Seismic refraction results over the d'Entrecasteaux Zone west of the New-Hebrides Arc

Bernard PONTOISE[1], Donald TIFFIN[2]

Abstract : *First refraction data from the d'Entrecasteaux Zone are presented here. The results of two OBS seismic refraction profiles taken over the d'Entrecasteaux Zone near its intersection with the New-Hebrides Island Arc, and preliminary data from three sonobuoys profiles near the same area, are used to determine crustal structure across the zone.*
Data analysis provides evidence that the crust of this region is oceanic in origin, thicker than usually found in the world oceans. Thicker crust and lower velocity of layer 3, compared to other areas, is support for interpreting the d'Entrecasteaux Zone as a significant plate boundary between different crusts, rather than a dislocation in one plate.

Key words : Seismic refraction - OBS - Subduction - New-Hebrides - SW Pacific.

Résumé : Résultats de sismique réfraction dans la zone d'Entrecasteaux, W de l'arc des Nouvelles-Hébrides. *Dans cet article les auteurs présentent les premières données de sismique réfraction obtenues sur la zone d'Entrecasteaux. Pour déterminer la structure crustale de la zone d'Entrecasteaux au voisinage de son intersection avec l'arc insulaire des Nouvelles-Hébrides, ils s'appuient sur les résultats de deux profils de sismique réfraction avec station sous-marine (OBS) et sur les résultats préliminaires de trois profils avec bouées dérivantes. L'interprétation des structures de vitesses indique que certaines couches pourraient demeurer horizontales, ou même remonter vers l'est, suggérant que la Zone d'Entrecasteaux ne plonge pas partout au niveau de la fosse de subduction. L'analyse des données montre que la croûte de cette région est d'origine océanique, mais d'épaisseur plus grande que ce que l'on trouve généralement dans les océans. Une croûte plus épaisse et des vitesses moins grandes comparativement aux régions avoisinantes indiquent clairement que la zone d'Entrecasteaux doit être considérée comme une frontière de plaques entre deux croûtes océaniques différentes plutôt qu'un accident de dislocation à l'intérieur d'une même plaque.*

Mots-clés : Sismique réfraction - Subduction - OBS - Rides asismiques -Sud-Ouest Pacifique.

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INTRODUCTION

The New-Hebrides Island arc system has been the subject of several recent studies (CARNEY and MACFARLANE, 1982 ; Equipe de Géologie-Géophysique, ORSTOM-Nouméa, 1982 ; BURNE *et al.* 1985 ; COLLOT *et al.*, 1985 ; GREENE *et al.*, in press). The northern and southern parts of the arc are typical of arc-trench systems elsewhere, however the central area is unusual in several respects. The well developed trench that occurs over most of the 1 700 km length of the arc is absent in this area. Instead, a prominent ridge on the subducting plate, the D'entrecasteaux Zone, abuts the island arc. The deep trench along the western side of the New-Hebrides arc marks the northeastward subduction of the Australia-India plate beneath the North Fiji Basin. The trench is continuous from the Santa Cruz Islands in the north, where it connects to the east-west trending South Solomon Trench, to the southern terminus south of Mathew and Hunter Islands where the trench turns sharply northeastward and the plate boundary continues from there as a transform fault. The central area west of the islands of Espiritu Santo and Malekula has no topographic deep trench morphology between the latitudes of about 14° 30' to 16° 30'. Instead, these islands protrude westward over a line joining the trends of the axes of the deep trenches to the north and the south, and the island slopes meet the high topography of the colliding D'Entrecasteaux Zone at relatively shallow depth.

The D'Entrecasteaux Zone is an aseismic, arcuate, submarine ridge of complex topography and unclear history. It extends westward from the New-Hebrides arc for about 200 km, then swings in a sweeping arc to the south to meet the northern platform of New Caledonia. The origin of the zone is obscure, and it has been variously interpreted as the site of a former northeast dipping subduction in the Eocene (DANIEL *et al.*, 1977), a south dipping subduction in the pre-Miocene (COLLOT *et al.*, 1985) or as a tectonic intraplate dislocation between crusts of similar age and origin (LAPOUILLE, 1982).

The D'Entrecasteaux Zone or DEZ (fig. 1) is approximately 100 km wide west of the New-Hebrides arc. It is characterized over much of its length by two linear bathymetrically high ridges separated by a median basin. In the eastern area, these are named (COLLOT *et al.*, 1985) the North D'Entrecasteaux Ridge, the Central D'Entrecasteaux Basin, and the South D'Entrecasteaux Chain. North of the D'Entrecasteaux Zone, and separated from it by the West Santo Basin, is the West Torres Massif, a probable oceanic plateau (DUPONT and RECY, 1981) about to collide with the New-Hebrides Trench. South of the D'Entrecasteaux Zone lies the North Loyalty Basin. DSDP Site 286 in the North Loyalty Basin about 70 km south of the DEZ, found 650 m of sediments overlaying volcanic basement (Shipboard Scientific Party, 1975). The sediments consist of Middle Eocene mudstones, siltstones and volcanic agglomerates overlain by Upper Eocene to Oligocene Silts and oozes. These in turn are overlain by Plio-Pleistocene ash.

The North D'Entrecasteaux Ridge near the New Hebrides Arc is steep sided on the north side, rising from the West Santo Basin at 5 400 m to a high of about 2 200 m on the ridge. Paleogene MOR-type basalts have been dredged from the north ridge (MAILLET *et al.*, 1982).

The South D'Entrecasteaux chain as described by COLLOT *et al.*, (1985) is a seamount chain although BURNE *et al.*, (1985) suggest that it may represent remnants of an Eocene proto-island arc resulting from subduction along the D'Entrecasteaux Zone. FISHER *et al.*, (1985) have indicated that it may have stratified, apparently sedimentary, rocks. Sabine Bank, the easternmost part of the chain, rises to about 8 m from the sea surface. The morphology of the central area of the New Hebrides arc and DEZ has been described by BURNE *et al.*, (1985) and COLLOT *et al.*, (1985).

DATA COLLECTION, PROCESSING, AND RESULTS

In 1982, the second of the Geovan cruises was undertaken jointly by ORSTOM-Noumea and CCOP/SOPAC to study the crustal structure of the complex central area of the arc and the adjacent D'Entrecasteaux Zone. The cruise, on the French research vessel 'Coriolis', obtained single channel seismic reflection profiles, gravity and magnetic data, and seismic refraction data using Texas University ocean bottom seismometers (OBS's). This paper concerns the OBS results on the subducting plate in the vicinity of the D'Entrecasteaux Zone adjacent to the island of Espiritu Santo. Two refraction profiles were obtained (fig. 2), a reversed profile in an east-west direction in the West Santo Basin, and an unreversed profile on the North D'Entrecasteaux Ridge. Table I lists their positions. We discuss the results of these profiles along with preliminary results of three sonobuoy refraction profiles in the same area (GREENE *et al.*, (1984)) also shown on figure 2, and compare them with two profiles southwest of Efate between 18°-20° S. One of these profiles was published by IBRAHIM *et al.*, (1980), and one by PONTOISE *et al.*, (1980).

In discussing and interpreting the refraction data, we have used seismic reflection profiles from BURNE *et al.*, COLLOT *et al.*, (1985), and Greene and Wong (Eds) (1985). Seismic reflection profiles GV 1009 and GV 1011 (BURNE *et al.*, 1985) were obtained during the 1982 'Coriolis' survey along the two OBS profiles while GV 1006 and GV 1010 are perpendicular to them (fig. 2).

The ocean bottom seismometers used in this study have been described by LATHAM *et al.*, (1978), and

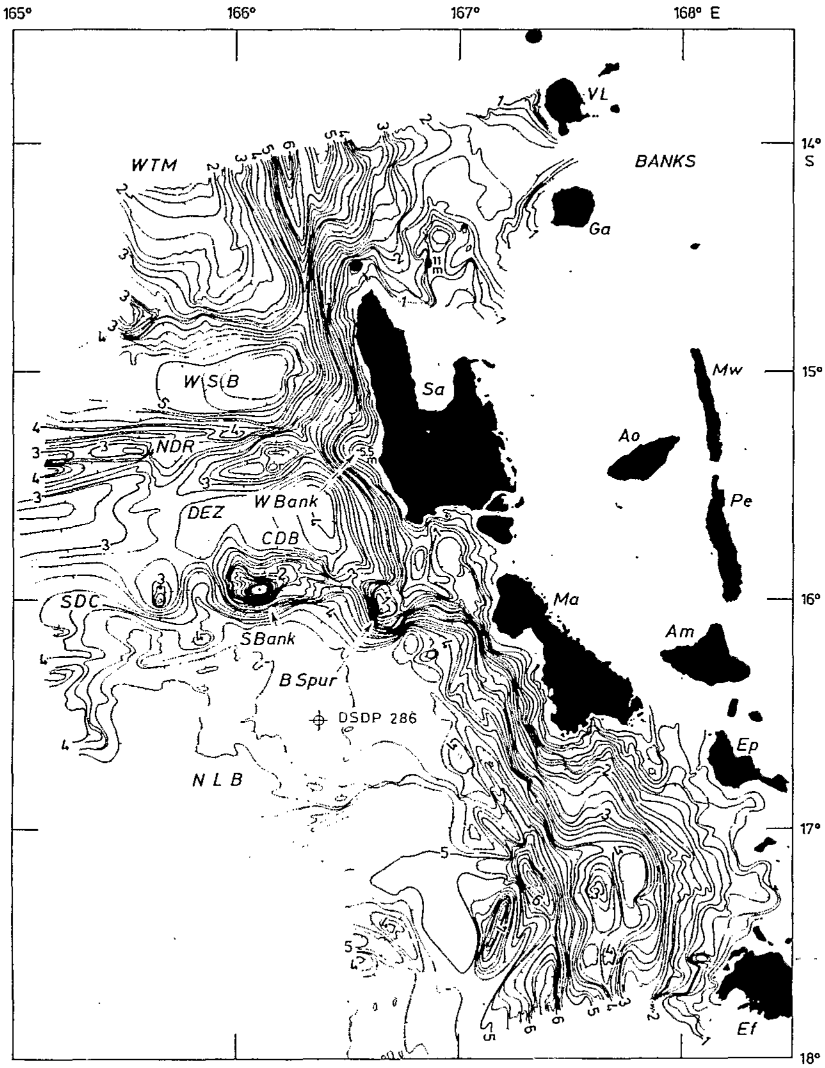

Fig. 1. — Bathymetric map of the eastern d'Entrecasteaux Zone and surrounding areas. Isobath are at 0.2 km interval. WTM : West Torres Massif ; WSB : West Santo Basin ; NDR : North d'Entrecasteaux Ridge ; DEZ : D'Entrecasteaux Zone ; CDB : Central d'Entrecasteaux Basin ; SDC : South d'Entrecasteaux Chain (after COLLOT *et al.*, 1985).
Carte bathymétrique de la partie est de la zone d'Entrecasteaux et des régions avoisinantes. Les isobathes sont à 0.2 km d'intervalle. WTM : Massif Torres W ; WSB : Bassin Santo W ; NDR : ride d'Entrecasteaux Nord ; DEZ : Zone d'Entrecasteaux ; CDB : Bassin central d'Entrecasteaux ; SCD : chaîne Sud d'Entrecasteaux (d'après COLLOT *et al.*, 1985).

IBRAHIM and LATHAM (1978). The geophone used for the refraction work is a vertical recording single channel element with a natural frequency of 8 Hz. A digital memory stores a preselected data window of 80 seconds length upon command from an internal clock. The stored digital data is then converted to analog and multiplex recorded on cassette tape via frequency modulation, along with a time code and a stable reference frequency. Since the cassette tape is shut off while the data is being stored in digital

Tableau I
Station locations

Station	LAT (S)	LON (E)	Water Depth (M)	Maximum First Arrivals (Km)	Profile Direction
E1OR14 WEST	15° 05.11	65° 44.22	5075	13 W - 60 E	085°
EAST	15° 00.53	166° 09.53	5480	15 E - 50 W	085°
E1OR15 WEST	15° 29.81	165° 53.17	2915	10 W - 25 E	075°

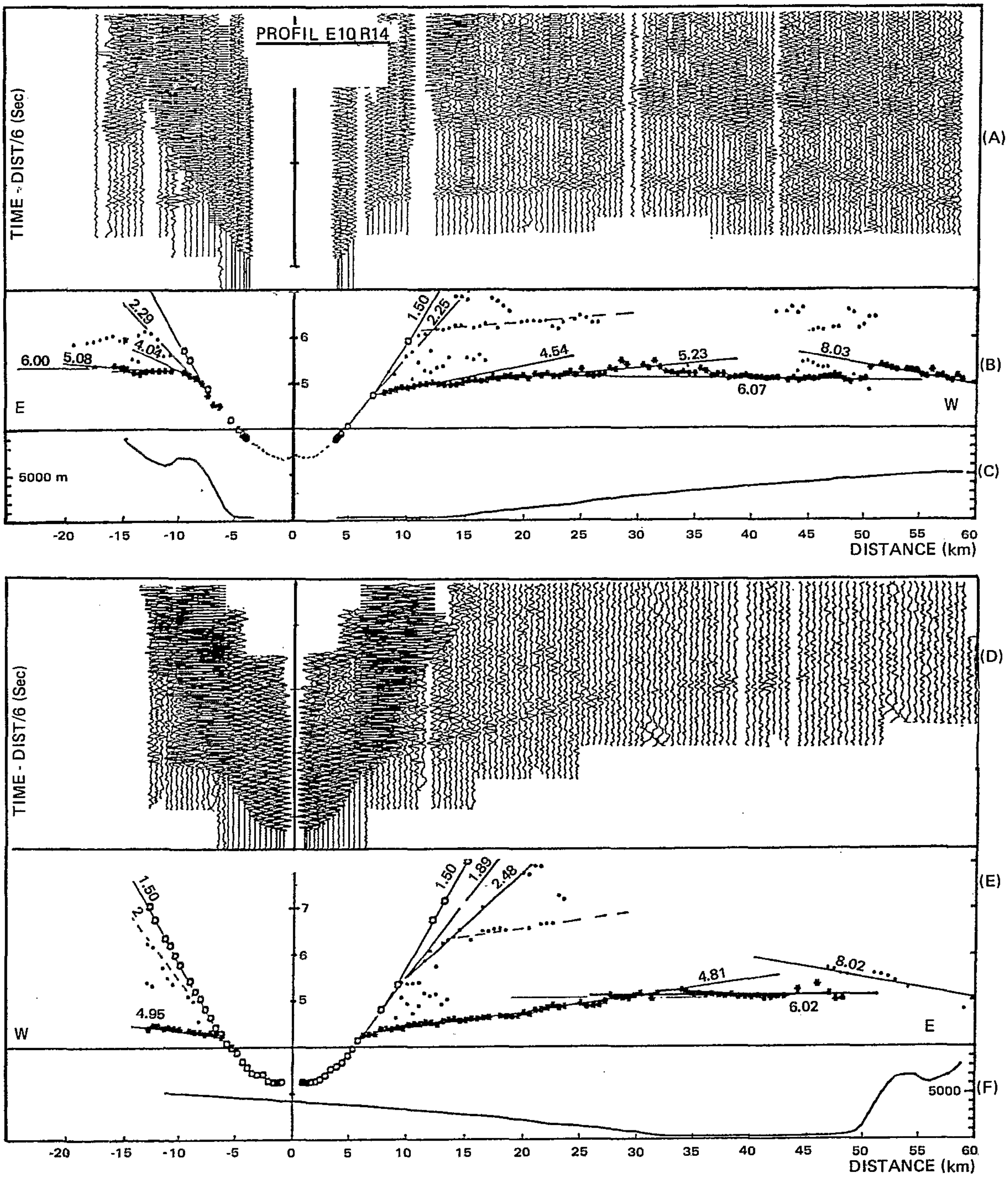

Fig. 3. — (A), (D) : Record section for E10R14 refraction line (raw data-uncorrected for bathymetry-band pass filtered 3 to 30 Hz-AGC applied). (B), (E) : Travel time curves deduced from record section above ; reduced time using 6 km/sec reducing, velocity is in sec, distances are in Km, velocities are in Km/sec. (C), (F) : Topographic line (scale 4 500-5 500 m, tic marks interval — 100 m).
(A), (D) : Section d'enregistrement pour la ligne de réfraction E10R14 (données brutes — non corrigées de la bathymétrie — filtrées entre 3 et 30 Hz-AGC). (B), (E) : *Courbes du temps de parcours déduites de la section d'enregistrement ci-dessus.* Réduction du temps de 6 km/s. Vitesse en km/s. Distances en km. (C), (F) : Ligne topographique (échelle 4 500-5 500 m) intervalle des points : 100 m.

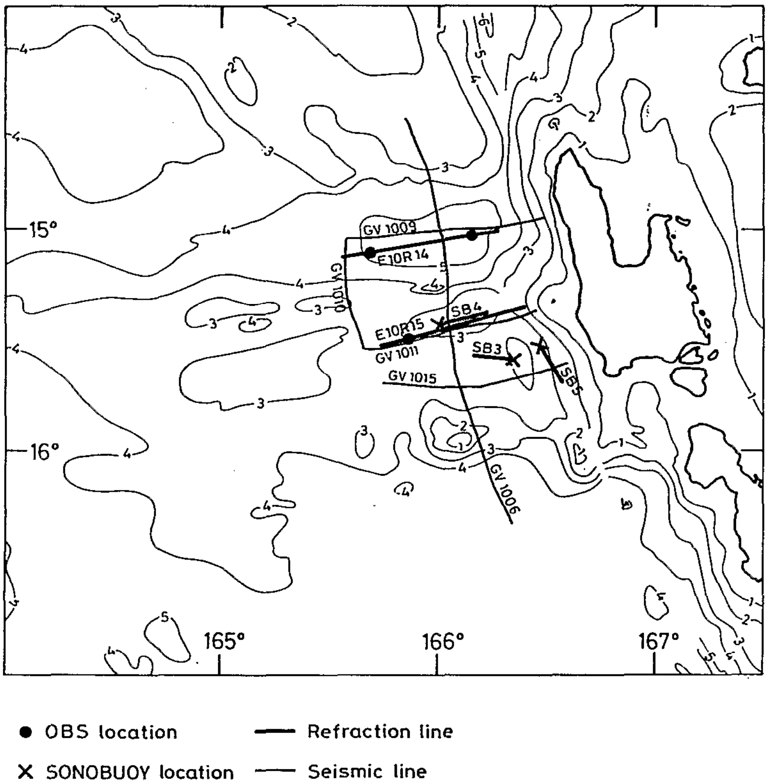

Fig. 2. — Location of seismic lines cited in the text. E10R14 et E10R15 are refraction lines using OBS's ; GV 1006, 1009, 1011 et 1015 are single channel seismic lines collected during EVA X (Geovan 2) Cruise. SB 3, 4 et 5 are sonobuoys refraction lines after GREENE *et al.*, 1984.
Situation des lignes sismiques citées dans le texte. E10R14 et E10R15 sont des lignes de réfraction faites avec OBS ; GV 1006, 1009, 1011, 1015 sont des lignes sismiques monotraces collectées pendant la campagne EVA X (Geovan 2), SB 3, 4 et 5 sont des lignes de réfraction citées par GREENE *et al.*, 1984.

memory, contamination of the data by vibrations from the tape recorder is avoided. This also permits high amplifier gains and sensitivities and high signal-to-noise ratios. Gains of 2-3 x 10^6 are currently achieved in deep water experiments.

A single air gun source of 18 l. (1100 cu. in.), pressurized to 180 bars and fired at 3 minute intervals, was used. At a ship's speed of 5.5 knots, the shot spacing is approximately 500 m. A denser shot spacing would have provided better information on low phase velocity arrivals. A depresser was used to maintain gun depth at about 30 m at which the direct water wave and the surface-reflected wave energies from the bubble pulse are constructive. Thus, the bubble effect of the air gun source is employed and, typically, frequencies of 12 Hz are obtained from this type of source for refraction work.

WEST SANTO BASIN PROFILE

The West Santo Basin is approximately 25 km wide, bordered by the West Torres Massif on the north, and the D'Entrecasteaux Ridge on the south. The floor of the basin dips smoothly eastward, deepening from 5 000 m at the western site to about 5 500 m at the base of the slope from Espiritu Santo island. Single channel seismic reflection profiles GV 1009, parallel to, and close by, the refraction profile, and GV 1006 perpendicular to it, show the basin contains up to about 1.5 seconds TWTT (Two Way Travel Time) of sediment over acoustic basement in this area (BURNE *et al.*, 1985, figs 4 and 5). Our profile E10R14 runs from west to east along the basin, using two OBS's to obtain a reversed profile. The distance between OBS's was 45 km, however, the refraction line started about 12 km west of the westernmost OBS and ended 16 km east of the easternmost OBS (see tabl. I) to give an overall length of about 74 km. This geometry allowed common ray paths for first arrivals within the layers of velocities between 5.5 km/sec and 8 km/sec while overlying layers were defined by local ray paths near each OBS. Fig. 3 shows the record section for this profile.

Observed refraction velocities range between 1.9 km/sec, typical of unconsolidated sediments, to 8.02 km/sec, a velocity associated with upper mantle material. Apart from some sedimentary arrivals, all the velocities are observed and measured using first arrival times. Because the ship's path did not pass directly over the OBS sites due to navigational error,

Tableau II
OBS Results.
Where Vi=Velocity (Km/sec). Zi=Thickness (Km); ti=Intercept time (sec). Ti=Two Way Travel Time (sec).

	E10R14 Stn. W		E10R14 Stn. E		E10R15	
	W	E	W	E	W	E
VI	1.50	1.50	1.50	1.50	1.50	1.50
ZI	5.07	5.07	5.48	5.48	2.91	2.91
tI	3.38	3.38	3.65	3.65	1.94	1.94
TI	6.76	6.76	7.30	7.30	3.88	3.88
V2	2.0	1.89	2.25	2.29	2.08	2.08
Z2	0.85	0.73	1.17	1.35	0.40	0.23
t2	2.20	2.01	2.85	2.86	1.31	1.21
T2	0.85	0.77	1.04	1.17	0.38	0.22
V3	4.95	2.48	4.54	4.04	3.18	4.01
Z3	-	0.22	0.97	1.24	1.40	2.21
t3	4.00	3.19	4.35	4.36	2.00	1.99
T3	-	0.18	0.43	0.61	0.88	1.10
V4	-	4.81	5.23	5.08	6.00	5.95
Z4	-	3.82	1.34	>1.6	-	-
t4	-	4.07	4.64	4.91	3.00	2.90
T4	-	1.59	0.51	>0.63	-	-
V5	-	6.02	6.07	6*	-	-
Z5	-	8.89	9.69	-	-	-
t5	-	5.65	5.05	5.4*	-	-
T5	-	2.95	3.19	-	-	-
V6	-	8.02	8.03	-	-	-
t6	-	7.77	7.42	-	-	-

some sedimentary layers were only recorded on later arrivals. Often these were very clearly seen on the water multiples, providing greater confidence in their interpretation than might be warranted otherwise. The OBS results are listed in tabl. II.

Layer I

Sedimentary layers with apparent velocities of 1.9 km/sec and 2.48 km/sec, and a total thickness of 1 km, are observed near the western OBS site but only a single layer of velocity 2.2 km/sec and thickness of 1.2 km is identified at the eastern station. The differing velocity structure in the shallow sedimentary layers is not considered unusual, particularly as the layers are thin and the shot spacing was large, as the experiment was designed to look at deep structures. On reflection profile GV 1009, sediment fill in West Santo Basin is seen to be rythmically bedded with a gentle apparent dip to the east in conformity with the basement. Near the base of the slope from Espiritu Santo these dipping sediments are overlain by horizontally layered sediments which fill the trough made by the eastward dipping layers and the island slope. These younger undeformed overlying sediments account for the observed thickening of the sediments at the eastern station. Reflection profile GV 1006, perpendicular to the refraction profile, shows that the basement reflector of West Santo Basin also has a strong component of dip to the south whereas the overlaying sedimentary layers are almost horizontal in the north-south direction. The profile of the basement in this north-south direction is an eccentric V shape, with one steeply dipping limb on the side of the D'Entrecasteaux Ridge. These relationships of sediment to basement indicate that the V form of the basement in this area was made prior to the deposition of the sediments, whereas the eastward dip toward Santo post-dates most of the sedimentary layer.

Layer 2

Layer 2 velocities range from 4.04 km/sec to 5.23 km/sec. These velocities are typical of oceanic crustal basalts and are so interpreted here. Total thickness of the basalt layer is about 3.9 km at the western site, but surprisingly, the layer appears to thin to the east by about 1.5 km. However, considerably more scatter in arrival times occurs at the eastern site, indicative of faulting in that area. Although topographic corrections were made for the refraction arrivals, no corrections were made for sediment thickness nor do such corrections consider faulting. Normal faulting of the basement could cause an apparent thinning of the layer, and such faulting can be expected due to the subduction process occurring near Espiritu Santo.

Reflection profile GV 1009 shows basement arches slightly under the eastern OBS site but no major faults are clearly apparent, although some minor faults may be seen. The onlapping of the deepest sediment layers against the arch suggests that it may represent an older structure, nevertheless faulting is considered to be the most probable interpretation for the eastern thinning of layer 2.

Layer 3

Beneath the basement layer, velocities of about 6 km/sec are found in a layer which ranges from 8.9 km thick in the west, to 9.6 km thick in the east. First arrivals from this layer are observed clearly between 30 to 50 km from the recording sites. A possible fault is noted about 45 km from the western station (i.e. — near the eastern station).

Mantle

Mantle arrivals are weak but clearly observed at both OBS sites. The mantle velocity is 8.03 km/sec and depth to Moho is 18.7 km under the sea surface. The most unusual feature about the mantle observations is that, with the exception of the fault noted in layer 3 above, the Moho surface is flat from west to east rather than dipping eastward toward the New Hebrides arc subduction zone.

NORTH D'ENTRECASTEAUX RIDGE PROFILE

South of West Santo Basin, the North D'Entrecasteaux Ridge rises from the basin depths of more than 5 400 m to less than 2 200 m depths. The north face of the ridge is steeper than the south side, which drops into the Central D'Entrecasteaux Basin whose greatest depths just exceed 4 000 m. The North D'Entrecasteaux Ridge extends eastward into the slope of Espiritu Santo where it meets the Wousi Bank, a prominent and shallow butress projecting westward from the island. The junction of the ridge and bank is marked by a narrow saddle at 2 900 m depth. The ridge topography is very irregular with peak to trough amplitudes sometimes reaching about 1 000 m. Topographic corrections were applied to the data recorded by OBS E10R15.

The OBS profile was shot along the crest of the ridge for a distance of 35 km. Although two OBS's were deployed, the easternmost OBS did not record data. The western one was inadvertently dropped near a fault which reduced its effectiveness somewhat, although good arrivals were obtained from 10 km west of the site, to 25 km to the east of it. Figure 4 shows the resulting record section obtained.

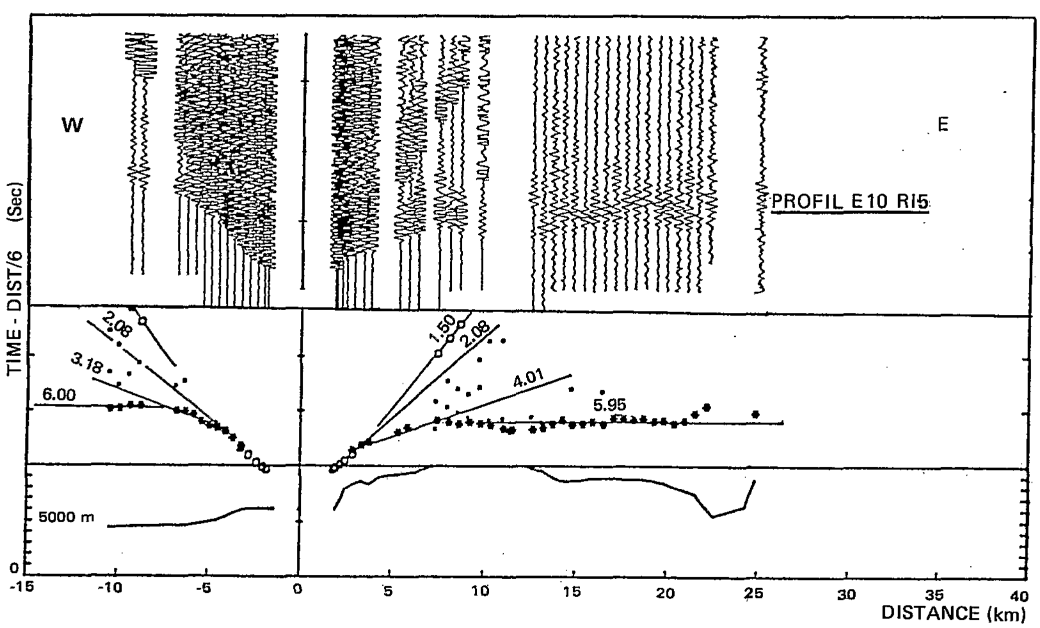

Fig. 4. — (A) : Record section for E10R15 refraction line. (B) : Travel time curves deduced from (A). (C) : Topographic line (scale 2 500-3 500 m). Units are the same as in figure 3. Only one station recorded reliable data.
Section d'enregistrement pour la ligne de réfraction E10R15. (B) : Courbe du temps de parcours déduite de A. (C) : Ligne topographique (échelle 2 500-3 500 m). Les unités sont les mêmes que pour la fig. 3. Une seule station d'enregistrement a des données fiables.

West of the recording OBS site (tabl. I), a sedimentary layer of 0.4 km thickness and velocity 2.08 km/sec is found to overlay a 1.40 km thick layer with a velocity of 3.18 km/sec. Below this layer, a velocity of 6.0 km/sec is registered. Considering the layer of 3.18 km/sec velocity is also of sedimentary origin, the total sediment thickness on the western part of the profile could be as much as 1.8 km. No intermediate velocity basement layer under the sediments is determinable from the data.

On the eastern part of the profile, a sediment thickness of only 0.23 km with a velocity of 2.08 km/sec is found. Beneath this sedimentary layer, a persistent layer of 4.0 km/sec velocity and a thickness of 2.21 km is interpreted as a basement layer. A layer of indeterminate thickness and velocity of 6.0 km/sec occurs beneath it. No mantle velocities were recorded.

ADDITIONAL REFRACTION DATA

Additional data is available from recent cruises in this area by the USGS ship 'S.P.Lee' (GREENE *et al.*, (1982) ; GREENE *et al.*, (1984)). Preliminary results of three sonobuoy refraction profiles obtained in 1984 are described here. No topographic corrections have been applied to these preliminary data and the discussion following is therefore based on the uncorrected results.

North D'Entrecasteaux Ridge — Sonobuoy # 4

Sonobuoy profile number four was taken along the North D'Entrecasteaux Ridge in the same direction as the OBS profile. The sonobuoy profile overlaps the OBS profile in the east and extends several kilometers eastward beyond it. Sonobuoy results indicate a relatively thick sedimentary layer of 1.05 km with a velocity of 2.80 km/sec. Under this is a 1.35 km thickness of velocity 3.6 km/sec, followed by a layer of velocity 5.7 km/sec with undefined thickness. The very rought topography of the ridge is likely to have significant effects on the data, leading to poor refraction interpretation until corrections are made.

Central D'Entrecasteaux Basin — Sonobuoy # 3

One sonobuoy profile was obtained in the Central D'Entrecasteaux Basin about 20 km south of Sonobuoy # 4. The profile lies close to the flank of the North D'Entrecasteaux Ridge on the west, but becomes more central in the east. The Central D'Entrecasteaux Basin has maximum water depths of slightly more than 4 000 m. It is a relatively smooth floored basin dipping eastward and covered with layered sediments which seismic reflection profile GV 1015 shows to be generally conformable with the basement. The basin is about 25 km wide and is bounded on the south by the South D'Entrecasteaux Chain.

The sonobuoy data give a sediment thickness of 0.81 km and a velocity of 2.26 km/sec, in good agreement with the 0.7 sec (TWTT) sedimentary layer seen on GV 1015. A second velocity layer has a thickness of 1.62 km and velocity of 3.3 km/sec and overlies a layer with a velocity of 6.15 km/sec.

Espiritu Santo Slope — Sonobuoy # 5

Sonobuoy # 5 was shot near the base of the slope from Espiritu Santo as it drops into the Central D'Entrecasteaux Basin. The profile is directed NNW-SSE parallel to the slope, sub-orthogonal to SB3 and about 10 km landward from its eastern end. It is in water depths about 1 300 m shallower than the basin floor at the base of the slope. SB5 results show a sedimentary thickness of 1.64 km with a velocity of 2.90 km/sec underlain by a 2.79 km thick layer of 4.66 km/sec. A velocity of 5.1 km/sec was registered below this but with no definable thickness.

DISCUSSION

Oceanic crustal layers have received considerable study in all parts of the oceans by many authors (LE PICHON *et al.*, (1973) ; LUDWIG *et al.*, (1970) ; SHOR *et al.*, (1971)). A simple model has emereged, despite small variations, based upon four major layers. Layer 1 is a sedimentary layer normally characterized by velocities of about 2.1 km/sec and with a thickness not usually exceeding 1 km on the average deep sea floor. Layer 2 velocities generally range between 4.5 to 5.5 km/sec and this layer is interpreted to be basaltic rocks forming the basement for overlying sediments. The velocity structure in layer 2 may be a gradient or may be a succession of intermediate velocities. When the crust is young, as near a spreading centre, the basement velocity may be as low as 3 km/sec. Based on core samples obtained by the Deep Sea Drilling Program and other data, the upper part of Layer 2 (Layer 2A) is formed of altered vesicular basalts and pillow lavas. The total thickness of Layer 2 is about 2 km on average.

Layer 3, often termed the oceanic layer, has a typical velocity of 6.7 km/sec and is interpreted as a thick gabbroic layer, about 5 km in total thickness. This layer is always thicker than layer 2. Total thickness of layers 2 and 3 is usually about 7 km. Below layer 3 is the mantle.

Mantle velocities below the Mohorovicic discontinuity, or Moho, are widely found to be 8.1 km/sec and under the standard ocean crust the Moho usually

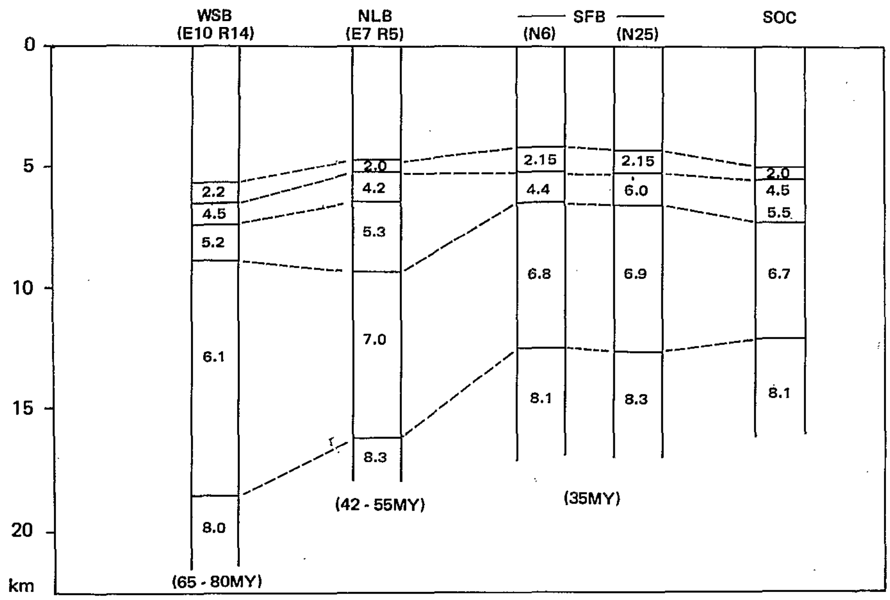

Fig. 5. — Structure sections of the crusts of marginal basins on the West Santo Basin (WSB), North Loyalty Basin (NLB) and South Fiji Basin (SFB) compared With Standard Ocanic Crust (SOC). Total crustal thickness increase with age from SFB to WSB.
Sections des structures de croûte de bassins marginaux dans la zone W du bassin de Santo (WSB), du bassin Nord Loyautées (NCB) et Sud Fidjien (SFB) comparée à la croûte océanique stadard (SOC). Les épaisseurs crustales totales augmentent avec l'âge de SFB vers WSB.

occurs about 12 km below sea level. Near spreading centres or in active back-arc regions such as the North Fiji Basin, mantle velocities may be as low as 7.5-7.8 km/sec (DUBOIS et al., (1973) ; LARUE *et al.*, (1982)).

WEST SANTO BASIN.

The West Santo Basin crustal velocity structure near the New Hebrides arc is similar to oceanic crustal velocity structure elsewhere, and the mantle velocity found is the expected 8.1 km/sec. The main difference between this crust and crust of other oceanic areas is in the total thickness of the layers, and in the velocity of layer 3.

The velocities found in the sediments are normal sedimentary velocities, the unusual feature being that two layers were found in the western area and only one in the east. This is only unusual because the seismic reflection profiles do not show clear evidence for a two layer system in the west, whereas they do in the east. GV 1006, the transverse reflection profile, provides some possibility of a thin sediment layer conforming to the southerly dip of at least one basement limb which is overlain by the thick, flat-lying and obvious sequence in the V of basement. Reflection profiles obtained by 'S.P. Lee' in 1984 (GREENE *et al.*, (1984)) are also unclear about a second thin sediment layer in this basin area at the depth required by the refraction data.

Figure 5 compares the crustal section of West Santo Basin, North Loyalty Basin and South Fiji Basin to that of standard oceanic crust. It can be seen that the thickness of Layers 2 ans 3 of West Santo Basin, reaching 12.8 km in the western part of the profile, is almost twice that of standard oceanic crustal thickness. However, this may not be so unusual for crust of the SW Pacific region, for, apart from areas of active back-arc basins such as the North Fiji Basin and Lau Basin, deeper than normal Moho has been found in many marginal basins in this region. According to IBRAHIM *et al.*, (1980, Table —) the average depth to Moho in the Southwest Pacific is about 15 km. It appears then, that in most cases, crust in older inactive marginal basins is thicker for the same age than oceanic crust of the deep oceans. We therefore interpret the West Santo Basin crust to be old, marginal basin crust of oceanic origin.

The layer 3 velocity of West Santo Basin is also seen to be much less, at 6.1 km/sec, than in the other basins (7.0 km/sec). While no refraction experiments have been conducted in the region to show if anisotropic conditions exist in the crust, it is possible that at least some of the difference in layer 3 velocity could be due to anisotropy. Profile E10R14 was conducted perpendicular to the subduction zone west of the New Hebrides arc while the OBS profiles in the North Loyalty basin were parallel to it. Thus the direction of crustal strain could be different for these profiles. Nevertheless, it is doubtfull that anisotropy could account for more than 8-10 % of the difference in the velocity. Also, any anisotropy present should affect more than one layer, which is not the case here.

The differences in crustal thickness of the basins can be explained by a progression in their ages. The crustal thickness of South Fiji Basin has been determined by RAITT (1956) to be 7.5 km and its age is given by MALAHOFF *et al.*, (1982) as 35 m.y. The North Loyalty Basin crust is 11 km thick (PONTOISE *et al.*, 1980) while its age is 42-55 m.y. (LAPOUILLE, 1982). The thickness determined here for the West Santo Basin crust (12.9 km) is thicker than most other areas even for the South Pacific. The West Santo Basin is structurally a part of the North D'Entrecasteaux Basin whose age is given by LAPOUILLE (1982) as 65-80 m.y., based mainly upon evidence from weak magnetic lineations. If these ages are correct, the thick crust of the WSB is due to its older age.

We believe that the difference in crustal thickness and in velocity of layer 3 between the North Loyalty Basin and the West Santo Basin supports the interpretation of DANIEL *et al.*, (1977) and MAILLET *et al.*, (1983) that the D'Entrecasteaux Zone separates plates of differing origins and histories.

NORTH D'ENTRECASTEAUX RIDGE

In the sedimentary layers of the North D'Entracasteaux Ridge there is a rather large discrepency between the OBS results in the eastern part of the profile and the sonobuoy results. While the OBS profile in the west shows 1.8 km of sediment is possible, the data in the eastern part, east of the fault near which the OBS was dropped, indicates much less sediment is present. Although a layer of 4.0 km/sec velocity could be well-compacted sediments, it is difficult to interpret the second layer in this way when it is not deeply buried. An interpretation as basaltic basement is more reasonable. However, the sonobuoy result of 3.6 km/sec velocity in the same area is too slow to be normal basaltic basement, and an interpretation of a sedimentary origin would be satisfactory based only on that data. Single channel seismic profile GV 1011, however, which parallels the line of the refraction profile indicates that while relatively thick sediments with possible faults and disturbed layering are present west of the OBS site, in the eastern part reflection basement rises to or near the sea floor. There is an indication of only very little sediment thickness if any at all, and no evidence for a reflective layer at or near 1.05 km depth (0.75 sec TWTT at 2.8 km/sec) as the sonobuoy data would indicate. Additionnaly, sampling of outcrops on the north flank of the ridge (MAILLET *et al.*, 1983) obtained MOR-type basalts at water depths between 2 800-3 100 m. Thus, although there is no clear evidence to discriminate between these differing results, the rough topography and lack of topographic correction suggests that the sonobuoy data in this region should be interpreted cautiously, particularly in the superficial layers. We therefore consider the layer of 4.0 km/sec to be basaltic basement rather than sediments. If this is indeed the case, the top of layer 3 (velocity 6.0 km/sec on OBS and 5.7 km/sec on SB-4) rises eastward following the general trend of the sea floor in this area. This may indicate that the North D'Entrecasteaux Ridge immediately west of Wousi Bank has experienced uplift, greater on the eastern end. It has been proposed that Wousi Bank itself is an obducted peice of the North D'Entrecasteaux Ridge (BURNE *et al.*, 1985 ; COLLOT *et al.*, 1985).

CENTRAL D'ENTRECASTEAUX BASIN

Sonobuoy 3 data indicating that the surficial sediment cover in the Central D'Entrecasteaux basin is 0.81 km thick, is in good agreement with reflection line GV 1015, which shows about 0.7 sec TWTT of sediment dipping eastward with the acoustic basement. The second velocity layer of 3.3 km/sec is not well supported by reflection data presently available, although some suggestions of stratification in the reflection profile may lend some support to a sedimentary interpretation. Thus the layer could be either a compacted sedimentary layer or a basement layer with lower than normal velocity, possibly due to intense fracturing and hydration. However, if a sedimentary interpretation is accepted, then no basalt layer appears to exist in this area above the 6.15 km/sec oceanic layer.

Comparison of the Central D'Entrecasteaux basin structure with sonobuoy 5 results over the toe of the Espiritu Santo slope shows very different velocity conditions exist. Nearby multi-channel seismic data obtained by the US Geological Survey vessel R/V "S.P. Lee" in 1982 (GREENE *et al.*, MCS Line 12) provides clear evidence for subduction under the slope. In fact the subducting crust can be traced seismically for about 20 km under the slope. The velocity layer of 2.90 km/sec lies above the subducting slab and includes all slope material over it. This material could be an accretionary wedge of sediment from the subducting plate or sediments derived from the arc platform above, or a mixture of both, deformed against the slope by the differential movement of the slab below.

CONCLUSIONS

The OBS data from West Santo basin provides evidence that the crust of that region is oceanic in origin, but thicker than oceanic crust normally found in the world oceans, with a total thickness of 18.7 km below sea level. The velocity of layer 3 is less than that usually found in the Southwest Pacific and the difference cannot be totally accounted for by anisotropy, if any anisotropy is present. The greater crustal thickness and lower velocity of layer 3 compared to crust of North Loyalty Basin is support for interpreting the D'Entrecasteaux Zone as a significant plate boundary between different crusts, rather than a dislocation in one plate.

The mantle under the WSB does not bend into the subduction zone as would normally be the case at the distance of the refraction profile from the trench, and such as occurs west of Efate (PONTOISE *et al.*, 1980), where observed dip of mantle is around 7°. The reason for the lack of a bend in the crust in this area is not clear. If it occurs closer to the trench axis then it must be a sharp bend, sharper than elsewhere along the trench, or else the initial angle of the subduction plane is not so steep here as in other parts of the New-Hebrides subduction zone. In general, the dip of the Benioff zone, although steep, is thought to be uniform along the total lenght of the arc (LOUAT *et al.*, 1985).

The eastward rise of layer 3 under the North D'Entrecasteaux Ridge is also unexpected near an area where thrust-type focal mechanisms of shallow earthquakes indicate subduction must be occuring. As suggested earlier, this may be related to obduction of part of the ridge onto the overriding plate at Wousi Bank. Whether or not the mantle also rises under the ridge is undetermined, as is any connection with the horizontal mantle interface under the West Santo Basin to the north.

The velocity-corrected section of multi-channel seismic Line 12 of GREENE *et al.* (1982), using the 2.90 km/sec velocity for all material under the slope above the oceanic basement reflector, provides another line of evidence that the D'Entrecasteaux Zone does not bend into a trench everywhere, as normal ocean crust, is expected to do. Instead, the basement layer on this seismic profile dips only very slightly, if at all, from its depth under the Central D'Entrecasteaux Basin. Clearly, the subduction of the D'Entrecasteaux Zone and its collision with the island arc is a complex occurrence not yet fully understood.

Manuscrit accepté par le Comité de Rédaction le 15-9-1986.

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