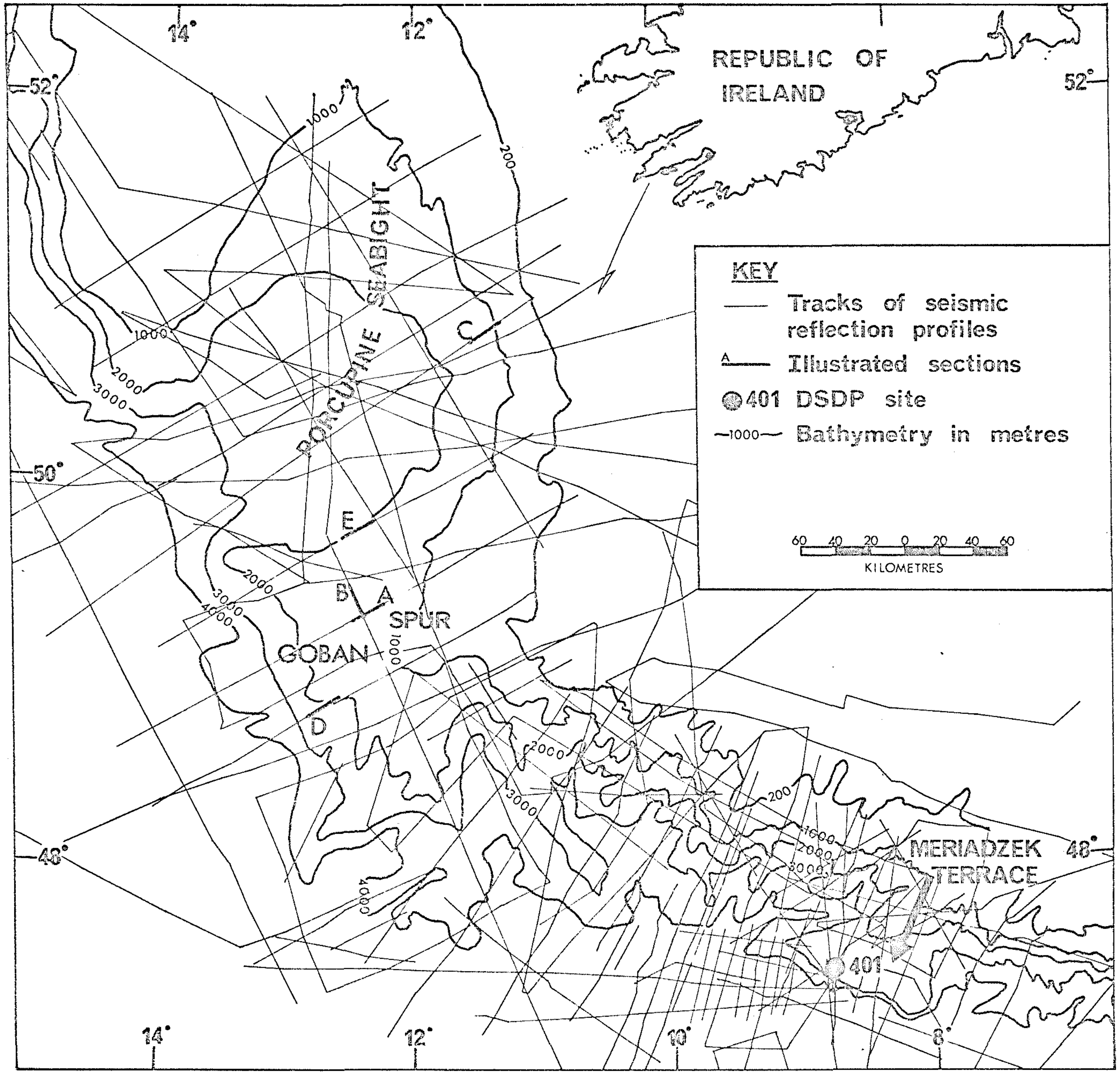
Fig. 4. Interpreted seismic profile from the eastern margin of the Porcupine Seabight (Figure 1), illustrating a reefal body. Key as for Figure 2.

Fig. 5. Interpreted seismic profile from the western Goban Spur (Figure 1). Note that the postulated reef now lies some 4 secs (two-way time) below sea-level, indicating considerable subsidence since the period of reef formation. Key as for Figure 2.

Fig. 6. Interpreted seismic profile from the southern Porcupine Seabight (Figure 1), illustrating the 'Mid-Cretaceous' erosion surface and its relationship to formation 3 of Montadert et al. 1979. Key as for Figure 2.

Fig. 7. Distribution of reefs and the areal distribution of the 'Mid-Cretaceous' erosion surface.

FIG. 1



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IRELAND
KEY
Tracks of seismic reflection profiles
Illustrated sections
401 DSDP site
Bathymetry in metres
KILOMETRES
PORCUPINE SEABIGHT
GOBAN SPUR
MERIADZEK TERRACE
401
A
B
C
D
E
14°
12°
10°
8°
52°
50°
48°

FIG. 2

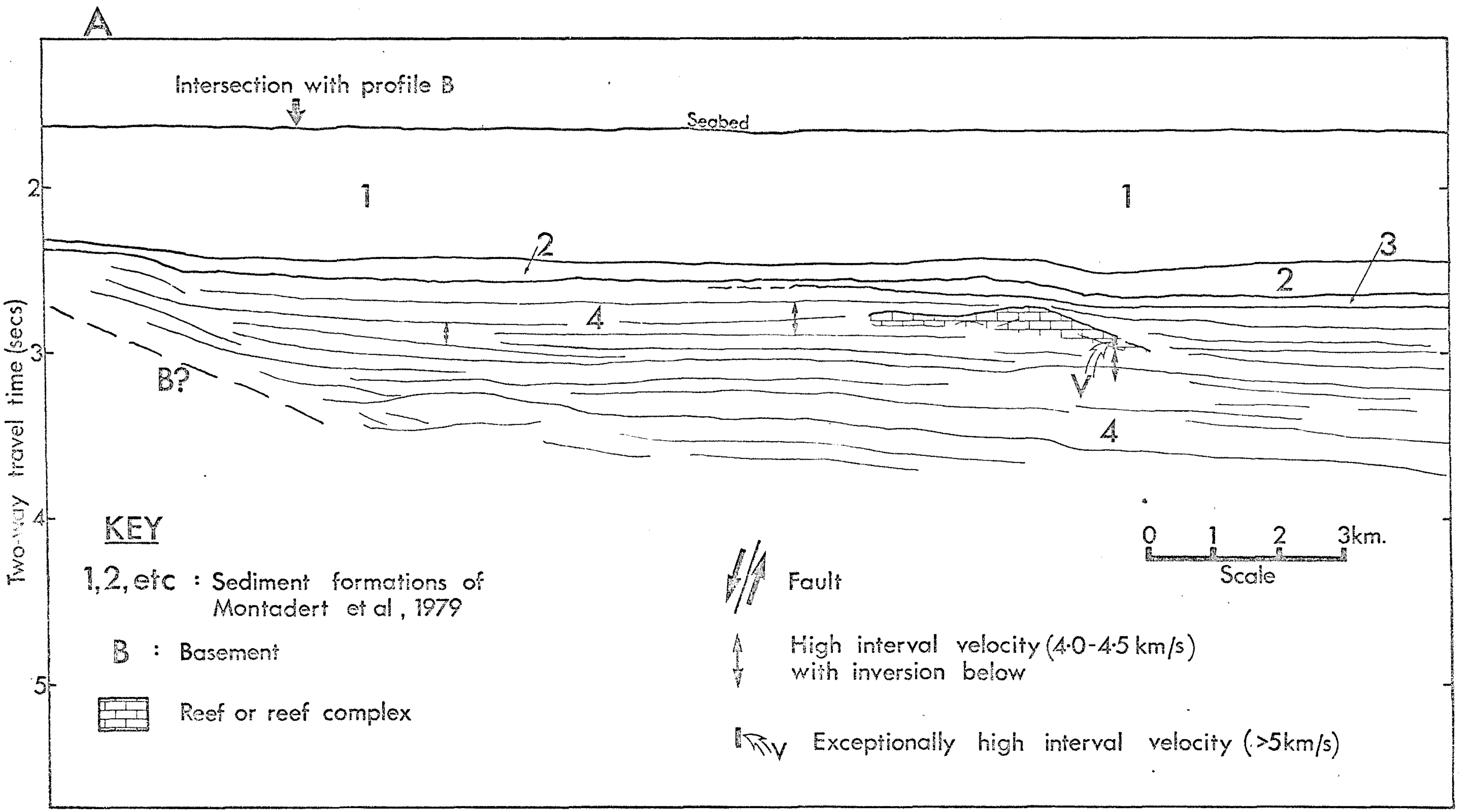

A
Intersection with profile B
Seabed
1
1
2
2
3
4
4
B?
Two-way travel time (secs)
2
3
4
5
KEY
1,2, etc : Sediment formations of Montadert et al, 1979
B : Basement
Reef or reef complex
Fault
High interval velocity (4·0-4·5 km/s) with inversion below
V Exceptionally high interval velocity (>5km/s)
0 1 2 3km.
Scale

FIG. 3a

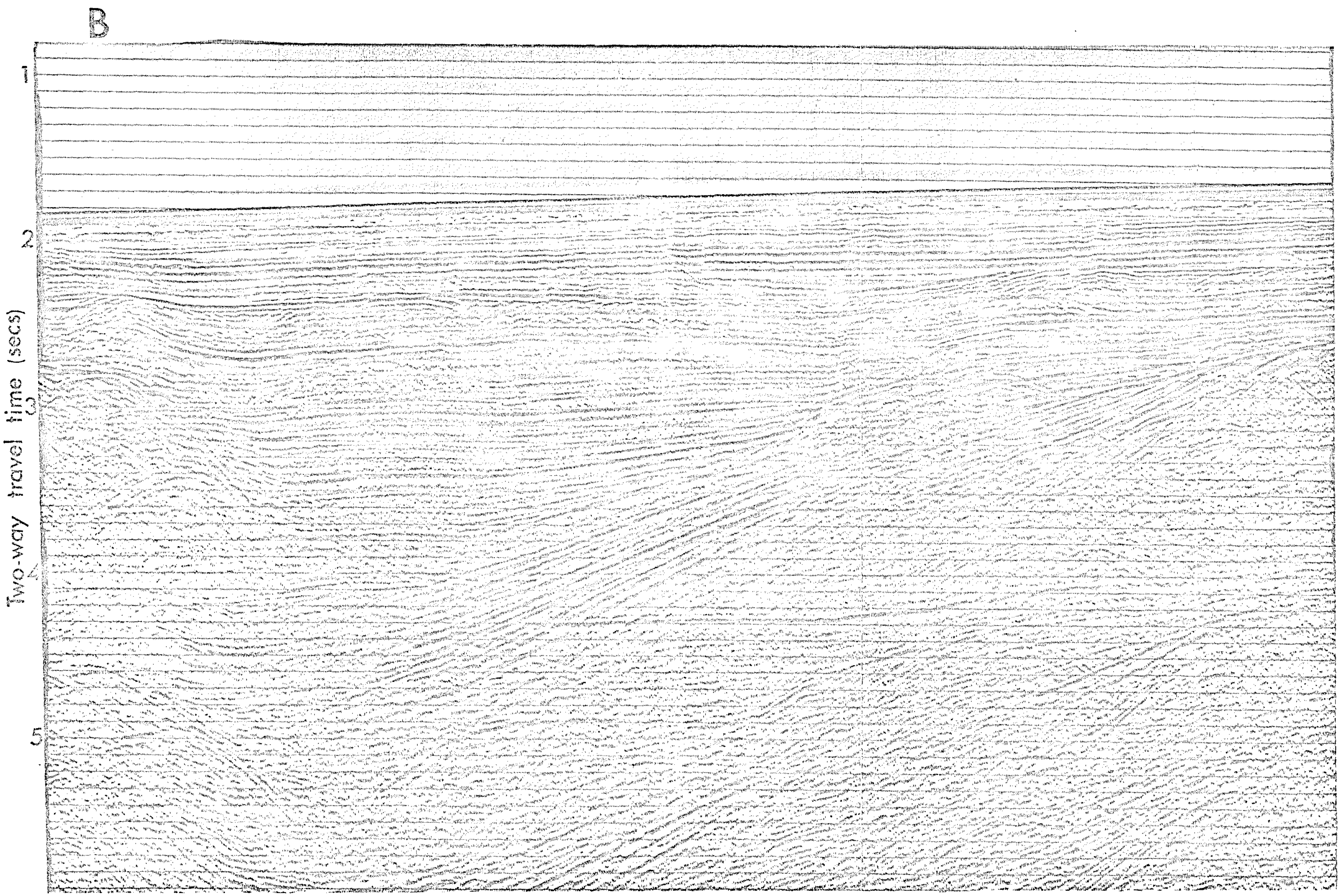


FIG. 3b

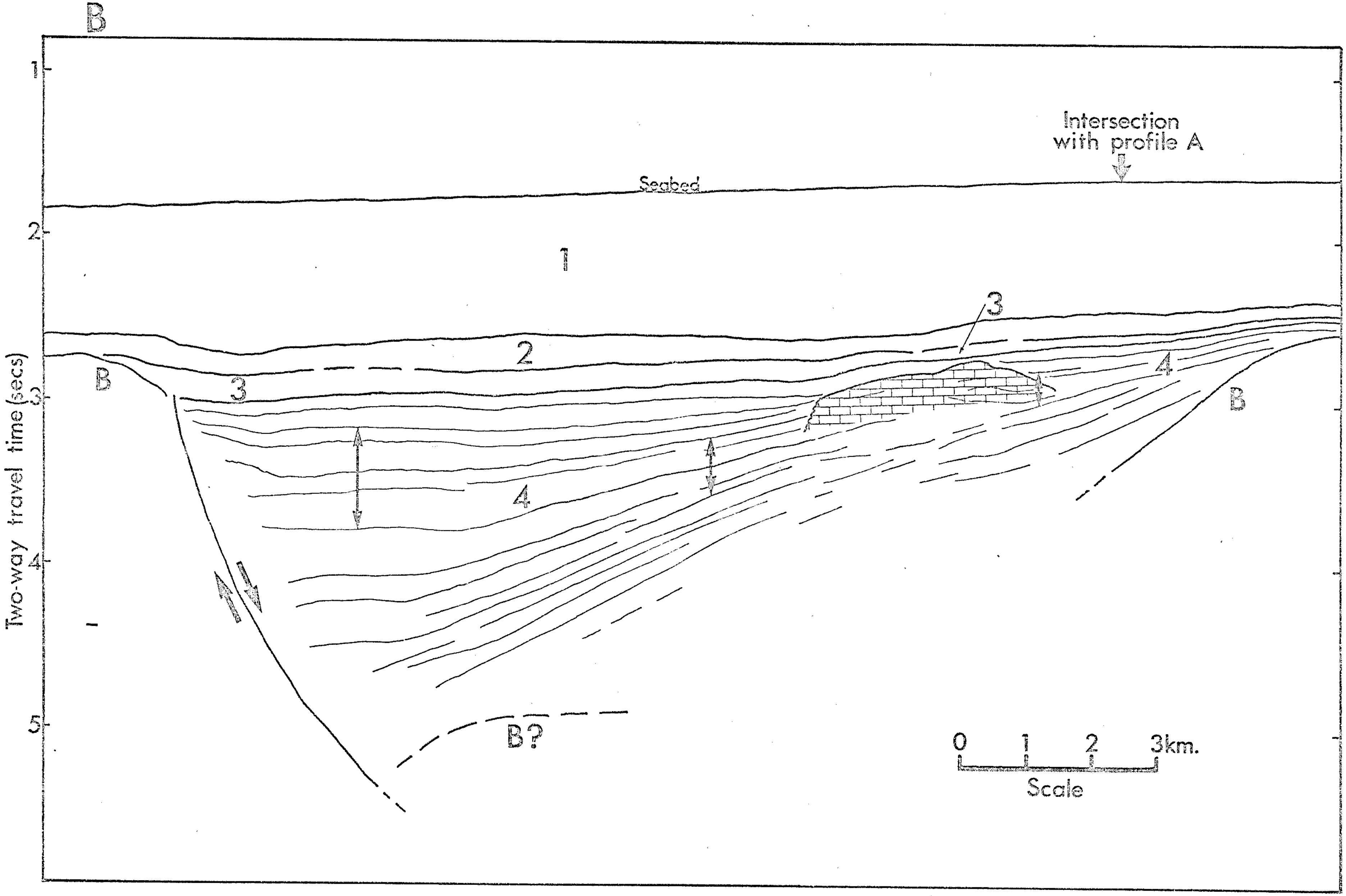

B
Intersection
with profile A
Seabed
1
2
3
3
4
4
B
B
B?
Two-way travel time (secs)
1
2
3
4
5
0 1 2 3km.
Scale

FIG. 4

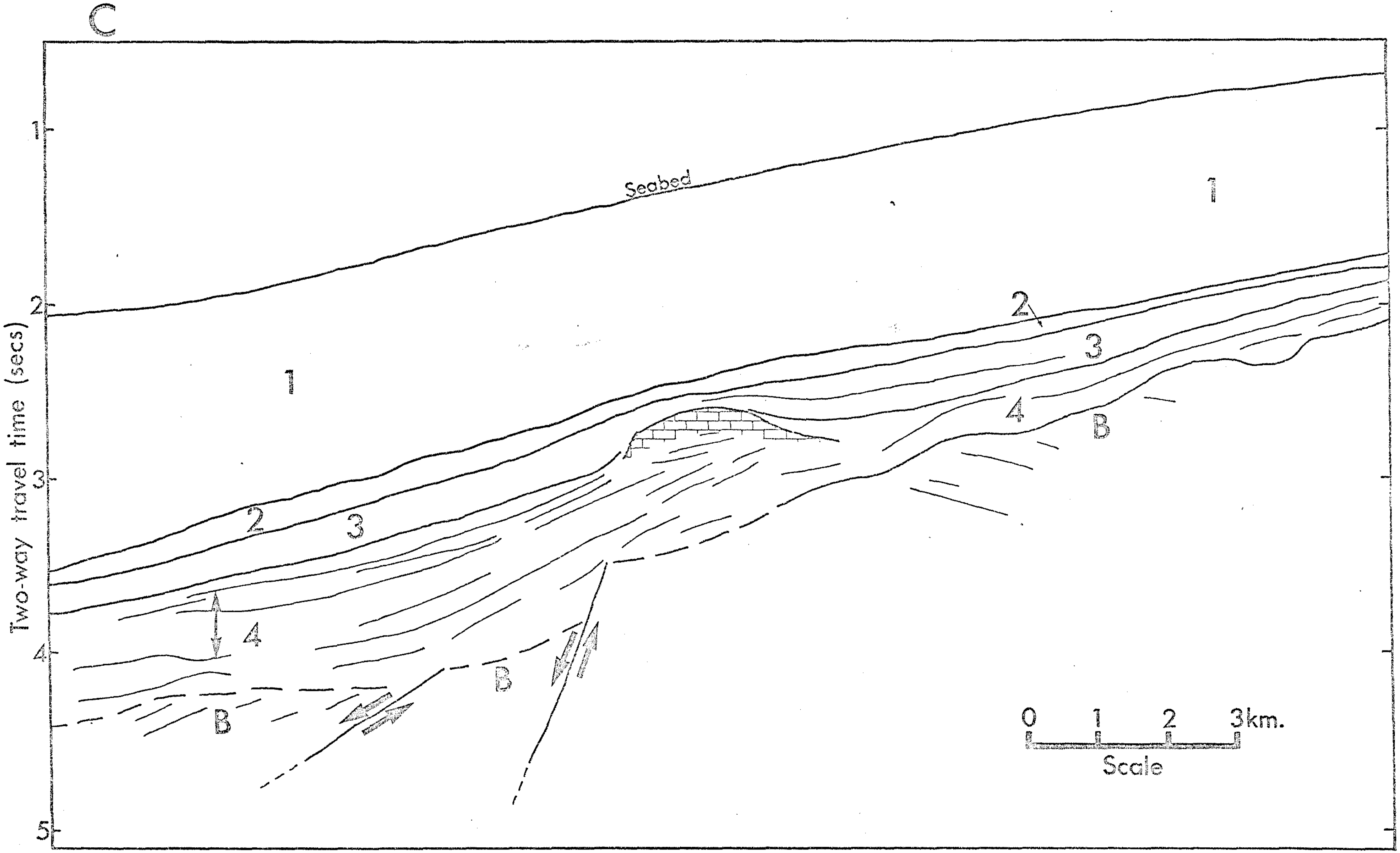
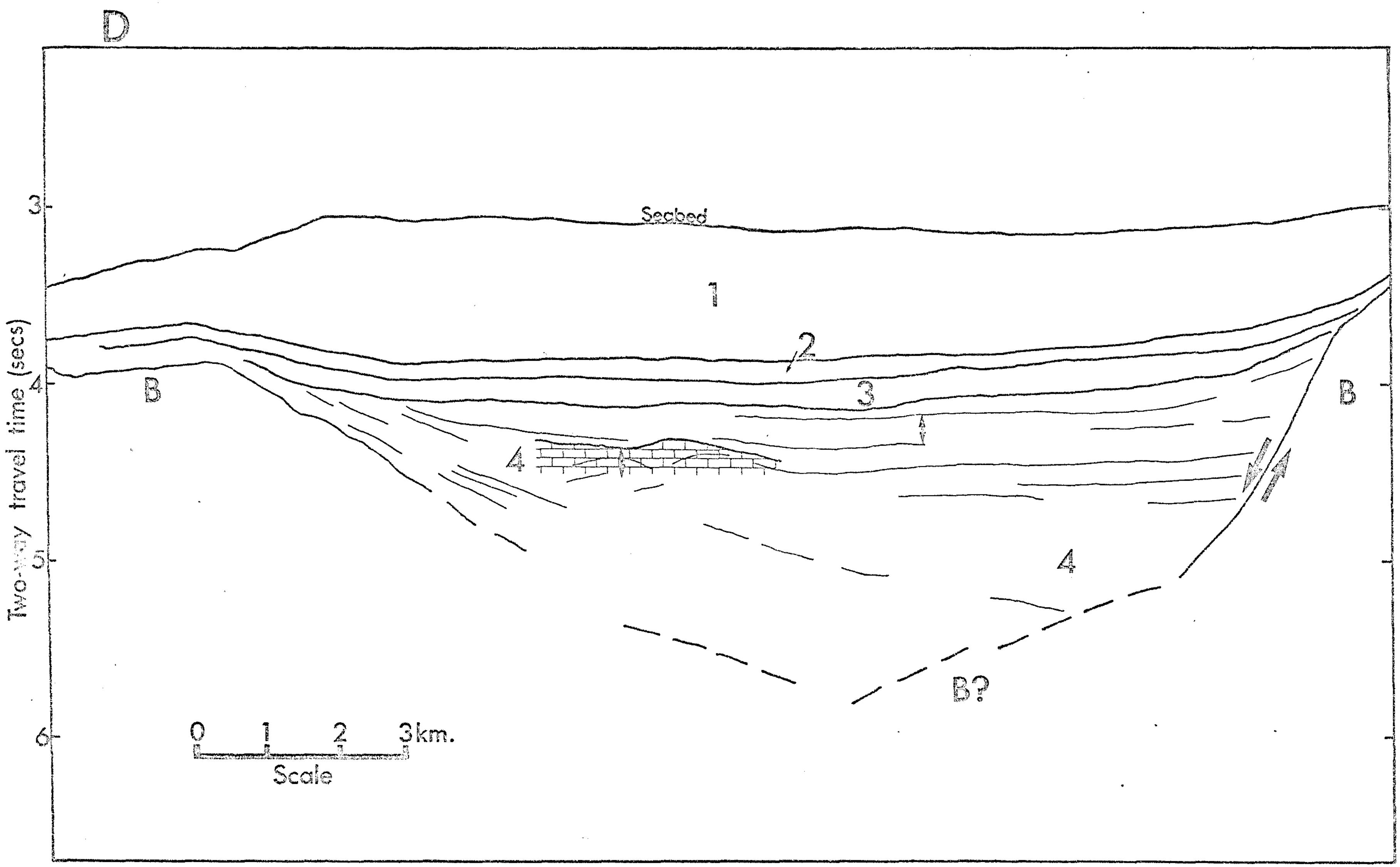


FIG. 5



D
Seabed
1
2
3
4
B
B
4
B?
Two-way travel time (secs)
3
4
5
6
0
1
2
3km.
Scale

FIG. 6

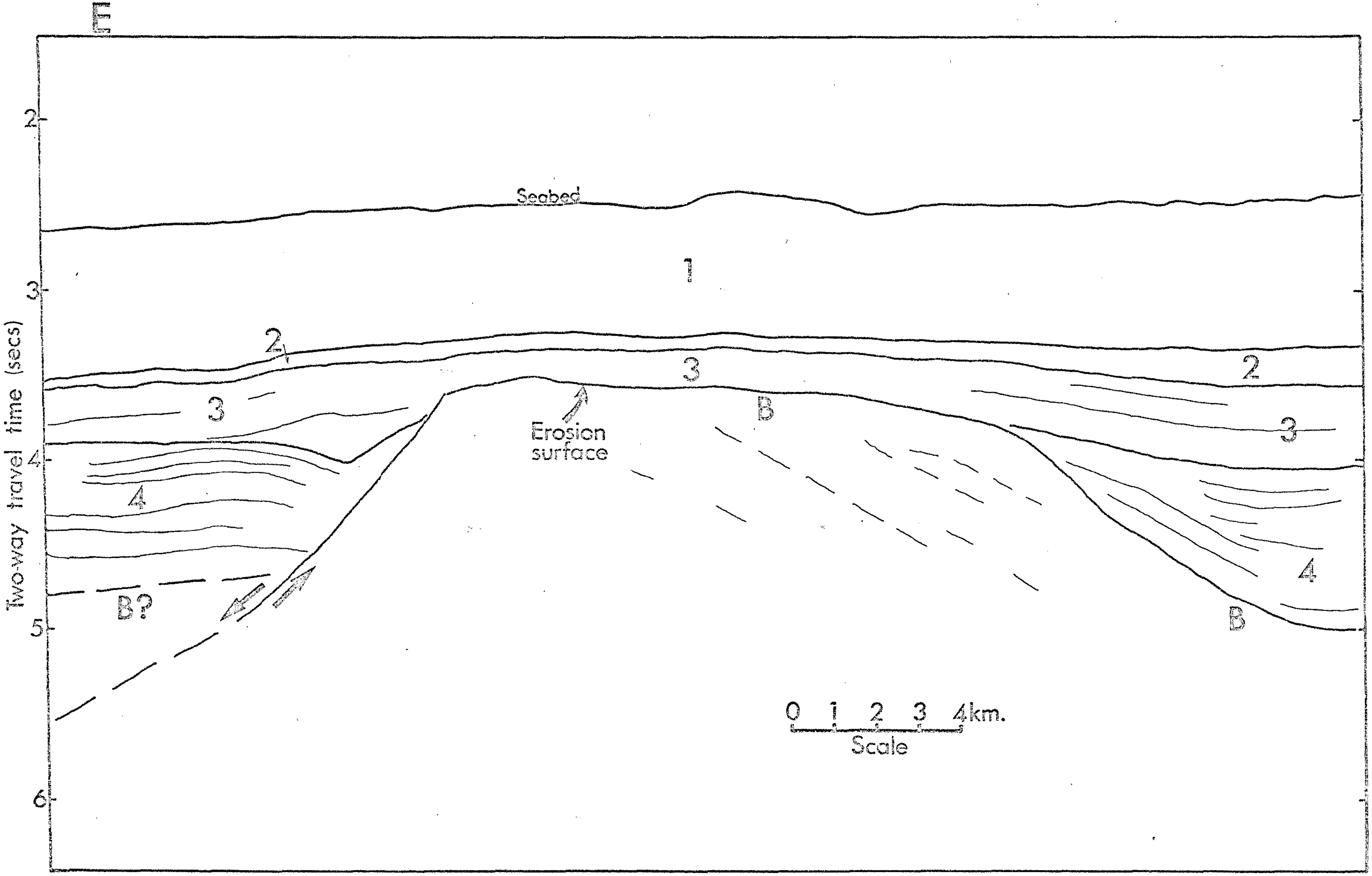
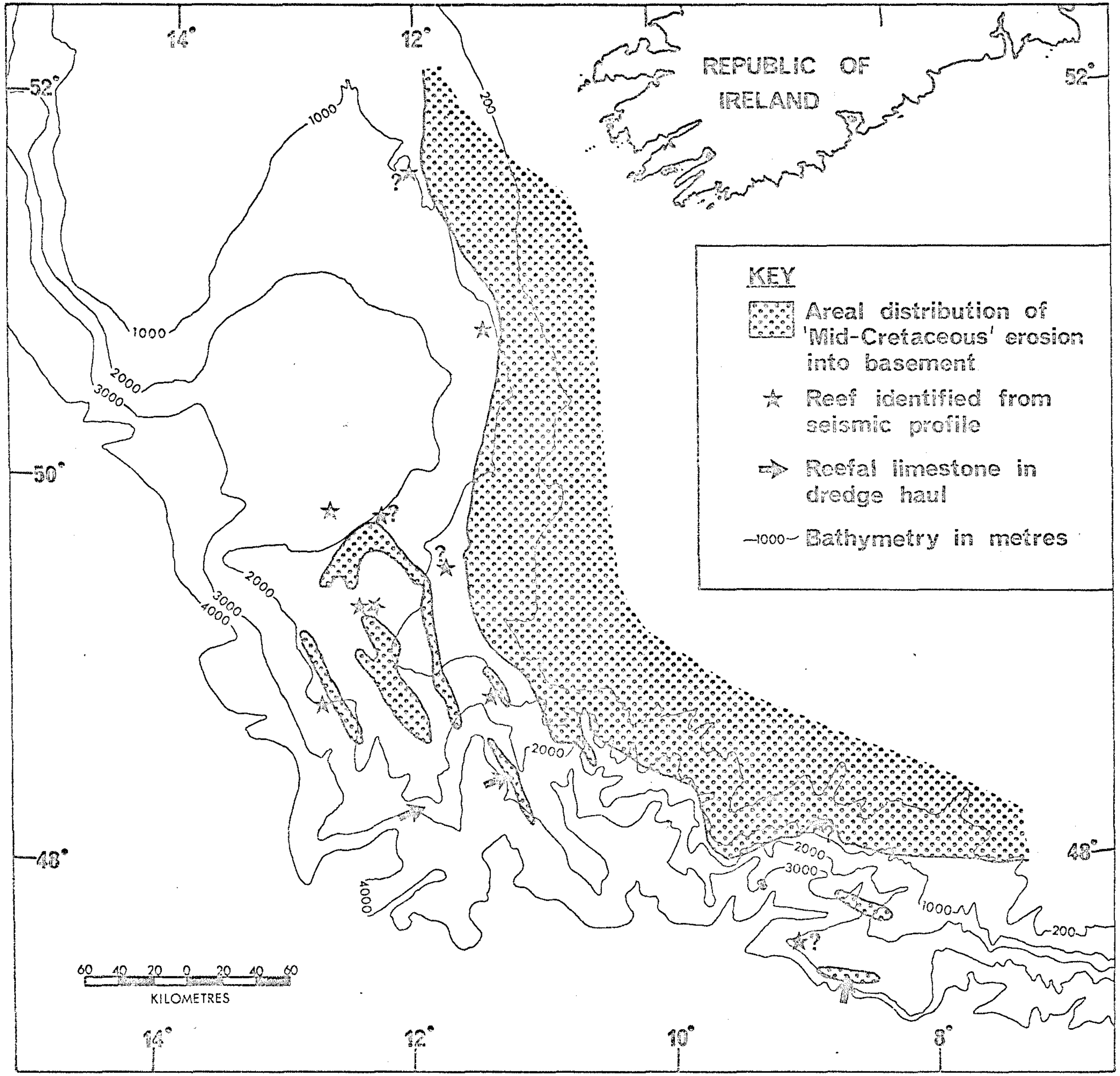

E
Two-way travel time (secs)
2
3
4
5
6
Seabed
1
2
3
2
3
3
B
Erosion surface
4
B?
3
4
B
0 1 2 3 4km.
Scale

FIG. 7



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KEY
Areal distribution of 'Mid-Cretaceous' erosion into basement
Reef identified from seismic profile
Reefal limestone in dredge haul
Bathymetry in metres
14°
12°
10°
8°
52°
50°
48°
200
1000
2000
3000
4000
KILOMETRES
60 40 20 0 20 40 60