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

Some Features of the Northwest African Margin and Magnetic Quiet Zone

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Some features of the northwest African margin and magnetic quiet zone

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[Plates 1 and 2]

A smooth basement reflector drilled in D.S.D.P./Ipod Site 367 as basalt extends throughout much of the magnetic quiet zone off North West Africa. Multichannel seismic lines show structures and layered rock complexes locally beneath this basalt reflector. Under the continental slope of Senegal and Mauritania, the basement reflexion is no longer distinguished beneath a Cretaceous carbonate front.

Refraction profiles between the Cape Verde Rise and Mauritania and from Conception Bank to Morocco establish the existence of a 7.1 km/s layer at a depth of 14 km. Off Mauritania the smooth basement seems to merge with this layer. Diapiric salt basins existing under the continental rise are only resolved as velocity layers off Mauritania. No sharp boundary from continental to oceanic crust was deduced from the seismic data.

Introduction

Since 1967, the Federal Institute for Geosciences and Natural Resources (B.G.R.) has carried out several geophysical and geological cruises to the NW African Margin between Morocco and Sierra Leone (figure 1). The Institute of Geophysics of the University of Hamburg co-operated during refraction survey legs. Latest cruises were Valdivia-10 and Meteor-39 in 1975 (see Seibold & Hinz 1976), which served as D.S.D.P./Ipod pre-site surveys for Legs 47 and 50 and post-site surveys for Leg 41.

The magnetic and gravity data collected have been processed and are still being analysed. This paper presents some results of the seismic investigation of the 1975 surveys for the areas off (*a*) Senegal, (*b*) Mauritania and (*c*) Ifni/Morocco.

Geological setting

The main structural features of NW Africa (figure 1, Querol 1966) are given by the offshore Miocene (Grunau *et al.* 1975; Schmincke 1977) volcanic islands of the Cape Verde and Canary Archipelago and a string of elongate marginal basins onshore (Lehner & de Ruiter 1976). These subsidence basins are separated from the African craton by the Palaeozoic fold belt of the Mauritanides (Machens 1966) and divided by the Anti-Atlas and Requibat Precambrian Highs into the Essaouira, Aaiun and Senegal–Mauritania basins (Choubert & Faure-Muret 1971). Mesozoic transgressive and Cainozoic (post-Eocene) regressive sediments of a flexured west-dipping monoclinal platform discordantly overlie the Hercynian folded Palaeozoic or metamorphosed Precambrian basement (Carrier 1961; Lehner & de Ruiter 1977).

* Presented paper at the meeting.

Senegal–Gambia

Single trace seismic reflexion records from site 367 where Oxfordian to Kimmeridgian red argillaceous limestones overlying basalt were drilled (Leg 41 scientific party 1975) show a smooth acoustic basement (VA-10-109 and 111, figure 2).

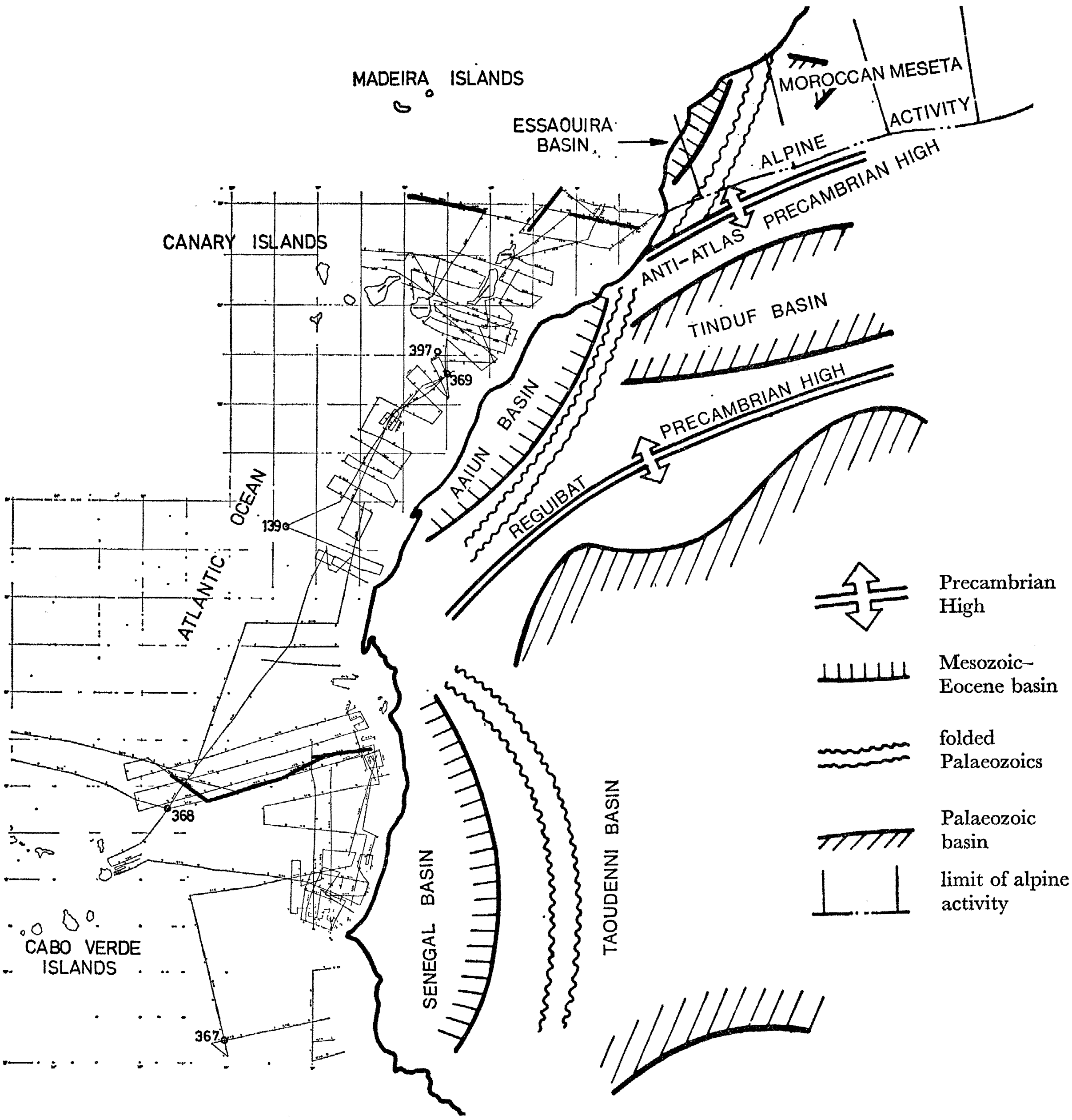

Figure 1. Track chart of reflexion seismic profiles collected offshore NW Africa by the Federal Institute for Geosciences and Natural Resources. Not shown is a D.S.D.P./Ipod site survey of the Mid-Atlantic ridge flank over the magnetic anomaly 33 to the NW of the Cabo Verde Islands. Reversed refraction profiles are drawn in heavy lines. Numbers denote D.S.D.P./Ipod drill sites. Schematic geology is taken from Querol (1966).

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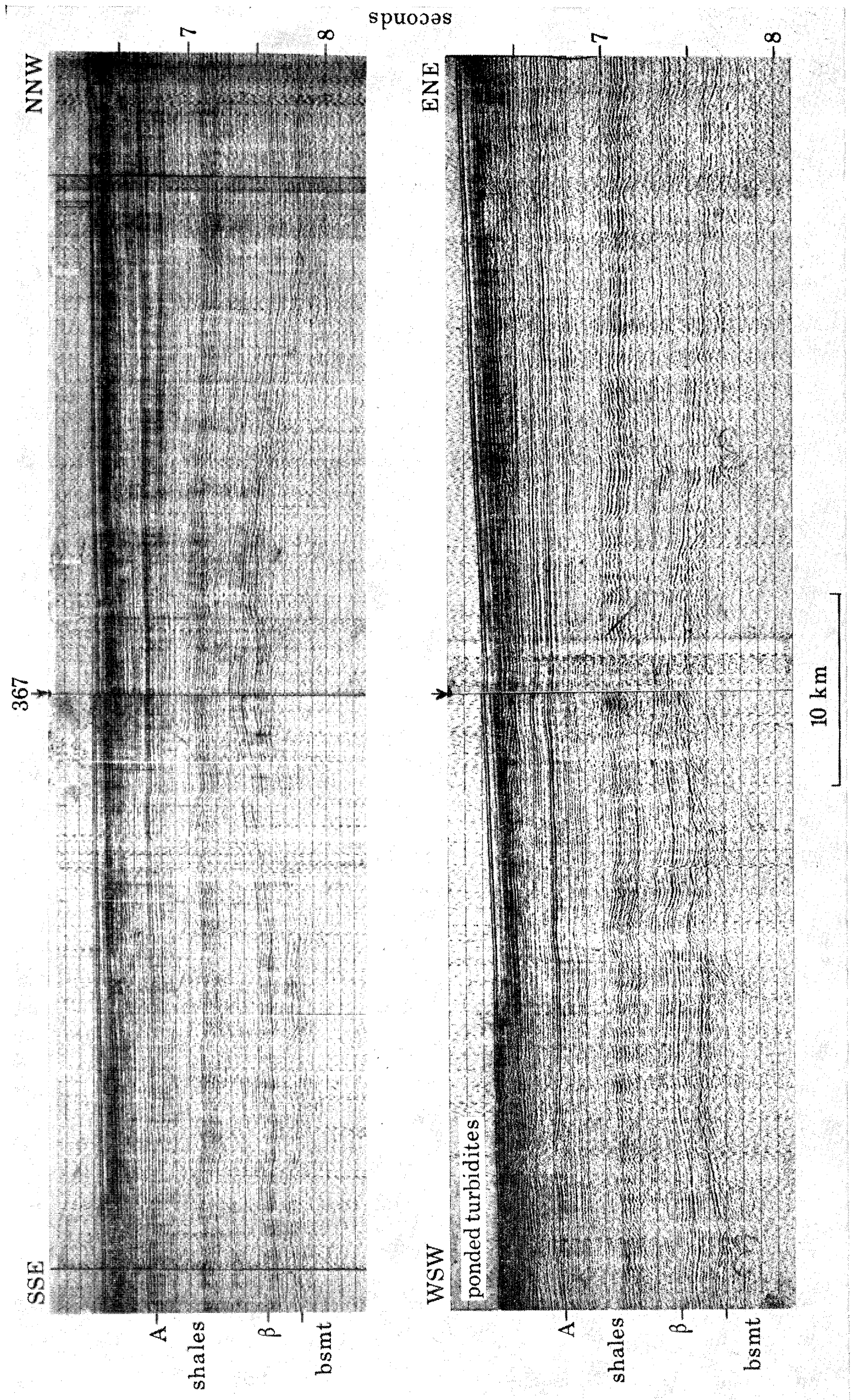

FIGURE 2. Single trace reflexion profiles VA-10-109 and 111 across D.S.D.P. site 367. For reflector nomenclature see figure 3. The ponded turbidites near the ocean bottom are spread in the Cabo Verde abyssal plain by the Cayer canyon turning south near 15° N, 21° W. (See Gambia–Senegal bathymetry survey chart 839–A of the Canadian Hydrographic Service.)

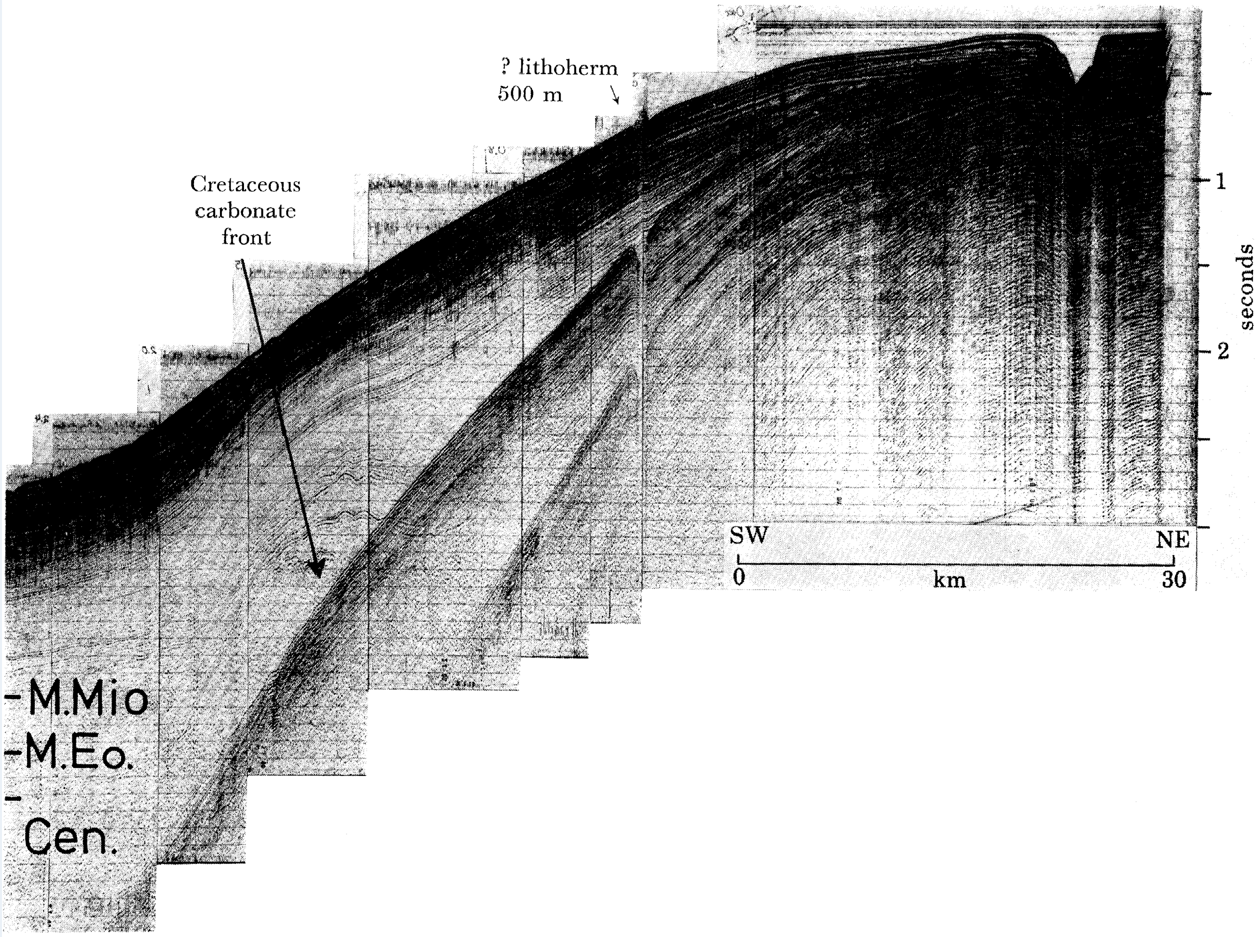

FIGURE 7. Reflexion profile VA-10-66 (D.S.D.P. site 368 to Mauritania) at 18° 40′ N. The record shows a Cretaceous carbonate front, a (possibly) reefal structure extending along the Mauritanian continental slope for more than 100 km at 500 m depth, and the Tiouilt canyon head. Dredges VA-10-45 and 46 from the canyon yielded Pleistocene glauconite sandstone (B. Zobel & U. von Rad, personal communication).

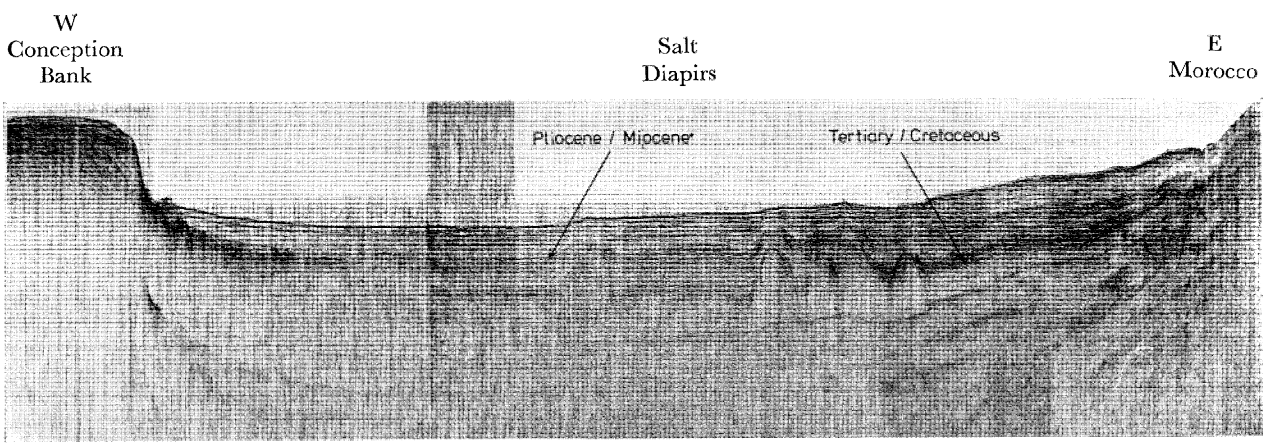

FIGURE 9. Twelve-channel reflexion profile M 39-07 along refraction line M 39-I from the Conception Bank with its Miocene volcanic apron to Ifni–Morocco.

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Digital seismic records (figure 3), however, indicate that the basalt drilled at Site 367 may only be the top of a sequence more than 500 m thick composed, presumably, of sills and flows overlying stratified rocks of unknown nature. As the site is reported south of a postulated fracture zone at 13° N between magnetic lineations M22 and M23 (Jones & Mgbatogu 1977), this places constraints on the age of the stratified rocks if they are sediments. This material in turn rests on a hummocky envelope of diffractions more typical of an oceanic layer 2 surface at about 1.5 km under the basalt drilled at Site 367 respectively 6.4 km below sea level. At about 10 km depth there are indications for stratified layering, which could correspond to the stratiform layered gabbro complex of the oceanic layer 3 in the model of the oceanic crust (Moores 1975).

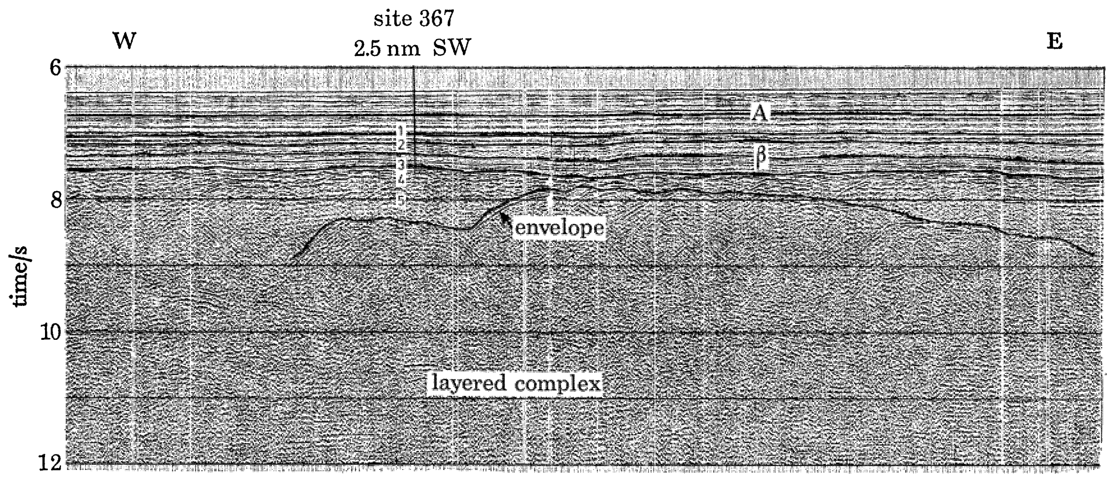

FIGURE 3. Digital seismic record showing a structured basement under D.S.D.P. Site 367. Horizontal scale is given by shot point interval of 50 m. Vertical exaggeration 1:3. A = M. Eocene, β = top Neocomian limestone, 1, L. Senonian; 2, M. Albian; 3, basalt; 4, sills; 5, layered rocks.

Other outstanding reflectors in the seismic record of Site 367 (figure 2) mark (1) the top of Neocomian limestones (horizon β), (2) the upper and lower boundary of the mid-Cretaceous black shale deposits, (3) the early to mid-Eocene chert horizon A. Near Site 367, horizon A is a rather distinct reflector, whereas north of a line Dakar–Cape Verde Islands, horizon A is masked by many highly reflecting turbidite layers. An example of recently deposited, distally ponded turbidites, which have been carried to the Gambia Rise by the southcurving Cayar canyon, is seen near the ocean bottom at the western end of the profile across Site 367 (figure 2).

The many Palaeogene turbidites in the seismic records north of Dakar are indications of a depocentre of the then northward flowing Senegal river between 17° and 18° N.

A compilation of our own with published data between 12° and 19° N produced isochron maps for horizon A (figure 4), the top of the black shales (figure 5) and the acoustic basement (figure 6). In the latter map the smooth acoustic basement ascertained as basalt at Site 367 is contoured. The region between the Cape Verde Islands and the continental slope of Africa is underlain by smooth basement which changes to a hummocky topography further west. After deposition of the Eocene horizon A submarine volcanic piles were intruded into the smooth basement of the Senegal rise.

Mauritania

At travel times of about 8 s under the upper rise the basement is sometimes branching out into several reflectors and the Jurassic carbonates overlying it are downfaulted to the east.

The seaward limit of the initial rift-grabens could be in this vicinity, perhaps in the form of a hinge-line for the continental slope sediment wedge, which may be associated with volcanic intrusives (VA-10-84 in figure 5 of Seibold *et al.* 1976).

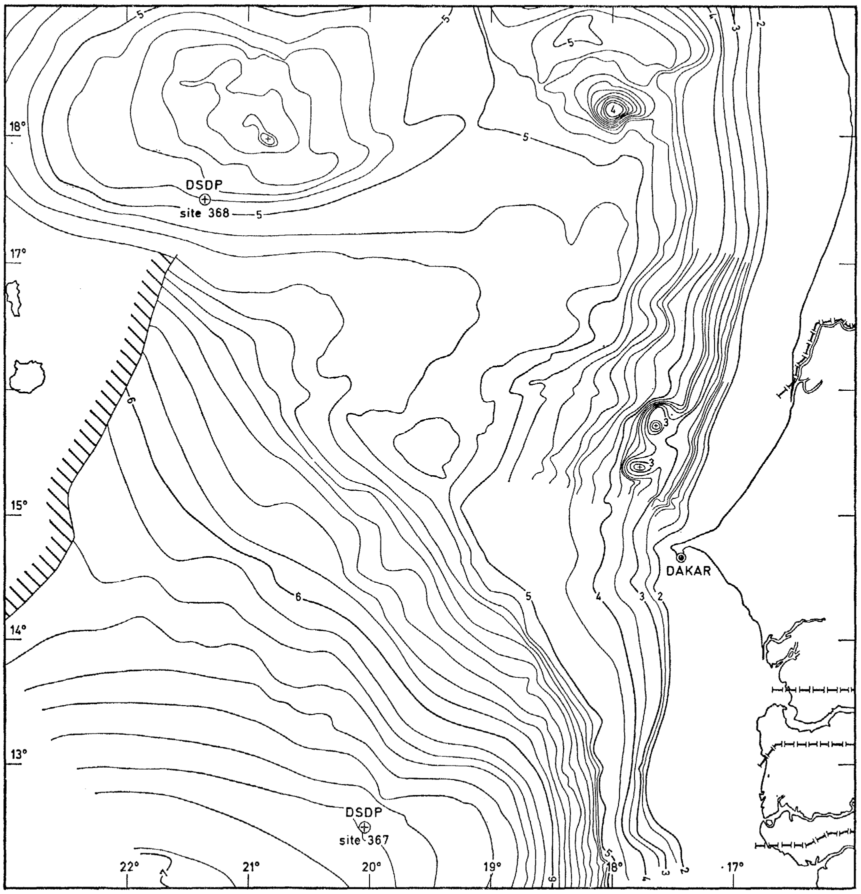

Figure 4. Reflexion time in seconds to the Mid-Eocene reflector A. Hachures limit extent of the Miocene volcanic apron of the Cape Verde Islands.

With the available data we cannot decide whether the smooth acoustic basement mapped is in fact the top of layer 2. We note that it is generally lost as a strongly reflecting surface near the base of the continental slope. Here the acoustic basement represents Miocene volcanics (Dakar, Cayar seamount) or the Lower Cretaceous slope. This slope, in a position almost identical with the present day shelf edge, is interpreted as a grown carbonate front of up to Aptian–Albian age. The carbonate front (figure 7) is the westernmost structure of the flexured Mesozoic platform in the Senegal–Mauritanian subsidence basin. This structure probably constituted a zone of facies change with terrestrial sediments deposited on the landward side and slope sedimentation to the west, until the Mesozoic shelf margin was buried under slope shales during late Cretaceous and Tertiary times (Lehner & de Ruiter 1977).

It is difficult to trace reflectors across the old continental margin as different time units pinch out and reflectors merge. Eocene reflectors still terminate against the drop-off of the carbonate front, while Oligocene to mid-Miocene layers envelop it and form an unconformity. The top of the carbonate front exhibits two strong reflexions similar to the seismic picture of Sites 390, 392 on the Blake nose, where they are caused by Cretaceous carbonate banks and reefs (Leg 44 scientific party 1976).

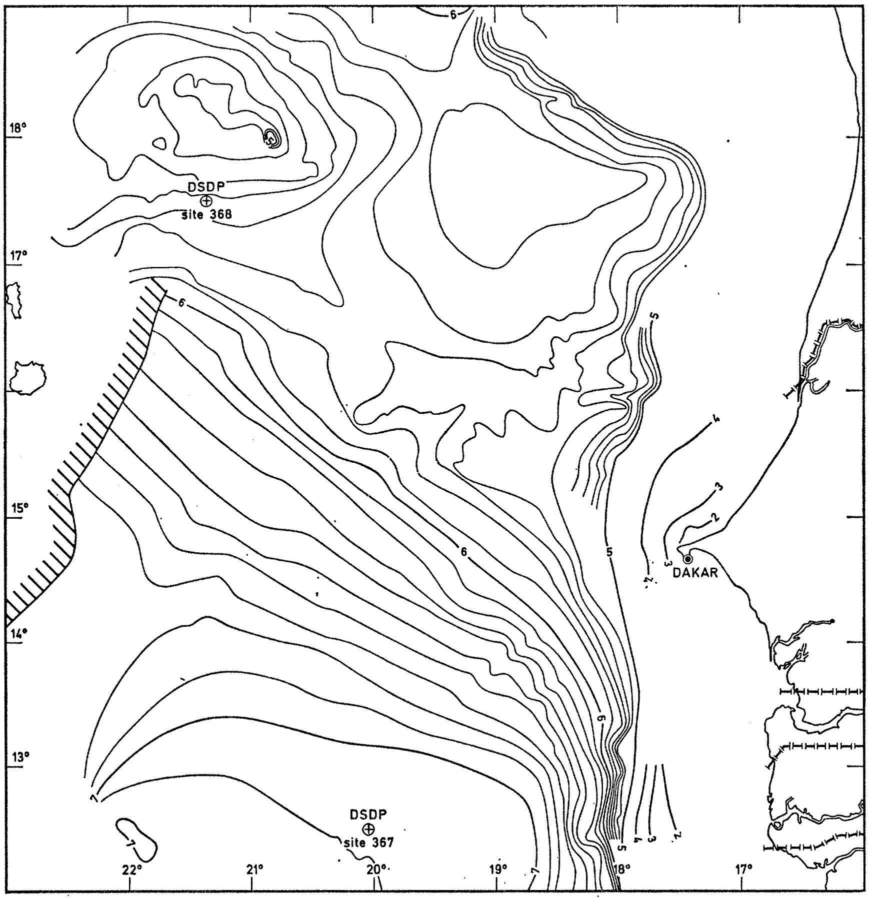

FIGURE 5. Reflexion time to Mid-Cretaceous black shales (or equivalent strata under the continental slope).

Strongly reflecting layers at the top of the sediment sequence point to a massive accumulation of coarse sediments during Pliocene and Pleistocene times, that have been brought down from the shelf by turbidity currents.

A crustal section from the Mauritanian basin out to D.S.D.P. Site 368 on the Cape Verde Rise has been established with about 600 km of refraction profiles shot in 1975. The section calculated by a ray method (figure 8*b*) has been superimposed on a line-drawing of a reflexion profile connecting the anchored (I.F.G., B.G.R.) and drifting sonobuoy (S) refraction stations (figure 8*a*). Stratigraphic control is provided in the deep sea by D.S.D.P. Sites 368 and 367 (Leg 41 scientific party 1975), on the shelf from oil wells Al Kinz 1A (Rona 1974), V-1 and OCT 1B (A.A.P.G. Petroleum Development Reports) and published onshore sections (Michel 1973).

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The acoustic basement with $v_p = 5.2$ km/s shown before in the contour map is seen dipping eastward from the Cape Verde Rise to a level where, if extrapolated from the basement contour map and taking refraction velocities as interval velocities, it seems to merge with $v_p = 7.1$ km/s refractor. Velocities of 6.3 km/s, which could represent Palaeozoic rocks have only been observed below the slope on a line shot parallel to the coast (Weigel & Wissmann 1977).

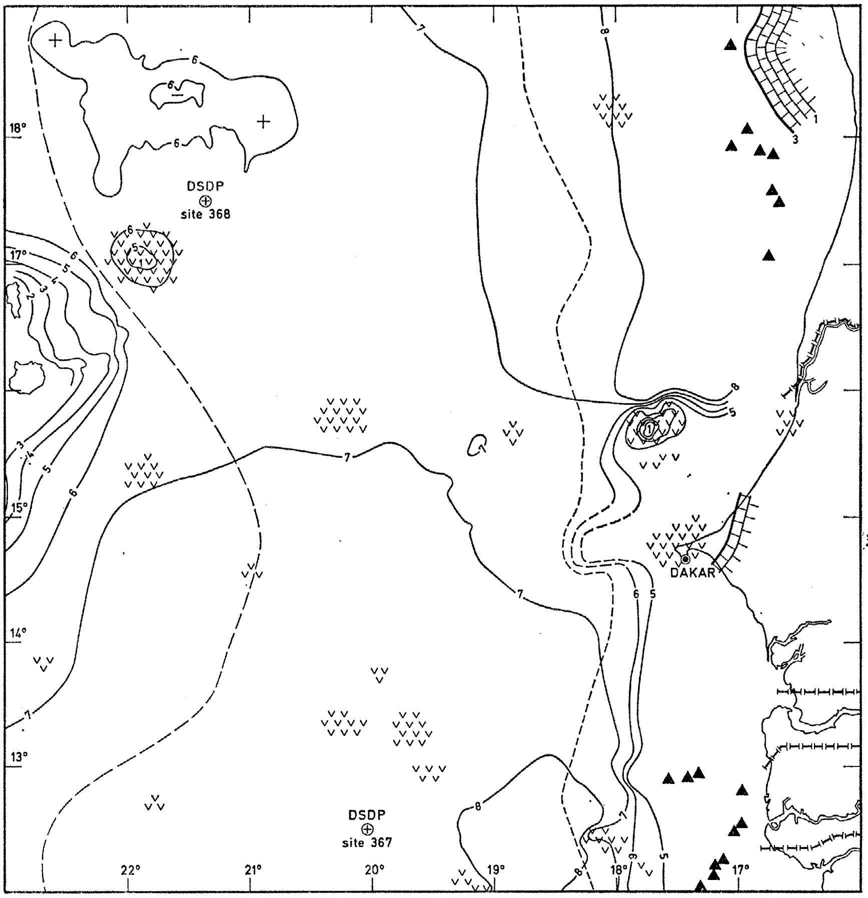

FIGURE 6. Reflexion time to basement.

Rough oceanic basement to W } of dashed line ----
Flat oceanic basement to E }

oceanic basement to W } of dashed line ------
oceanic basement or volcanic basement or carbonate platform } to E

ᵛᵥᵛ Volcanic intrusives or seamounts (of post-Senonian to predominantly Miocene age).
▲ (Lower Jurassic) salt diapirs.
(Lower) Cretaceous carbonate platform.

Within the sediments under the continental rise, horizon A and the Cenomanian sill horizon D1 of Site 368 have been marked by thicker lines.

Two peculiar occurrences of west-dipping sediment layers have been ruled out as possibly constituting third multiples and are considered to be real. Therefore the deeper unit is tentatively identified as prograded Lower Cretaceous delta deposits which may have been channelled via a canyon through the carbonate front barrier. This situation could then have reoccurred during the Late Cretaceous (Senonian). Below the upper rise and slope the layer with velocities of 4.0–4.6 km/s is interpreted as Jurassic to Lower Cretaceous sediments with evaporites and carbonates.

Also the layer with v_p = 2.7 km/s is thought to represent Aptian–Albian carbonates, as they occur further east in the carbonate front.

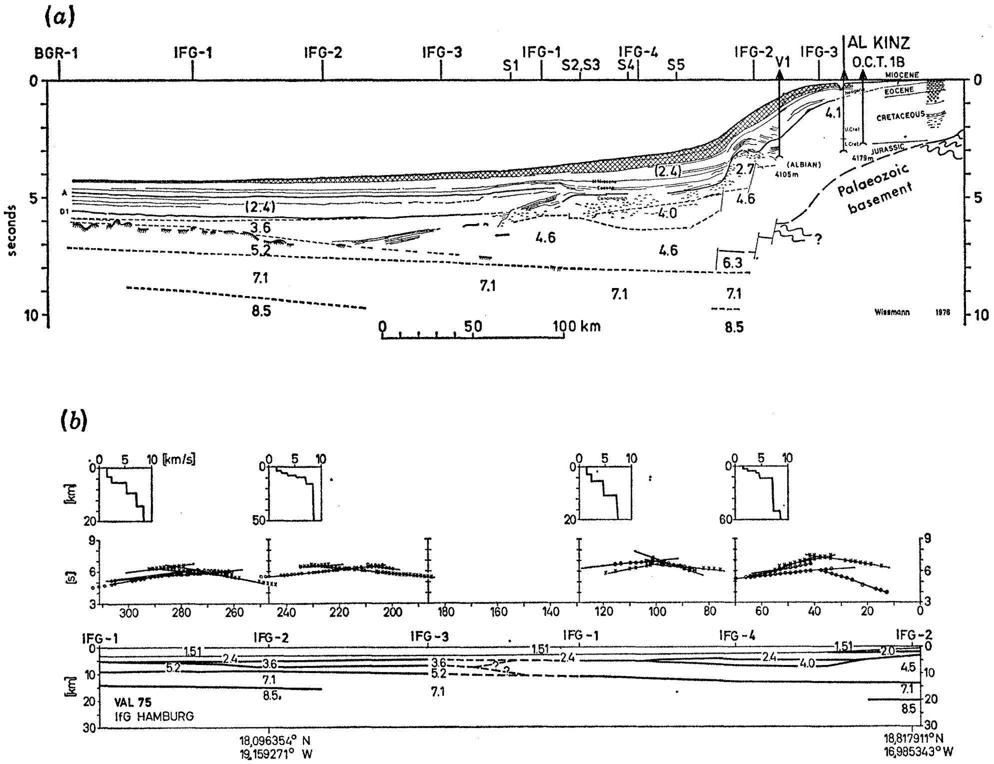

FIGURE 8. (*a*) Reflexion time section of the Mauritanian refraction profile. Velocity layers are separated by short-dashed lines. Cross hachures show prism of Plio–Pleistocene turbidites. Well stratigraphy was converted to reflexion time by the velocity function $v = 1.63 + 0.50\,z$ derived from moveout analysis.

(*b*) Mauritanian refraction profile depth section computed with the Stein (B.G.R.) ray method. The extent of refraction control (first arrivals, multiple refractions, reflexions) and the velocity-depth functions derived are also shown.

The gap between anchored buoys IFG–3 and IFG–1 was caused by a buoy malfunction. The Moho was not recorded between 20 and 230 km and only as apparent velocity from secondary arrivals under the slope.

At the time of review (1979) at least the upper west-dipping unit is tentatively identified as volcaniclastic material from the intrusion near 18° N, 18° W (figure 6).

IFNI–MOROCCO

Refraction seismic studies were also carried out along a traverse from Salvagem Grande Island to Ifni–Morocco (figure 1). Line 39/1 is located across a sedimentary basin characterized by diapiric salt structures (figure 9). It probably extends into the onshore Essaouira basin.

In the seismic reflexion record of line 39/1, two horizons were identified by extrapolation of Site 415/416 as Miocene–Pliocene and Cretaceous–Tertiary boundaries. The base of the (probably Jurassic) salt as well as the top of the basement is not recognizable in our seismic reflexion records.

Figure 10 shows the derived crustal model. The velocities of 2.2–3.0 km/s were obtained from reflexion results. This layer represents Cainozoic sediments. The layer below with velocities of 3.0–4.9 km/s is interpreted as Cretaceous to Lower Jurassic sediments.

Contrary to our observations in the Mauritanian section, we observed here a layer 5–10 km thick, with a velocity of 5.8 km/s, which extends continuously from the shelf to the Conception Bank, and is, as in the case of Mauritania, underlain by a rock complex with $v_p = 7.1$ km/s.

From the obtained data it is obvious that the 200 km wide sedimentary basin between the inner Canary Island – Conception Bank complex and the shelf off Morocco is not underlain by a typical oceanic crust. The latter can be found west of Conception Bank (Weigel *et al.* 1978) and west of the magnetic quiet zone (Uchupi *et al.* 1976; Bosshard & McFarlane 1970; Grunau *et al.* 1975).

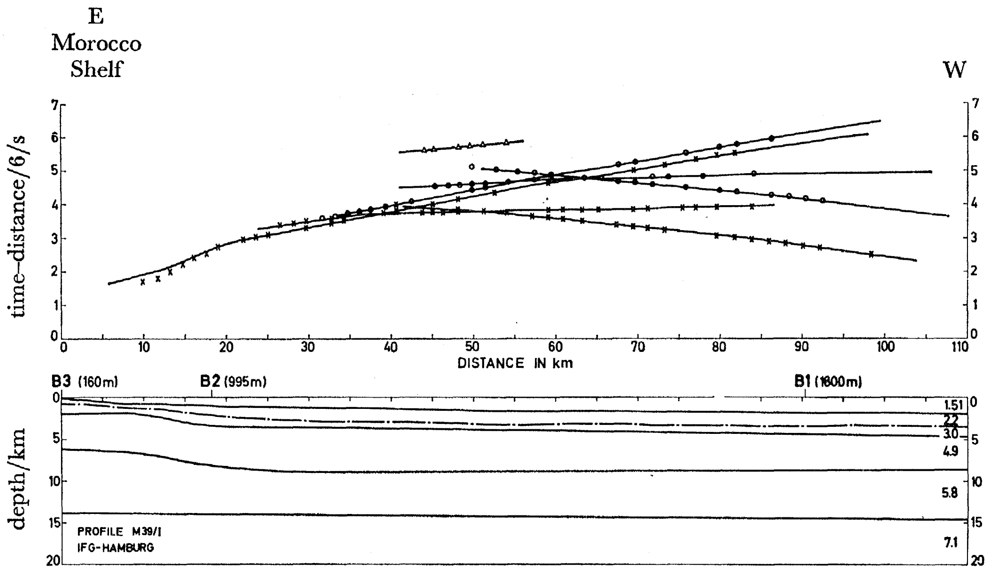

FIGURE 10. Refraction line M 39-I depth section computed with the Stein (B.G.R.) ray method. Velocities 2.2 and 3.0 km/s were taken from 12-channel moveout analysis. Moho arrivals were not recorded in spite of dense shot-points (*ca.* 1 nm), shot size 25–100 kg, and range (100 km). — · —, From reflexion results (air gun); ——, refraction horizons; ×, travel times B3; ○, travel times B2; △, travel times B1.

The nature of the layer with a velocity of 5.8 km/s is unknown. If we interpret this layer as an abnormally thick oceanic layer 2 and the 7.1 layer as an equivalent of oceanic layer 3, the ocean–continent boundary has to lie within the shelf. If the 5.8 km/s layer is interpreted as mainly Palaeozoic–Precambrian basement and the 7.1 layer is regarded as anomalous upper mantle material then attenuated and modified continental crust extends, in the case of Ifni–Morocco, far into the magnetic quiet zone.

CONCLUSIONS

We have pointed out that off NW African there seem to exist structures and layered rock complexes under an unusually smooth basaltic basement reflector, which in itself warrants explanation in the models of ocean crust evolution.

The Mesozoic carbonate front shelf margin earlier described off Senegal (Lehner & de Ruiter 1977) was identified also to extend further north offshore Mauritania.

A principal result of our studies is the proof of a rock complex with $v_p = 7.0$–7.2 km/s, at least in the inner part of the magnetic quiet zone off NW Africa, which seems to thicken landwards. Such a layer has earlier been interpreted as high-grade metamorphic equivalents of the gabbroic oceanic layer 3 near the the Sierra Leone Rise (Sheridan *et al.* 1969) and intrusion, mixing and differentiation of mantle-like material with the oceanic layer 3 near Teneriffe (Dash & Bosshard 1969), while it was not encountered in the Cape Verde Archipelago (Dash *et al.* 1976).

From the seismic data alone a precise definition of the continent–ocean boundary is still eluding us, because a lithological interpretation of the velocities observed remains a matter of debate until drilled. However, a combined study incorporating also the gravity and magnetic data for interpreting the NW African continental margin structure is planned, and may shed more light on the described problems.

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Discussion

D. J. Blundell (*Chelsea College, University of London, London, U.K.*). Please could Mr Wissmann show the extent of reversed control in the seismic refraction profiles off Senegal and Mauritania relating to the lower crust layer with p-wave velocity of 7.1 km/s?

G. Wissmann. All profiles were reversed except for the gap in figure 8(*b*). The seismogram sections shown here in answer to Dr Blundell's question will soon be presented with detailed explanations in another paper.

E. J. W. Jones (*Department of Geology, University College London, Gower Street, London WC1E 6BT*). Most of the magnetically quiet zone seaward of the West African continental slope off Sierra Leone is underlain by normal oceanic crust. In this region the continent–ocean boundary appears to be defined by a positive magnetic anomaly and a steep isostatic gravity gradient (E. J. W. Jones & C. C. S. Mgbatogu, *Nature, Lond.* **267**, 688–690). The same appears to be true off the Gambian margin further north and in other areas of the Atlantic (M. Talwani & O. Eldholm, *Nature, Lond.* **241**, 325–330; P. D. Rabinowitz, & J. L. Labrecque, *Earth planet. Sci. Lett.* **35**, 145–150). Have Mr Wissmann and his colleagues observed a similar relation between gravity and magnetic anomalies on the eastern side of the magnetically quiet zone off northwest Africa?

G. Wissmann. Our seismic profiles offshore Sierra Leone also show 'normal oceanic crust' in the magnetic quiet zone to about 15° W, 6° N. In contrast to the flat basement observed off Senegal and Gambia, the oceanic basement off Sierra Leone, however, exhibits a pronounced relief of more than 500 m. In our records we cannot follow it to the foot of the continental slope, but only to 4800 m water depth.

We have gravity and magnetic data only north of Dakar. Between 15 and 20° N the magnetic records contain no anomalies in the magnetic quiet zone except those caused by volcanic bodies, the free air gravity maps outline a coast parallel belt of a positive anomaly over the slope followed by a negative anomaly over the upper rise between 16° and 19° N. The general shape of such an anomaly is caused by the combined gravity effect of the continental margin bathymetry and a landward deepening of dense (sub-Moho) material. Isostatic gravity calculations, however, assume crustal models for which some degree of (refraction) seismic control ought to be required. The B.G.R. team is working on an integrated analysis of its geophysical data off NW Africa.

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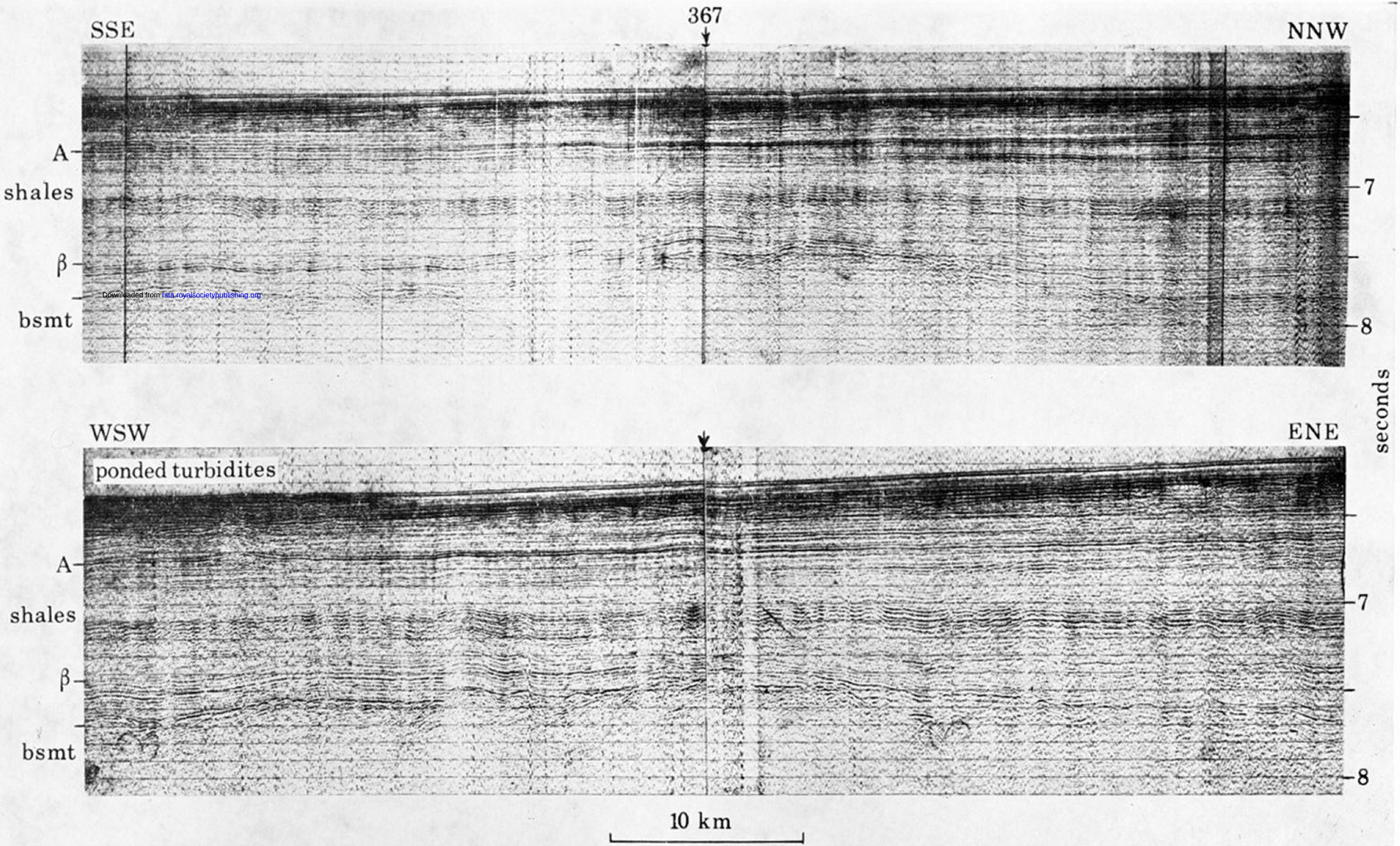

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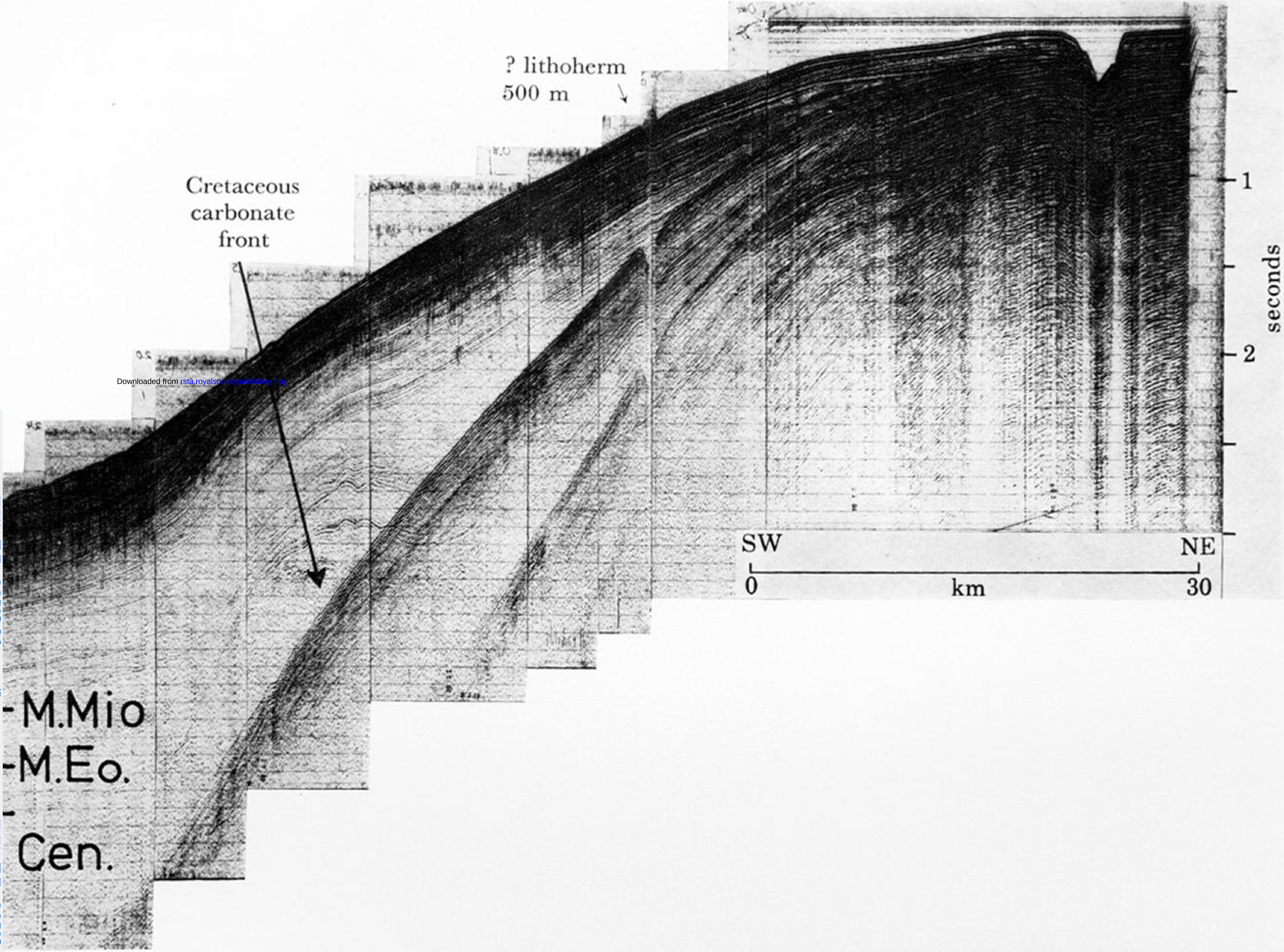

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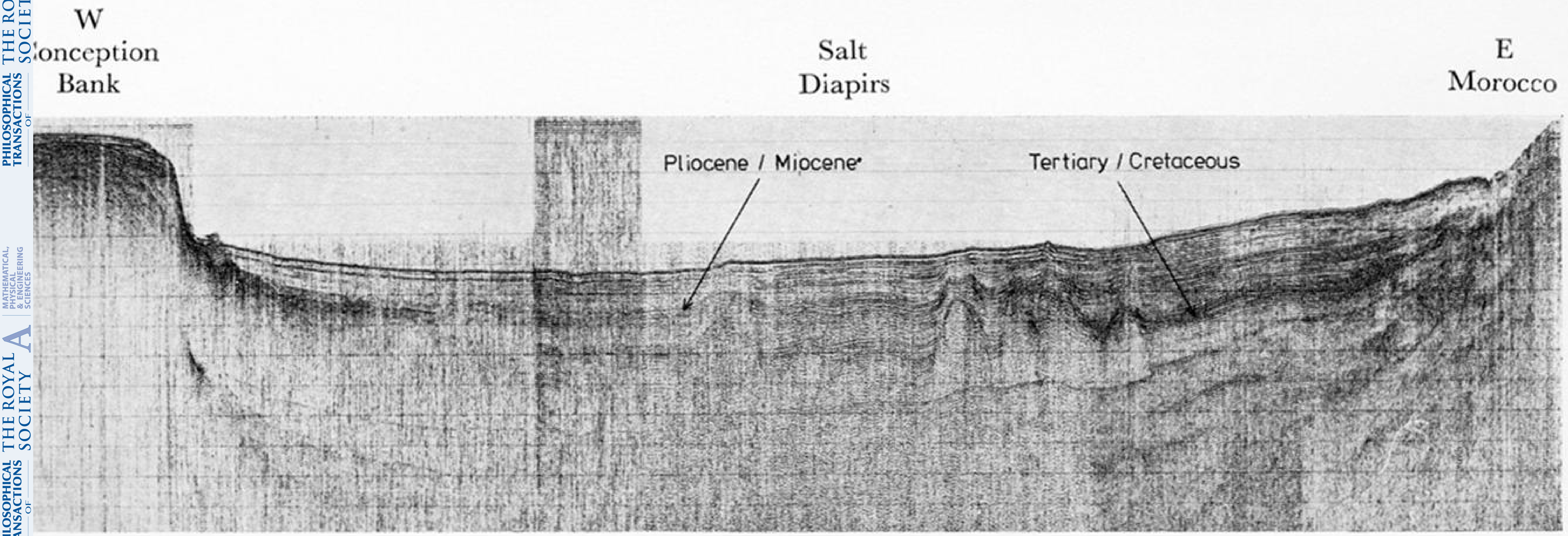

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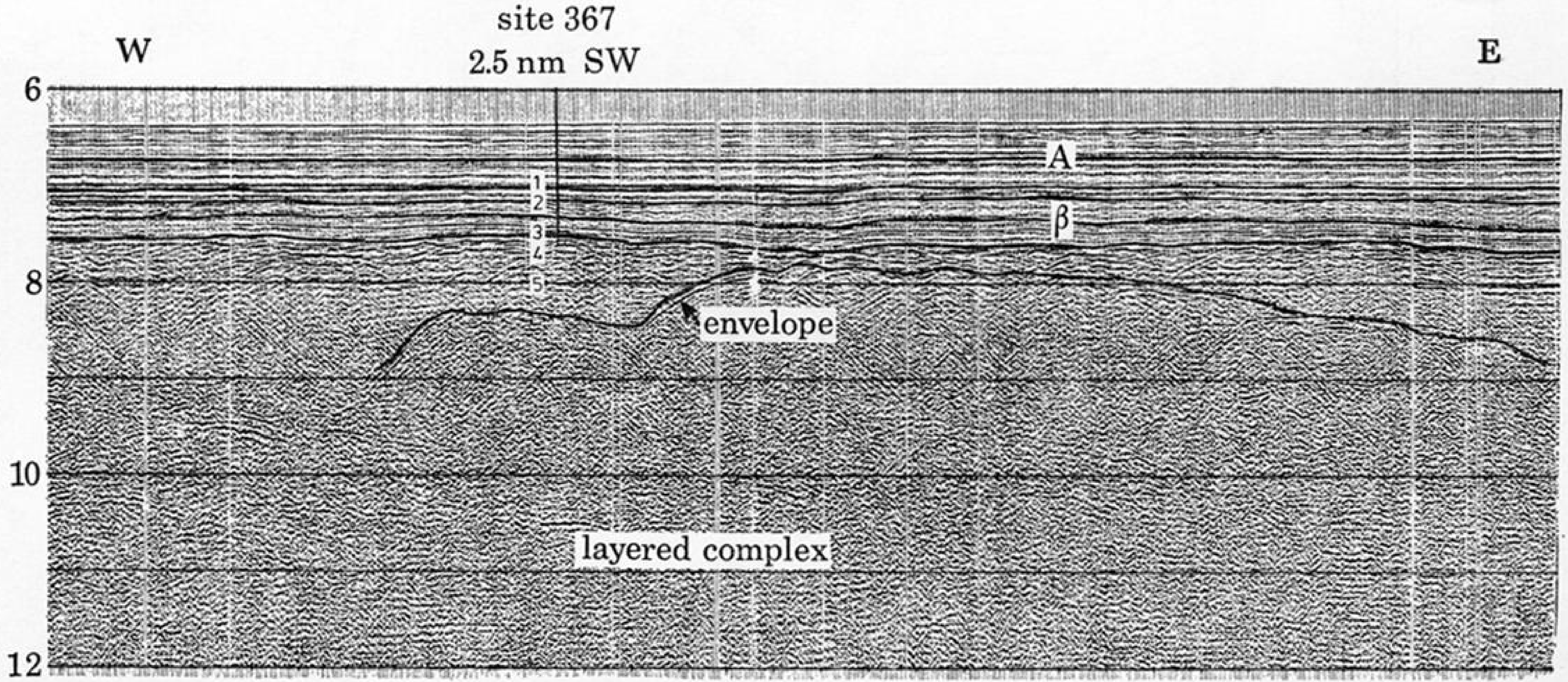

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