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Tectonic history of northern New Caledonia Basin from deep offshore seismic reflection: Relation to late Eocene obduction in New Caledonia, southwest Pacific

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Abstract

[1] New, high-quality multichannel seismic reflection data from the western New Caledonia offshore domain allow for the first time the direct, continuous connection of seismic reflectors between the Deep Sea Drilling Project 208 drill hole on the Lord Howe Rise and the New Caledonia Basin. A novel seismic interpretation is hence proposed for the northern New Caledonia Basin stratigraphy, which places the Eocene/Oligocene unconformity deeper than previously thought and revisits the actual thickness of the pre-Oligocene sequences. A causal

link is proposed between the obduction of the South Loyalty Basin over New Caledonia (NC) and the tectonic history of the northern New Caledonia Basin. Here it is suggested that as the South Loyalty Basin was being obducted during early Oligocene times, the NC Basin subsided under the effect of the overloading and underthrust to accommodate the compressional deformation, which resulted in (1) the uplift of the northern Fairway Ridge and (2) the sinking of the western flank of New Caledonia. This event also had repercussions farther west with the incipient subsidence of the Lord Howe Rise.

1. Introduction

[2] The southwest Pacific region east of Australia consists of a succession of ridges and basins that result from the fragmentation of Gondwanaland since Cretaceous time [Symonds et al., 1996; Gaina et al., 1998; Auzende et al., 2000b; Crawford et al., 2002]. From west to east these ridges and basins are the Tasman Sea, the Dampier Ridge (DR), the Middleton Basin (MB), the Lord Howe Rise (LHR), the Fairway Basin (FB), the Fairway Ridge (FR), the New Caledonia Basin (NCB), the Norfolk Ridge (NR), the South Loyalty Basin (SLB), and the Loyalty Ridge (LR). Since late Miocene, this region is the foreland area of the Vanuatu Subduction Zone where the Australian Plate subducts beneath the Pacific Plate. A crustal flexure associated to this process is observed with the uplift of the Loyalty Islands [Dubois et al., 1974; Dubois et al., 1977; Guyomard et al., 1996] and the southern tip of New Caledonia and the Island of Pines [Launay and Recy, 1972; Launay, 1985; Cabioch, 1988; Cabioch et al., 1996]. Vertical motions from the 125 Ka reef indicate different tectonic blocks and a general slow subsidence (0.03 to 0.16 mm/a) of New Caledonia west coast [Lagabrielle et al., 2005]. This paper more particularly focuses on the tectonics and the sedimentary history of the New Caledonia Basin.

[3] The New Caledonia Basin is generally thought to have formed during the Cretaceous, based on rifting evidence from the Taranaki Basin, or during the Late Cretaceous–early Paleocene [Burns and Andrews, 1973; Ravenne et al., 1976; Mignot, 1984; Collot et al., 1987; Uruski and Wood, 1991; Willcox et al., 2001; Lafoy et al., 2005a, 2005b], as mid-Paleocene fossil oozes were found at Deep Sea Drilling Project (DSDP) 206 [Burns et al., 1973a] drill site (see Figure 1 for location and Figure 2 for stratigraphy). The basin can be divided into two parts, having different structural characteristics, separated by a NE trending morphotectonic feature at 23°S (Figure 3) [Lafoy et al., 2005a]: on the basis of recent, wide-angle seismic data [Klingelhoefer et al., 2007], the NW trending northern New Caledonia Basin (NNCB) is characterized by a thick sedimentary cover and a 15 km thick crust of undetermined type with velocities of 6.4–7.4 km/s, whereas the north trending southern New Caledonia Basin has a thinner sedimentary cover with a back-arc basin type oceanic crust (8–9 km thick) with velocities of 6 km/s. Although the nature of the crust underlying the New Caledonia and Fairway basins is now documented, the history of the sedimentary infill remains unclear, mainly because of the lack of age determinations.

[4] Rock outcrops on land provide well dated milestones that help us understand the tectonic history of New Caledonia [Avias, 1958; Aitchison, 1995; Cluzel et al., 1997; Aitchison et al., 1998; Baldwin et al., 2007]. By contrast, in the offshore domain, the ages of the sedimentary sequences are known only at a limited number of widely spaced, isolated drill hole sites (Figure 1). The base of the Eocene/Oligocene unconformity that is documented at some sites has been used for a long time as a major, regional milestone for seismic stratigraphy. However, because of the lack of seismic data, no direct link was possible until now between the borehole sites and the New Caledonia Basin.

[5] In this paper, we use all available seismic data, including new high-quality, 3.5 km long 360-channel, seismic reflection data collected during the Noucaplac-2 [Loubrieu et al., 2004] (August 2004) and ZoNeCo-11 [Lafoy et al., 2004] (September 2004) cruises of R/V L'Atalante to construct NE trending transects between the Lord Howe Rise and the western margin of the New Caledonia/Norfolk Ridge system, which, for the first time ever, extend the Eocene/Oligocene unconformity documented at the DSDP 208 Drill hole site [Burns et al., 1973c], without interruption into the NNCB. The previous attempts that have been made by correlating the seismic reflectors within this basin [Van de Beuque, 1999, 2003; Vially et al., 2003] are hence revisited.

2. Marine Stratigraphy From Regional Borehole Data: Eocene/Oligocene Unconformity

[6] Few boreholes were drilled in the geological structures linked to the New Caledonia Basin. The eight closest holes were drilled during the early 1970s, during leg 21 and leg 90 of the DSDP program. These sites are DSDP 587, DSDP 591, DSDP 590, DSDP 593, DSDP 206, DSDP 207, DSDP 208, and DSDP 284 (Figure 1). All sites but one (DSDP 206) are located in relatively shallow areas, on the crest or on the flanks of the Lord Howe Rise, and the penetration beneath seafloor varies from one site to another:

[7] 1. Five sites (small blue circles on Figure 1), DSDP 587, DSDP 591, DSDP 590, DSDP 593, and DSDP 284, do not reach the Eocene/Oligocene section [Kennett James et al., 1986d, 1986b, 1986a, 1986c; Kennett et al., 1975].

[8] 2. On the other hand, DSDP 206, 207, and 208 [Burns et al., 1973a, 1973b, 1973c] (big blue circles on Figure 1) penetrated Eocene and older rocks, and are important to this study. Late Eocene to mid-Oligocene sediments are absent in the regional unconformity (U1) at all three sites. Late Paleocene and early Eocene sediments are also missing (U2) at all three sites [Burns et al., 1973a, 1973b, 1973c]. U1 has a common base over all three sites (mid-Eocene), whereas its top varies from mid-Oligocene to mid-Miocene (Figure 2d).

[9] DSDP 208 being the nearest hole of the studied area and the only one that intersects our available seismic line FAUST1-S206-2 [Lafoy et al., 1998], it will be taken as the reference for this interpretation.

[10] Taking into account U1 at site DSDP 208, we suggest that erosion of the Lord Howe Rise started after the mid-Eocene (circa 45 Ma) [Burns et al., 1973c] and that the northern part of the LHR returned to bathyal water depth in the early Oligocene, circa 34–28.5 Ma [Burns et al., 1973c].

[11] U1 has a particular property of being the boundary between calcareous sediments (overlying) and calcareous sediments with an important radiolarian siliceous component (underlying) [Burns et al., 1973c]. The presence of radiolarians in the underlying layer induces a contrast of porosity between the two layers and therefore a contrast of density with a less dense underlying layer. The reflection coefficient associated with U1 is therefore negative and a local negative jump of seismic and sonic velocities is observed. The bottom of hole DSDP 208 reaches Campanian sedimentary strata.

3. Seismic Data Description

[12] The seismic lines that we use here to connect DSDP 208 site to the NNCB, were all collected after 1998 (in the digital era), using modern multichannel seismic facilities (see details in Table 1). These lines (underlined in yellow in Figure 3) are the following:

[13] 1. Lines FAUST1-S206 from the French-Australian-Seismic-Transect surveys [Lafoy et al., 1998] (also known as LHRNC, Lord Howe Rise/New Caledonia) –2 and –1 were collected in 1998 with R/V Rig Seismic using a 3.3 km long, 264-channel streamer and a 3000 cubic inch, tuned, seismic array producing signal in the 50–60 Hz frequency band. Line FAUST1-S206-2 runs over DSDP 208 drill site, heading northward along the western, upper slope of the Lord Howe Rise. Line FAUST1-S206-1 bears northeast, from the crest of the Lord Howe Rise to the Fairway Basin.

[14] 2. High-resolution seismic lines from the Fairway Basin were collected during the ZoNeCo-11 cruise [Lafoy et al., 2004] (September 2004) to characterize the reflectors that were once interpreted as gas hydrate-related bottom simulating reflectors (BSR) [Exon et al., 1998; Auzende et al., 2000a; Pecher, 2004]. These lines are used to connect the Fairway Basin and regional seismic transects across the New Caledonia Basin.

[15] 3. Deep frequency, regional seismic transects collected in 2004 during the Noucaplac-2 [Loubrieu et al., 2004] and ZoNeCo-11 [Lafoy et al., 2004] cruises of R/V L'Atalante, using a 4.5 km long, 360-channel streamer, together with a large (8000 cubic inch) air gun array tuned in the single bubble mode [Avedik et al., 1993]. These lines fill the data gap that used to exist between the Fairway Basin and the New Caledonia Basin.

[16] In addition, we use the ZoNeCo-5 lines [Auzende et al., 1999] collected in 1999 (and reprocessed in 2006) with R/V L'Atalante, using a 300 m long, six-channel streamer and two 250 cubic inch GI guns. Although the penetration of the seismic energy is restricted to the upper part of the sediment cover (the maximum penetration depth is ~1.5 to 2 s two-way traveltime (twt)), these closely spaced lines (spacing is less than 12 km) are of particular interest because they cover the entire Fairway Basin and the eastern flank of the Lord Howe Rise.

4. Linking DSDP 208 Stratigraphy to the New Caledonia Basin

4.1. Correlation Between Seismic and Drill Hole Data at DSDP 208

[17] The starting point is the DSDP 208 borehole, where the Eocene/Oligocene unconformity (U1) has been found to be at 488 m below seafloor. Using the velocity analysis of Van de Beuque et al. [1998a] and Van de Beuque [2003], a correspondence is established between the unconformity and reflector RN on seismic line FAUST1-S206-2 (Figure 2e). Reflector RN has two remarkable characteristics:

[18] 1. It corresponds to a seismic phase inversion, because the presence of radiolarians in Eocene sediments induces lower seismic velocity in the lower layer (see section 2). The phase inversion can be followed all the way along seismic line FAUST1-S206-2, except in some places where the unconformity sits on basement (basement which corresponds to the top of the crust, confirmed by the wide-angle seismic data), in which case RN swaps to a positive phase [Nouzé et al., 2005, also Geophysical characterization of bottom simulating reflectors in the Fairway Basin (off New Caledonia, southwest Pacific), based on high-resolution seismics and heat flow data, submitted to Journal of Geophysical Research, 2008] (Figure 4).

[19] 2. Sediments overlying RN have a characteristic, transparent seismic facies with a single intra-Miocene reflector (highlighted in pink in Figure 2e), whereas sediments underlying RN present rather well-bedded sequences.

[20] These two well-marked characteristics are used hereafter to identify and follow reflector RN over the Lord Howe Rise, the Fairway Basin, the Fairway Ridge, and the New Caledonia Basin. The path we use is highlighted in yellow on Figure 3.

4.2. Link From LHR Down Into the Fairway Basin

[21] Reflector RN is continuous along profile FAUST1-S206-2, from Site DSDP 208 to the junction with FAUST1-S206-1 (Figure 5). The reflector can then be followed along line FAUST1-S206-1 (Figure 6), up to the crest of Lord Howe Rise. On the eastern flank of Lord Howe Rise, a reflector is found that is related to a seismic phase inversion and located at the base of a seismically transparent layer. Hence, this reflector is identified as being RN. This interpretation is strongly supported by the presence of toplaps truncated by this reflector (black arrows on Figure 6). The interpolation of RN from the crest of Lord Howe Rise down to the Fairway Basin is shown in Figure 6. Because of the presence of the Fairway Ridge, it is difficult to follow reflector RN all the way along line FAUST1-S206-1 down to the New Caledonia Basin. We thus use seismic profiles Z11-11, Z11-10, and Z11-09 (Figures 7, 8, and 9) that link the northern and the central parts of the Fairway Basin (see location on Figure 3).

[22] In the northern Fairway Basin, a specific seismic survey was conducted during the Zonoco-11 cruise near 23°15'S, 163°30'E, in order to confirm or deny the presence of gas hydrates in the area. Five high-resolution profiles, simultaneously recorded on a 3.5 km long 360-channel seismic streamer and on 12 ocean bottom seismometers (OBSs), provided the detailed velocity structure of the substratum, in a narrow zone of $30 \times 40 \text{ km}^2$. Nouzé et al. [2005, also submitted manuscript, 2008] identified two distinct reflectors (RN and RP on Figure 7), both located at the base of a seismically transparent, upper sedimentary sequence: the first one (identified as RN) is located between 3 and 3.5 s twt below sea level and related to a seismic phase inversion, whereas the second one (identified as RP) is a bottom simulating reflector, as documented by previous authors [Exon et al., 1998; Auzende et al., 2000a; Exon et al., 2004; Pecher, 2004]. The presence of a seismically transparent layer overlying reflector RN and the phase inversion suggests that RN likely corresponds to the regional Eocene Oligocene unconformity.

[23] Profiles z11-11, z11-10, and z11-09 (Figures 7, 8, and 9) allow us to follow reflector RN farther south in the Fairway Basin, down to the intersection with profile NCP2-2 (Figure 10).

4.3. Linking the Fairway Basin to the New Caledonia Basin Across the Fairway Ridge

[24] Profile NCP2-2 (Figure 10) is the only profile that enables us to continuously follow reflector RN, from the Fairway Basin to the New Caledonian Basin without interruption across the Fairway Ridge. Hence, it is the key profile for this new seismic interpretation. NCP2-2 shows a clear and continuous reflector RN, which runs over the Fairway Ridge and down in the New Caledonian Basin where all other eastward oriented profiles reveal RN as an onlap reflector truncated by the Fairway Ridge (see for example profile z11-01A on Figure 11) or lead to ambiguous interpretations using a seismic facies recognition method. The position of the Eocene-Oligocene unconformity in the New Caledonia Basin is the main new

result of this interpretation, positioning it deeper than in previous interpretations [Van de Beuque, 1999, 2003; Vially et al., 2003].

[25] Following RN along profile z11-04 (Figure 12) northward, we identify the position of RN in the northern New Caledonian Basin, and match it to the tilted reflector observed on profile z11-01A (Figure 13). Previous authors [Willcox et al., 1980; Exon et al., 1998; Lafoy et al., 1998; Van de Beuque, 1999; Auzende et al., 2000a; Vially et al., 2003; Lafoy et al., 2005b] interpreted the New Caledonia Basin as Cretaceous-Paleocene and placed the Eocene Oligocene unconformity U1 around 4–5 s twt below sea level (bsl) in the New Caledonia Basin and around 4 s twt (bsl) in the Fairway Basin. U1's position is here confirmed in the Fairway Basin and revised in the NCB where we suggest it to be at 8 s twt at its deepest position.

4.4. A Rapid Post-Early Oligocene Eastward Tilt of the NNCB

[26] The stratigraphic analysis of the profile z11-01A suggests that the depocenter of the NNCB migrated eastward before late Oligocene, as a response to a rapid eastward tilt of its basement:

[27] 1. Well-stratified reflectors onlapping the pre-Oligocene series beneath RN on profile z11-01A (black arrows pointing to the right on Figure 13) indicate the existence of a tilted paleobasin that had its depocenter beneath the western flank of the present-day NNCB (see reconstitution of profile z11-01A's history on Figure 14). This basin was tilted eastward during RN time as indicated by its eastward dipping reflectors (dark blue reflector).

[28] 2. The post-early Oligocene onlap series (black arrows pointing to the left on Figure 13) does not show evidence for syntectonic sedimentation, which would be distinguished by a fanning reflector pattern. Instead, the entire post-early Oligocene fill is horizontal, with parallel bedding. The geometrical relationship between unconformity RN and the basin stratification denotes a rapid tilt of the basin that terminated prior to massive post-early Oligocene sedimentation. The thin post-RN sequence (top of which is marked by a dark green reflector on Figure 13) on the flank of the FR (SP3000) is drapped sediment or, more likely, contourites.

[29] These observations indicate that the NNCB's history evolved following two major phases: pre- and post-early Oligocene, with a major tectonic event as boundary.

5. Implications

5.1. Causal Relationship With Early Oligocene Obduction in New Caledonia

[30] Seismic reflector RN (the Eocene/Oligocene unconformity) dips eastward in the NNCB (profile z11-01A on Figure 13), indicating that the basin subsided, whereas the Fairway Ridge was uplifted some time in-between mid-Eocene and early Oligocene times (i.e., the upper and lower age boundaries of the tilt are ~45 and 34–28.5 Ma, respectively, corresponding to the dating of U1 in the works of Burns et al. [1973c]). The tilting of the FR appears to be small compared to the subsidence of the NNCB which denotes that the formation of a foredeep basin is the significant part of the event. This new result has several implications regarding the New Caledonia Basin in terms of age, tectonic and sedimentary evolution and links with

its neighboring structural elements. Taking a close look at the New Caledonia onshore geology [Avias, 1967; Brothers and Blake, 1973; Prinzhofer et al., 1980; Paris, 1981; Collot et al., 1987; Aitchison and Meffre, 1992; Aitchison, 1995; Cluzel et al., 1997; Aitchison et al., 1998; Cluzel, 1998; Cluzel et al., 1998; Ali and Aitchison, 2000; Cluzel et al., 2001; Ali and Aitchison, 2002; Spandler et al., 2004; Fitzherbert et al., 2005; Spandler et al., 2005; Cluzel et al., 2006], we here propose to establish links between the marine tectonic event observed in the seismic data and the tectonic events observed onshore.

[31] Rigolot and Pelletier [1988] and Rigolot [1989] have described from single-channel seismic data (ZOE-400) compressional features, reverse faulting and duplexes along the western margin of New Caledonia. They claimed that this compressive phase was active during New Caledonia's obduction episode from latest Eocene until late Miocene/Pliocene and resulted from displacements along a major boundary located west of New Caledonia.

[32] The mafic allochthon that crops out over more than 250 km along the west coast of New Caledonia (the Poya Terrane), and extends farther north over 150 km beneath the Belep Islands [Collot et al., 1987] is evidence of the South Loyalty Basin. On micropaleontological and geochemical evidence, the South Loyalty Basin oceanic crust is known to have been formed from the Campanian to earliest Eocene in a back-arc basin setting [Aitchison, 1995; Cluzel et al., 2001]. Cluzel et al. [2001] proposed three main steps regarding the evolution of the South Loyalty Basin (Figures 15a, 15b, and 15c):

[33] 1. In circa 53 Ma, phase 1 (Figure 15a), inception of east dipping intraoceanic subduction of the South Loyalty Basin and onset of the Loyalty Arc (LR) occurs. This phase is dated at 53 Ma by the arc related magmatism (dykes) that crosscut the New Caledonian ophiolites without piercing the underlying strata [Cluzel et al., 2006]. These dykes testify that the peridotites, at present obducted upon New Caledonia, were part of the upper plate in the subduction system.

[34] 2. In 53–37 Ma, phase 2, subduction of the western South Loyalty Basin occurs. This event is recorded by the Pouebo Terrane, an eclogitized mélange that contains mafic rocks from the Poya Terrane. At circa 45 Ma, elements of the oceanic crust from the South Loyalty Basin were brought into the subduction zone down to 70 km equivalent pressure depth [Clarke et al., 1997; Spandler et al., 2004, 2005].

[35] 3. In 37–34 Ma, phase 3, the arrival of the Norfolk Ridge near the trench at circa 37 Ma, progressively blocked the subduction and initiated a compressive phase. This phase is expressed by three diachronous events observed onshore New Caledonia: (1) the thrusting of mafic oceanic crust slices scraped off the South Loyalty Basin (the Poya Terrane) onto the Norfolk Ridge at 37 Ma, is recorded by the foreland deposits (the Bourail flysch of [Cluzel et al., 2001]) (Figure 15b), (2) the exhumation (supposedly buoyancy driven [e.g., Chemenda et al., 1996]) between 44 and 34 Ma of eclogitized mafic mélange (the Pouebo Terrane) and Cretaceous metasediments (the Diahot Terrane) in northern New Caledonia [Spandler and Hermann, 2006; Baldwin et al., 2007], and (3) the late Eocene obduction of the ultramafic lower part of the upper plate (the Ophiolitic Nappe) onto the Norfolk Ridge (Figures 15c and 15d). The end of this phase is poorly constrained by the late Priabonian sediments (circa 34 Ma) that underlie the ophiolites [Cluzel, 1998], and mid-Oligocene postobduction granitoids at circa 27 Ma [Cluzel et al., 2005; Paquette and Cluzel, 2007].

[36] We here hypothesize that the tilting of the NNCB (the age range of which is bounded between 45 Ma and 34–28.5 Ma) occurred during this compressive phase (37–34 Ma).

[37] Prior to Oligocene times the depocenter was on the western side of the NNCB (observation 1 of section 4.4) implying a westward dip of the NCB basement.

[38] As documented by the postobduction tectonosedimentary records [Dubois et al., 1974; Coudray, 1976; Chevillotte, 2005; Chardon and Chevillotte, 2006; Chevillotte et al., 2006], New Caledonia underwent a postobduction uplift through erosional unloading of the high-density obducted allochthon. However, by contrast, on the basis of the analysis of seismic data, no vertical movements were involved in the NNCB after Oligocene times (observation 2 of section 4.4). Together, these facts indicate that the NNCB and the NR did not react as a single block after Oligocene times but rather that the differential motion must have been controlled by a structural break (decoupling) between the NNCB and the NR. We suggest that this structural limit was inherited from the eastward thrusting during obduction described below (part 2 of the diachronic model).

[39] In this context, we propose a diachronous model explaining the rise of the northern Fairway Ridge and the associated creation of a vast depocenter along New Caledonia's western margin:

[40] 1. As the NR was plunging into the subduction zone and subsiding, the NR and the NNCB reacted as a single rigid block. The NNCB initiated its eastward tilt by accompanying this downward motion and acted therefore as a subsiding flexural basin (Figure 15c).

[41] 2. As the horizontal compressive stress increased within the obduction taking place, the NR and the NNCB decoupled into two separate blocks, the NNCB absorbing part of the shortening by underthrusting beneath the NR. This differential motion between the two blocks is simplified into a single thrust fault on Figure 15d, as documented by the analog modeling of a horizontal lithospheric compression physical modeling by Shemenda [1992] (Figure 15e). This hypothesis further places the Eocene/Oligocene New Caledonia Basin stage close to that of the initiation of a subduction. The present knowledge and available marine data do not allow us to give an objective answer to this question of “subduction along New Caledonia's western margin” suggested by Regnier [1988] and Cluzel et al. [2005]. Discussing whether or not true subduction occurred and continued until late Oligocene times in the NNCB is beyond the scope of this paper.

[42] The positive topography of the Fairway Ridge is well expressed only between 20°S and 24°S, where it faces New Caledonia. This suggests that the FR and the NCB are tectonically related north of 24°S: the Fairway Ridge uplifted to form a prominent topographic high only where it faces New Caledonia, contributing to the tilt of the NNCB. The regional gravity map south of 24°S indicates that the Fairway Ridge extends southward down to 31°S in a N-S direction [Dupont et al., 1975; Ravenne et al., 1976; Eade, 1988; Lafoy et al., 2005a]. The seismic profiles recorded from R/V Franklin in 2001 [Exon et al., 2004] show that an intermittent ridge extends southward from the NW trending Fairway Ridge, to join the West Norfolk Ridge SSW of Norfolk Island. Exon et al. [2007] named this intermittent ridge the northern West Norfolk Ridge.

5.2. Causal Relationship Between Early Oligocene Obduction and LHR's Return to Marine Environment

[43] Because reflector RN coincides with the regional Eocene-Oligocene unconformity U1 observed at DSDP 208, it is here suggested that the NNCB tilting is synchronous with LHR's return to a bathyal marine environment: while the NNCB was tilting and the Fairway Ridge rising, 300 km farther west the LHR was subsiding. In the literature, this return to a bathyal marine environment of the LHR is either attributed to its subsidence associated with a major tectonic event [Launay et al., 1977; Lafoy et al., 1994; Van de Beuque et al., 1998b] or to variations of the oceanic currents related to the opening between Australia-Antarctica in Eocene times [Andrews et al., 1973]. Profile z05-12 (Figure 16) right on top of the LHR (see location on Figure 3) shows U1 as an angular unconformity with a clear erosional surface which favors a tectonic origin hypothesis. Variations of oceanic currents alone would show a paraconformity corresponding to a lack of sedimentation with subparallel strata over and under the unconformity. The tilted strata underlying the hiatus being Eocene, we therefore reach the conclusion that the strata was tilted tectonically after the Eocene. LHR's return to a marine environment (marked by U1) is of post-Eocene tectonic origin.

[44] The Eocene-Oligocene unconformity is regionwide, its base is roughly common to all wells but its top varies from a well to another (see section 2 and Figure 2). This means that the timing of the return in calm sedimentary deposit is different from a place to another. Looking at this fact on the LHR, it is remarkable to notice that the return in normal sedimentary deposit conditions is mid-Miocene in the southern LHR and mid-Oligocene in the northern LHR. This correlates very well with obduction in New Caledonia (37–34 Ma) and obduction in Northland–New Zealand (25–22 Ma) [Ballance and Sporli, 1979; Brothers and Delaloye, 1982; Hayward et al., 1989; Herzer, 1992] and shows the local uniqueness of the northern LHR's subsidence during the Oligocene.

[45] This leads us to propose that as the obduction event terminated in New Caledonia, the stress was simultaneously released farther west which was manifested by the beginning of subsidence in the northern LHR. (Figure 15).

5.3. Age Constraints on the Sedimentary Sequences Within the NNCB

[46] Using the refraction seismic velocities [Klingelhoefer et al., 2007], the absolute thickness of the sedimentary cover can be determined (nonsedimentary layers are discriminated as having velocities >6 km/s).

[47] The position of U1 (Figures 6 and 13) indicates that the pre-Oligocene section is thinner than previously reported [Van de Beuque, 1999, 2003; Vially et al., 2003].

[48] By comparing the sedimentary thicknesses of the Fairway (Figure 6) and New Caledonia (Figure 13) basins, it is noteworthy that the pre-Oligocene sediment of the Fairway Basin is much greater than that of New Caledonia (2.5 s twt against 1.1 s twt in the NNCB). On the other hand the post Oligocene sediment thickness of the New Caledonia Basin is much greater than that of the Fairway Basin one (3.5 s twt against 0.5 s twt in the Fairway Basin). This observation is compatible with the fact that the LHR was in a subaerial state between 45 and 34/28.5 Ma and NC in a subaerial state after circa 34 Ma.

[49] We therefore propose that most of the thick pre-Oligocene sedimentary sequences of the Fairway Basin correspond to the product of erosion of the LHR and FR and most of the thick post-early Oligocene sedimentary sequences of the NNCB correspond to the product of erosion of the New Caledonian allochthon material. This corroborates the interpretation of

Jongsma and Mutter [1978], who proposed that the Fairway Basin is the eastern equivalent of the Middleton Basin (west of LHR) and that their sedimentary infill corresponds with the erosion of the LHR.

6. Conclusions

[50] The interpretation of reflector-RN and its trace without interruption from DSDP 208 to the NNCB enable to identify a post Eocene depocenter located adjacent to New Caledonia western margin which fits with the obduction and postobduction story of New Caledonia. The uplifting of the NNCB's western margin (e.g., the Fairway Ridge) and the deepening of its eastern margin is a direct result of New Caledonia's major obduction-compressive phase from 37 Ma to 34 Ma. The plunging of the Norfolk Ridge into the Loyalty subduction zone initiated the eastward subsidence of the NNCB, and compression continued as underthrusting under west of NC until the end of obduction to accommodate the shortening. As the shortening was taking place in New Caledonia and in the NNCB, stress was simultaneously released farther west which was manifested by the beginning of subsidence in the LHR. As the LHR was subsiding and becoming more deeply submerged, NC was rising with the emplacement of the allochthon and becoming emergent. This is shown by the migration of the major sedimentary source from the LHR to NC, which is supported by our interpretation of the position of the pre- and post-Oligocene sedimentary depocenters in the NNCB and the Fairway Basin.

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Figures

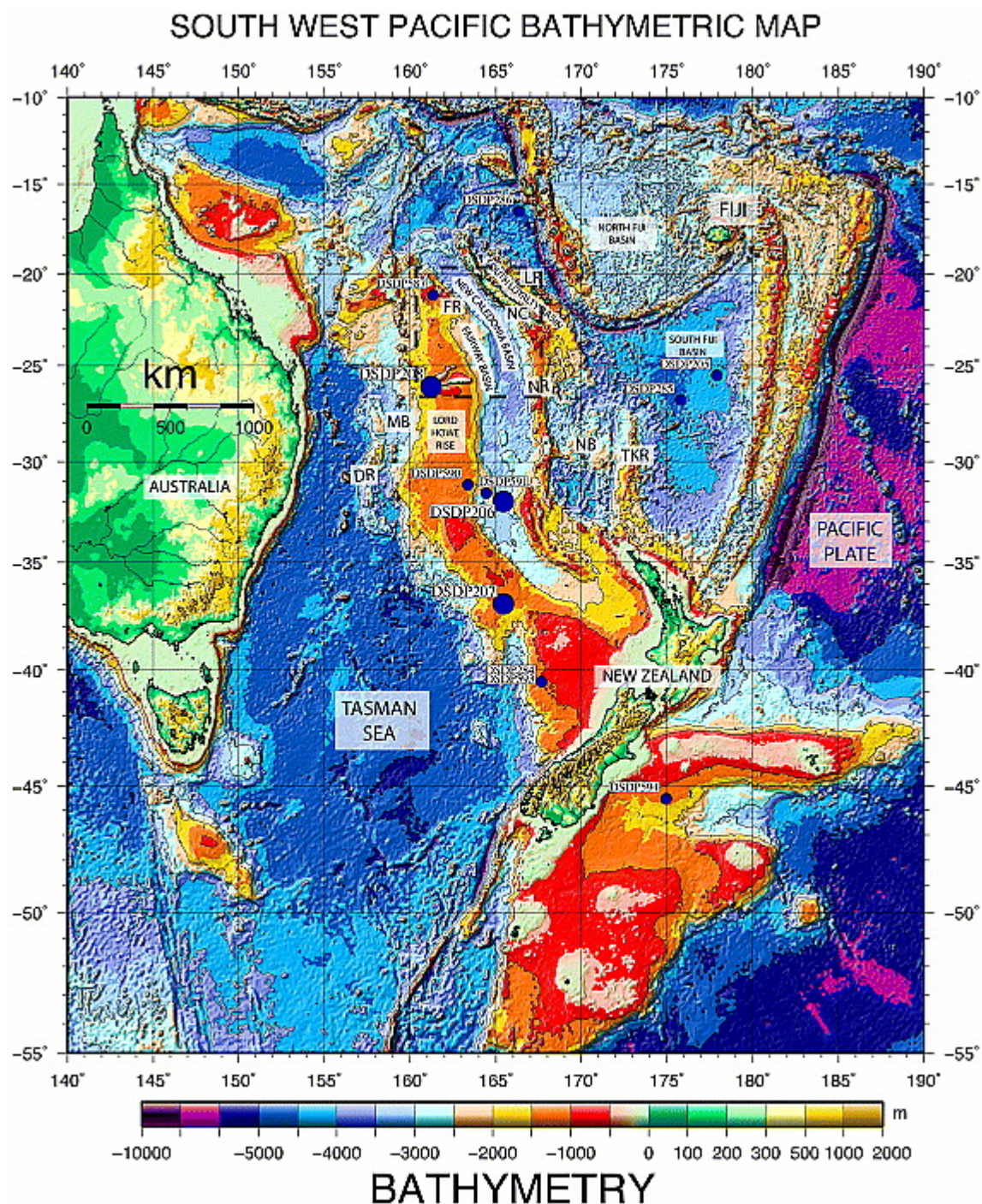


Figure 1. SW Pacific bathymetric location map with main regional Deep Sea Drilling Program boreholes (blue circles) and names of the main structural elements (DR, Dampier Ridge; MB, Middleton Basin; FR, Fairway Ridge; NC, New Caledonia; NR, Norfolk Ridge; LR, Loyalty Ridge; NB, Norfolk Basin; TKR, Three Kings Ridge). Seafloor topography from [Smith and Sandwell, 1997]. Black dashed rectangle locates the study zone

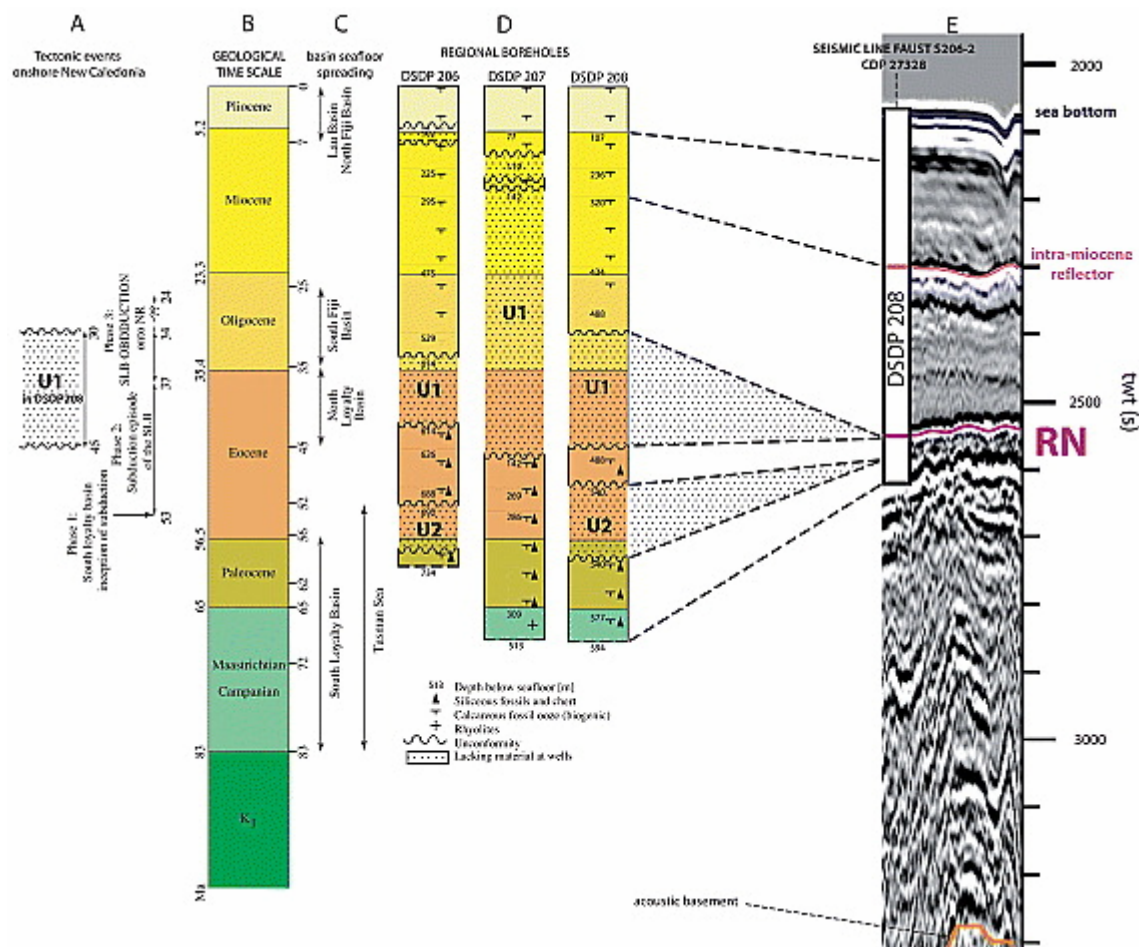


Figure 2. Diagram synthesizing the regional geological data (boreholes and tectonic onshore events). (a) Tectonic events related to the history of the South Loyalty Basin observed onshore New Caledonia [Cluzel et al., 1997; Cluzel, 1998; Cluzel et al., 1998, 2001, 2006]. (b) Geological timescale. (c) Seafloor spreading of main SW Pacific oceanic basins in literature. (d) SW Pacific regional boreholes reaching the Eocene/Oligocene unconformity U1 [Burns et al., 1973c, 1973b, 1973a]. (e) Correlation of borehole DSDP 208 with seismic line FAUST1-S206-2 using the velocity analysis of CDP 27328 [Van de Beuque, 1999]. Reflector RN marked in violet is identified with U1 and is characterized by a transparent overlying seismic facies and a negative polarity. Pink indicates the characteristic intra-Miocene reflector.

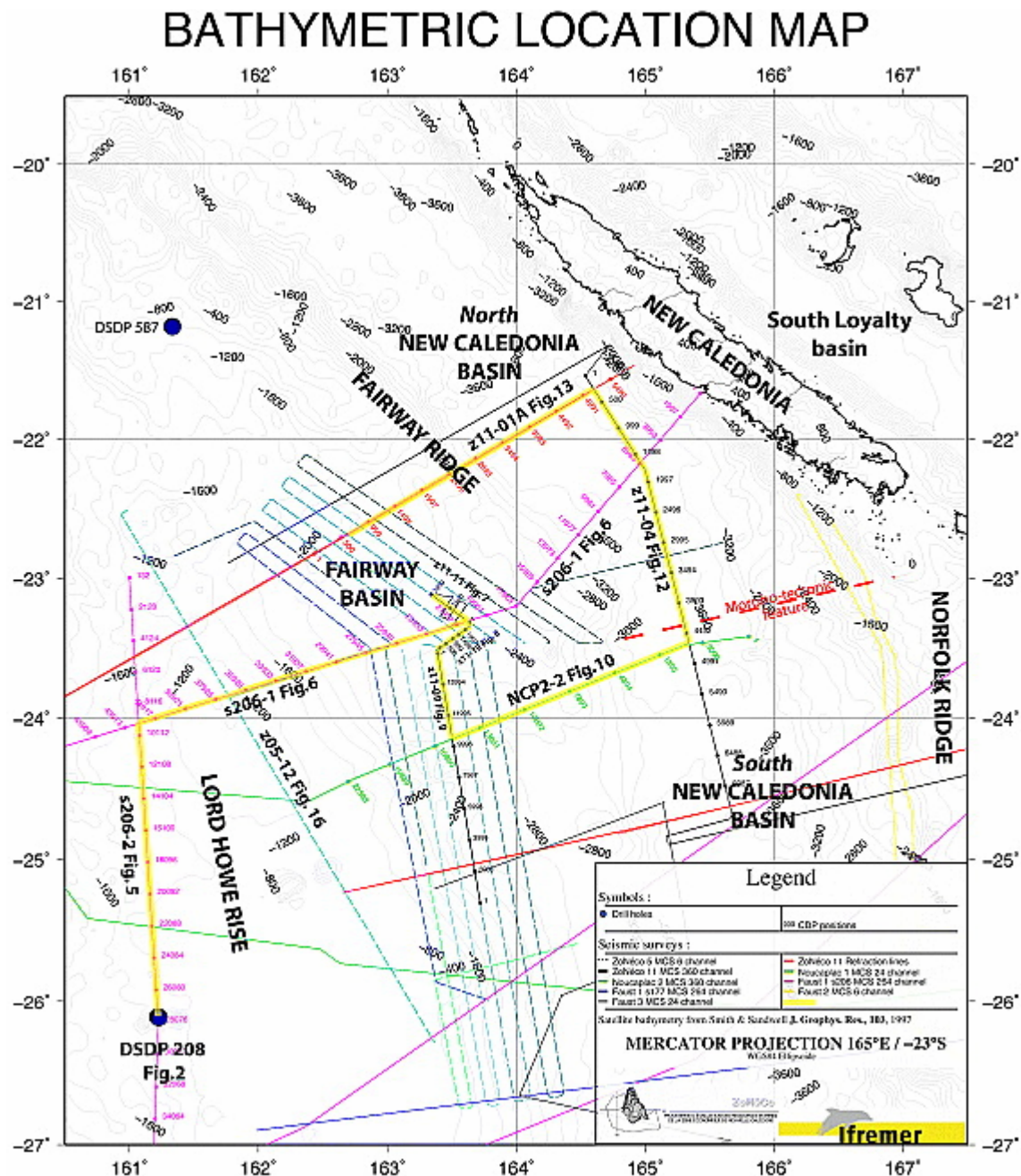


Figure 3. Bathymetric location map of all available seismic lines in the study zone. This zone corresponds with the black dashed rectangle on Figure 1. Highlighted in yellow is the path that we use to identify and follow continuously reflector RN from DSDP 208 over the Lord Howe Rise, the Fairway Basin, the Fairway Ridge, and down into the New Caledonia Basin. The red dashed line is the morphotectonic feature described by Lafoy et al. [2005a] which separates the north from south New Caledonia Basin. Seafloor topography is from Smith and Sandwell [1997].

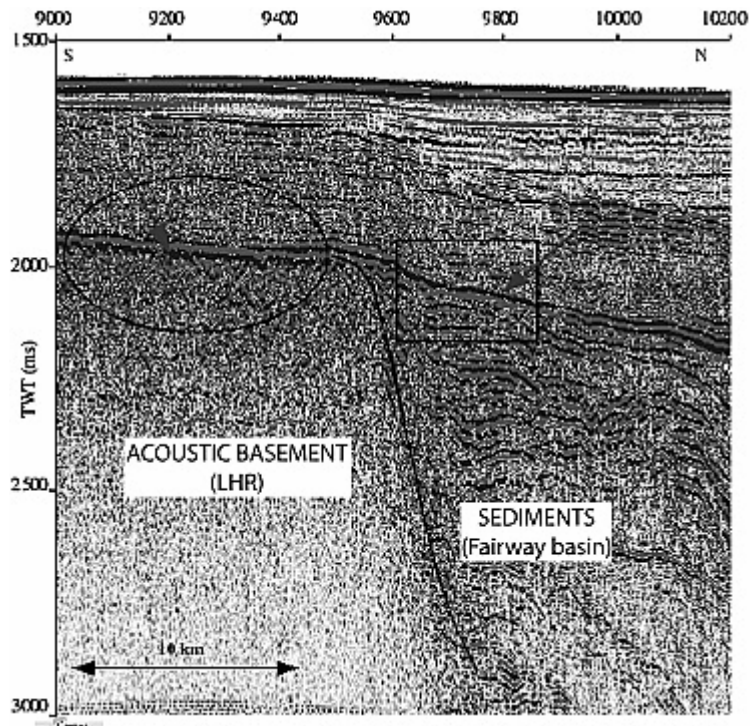


Figure 4. Phase inversion of the reflector associated with the Eocene/Oligocene unconformity [Nouzé et al., 2005, also submitted manuscript, 2008] on profile z05-11 from the ZoNeCo-5 survey. Where the unconformity sits on basement (ellipse), RN has a positive phase, and where the unconformity is in the basin (rectangle), RN has a negative phase

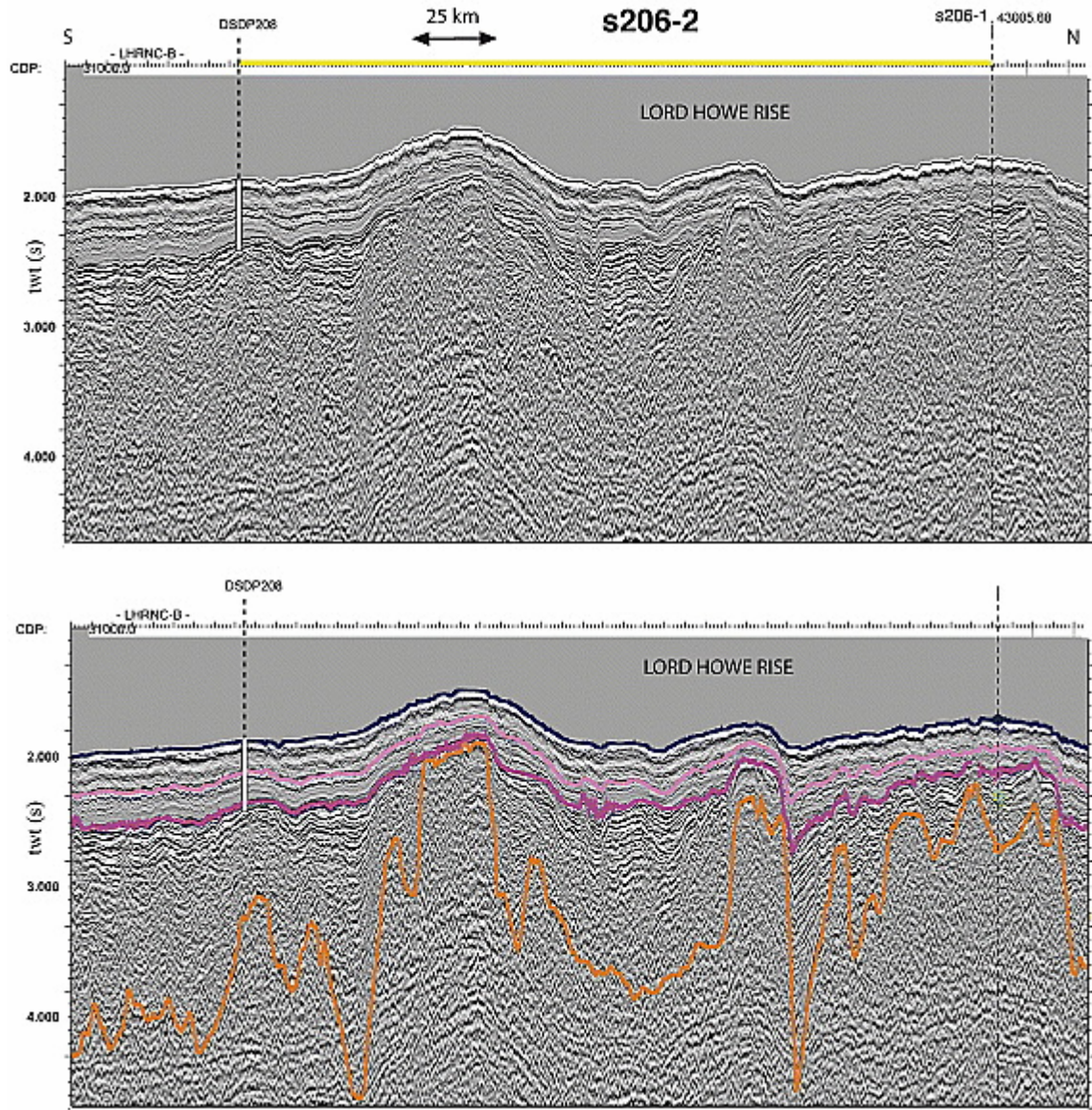


Figure 5. Seismic profile FAUST1-S206-2 modified from Lafoy et al. [1998]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene unconformity from well DSDP 208 to line FAUST1-S206-1. This path is also underlined in yellow on the location map (Figure 3). Acoustic basement is orange, reflector RN associated to the Eocene/Oligocene unconformity is violet, and intra-Miocene reflector is pink (see Figure 2e for more details). Other reflectors picked on the following Figures 6–14 are not dated and are not the focus of this paper. Their presence is for information only.

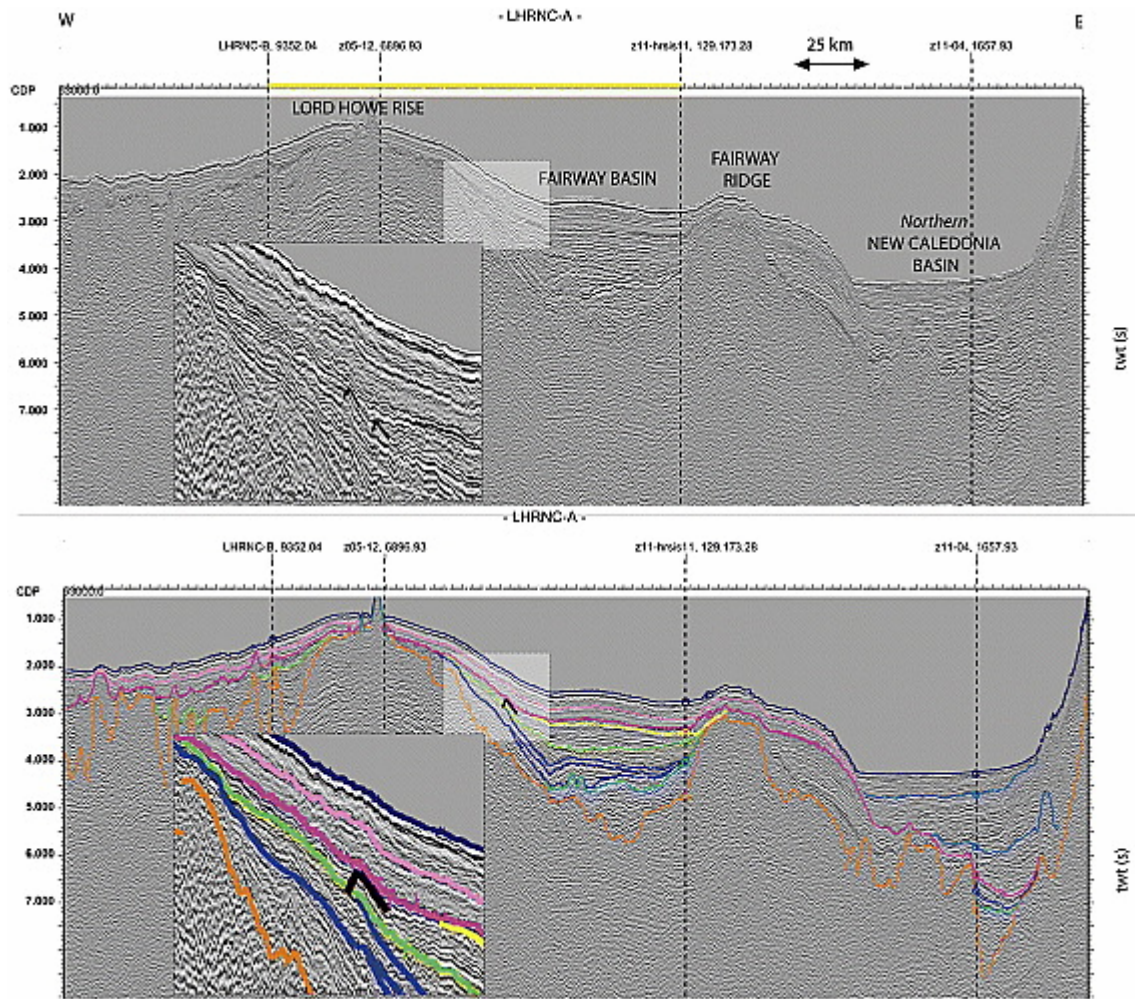


Figure 6. Seismic profile FAUST1-S206-1 modified from Lafoy et al. [1998]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene unconformity from line FAUST1-S206-2 to line z11-11. This path is also underlined in yellow on the location map (Figure 3). See Figure 5 for color code of seismic reflectors. Black arrows show toplaps beneath RN.

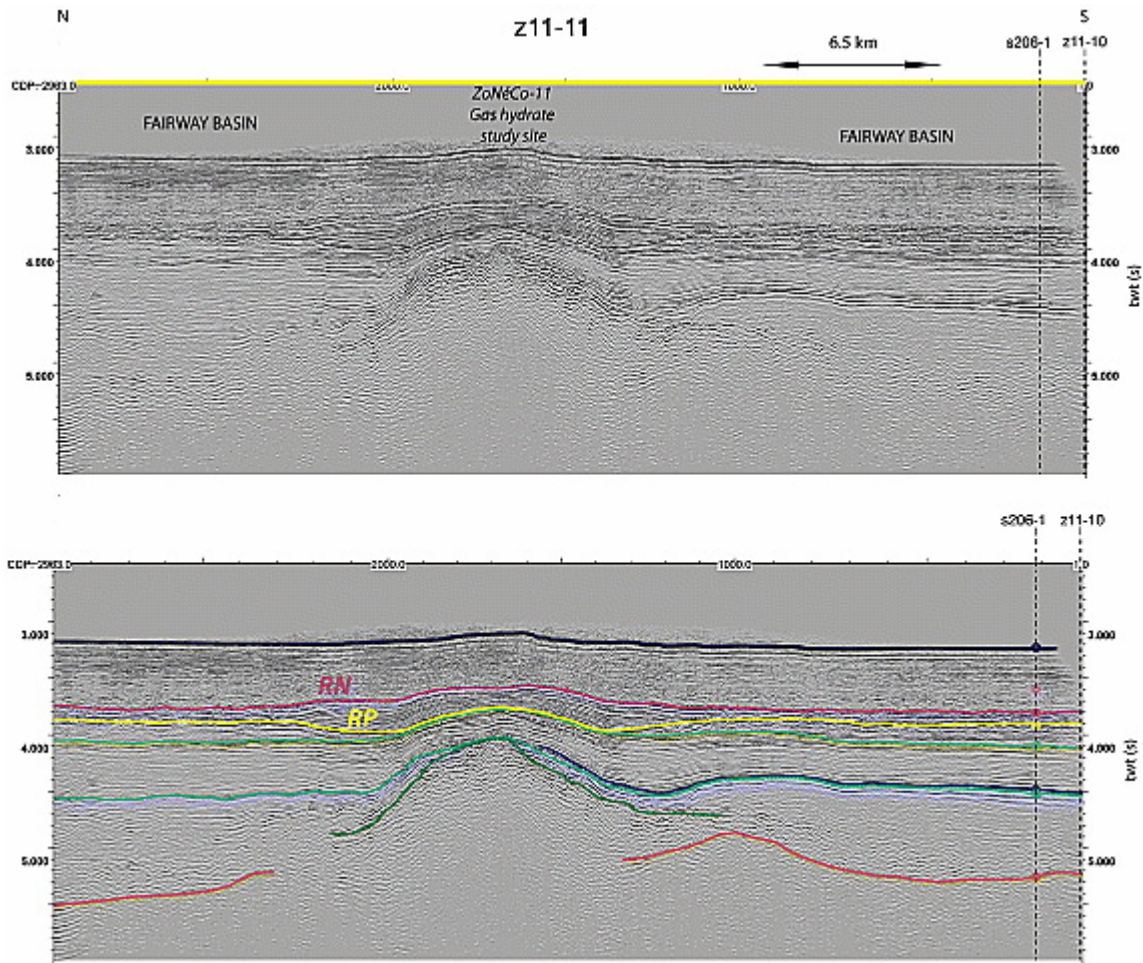


Figure 7. Seismic profile z11-11 modified from Nouzé et al. [2005, also submitted manuscript, 2008]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene unconformity from line FAUST1-S206-1 to line z11-10. This path is also underlined in yellow on the location map (Figure 3). RN and RP identified by Nouzé et al. [2005, also submitted manuscript, 2008] are the Eocene/Oligocene unconformity and the regional BSR, respectively, which confirms our position of U1. See Figure 5 for color code of seismic reflectors.

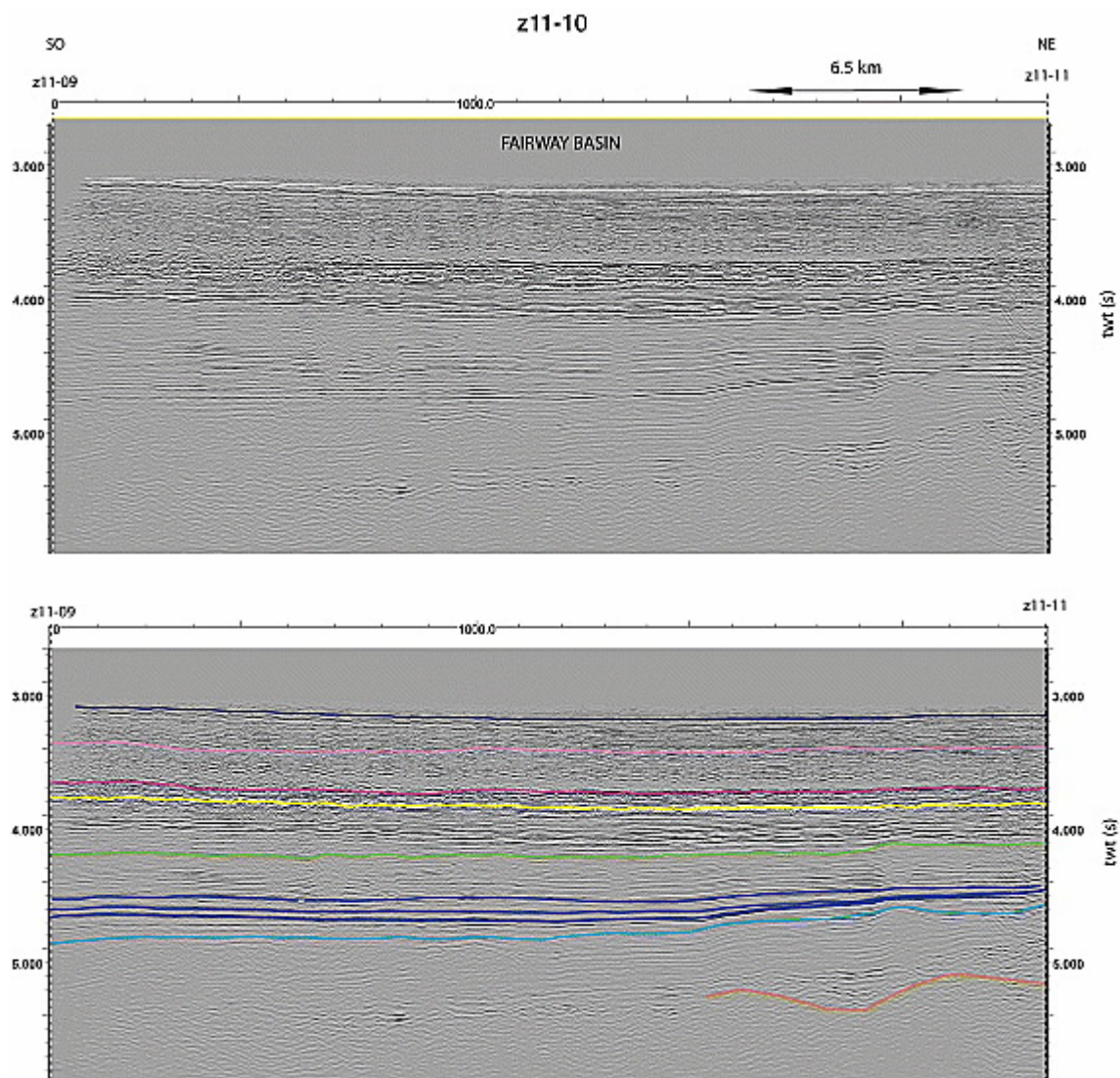


Figure 8. Seismic profile z11-10 modified from Nouzé et al. [2005, also submitted manuscript, 2008]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene unconformity from line z11-11 to line z11-09. This path is also underlined in yellow on the location map (Figure 3). See Figure 5 for color code of seismic reflectors

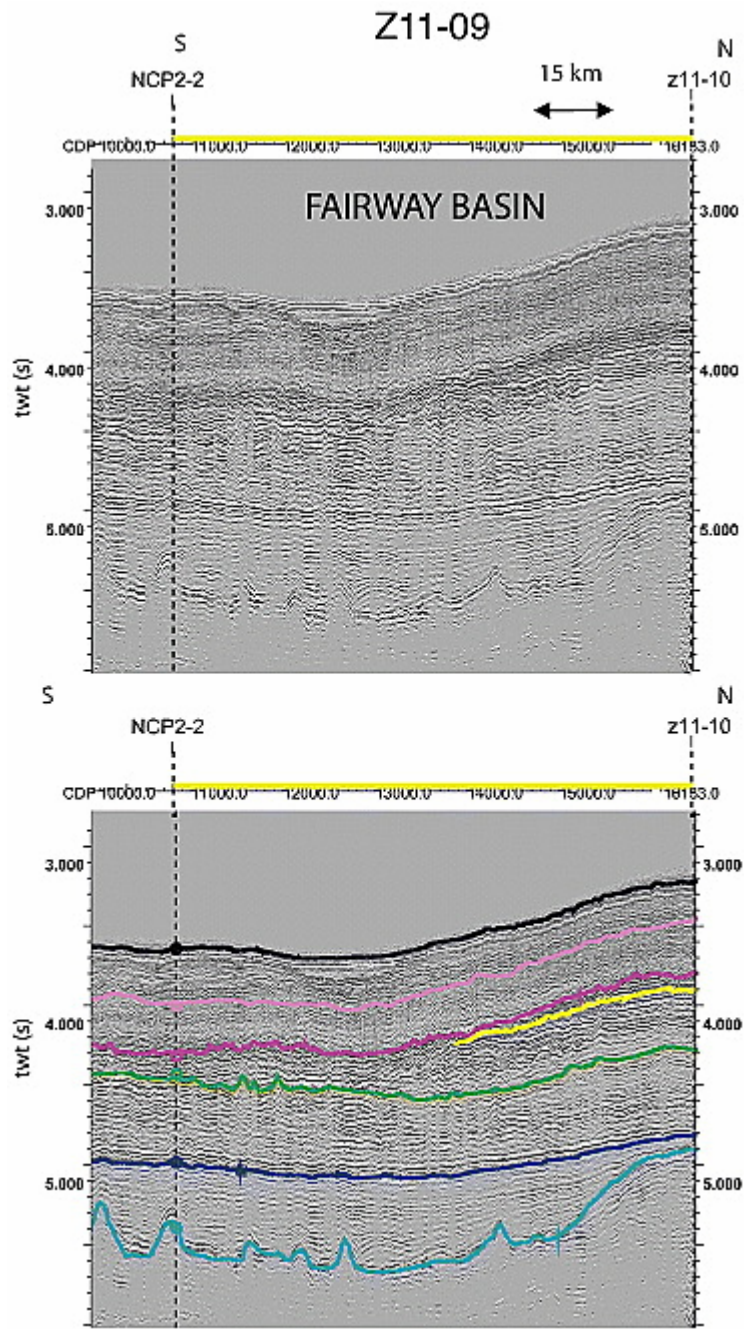


Figure 9. Seismic profile z11-09 modified from Lafoy et al. [2004]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene unconformity from line z11-10 to line NCP2-2. This path is also underlined in yellow on the location map (Figure 3). See Figure 5 for color code of seismic reflectors.

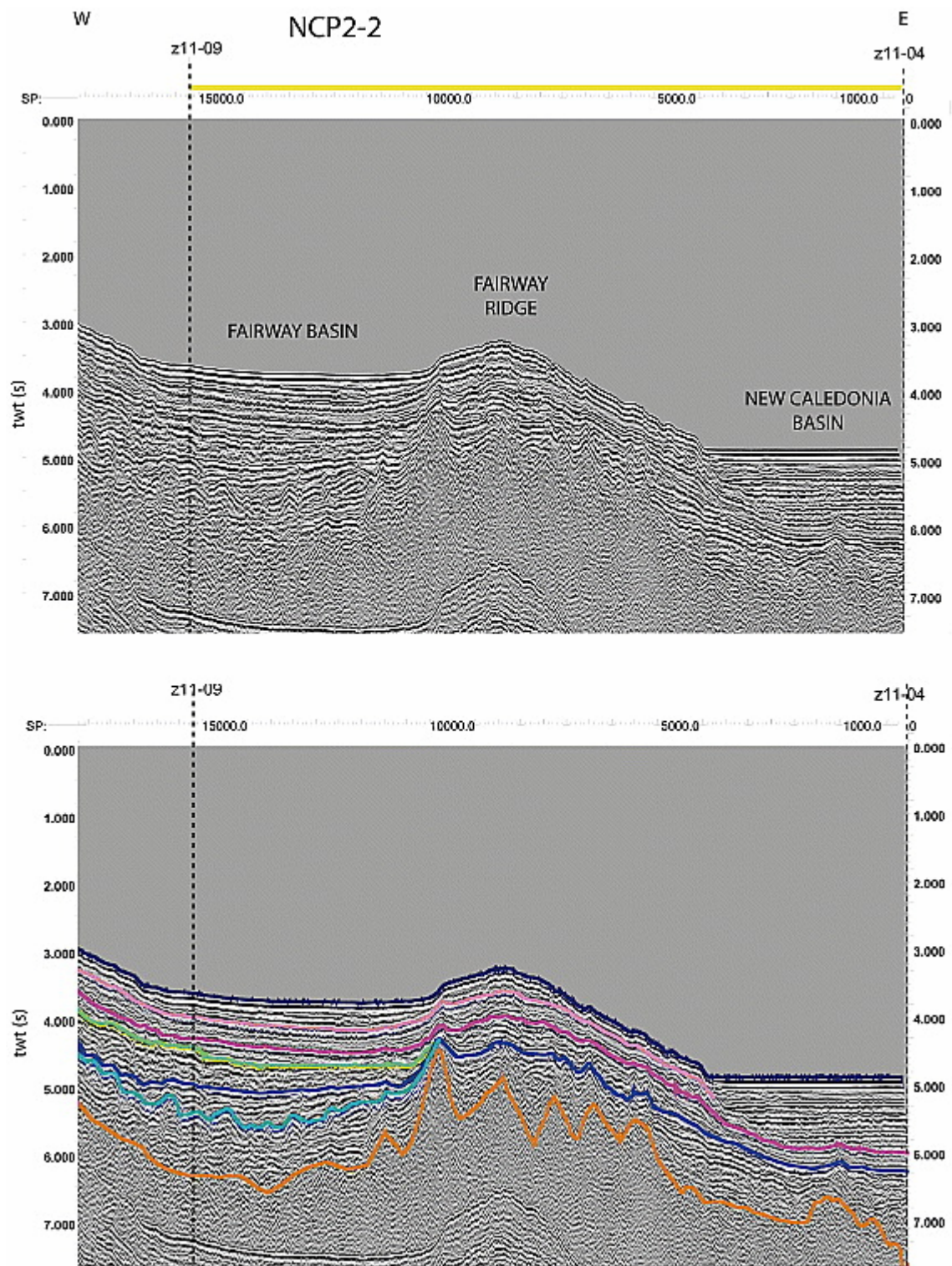


Figure 10. Seismic profile NCP2-2 modified from Loubrieu et al. [2004]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene unconformity from line z11-09 to line z11-04. This path is also underlined in yellow on the location map (Figure 3). Reflector RN is continuous over the Fairway Ridge. See Figure 5 for color code of seismic reflectors.

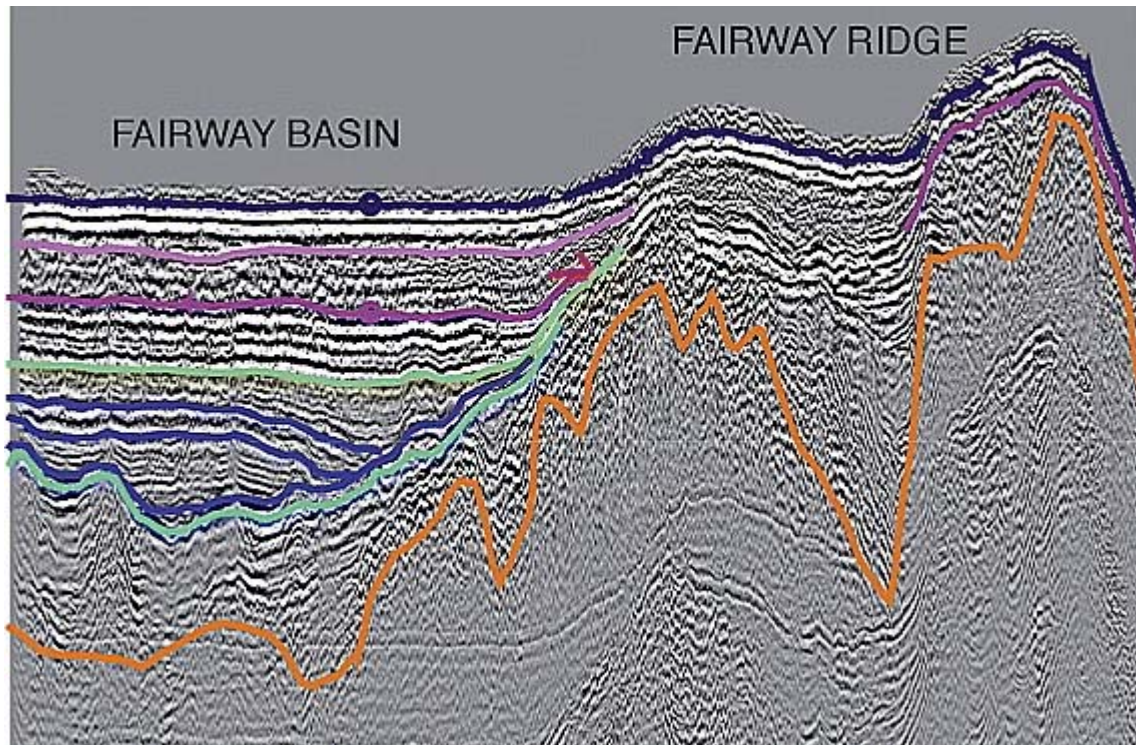


Figure 11. Onlaps along Fairway Ridge (seismic profile z11-01 A). RN is here truncated by the Fairway Ridge (red arrow), and no correlation between the Fairway Basin and the New Caledonia Basin is therefore possible. See Figure 5 for color code of seismic reflectors.

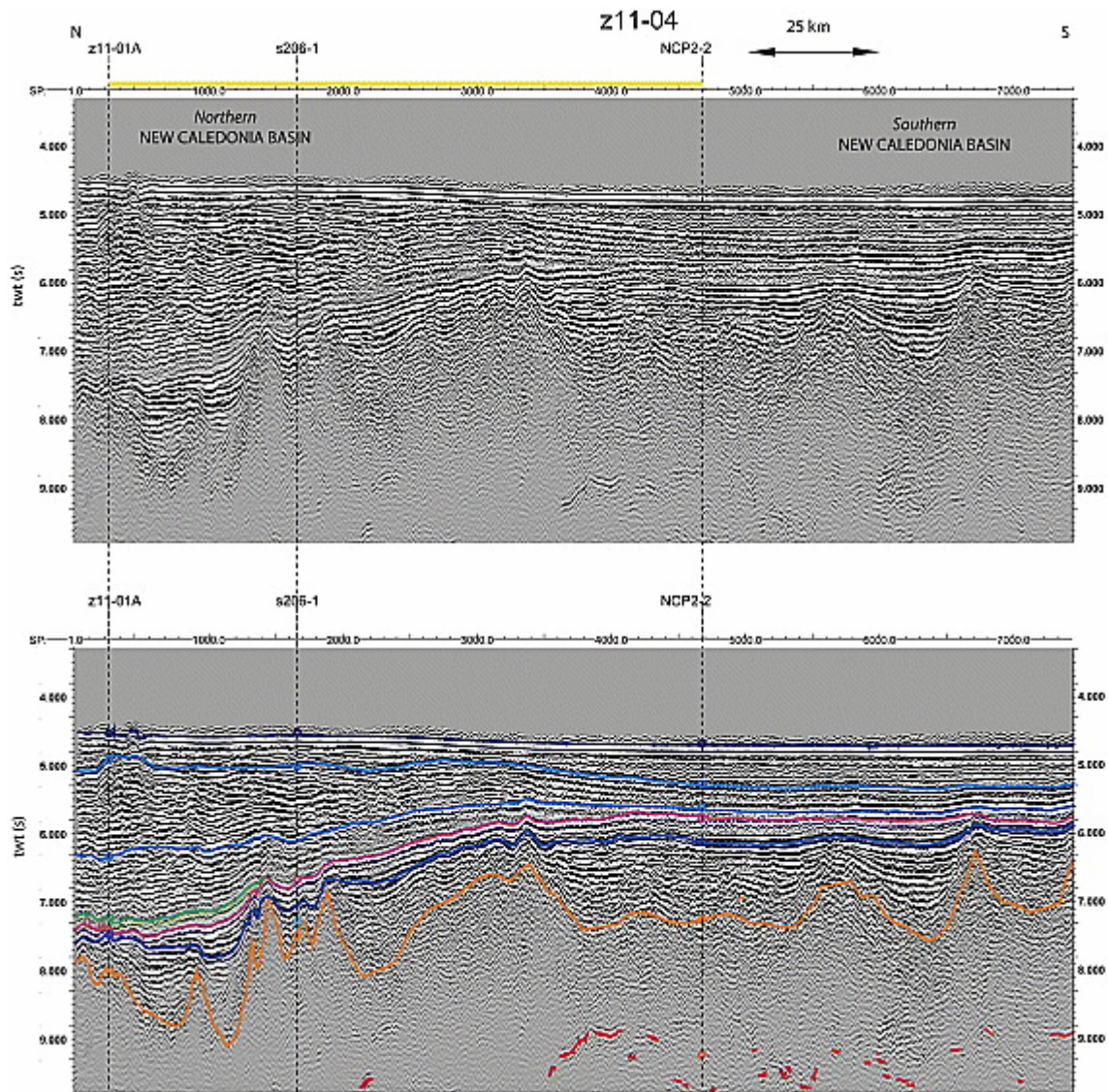


Figure 12. Seismic profile z11-04 modified from Lafoy et al. [2004]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene unconformity from line NCP2-2 to line z11-01A. This path is also underlined in yellow on the location map (Figure 3). RN deepens as it gets closer to the New Caledonia main land. See Figure 5 for color code of seismic reflectors.

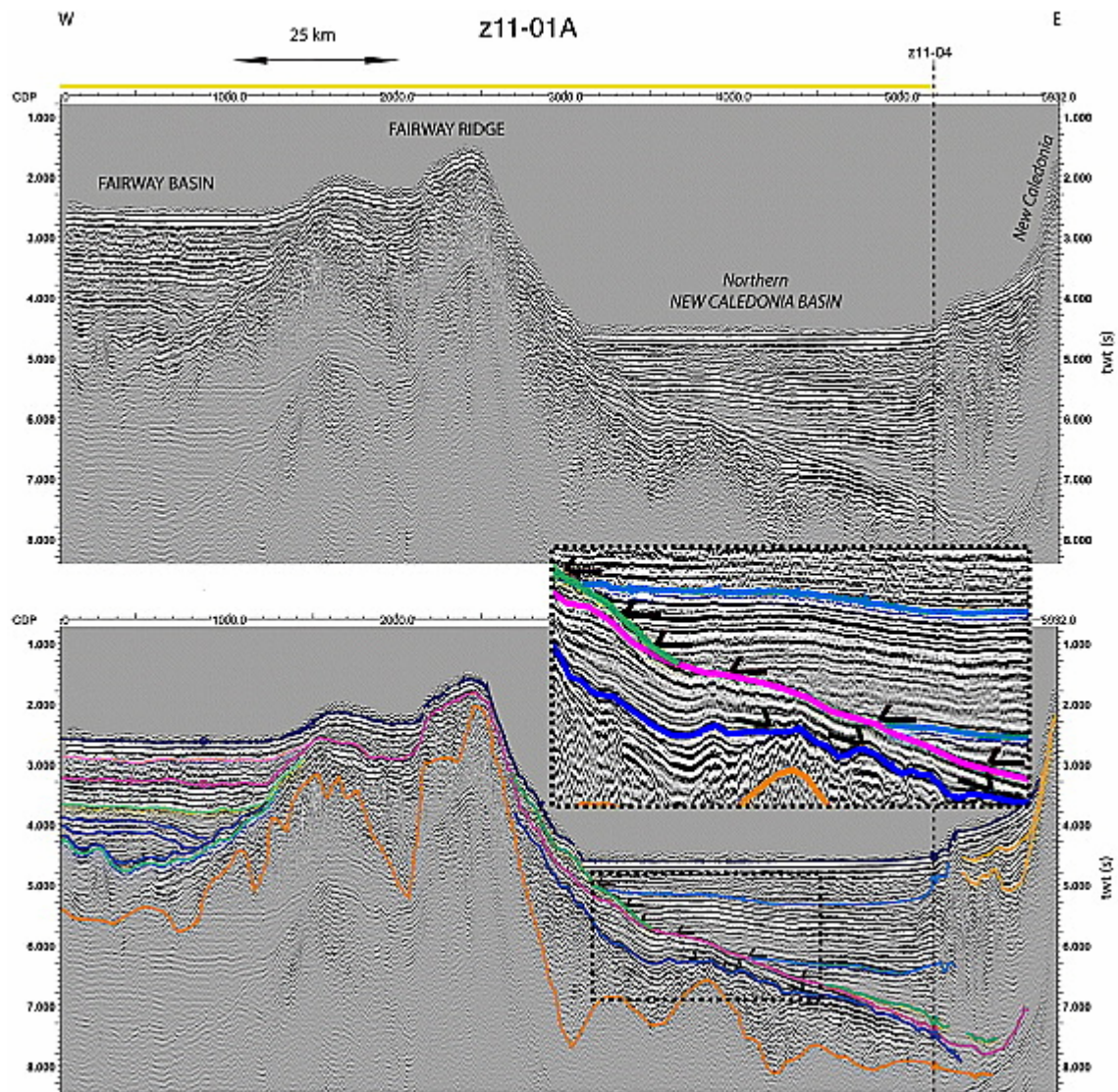


Figure 13. Seismic profile z11-01A modified from Lafoy et al. [2004]. The yellow line in the horizontal scale indicates the seismic path we use to follow the Eocene/Oligocene down in the New Caledonia Basin. This path is also underlined in yellow on the location map (Figure 3). RN coincides with a main tilted reflector. Black arrows pointing to the right show toplaps beneath RN and testify to the existence of a pre-Oligocene basin with its deep part on the western side. Black arrows pointing to the left show onlaps on RN, and the absence of fanning reflectors testifies to the rapidity of the tilting. The deep part of the basin is on the eastern side after Oligocene time. See Figure 5 for color code of seismic reflectors.

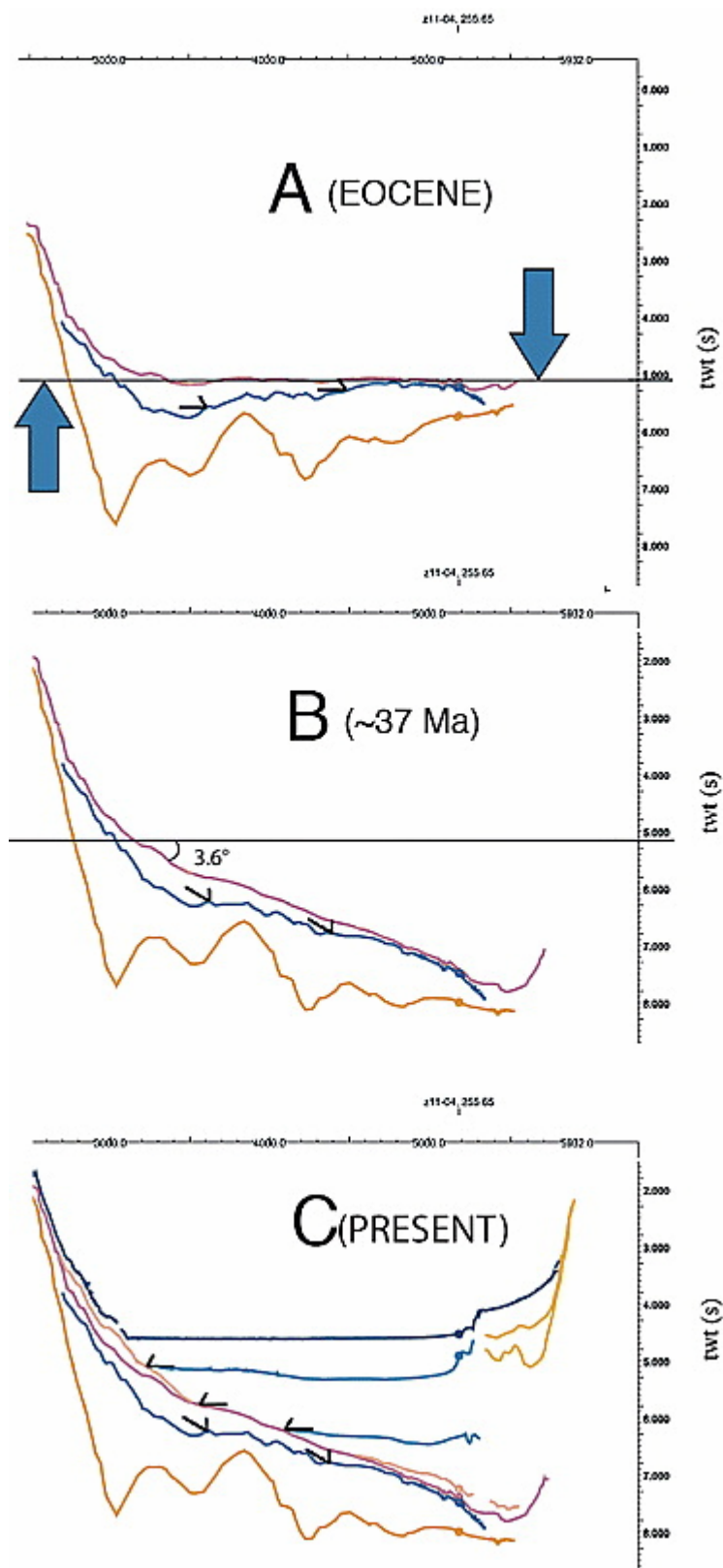


Figure 14. Reconstitution of New Caledonia Basin history using z11-01A's reflectors (Figure 13) from Eocene times to the Present by flattening RN. (a) The deep part of the basin is on the western side and the obduction event in New Caledonia creates an overloading (represented by the blue arrows) and a compressive field. (b) Uplift of the Fairway Ridge and eastward

deepening of the NNCB during the obduction episode. (c) Sedimentary filling of the newly created depression in a quasi-static tectonic setting

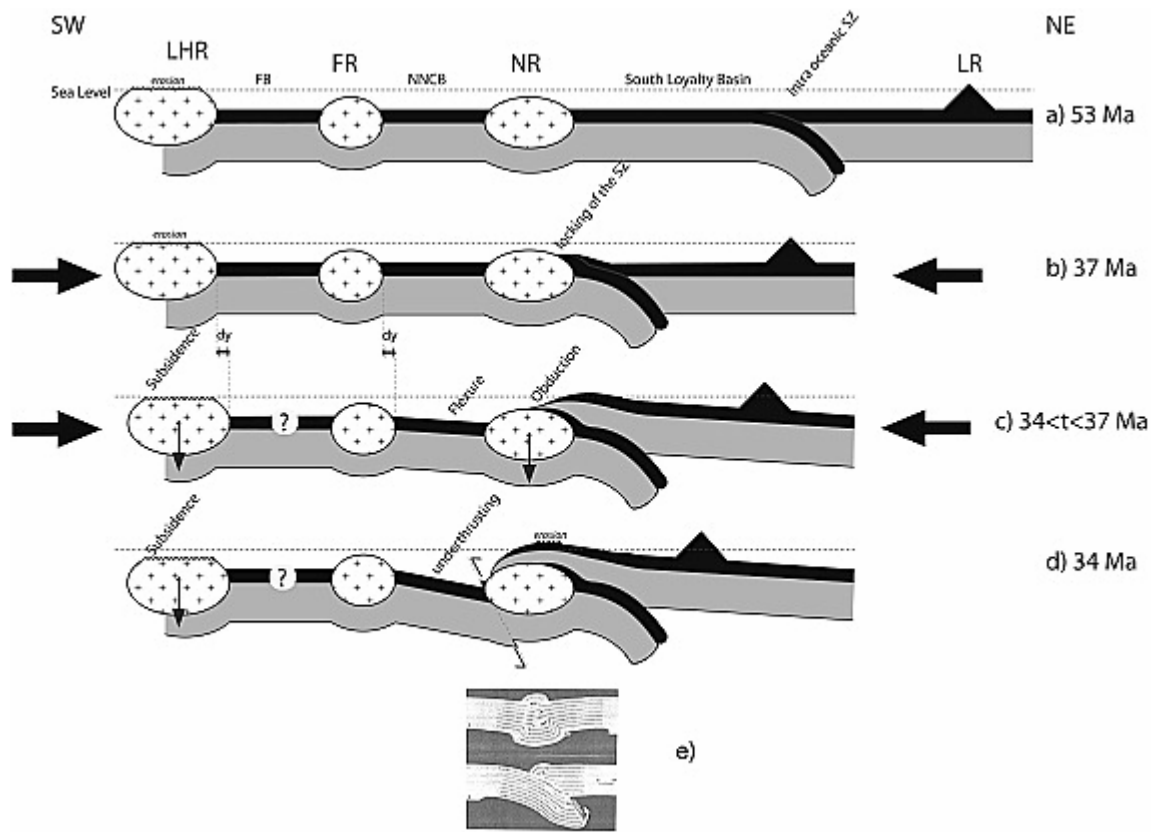


Figure 15. Mid-Eocene to upper Oligocene geodynamic evolution of the basin and ridge system affected by the New Caledonian obduction (LHR, Lord Howe Rise; FB, Fairway Basin; FR, Fairway Ridge; NNCB, northern New Caledonia Basin; NR, Norfolk Ridge; LR, Loyalty Ridge; SZ, subduction zone). For other acronyms, see Figure 1. (a) At 53 Ma, eastward inception of subduction of the South Loyalty Basin [Cluzel et al., 2006]. (b) At 37 Ma, arrival of the NR in the subduction. Regional compression begins; the LHR is in a subaerial position and subject to erosion, as evidenced by the unconformity U1 documented at drilling site DSDP 208. (c) Between 37 and 34 Ma, overriding of the SLB's oceanic crust onto the NR creates subsidence of the NR (marked by the vertical arrow). This subsidence triggers the tilting of the NNCB while compression continues. The tilting absorbs part of the shortening (Δy) which releases strain farther west at the LHR and makes the LHR subside. (d) As the allochthon progressively overrides toward the west onto New Caledonia, the deformation front migrates toward the west, and the NNCB is underthrust beneath New Caledonia. At 34 Ma, the end of obduction and general release of strain, the LHR continues to subside. (e) Physical modeling of a horizontal lithosphere compression from the work of Shemenda [1992]. Then isostatic uplift of NC begins, related to its unloading by erosion of the allochthon. By contrast, no vertical movements are observed in the NNCB, confirming the hypothesis of a dissociation between the two blocks. The question marks indicate that the role played by the FB in this system is unknown.

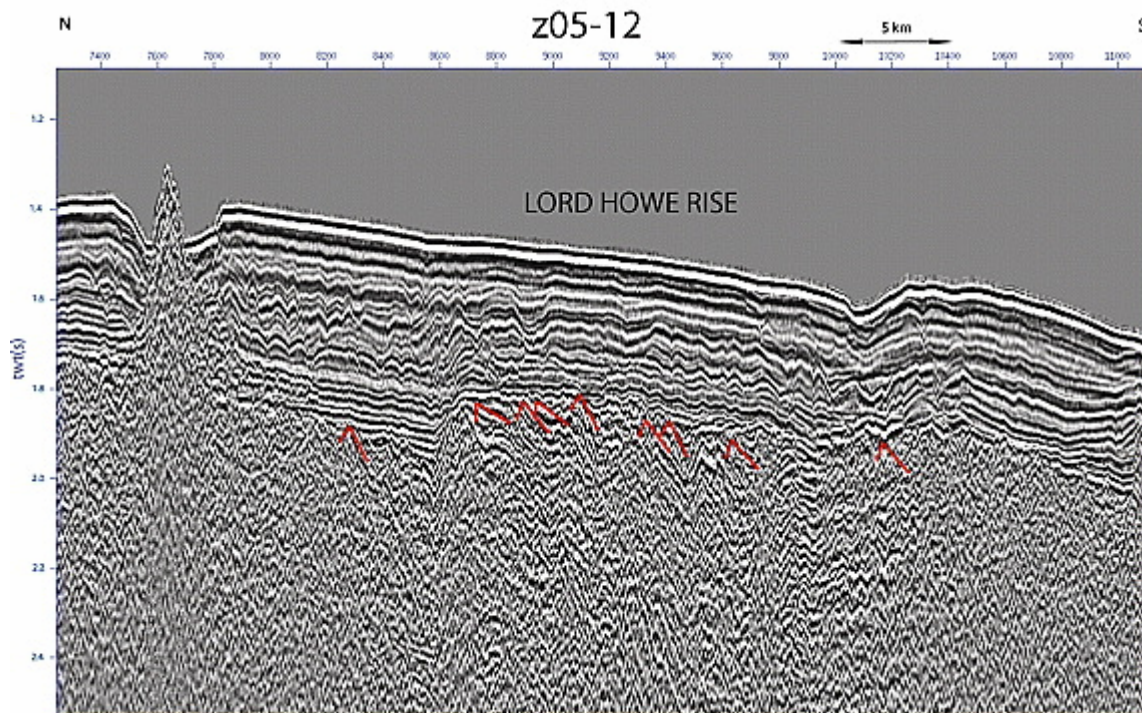


Figure 16. Seismic profile z05-12 on the top of the LHR modified from Auzende et al. [1999]. Red arrows show toplaps, revealing U1 as an angular unconformity over the LHR.

Table 1. Characteristics of the Seismic Acquisition Devices^a

Cruise or Profile	Streamer Length (km)	Number of Channels	Receiver Immersion (m)	Source Type	Source Immersion (m)	Source Band Width (Hz)	Shot Interval (m)	Interpreted Seismic Data
FAUST FAUST1-S206 (LHRNC)	3.3	264	10	First peak	10	50–60	50	Time migrated
Noucapla c-2	4.5	360	15	Single bubble	15	4–80	75	Time migrated
Z11-01, z11-04, and z11-07	4.5	360	15	Single bubble	20	4–60	150	Time migrated
ZoNeCo-5	0.6	6	7	First peak	10	50–130	50	Stacked
Z11-09,	3.3	264	3	First	3	50–	25	Time

z11-10, and z11-11				peak		130		migrated
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^aThe single-bubble source [Avedik et al., 1993] used during the ZoNeCo-11 [Lafey et al., 2004] and Noucaplac-2 [Loubrieu et al., 2004] campaigns explains the low-frequency content of profiles z11-01A (Figure 13), z11-04 (Figure 12), and NCP2-2 (Figure 10).