Gravity and Seismic Reflection Investigations into the Crustal Structure of the Aves Ridge, Eastern Caribbean

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Summary

The results of bathymetric, gravimetric and seismic reflection surveys over the Aves Ridge and Grenada Trough (eastern Caribbean) are presented. The Aves Ridge is a submerged linear prominence typically formed of two flanking ridges enclosing a sediment filled trough in which occur seismic reflectors similar to those found in the Venezuela Basin and Grenada Trough. The short wavelength gravity anomalies of the Aves Ridge may be adequately explained in terms of structures in the sediment/basement interface. The Aves Ridge is underlain by a mass deficiency which may be interpreted in terms of a thickened crust with consequent depression of the Moho and lowest crustal layer. The positive Bouguer anomalies of the Grenada Trough are probably due to a relatively shallow Moho. The Aves Ridge and Grenada Trough typically exhibit negative isostatic anomalies and the Lesser Antilles define a linear belt of positive isostatic anomalies.

These new results support the suggestion that the Aves Ridge is an ancient island arc.

Introduction

During the summers of 1971 and 1972, Durham University, working in conjunction with the Hydrographic Department of the Royal Navy from HMS Hecla, performed gravity, magnetic, and seismic refraction and reflection experiments in the eastern Caribbean. These surveys, the locations of which are illustrated in Fig. 1, formed part of the United Kingdom contribution to CICAR (Cooperative Investigation of the Caribbean and Adjacent Regions). Preliminary results for the eastern part have been published elsewhere (Westbrook, Bott & Peacock 1973), and this paper describes the results of gravity and seismic reflection surveys of the western part including the Aves Ridge.

Geological and tectonic environment of the survey area

The Aves Ridge or Swell (Fig. 1) is a submerged linear prominence striking north-south parallel to, and approximately 240 km west of, the volcanic island arc of the Lesser Antilles. The Aves Ridge is flanked to the west by the Venezuela Basin which is an area of subdued topography with sea depths between 4.5 and 5 km. The Grenada Trough separates the Aves Ridge from the Lesser Antilles.

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The Aves Ridge typically exhibits depths to its crestal region of the order of 1 km, but in the north culminates in Aves Island, a small island surrounded by coral reefs with a maximum elevation of 5 m. Aves Island consists entirely of calcareous and arenaceous sediments, and cobbles of volcanic rocks which are quite common on the island are almost certainly discarded ships’ ballast.

Geological sampling of the southern Aves Ridge has produced rocks of granodioritic and basaltic compositions (Fox, Schreiber & Heezen 1971) and metavolcanic and volcanic conglomerates (Nagle 1971). Radiometric dating of the granitic samples has given ages between middle Cretaceous and Palaeocene. This occurrence of granitic rocks in an oceanic environment is almost unique. However, rocks of similar composition have been described from the Lesser Antilles (Christman 1953) where they may represent an acid plutonic differentiate of the parental magma whose calc-alkaline differentiates are represented by surface volcanism. Dredging in the vicinity of Aves Island has produced rocks of andesitic, basaltic and dacitic compositions (Nagle 1971).

JOIDES investigations on the Aves Ridge at site 30, Leg 4 (JOIDES 1970) have provided a sediment section from Pleistocene to Miocene in clays, siltstones and globigerina oozes with ash bands in the lower beds. A very high sedimentation rate is indicated for the Pleistocene, during which parts of the Ridge may have been emergent. Site 148, Leg 15 (Edgar et al. 1971a) revealed a subaerial unconformity between a sequence of Plio/Pleistocene marls and a reworked sequence of Miocene, Palaeocene and Cretaceous volcanic sands and clays. Marlowe (1971) has also concluded that a prominent seamount on the Ridge was emergent during Pleistocene/early Holocene times. The present-day depths of these subaerial erosional surfaces indicates that eustatic changes in sea level cannot have been wholly responsible for their formation, and that vertical tectonic movements must have occurred. These geological investigations indicate that the geology of the Aves Ridge is similar to that of the Lesser Antilles, whose history of calc-alkaline volcanism extends from the Eocene (Weyl 1966).

The seismic refraction surveys of Officer et al. (1959) and Edgar, Ewing & Hennion (1971b) have revealed that the crustal structure of the Caribbean differs from that of typical oceanic crust in that three rather than two sub-sediment seismic layers are present, characterized by velocities of 3.3-5.5, 6.2 and 7.4 km s⁻¹, and overlie an upper mantle with a normal seismic velocity. The Moho has not been identified beneath the Aves Ridge or Grenada Trough, although the upper crustal layers are similar to those encountered in the Venezuela Basin, where it has been. Edgar et al. (1971b) have concluded that a thickened 6.2 km s⁻¹ layer is responsible for the major part of the Aves Ridge. Another difference from normal oceanic crust is the absence of the magnetic lineations typifying oceanic crust.

The Caribbean plate is seismically inactive and its boundaries marked by an almost continuous zone of seismic activity (Sykes & Ewing 1965), implying that the plate is stable and that the activity is caused by the interaction of plate boundaries. Consequently the survey area is seismically inactive, although rare events (Molard 1952) are located on the flanks of the Aves Ridge.

Previous studies of gravity and seismic reflection

The first studies of the gravity field of the Caribbean were performed by Vening Meinesz (1948). Edgar (1968) has noted that the Caribbean ridges are marked by positive free-air anomalies, and the basins by negative free-air anomalies. He has computed the mass per unit area for several locations based on seismic refraction data and found values negative with respect to the mean for ocean basins, which may be indicative of a slightly less dense upper mantle underlying the area. Talwani (1965) described the major anomaly belts of the Caribbean. Andrew, Masson Smith
Robson (1970) published isostatic anomaly maps of the islands of the Lesser Antilles and the results of some marine gravity lines. Bunce, Chase & Bowin (1971) performed several traverses across the eastern Caribbean and concluded that the curvature of the free-air anomaly maximum of the Aves Ridge is far smaller than that of the Lesser Antilles. However, examination of the results of the present survey indicates that the Aves Ridge is somewhat more complex structure and that these maxima are dependent on local topographic features which make the regional trend difficult to delineate.

Ewing, Talwani & Ewing (1965) have shown that the sediments of the Caribbean exhibit uniformity in that two principal reflectors are almost always present. These reflectors, named A" and B" for upper and lower respectively, define the bases of two beds of total thickness 1 km for which Ewing et al. (1965) have proposed the name 'Carib Beds'. The Carib Beds are overlain by an acoustically transparent sequence for which the name 'younger turbidites' has been proposed. Reflectors A" and B" are both very smooth, and the presence of weak sub-B" reflectors (Eaton & Driver 1967) has been taken to indicate that B" does not everywhere represent true basement. JOIDES investigations have identified the younger turbidites as a red zeolitic clay. Reflector A" has been identified both by coring and drilling as a chert bed of lower Eocene age. Identification of B" has been less certain as it may be represented by a chert horizon of Campanian age in some locations and in others by dolerite underlying upper Cretaceous deep-sea sediments. The Carib Beds have been shown to represent a time of pelagic siliceous sedimentation. Several seismic reflection profiles have been recorded over the Aves Ridge and Grenada Trough, including studies by Bunce et al. (1971), Edgar et al. (1971b), the US Geological Survey (1972) and Durham University (this work). The profiles extend from a possible extension of the Aves Ridge at 18° N to 12° 54' N, and provide a reasonably complete coverage of the area.

The surveys

The survey area (Fig. 2) is bounded by latitudes 12° 54' N, 16° 10' N and by longitudes 61° W, 65° W in the south and 61° 40' W, 64° 30' W in the north. East-west ship's tracks traversing the entire area were run at 10 nautical mile spacing, with interlines defined approximately by the 1000-fm isobath run to give 5-nm spacing.

Navigation was by the Decca phase comparison system 'Lambda', which provided fix position errors of only ± 200 m, using slave transducers on the islands of St Lucia and St Kitts. Bathymetry was monitored continuously by a precision depth recorder (pdr), with an accuracy of ± 3 m. Three seismic reflection profiles were obtained at 12° 54' N, 13° 24' N and 13° 54' N using an air-gun system devised at Durham University by Mr J. H. Peacock. Original records were of poor quality due to the ship's cathodic protection imparting noise to the system, but later processing by stacking the two hydrophone sets and band pass filtering greatly enhanced their quality. Incompleteness of the profiles was a result of instrument malfunction.

Gravity was monitored continuously by an Askania sea gravimeter. The meter was run in manual mode during the 1971 survey, since it was considered that the steep gravity gradients expected as the island arc was approached would be too extreme for the gravimeter servo-motor to keep the instrument level in automatic mode. During the 1972 survey the meter was run in automatic mode after tests had been performed to select the optimum survey speed. Input of gravimeter and navigational data into a ship-board computer allowed the on-line computation of free-air anomalies while on survey.

The free-air anomalies were reduced to Bouguer anomalies in Durham. The Bouger correction applied was two-dimensional in an east-west sense since the Aves Ridge and Grenada Trough approximate well to a two-dimensional system striking
north-south. The correction applied for each datum point was thus computed by approximating the underlying body of sea water to a polygon with its corners defined by digitized bathymetry, and summing the effects of the semi-infinite prisms defined by its edges after the fashion of Talwani, Le Pichon & Ewing (1959). The density chosen for this reduction was 2.00 g cm\(^{-3}\) since this density represents that of the uppermost sedimentary layer, and as such is the most convenient for interpretation.

The bathymetric chart is presented in Fig. 3. The western boundary of the Aves Ridge with the Venezuela Basin is linear, and in the north is marked by rough topography, a feature which has not previously been reported. The western flank of the Aves Ridge is marked by a series of north–south trending ridges. In the south a large, flat-topped seamount occurs centrally on the Ridge, and has been studied by Marlowe (1971), and other small subcircular features occur on the central and eastern parts of the Ridge. Aves Island lies on a broad north–south trending ridge. The eastern flank of the Ridge is marked by a less pronounced series of ridges, and the boundary with the Grenada Trough is considerably more curved than the western boundary. Its radius of curvature of about 400 km is similar to that of the Lesser Antilles. This eastern boundary is marked by higher gradients in the south than in the north, and north of about 15° N the boundary between Ridge and Trough is difficult to define on bathymetric data alone. The southern Grenada Trough exhibits extremely subdued topography with depths deviating by no more than a few metres from its mean value, which is indicative of a substantial sediment cover. The topography becomes increasingly more rugged towards the north.

The free-air anomaly chart is presented in Fig. 4. Free-air anomalies decrease to negative values as the Aves Ridge is approached from the Venezuela Basin, a
phenomenon due to a mass deficiency underlying the Aves Ridge. The Ridge itself is characterized by positive free-air anomalies. Steep gradients are apparent over several positive bathymetric features, for example the series of north–south ridges on the western flank of the Ridge, over which reflection profiles indicate a lack of sediment cover. The eastern boundary of the Aves Ridge with the Grenada Trough is marked by far higher gradients in the south than in the north, where the boundary with the Trough is less clearly defined. The Grenada Trough is characterized by negative anomalies in the south with values reaching less than −70 mgal in places. These negative anomalies are probably due in part to mass deficiencies underlying both the Aves Ridge and Lesser Antilles. Free-air anomalies increase northwards in the Grenada Trough to small positive values. The Lesser Antilles are marked by extreme free-air anomaly gradients reaching maximum anomalies between the islands in excess of 150 mgal. The abrupt change in gradient observed when passing from the Grenada Trough onto the Lesser Antilles is probably due to a rapid decrease in sediment thickness.

The Bouguer anomaly chart is presented in Fig. 5. Bouguer anomalies decrease from a regional high in the Venezuela Basin as the Aves Ridge is approached. Bouguer anomalies over the Aves Ridge still reflect topographic features because of the low density used in the Bouguer correction. The short wavelength anomalies of the Ridge are superimposed on a long wavelength regional negative anomaly. The Grenada Trough is a Bouguer anomaly high, with anomalies increasing northwards to a maximum at 14° 30' N, and thence decreasing gently northwards. The extreme free-air anomaly gradients over the island arc are decreased by the Bouguer correction.

Seismic reflection profiles

Almost all profiles across the Aves Ridge including those presented here show the western flank to be mantled by the gently rising sediment layers of the Venezuela Basin, with true basement not clearly identified. Basement is always distinguishable over the Aves Ridge, and in places crops out. The typical form of the Ridge is of two outer ridges enclosing a central trough (Fig. 6(a)). The western ridge is visible on every profile, but the eastern ridge is locally only poorly developed although in places it is larger than the western ridge. Within the inter-ridge troughs, sediment layering is usually apparent, for example, two reflectors are developed above the basement in Fig. 6(a) at 12° 54' N, while three reflectors are developed in the profile presented in Fig. 6(b) at 13° 24' N. These reflectors are similar to those developed in the flanking basins, and if they are the same horizons imply either elevation of the Ridge after deposition of the sediments or deposition on a pre-existing structure with sediment transport in the upper water layers. The undeformed nature of the sediments in the inter ridge troughs precludes post-depositional uplift of the Ridge by horizontal compression. The profile presented in Fig. 6(c) at 13° 54' N indicates that the Aves Ridge may extend beyond its topographic expression into the Grenada Trough. The disturbance of overlying sediment horizons may indicate that it may be of post-depositional origin.

Interpretation of gravity anomalies

The interpretation of gravity anomalies in this region was hampered by the lack of seismic control on the Moho beneath the Aves Ridge and Grenada Trough, data being limited to profiles in the Venezuela Basin. The long wavelength regional anomalies are attributed to variation in depth to the Moho and lowest crustal layer. Consequently the Moho must descend beneath the Aves Ridge. The Grenada Trough is a Bouguer anomaly high, although seismic refraction profiles (Officer et al. 1959; Edgar et al. 1971b) indicate that it contains a thick sediment infill, in places in excess
of 3 km. Consequently the Moho must rise from the Aves Ridge towards the Grenada Trough. Bunce et al. (1971) have suggested that a possible cause of the gravity high over the Grenada Trough is the presence of high density crustal rocks. Refraction profiles in the Trough, however, indicate that the seismic velocities are similar to those present beneath the Aves Ridge and Venezuela Basin. Since P-wave velocities are related to density (Nafe & Drake 1963), the explanation advanced here is more satisfactory.

Three interpreted profiles are presented. For each a two-dimensional structure was assumed, and a non-linear optimization procedure used to vary the spatial position of body points so that the sum of the squares of the differences between the observed and computed anomalies was minimized. Seismic basement beneath the Aves Ridge was defined by seismic reflection data, assuming a sedimentary velocity of 2.0 km s⁻¹. The lowest crustal layer was assumed to retain a constant thickness beneath the Aves Ridge, and so the deep structure must not be considered unambiguous. Residual anomalies are of the same order as the expected accuracy of the survey.

The profile at 12° 54' N (Fig. 7) uses Durham reflection data for control on the basement, and extrapolated data from refraction line 29 of Officer et al. (1959). This refraction line did not reach the Moho, and so control on the thickness and depth of the lowest crustal layer was obtained from lines 7 and 25 to the west of the profile.
The interpretation indicates that (1) the short wavelength anomalies of the Aves Ridge are caused principally by structures in the sediment basement interface, (2) that a thickening of the 6.2 km s\(^{-1}\) layer is responsible for the major part of the Aves Ridge (a conclusion also reached by Edgar et al. 1971b), and (3) that the Moho is relatively deep beneath the Aves Ridge and relatively shallow beneath the Grenada Trough.

The second profile considered (Fig. 8) is a composite of data at 14\(^\circ\) 10' N in the west and at 14\(^\circ\) 15' N in the east, and was compiled to approximate the position of a Wood Hole Institute reflection profile at similar latitudes (Bunce et al. 1971). Four seismic refraction profiles are available for control on the structure (lines 10, 22/23, 29 and 30 of Officer et al. 1959) although none of these recorded the Moho. The profile crosses one of the ridges marking the western flank of the Aves Ridge, whose gravity field is represented by a single sharp peak. It was found that the density contrast between the basement and sediments was insufficient to cause the whole of the anomaly of the ridge, and that a further body of somewhat denser material was also required. This body forms the core of the ridge, and it is possible that it represents a central body of gabbroic material surrounded by less dense andesitic material which forms the basement elsewhere on the Ridge. The profile also attributes the crustal thickness of the Aves Ridge to a thickened 6.2 km s\(^{-1}\) layer.

The profile at 15\(^\circ\) 30' N (Fig. 9) also crosses one of the north–south trending ridges of the western flank of the Aves Ridge, and also the ridge culminating in Aves Island 16 km to the north. The sediment–basement interface was defined by a Woods Hole Institute reflection profile (Bunce et al. 1971). No seismic refraction lines cross the profile, but refraction line 31 of Officer et al. (1959), 55 km to the west, was available for structural control. Three principal peaks define the gravity field of the Aves Ridge at this latitude. The two westerly peaks are seen to be caused by structures
Fig. 8. Interpretation of the composite Bouguer anomaly profiles at 14° 10' and 14° 15' N. Horizontal axis origin is 65° W and densities are in g cm$^{-3}$.

Fig. 9. Interpretation of the Bouguer anomaly profile at 15° 30' N. Horizontal axis origin is 65° W and densities are in g cm$^{-3}$.
Gravity and seismic reflection investigations

in the sediment–basement interface. The eastern peak, however, does not correspond to a basement feature, and its bounding gradients are too steep for the causative structure to be due to the underlying 6.2 km s⁻¹ seismic layer. An anomalous body of density 3.1 g cm⁻³ was required to simulate the gravity anomaly. This body must clearly be composed of dense igneous or metamorphic rocks. Volcanic cumulus rocks occur on the Lesser Antilles, and those composed of a mixture of hornblende and anorthite would have a density of approximately 3.1 g cm⁻³ (K. Wills, private communication). Further, the depth of this body is that at which calcic plagioclase is stable. As with the other profiles considered, a thickened 6.2 km s⁻¹ seismic layer accounts for the major topography of the Aves Ridge.

Isostatic anomalies

In a region where the free-air anomalies vary from −70 to +150 mgal, the state of isostatic equilibrium is of considerable interest. A Pratt isostatic anomaly map of the eastern Caribbean has been compiled from the results of several workers by Bush & Bush (1969). Andrew et al. (1970) have published Airy isostatic maps of the islands of the Lesser Antilles and some marine profiles. In addition to these reductions, I have performed Airy isostatic reductions for 12 locations in the survey area using standard procedures for Hayford zones A to O and 18 to 11 (Heiskanen & Vening Meinesz 1958) and the world charts of Niskanen & Kivioja (1951) for the contributions of zones 10 to 1. These anomalies were computed relative to a standard crustal thickness of 40 km. The results of these reductions are presented in Table 1.

From a consideration of my results and those of Bush & Bush (1969) (Fig. 10), the major trends of isostatic anomalies are apparent. The central Venezuela Basin exhibits positive isostatic anomalies of the order of 20 mgal which are probably caused by the gentle crustal doming noted by Edgar et al. (1971b), and may reflect a response of the Caribbean plate to the compressive forces which are clearly expressed at its margins. Isostatic anomalies on the Aves Ridge are typically negative, of the order of −15 mgal, although occasional anomalies, especially in the south, are positive. Anomalies increase from negative values to positive values of the order of 10 mgal in an east–west direction across the Grenada Trough. The region of negative free-air anomalies in the south of the Trough exhibits the most negative isostatic anomalies.

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with values less than \(-30\) mgal, indicating that the negative free-air anomalies are not solely due to the mass deficiencies underlying the Aves Ridge and Lesser Antilles. The Lesser Antilles exhibit large positive isostatic anomalies of the order of 50 mgal, consequently the island arc would have to sink to attain isostatic equilibrium. It would seem that the maintenance of elevation of the Lesser Antilles is related to some mechanism caused by the lithospheric plate descending beneath the islands (Chase & Bunce 1969), and if the Aves Ridge were an active island arc at some time in the past, its present isostatic state implies that this mechanism must have been removed for it to attain its present isostatic condition.

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**FIG. 10.** Isostatic anomalies of the eastern Caribbean. Solid circles, Pratt anomalies (Bush & Bush 1969), \(D = 113.7\) km; crosses, Airy anomalies (this work), \(T = 40\) km. The positions of the contour lines are approximate since isostatic data of different types are plotted.
Conclusions and discussion

(i) Both seismic and gravity investigations show that the typical form of the Aves Ridge is of two sets of north–south ridges marking its western and eastern flanks, with the western ridges more persistently developed.

(ii) True basement was recorded only under the Aves Ridge.

(iii) The presence of reflectors in the inter-ridge troughs of the Aves Ridge which are very similar to those found in the flanking basins may indicate that the Ridge was formed by post-depositional uplift.

(iv) The Aves Ridge extends in places beyond its topographic expression into the Grenada Trough.

(v) The Aves Ridge is underlain by a mass deficiency which may be interpreted in terms of a thickened crust with consequent depression of the Moho and lowest crustal layer.

(vi) The short wavelength positive gravity anomalies of the Aves Ridge are principally explained by structures in the sediment–basement interface, although some anomalies appear to be caused in part by a lateral change in density.

(vii) The positive Bouguer anomalies of the Grenada Trough may be explained by an elevated Moho rather than the presence of dense rocks in the crust.

(viii) The Venezuela Basin exhibits positive isostatic anomalies, the Aves Ridge negative anomalies, the Grenada Trough negative anomalies in the west and positive anomalies in the east and the Lesser Antilles define a belt of large positive isostatic anomalies.

(ix) The presence of subaerial erosional surfaces on the Aves Ridge which are at too great depths to be explained by eustatic changes in sea level indicates that the Aves Ridge must have undergone tectonic subsidence during its history.

There are several hypotheses for the origin of the Aves Ridge, only two of which deserve serious consideration. The linearity may suggest that it is an ancient ocean ridge. However, the interpretations here presented indicate that the Aves Ridge is underlain by a thickened crust, while mid ocean ridges are composed of normal oceanic crust underlain by anomalous upper mantle (Talwani, Le Pichon & Ewing 1965). Consequently after the ridge becomes inactive it should subside to normal ocean depths and no longer retain a topographic expression. Also the linearity may suggest that it is an aseismic ridge of Iceland–Faeroe type. However, although there are several similarities (Bott, Browitt & Stacey 1971), the geology of the Iceland–Faeroe ridge is allied to that of Iceland, and the recovery of andesitic rocks from the Aves Ridge would seem to preclude this possibility, as such rocks constitute only a minor part of Icelandic geology.

The spatial association of the Aves Ridge with an active island arc, and the recovery of a suite of rocks which are similar to those encountered on the Lesser Antilles strongly suggest that the origin of the Aves Ridge is closely allied to that of the island arc. Consequently it would seem that there are two main possibilities for its origin. Firstly that it is an ancient island arc isolated when the location of underthrusting stepped back to its present-day position during the lower Eocene to coincide with the commencement of volcanism on the Lesser Antilles. Secondly, the Aves Ridge may represent an original portion of the Lesser Antilles which remained stationary while the present active arc was translated eastwards by some secondary process generated by the primary underthrusting mechanism.

The first of these suggestions has been proposed by several other workers (e.g. Freeland & Dietz 1971; Malfait & Dinkelman 1972; Mattinson, Fink & Hopson
1973). If this were the case, the Grenada Trough would be the spatial equivalent of
the Tobago Trough in the present-day situation. The location of the deformed
sediments which would be the equivalent of the present-day Barbados Ridge (Chase
& Bunce 1969) is unknown. However, by analogy with the present-day situation,
these sediments must lie quite close to the present location of the Lesser Antilles, and
if, indeed, the Lesser Antilles were the actual site of these sediments, their evidence
would have been destroyed by the later volcanism. This would imply that the Tobago
Trough is underlain by a section of Atlantic crust which would have been isolated by
the step back in underthrusting. Preliminary results of the Durham University
seismic refraction project in this region (Boynton, Kearey & Westbrook in MS.)
indicate that the Tobago Trough may be underlain by crust which has greater affinities
with the Atlantic than the Caribbean.

The second of these suggestions is a consequence of the work of Karig (1970,
1971a, b) on the basins behind the island arcs of the western Pacific, in which he
suggests that these basins were the result of secondary spreading processes occurring
behind the active island arc. As such the Grenada Trough would be an example of
an inactive basin with normal heat flow in the classification of Karig (1971b), and
would have formed as the Aves Ridge remained stationary while the Lesser Antilles
were translated eastwards. A major criticism of this hypothesis is that there are no
volcanic rocks older than the Eocene on the Lesser Antilles, while dating of samples
from the Aves Ridge indicate that it is a somewhat older structure than the Lesser
Antilles.

Data are thus not conclusive as to the origin of the Aves Ridge. It is hoped that the
results of the Durham University Lesser Antilles Seismic Project (LASP) will be of
help in this respect. The present data would seem to support the formation of the
Aves Ridge by a step back in underthrusting.

This model implies that a strip of the Atlantic Plate would have been incorporated
onto the eastern edge of the Caribbean Plate. Preliminary results of LASP (Boynton
et al. in MS.) indicate that this may have been the case, with the Tobago Trough
underlain by Atlantic-type, rather than Caribbean-type crust.

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