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SUPERFICIAL STRUCTURES AND STRESS REGIMES OF THE DOWNGOING PLATE ASSOCIATED WITH SUBDUCTION-COLLISION IN THE CENTRAL NEW HEBRIDES ARC (VANUATU)

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ABSTRACT

Single-channel seismic-reflection profiles collected across the convergent plate boundary in the central New Hebrides Arc display structures that can account for the observed absence of a deep geotectonic trench. These structures include (1) the protrusion of the Santo-Malakula block at the leading edge of the overriding plate, (2) collision of ridges on the downgoing plate with this block, (3) slumping of sediment from the insular wall of the trench, and/or the tectonic displacement of material outward to compensate for adjacent indentation by colliding features, (4) compressive doming of the downgoing plate adjacent to the zone of plate contact, and (5) sediment filling of incipient trenches.

The superficial structures indicate that there are three major zones of dominant stress affecting the top of the downgoing plate in this region. North of the North D'Entrecasteaux Ridge and south of latitude 17°S, tensional stress regimes are related to the passive bending of the plate under the weight of the downgoing slab. There is weak coupling between the plates and subduction is mainly controlled by creep. Between the North D'Entrecasteaux Ridge and latitude 17°S, a compressional stress regime indicates relatively strong coupling between the plates. The highest compressional stresses occur at the Bougainville Spur and probably at the North D'Entrecasteaux Ridge—collision points that can be related to localized shallow asperities in the Benioff zone. The transitions between these regions of contrasting stress regime that occur at latitude 17°S and along the northern flank of the D'Entrecasteaux zone are probably areas of shearing transverse to the trench.

INTRODUCTION

The New Hebrides Arc marks the underthrusting of the northeastern margin of the Australia-India plate beneath the young, actively spreading North Fiji Basin. Subduction is proceeding at 10 cm/yr along a slip vector of 75°N (Dubois et al, 1977; Isacks et al, 1981). A conventional association of ocean basin, geotectonic trench, arc-trench gap, arc, and backarc basin has developed north of latitude 13°S and south of latitude 17°S. Between these latitudes, the structure of the arc is more complex (Figure 1). The underthrusting plate carries with it the West Torres Massif, the West Santo Basin, the D'Entrecasteaux zone, and the oceanic North Loy-

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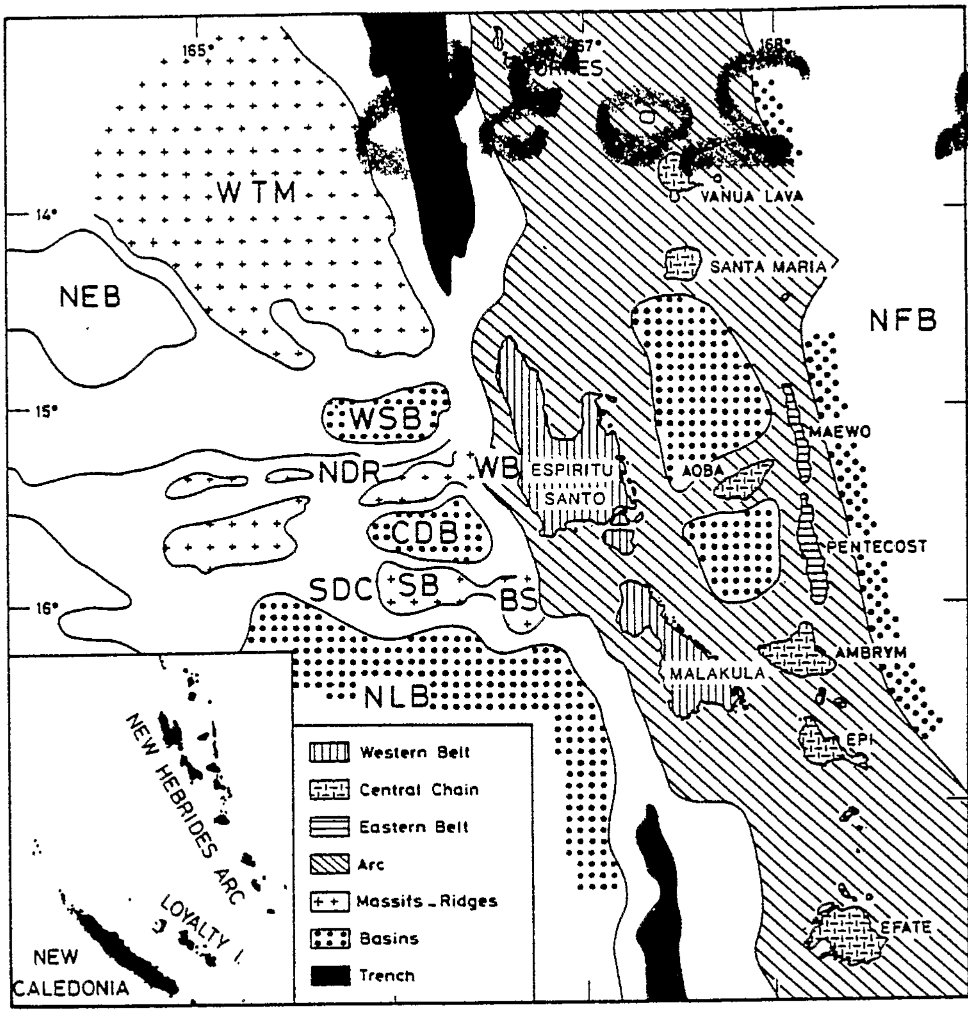

Figure 1. Map of the central New Hebrides Arc showing regional setting (inset), structural units, and simplified geology. WTM: West Torres Massif, NEB: North D'Entrecasteaux Basin, WSB: West Santo Basin. NDR: North D'Entrecasteaux Ridge, CDB: Central D'Entrecasteaux Basin, WB: Wousi Bank, SDC: South D'Entrecasteaux Chain, SB: Sabine Bank, BS: Bougainville Spur, NLB: North Loyalty Basin, NFB: North Fiji Basin.

alty Basin. The islands of Espiritu Santo and Malakula, which are composed primarily of Oligocene-Miocene volcanic rocks (Mitchell and Warden, 1971; Carney and Macfarlane, 1982), form an emergent block protruding over the expected location of the trench and the arc-trench gap (Mammerickx et al, 1971; Daniel and Katz, 1981; Collot, Daniel, and Burne, 1985). The active arc, including the islands of Santa Maria (Gaua), Aoba, and Ambrym, extends along the axis of the deep sedimentary North and South Aoba basins. The eastern boundary of this basin is flanked by Maewo and Pentecost Islands, which are composed of volcanic rocks of Miocene-Pliocene age (Mitchell and Warden, 1971; Carney and Macfarlane, 1982).

Collot and Daniel (1983) and Collot, Daniel, and Burne (1985) found that the front of the overriding plate, which forms the inner (east) wall of the trench north and south of the D'Entrecasteaux zone, is displaced westward in this central part of the arc and generally follows the slope of the Espiritu Santo and Malakula Islands. They suggest that along this slope, local compressive deformation could occur, possibly resulting from indentation of the slope by topographic features borne on the downgoing plate. Moreover, they describe large-scale compressive deformation affecting the central New Hebrides Arc and propose a simple model for the main tectonic features and stress regimes of the arc. However, the superficial deformation of the downgoing plate has not been well documented.

The absence of a deep trench is noted on

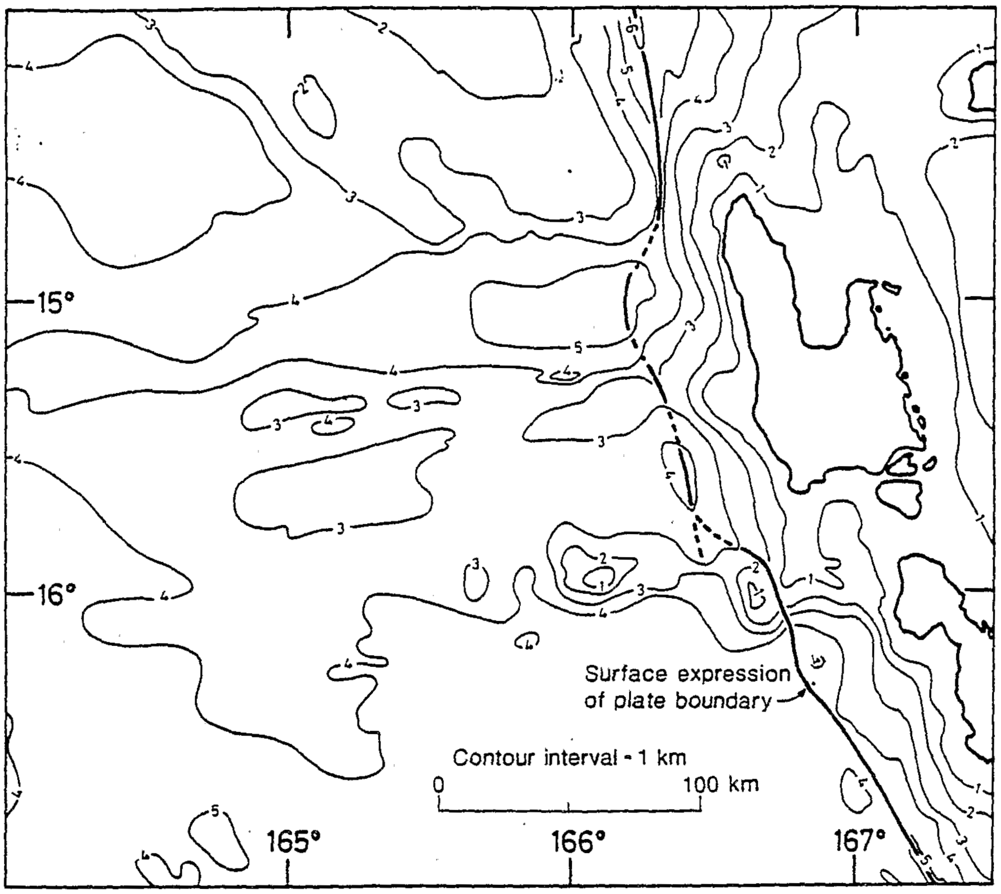

Figure 2. Simplified bathymetric chart after Jouannic (1975), Ravenne et al (1977), and Collot, Daniel, and Burne (1985).

bathymetric charts (Figure 2; Mammerickx et al, 1974; Collot, Daniel and Burne, 1985) and has been discussed by Daniel and Katz (1981) and Collot, Daniel, and Burne (1985). However, Greene et al (1982) suggested that the New Hebrides Trench is absent only between 15°S and 15°30′ S.

Teleseismic earthquake data confirm that eastward subduction is taking place in the central New Hebrides Arc (Pascal et al, 1978; Louat, Daniel, and Isacks, 1982). However, these data relate to the large-scale behavior of the Australia-India plate. The tectonic processes affecting the upper part of the plate may not be representative of the plate behavior overall, and may give rise to very localized deformation. The purpose of this paper is to study all available single-channel seismic-reflection data in an attempt to shed light on the tectonic regime controlling the superficial deformation of the plates and to explain the general absence of a deep geotectonic trench along the central New Hebrides Arc.

COLLECTION OF DATA

The location of cruise tracks along which single-channel seismic-reflection profiles have been obtained are shown in Figure 3. Published profiles (Table 1) include those obtained by Woods Hole Oceanographic Institution aboard the R/V *Chain* (Luyendyk, Bryan, and Jezek, 1974), the Austradec cruise program (Ravenne et al, 1977), the Georstom cruise program (Daniel et al, 1977), and Gulf and Mobil Oil Companies (Daniel and Katz, 1981). Most of the new data published here come from a joint ORSTOM-CCOP/SOPAC cruise (Geovan II) on the N.O. *Coriolis* in October 1982 (Table 1). Navigation was by a fully automatic satellite system, and the seismic source was a water gun firing every 15 s (Burne and Tiffin, 1982). These data were augmented by several single-channel profiles made across the plate contact zone by the U.S. Geological Survey's R/V *S.P. Lee* (L6-82-SP, Greene et al, 1982), and one profile across the D'Entrecasteaux zone made by

Table 1. Seismic-reflection data sources for the New Hebrides Arc used in this report.

YEAR	ORGANIZATION	SHIP	PROJECT	REFERENCE
1971	Woods Hole Oceanographic Institution	*Chain*		Luyendyk, Bryan, and Jezek, 1974
1972	CEPM: IFP, ORSTOM, CNEXO[1]	*Coriolis*	Austradec-I	Ravenne et al 1977
1972	Mobil Oil Corporation	*Fred H. Moore*		Daniel and Katz, 1981
1973	Gulf Oil Corporation	*Gulfrex*		Daniel and Katz, 1981
1973	ORSTOM	*Le Noroit*	Georstom I	Daniel et al 1977
1974	ORSTOM	*Coriolis*	Georstom II	Daniel et al 1977
1982	U.S. Geological Survey	*S.P. Lee*	Australia-New Zealand-United States Tripartite-CCOP/SOPAC[2]	this volume
1982	Hawaii Institute of Geophysics	*Kana Keoki*	Australia-New Zealand-United States Tripartite-CCOP/SOPAC	Taylor, 1984
1982	ORSTOM-CCOP/SOPAC	*Coriolis*	Geovan II	Collot, Daniel, and Burne, 1985

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[2] United Nations Economic and Social Commission for Asia and the Pacific, Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas.

the Hawaii Institute of Geophysics' R/V *Kana Keoki* (Taylor, 1984) as part of the 1982 ANZUS Tripartite-CCOP/SOPAC cruise program (Exon, 1982).

SUPERFICIAL STRUCTURES OF THE DOWNGOING PLATE

Daniel and Katz (1981) concluded that the protrusion of the rigid Santo-Malakula block at the leading edge of the overriding plate has prevented the development of a deep geotectonic trench in the central New Hebrides. However, Collot, Daniel, and Burne (1985) showed the effect of the various topographic features of the subducting plate on the deformation at the plate contact zone. We will therefore describe the superficial structures of these features on the downgoing plate (Figure 1) before analyzing their deformation at the plate boundary.

West Torres Massif

Dupont and Recy (1980) considered the 200-km-long and 150-km-wide West Torres Massif to be oceanic plateau with a crustal thickness between that of the continental and oceanic crusts. Over the massif, water is as shallow as 1,100 m (Jouannic, 1975; Collot, Daniel, and Burne, 1985). As shown on profile GEOV 1006 (Figures 4 and 5d) across the massif, a small, perched sedimentary basin contains about 0.4 km of faulted and deformed sediment abutting a possible volcanic structural high to the south. The deformation affects both sediment and basement, especially on the northern and southern flanks of the basin.

North of the basin, approximately 10 km from the northern end of profile GEOV 1006, the deformed basement is capped by relatively undisturbed sediments. The 4,000-5,500-m depths of the southern flank are overlain by slope deposits with poorly defined layering. This unit can be traced beneath the sediment of the West Santo Basin to a depth of 8.8 s (at least 6.6 km). The ocean floor west of the West Torres Massif (the North D'Entrecasteaux Basin of Maillet et al, 1983) has a thin 0.2 km sedimentary cover that is in fault contact with the West Santo Basin (Figure 5a).

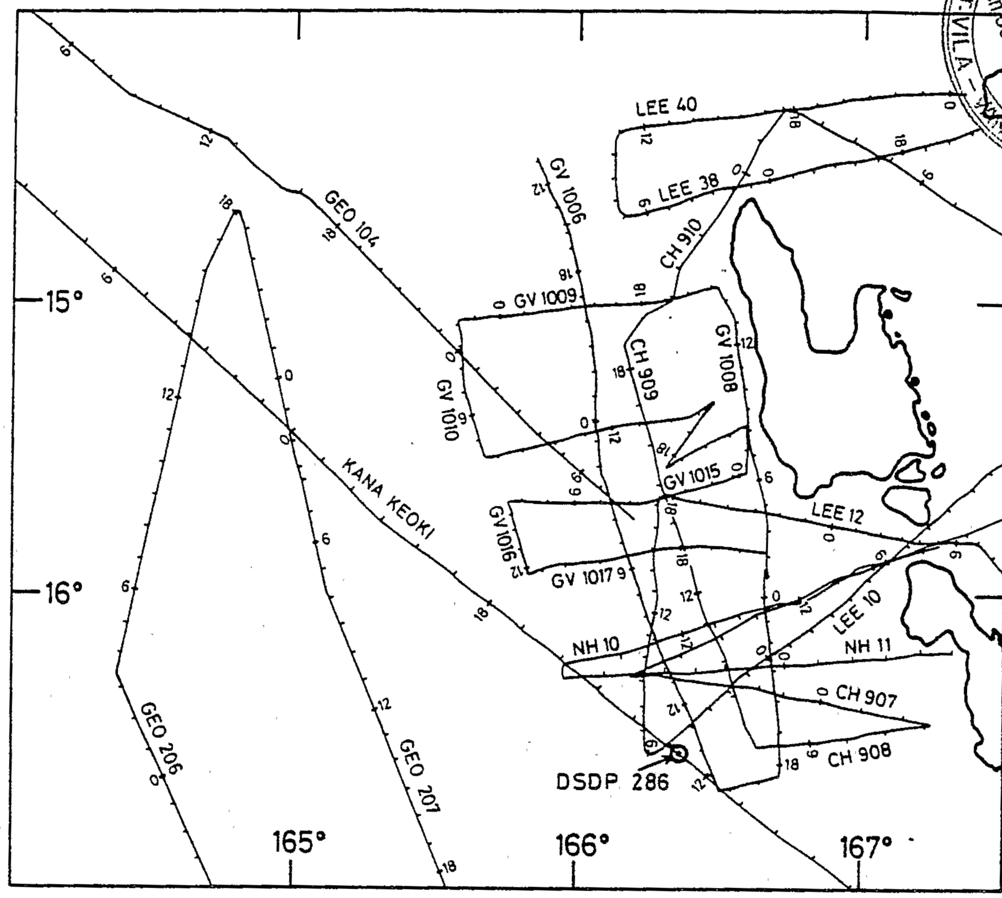

Figure 3. Location of seismic-reflection profile tracks. CH: Woods Hole Oceanographic Institute cruise (1971); NH: Gulf cruise (1973); GEO: Georstom I and II cruises (1973, 1974); LEE: USGS Tripartite cruise (1982); KANA KEOKI: HIG Tripartite cruise (1982); GV: Geovan II cruise (1982).

Eastern D'Entrecasteaux Zone

The D'Entrecasteaux zone is an arcuate complex of ridges and sedimentary basins that extends from north of New Caledonia to the New Hebrides Arc, west of Espiritu Santo and Malakula Islands (Daniel et al, 1977). Maillet et al (1983) noted distinctions between the western and eastern sectors of the zone. In the west, a sedimentary basin with as much as 2.3 km of sedimentary fill is bisected by a central horst. The northern half of the basin is deformed into a monocline. Secondary horsts occur along the boundary between this and the North Loyalty Basin. Collot, Daniel, and Burne (1985) have recognized the following features from north to south across the eastern sector of the D'Entrecasteaux zone (Figure 1): the West Santo Basin, the North D'Entrecasteaux Ridge, the Central D'Entrecasteaux Basin, and the South D'Entrecasteaux Chain

(a) West Santo Basin

The West Santo Basin lies in water depths of 5 km, and contains a maximum of about 1.5 km of sediments. Lapouille and Dugas (1975) and Collot, Daniel, and Burne (1985) believe it to be an old trench-like feature.

About 200 km west of Espiritu Santo, the West Santo Basin is a graben filled with about 1.5 km of deformed sediment (Figure 5a). The overall deformation in the basin decreases eastward and the faulting of the southern margin of the basin is replaced by monoclinal folding (Figure 5b). There is a distinct unconformity within the sediments of this basin along the southern flank of the West Torres Massif (Figures 4 and 5d).

The configuration of the basement of the West Santo Basin indicates that a portion of this basin could have been thrust or subducted(?) beneath the

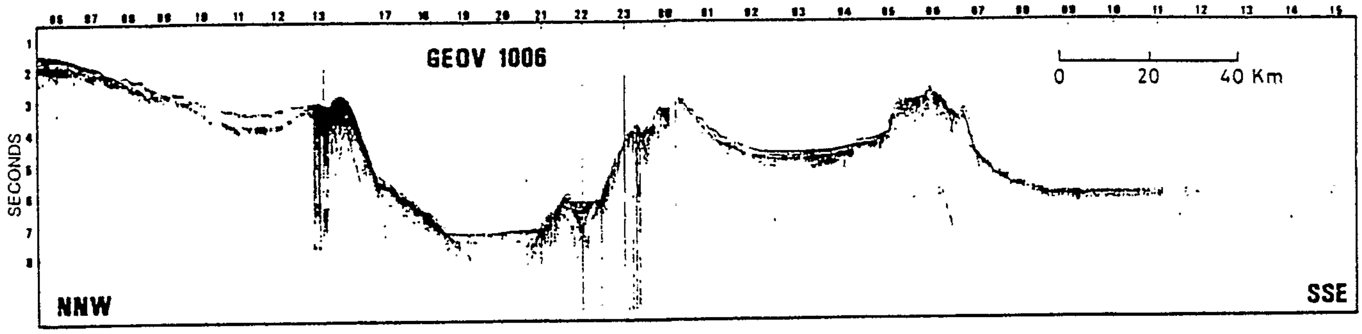

Figure 4. Original seismic profile GEOV 1006 across the West Torres Massif (left) and the D'Entrecasteaux zone (right).

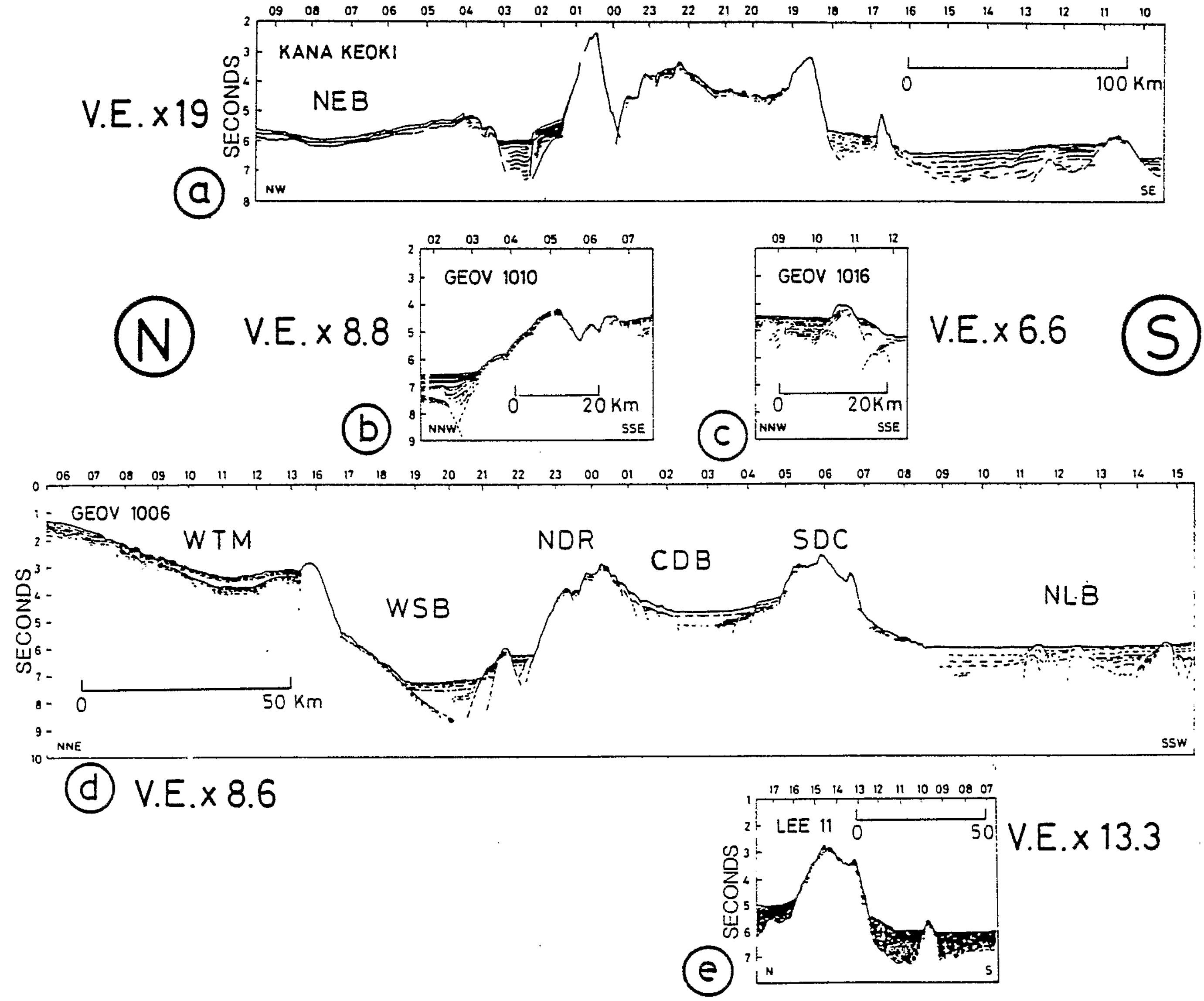

Figure 5. Traced seismic profiles KANA KEOKI, GEOV 1010, 1016, 1006, and LEE 11 across the D'Entrecasteaux zone. Locations of the profiles are shown in Figure 3. Abbreviations as in Figure 1.

North D'Entrecasteaux Ridge (profiles GEOV 1006, Figures 4 and 5d; and GEO 104, Daniel et al, 1977). This configuration is not apparent in the profiles to the west, i.e., KANA KEOKI (Figure 3), GEOV 206 (Maillet et al, 1983, their Figure 5), or GEO 207 (Daniel et al, 1977, their Figure 5).

(b) North D'Entrecasteaux Ridge

The North D'Entrecasteaux Ridge is a double-horst structure divided by a sediment-filled graben. This double-horst is bounded by a major scarp on the north side. The morphology and elevation of this ridge varies considerably from west to east. In the east, a small basin lying between the horsts is filled with slightly deformed sediment about 1 km thick (Figures 4 and 5d; profile GEO 104 in Daniel et al, 1977); whereas in the west, the basin contains no sediment (Figure 5a). Maillet et al (1983) have described 37-Ma mid-oceanic ridge basalt dredged from these horsts.

(c) Central D'Entrecasteaux Basin

The Central D'Entrecasteaux basin is a perched (3,000-4,000 m of water depth) graben containing 0.6-1.2 km of deformed and faulted sediment. Faulting extends down to the basement, and the thickness of the sediment fill increases eastward (Figures 5a, c, d, 11, and 12d).

(d) South D'Entrecasteaux Chain

The South D'Entrecasteaux Chain includes Sabine Bank (Figure 1), which rises to 7 m below sea level, and a small 2.3-km deep seamount west of Sabine Bank (Figure 2). These highs are generally not accoustically layered (Figures 4, 5a, c, d, and e). However, the western flank of Sabine Bank (profile GEOV 1017, Figures 13 and 14a) shows smooth slope deposits and poorly defined layering that contrasts with the rough, irregular surface on the eastern slope. The seamounts are believed to be volcanic edifices because of their morphology and magnetic signature (Collot, Daniel and Burne, 1985). East of Sabine Bank, the Bougainville Spur (Figure 1), connected to the Santo-Malakula block, is a structural high capped by sediment (Figures 14b and c); its origin is discussed below.

North Loyalty Basin

As shown by seismic-reflection profiles, the North Loyalty Basin is floored by a highly irregular basement surface that locally crops out and is overlain by sediment that may reach a thickness of more than 1 km (Figures 5a, d, and e). Water depth over the basin shallows to the east, and this shallowing corresponds with an increase in deformation, particularly faulting.

At DSDP site 286 (Figure 3), the sediment of the North Loyalty Basin was sampled (Andrews et al, 1975). The cored sedimentary section consisted of 0.65 km of Pliocene-Pleistocene ash, and Oligocene and upper Eocene silts and oozes, underlain by middle Eocene vitric sandstones, siltstones, and volcanic agglomerates. These sedimentary rocks directly overlie a basaltic basement. This DSDP site was crossed by the R/V *Kana Keoki* in 1982 (Figure 5a).

Discussion

Lapouille (1982) has suggested, on the basis of paleomagnetic data, that the North Loyalty Basin and the North D'Entrecasteaux Basin originally formed a single basin that originated at a spreading center to the south. The basin was later split by tectonic movements along the D'Entrecasteaux zone, which is thought by Daniel et al (1977) to have been a fracture zone. Maillet et al (1983) suggest the alternative possibility that the D'Entrecasteaux zone marks an Eocene zone of plate convergence, which was modified by a middle Miocene tensional phase that gave rise to the present morphology of the D'Entrecasteaux zone. Recently, Collot, Daniel, and Burne (1985) have concluded that the eastern D'Entrecasteaux zone may be a pre-Miocene south-dipping subduction zone.

The seismic-reflection data presented above indicate a substantial contrast between the highly irregular basement surface and faulted sediments of the North Loyalty Basin, and the smooth basement surface and the thin slightly deformed sedimentary cover of the North D'Entrecasteaux Basin. This contrast would either argue against the suggestion of Lapouille (1982) that the two basins were formerly one, or suggest that, after their formation, they have undergone deformation by different stress regimes. Collot, Daniel, and Burne (1985) believe that the

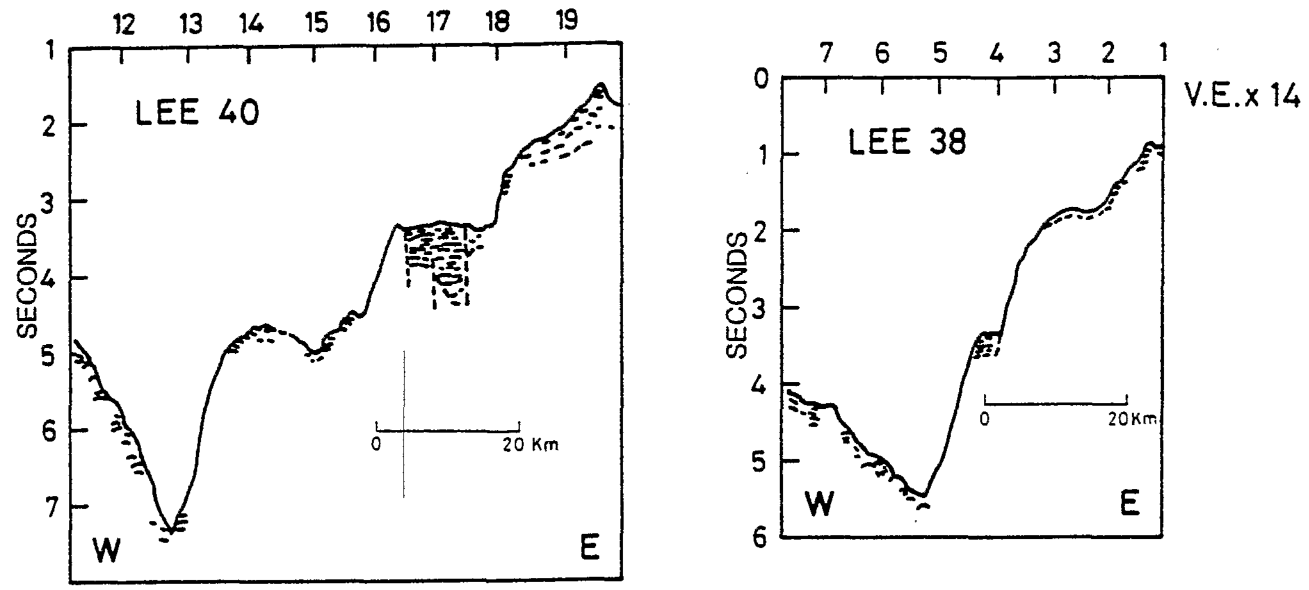

Figure 6. Traced seismic sections LEE 40 and LEE 38 across the West Torres Massif-Espiritu Santo plate boundary.

West Santo Basin is a trench that formed at the site of an earlier south-directed subduction zone. We suggest that the West Santo Basin is the eastward extension of the trench that is deformed and bisected by the main horst in the western D'Entrecasteaux zone. Our data are consistent with those of Maillet et al (1983) who believe that the North D'Entrecasteaux Ridge consists of a 37-Ma ocean floor uplifted during middle Miocene time. The South D'Entrecasteaux Chain may represent the remnants of an Eocene proto-island arc formed contemporaneously with subduction along the northern line of the D'Entrecasteaux zone.

PLATE CONTACT ZONE

The complex structure of the downgoing plate has a dramatic effect on the superficial structure of the plate contact zone which we describe below. The superficial structural variation along the zone is divided into the following sections: east of West Torres Massif, adjacent to West Santo Basin, east of the North D'Entrecasteaux Ridge, east of the Central D'Entrecasteaux Basin, east of the South D'Entrecasteaux Chain and the Bougainville Spur, and between North Loyalty Basin and Malakula Island.

East of West Torres Massif

Collot, Daniel, and Burne (1985) have shown that the trench between the West Torres Massif and Espiritu Santo Island differs from the trench found elsewhere along this arc. The trench near the massif is 5.5-4.1 km deep, shallower by about 2.5 km than elsewhere (Figure 6), and the juncture between the steep slopes of the massif and the arc forms this trench. An area of normal ocean-floor depth is isolated between this massif and the island. Collot, Daniel, and Burne (1985) follow Daniel and Katz (1981) in suggesting that the surface expression of the subduction zone is displaced westward from its projected position by the protrusion of the Santo-Malakula block. Neither topography nor focal mechanisms provide much evidence for tensional deformation of the West Torres Massif from topography and focal mechanisms (Isacks et al, 1981). The inner wall of the trench-like feature (the western wall of Espiritu Santo) shows some slope breaks, and profile LEE 40 (Figure 6) shows a small perched basin filled with 0.7 km of deformed sediments. These features are consistent with the interpretation of Collot, Daniel, and Burne (1985) who believe that the hinge of flexure of the downgoing plate in this area lies beneath the protruding massif of Espiritu Santo. The trench observed here lacks the depth of a geotectonic trench associated with a conventional subduction zone.

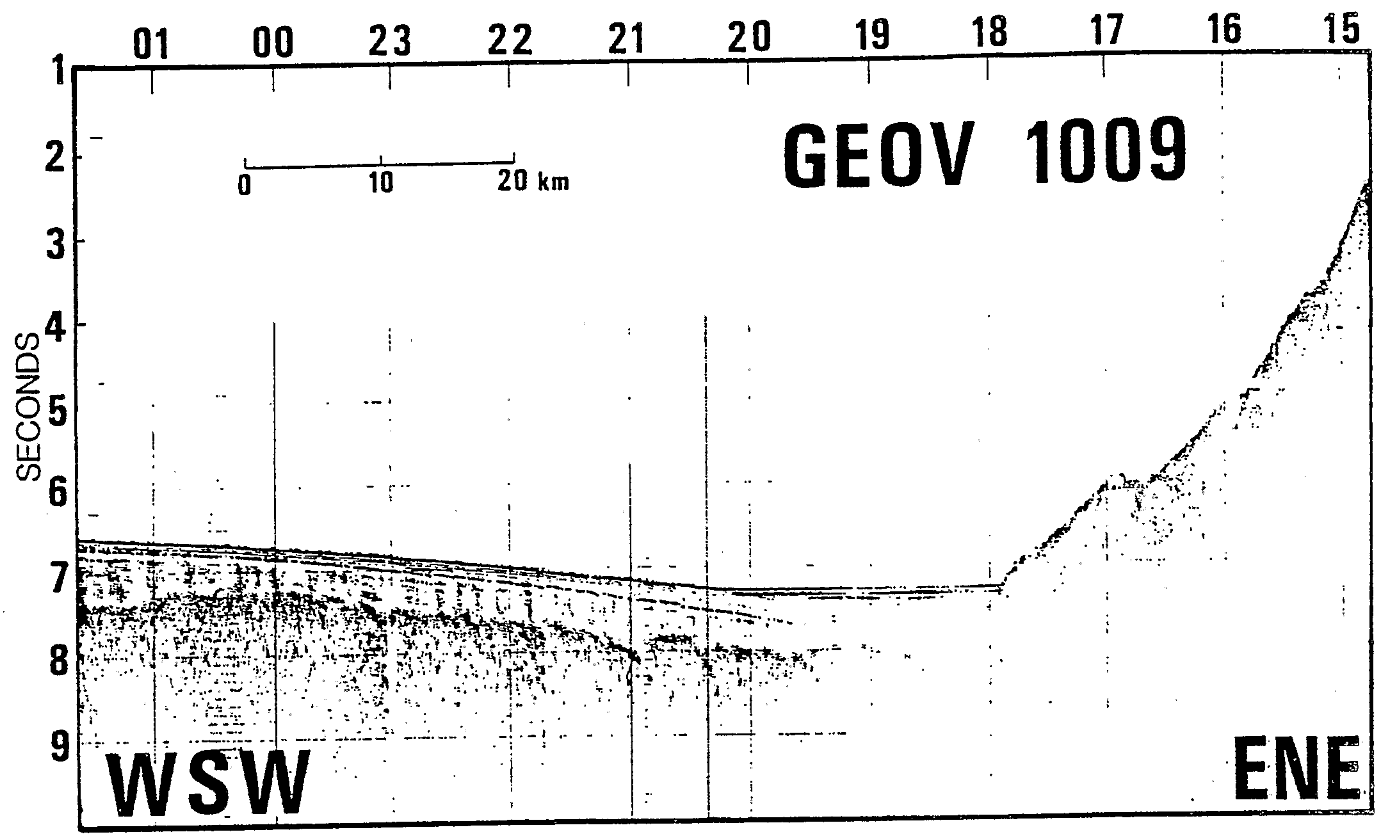

Figure 7. Original seismic profile GEOV 1009 across the junction between the West Santo Basin and Espiritu Santo.

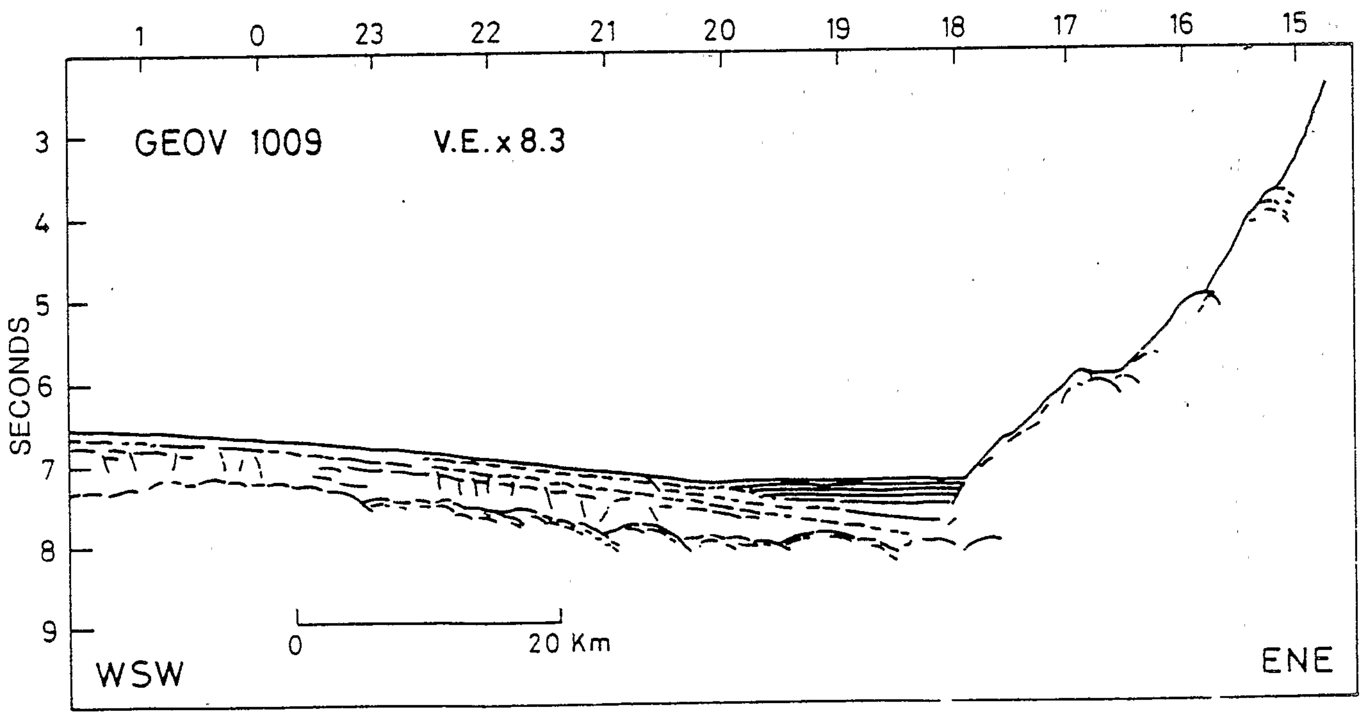

Figure 8. Traced seismic section GEOV 1009 across the plate boundary between the West Santo Basin and Espiritu Santo.

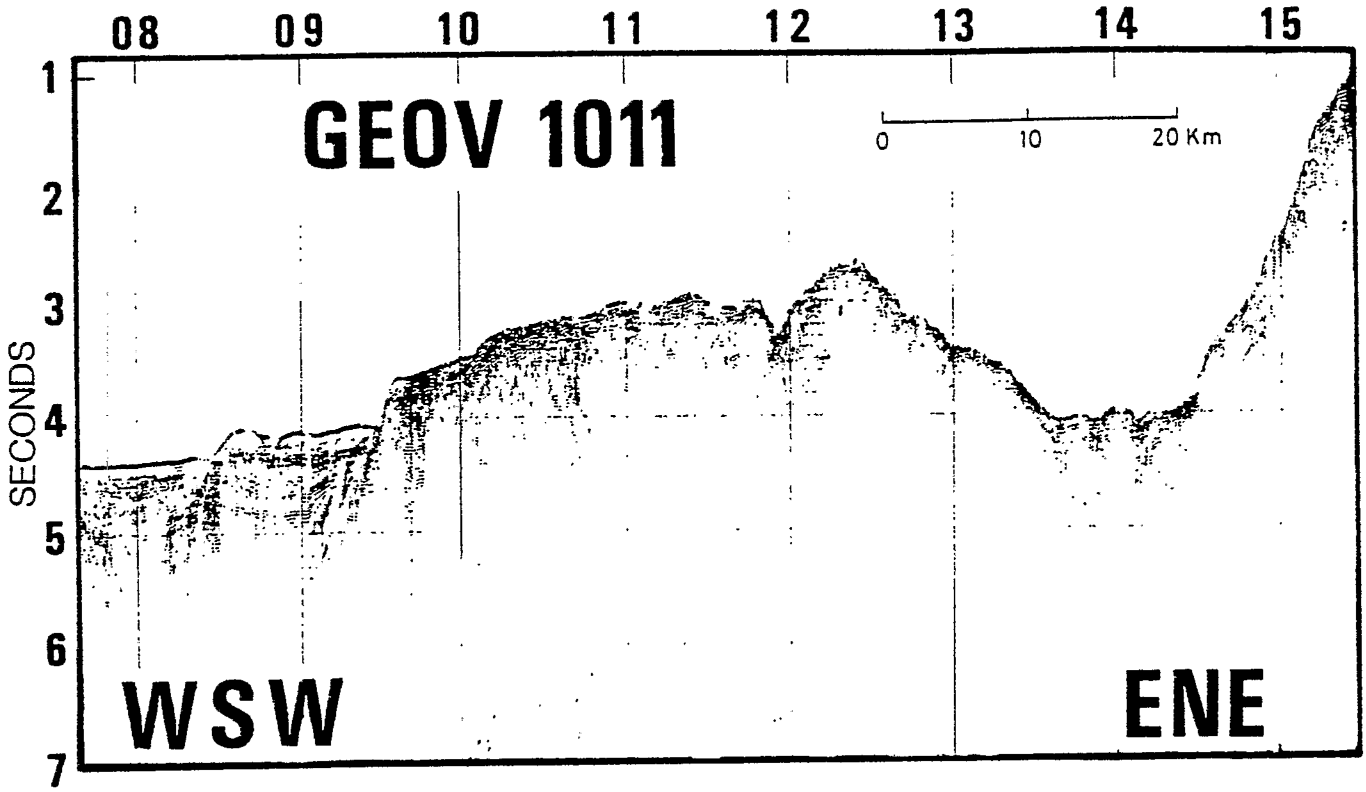

Figure 9. Original seismic profile GEOV 1011 across the junction between the North D'Entrecasteaux Ridge and Espiritu Santo.

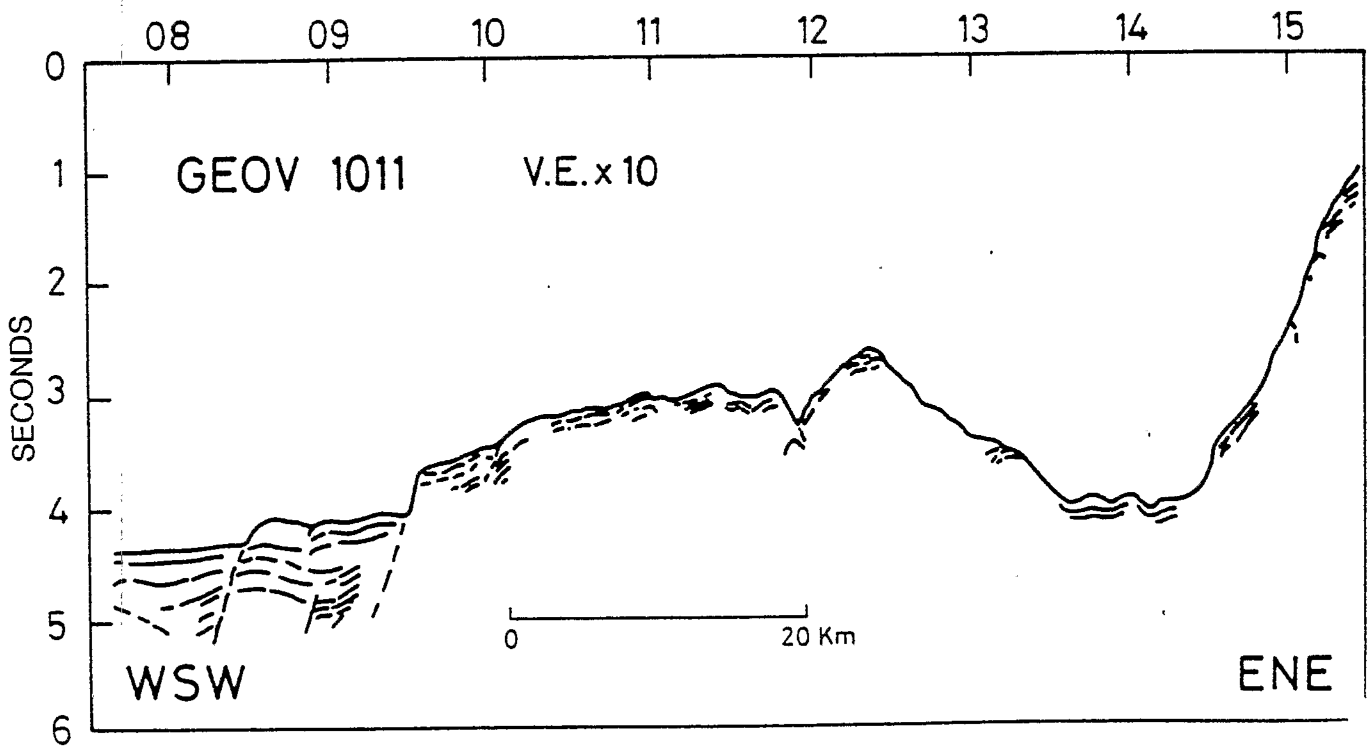

Figure 10. Traced seismic section GEOV 1011 across the junction between the North D'Entrecasteaux Ridge and Espiritu Santo. Note thin deformed sediments in the saddle which is taken to be the plate contact zone.

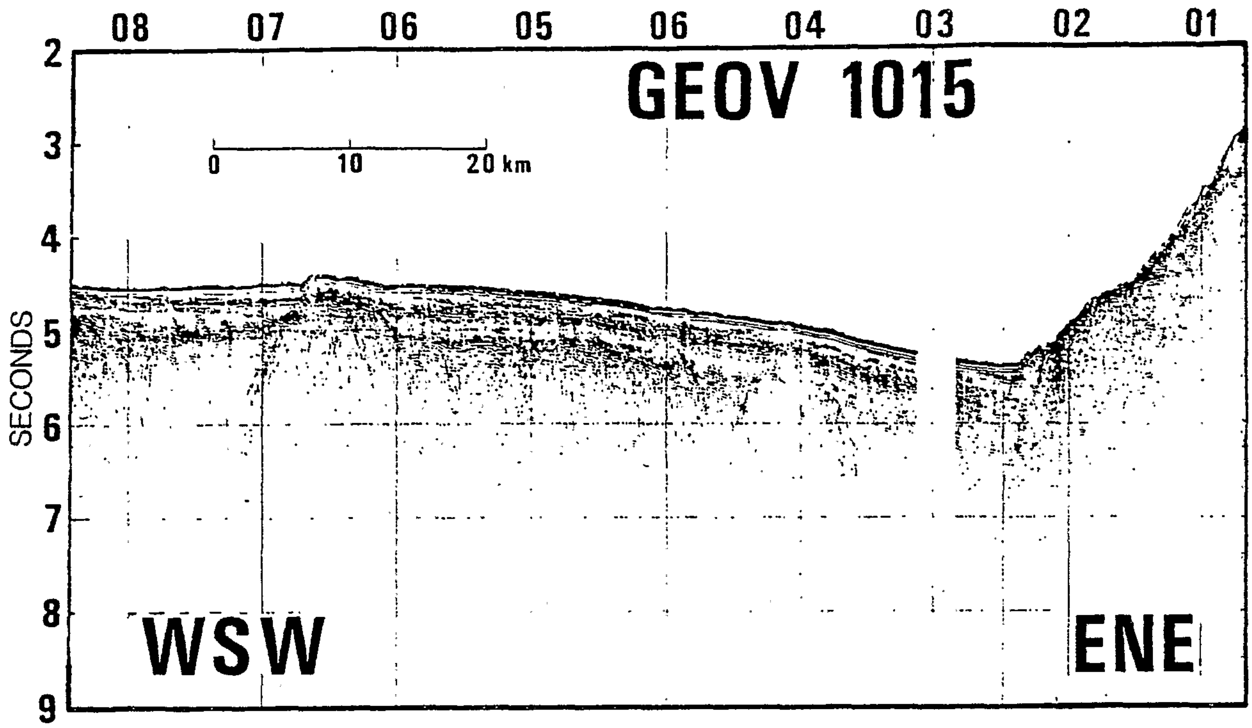

Figure 11. Original seismic profile GEOV 1015 across the junction between the Central D'Entrecasteaux Basin and Espiritu Santo.

Adjacent to West Santo Basin

Collot, Daniel, and Burne (1985) found that the trench topographically disappeared adjacent to the West Santo Basin. Profile GEOV 1009 (Figures 7 and 8), which crosses the plate boundary in this region (Figures 2 and 3), shows a slight (0.6-km) depression of the seafloor adjacent to Espiritu Santo. There is deformation of both sediments and basement, indicating flexure and downwarping. The deformed sediments are overlain by 0.5 km of subhorizontal undeformed "trench fill" sediments. The total depth of the "trench" (topographic depression plus trench fill) is thus about 1 km.

The lower slope west of Espiritu Santo is irregular, and, although no clear reflectors are seen, it is possible that slope deposits have slumped down over the sediments of the trench fill. Alternatively, the outward deformation of the slope adjacent to the basin could be, in part, the result of the horizontal impact of the ridge and consequent lateral westward bulging of the rocks on either side of the ridge, as suggested by Collot, Daniel, and Burne (1985). These bulging rocks may mask the deepest part of the geotectonic trench. Despite the lack of a pronounced topographic trench, the superficial structures shown in profile GEOV 1009 (Figures 7 and 8) are consistent with flexure associated with crustal downwarp at a subduction zone.

East of the North D'Entrecasteaux Ridge

Collot, Daniel, and Burne (1985) have suggested that the surface expression of the plate contact zone follows the tectonically disturbed saddle that separates the North D'Entrecasteaux Ridge from Wousi Bank (Figures 1 and 2)—a submarine promontory of Espiritu Santo.

Profile GEOV 1011 (Figures 9 and 10) crosses this boundary, and shows about 1.5 km of deformed sediment in a small faulted basin within the North D'Entrecasteaux Ridge. The ridge is an extensive (125 km by 600 km) structure with irregular topography, and has either a very thin covering of sediments or, in the east, no sediment at all. The ridge is separated from the steep flank of Wousi Bank by a 3-km depression, which is underlain by at least 0.4 km of deformed sediments.

East of the Central D'Entrecasteaux Basin

Collot, Daniel, and Burne (1985) suggest that,

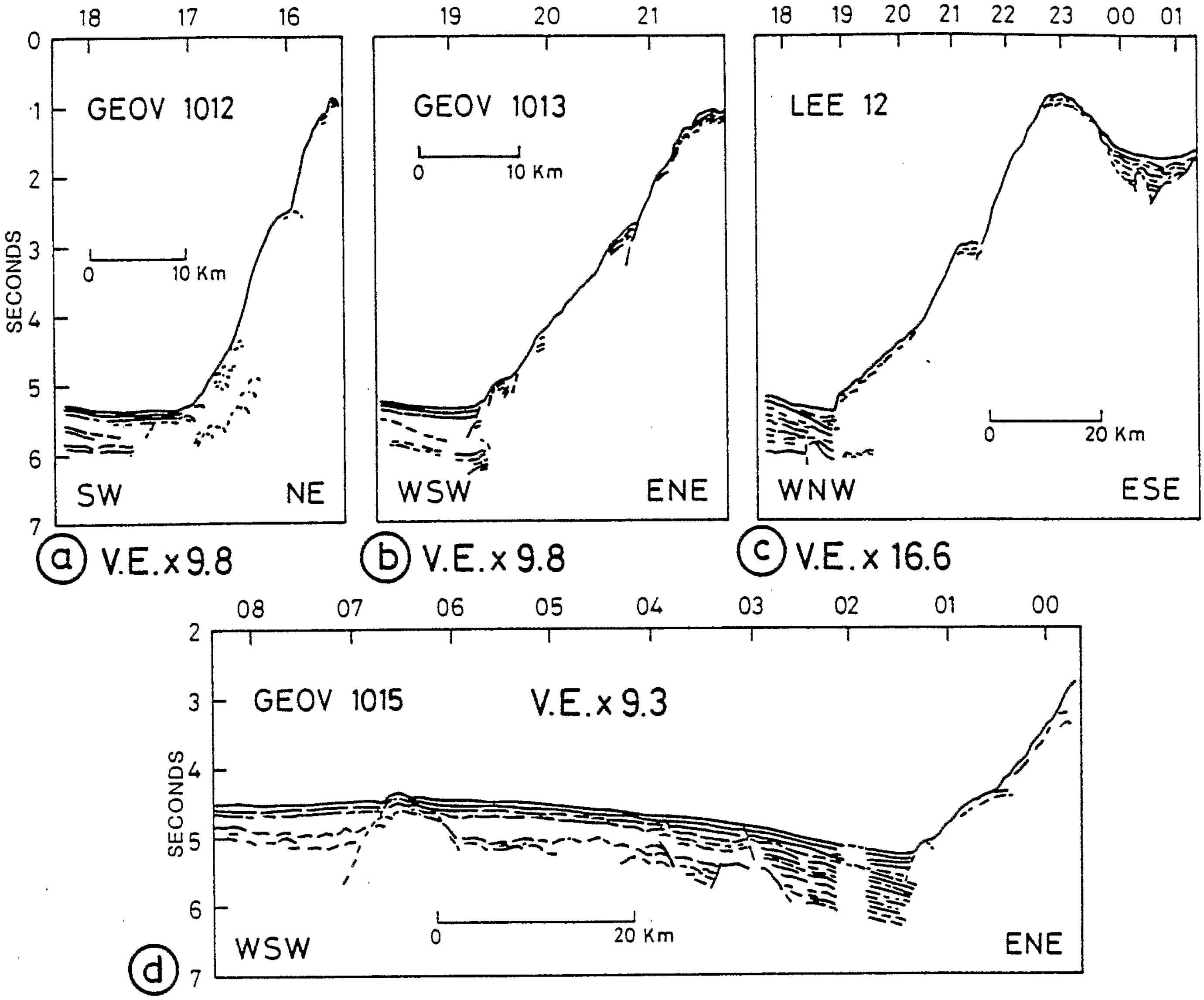

Figure 12. Traced seismic sections GEOV 1012, 1013, LEE 12, and GEOV 1016 across the junction between the Central D'Entrecasteaux Basin and Espiritu Santo.

similar to the West Santo Basin, the Central D'Entrecasteaux Basin is undergoing normal subduction beneath Espiritu Santo. Greene et al (1982) have suggested that the southern New Hebrides Trench continues this far north.

Lines GEOV 1012, 1013, 1015 and LEE 12, which cross this boundary (Figures 11, 12a-d), show deformed and faulted basement of the Central D'Entrecasteaux Basin downwarped to the east. This basement is overlain by up to 1.5 km of deformed and east-dipping downwarped sediment. A thin (0.3-0.5 km) trench fill sedimentary sequence overlies these downwarped sediments at the base of the steep flank of the New Hebrides Arc. These trench fill sediments are folded synclinally on profile LEE 12. The island arc slope shows a marked slope break on profile LEE 12, and some sedimentary layering is detectable at the base of the slope. The slope deposits may have slumped down over the trench fill sequence. Underthrusting of the Central D'Entrecasteaux Basin beneath the New Hebrides Arc is not characterized by a pronounced topographic trench, but by a minor 0.45-km depression of the seafloor. The total relief of the Central D'Entrecasteaux Basin, including the thickness of the trench fill, is less than 1 km.

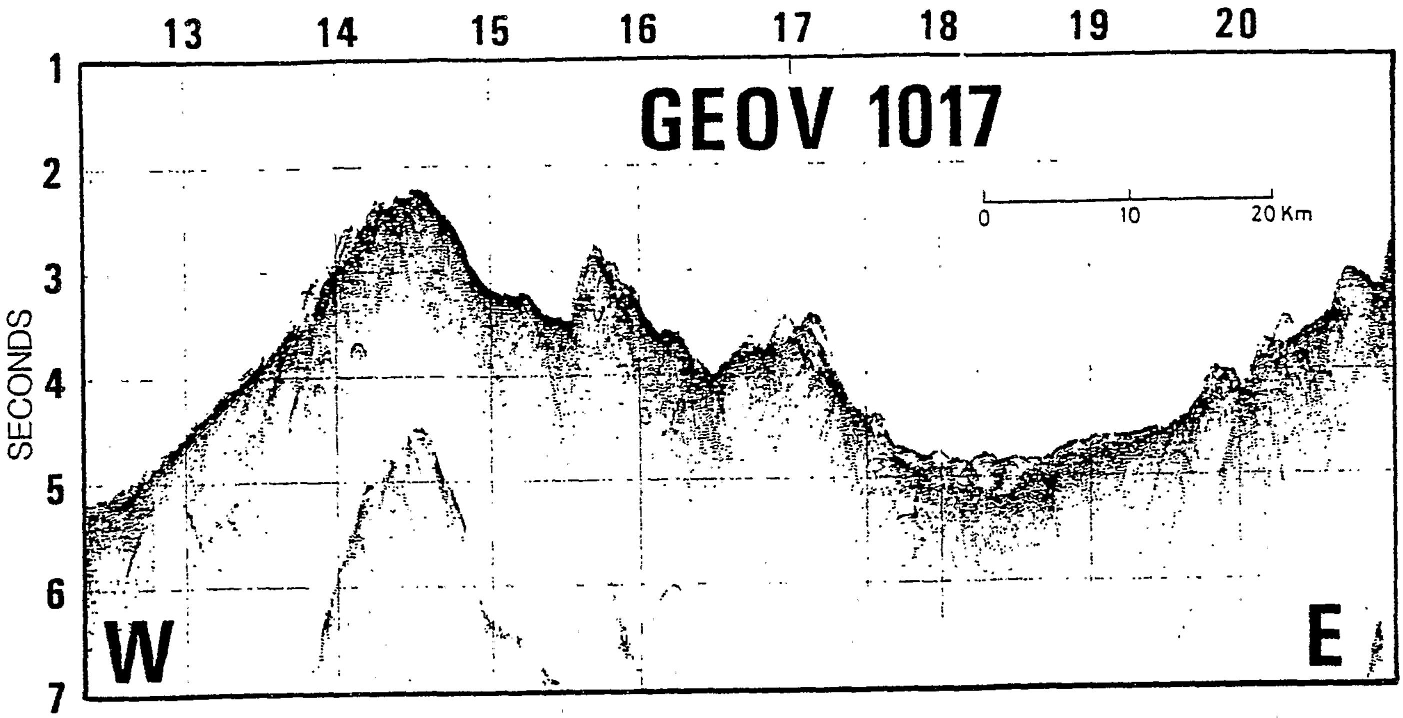

Figure 13. Original seismic profile GEOV 1017 across the South D'Entrecasteaux Chain and the west flank of Espiritu Santo.

East of the South D'Entrecasteaux Chain and the Bougainville Spur

Daniel and Katz (1981) examined Gulf line NH10D (Figure 14b) and proposed that the surface expression of the plate boundary lies east of the Bougainville Spur. Collot, Daniel, and Burne (1985) concur with this proposal and draw a transitional boundary separating the topographic high, capped by accoustic sedimentary units similar to those of the adjacent seafloor, and the rugged acoustic basement of the southern extension of Espiritu Santo, covered by a thin sequence of disturbed sediments. This transitional boundary was crossed by line GEOV 1017 (Figures 13 and 14a) from west to east, north of the Bougainville Spur. On this profile, upwarping of sediments west of the Sabine Bank is similar to that seen west of the Bougainville Spur on Gulf line NH10D (Figure 14b). A wide 3.6-km-deep depression between the Sabine Bank and the slope of the New Hebrides Arc is underlain by a thin sequence of deformed sediments. This depression, which is abruptly terminated to the south by the flank of the Bougainville Spur, is similar to the depression identified as the plate boundary east of the North D'Entrecasteaux zone. Thus, we suggest that the plate contact zone east of Sabine Bank runs along this depression where the recent sediments are deformed.

Line GEOV 1008 (Figure 14c) extends northward across the Bougainville Spur and onto the rugged toe of the west slope of the New Hebrides Arc. The morphologic contrast between the spur and the arc slope is clear; moreover, the northern and southern flanks of the spur are bounded by very steep scarps. The northern faulted boundary appears to separate two areas of differing sedimentation similar to those described along profile NH10D (Figure 14b). Thus, the surface expression of the plate boundary east of Bougainville Spur and northwestward in the Central D'Entrecasteaux Basin could extend somewhere along the junction between the northern scarp of the spur and the island arc slope. However, this area remains tectonically complex, and evidence for the precise location of this plate contact zone is poor. As indicated in Figure 2 by the two dotted lines suggested for a plate limit, at least two extreme possibilities exist—a continuous arcuate line or a discontinuous line offset by a strike-slip fault running approximately along the northern scarp of the Bougainville Spur.

Between North Loyalty Basin and Malakula

North of the abrupt termination of the south-

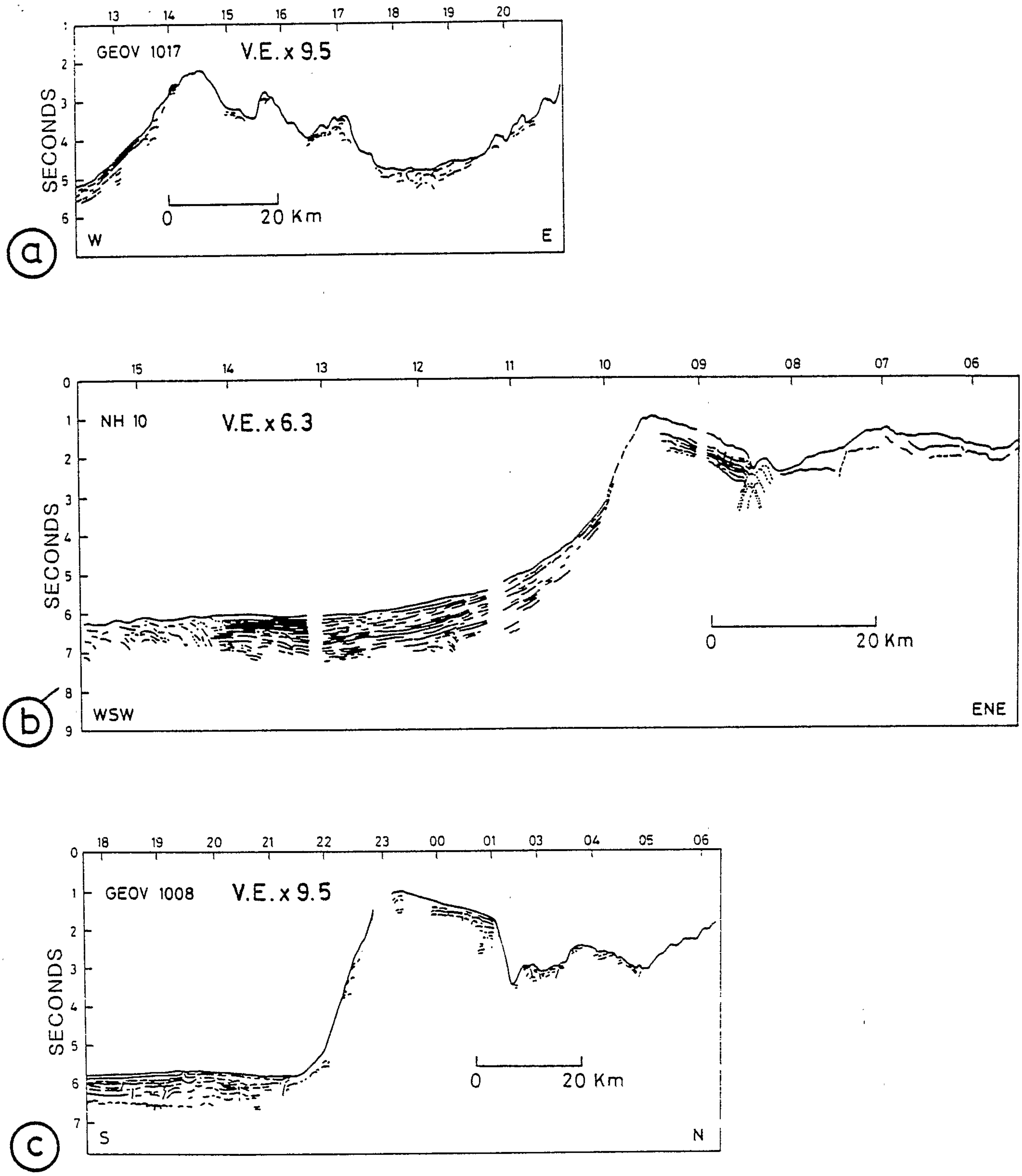

Figure 14. Traced seismic sections (a) GEOV 1017 across the South D'Entrecasteaux Chain and (b, c) NH 10 and GEOV 1008 across the Bougainville Spur.

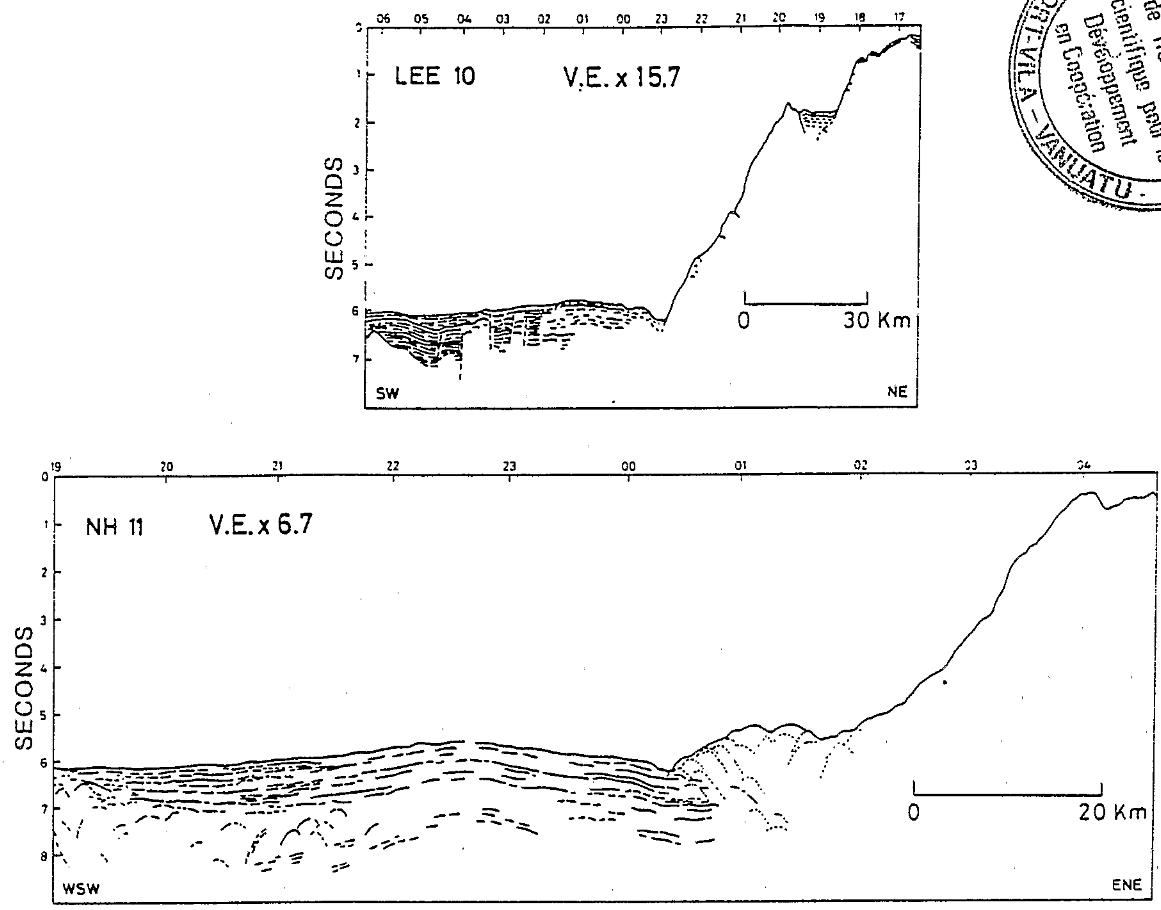

Figure 15. Traced seismic sections LEE 10 and NH11 across the junction between the North Loyalty Basin and the Santo-Malakula block.

ern New Hebrides Trench at 17°05′ S, the plate boundary is marked either by a shallow depression or by an abrupt transition between the abyssal plain and the disturbed toe of the insular slope. Although a subduction zone extends through this area, no topographic trench is visible on line LEE 10 (Figure 15) except for a narrow 0.3-km depression, which occurs at the junction between the abyssal plain and the insular slope. The abyssal plain is underlain by as much as 1 km of faulted, deformed sediments which thicken eastward and overlie faulted and deformed basement. Daniel and Katz (1981) have described Gulf line NH11 (Figure 15), and again, they see no clear morphologic trench. On both sections the steep western slope of the island arc exhibits irregular topography. This irregularity is especially apparent at the toe of this slope (Gulf line NH11, Figure 15), which is consistent with an accumulation of slope debris over the sediments of the downgoing plate.

DISCUSSION

Absence of a Deep Geotectonic Trench

Despite the continuity of eastward subduction along the plate boundary in the central New Hebrides Arc, the superficial structures of the plate contact zone between 13° and 17°S differ markedly from the conventional deep trench system encountered south of 17°S (Figure 16h). However, various scenarios may be called upon to account for the absence of a deep trench (Figures 16a-g and 17). The existence of the Santo-Malakula block in the position conventionally occupied by the arc-trench gap is a major factor in the suppression of deep trench development throughout the region. The western portion of the block actually lies over the expected position of the deep trench as extrapolated from the axis of the adjacent trenches (Figure 1). The collision of topographic features on the downgoing plate with

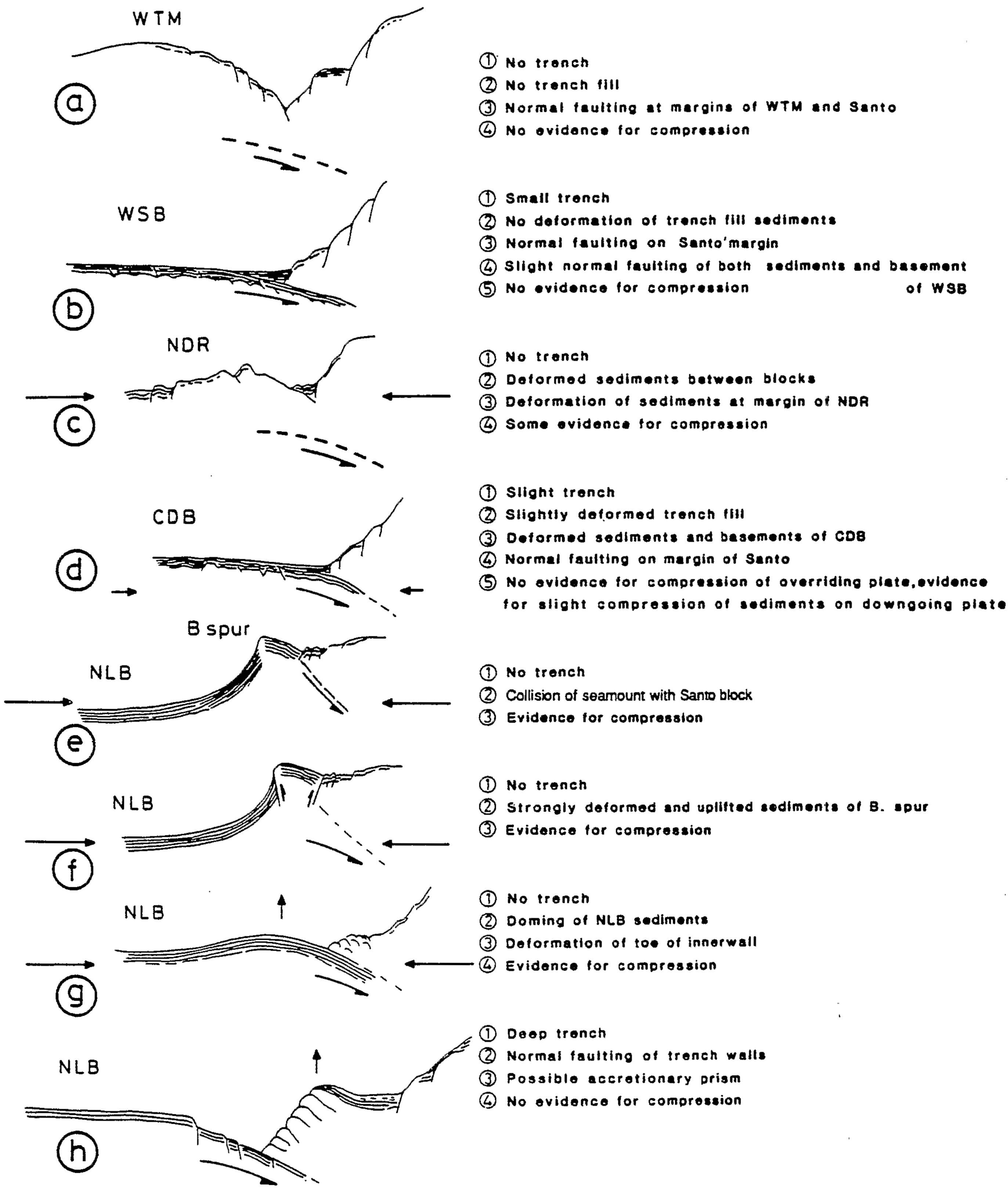

Figure 16. Diagram of various subduction scenarios observed along the central New Hebrides Arc. For location of examples, see Figure 17. Abbreviations as in Figure 1. Black horizontal arrows indicate compressive regime.

the Santo-Malakula block has completely suppressed trench development in the region of plate contact adjacent to the North D'Entrecasteaux Ridge and the South D'Entrecasteaux Chain (Figures 16c and f). This collision is only superficial, and does not inhibit overall subduction processes (Collot, Daniel, and Burne, 1985).

The West Torres Massif (Figure 16a) shows an incipient stage of contact where the gap between the massif and the Santo-Malakula block has not yet closed. Deformation of the walls of these features is tensional as indicated by topography, normal faulting, and focal mechanisms (Isacks et al, 1981). The intervening trench is shallow compared to the depth of the trench elsewhere, and it is formed by the intersection of the slopes of the arc and the massif.

Figure 16c shows a later stage in the collision process where the North D'Entrecasteaux Ridge has collided with the Santo-Malakula block, and is separated from it by a shallow basin containing deformed sediments. Collot, Daniel, and Burne (1985) consider that the ultimate stage of this process would cause the colliding features to separate from the downgoing plate and become incorporated onto the front of the overriding plate, thus causing a westward jump in the surface trace of the plate contact. It is possible that Wousi Bank may represent a piece of the North D'Entrecasteaux Ridge that has been incorporated into the Santo-Malakula block by this process, although Wousi Bank could also result from the elevation of the western slope of Espiritu Santo during the subduction of the North D'Entrecasteaux Ridge.

The junction between the North Loyalty Basin and the Bougainville Spur shows upwarped sediments at the margin of the spur, but no evidence of a geotectonic trench or trench fill sediments. Two possible explanations for these structures are given here (Figure 16e and f): (1) the Bougainville Spur is a seamount that collided with the arc (Figure 16e); or (2) intense compressional doming of the North Loyalty Basin as it approaches the underthrusting zone of the Santo-Malakula block has resulted in fracturing of the structure, and uplift of a keystone-shaped block of the downgoing plate, which then collides with, and adheres to, the front of the overriding plate (Figure 16f). An earlier stage of the latter process is observed west of northern Malakula (Figures 16g and 17), where there is marked compressional doming of the North Loyalty Basin sediments adjacent to the plate contact zone. Here, the possible location of the trench is obscured by sediments slumped from the steep insular slope.

The Central D'Entrecasteaux Basin is thought to be an incipient geotectonic trench at its contact with the Santo-Malakula block (Figure 16d), where slightly deformed trench fill appears to exist. There is no evidence for compression of the overriding plate; rather, the insular slope of Espiritu Santo is affected by normal faulting. However, slight compression of sediments on the downgoing plate indicates the influence of collision on the D'Entrecasteaux zone.

A similar incipient trench has developed at the plate boundary adjacent to the West Santo Basin (Figure 16b). In this case, deformation of the downgoing plate is due to tensional normal faulting. Here the 75°N dip of the downgoing plate means that the absence of a deep trench cannot be attributed to the clogging influence of the D'Entrecasteaux zone, which lies to the south. In this case, the absence of a trench must be explained by the protrusion of the Santo-Malakula block over the hinge of flexure of the downgoing plate or by filling of the trench with sediment. This explanation is supported by the presence in the trench of slumped sediments from the steep insular slope and by the westward displacement of the slope of the Santo-Malakula block. This protrusion of the block compensates for its adjacent indentation by the colliding North D'Entrecasteaux Ridge.

Thus, five specific processes can be described to show why a deep trench did not develop along the central New Hebrides Arc:

1. The protrusion, across the hinge of flexure, over the downgoing plate of the Santo-Malakula block at the leading edge of the overriding plate (Figures 16a-g).
2. Collision of topographic features carried on the downgoing plate with the leading edge of the overriding plate (Figures 16c and e).
3. Much slumping from the insular slope, and/or the tectonic displacement of material outward (westward) to compensate for the adjacent indentation by colliding features (Figures 16b, d, g).
4. Updoming of the downgoing plate adjacent to the zone of plate contact (Figures 16f and g).
5. Filling of any incipient trench with sediments (Figures 16b and d).

Stress Regime at the Top of the Downgoing Plate

The superficial structures described above can provide an insight into the stress regime at the top of the downgoing plate. We have analyzed the selected profiles shown in Figure 16 to determine the

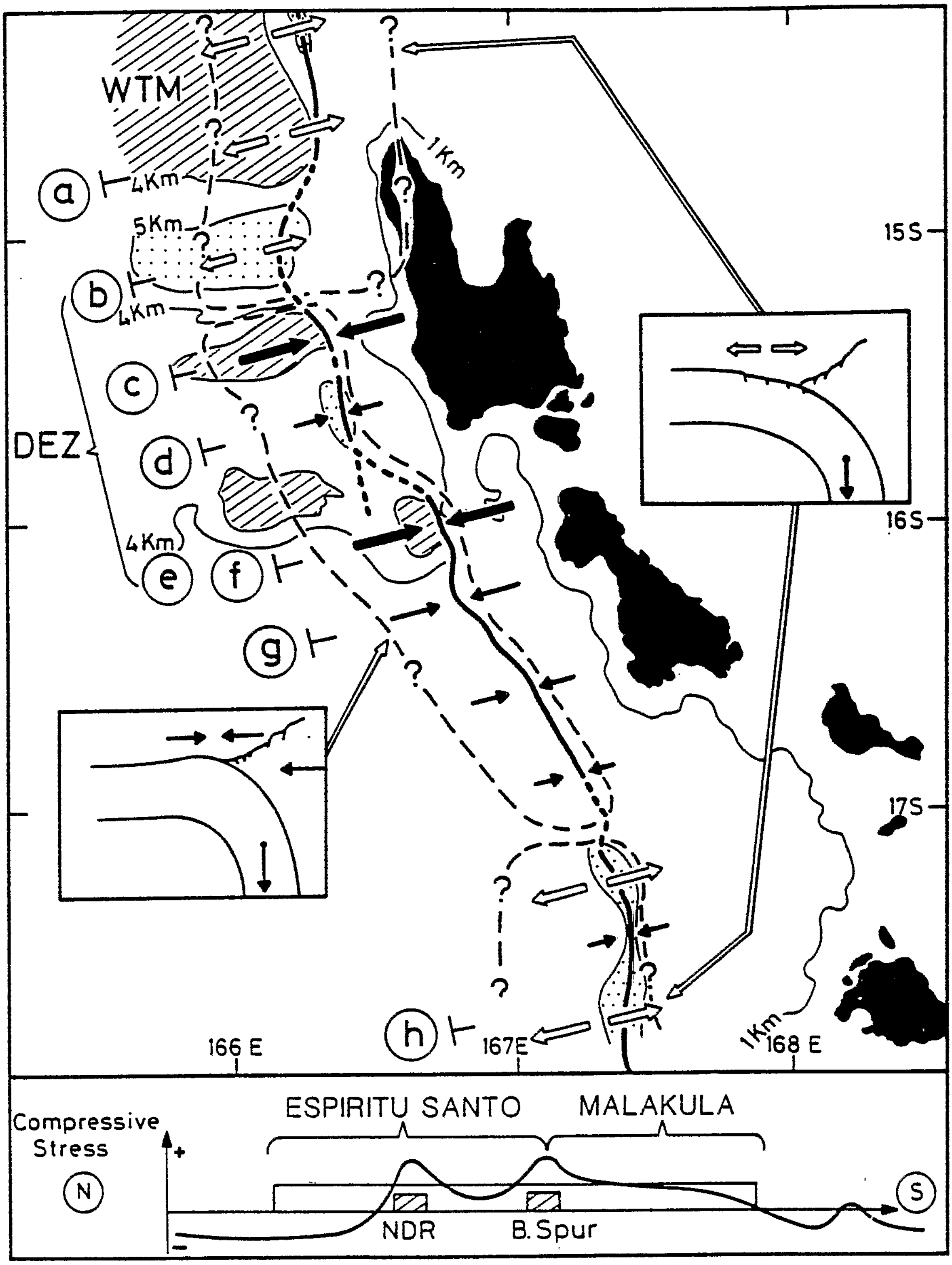

Figure 17. Diagram of stress regimes at the top of the downgoing plate showing compressive regime (solid arrows, left inset) in central region, flanked by tensional regimes to the north and south (open arrows, right inset). Stippled areas are trenches and sedimentary basins; hatchured areas massifs and ridges. Circled letters refer to Figure 16. Lower inset: diagram of variation of horizontal compressive stress at the top of the downgoing plate along the central New Hebrides plate contact zone. Values are strictly qualitative and show relative intensities only. Maximum compressive stresses are related to the colliding features of the North D'Entrecasteaux Ridge and the Bougainville Spur.

different types of shallow structures, such as anticlines and faults, which developed upon the downgoing plate. We assume that these observed structures are evidence for the stress regime in these rocks. In addition, because the seismic profiles roughly parallel the plate convergence vector, we have simplified the analysis by assuming a two-dimensional stress regime paralleling the plate convergence motion. We propose a simple stress regime at the top of the oceanic plate west of the trench and suggest qualitative stress variations.

South of 17°S, profile h in Figure 16 displays well-developed normal faulting on the outer wall of the trench. These structures are evidence for a tensional regime of the downgoing plate, which coincides with the presence of a deep trench and a typical arc-trench gap. North of this, around 17°25′ S, Orstom Seamount divides the trench. Although active normal faulting was reported by Collot, Daniel, and Burne (1985) along its eastern flank, suggesting tensional stress, local compressive stress is probably present within the impact area.

North of 17°S, profile g in Figure 16 shows an anticline with a 50-km wavelength that is different from the outer bulge characterized by a 250-km wavelength and described by Dubois et al (1977). This anticline is associated with the absence of a deep trench and with an elevated and much thicker forearc (Malakula Island) than found further south. We interpret this anticline as the result of horizontal compressive stress.

Between 17°S and profile g (Figure 16 and 17), some of the bathymetric profiles published by Collot, Daniel, and Burne (1985) suggest that compressive horizontal stress is present in that area. Unfortunately, no seismic profiles were obtained in this zone.

As described above, structures observed in profile f of Figure 16 across the Bougainville Spur can be interpreted as the result of an intense compressional stress field acting on the North Loyalty Basin crust. Other evidence (Collot, Daniel, and Burne (1985) for compression in this area is the radial stress pattern developed across the arc, indicating that major compressive stress lines converge on the Bougainville Spur.

Profile d of Figure 16 across the Central D'Entrecasteaux Basin shows a slightly deformed trench fill and deformed sediments and basement rocks. These features are evidence for slight horizontal compression of sediments in this region.

Along the North D'Entrecasteaux Ridge, profile c of Figure 16 indicates some recently deformed sediments that seem to have been compressed between the ridge and arc. Some deformation of sediments at the margin of the ridge is also reported. The compressive stress field related to that deformation is probably less intense than that encountered in the Bougainville Spur area. However, it seems to be more severe than that affecting the Central D'Entrecasteaux Basin.

Farther north across the West Santo Basin (Figure 16b), no evidence for compression is noted—only some minor normal faulting. Based on this evidence, the basin appears to be dominated by tensional stress.

At the incipient contact of the West Torres Massif with the western flank of Espiritu Santo Island, the slopes do not display any evidence for compression, as expected, but instead show some tensional features mainly deduced from topographic analysis and from normal faulting and shallow focal mechanisms (Isacks et al, 1981) located on the east flank of the massif.

The dominant stress patterns affecting the upper parts of the downgoing plate adjacent to the plate boundary may be grouped into three major areas: (1) north of the D'Entrecasteaux Ridge, (2) south of 17°S, and (3) between the North D'Entrecasteaux Ridge and 17°S (Figure 17).

North of the North D'Entrecasteaux Ridge and south of 17°S, the dominant tensional regime is probably related to the passive bending of the downgoing plate under the weight of the subducted slab. According to Isacks et al (1981), the coupling between the plates in such an area should be weak, and subduction should be controlled mainly by creep. Between the North D'Entrecasteaux Ridge and 17°S, evidence of a deformed weak sedimentary layer overlying a more competent elastic plate suggests that the origin of the stresses is shallow and compressional. This relationship may reflect a relatively strong coupling of the upper and lower plates beneath Malakula and Espiritu Santo, resulting from the subduction of the D'Entrecasteaux zone. Although it is difficult to qualitatively assess variations in the intensity of stresses, we suggest that relative variation in horizontal compressive stress does occur at the top of the downgoing plate in front of the central New Hebrides Arc. The greatest apparent stress occurs across the North D'Entrecasteaux Ridge and adjacent to the Bougainville Spur, since deformation is more intense here. These areas have been interpreted by Collot, Daniel, and Burne (1985) as sites of high horizontal stress concentrated at impact points, which may be considered areas of high coupling between the plates, where there is evidence of localized and shallow roughness or irregularity of the surface of the Benioff zone (Figure 17).

The transition zone between the central region of compressive stress and the adjacent tensional regimes should be places where the downgoing plate is affected by transverse shearing (Figure 17). Some evidence for this exists at the following locations. At 17°S, where deformation of the plate boundary and disappearance of the trench are observed, the downgoing plate displays an east-west-trending topographic feature delineated by the 5000-m isobath (Collot, Daniel, and Burne, 1985, their Figure 2). Along the northern limit of the D'Entrecasteaux zone, there is even more striking evidence for cross horizontal shearing (Figures 4a,b and d)—relatively strong deformation occurring at the transition between the West Santo Basin and the North D'Entrecasteaux Ridge. Thus, this boundary which has been interpreted as the trace of a pre-Miocene subduction zone (Collot, Daniel, and Burne, 1985) may be reactivated at the present time as a strike-slip or transform fault.

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