A drastic lower Miocene regolith evolution triggered by post obduction slab break-off and uplift in New Caledonia

Brice Sevin, Dominique Cluzel, Pierre Maurizot, Caroline Ricordel-Prognon, George Chaproniere, Nicolas Folcher, Florence Quesnel

AGU PUBLICATIONS

Tectonics

RESEARCH ARTICLE
10.1002/2014TC003588

Key Points:
- The Lower Miocene erosion was due to uplift subsequent to slab break-off
- The erosion of regolith and the Népoui conglomerate are influenced by uplift
- The Népoui conglomerate is interpreted differently from previous authors

Correspondence to:
B. Sevin,
brice.sevin@gouv.nc

Citation:
Sevin, B., D. Cluzel, P. Maurizot, C. Ricordel-Prognon, G. Chaproniere, N. Folcher, and F. Quesnel (2014), A drastic lower Miocene regolith evolution triggered by post obduction slab break-off and uplift in New Caledonia, *Tectonics*, *33*, 1787–1801, doi:10.1002/2014TC003588.

Received 19 MAR 2014
Accepted 26 AUG 2014
Accepted article online 29 AUG 2014
Published online 25 SEP 2014

A drastic lower Miocene regolith evolution triggered by post obduction slab break-off and uplift in New Caledonia

Brice Sevin[1,2], Dominique Cluzel[2], Pierre Maurizot[3], Caroline Ricordel-Prognon[4,5], George Chaproniere[6], Nicolas Folcher[2], and Florence Quesnel[4,5]

[1]Geological Survey of New Caledonia, Department of Industry, Mines and Energy, Nouméa, New Caledonia, [2]Pôle Pluridisciplinaire de la Matière et de l'Environnement, Université de la Nouvelle-Calédonie, Nouméa, New Caledonia, [3]BRGM New Caledonia, Nouméa, New Caledonia, [4]BRGM (French Geological Survey), Georesources Division, Nouméa, New Caledonia, [5]UMR 7327 du CNRS/Université d'Orléans/BRGM, Orléans, France, [6]Research School of Earth Sciences, Australia National University, Canberra, ACT, Australia

Abstract A lower Miocene coarse conglomerate that crops out in the Népoui Peninsula does not represent the base of the marine transgression that followed obduction in New Caledonia. Instead, the conglomeratic alluvial fan that contains peridotite cobbles and reworked weathering products records a short-lived episode of terrestrial erosion intercalated between two intervals of subsidence marked by marine carbonate deposition. Considering the Miocene sea level evolution reported in the literature, it is concluded that neither lower Miocene transgression nor erosion were driven by sea level variation. In contrast, a southeastward propagating slab tear that initiated at the latitude of the high pressure/low temperature metamorphic complex of northern New Caledonia likely generated east to west tilting of New Caledonia, subsidence along the West Coast and hence fringing reef development together with moderate erosion of older regolith. Coincidence between conglomerate deposition and hence prominent erosion that closely followed emplacement of postobduction granitoids influenced by a slab window suggests a genetic link. Therefore, it is concluded that short-lived lower Miocene erosion was due to slab breakoff and subsequent uplift that occurred at ~ 22 Ma. Lower Miocene erosion profoundly dissected the Peridotite Nappe and in the northern half of New Caledonia only left isolated klippes along the West Coast.

1. Introduction

About one third of the main island of New Caledonia ("Grande Terre") is covered by an ultramafic unit termed Peridotite Nappe (Figure 1); this allochthonous terrane [*Avias*, 1967] was tectonically emplaced by obduction [*Collot et al.*, 1987] during latest Eocene or earliest Oligocene times. The Peridotite Nappe is important not only because it represents one of the largest terranes of New Caledonia but also because it hosts one of the world's largest supergene nickel deposits, formed by the weathering of peridotites.

A relatively clear picture of the preobduction history of New Caledonia is provided by marine foreland and piggyback basins [*Cluzel et al.*, 1998, 2001; *Maurizot*, 2011]. Preobduction tectonothermal evolution is recorded by lower Eocene lenses of high-temperature amphibolites that occur at the base of the ultramafic rocks, and middle to upper Eocene HP-LT eclogite-blueschist complex of northern New Caledonia. These metamorphic rocks record the birth of a northeast dipping subduction zone, its cooling through time, and the exhumation of deeply buried rocks that preceded and accompanied obduction [*Baldwin et al.*, 2007; *Clarke et al.*, 1997; *Cluzel et al.*, 2012; *Spandler et al.*, 2005]. Obduction in New Caledonia is not tightly time constrained by field evidence; it occurred after the Late Priabonian (circa 34 Ma), age of the youngest preobduction sediments [*Cluzel et al.*, 1998], and prior to the intrusion of the upper Oligocene Saint Louis granodiorite (circa 27 Ma) [*Paquette and Cluzel*, 2007], which crosscuts the basal thrust of the Peridotite Nappe and its autochthonous basement as well.

Unconformable postobduction marine sediments are restricted to a narrow coastal area and did not deposit before the early Miocene [*Coudray*, 1976] (Figure 1). Apatite fission track thermochronological data suggest that exhumation of the high-pressure metamorphic complex through the fore-arc mantle was already completed by as early as the Eocene-Oligocene boundary (34 ± 4 Ma) [*Baldwin et al.*, 2007]; conversely, some

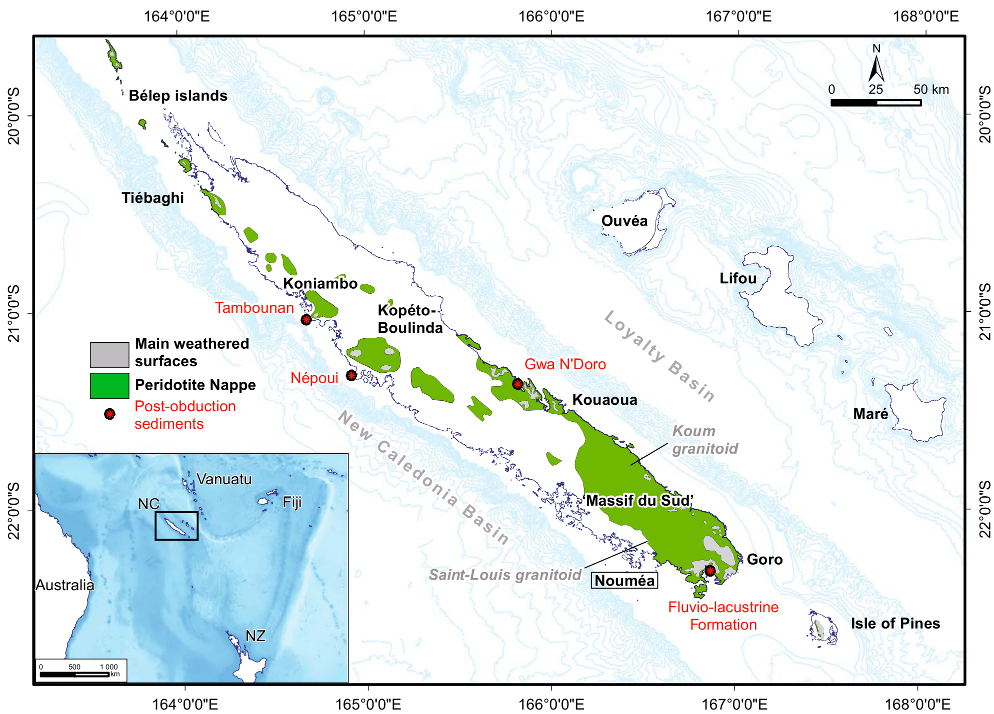

Figure 1. Simplified geological map of the Peridotite Nappe of New Caledonia, indicating the location of the main weathered surfaces and postobduction sediments (sites cited in the text are also located).

authors have suggested a long-term uplift from Oligocene to Recent times [*Lagabrielle et al*., 2005]. The development of stepped erosion/weathering surfaces on the "Massif du Sud" and tectonic klippes that are spread along the West Coast has been tentatively correlated to repeated epeirogenic phases, and/or sea level variation due to climate change [*Chardon and Chevillotte*, 2006; *Chevillotte*, 2005; *Chevillotte et al*., 2006], but absolute time constraints are lacking. Therefore, the postobduction history of New Caledonia in terms of reequilibration, weathering and erosion is still poorly time constrained.

The coarse conglomerate that overlies the upper Eocene Népoui Flysch and the Poya Terrane near Népoui peninsula (West Coast; Figure 2) was thought to form the base of the Miocene transgression, with peridotite cobbles up to 50 cm, derived from the erosion of ultramafic rocks obduction [*Paris*, 1981]. However, this simple explanation does not fit all the features of Népoui conglomerate, especially the occurrence of reworked weathering products of peridotites such as iron crust and supergene silica that suggest erosion of an older regolith [*Coudray*, 1976]. The occurrence of pre-Miocene tropical weathering that likely developed during an interval of relative stability is confirmed by paleomagnetic dating of ferricrete on top of the weathering profile in Tiébaghi, which consistently indicates a latest Oligocene age (~25 Ma) [*Sevin et al*., 2012].

In addition, conglomerate does not actually form the base of the Népoui series; it is underlain by previously unrecorded coralline limestone and calcareous sands, 120 m thick, which have been drilled in the southwest of Pindaï Peninsula (Figure 3). Therefore, the Népoui conglomerate does not record a marine transgression closely following obduction, but merely prominent subaerial erosion after an interval marked by subsidence and reef development.

This article is a reappraisal of the early Miocene Népoui series, based upon new field and analytical data. The prominent erosion recorded by the Népoui conglomerate and especially that of an older regolith will be tentatively integrated into the postobduction history of New Caledonia.

2. Outline of the Post-Cretaceous Geology of New Caledonia

The Norfolk Ridge and New Caledonia were rifted from the Australian margin during Late Cretaceous times (Campanian), [*Aitchison et al*., 1995; *Cluzel et al*., 2001; *Hayes and Ringis*, 1973; *Shor et al*., 1971]. New Caledonia

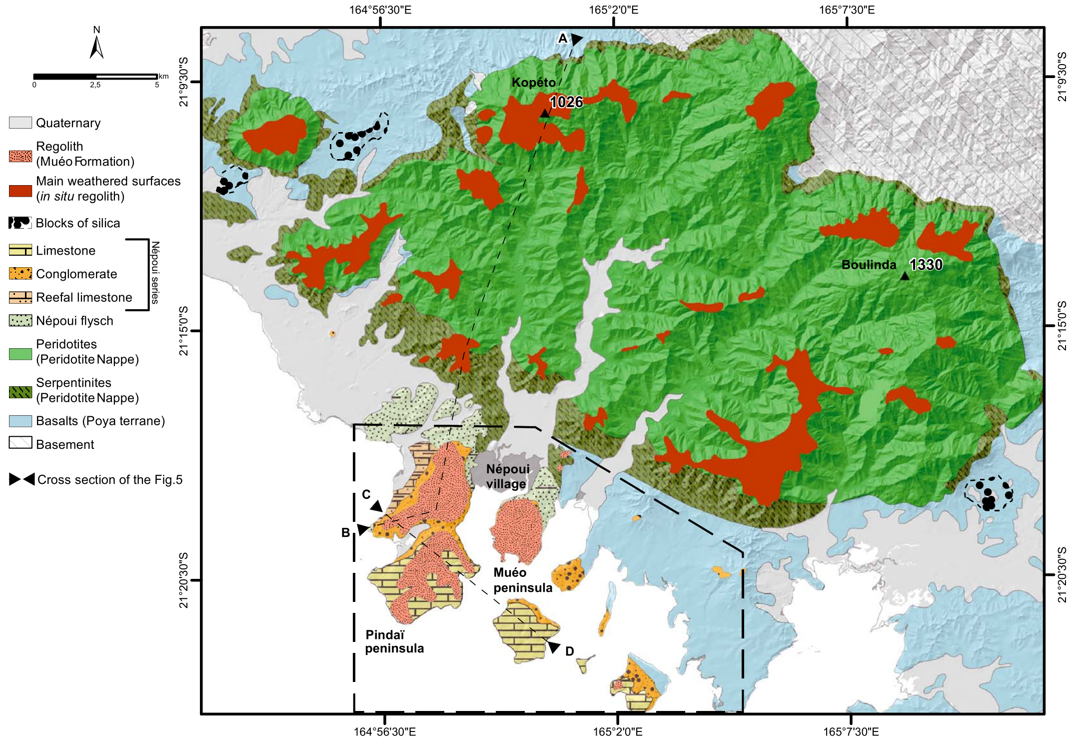

Figure 2. Simplified geological map of the Népoui area.

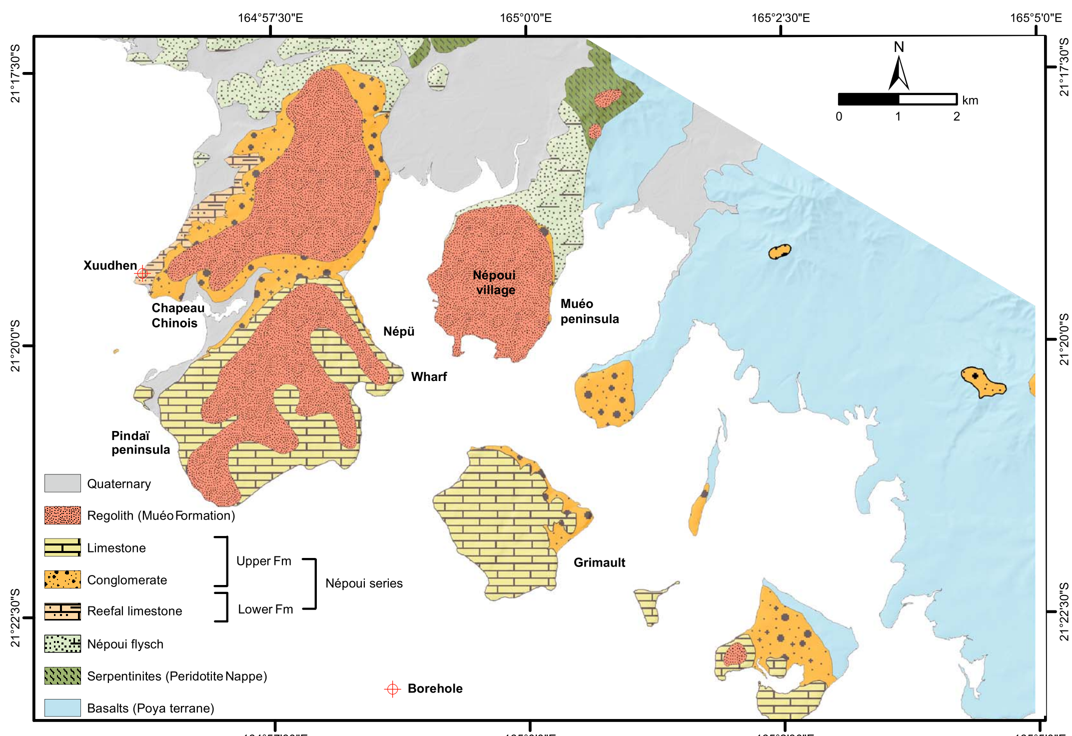

Figure 3. Simplified geological map of the Bay of Népoui with borehole location (inset of Figure 2).

mainly evolved in a pelagic environment during the Paleocene and the early Eocene. However, at the onset of the Eocene (circa 56 Ma, [*Gradstein et al*., 2012]) a new northeast dipping subduction began in the South Loyalty Basin, which was located to the east of the Norfolk Ridge; this subduction "consumed" the Australian plate and probably formed the Loyalty Arc [*Cluzel et al*., 2001, 2012; *Maillet et al*., 1983]. The subduction probably originated at or near the spreading ridge [*Cluzel et al*., 2006; *Crawford et al*., 2003; *Eissen et al*., 1998; *Ulrich et al*., 2010] and generated the metamorphic sole at 56 Ma [*Cluzel et al*., 2012], boninites and adakitoïds at 50–55 Ma [*Cluzel et al*., 2006; *Eissen et al*., 1998], that are found in dykes within the Peridotite Nappe. The forced [*Cloos*, 1993] shallow dipping subduction of the young oceanic lithosphere of the South Loyalty Basin provoked the peeling of the upper oceanic crust. This leads to the accretion of slices of basalt and bathyal sediments in the fore-arc region, forming the Poya Terrane. Eventually, the buoyant Norfolk/New Caledonia Ridge obliquely reached the trench and progressively blocked subduction [*Cluzel et al*., 2001]. Meanwhile, syntectonic basins developed during the Paleocene and Eocene on the Norfolk/New Caledonia Ridge in front of the southward propagating thrusts. Foreland and piggyback basins were fed by the erosion of allochthonous/parautochthonous units and foreland bulges as well [*Maurizot and Cluzel*, 2014]. The north or northeastward subduction of New Caledonia at depth up to 80 km generated the Eocene high-pressure metamorphic complex, which was exhumed at shallow levels of the crust during the 44–34 Ma interval [*Baldwin et al*., 2007; *Spandler et al*., 2005]. Finally, fore-arc upper mantle rocks were thrust over upper Eocene and older rocks, forming New Caledonia's Peridotite Nappe (Figure 1).

3. Postobduction Events

3.1. Upper Oligocene Granitoids

A relatively clear picture of postobduction events can be drawn from the available stratigraphic and thermochronological evidence [*Baldwin et al*., 2007; *Cluzel et al*., 1998; *Paquette and Cluzel*, 2007; *Quesnel et al*., 2012]. Obduction probably occurred at circa 34 Ma [*Cluzel et al*., 1998]; while the postobduction Saint Louis granodiorite and Koum-Borindi granodiorite and adamellite (Figure 1) intruded the base of the Peridotite Nappe and its underlying basement, at 27 and 24.5 Ma, respectively [*Paquette and Cluzel*, 2007], and therefore postdate obduction. Koum-Borindi and Saint Louis intrusive rocks contains rare inherited zircons [*Paquette and Cluzel*, 2007] possibly coming from the assimilation of basement (Upper Cretaceous?) enclaves. Despite this, these high-K to medium-K calc-alkaline granitoids display the geochemical and isotopic features of volcanic arc magmas uncontaminated by middle to lower crust-derived melts [*Cluzel et al*., 2005]. They have been related to a short-lived post-Eocene subduction [*Cluzel et al*., 2006], the geophysical traces of which have been detected along the West Coast of New Caledonia by teleseismic tomography [*Regnier*, 1988]. Alternatively, some authors consider that the structure of the New Caledonia Basin only reflects tectonic subsidence due to foreland flexure [*Collot et al*., 2008]. This postulated short-lived subduction probably appeared along the West Coast of New Caledonia when the narrow Norfolk-New Caledonia Ridge blocked the older (Eocene) subduction. Sr, Nd, and Pb isotopic ratios indicate derivation from an almost isotopically homogeneous mantle wedge. In contrast, some variation in trace element ratios uncorrelated to differentiation is diagnostic of the mineralogical heterogeneity of the source. Prominent heavy rare earth element depletion of the younger (~24 Ma) granitoids may be due to an equilibrium with garnet-bearing subcrustal material (granulite) found as xenoliths [*Paquette and Cluzel*, 2007]; whilst a relative Nb, Ta, and Hf enrichment, irrespective of crystal fractionation, may be related to either modest contamination by previously underplated mafic material, heterogeneous hydration of the mantle wedge, or mixing with uplifted unmetasomatized mantle. Sublithospheric mantle mixing and subsequent heterogeneity have been tentatively related to postobduction slab breakoff and formation of a slab window [*Cluzel et al*., 2006]. It is worth noting that the time elapsed between the end of obduction and emplacement of the older granitoid (34 to 27.5 Ma) is consistent with the latency interval necessary to create a mantle wedge and generate active margin magmas since subduction inception [*Cluzel et al*., 2005]. Apatite fission tracks thermochronology performed on samples of the Saint Louis intrusive complex ("Comète" granodiorite) provides cooling ages at circa 30–25 Ma [*Quesnel et al*., 2012] very close to the time of intrusion (27 Ma U-Pb on zircon) and K-Ar biotite cooling ages at 25–24.5 Ma as well (*Guillon* [1975] in *Black et al*. [1994] and *Paris* [1981]). Thus, fast cooling suggests either (i) very shallow intrusion inconsistent with the overall features of Saint Louis plutons or (ii) fast exhumation soon after emplacement, supporting the slab breakoff interpretation [*Cluzel et al*., 2005].

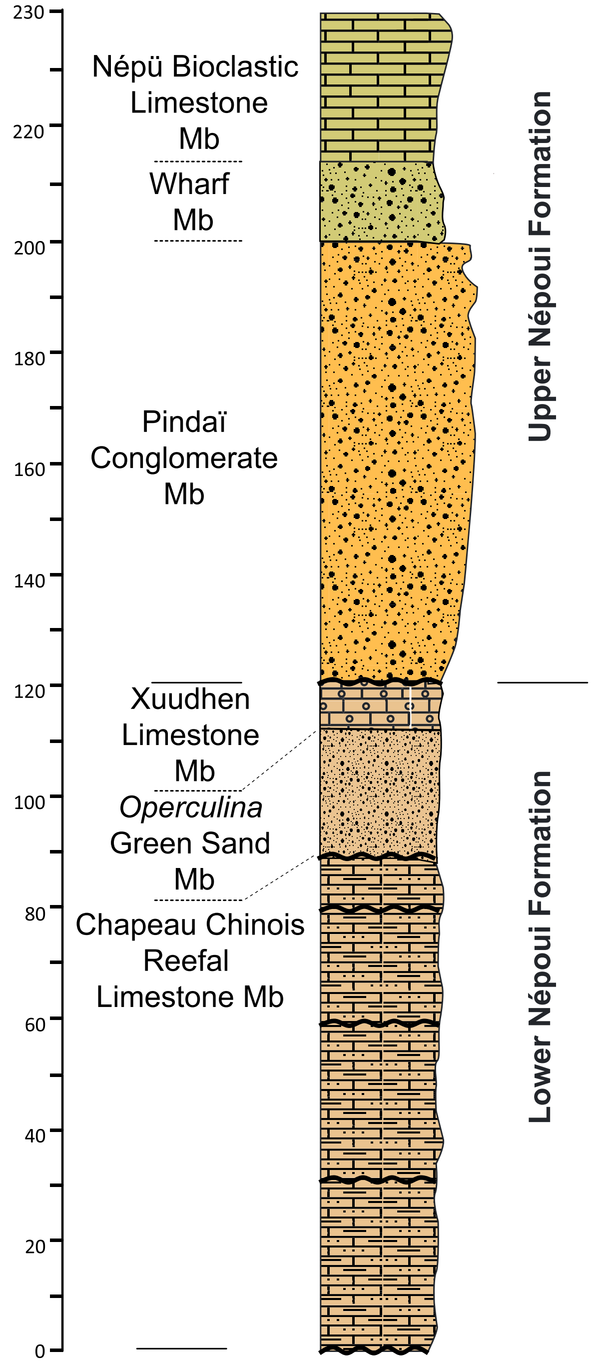

Figure 4. Composite log of the Népoui Fm (early Miocene in age) in the Népoui area.

3.2. The Miocene Népoui Series

Miocene sediments crop out in cliffs of the Muéo and Pindaï peninsulas and islets of the Népoui Bay [*Coudray*, 1976] (Figure 2); this is the only known occurrence of marine sediments of this age in the main island of New Caledonia. Classically, the Pindaï Conglomerate Member (Mb) was thought to represent a Miocene transgression that directly followed obduction of the Peridotite Nappe, its coarse character being due to active uplift and steep slopes [*Latham*, 1974, 1975, 1977; *Paris*, 1981; *Routhier*, 1953]. However, this interpretation is questioned by the discovery of a lower Miocene reefal limestone unit ~120 m thick (Maurizot et al., manuscript in preparation) (Figure 4) underneath the Pindaï Conglomerate Mb, indicating that postobduction uplift was already terminated by early Miocene times. Therefore, the overall significance of the Pindaï Conglomerate Mb must be reevaluated.

Miocene sediments of the Népoui area are gently dipping (<5°) (Figure 5) and overlie unconformably the Poya Terrane and the associated upper Eocene Népoui Flysch. It consists of two formations (from base to top): (i) the Lower Népoui Fm (Chapeau Chinois Reefal Limestone Mb, *Operculina* Green Sand Mb, and Xuudhen Limestone Mb) and (ii) the Upper Népoui Fm (Pindaï Conglomerate Mb, Wharf Mb, and Népü Bioclastic Limestone Mb).

The Lower Népoui Fm is formed principally of thick (>120 m) coralgal limestone (Figure 4), of which only the upper 20 m crop out on the West Coast of the Pindaï Peninsula (Xuudhen) (Figure 5). The Fm disappears rapidly to the north below the Pindaï Conglomerate Mb and thickens to the south where it is concealed below sea level. It has been recognized over a depth of 105 m in a drill hole. A detailed description of this new Fm will be published elsewhere (P. Maurizot et al., manuscript in preparation, 2014) and is beyond the scope of the present article, which only addresses the geodynamic inferences of this discovery.

The base of the Lower Népoui Fm consists of 10 cm thick medium-grained conglomerate formed of weathered pebbles and fragments of Eocene Népoui Flysch mixed up with Miocene bioclasts. The basal conglomerate is overlain by fine-grained sandstone made up of rounded and more or less oxidized serpentinite elements together with some chromite, deposited on an erosion surface. The bulk of the section upward consists of reefal and bioclastic limestone with in situ coral or algal patches and mounds (Chapeau Chinois Reefal Limestone Mb), in which several sequences can be distinguished, each 20 to 30 m thick. Characteristically, the yellowish limestone contains streaks and small pockets of ferruginous material coming

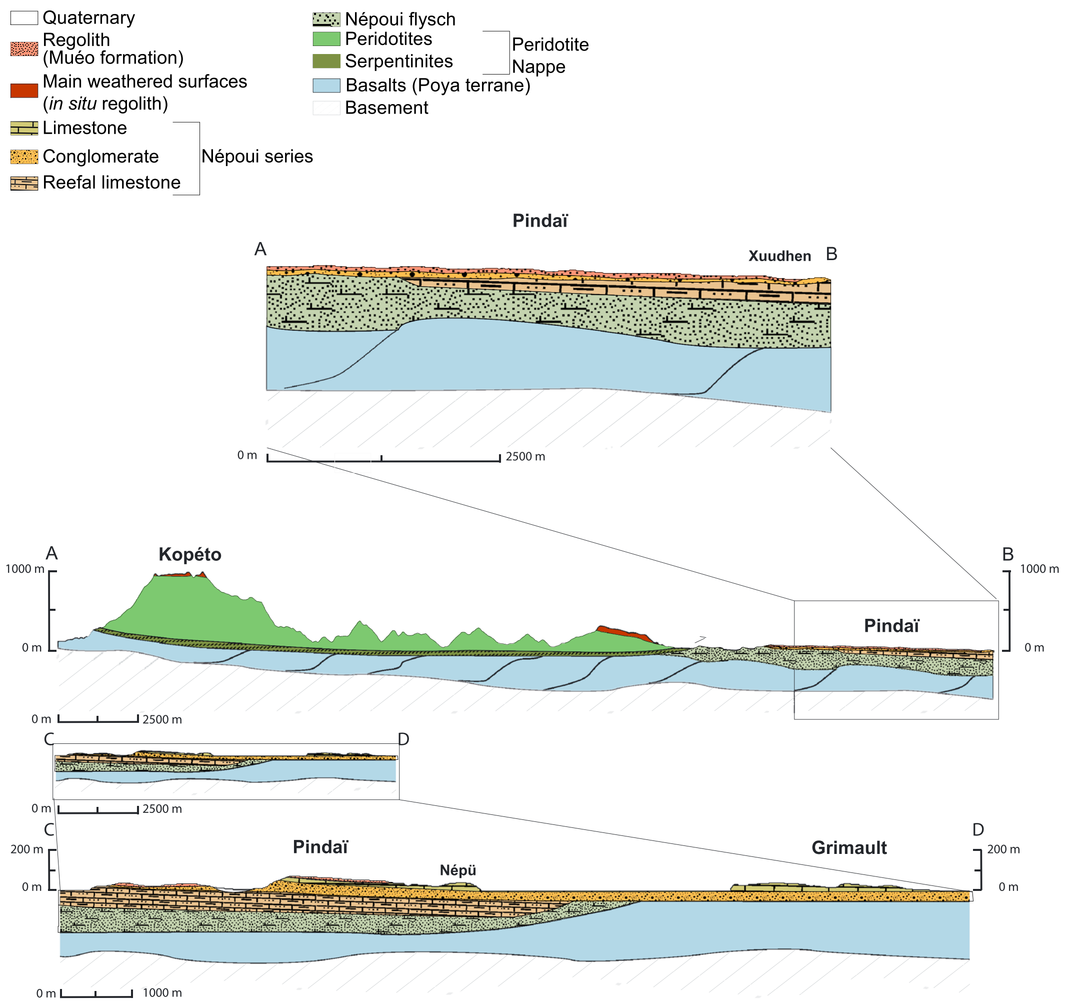

Figure 5. Cross section in the Népoui area; (vertical exaggeration X2) for location, see Figure 2.

from the erosion of laterite. The top is formed of whitish bioclastic calcareous sands (*Operculina* Green Sand Mb), rich in large benthic foraminifera, with rare planktic species and isolated flat coral patches and rhodoliths in living position (Xuudhen Limestone Mb). The sedimentary association and faunal assemblage as well are typical of a fringing reef environment with lagoon sands on top.

The Upper Népoui Fm, about 110 m thick (Figure 4), is formed of three members which are in ascending order: (i) the cobble conglomerate (Pindaï Conglomerate Mb), (ii) the transitional conglomerate-limestone (Wharf Mb), and (iii) the upper bioclastic limestone (Népü Bioclastic Limestone Mb).

The base of the Upper Népoui Fm exhibits an erosive lower boundary and starts with an unconformable very coarse conglomerate, approximately 80 m thick, indicating a proximal alluvial fan depositional environment and constituting the Pindaï Conglomerate Mb [*Coudray*, 1976; *Paris*, 1981]. The conglomerate consists of several sequences, each 10 to 20 m thick in which coarse elements prevail over fine-grained sediments (Figure 4). Well-rounded cobbles (up to 1 m in diameter), pebbles, gravels, and sands, have been typically deposited in an alluvial fan context as shown by very irregular erosive and scoured surfaces at the baseand within the conglomerate sequence. Nontronitic argillite beds, a few centimeters thick, are intercalated in the upper part of the conglomerate [*Coudray*, 1976] (Figures 6a and 6b). The reworked elements found in the conglomerate come from the underlying limestone (coral boulders) and the Peridotite Nappe (serpentinite, serpentinized peridotite, minor dolerite, and rare amphibole-bearing felsic rocks) (Figure 6c). Characteristically, dolerite pebbles are island arc tholeiites, geochemically identical to the dolerites of the Peridotite Nappe that cannot come from the erosion of the underlying Poya Terrane. Thus,

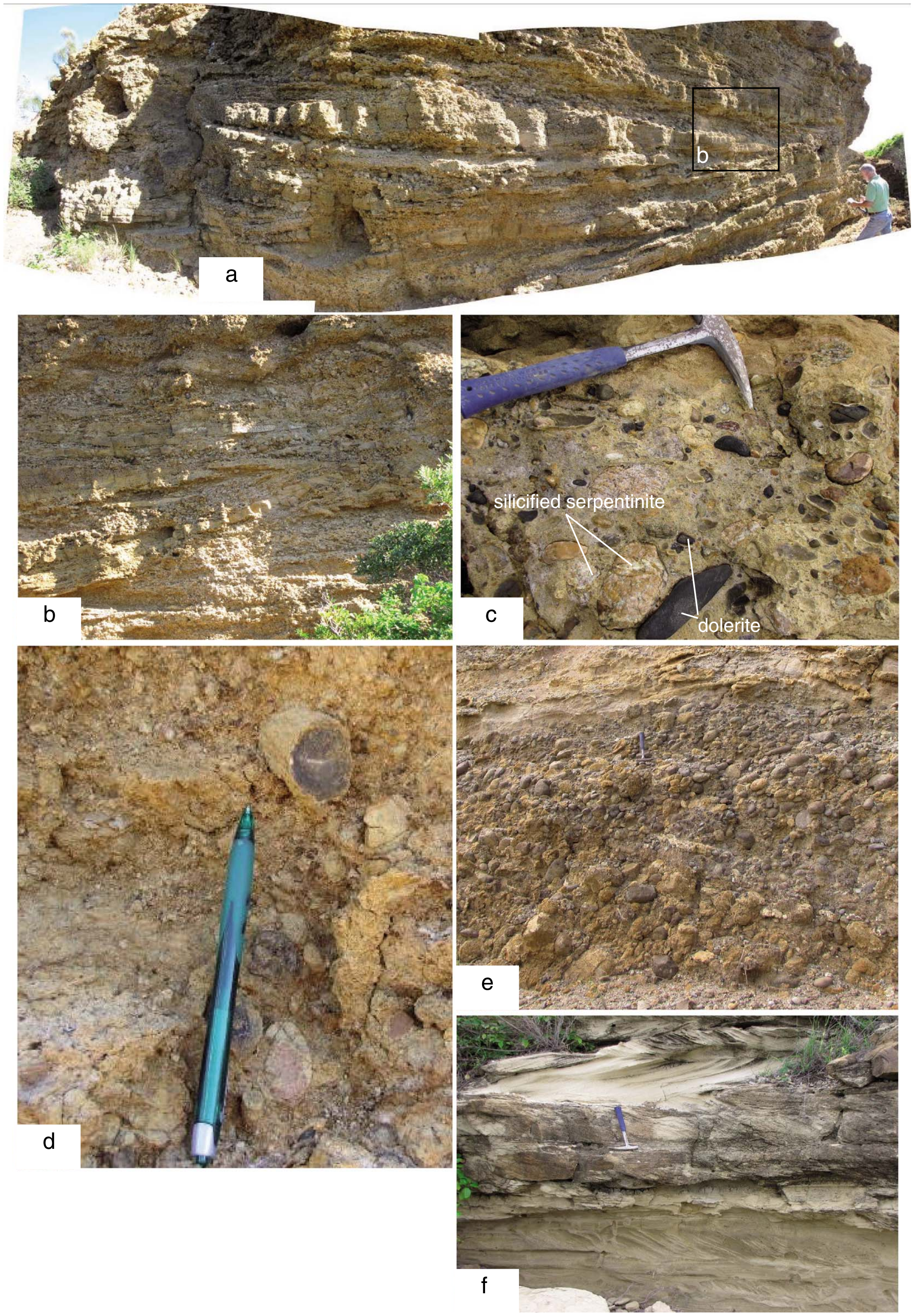

Figure 6. (a) Large low-angle trough cross bedding in the Népoui Conglomerate Mb. (b) Zoom on the cross bedding of Figure 6a. (c) Conglomerate with clasts of dolerite and silicified serpentinite. (d) Silicified wood fragment in conglomerate. (e) Conglomerate with pebbles and cobbles of peridotites, ferricretes, silica, and magnésite. (f) Cross bedding formed by the superposition of current ripples in opposite direction: herringbone cross bedding.

these elements provide evidence for deep erosion of the Peridotite Nappe upstream. Silicified and ferruginous fossil wood fragments (Figure 6d) (trunks, branches, leaves, and seeds) are common in conglomerate beds. The top of the conglomerate is locally overlain by reworked laterite and in situ ferricrete with rhizo concretions and silicified tree roots in living position, thus providing evidence for significant emersion and weathering.

Both elements and matrix of the conglomerate are weathered to various degrees and locally display silicification and magnesite crystallization that resulted from the supply of Si (chalcedony or quartz), and Mg (magnesite) by supergene fluids. Local nickel enrichment has also been reported [*Coudray*, 1971]. Peridotite pebbles are generally deeply weathered, while in contrast, dolerite and felsic rocks clasts are generally very fresh. Another noteworthy feature of the conglomerate is the occurrence of pebbles and cobbles of ferricrete, up to 1 m in diameter, supergene silica and magnesite (Figure 6e). The occurrence of reworked supergene material in the conglomerate gives evidence for erosion of pre-Miocene lateritic profiles formed upon peridotites, while the development of in situ ferricrete and silicification records continuous weathering during and after the conglomerate deposition.

The cobble conglomerate passes gradually upward into mixed marine and terrestrial clastic sediments (Wharf Mb) (Figure 5), less than 15 m thick (Figure 4). The end members are represented by green to rusty sands with weathered serpentinite grains similar to those intercalated in the Lower Népoui Fm and channelized conglomerate. Conglomerates currently contain fossil wood fragments and are intercalated with bioclastic benthic foraminiferal sands with herringbone cross bedding or wave ripples, typical of shallow subtidal current deposition (Figure 6f). Although less weathered than the underlying peridotite conglomerate, the matrix and fossil woods are often silicified. The lithoclasts are serpentinized peridotite, serpentinite, olivine, pyroxene, chromite, dolerite, jasper, silica, magnesite, iron oxihydroxides, and ferricrete.

The Népü Bioclastic Limestone Mb is 20 to 30 m thick (Figure 4). It is composed of several sequences of bioclastic limestone intercalated with more terrigenous layers, such as reworked lateritic mud, green to brown serpentinite sandstone, and microconglomerate. Noteworthy are some pebbles of basement rocks (black chert and schist) derived from the Central Chain, in addition to the common ultramafic and mafic clasts, providing evidence for deeper erosion. Highly fossiliferous bioclastic sediments with fragments of corals, algae, bivalves, echinoids, gastropods, and worm tubes, are diagnostic of perireefal environment [*Coudray*, 1976]. The overall succession of the Upper Népoui Fm records a transition from alluvial fan to subtidal environment.

New micropaleontological data allow a reassessment of the age of the Népoui series. The lagoonal sands that underlie the conglomerate have yielded large benthic foraminifera typical of the Te 1–4 letter stage [*Adams*, 1970, 1984] equivalent of the Chattian (late Oligocene). However, rare planktic foraminifera species allow correlation to the M1 biozone [*Berggren and Pearson*, 2005; *Wade et al*., 2011] most probably M1b, which equates to the Late Aquitanian (early Miocene [*Hilgen et al*., 2012]). In addition, the limestone that overlies the conglomerate similarly displays only large benthic foraminifers typical of the Te 5 letter stage which equates to the early Miocene excluding the latest Burdigalian. Thus, the Pindaï Conglomerate Mb accumulated during an interval between the Late Aquitanian and the Early Burdigalian (22–19 Ma).

3.3. Other Postobduction Sediments

The coarse fluvial deposits that crop out on the East Coast of New Caledonia near Kouaoua (Figure 1) and referred to as Gwa N'Doro Fm [*Orloff*, 1968] are composed of two subunits [*Orloff*, 1968; *Orloff and Gonord*, 1968]. In the type locality, the lower unit is formed of a basal conglomerate 10 m thick, overlain by argillaceous sandstone interbedded with conglomerate beds a few centimeters thick. This unit, which does not crop out elsewhere in the East Coast area, has been tentatively correlated with the late Oligocene on a geomorphological basis [*Chardon and Chevillotte*, 2006], yet without any direct dating. The upper unit is a massive and coarser conglomerate, dominantly composed of unserpentinized peridotite with subordinate dolerite, diorite, and gabbro pebbles, it could be a lateral equivalent of the lower Miocene Pindaï Conglomerate Mb [*Chardon and Chevillotte*, 2006; *Chevillotte et al*., 2005], again without any supporting stratigraphic data. Similar conglomerate occurrences in the Kouaoua area (Kadjitra, Ouena, and Kassouri formations) [*Orloff*, 1968] (Figure 1) could be correlated to the Gwa N'Doro Fm. Tiny patches of silicified conglomerate that sporadically crop out along the West Coast such as on top of the Tambounan Peak

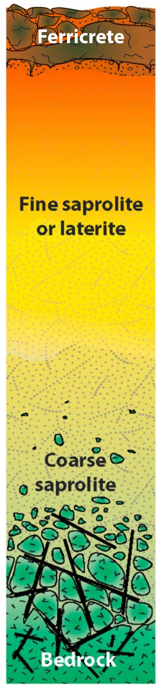

Figure 7. Regolith profile developed on peridotite in New Caledonia.

(Figure 1) have been considered as lateral equivalents of the lower unit of Gwa N'Doro Fm as well and hence of late Oligocene age [*Chardon and Chevillotte*, 2006]; however, more investigations are needed to better constrain the ages and correlations of these fluvial sediments, which have never been directly or indirectly dated.

The Fluvio-lacustrine Fm (Figure 1) refers to the sedimentary infill of depressions that are mainly located in the Massif du Sud [*Trescases*, 1975]. This unit, 40 to 50 m thick, results from the erosion of weathering profiles developed over peridotites or gabbro cumulates [*Augé*, 2002; *Guillon and Trescases*, 1975; *Quesnel et al*., 2008]. Its base is locally formed of coarse conglomerate that contains cobbles of peridotite and ferricrete. It is characteristically formed of fine-grained ferruginous material and serpentine and displays reconcentration of iron oxihydroxide (iron crusts and liesegang rings). The Fluvio-lacustrine Fm records a succession of events, which are (i) a first stage of torrential incision that eroded a preexisting weathering profile and the underlying bedrock as well, followed by (ii) a second stage during which the resulting hydrographic network was filled up in lower but variable fluvial energy conditions, and (iii) a final phase of incision that leads to the current morphology. Such a succession implies prominent variations of the base level that may be correlated to sea level variations, or alternatively to tectonic or epeirogenic events. A correlation of the first stage of erosion with that recorded by the Népoui conglomerate is tantalizing; however, it needs to be supported by appropriate evidence, particularly accurate dating.

3.4. Regolith Development

After obduction and emersion, peridotites underwent weathering under tropical climate [*Avias*, 1952, 1969; *Chevillotte*, 2005; *Latham*, 1986; *Trescases*, 1972]. Supergene hydrolysis dissolved olivine and orthopyroxene, leached Si and Mg, and accumulated residual iron oxihydroxides (goethite and hematite) and nickel-manganese ore. A typical weathering profile exhibits from the bottom to the top, i.e., increasing weathering: bedrock, coarse saprolite, and fine saprolite (yellow and red laterite) and (not everywhere) ferricrete (Figure 7). The relatively high-nickel content of refractory harzburgites and dunites of the Peridotite Nappe (0.20–0.25%) is greatly enhanced by weathering (up to 4% Ni), Ni being fixed either by silicates in saprolite, (garnieritic ore), or by goethite (laterite ore). There are two types of nickel deposits in New Caledonia: basin type and plateau type. Basin-type deposits are dominantly formed of low-grade oxidized ore (Ni-laterite); they are located in low-elevation areas, mainly in the southern part of the Massif du Sud (Goro). Plateau-type deposits are located in the northern part of the Massif du Sud and on the tectonic klippes of the West Coast; they have currently elevations above 600 m (some of them reach 1000 m) and dominantly bear silicate (garnierite) ore. Along a NW-SE profile of the Grande Terre, one single paleosurface wraps the plateaus and the highest points of ultramafic massifs; this surface, which is marked by in situ lateritic profiles capped by ferricrete has been dated of the latest Oligocene (~25 Ma) on paleomagnetic evidence [*Sevin et al*., 2012].

Supposed younger planation surfaces (because located at a lower elevations) only bear reworked regolith material (iron oxihydroxides and supergene silica as well) [*Latham*, 1975; *Ricordel-Prognon et al*., 2011] and hence are erosion glacis, although also affected by weathering. Therefore, the late Oligocene represents an interval of major weathering; thereafter, the latest Oligocene surface was deeply eroded, an event that probably prevented weathering to significantly continue on isolated massifs with restricted water table. Again, post-Oligocene erosion may be tentatively related to the same event that produced the deposition of the Pindaï Conglomerate Mb (Figure 8).

4. Discussion

4.1. Eustatic Versus Tectonic Processes

After postobduction uplift of unknown duration, a relative quiescence occurred during Oligocene times; this interval partly coincides with a relative climatic optimum, the lower Oligocene Warm Event [*Zachos et al*.,

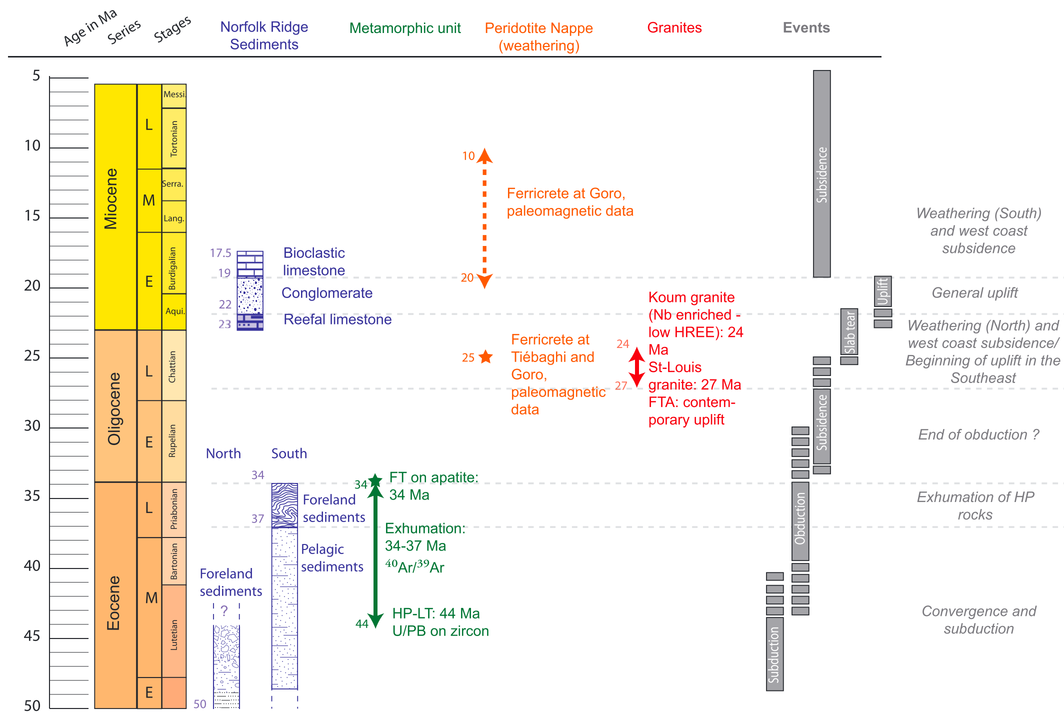

Figure 8. Summary of the geological events that occurred in New Caledonia from the early Eocene to the late Miocene. Geologic timescale [*Gradstein et al.*, 2012].

2001, 2008] (Figure 9), 26 to 23 Ma ago during the upper part of the Chattian and the northward migration of the Australian Plate on which New Caledonia is located. Northward migration resulted in warmer and wetter climate and allowed the first coral reef development in the Great Barrier Reef of Australia [*Hopley et al.*, 2007], and in New Caledonia as well. Meanwhile, tropical weathering developed in New Caledonia during the latest Oligocene (25 Ma), and thick weathering profiles formed upon peridotites [*Sevin et al.*, 2012].

The occurrence of 120 m thick reefal limestone in the Népoui area is unlikely an isolated feature and possible lateral extent should be considered along the approximately 300 km of unexplored shallow water plateau, 1 to 5 km wide, that apparently does not exist along the East Coast [*Andréfouët et al.*, 2009; *Chardon et al.*, 2008]. Although no data on the deep parts of the West Coast fringing plateau are available yet, it may be suggested that at least part of the latter structure may be based upon an older Neogene fringing reef. This hypothesis raises the problem of asymmetrical development of this reef.

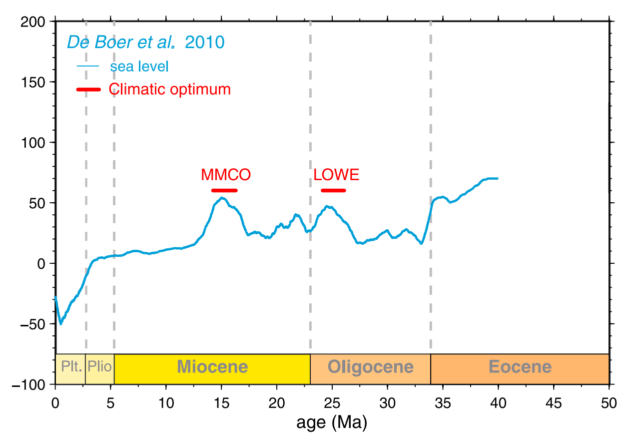

Figure 9. Tertiary sea level variation (according to de *Boer et al.* [2010]) and climate thermal highs from *Zachos et al.* [2001, 2008].

There are several possible interpretations to account for >120 m postobduction vertical coral growth in the Lower Népoui Fm:

1. Climate-driven sea level rise. One may postulate that New Caledonia was in a steady state at the end of the Oligocene and that vertical coral growth was driven by ~120 m Aquitanian sea level rise; however, such an order of magnitude is well above any estimation of the sea level variation during this geological interval (~15 m) [*de Boer et al.*, 2011]; therefore, this interpretation should be rejected.

2. Another possibility is a uniform subsidence of New Caledonia; however, it fails to explain why Miocene reef seems to have developed on the West Coast only, unless an east to west tilt occurred inducing the vertical development of fringing reef and the erosion of the eastern side. Although there is no evidence of uplifted fringing reef of this age along the East Coast, this hypothesis has already been forwarded to account for the occurrence of uplifted canyons infill, e.g., the Gwa N'Doro Fm [*Orloff*, 1968], located at mid-island near the East Coast [*Chardon and Chevillotte*, 2006]. Yet this event is not time constrained because the Gwa N'Doro Fm remains undated.
3. The development of asymmetrical fringing reef may also result from post-Oligocene tectonic subsidence restricted to the West Coast. The role of the so-called "West Caledonian Fault" has been often advocated to account for the location and isolation of West Coast peridotite klippes and interpreted to result from postobduction marginal collapse [*Lagabrielle et al.*, 2005]. However, a careful examination of the West Caledonian Fault reveals that it mainly corresponds to the fortuitous alignment of ultramafic klippe limits, erosion boundary of the Poya Terrane, and only locally, to southwest regarding faults. In addition, there is no evidence that the pre-Miocene planation surface was offset by such a fault. Therefore, there is no regional fault running along the island that may account for Miocene tectonic subsidence of the West Coast.
4. Uplift may also have been triggered the arrival of topographic highs in the West Coast subduction zone. Actually, the buildup of Népoui Fm records uplift that could be due to the arrival of Lord Hoxe Rise in the subduction zone. This type of observation was made in Costa Rica [*Sak et al.*, 2004]. However, it does not account for the overall SW ward tilt of New Caledonia or the genesis of the younger granitoids.
5. Alternatively, subsidence restricted to the West Coast may result from synreef southwestward regional tilt that may explain why the deposition of coralline limestone was constantly associated with the erosion products of an ultramafic regolith cover; whilst the West Coast was subsiding and the reef was vertically growing, the East Coast and the central part of the island were uplifted; their regolith cover was eroded. This is the simplest way to explain all the features of the West Coast fringing reef if any, and this interpretation will be preferred. It is worth noting that the lower Miocene fringing platform was probably discontinuous and let large embayments, allowing fresh water and significant sedimentary transit to flow directly into deep waters as in the modern reef configuration.

Prominent erosion occurred during early Miocene times and resulted in the occurrence of reworked lateritic material along toposequences from the elevated parts of the paleolandscape and eventually of the presence of ferricrete pebbles and cobbles in the Pindaï Conglomerate Mb [*Ricordel-Prognon et al.*, 2011]. Erosion is apparently due to a sudden change in the equilibrium profile of the drainage basin, which suggests two different interpretations: (i) a sea level drop that drastically increased the average slope and hence generated intense erosion or (ii) a tectonically generated uplift.

Since the Oligocene-Miocene boundary, i.e., during the deposition of the Népoui Conglomerate Mb, the sea level was rising about 15 m (Figure 9) [*de Boer et al.*, 2011]; therefore, the renewed erosion cannot be explained by a sea level drop.

The total thickness of the underlying and overlying carbonate units infers about 220 m of almost continuous subsidence during the early Miocene; thus, conglomerate deposition appears as a consequence of an unexpected and short-lived event of obvious tectonic origin. Considering the elevation of the latest Oligocene weathering surface in the Népoui area (−25 Ma at Tiébaghi [*Sevin et al.*, 2012]), the maximum size (1 m) of transported cobbles, together with the occurrence of basement rock clasts and taking into account the profile inferred from the base of the Népoui conglomerate, the incision and hence the corresponding uplift reached a minimum of ~200 m and probably very much more (>500 m) in places where erosion reached the autochthonous basement.

4.2. Slab Tear and Slab Breakoff Model

There is a close coincidence between the timing of postobduction Nb-enriched granitoid intrusion (i.e., influenced by slab window), rapid uplift, and exhumation of these granitoids and short-lived erosion; therefore, a genetic link may be suspected. However, there is a time lapse of circa 2 Ma between the occurrence of Nb-enriched granitoids at 24 Ma and the erosion event on the West Coast at circa 22 Ma. This temporal gap may be explained by the southeastward propagation of the slab tear that probably initiated at the latitude of the HP-LT complex of northern New Caledonia [*Paquette and Cluzel*, 2007]. Southeastward

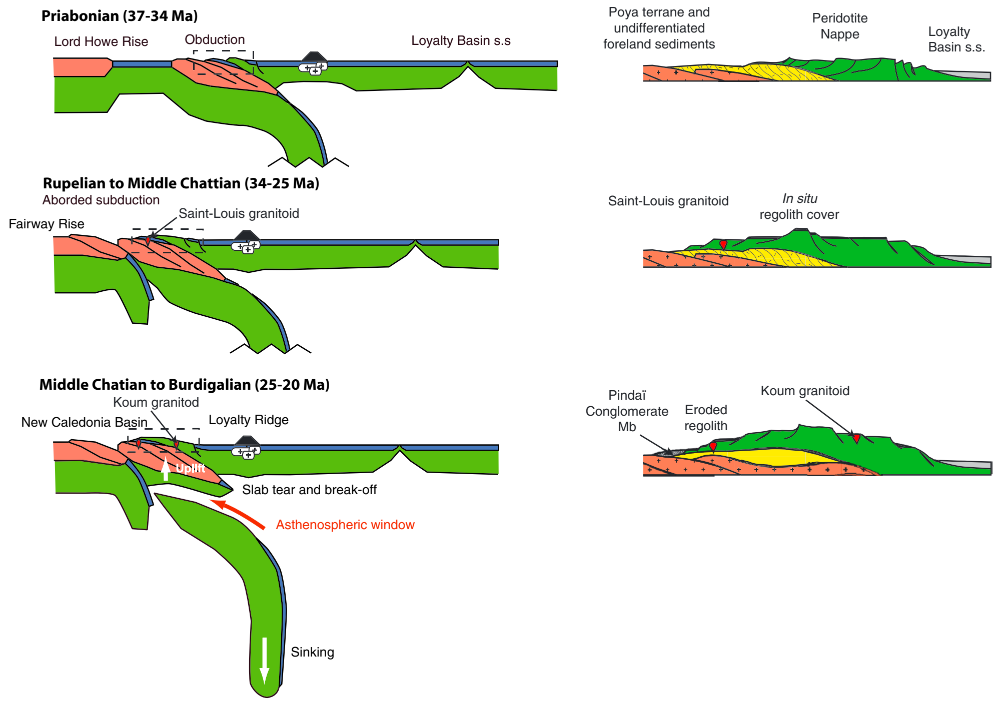

Figure 10. Geological model of a slab breakoff and subsequent uplift, from the Priabonian to the Burdigalian.

propagating slab window may have influenced granitoid genesis as soon as 24 Ma, before the slab eventually broke off at 22 Ma (Figure 10). This hypothesis is supported by current tectonic reconstructions [*Schellart*, 2007] and seismic tomography (*P* wave and *S* wave) that show evidence for an abandoned slab to exist to the north of New Zealand [*Schellart et al*., 2009].

This view is supported by the results of thermomechanical modeling of the postcollision shallow breakoff of an oceanic lithosphere [*Baumann et al*., 2010; *Duretz et al*., 2011, 2012; *van Hunen and Allen*, 2010]. Considering the timing of collision (34 Ma [*Cluzel et al*., 2006]), the age of South Loyalty Basin at subduction inception (≲30 Ma [*Cluzel et al*., 2012]) and taking into account a subduction speed of 5 cm/yr [*Cohen et al*., 2013], computation of Duretz model shows that breakoff may have occurred ~4.5 Ma after the collision. In New Caledonia, the formation of slab window and emplacement of Koum granite (24.3 ± 0.1 Ma) [*Cluzel et al*., 2005] occurred about ~10 Ma after the collision, 2 times the delay inferred from Duretz model. However, the application of simple mechanical models to the case of New Caledonia probably misses some parameters and needs more investigations. In addition, thermomechanical models are based upon a cylindrical geometry (i.e., subduction/exhumation perpendicular to the trench); in New Caledonia, subduction was oblique [*Cluzel et al*., 2001] and the southeastward propagation of slab tear probably delayed the breakoff.

According to thermomechanical models, the formation of a slab window results in prebreakoff subsidence, which may have been recorded in New Caledonia by lower Miocene asymmetrical subsidence. About two thirds of the bulk subsidence occurred before the slab breakoff and subsidence resumed shortly after the deposition of the conglomerate; thus, the lower Miocene erosion appears to be a very short lived response to breakoff within a longer interval of subsidence.

Uplift is the response to the influx of mantle asthenosphere following the breakoff and sinking of the slab [*Ely and Sandiford*, 2010; *van Hunen and Allen*, 2010]. Slab breakoff models, and modern examples as well, show that the topographic response to breakoff generates uplift of a few kilometres. In northern Central America, *P* wave tomographic imagery and geomorphology of the Central American plateau have revealed an epeirogenic uplift of approximately 0.25–0.5 mm/yr that followed arc-continent collision at 23 Ma [*Rogers et al*., 2002]. Such an amplitude is not observed in New Caledonia probably because of the small volume of buoyant continental crust of the northern Norfolk Ridge involved in the subduction/obduction process, and also because largely oblique processes have likely attenuated the epeirogenic uplift. However, alike New Caledonia, the formation of slab window that followed collision in Eastern Anatolia (Turkey) during the late Miocene generated both regional doming and magmatic activity [*Dilek and Altunkaynak*, 2009; *Keskin*, 2007; *Schildgen et al*., 2012]. The evidence of a subducting slab under Eastern Turkey was confirmed by a teleseismic tomography [*Lei and Zhao*, 2007].

4.3. Uplift and Nickel Ore Deposits

The lower Miocene uplift and associated erosion are at least partly responsible for the mountainous morphology observed along the West Coast and in the northern part of the Massif du Sud today. Vertical motion 200–500 m of these massifs may have (i) likely changed the smooth Oligocene weathering morphology into elevated plateaus surrounded by steep slopes, (ii) eroded about two thirds of Peridotite Nappe along the West Coast and in the center of the island, removed the bulk of weathering profiles and hence only left isolated patches of nickel ore deposits, and (iii) changed the hydrologic regime by narrowing the water table in isolated plateaus and hence stopped the development of ferricrete, already formed before (cf. late Oligocene paleomagnetic ages).

5. Conclusion

At variance with previous interpretations, lower Miocene coarse conglomerate that crop out in the Népoui peninsula does not represent the onset of the marine transgression that followed obduction in New Caledonia. Actually, marine coastal sedimentation resumed well before, with the buildup of lower Miocene fringing reef. Alternatively, the thick and very coarse conglomerate represents a proximal alluvial fan deposit and records a short-lived episode of intense erosion intercalated between two intervals of subsidence recorded by reefal and perireefal carbonate. Miocene sea level variation fails to account for erosion; in contrast, there is a narrow coincidence between the conglomerate deposition (and hence prominent erosion) and the emplacement of the younger postobduction granitoids influenced by slab window. Therefore, it is concluded that (i) the lower Miocene subsidence was triggered by the formation of a slab window due to the southeast propagating postobduction slab tear and (ii) the erosion event recorded at circa 22 Ma was induced by the lower Miocene slab breakoff and associated uplift, which would also be responsible for the high elevation of plateau-type nickel deposits of New Caledonia.

Acknowledgments
This study was carried out under the "Régolithe" programme of the Geological Survey of New Caledonia, the "Typologie des laterites" programme of the Centre National de Recherche Technologique (CNRT) "Nickel et son environnement," and the "Genèse et caractéristiques des régolithes" scientific programme of the "Bureau de Recherches Géologiques et Minières" (BRGM: French Geological Survey). Special thanks are due to Laurent Bailly (BRGM), chief of the "Typologie des laterites" project, and to Jocelyn Barbarand (Orsay-Paris Sud University), who provided thermochronological data (which will be published in details elsewhere). We thank also the following organizations: IRD, UNC, SLN, Vale NC, KNS, NMC, SMGM, and SMT.

References

Adams, C. J. (1970), A reconsideration of the East Indian letter classification of the tertiary, Bulletin of the British Museum (Natural History), *Geology*, *19*(85–137).

Adams, C. J. (1984), Neogene larger foraminifera, evolutionary and geological events in the context of datum planes, in *Pacific Neogene Datum Planes: Contributions to Biostratigraphy and Chronology*, edited by N. Ikebe and R. Tsuchi, pp. 47–67, Univ. of Tokyo Press, Tokyo.

Aitchison, J. C., G. L. Clarke, S. Meffre, and D. Cluzel (1995), Eocene arc-continent collision in New Caledonia and implications for regional southwest Pacific tectonic evolution, *Geology*, *23*(2), 161–164.

Andréfouët, S., G. Cabioch, B. Flamand, and B. Pelletier (2009), A reappraisal of the diversity of geomorphological and genetic processes of New Caledonian coral reefs: A synthesis from optical remote sensing, coring and acoustic multibeam observations, *Coral Reefs*, *28*(3), 691–707.

Augé, T. (2002), *Etude d'un Gisement de Chromite et de Minéralisations en Platinoïdes Rep*, BRGM, Orléans, France.

Avias, J. (1952), Note sur la genèse des gîtes nickélifères en Nouvelle-Calédonie, in *XIXème Congrès Géologique International, Sect. XII, Fasc. XII*, pp. 271–272, C.R. Congrès Géol. Intern., Alger.

Avias, J. (1967), Overthrust structure of the main ultrabasic new caledonian massives, *Tectonophysics*, *4*(4–6), 531–541.

Avias, J. (1969), Note sur les facteurs contrôlant la genèse et la destruction des gîtes de nickel de la Nouvelle-Calédonie. Importance des facteurs hydrologiques et hydrogéologiques, *C. R. Acad. Sci.*, *268*, 244–246.

Baldwin, S. L., T. Rawling, and P. G. Fitzgerald (2007), Thermochronology of the New Caledonian high-pressure terrane: Implications for middle Tertiary plate boundary processes in the southwest Pacific, *Geol. Soc. Am., Spec. Pap.*, *419*, 117–134.

Baumann, C., T. V. Gerya, and J. A. Connolly (2010), Numerical modelling of spontaneous slab breakoff dynamics during continental collision, *Geol. Soc. London Spec. Publ.*, *332*(1), 99–114.

Berggren, W. A., and P. N. Pearson (2005), A revised tropical to subtropical Paleogene planktonic foraminiferal zonation, *J. Foraminiferal Res.*, *35*(4), 279–298.

Black, P. M., T. Itaya, T. Ohhira, I. E. M. Smith, and M. Takagi (1994), Mid-Tertiary magmatic events in New Caledonia: K-Ar dating of boninitic volcanism and granodiorite intrusives, *Geosci. Rep. Shizuoka Univ.*, *20*, 49–53.

Chardon, D., and V. Chevillotte (2006), Morphotectonic evolution of the New Caledonia ridge (Pacific Southwest) from post-obduction tectonosedimentary record, *Tectonophysics*, *420*(3–4), 473–491.

Chardon, D., J. A. Austin Jr., G. Cabioch, B. Pelletier, S. Saustrup, and F. Sage (2008), Neogene history of the northeastern New Caledonia continental margin from multichannel reflection seismic profiles, *C. R. Geosci.*, *340*, 68–73.

Chevillotte, V. (2005), *Morphogenèse Tropicale en Contexte Epirogénique Modéré, Exemple de la Nouvelle-Calédonie (Pacifique Sud-Ouest)*, 166 pp., Univ. of New Caledonia, Nouméa, New Caledonia.

Chevillotte, V., P. Douillet, G. Cabioch, Y. Lafoy, Y. Lagabrielle, and P. Maurizot (2005), Evolution géomorphologique de l'avant-pays du Sud-Ouest de la Nouvelle-Calédonie durant les derniers cycles glaciaires, *C. R. Geosci.*, *337*(7), 695–701.

Chevillotte, V., D. Chardon, A. Beauvais, P. Maurizot, and F. Colin (2006), Long-term tropical morphogenesis of New Caledonia (Southwest Pacific): Importance of positive epeirogeny and climate change, *Geomorphology*, *81*(3–4), 361–375.

Clarke, G. L., J. C. Aitchison, and D. Cluzel (1997), Eclogites and blueschists of the Pam Peninsula, NE New Caledonia: A reappraisal, *J. Metamorph. Petrol.*, *38*(7), 843–876.

Cloos, M. (1993), Lithospheric buoyancy and collisional orogenesis: Subduction of oceanic plateaus, continental margins, island arcs, spreading ridges, and seamounts, *Geol. Soc. Am. Bull.*, *105*(6), 715–737.

Cluzel, D., D. Chiron, and M.-D. Courme (1998), Discordance de l'Eocène supérieur et Evénements pré-obduction en Nouvelle-Calédonie, *C.R. Acad. Sci., Ser. IIa: Earth Planet. Sci.*, *327*(7), 485–491.

Cluzel, D., J. C. Aitchison, and C. Picard (2001), Tectonic accretion and underplating of mafic terranes in the Late Eocene intraoceanic fore-arc of New Caledonia (Southwest Pacific): Geodynamic implications, *Tectonophysics*, *340*(1–2), 23–59.

Cluzel, D., D. Bosch, J.-L. Paquette, Y. Lemennicier, P. Montjoie, and R.-P. Ménot (2005), Late Oligocene post-obduction granitoids of New Caledonia: A case for reactivated subduction and slab break-off, *Island Arc*, *14*(3), 254–271.

Cluzel, D., S. Meffre, P. Maurizot, and A. J. Crawford (2006), Earliest Eocene (53 Ma) convergence in the Southwest Pacific: Evidence from preobduction dikes in the ophiolite of New Caledonia, *Terra Nova*, *18*, 395–402.

Cluzel, D., F. Jourdan, S. Meffre, and S. Lesimple (2012), The metamorphic sole at the base of the ophiolite of New Caledonia; 40Ar/39Ar, U-Pb, and geochemical evidence for subduction inception at a spreading ridge, *Tectonics*, *31*, TC3016, doi:10.1029/2011TC003085.

Cohen, B. E., K. M. Knesel, P. M. D. Vasconcelos, and W. P. Schellart (2013), Tracking the Australian plate motion through the Cenozoic: Constraints from $^{40}Ar/^{39}Ar$ geochronology, *Tectonics*, *32*, 1371–1383, doi:10.1002/tect.20084.

Collot, J. Y., A. Malahoff, J. Recy, G. Latham, and F. Missegue (1987), Overthrust emplacement of New Caledonia ophiolite: Geophysical evidence, *Tectonics*, *6*(3), 215–232, doi:10.1029/TC006i003p00215.

Collot, J., L. Geli, Y. Lafoy, R. Vially, D. Cluzel, F. Klingelhoefer, and H. Nouzé (2008), Tectonic history of northern New Caledonia Basin from deep offshore seismic reflection: Relation to late Eocene obduction in New Caledonia, southwest Pacific, *Tectonics*, *27*, TC6006, doi:10.1029/2008TC002263.

Coudray, J. (1971), Sur un nouveau type de gisement de nickel en Nouvelle-Calédonie associé à un complexe argilo-conglomératique d'âge néogène-quaternaire, *C. R. Acad. Sci.*, *273*, 603–606.

Coudray, J. (1976), Recherches sur le néogène et le quaternaire marins de la Nouvelle Calédonie, Expédition française sur les récifs coralliens de la Nouvelle-Calédonie, Fondation Singer-Polignac thesis, 275 pp., Université de Montpellier II, Montpellier, France.

Crawford, A. J., S. Meffre, and P. A. Symonds (2003), 120 to 0 Ma tectonic evolution of the southwest Pacific and analogous geological evolution of the 600 to 220 Ma Tasman Fold Belt System, *Geol. Soc. Am. Spec. Pap.*, *372*, 383–403.

de Boer, B., R. S. W. van de Wal, L. J. Lourens, and R. Bintanja (2011), Transient nature of the Earth's climate and the implications for the interpretation of benthic δ18O records, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *335–336*, 4–11.

Dilek, Y., and Û. Altunkaynak (2009), Geochemical and temporal evolution of Cenozoic magmatism in western Turkey: Mantle response to collision, slab break-off, and lithospheric tearing in an orogenic belt, *Geol. Soc. London Spec. Publ.*, *311*(1), 213–233.

Duretz, T., T. V. Gerya, and D. A. May (2011), Numerical modelling of spontaneous slab breakoff and subsequent topographic response, *Tectonophysics*, *502*(1–2), 244–256.

Duretz, T., S. M. Schmalholz, and T. V. Gerya (2012), Dynamics of slab detachment, *Geochem., Geophys., Geosyst.*, *13*, Q03020, doi:10.1029/2011GC004024.

Eissen, J.-P., A. J. Crawford, J. Cotten, S. Meffre, H. Bellon, and M. Delaune (1998), Geochemistry and tectonic significance of basalts in the Poya Terrane, New Caledonia, *Tectonophysics*, *284*(3), 203–219.

Ely, K. S., and M. Sandiford (2010), Seismic response to slab rupture and variation in lithospheric structure beneath the Savu Sea, Indonesia, *Tectonophysics*, *483*(1), 112–124.

Gradstein, F. M., J. G. Ogg, M. D. Schmitz, and G. M. Ogg (2012), *The Geologic Time Scale 2012*, Elsevier, Oxford, U. K.

Guillon, J. H. (1975), Les massifs péridotitiques de Nouvelle-Calédonie: Type d'appareil ultrabasique stratiforme de chaîne récente (No. 76). IRD Editions, Nouméa, New Caledonia.

Guillon, J. H., and J. J. Trescases (1975), *Carte Géologique de la Nouvelle-Calédonie à 1/ 50 000 et Notce Explicative*, Saint-Louis, BRGM, Orléans, France.

Hayes, D. E., and J. Ringis (1973), Seafloor spreading in the Tasman Sea, *Nature*, *244*, 454–458.

Hopley, D., S. G. Smithers, and K. E. Parnell (Eds.) (2007), *The Geomorphology of the Great Barrier Reef: Development, Diversity, and Change*, Cambridge Univ. Press, Cambridge, U. K.

Keskin, M. (2007), Eastern Anatolia: A hotspot in a collision zone without a mantle plume, *Geol. Soc. Am., Spec. Pap.*, *430*, 693–722.

Lagabrielle, Y., P. Maurizot, Y. Lafoy, G. Cabioch, B. Pelletier, M. RÈgnier, I. Wabete, and S. Calmant (2005), Post-Eocene extensional tectonics in Southern New Caledonia (SW Pacific): Insights from onshore fault analysis and offshore seismic data, *Tectonophysics*, *403*(1–4), 1–28.

Latham, M. (1974), Nouvelle observation de la coupe de Népoui (Nouvelle-Calédonie): Conséquence sur la chronologie de l'étagement des niveaux cuirassés sur les massifs de roches ultrabasiques, *C. R. Acad. Sci.*, *279*, 1055–1058.

Latham, M. (1975), *Géomorphologie d'un Massif de Roches Ultrabasiques de la Côte Ouest de la Nouvelle-Calédonie, le Boulinda*, Cah. O.R.S.T.O.M, sér. Géol., vol. VII, pp. 17–37, Cahiers ORSTOM, Série Pédologie, Nouméa, New Caledonia.

Latham, M. (1977), On geomorphology of northern and western New Caledonian ultramafic massifs, in *International Symposium on Geodynamics of the South-West Pacific*, edited, pp. 235–244, O.R.S.T.O.M, Nouméa, New Caledonia.

Latham, M. (1986), Altération et pédogenèse sur roches ultrabasiques en Nouvelle-Calédonie: Genèse et évolution des accumulations de fer et de silice en relation avec la formation du modelé, 331 pp., Th. Sci. Dijon.

Lei, J., and D. Zhao (2007), Teleseismic evidence for a break-off subducting slab under Eastern Turkey, *Earth Planet. Sci. Lett.*, *257*(1,Äì2), 14–28.

Maillet, P., M. Monzier, M. Selo, and D. Storzer (1983), The d'Entrecastaux zone 'Southwest Pacific)—A petrological and geochronical reappraisal, *Mar. Geol.*, *53*(3), 179–197.

Maurizot, P. (2011), Premiers enregistrements sédimentaires de la convergence pré-obduction en Nouvelle-Calédonie: Formation d'un complexe d'accrétion à l'Eocène inférieur dans le Nord de la Grande-Terre et mise en place de la nappe des Montagnes Blanches, *Bull. Soc. Geol. Fr.*, *182*, 479–491.

Maurizot, P., and D. Cluzel (2014), Pre-obduction records of Eocene foreland basins in central New Caledonia: An appraisal from surface geology and Cadart-1 borehole data, *N. Z. J. Geol. Geophys.*, *1–12*, doi:10.1080/00288306.2014.885065.

Orloff, O. (1968), *Etude géologique et géomorphologique des massifs d'ultrabasites compris entre Houailou et Canala*, Faculté des Sciences de Montpellier, Nouvelle-Calédonie.

Orloff, O., and H. Gonord (1968), Note préliminaire sur un nouveau complexe sédimentaire continental situé sur les massifs du Goa N'Doro et de Kadjitra (région côtière à l'Est de la Nouvelle-Calédonie), définition de la formation et conséquences de cette découverte sur l'âge des fractures majeures récemment mises en évidence dans les mêmes régions, *C. R. Acad. Sci.*, *267*, 5–8.

Paquette, J.-L., and D. Cluzel (2007), U–Pb zircon dating of post-obduction volcanic-arc granitoids and a granulite-facies xenolith from New Caledonia. Inference on Southwest Pacific geodynamic models, *Int. J. Earth Sci.*, *96*(4), 613–622.
Paris, J. P. (Ed.) (1981), *Géologie de la Nouvelle-Calédonie. Un Essai de Synthèse (Including 1/ 200 000 Geological Map)*, 278 pp., BRGM, Orléans, France.
Quesnel, F., P. Maurizot, C. Ricordel-Prognon, and K. Lucien (2008), Appui scientifique à la cartographie du régolithe (Grande-Terre de Nouvelle-Calédonie) Rapport intermédiaire, phase 1 (2007–2008) *Rep*., 96 pp., BRGM.
Quesnel, F., J. Barbarand, B. Sevin, C. Ricordel-Prognon, D. Cluzel, P. Maurizot, and C. Gautheron (2012), Can we use the planation surface concept to reconstruct the morphogenesis of New Caledonia? Electronical abstract GC126668, paper presented at 34th International Geological Congress, Australian Geosciences Council, Brisbane, Australia.
Regnier, M. (1988), Lateral variation of upper mantle structure beneath New Caledonia determined from P-wave receiver function: Evidence for a fossil subduction zone, *Geophys. J.*, *95*, 561–577.
Ricordel-Prognon, C., F. Quesnel, B. Sevin, L. Alizert, and P. Maurizot (2011), Appui à la cartographie du régolithe (Grande Terre de Nouvelle-Calédonie)—Rapport intermédiaire, phase 3 *Rep*.
Rogers, R. D., H. Karason, and R. D. van der Hilst (2002), Epeirogenic uplift above a detached slab in northern Central America, *Geology*, *30*(11), 1031–1034.
Routhier, P. (1953), Etude géologique du versant occidental de la Nouvelle-Calédonie entre le col de Boghen et la pointe d'Arama. Mém. Soc. géol Rep., 271 pp., France.
Sak, P. B., D. M. Fisher, and T. W. Gardner (2004), Effects of subducting seafloor roughness on upper plate vertical tectonism: Osa Peninsula, Costa Rica, *Tectonics*, *23*, TC1017, doi:10.1029/2002TC001474.
Schellart, W. (2007), North-eastward subduction followed by slab detachment to explain ophiolite obduction and Early Miocene volcanism in Northland, New Zealand, *Terra Nova*, *19*(3), 211–218.
Schellart, W., B. Kennett, W. Spakman, and M. Amaru (2009), Plate reconstructions and tomography reveal a fossil lower mantle slab below the Tasman Sea, *Earth Planet. Sci. Lett.*, *278*(3), 143–151.
Schildgen, T. F., D. Cosentino, B. Bookhagen, S. Niedermann, C. Yildirim, H. Echtler, H. Wittmann, and M. R. Strecker (2012), Multi-phased uplift of the southern margin of the Central Anatolian plateau, Turkey: A record of tectonic and upper mantle processes, *Earth Planet. Sci. Lett.*, *317-318*, 85–95.
Sevin, B., C. Ricordel-Prognon, F. Quesnel, D. Cluzel, S. Lesimple, and P. Maurizot (2012), First palaeomagnetic dating of ferricrete in New Caledonia: New insight on the morphogenesis and palaeoweathering of "Grande Terre", *Terra Nova*, *24*(1), 77–85.
Shor, G. G., H. K. Kirk, and H. W. Menard (1971), Crustal structure of the Melanesian area, *J. Geophys. Res.*, *76*, 2562–2586, doi:10.1029/JB076i011p02562.
Spandler, C., J. Hermann, and D. Rubatto (2005), Late Cretaceous-Tertiary tectonics of the Southwest Pacific: Insights from U-Pb sensitive, high-resolution ion microprobe (SHRIMP) dating of eclogite facies rocks from New Caledonia, *Tectonics*, *24*, TC3003, doi:10.1029/2004TC001709.
Trescases, J.-J. (1972), *L'altération des Roches Ultrabasiques en Nouvelle-Calédonie*, O.R.S.T.O.M, Nouméa, New Caledonia.
Trescases, J.-J. (1975), *L'evolution Géochimique Supergène des Roches Ultrabasiques en Zone Tropicale: Formation des Gisements Nickélifères de Nouvelle-Calédonie Edited, Paris*, O.R.S.T.O.M., France.
Ulrich, M., C. Picard, S. Guillot, C. Chauvel, C. Cluzel, and S. Meffre (2010), Multiple melting stages and refertilisation process as indicators for ridge to subduction formation: The New Caledonia Ophiolite, *Lithos*, *115*, 223–236.
van Hunen, J., and M. B. Allen (2010), Continental collision and slab break-off: A comparison of 3-D numerical models with observations, *Earth Planet. Sci. Lett.*, *302*(1–2), 27–37.
Wade, B. S., P. N. Pearson, W. A. Berggren, and H. Pälike (2011), Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale, *Earth Sci. Rev.*, *104*, 111–142.
Zachos, J., M. Pagani, L. Sloan, E. Thomas, and K. Billups (2001), Trends, rhythms, and aberrations in global climate 65 Ma to present, *Science*, *292*, 686–693.
Zachos, J., G. R. Dickens, and R. E. Zeebe (2008), An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics, *Nature*, *451*, 279–283.

