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Age and Structure of the Southern Rockall Trough - a new assessment

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Introduction

The Rockall Trough separates the Rockall Plateau from the continental margin to the west of the British Isles. Although the continental nature of the Rockall Plateau has been amply confirmed by several independent lines of geological and geophysical evidence (summarized by Roberts et al., 1979) the origin, structure and age of the Rockall Trough, widely considered to be an initial abortive split in the North Atlantic Ocean, (Vine 1966) has remained the subject of considerable discussion.

The discussion has arisen because of the largely circumstantial evidence for the age and nature of the sediments and basement within the Trough and has been further compounded by the lack of deep drilling data that might unequivocally resolve these questions. The discussion has importance in both the assessment of hydrocarbon prospectivity to the west of the British Isles and in the wider context of the plate tectonic history of the North Atlantic Ocean.

The purpose of this report is to further assess the age and structure of the southern Rockall Trough by relating new deep seismic data to the Leg 48 IPOD holes and to oceanic magnetic anomalies of known age. The southern Rockall Trough (Figure 1) is of critical importance because the section is thinner and less complex than that of the more northern part of the Trough, and seismic profiles from this area can easily be tied to the IPOD sites in the Bay of Biscay. The report also discusses the continental margin off the Goban Spur in view of its direct relevance as a link between the Rockall Trough and Bay of Biscay.

2. Data sources

2.1 Magnetic data

The magnetic anomaly maps used in this report (figure 2) have been based on shipborne data previously compiled by Vogt and Avery (1974) and Roberts and Jones (1979) modified with data added from proprietary aeromagnetic surveys.

2.2 Seismic reflection profiles

Seismic reflection profiler data used in this study (figure 1) were as follows:

2.2.1 A multichannel seismic survey of the continental margin southwest and west of the British Isles made by S & A Geophysical under contract to the Institute of Oceanographic Sciences for the Department of Energy.

2.2.2 Speculative multichannel seismic surveys purchased by the Institute of Oceanographic Sciences for the Department of Energy.

2.2.3 Single channel seismic reflection profiles obtained during RRS Discovery Cruises 29, 33, 47, 60, 74 and 84, and single channel data published by CNEXO

(1971) and Ewing et al (1974).

3. Magnetic Anomalies

3.1 Regional character

The magnetic anomalies observed within the study area can be divided into three distinct provinces:

(a) High amplitude irregular magnetic anomalies characterise the shelf west of the British Isles and Rockall Plateau (figure 2). These anomalies are probably related to the Pre-Cambrian basement and Lower Palaeozoic formations considered to underlie these areas, although Tertiary (and late Cretaceous?) extrusives and intrusives are also likely to be present (Vogt and Avery, 1974; Roberts, 1975; Riddihough and Max 1976; Roberts and Jones, 1979).

(b) Prominent oceanic magnetic lineations characterise the abyssal plain west of the Goban Spur and Porcupine Bank (figure 2). The more westerly of these lineaments terminate northward against the prominent east-west trending magnetic lineament at 52°N associated with the buried easternmost trace of the Gibbs Fracture Zone.

(c) In the southernmost part of the Rockall Trough, immediately to the north of the Gibbs Fracture Zone, weak N-S trending magnetic lineations are present but give way northward to the magnetic quiet zone characteristic of much of the Trough (figure 2). The linear anomalies are effectively divided from the quiet magnetic zone by a complex of NW-SE trending anomalies near 53°30'N, 17°W, which may be related to a now buried fracture zone within the Rockall Trough.

3.2 Identification and age of the oceanic anomalies

(a) West of the Goban Spur

Identifications and age assignments of the oceanic anomalies west of Goban Spur have been made by Pitman et al (1971), Williams and McKenzie (1971), Vogt and Avery (1974), Williams (1975), Roberts (1975) and Srivastava (1978). According to these authors, anomaly 32 (70 m.y., La Brecque et al., 1977) is the oldest clearly defined anomaly identified in the region. However, it lies about 90 km from the base of the slope and about 60 km from the continent-ocean boundary interpreted from seismic reflection profiles and gravity data (this report; Montadert, Roberts et al, 1979; Scrutton, 1979), and accordingly, weaker lineations between anomaly 32 and the continent-ocean may represent anomalies 33 and 34 (74 and 82 m.y. La Brecque et al 1977). Alternatively, Cande and Kristoffersen (1977) have proposed that the anomalies previously identified as 31 and 32 are 33 and 34. However, this small re-adjustment makes little difference to the important point that only around 60 km of pre 82 (or 70) m.y. oceanic crust is present between these anomalies and the continent-ocean boundary. If the latter authors are correct, this crust may have formed during the later part of the Late Cretaceous normal polarity interval (90-95 m.y.).

(b) South Rockall Trough

Examination of the magnetic anomaly map (figure 2) shows that the suite of older anomalies (i.e. the pre-32 (or 34) sequence) can be followed northward past the end of the Gibbs Fracture Zone into the south Rockall Trough where they comprise the eastern part of a suite of weak linear anomalies.

If this correlation is correct, at least part of the crust in the Rockall Trough is implied to be oceanic, and contemporaneous with the pre-anomaly 32 (or 34) (Late Cretaceous) oceanic crust to the south.

4. Seismic Stratigraphy

4.1 Principal Reflectors

The seismic sequences and post-basement stratigraphy of the Rockall Plateau were studied by Roberts (1975) who recognised four prominent reflectors R4, X, Y and Z above 'basement' (figure 4).

Reflector R4 is a reflector of regional importance that can be followed continuously from the Bay of Biscay to the Rockall Plateau. Deep sea drilling results indicate a Middle Eocene to Oligocene age in Biscay and an Eocene-Oligocene age of the Rockall Plateau (Roberts 1975; Montadert, Roberts et al., 1979). In the Rockall Trough both reflectors R4 and X appear to be accommodated within the Middle Eocene-Oligocene hiatus of Montadert, Roberts et al (1979).

Reflector Y was considered by Roberts (1975) to have a Campanian age because it apparently pinched out on oceanic crust dated at 76 m.y. The new data now indicate a substantially younger age. In the Bay of Biscay, reflector Y can be correlated with a hiatus of Maastrichtian to Late Palaeocene age at site 400A, and with a shorter hiatus of mid-Palaeocene age at site 401. In Rockall Trough, reflector Y occurs at the same level or slightly lower than the youngest lavas observed on the seismic sections. If the igneous episode was contemporaneous with the well documented peak in early Tertiary igneous activity at about NP 12 time (Fitch et al., 1978; Harrison et al., 1979; Roberts et al., 1979), reflector Y must be assigned a Late Palaeocene age of about 55 m.y. New seismic data to the west of Goban Spur shows that reflector Y can be traced considerably farther west than anomaly 32, thus again indicating a substantially younger age than 70 m.y.

In the Rockall Trough reflector Y is thus considered to be of Late Palaeocene age.

Pre-reflector Y sediments comprise the oldest sediments within the Rockall Trough and are further subdivided into two units by prominent reflector 'Z' (Roberts 1975).

The upper unit is largely acoustically transparent but contains occasional laterally persistent flat-lying reflectors and is interpreted as interbedded lava flows and sediments, possibly equivalent to the pre-Late Palaeocene interval observed at sites 403 and 404 (Montadert, Roberts et al., 1979).

The lower unit, best developed north of 53°N, contains many strong reflectors that often prograde toward the Trough axis. These reflectors rest on the 'basement', both within the Rockall Trough and beneath its margins, indicating that they post-date its formation although they may in part be contemporaneous with the rifting at the margins. In some cases, especially in the northern part of the Trough, no obvious boundary can be seen between the series of strong reflectors and 'basement', indicating that the deposition of the oldest sediment unit may be contemporaneous with the formation of the oceanic crust in the Trough. There is no evidence for the age of reflector 'Z' other than that it is pre-Late Palaeoceone and younger than the presumed oceanic basement of the Trough.

4.2 Basement

4.2.1 Oceanic or continental?

The various older seismic refraction profiles occupied in the Rockall Trough do not conclusively resolve an oceanic or continental structure (Hill 1952, Ewing and Ewing 1959; Scrutton 1972; Roberts 1974, 1975). In the most recent study Bott et al. (1979) have suggested that the northern Rockall Trough may be underlain by an abnormally thick oceanic crust.

Further to the south, refraction stations between anomaly 32 and the continent-ocean boundary west of Goban Spur show a typical oceanic structure confirming that the weak lineations east of this anomaly are associated with oceanic and not deeply subsided continental crust. The northward continuation of these oceanic lineaments into the Rockall Trough is strong support for the existence of oceanic crust at least in the southern part of the Rockall Trough. Between the southern Rockall Trough and the refraction profile of Bott et al (1979) at 57°N, the magnetic field is generally smooth (although weak lineations may be present) and there are no refraction stations that would provide data on the deeper structure.

Gravity models provide a contributory but non-unique approach and Scrutton (1972) has shown that the Moho may lie at a depth of about 12 km. A prominent isostatic gravity gradient is present on both sides of the Rockall Trough (Kristoffersen, 1978) that has elsewhere been correlated with the transition between continental and oceanic crust.

4.2.2 Other evidence for oceanic crust

Evidence of continuity between structures or lineaments known on the shelf and those observed in the deep sea can be useful in defining the areal extent and geometry of oceanic crust.

The Gibbs Fracture Zone is a large transform fault in the North Atlantic near 52°N, (Fleming et al., 1970), the buried eastern end of which is located in the mouth of the Rockall Trough (figure 5) (Cherkis et al. 1973, Olivet et al., 1974). Cherkis et al (1973) proposed a link between the Gibbs Fracture Zone and the Hercynian Front in Southern Ireland, and Max (1978) a relationship with a prominent E-W magnetic lineament on Porcupine Bank at 52°25'N.

The magnetic anomaly map (figure 2) shows a clearly defined E-W trending lineament that ends abruptly at 17°20'W. This lineament is associated with a basement ridge and trough structure that again terminates at 17°20'W (figure 3). East of this longitude, the basement topography trends almost N-S, cutting across the former trend. There is thus no magnetic or seismic reflection evidence for a link between the fracture zone and any continental structure. This shows that the continental structures end at the continent ocean boundary west of Porcupine Bank.

Kristoffersen (1978) has examined the relative position of Europe and North America prior to anomaly 34 (or 32) time using plate boundaries defined by anomaly 34 (or 32). His fit, which is severly constrained by the presence of two offsets in the anomaly at the Gibbs Fracture Zone and south-west Rockall, juxtaposes a zone of weak magnetic lineations south of 52°N with a zone of similar magnetic character at the southern end of Rockall Trough, strongly suggesting a continuation between the two. As previously noted by Roberts (1975) the width of the Rockall Trough approximately equals the total width of the zone of weak magnetic lineations juxtaposed by this reconstruction.

It should be noted that the weak development or even lack of magnetic lineations over much of the Rockall Trough is not evidence against the presence of oceanic crust, since such crust could easily have been generated during an interval of normal polarity. However, the northward change in magnetic character remains problematic. Speculatively, it may be related to the change in basement character seen on seismic records, and possibly to a change in the environment of crustal accretion northwards. This is further discussed in the next section.

It is thus concluded that oceanic crust is present between the end of the Gibbs Fracture Zone and the continent-ocean boundary west of Porcupine Bank, and that this crust continues northwards into the Rockall Trough.

4.2.3 Character of the oceanic basement

We have formed the general impression that there is a perceptible northward change in the character of the oceanic basement from the area west of Goban Spur to the Rockall Trough. We wish to stress that the change may be a reflection of data quality rather than a real change.

West of Goban Spur, the basement gives rise to a strong reflection typically associated with numerous diffractions. Within the Rockall Trough, particularly north of 53 °N, numerous strong reflectors (the pre-Z sequence) infill hollows in the basement and often mask the basement reflection. If the oceanic crust is contemporaneous in these areas, as is suggested by the magnetic evidence, this change may imply a difference in the environment of formation of the ocean crust, possibly related to the 'sediment damming' effect of the NE-SW trending basement ridge (? fracture zone) at 53 °N (figure 3) coupled with a greater input of clastic sediments in the northern area.

5. Amount of Oceanic Crust

Estimates of the width of oceanic crust within an ocean basin depend on the criteria (and their availability) used to define oceanic crust, continental crust and the transition between them. Criteria used to define the limits of oceanic crust include the presence or absence of oceanic magnetic anomalies, a typical oceanic crustal seismic refraction structure, isostatic gravity gradients and a 'typical' oceanic basement seismic reflection signature. In the Rockall Trough, the width of oceanic crust has been estimated collectively from the change in magnetic character, the presence of isostatic gravity gradients and to a lesser extent, from seismic reflection evidence. Geological evidence is lacking because of the great thickness of sediment.

West of the Goban Spur, the transition from continent to ocean is marked by the abrupt termination of the oceanic lineations in coincidence with a strong isostatic gravity gradient and marked change in basement character. To the west of the continent-ocean boundary the seismic basement is a strong reflector associated with many diffractions and is considered to be the top layer 2. To the east, a series of tilted and rotated fault blocks containing interval reflectors are present. The transition, defined in this way, can be followed northward past the end of the Gibbs Fracture Zone. Between 50 and 60 km of oceanic crust is present between the end of the Gibbs and the transition. North of the Gibbs, the continent-ocean boundary cannot be recognised uniquely from seismic profiles. A change in the magnetic character of the basement, coupled with an increase in basement depth probably defines the transition on the east side of the Trough and a comparable change may be present on the west side. Further north, magnetic lineations are not present and basement cannot always be seen beneath the strongly reflective pre-Z sequence. However, the presence of strong isostatic gravity gradients suggests the presence of oceanic crust.

The width of oceanic crust within the Trough has been independently calculated using the estimated position of the continent-ocean boundary within the Trough, and the distance between the eastern end of the Gibbs Fracture Zone and the continent-ocean boundary west of Porcupine Bank. This latter value should equal half the width of the oceanic crust within the Trough, assuming a symmetrical spreading geometry. Both estimates suggest a width of some 120 km (see figure 5).

6. Age of the oceanic crust

Estimates of the age of the oceanic crust in the Rockall Trough have ranged widely between the Permian (Russell, 1976; Russell and Smythe, 1978) and the Cretaceous (Vogt and Avery, 1974; Roberts, 1974, 1975). Arguments for one age or another have been based largely on circumstantial evidence gleaned from the geological history of onshore and offshore sedimentary basins west of the British Isles and the inferred age of the deep reflectors in the Rockall Trough. Much has been made, for example, of the sequence of supposed Early Mesozoic or Permian sediments revealed as the pre-Z interval but there has been no independent geological evidence to support this age estimate.

The age of the deep reflectors in the Rockall Trough is now constrained by the magnetic anomaly data and the correlation of the new seismic profiles with the IPOD sites in the Bay of Biscay. At site 400A a reflector marking the Campanian-Albian hiatus defines the top of the underlying Albian-Aptian black shale interval. This reflector and the underlying unit cannot be followed from the Bay of Biscay onto the oceanic crust west of Goban Spur and is apparently absent there. Its absence on this crust implies that the crust is post Albian in age - a conclusion which is independently supported by the evidence from the magnetic anomalies discussed earlier. A careful examination of the seismic profiles has not revealed this reflector and the underlying unit anywhere west of Porcupine Bank. Indeed, the interval between the oceanic basement and the overlying reflector 'Y' of Late Palaeocene age is typically less than 0.3 seconds, precluding any substantially greater age for the thin section below.

It must be stressed that the post-Albian age shown by these data applies to the oldest crust adjacent to the continent-ocean boundary. Any oceanic crust to the west must therefore be younger.

It has not proven possible, however, to conclusively demonstrate the presence or absence of pre-upper Cretaceous sediments in the Rockall Trough north of 53°N. This is because there is a substantial increase in thickness of the pre-Late Palaeocene interval from less than 0.3 seconds to locally in excess of 1.5 seconds. The change is accompanied by the appearance of many strong laterally impersistent reflectors that characterise the pre-'Z' interval and appear to pass both laterally and downward into the basement. However, the continuity of the magnetic anomalies between the Goban Spur and south Rockall Trough in turn largely precludes any possibility that the oceanic basement might be diachronous. This suggests that the change is one of facies, rather than age, and reaffirms the inference of a post-Albian age for this interval. In the context, it can be recalled that this seismic interval first assumes importance north of 53 °N and its appearance seems to coincide with the appearance of the quiet magnetic field that characterises much of the Trough.

7. Conclusions

1. The Rockall Trough is probably underlain at least in its southern part by oceanic crust. The oceanic crust may be abnormally thick and shallow in north Rockall Trough. The width of the oceanic crust is about 120 km.

2. Based on magnetic anomalies, continental reconstructions and tie lines to IPOD wells in the Bay of Biscay, the age of the oldest sediments resting on the ocean crust in the Rockall Trough is likely to be younger than Albian but is not younger than 70 m.y.

3. The nature of the basal sedimentary section and underlying oceanic crust seems to change southward. In the north, strong flat-lying or gently dipping reflectors rest on or pass into the basement. These reflectors are absent in the south. The change may reflect a greater input of clastic sediments and abnormal conditions of oceanic crust accretion in the north. Clastic sediments may have been prevented from reaching the southern Rockall Trough by a prominent 'basement high', which probably relates to a buried NW-SE trending fracture zone near 53 °N.

8. Hydrocarbon Prospectivity

Much of the discussion on the age and structure of the Rockall Trough has been stimulated by hydrocarbon prospectivity considerations and it would be inappropriate to conclude this report without a brief comment.

Within the Rockall Trough prospects can most easily be considered in terms of two groups: the pre-rift sedimentary section and the post-Albian section of the Trough.

The pre-rift section has not been tested and is therefore unproven. However, a section from the Late Palaeozoic to the Early Cretaceous could possibly be expected in the fault blocks that underlie the margins of the Trough. If a Jurassic epi-continental basin existed on the site of the Trough prior to the spreading, organic rich shales (Kimmeridgian equivalent?) may have been laid down and thus offer a potential source. Sands in the pre and syn-rift section may offer potential reservoirs with seals being provided by post-Albian pelagic and hemipelagic sedimentary cover. Maturation may have been aided by thermal events associated with the Late Cretaceous spreading and the Lower Tertiary igneous event, as well as subsequent deep burial.

In the northern part of the Trough, the thick post-Albian sequence may contain stratigraphic traps such as sub-sea fans. However, the presence of source rocks in this part of the succession remains unproven.

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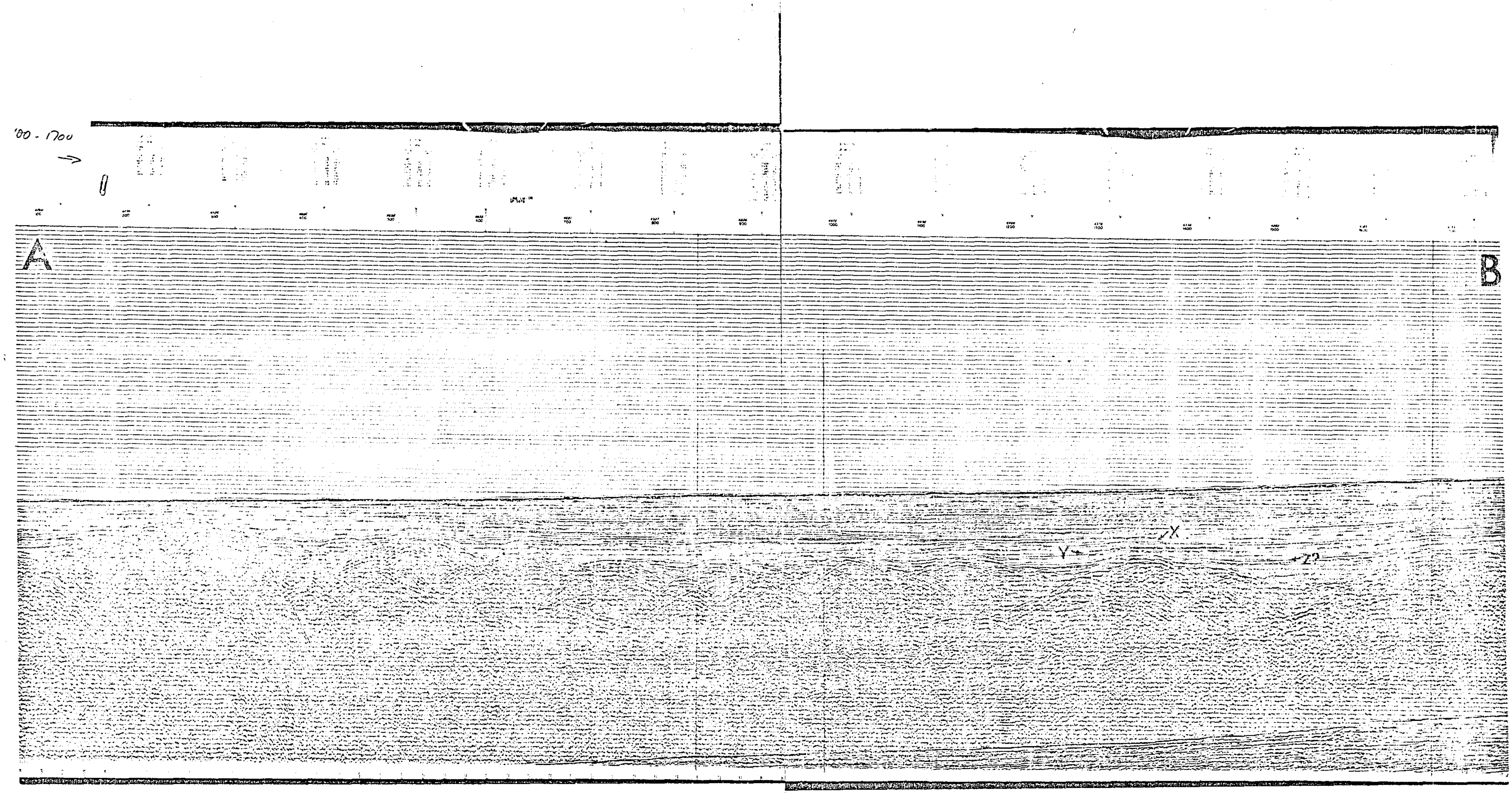

Fig. 4a

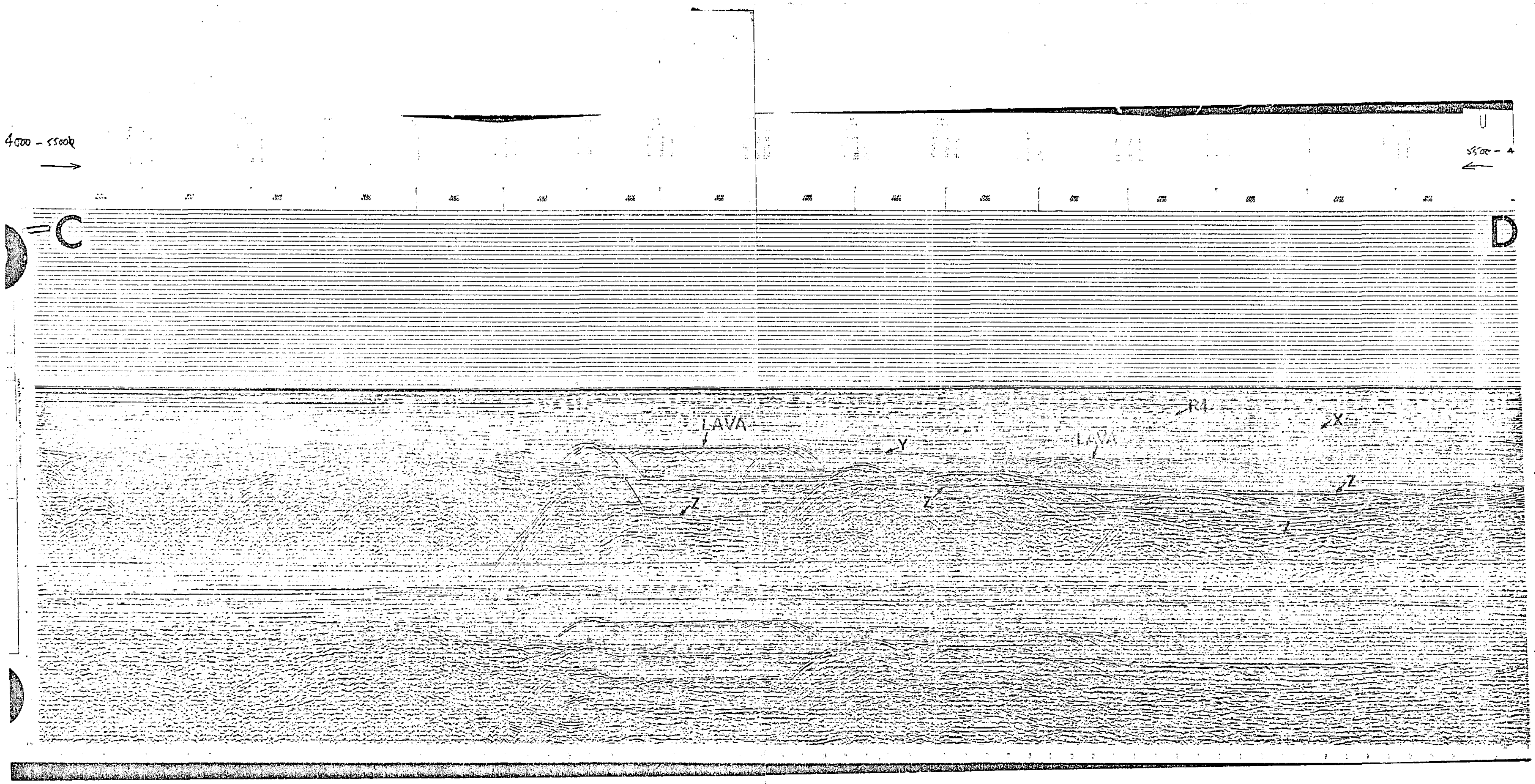

Fig. 4b

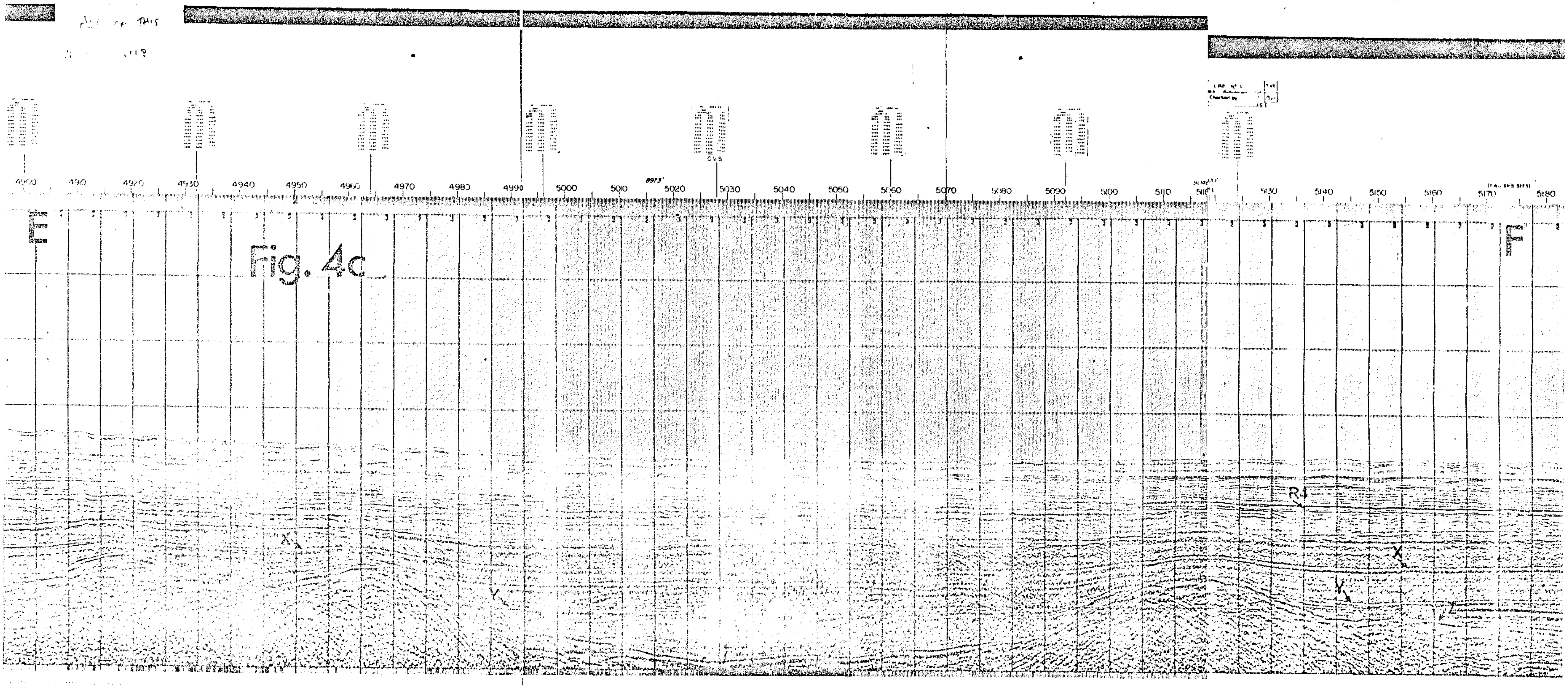

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Fig. 4c

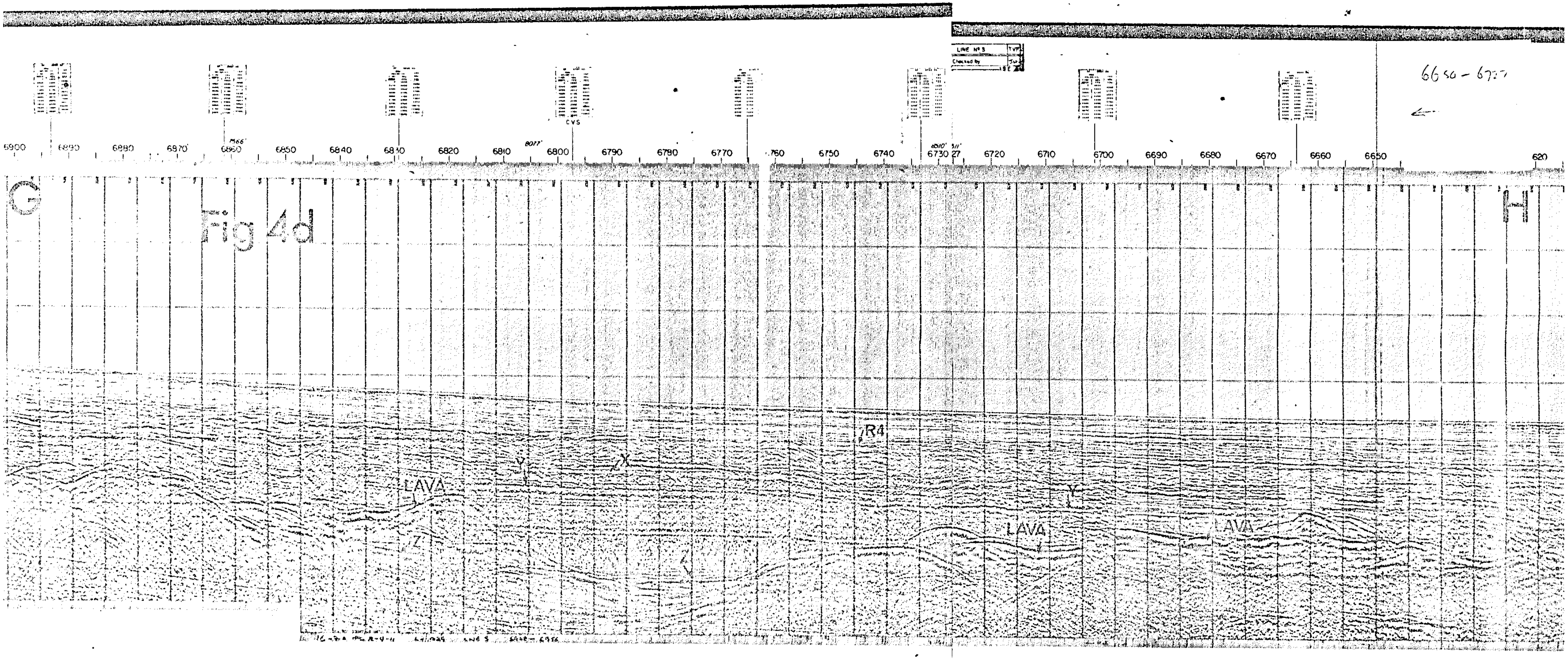

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Fig 4d
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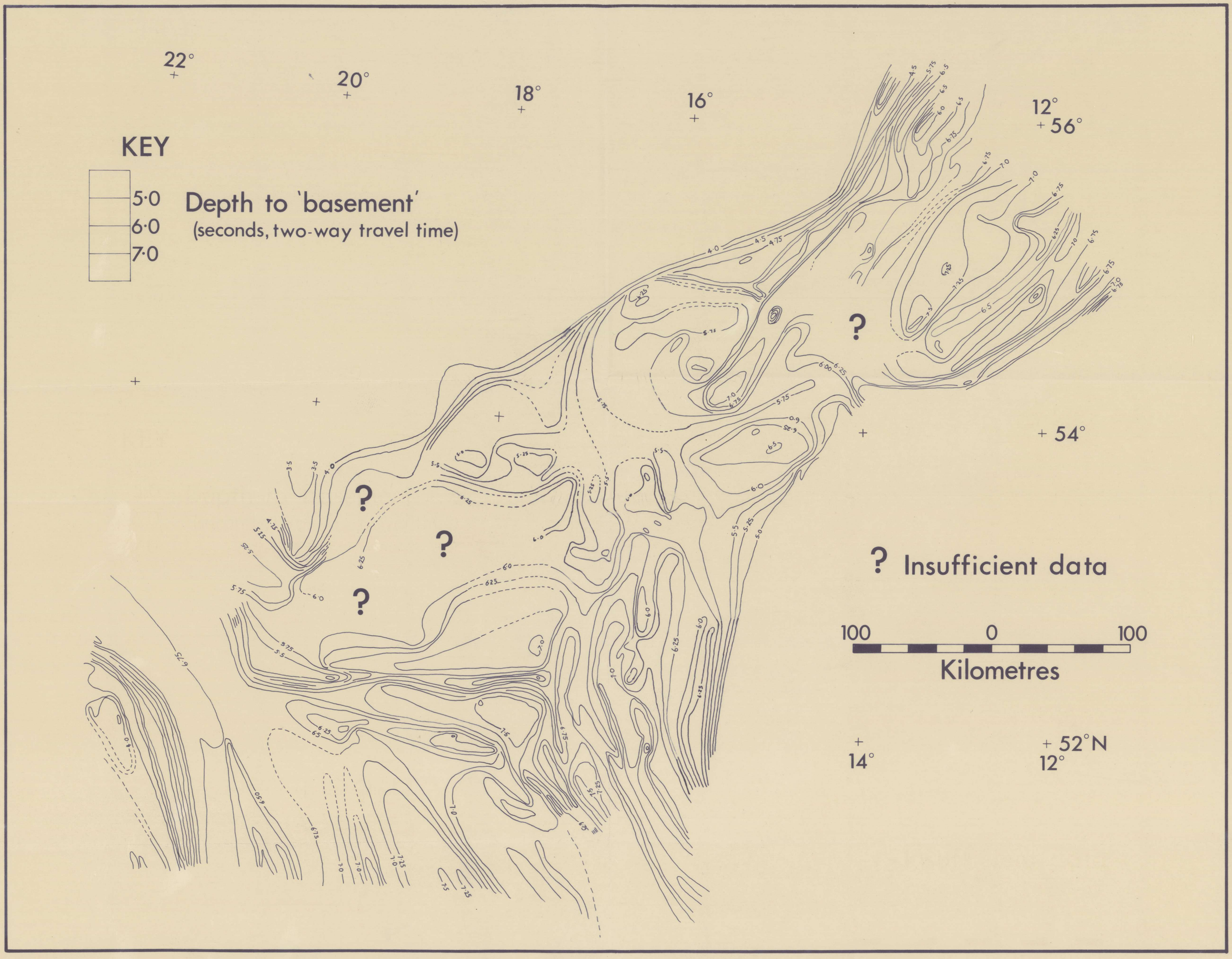


Fig. 3 ISOCHRONS TO BASEMENT

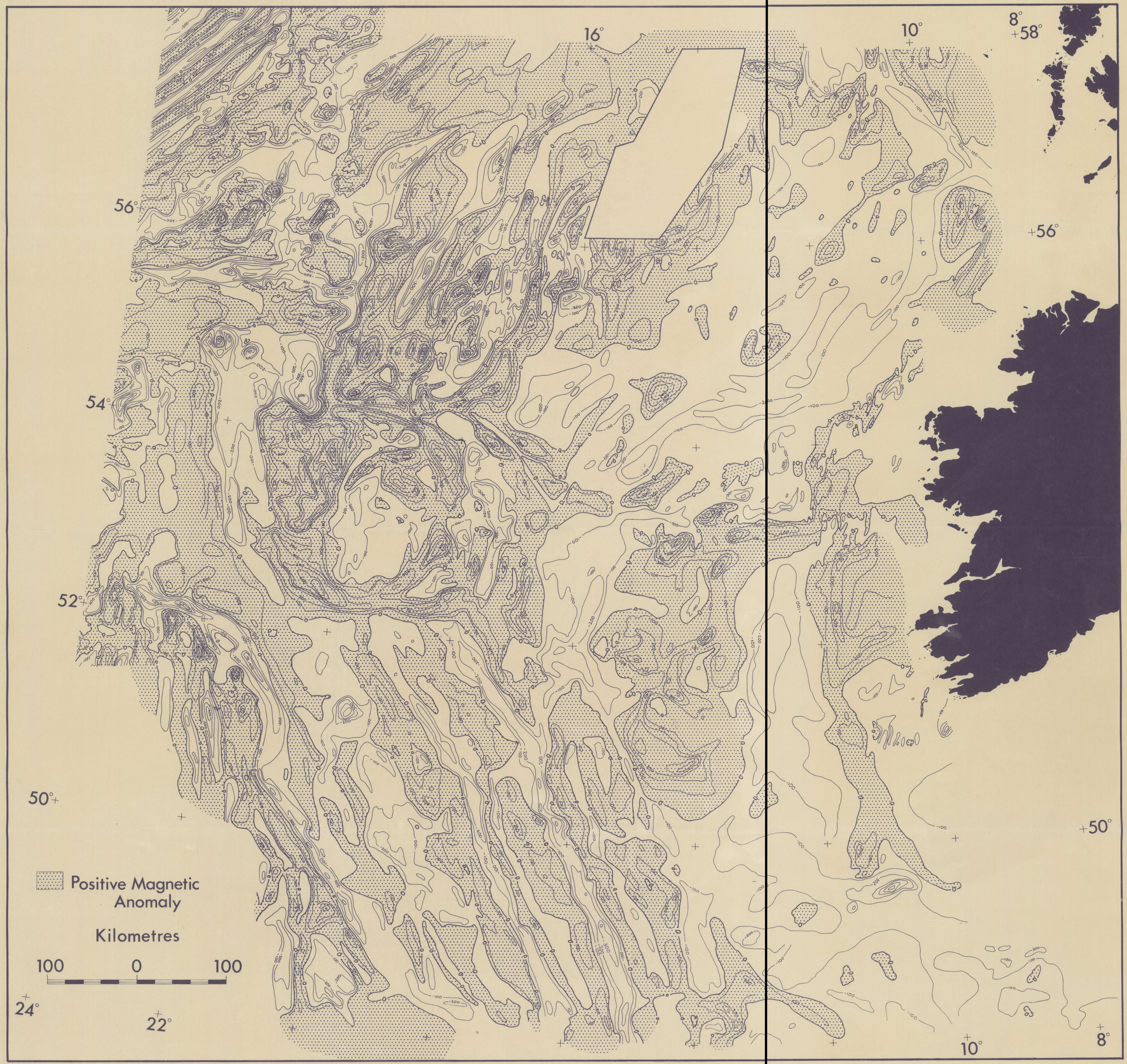


Fig.2

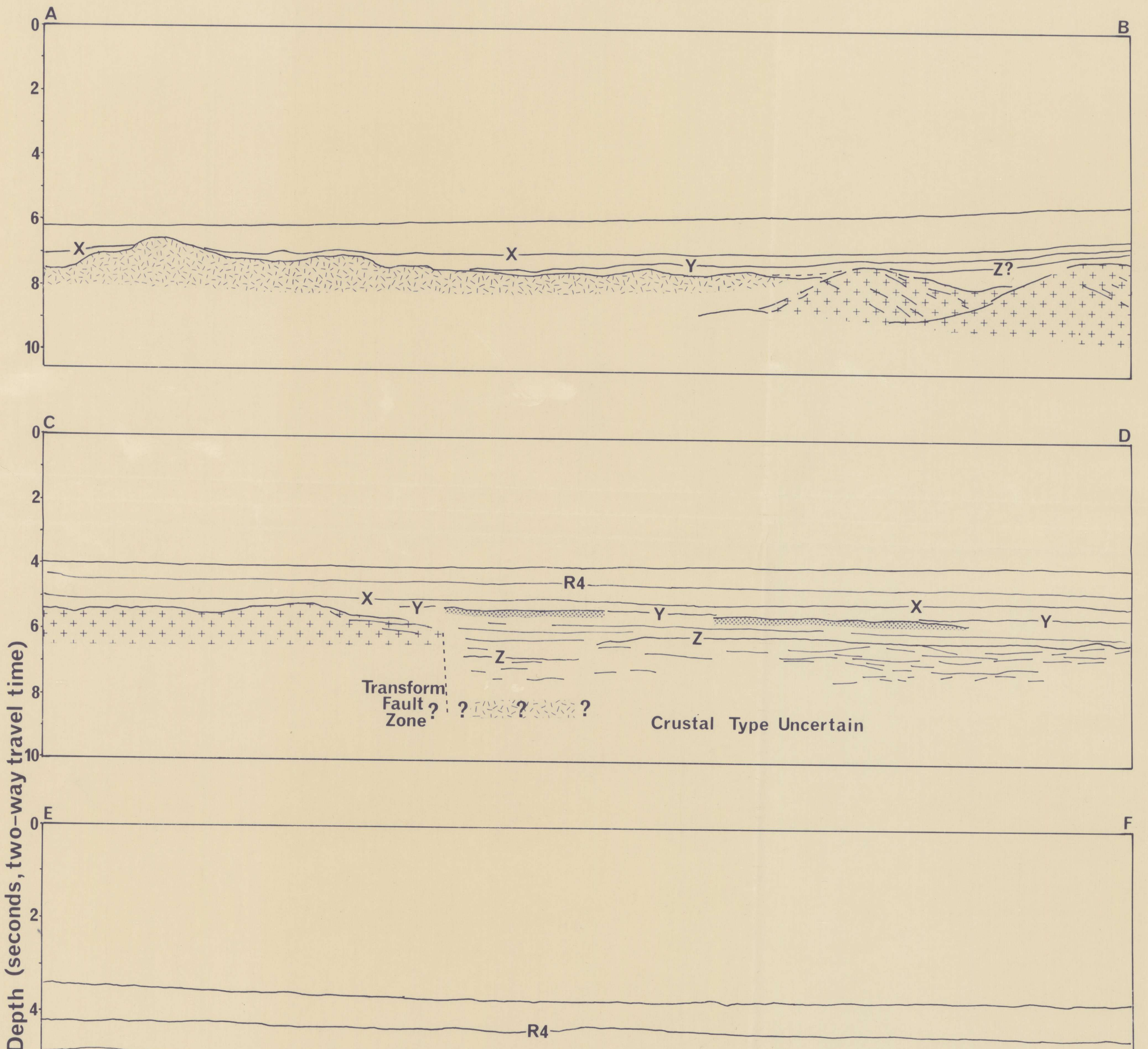
MAGNETIC ANOMALY

Fig.1

TRACK CHART

Fig. 5

STRUCTURAL INTERPRETATION



Sections located on fig.1 See also figs. 4a-d

Fig. 4 **INTERPRETED SEISMIC PROFILES**