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DISPERSION OF SURFACE WAVES IN THE IBERIAN PENINSULA AND THE ADJACENT ATLANTIC AND MEDITERRANEAN AREAS

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RESUMEN

Se han aplicado las técnicas del análisis de Fourier para determinar la velocidad de grupo y fase de las ondas superficiales, a través de las siguientes regiones: a) la Península Ibérica, b) el Océano Atlántico entre Azores y Portugal y c) el Mar de Alborán. La estructura corteza-manto, correspondiente a las curvas de dispersión obtenidas, se ha determinado por los métodos usuales de inversión aplicados a varios modelos teóricos de corteza-manto.

Comparando las curvas teóricas y empíricas se ha llegado a fijar la estructura más probable para estas tres regiones. Los trayectos estudiados entre Ebro-Oporto y Ebro-Málaga parecen ser de una estructura similar al del triángulo Toledo-Oporto-Málaga, previamente estudiado.

Los trayectos Azores-Oporto y Azores-Málaga son de tipo claramente oceánico con una corteza de sólo 6 km de espesor, incluyendo los sedimentos.

Finalmente, la estructura del mar de Alborán y la de la cuenca Balear, entre Argelia y España, presenta algunos rasgos oceánicos. Esto apoya la idea de que el mar de Alborán es una parte de una pequeña placa, del tipo descrito como "buffer plate" que, en este caso, está siendo fuertemente comprimida entre las dos grandes placas Africana y Euroasiática.

ABSTRACT

Fourier analysis techniques have been applied to determine the phase and group velocity of surface waves through the following regions: a) the Iberian Peninsula, b) the Atlantic Sea between Azores and Portugal and c) the Alboran Sea. The crust-mantle structure corresponding to the dispersion curves obtained has been determined by the normal inversion methods, applied to several theoretical crust-mantle models. Comparison of theoretical and empirical curves leads to fix the most probable type of structure for those three regions. The paths studied between Ebro-Porto and Ebro-Malaga turn out to be of similar structure to that of the triangle Toledo-Porto-Malaga.

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The paths Azores-Porto and Azores-Malaga are of clear oceanic type with a crust thickness of only 6 km, including the sediments.

Finally, the structure of the Alboran Sea and that of the Balearic Basin, between Algeria and Spain, presents some oceanic features. This supports the idea that the Alboran Sea is a part of a small plate of the type described as "buffer plate" that, in this case, is being squeezed between the two large African and Euroasiatic plates.

INTRODUCTION

Within the complicated tectonics of the Mediterranean area, the knowledge of the crust-mantle structure of the Iberian Peninsula and adjacent zones is of fundamental interest to interpret the problem of the junction of the western border of the European Plate with the African Plate.

In a previous paper (Payo, 1972) we have summarized the results on velocities and thicknesses that have been obtained by different procedures for the crust and upper mantle of this zone.

The average model there proposed, mainly represents the structure of the southern-half of the Peninsula and it can be taken as a point of departure for further geophysical studies on that region.

In this work, it is intended to complete the above results by studying the crust-mantle structure along several selected paths in the northern and eastern part of the Peninsula, the Alboran sea and the Atlantic Ocean between Azores and Portugal. Surface wave dispersion methods have been applied and Rayleigh wave phase and group velocities have been determined for those seismic paths.

IBERIAN CRUST-MANTLE STRUCTURE

The study of the continental part of the zone has been completed with the new paths EBRO-PORTO and EBRO-MALAGA, by installing a temporary long-period station at EBRO. The method used has been that of the phase differences between the records at the two stations, deduced from the Fourier analysis of the seismograms. The program eliminates the high frequencies, smooths the phases, and afterwards computes the phase velocities. In spite of the large number of records used, few of them were undisturbed enough to give admissible results. Probably the application of group velocity filters to reject late arrivals, and the use of the moving window methods, would have increased the number of usable seismograms. We will do that in the near future.

The data, as can be seen in Fig. 1, show some dispersion and the differences between the two paths (black and open points) does not appear to be significant. However, the velocities across the path EBRO-MAL are somewhat lower than the others.

The dispersion corresponding to the path EBR-PTO is quite similar to that corresponding to the "reverse" profile PTO-EBR. The same happens with the other pair of stations (EBR-MAL). Therefore if dipping layers are present in the structure, the dipping angle is not large enough to produce different dispersion curves for the two opposite directions of approach of the wave trains.

The average value of all data (continuous line in the figure) is compared with the model IBE (broken line) that we computed (Payo, 1970) for the triangle Toledo-Porto-Malaga. As we can see, the coincidence is fairly good; this is why we deduce that the new paths have a similar structure to that of the triangle Toledo-Porto-Malaga.

STRUCTURE OF ATLANTIC ZONE BETWEEN AZORES AND PORTUGAL

The same method of the phase differences has been applied to the study of the crust and upper mantle of the Atlantic along the two segments Punta Delgada (Azores)-Porto and Punta Delgada-Malaga.

In this case the phase velocities of the earthquakes used appear less scattered (Fig. 2), though we had also to revise and analyze a large number of seismograms to be able to select those of the figure.

The average Rayleigh dispersion curve for the path Punta Delgada-Porto appears somewhat higher than that of Punta Delgada-Malaga; but this is not surprising since the first path is purely oceanic while the second goes though a small continental segment. This difference might be attributed to the existence of a real difference between the structure along the Azores-Gibraltar fracture and that of the aseismic region of the path Punta Delgada-Porto.

In any event, this difference is small as it can be seen in the same Fig. 2, so that, we have considered an average of all data (open points of Fig. 3) to fit the observations with a theoretical dispersion curve. Vertical bars indicate the standard deviation of the velocities, at several selected periods.

The model ATO has been found by trial and error after trying a large number of structures.

The model proposed is quite simple and we must emphasize the thinness of the oceanic layer, which has only 5 km of thickness. Other theoretical curves corresponding to larger thicknesses disagreed with the observed data.

The low velocity channel of the asthenosphere appears rather well developed, with a shear velocity of only 4.1 kms^{-1}. To achieve the best fit we had to admit large velocity contrasts at both sides of the channel, mainly in the lower part of it, where a velocity of 4.98 km s^{-1} has been used.

The velocity 7.7 km s^{-1} for the first mantle layer is in agreement with the two small refraction profiles made in this zone by Ewing and Ewing (1959). The corresponding shear velocity admitted, 4.55 km s^{-1} is of the order of the values obtained by Hart and Press (1973) using Sn phases. Ewing and Ewing gave also 5 km of thickness for the first layer of high velocity rocks, as in our model, based on refraction data.

As it can be seen, the phase velocity data in the range of periods lower than 20 seconds are very scanty. That is due to the phase irregularities that appear in the short periods. Therefore, we have compared, in this range of periods, the curve of the model adopted with the group velocity observations (Fig. 4) that Bravo and Udias (1974) have collected for some Atlantic paths very similar to ours. The agreement is fairly good, despite the large scatter of these group velocity data. All this supports the parameter distribution of our admitted model. The group velocities for the path Punta Delgada-Malaga appear, as in the case of phase velocities, below the data for the path Punta Delgada-Porto (see Fig. 3).

CRUST-MANTLE STRUCTURE OF THE ALBORAN SEA

In the study of the complicated problem of the junction of the European and African Plates, it is interesting to know as much as possible about the oceanic zones to the south of the Iberian Peninsula.

The lack of long period stations around this region makes impossible the application of phase velocity methods between pairs of stations. Therefore, we have used in this preliminary study the coastal standard stations MAL to compute the group velocity dispersion for several seismic paths.

Though the number of near earthquakes with clear surface waves was scanty, we were able to select several of them along three substantially different paths. The first group corresponds to the semiatlantic path between Malaga and the seismic region to the south-western of San Vicente Cape (Fig. 5), the second to the Alboran Sea and the third to the mixed path between Algeria and Malaga, whose Mediterranean part differs substantially from the Alboran Sea. Two earthquakes in North Morocco gave a similar dispersion to those in Algeria.

The corresponding dispersion data appear in the figure. Black points correspond to the Algeria region, open points to the Alboran Sea and those from the Atlantic side appear with crosses. To explain these dispersion data, more than fifty models have been computed following the method of trial and error to study the effect of the different parameters.

Finally we have selected the three that appear in the figure as those fitting the observations best.

Though the solution is not, in fact, unique we can draw some conclusions from the computed models:

First, for the Alboran Sea and the Mediterranean zone, at the west of this sea, it was necessary to admit the existence of a thick sedimentary layer of about 5 km; without it, the models disagreed with the data in the short period range. Also, a thick granitic layer was not compatible with the data. Therefore, we tentatively think that either the granitic layer does not exist or it is really very thin, as in the model assumed for the Alboran Sea region, which has been supposed with 5 km of thickness. Finally, the Mantle just below the Moho must have a low velocity: 4.2 or 4.3 km s^{-1} to achieve the coincidence in the long period range.

Though the data of the figure refer to Rayleigh waves, the Algerian earthquake show also some clear Love waves whose dispersion agrees with that of the assumed model, withing expected errors: therefore lateral anisotropy may, in principle, be discarded, considering that the same model is valid for Love and Rayleigh waves.

The zone at the South of San Vicente Cape also appears with thick sediments and a low velocity mantle, but the model needs a rather thick granitic layer; that is, the seismic path seems to be close to a continental type of structure.

These low velocities in the upper mantle proposed in the models of Fig. 5, could lead us to believe that the low-velocity channel is rather shallow in this region of the prolongation of the Azores-Gibraltar fracture. However, the only heat flow value we know in the Alboran Sea (Nason and Lee, 1964) is fairly low (1.28 cal cm^{-2} s^{-1}). Another interpretation may be the existence of a deep lithosphere intrusion into the upper mantle in this region, as it happens in other regions like in the Lipari Arch. But this last hypothesis does not seem to be supported by the existence of intermediate earthquakes in this zone. Relative to this, it is interesting to note that recently a new small magnitude shock (4.5) has been recorded at the same depth as the famous deep earthquake (650 km of depth) of 1954 at the south of Spain. But they are two isolated cases.

Further arguments in favour of the velocities and thicknesses we have assumed for this regions can be found in Fig. 6. The figure shows that the average dispersion data, for the Alboran Sea and the western Mediterranean region being considered, are in disagreement with models with a thin sedimentary layer, A_1, or a thick granitic layer, A_2. Also the dispersion data are compared in the figure with the gravity models assumed by Bonini et al, (1973) for the Alboran Sea. We used the Nafe and Drake (1963) curves to pass from their density distribution to the velocity distribution. The disagreement is fairly large due, undoubtedly, to the high velocity they suppose in the upper mantle and to the thinness of the sedimentary layer in his models. On the other hand, the density distribution does not give a unique solution, as is well known.

Another comparision (Fig. 6) has been made considering the average of the Bouguer anomalies, given by Gaibar-Puertas (1972), along our dispersion profiles in the Mediterranean and Alboran Seas. We got 63 ± 33 mgals and 49 ± 14 mgals, respectively, that correspond to crustal thicknesses of about 23 and 26 km. Both average values are not of a pure continental type.

In summary, the thick sediments, the lack of a granitic layer and the low mantle velocity of this zone of the Alboran Sea and western Mediterranean, might be interpreted as if the junction between the Iberian and African plates were formed by the remainder of a paleo-ocean, now almost totally consumed, whose old sedimentary layers were thickned possibly, by folding, forming the present upper structure of the Alboran Sea.

These results together with those obtained from our previous study on the seismicity of the region (Payo, 1972), support the idea of being the Alboran plate as a "buffer plate" of the type described by Roman (1973). In fact, the Alboran plate presents several characteristics of such small plates, since it is formed by a tectonic unit of continental and oceanic crust; the largest earthquakes of the zone are located on its edges and small magnitude earthquakes occur, all the time, within the boundaries of the plate. In addition, two deep earthquakes in the northern part of the plate testify to the existence, in the past, of an active intrusion of oceanic crust which now remains in the upper mantle, as a lithospheric relic with very little activity.

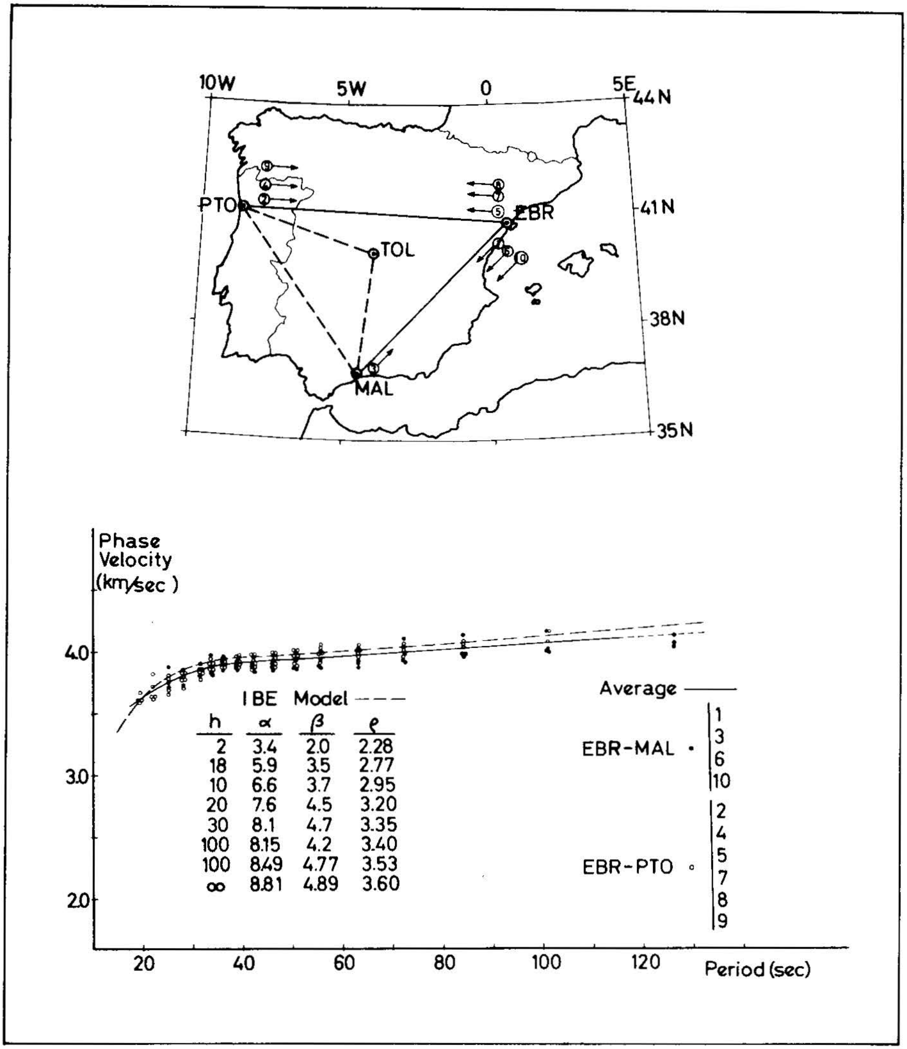


Figure 1. Rayleigh wave dispersion across the two continental paths EBRO-PTO and EBR-MAL. The average of all dispersion data is compared with the model IBE.

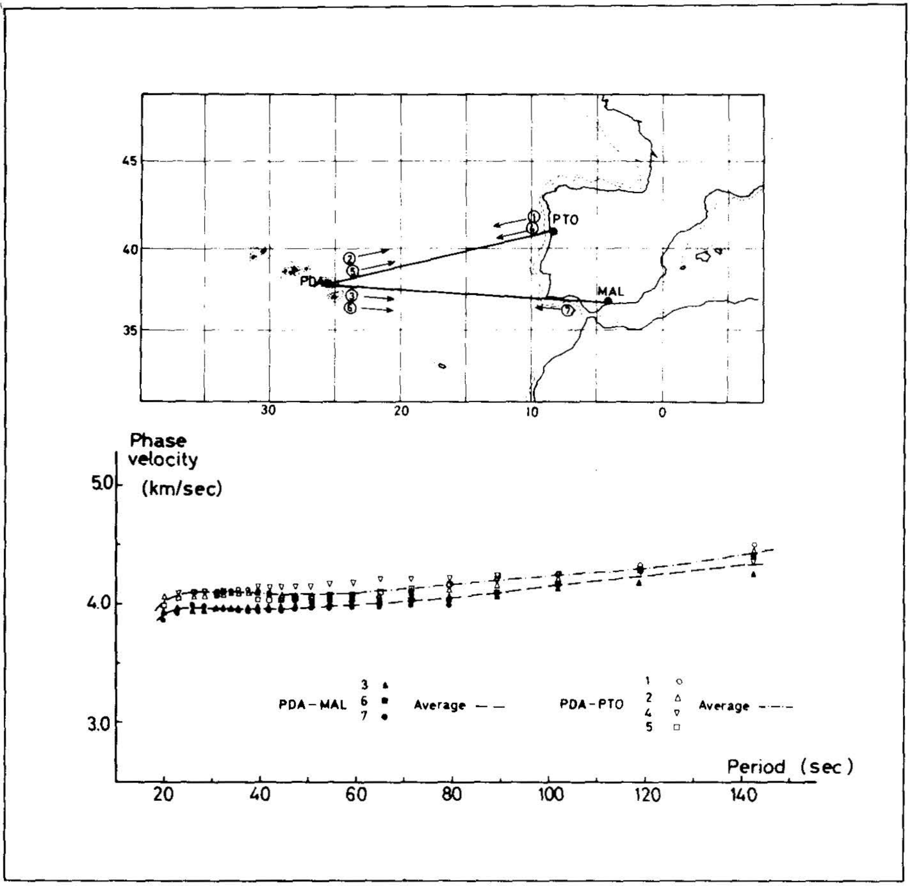


Figure 2. Rayleigh wave dispersion across two Atlantic paths.

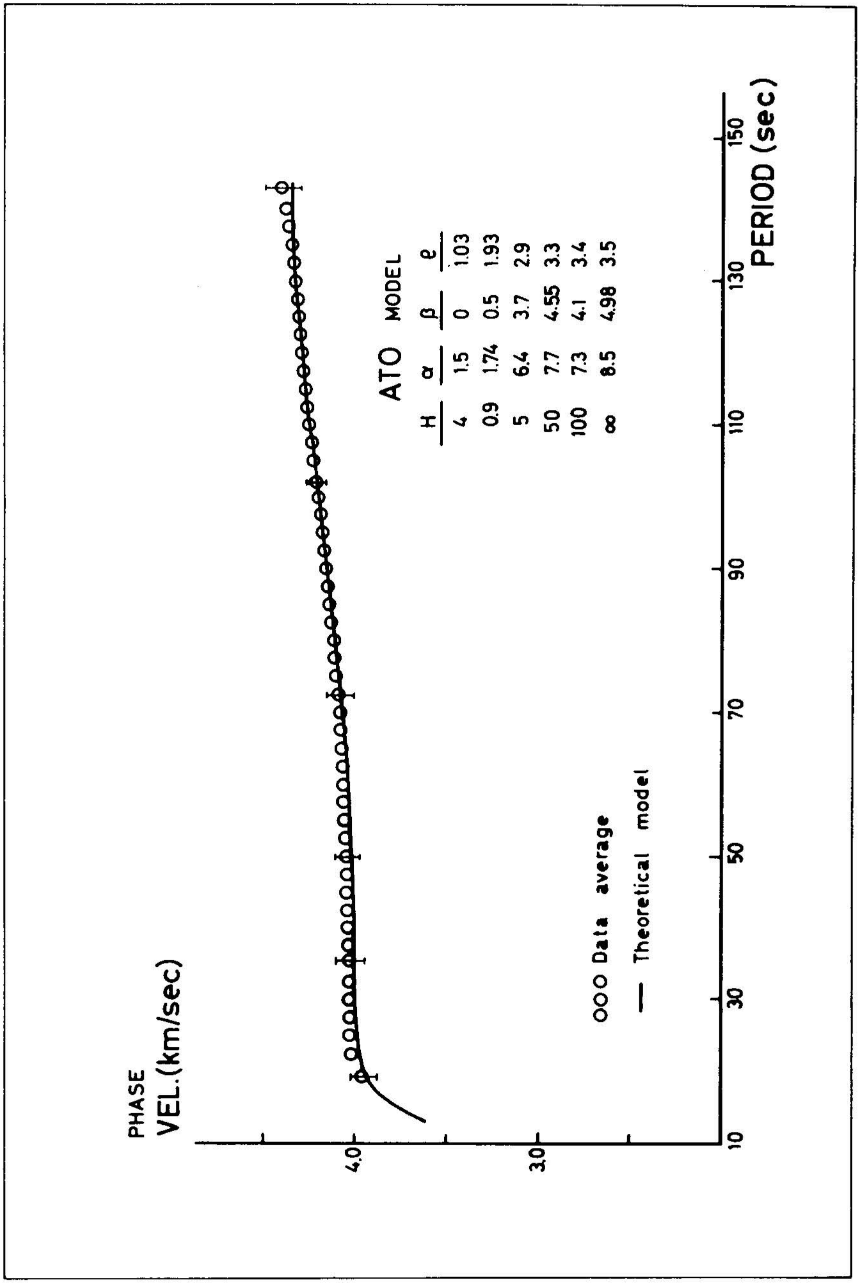


Figure 3. Comparison of the average dispersion data and the theoretical model ATO.

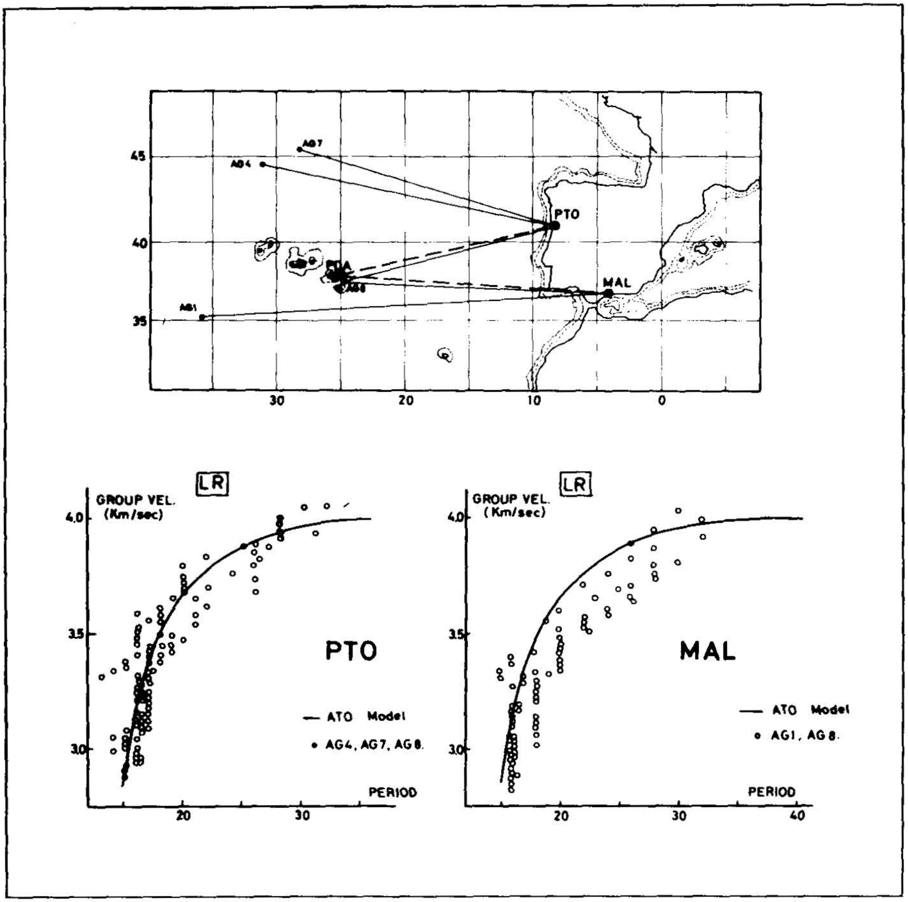
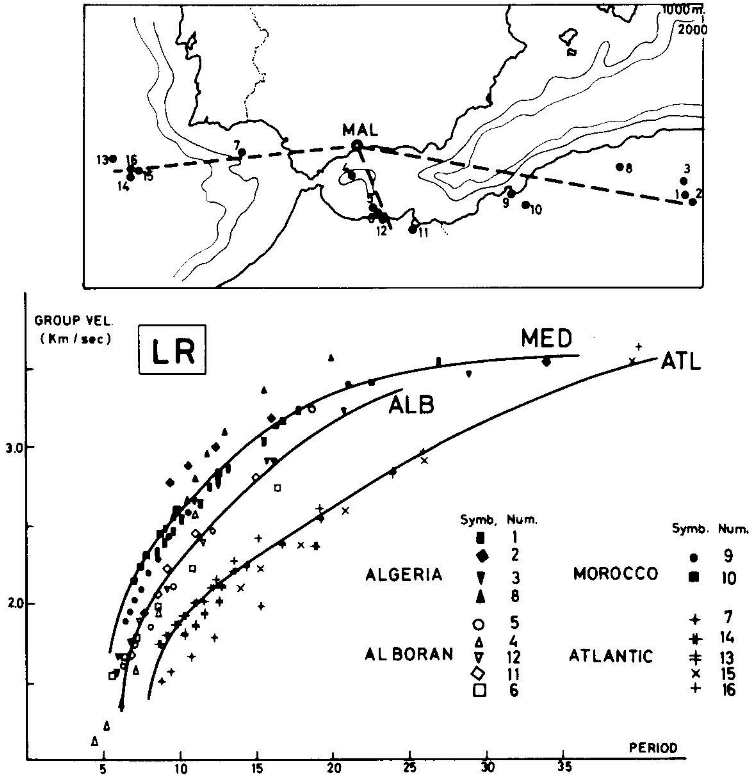


Figure 4. Comparison of the theoretical dispersion curve (model ATO) with the group velocity observations computed by Bravo and Udias (1974).



MED. Model

H	α	β	ρ
0.5	1.5	0	1.03
1.5	2.6	1.5	2.0
2	4.0	2.0	2.5
2	5.2	3.0	2.6
10	6.7	3.7	2.9
∞	7.5	4.2	3.3

ALB Model

H	α	β	ρ
1	1.5	0	1.03
1	1.75	1.0	2.0
2	4.0	2.0	2.5
3	5.2	3.0	2.6
5	5.6	3.3	2.8
10	6.7	3.7	2.9
30	7.6	4.3	3.3
100	7.4	4.1	3.35
∞	8.5	4.7	3.4

ATL Model

H	α	β	ρ
0.75	1.7	0.5	2.0
4	3.5	2.0	2.5
2	4.8	2.8	2.6
10	5.6	3.3	2.8
15	6.7	3.7	2.9
50	7.6	4.3	3.3
100	7.4	4.1	3.35
∞	8.5	4.75	3.4

Figure 5. Group velocity observations and the corresponding theoretical models for several seismic paths along the Atlantic Sea, Alboran Sea and Southern Balearic Sea.

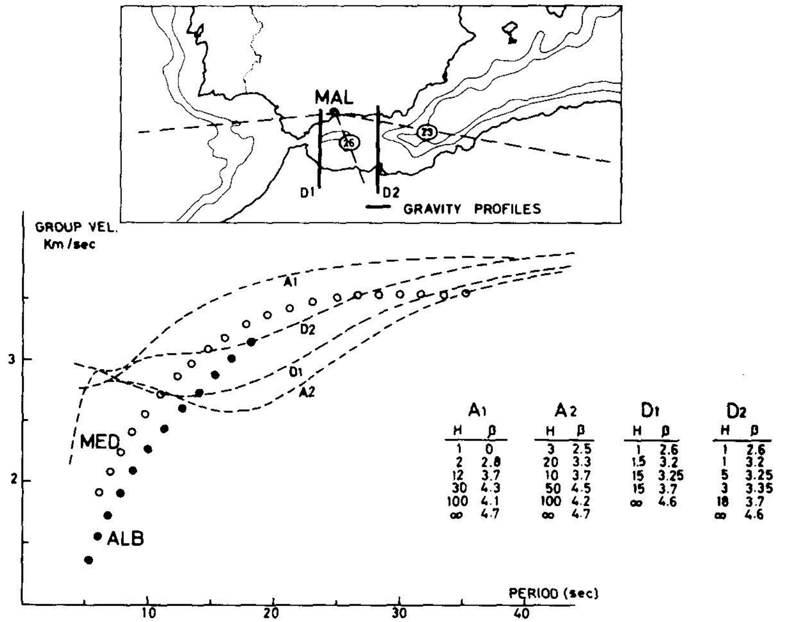


Figure 6. Comparison of the average dispersion data in the Alboran Sea with several inadequate theoretical models to show the importance of parameters of the layers (see the text).

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