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Subduction erosion: contributions of footwall and hanging wall to serpentinite mélange; field, geochemical and radiochronological evidence from the Eocene HP-LT belt of New Caledonia.

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Abstract

Slivers of mixed and metamorphosed ultramafic, mafic and sedimentary rocks crop out within the Eocene HP-LT metamorphic complex of northern New Caledonia. These units consist of: (1) slices of the serpentinite sole of Peridotite Nappe (upper plate), which characteristically contain fragmented supra-subduction dykes; (2) Intermediate Mélange units composed of elements of the serpentinite sole mixed with basalt and red chert clasts, and supra-subduction magmatic rocks which represent the interface of Peridotite Nappe and Poya Terrane (lower plate); (3) the Pouebo Terrane, an eclogite-blueschist facies mélange, which crops out over 150 km along the NE coast of the island. Intermediate Mélange units are transitional between shallowly accreted oceanic crust rocks of the Poya Terrane and the deeply subducted Pouebo Terrane. Their metamorphic grade is similar to that of the enclosing metasedimentary units of the Diahot Terrane and steeply increases northeastward.

The composition of blocks in the Pouebo mélange suggests that they come from: (1) subducted oceanic material (Poya Terrane Basalts, abyssal argillite/chert, passive margin sedimentary and magmatic components (terrigenous turbidites, limestone and dolerites), and (2) supra-subduction components (mantle wedge serpentinite, 55-52 Ma supra-subduction dykes, fore-arc basin, which characteristically refer to the lower plate and upper plate of the subduction/obduction system respectively).

Keywords: mélange, serpentinite, subduction erosion, fore-arc accretion, fore-arc basin

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1. Introduction

Subduction erosion is a major process of active margins (i.e. Andes, Japan), which however does not leave a prominent trace in the geological record. Evidence used to indirectly demonstrate this process includes margin subsidence through swath bathymetry (e.g., Cloos & Shreve, 1988), reflection seismology (for a review see Von Huene et al., 2004; Stern, 2011 and references therein), or some peculiar geochemical features of supra-subduction zone magmatism (Stern, 2011). Prominent surface roughness (horst-graben structure, seamounts) of the lower plate, high frictional forces and fluid overpressure are generally advocated to explain enhanced rock fragmentation and abrasion at converging plate boundaries. Analogic modelling mainly aimed at exploring the behavior of the sedimentary cover transported by the lower plate of the subduction systems (Lallemand et al., 1994; Gutscher et al., 1998); in contrast, involvement of the oceanic crust itself, judged too strong or out of reach of the shearing stress due to the overriding plate, was rarely considered in spite of some prominent occurrences (e.g., Cluzel et al., 2001). Conversely, a few authors explored the possibility of subtraction of large parts of the upper plate dragged into subduction zones (Boutelier et al., 2003; Lallemand, 1995; Shemenda, 1993).

The occurrence of chaotic associations of various high-strength blocks (crust) enclosed in a soft serpentine matrix (mantle) is a rather sound evidence for a prominent mixing process termed *mélange*. *Mélange*-like units may form from sedimentary, tectonic or diapiric mixing (Festa et al., 2010; Wakabayashi, 2015). In the case of tectonic mixing, the source for serpentinite matrix may be the serpentinised mantle wedge of the subduction zone and previously exhumed serpentinites from the lower plate. In most cases, deciphering whether serpentinites come from the hanging wall or the footwall of the subduction zone is problematical because these rocks are almost impossible to distinguish. It is therefore necessary to identify the markers of upper vs. lower plate provenance.

The type locality for models of subduction inception is the Izu-Bonin-Mariana (IBM) subduction system in the western Pacific Ocean (Bloomer et al., 1995; Ishizuka et al., 2006; Reagan et al., 2013; Stern & Bloomer, 1992), which likely extended southward into Vitiaz-Tonga-Kermadec (VTK) zone (Stern et al., 2012) through Solomon (Tapster et al., 2014), Vanuatu (Buys et al., 2014) and Fiji (Cluzel & Meffre, 2018), giving birth to one of the largest subduction systems on Earth. In this area, west-dipping intra-oceanic subduction started in the early Eocene (~50 Ma), involved cold and dense western Pacific lithosphere, thus giving birth to a steeply-dipping non-accretionary wedge. In contrast to IBM (VTK), the almost coeval New Caledonia subduction started earlier, before 56 Ma, was east- or northeast-dipping, involved young and buoyant lithosphere and therefore was shallow-dipping and strongly accretionary (Cluzel et al., 2001, 2012a). As a consequence, the Eocene New Caledonia wedge gave birth to fore-arc accretion and deep subduction of oceanic crust fragments (Cluzel et al., 2001, 2017).

In this article, the process and timing of subduction erosion will be addressed by determining the age and provenance of *mélange* rocks exhumed along the subduction channel. Direct evidence for subduction erosion and *mélange* derivation from both the hanging wall and the footwall of a subduction zone comes from the Peridotite Nappe of New Caledonia, which represents the exposed roof of the Eocene paleo-subduction zone,

and from mélange units squeezed in the HP-LT belt. Block provenance in the metamorphosed mélanges was assessed geochemically and through U-Pb zircon geochronology.

2. Geological setting

New Caledonia is an elongate (400 km x 45 km) island forming the emerged northern part of the Norfolk Ridge, a narrow submarine ribbon of continental nature bound to the southwest by the New Caledonia Basin and to the northeast by the Loyalty Basin. The Norfolk/New Caledonia Ridge is connected southward to New Zealand and forms the northern part of a continent-size largely submarine area of thinned continental crust termed Zealandia (Luyendik, 1995; Mortimer et al., 2017), originally connected to Southeast Gondwana and rifted during the Late Cretaceous.

The geology of New Caledonia is characterised by: (1) a pre-Late Cretaceous basement formed of amalgamated arc-derived terranes (Meffre, 1995; Maurizot et al., 2020a), which relate to the southeast Gondwana margin; (2) Late Cretaceous to late Eocene sedimentary cover (Maurizot et al., 2020b); (3) Eocene high-pressure metamorphic belt exposed in the northern part of the island (Maurizot et al., 2020c); and, (4) two large allochthonous terranes emplaced during the Eocene, the Poya Terrane and Peridotite Nappe, which together represent almost one half of island's surface (Figure 1a); (Cluzel et al., 2012a; Maurizot et al., 2020c).

In northern New Caledonia where the HP-LT belt is exposed, five litho-tectonic units are recognized from the top downwards: (1) Peridotite Nappe, (2) Pouébo Mélange, (3) Intermediate Mélange, (4) Poya Terrane, (5) Parautochthonous substrate.

The Peridotite Nappe of New Caledonia (Avias, 1967), resulted from obduction of the Loyalty Basin lithosphere upon the continental Norfolk/New Caledonia Ridge (Collot et al, 1987) when the latter obliquely entered the subduction zone (Cluzel et al., 2001, 2017). It originally covered most of the island and further south, part of the submarine Norfolk Ridge (Patriat et al., 2018); however, several phases of erosion on the island only let isolated tectonic klippe spread along the west coast, a larger unit termed "Massif du Sud" in the south of the island, and insular extensions in Belep Islands (north) and Isle of Pines (south).

Inception of the intra-oceanic subduction that eventually led to obduction is time-constrained by the granulite-facies metamorphic sole, dated at *ca* 56 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$ on hornblende and U-Pb on zircon overgrowths) (Cluzel et al., 2012b). From to the thermal gradient recorded by the metamorphic sole (60°C/km) it may be inferred that subduction started near the ridge and that the lower plate (the South Loyalty Basin), which was young and buoyant at subduction inception, was shallow dipping. Such a thermo-mechanical regime likely resulted for a while in strong frictional forces at the plates interface (for a review, see Dmowska & Eckström Eds, 1993) until older and colder parts of the lower plate were involved into the subduction. Cooling of the subduction zone is documented in New Caledonia by the change of latest Paleocene HT-LP gradient of the metamorphic sole (~60°C/km); (Cluzel et al, 2012a) into mid-Eocene HP-LT gradient (~10°C/km) recorded by eclogites of the HP-LT belt (Clarke et al., 1997; Carson et al., 1999; Fitzhebert et al., 2003; Vitale-Brovarone et al., 2017).

The Poya Terrane (or Poya Nappe) (Cluzel et al., 1997, 2001) consists of a main unit 10 to 20 km wide, which extends for over 160 km along the west coast of the island and km-sized lenses pinched beneath the Peridotite

1 Nappe of the Massif du Sud, the northernmost massifs and along the east coast. It is composed of oceanic
2 basalts associated with abyssal argillite (2/3 of the unit) and passive margin turbidites intruded by thick dolerite
3 sills (1/3).

4 The Eocene HP-LT metamorphic belt comprises two terranes: a dominantly metasedimentary unit referred
5 to as the Diahot-Panié Terrane and a mafic-ultramafic mélange termed Pouebo Terrane. The Diahot-Panié
6 Terrane is principally composed of terrigenous metasediments and metavolcanic rocks of the Late Cretaceous-
7 Eocene cover and volumetrically minor metavolcaniclastic rocks representing the pre-Late Cretaceous
8 basement terranes. Little is known on the pre-Late Cretaceous part of this terrane, which is largely exposed in
9 the poorly explored Mt Panié Massif. The Pouebo Terrane is formed of cm- to km-size blocks enclosed in a
10 sheared metaserpentinite (i.e. chlorite, talc and tremolite-bearing) matrix.

11 The post-Early Cretaceous geological evolution may be summarized as follows:

- 12 - The rifting period (Coniacian to Santonian, 90 Ma to 84 Ma) is recorded on the Norfolk Ridge by
13 terrigenous coal-bearing shallow water marine sedimentation and moderate volcanic activity. Coeval
14 coarse- to medium grain turbidites and black shales of the Diahot-Panié Terrane formed as deeper
15 water half-graben deposits, while more distal passive margin turbidites are found in the Kone Facies
16 (Poya Terrane). Marginal rifting is generally attributed to the eastward rollback of the west Pacific
17 subduction zone, although no trace of a Late Cretaceous volcanic arc has been hitherto discovered
18 (Cluzel & Meffre, 2018);
- 19 - The post-rift (oceanization) period is represented by Campanian to Lower Eocene (84 Ma to 44 Ma)
20 fining upward sequence of siltstone, argillaceous black cherts, siliceous micrite and finally micrite,
21 which recorded thermal subsidence and Eocene global warming (Maurizot et al., 2020b), meanwhile,
22 marginal basins opened on both sides of the Norfolk Ridge;
- 23 - At the end of the Paleocene, a new NE-dipping subduction zone started to the NE of New Caledonia
24 and consumed the basin located to the east of Norfolk Ridge, termed South Loyalty Basin (Cluzel et al,
25 2001). When the northern part of the Norfolk Ridge reached the trench, the fore-arc bulge of the
26 Australian Plate provoked local southward propagating emersion and tectonic instability, and thus a
27 change of sedimentary regime from pelagic platform into upward coarsening middle to upper Eocene
28 turbiditic foreland. The latter witness the syn-sedimentary thrusting of approaching parautochthonous
29 (Montages Blanches Nappe) and allochthonous (Poya Terrane) units (Maurizot & Cluzel, 2014);
- 30 - Finally, the Loyalty Basin was in turn underthrust by the Norfolk Ridge and obducted at the end of the
31 Eocene-early Oligocene without a known sedimentary record.

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33 **3. Analytical procedures**

34 Gathering a sample set representative of ophiolitic mélanges is an uncertain task and a large number of
35 samples is needed to prevent omission of minor but significant elements. The data presented in this article is
36 based upon 108 samples from the Pouebo Terrane and Intermediate Mélange coming from already published
37 data (Cluzel et al., 2001, Spandler et al., 2005, 2006) and newly sampled material (online supplementary
38 material is available at <https://hal.archives-ouvertes.fr/hal-02495589>, see “Fichiers annexes”:

CluzelSubdErosionSuplData.xlsx). Correlation was based upon a data base of 113 samples of Lower Eocene dykes from the Peridotite Nappe (Cluzel et al., 2006 and unpublished data) and 171 samples from the Poya Terrane (Cluzel et al., 2001, 2017; Eissen et al 1998).

The new samples have been analysed for whole-rock geochemistry at the Service d'Analyse des Roches et Minéraux (CNRS-CRPG Nancy, France) by ICP-AES for major elements and ICP-MS for trace elements and rare earth elements (REE). For details about analytical procedures, see Carignan et al. (2001), accuracy and detection limits are provided at: <http://helium.crpq.cnrs-nancy.fr/SARM/pages/roches.html>.

U–Pb zircon analyses were performed on an Agilent 7500cs quadrupole ICPMS with a 193 nm Coherent Ar–F gas laser and the Resonetics S155 ablation cell at the School of Earth Sciences, University of Tasmania. Each analysis was pre-ablated with 5 laser pulses to remove the surface contamination then the blank gas was analysed for 30 s followed by 30 s of zircon ablation at 5 Hz and ~ 2 J/cm² using a spot size of 13 μ m; keeping U and Th in the pulse counting mode of detection on the electron multiplier. A flow of He carrier gas at a rate of 0.35 l/min carried particles ablated by the laser out of the sample chamber to be mixed with Ar gas before transfer to the plasma. Elements measured include ⁴⁹Ti, ⁵⁶Fe, ⁹⁰Zr, ¹⁷⁸Hf, ²⁰²Hg, ²⁰⁴Pb, ²⁰⁶Pb, ²⁰⁷Pb, ²⁰⁸Pb, ²³²Th and ²³⁸U with each element being measured sequentially every 0.16 s with longer counting time on the Pb isotopes compared to the other elements. The down hole fractionation, instrument drift and mass bias correction factors for Pb/U and Pb/Th ratios on zircons were two analyses on the primary standard (91500 of Wiedenbeck et al., 1995) and one analysis on each of the secondary standard zircons (TEMORA 1 of Black et al., 2003; GJ-1 of Jackson et al., 2004) analysed at the beginning of the session and every 16 unknowns using the same spot size and conditions as used on the samples to provide an independent control to assess accuracy and precision. Additional secondary zircon standards (Mud Tank of Black and Gulson, 1978; Plšovice of Sláma et al., 2008) were also analysed. The correction factor for the ²⁰⁷Pb/²⁰⁶Pb ratio was calculated using six analyses of the international glass standard NIST610 analysed throughout analytical session and corrected using the values recommended by Baker et al. (2004) to provide an independent control to assess accuracy and precision. (online supplementary material is available at <https://hal.archives-ouvertes.fr/hal-02495589>, see “Fichiers annexes”: dataU-Pb_zircons_Melange.xlsx)

Incompatible trace element ratios, which are considered to reflect source compositions and melting processes, are widely used to discriminate the various magmatic rock series. In contrast, mobile elements (Ba, Rb, K, P, Sr), which display erratic variations under metamorphic conditions cannot be considered. In this study chondrite-normalized REE patterns (Evensen et al., 1978), NMORB-normalized expanded REE and trace-elements patterns (Sun & McDonough 1989), Zr/TiO₂ vs. Nb/Y binary diagram (Winchester & Floyd, 1977) and Hf/3-Th-Ta ternary diagram (Wood, 1980; Vermeesch, 2006) were used for geochemical discrimination.

Key for abbreviations: NMORB: normal mid-oceanic ridge basalt; EMORB: enriched (or undepleted) MORB; OIB: oceanic island basalt; BABB: back-arc basin basalt; IAT: island-arc tholeiite; IAB: Island-arc basalt; HT-LP high temperature -low pressure (metamorphic rocks/gradients).

4. Geological features of allochthonous terranes

4.1. Peridotite Nappe

The Peridotite Nappe is representative of depleted supra-subduction mantle lithosphere as it is dominantly composed of harzburgite (>80%), dunite and minor lherzolite (in northern massifs only) (Marchesi et al., 2009; Pirard et al., 2013; Prinzhofer, 1981). Owing to their depletion in incompatible elements compared to primitive mantle composition, highly depleted residual harzburgites underwent (roughly) 20-25 % partial melting (Prinzhofer, 1981), while Nd-Sr and Pb Isotope signatures and trace-elements petrological modelling suggest that prominent depletion was due to one episode of dry melting followed by supra-subduction re-melting assisted by fluids influenced by subducted sediments (Secchiari et al., 2019).

The harzburgites-dunite association is overlain by dunite, pyroxenite, websterite and gabbro cumulates (Prinzhofer, 1981). Cumulate websterite and gabbro probably crystallized in equilibrium with depleted melts intermediate between boninite and island-arc tholeiite (Marchesi et al., 2009; Pirard et al., 2013; Cluzel et al., 2016; Secchiari et al., 2018), which at present are not preserved. Whole rock and mineral chemical constraints on lherzolites allow a polyphase evolution to be drawn, from oceanic accretion to mantle metasomatism during subduction (Marchesi et al., 2009; Secchiari et al., 2016, 2019; Spandler et al., 2004a; Ulrich et al., 2010).

A highly sheared, phacoid-bearing serpentinite sole, 20-300 m thick, generally indicates top-to-the-southwest emplacement kinematics (Quesnel et al., 2013, 2016). Thrust-related deformation rapidly vanishes upward; in contrast serpentinitisation, decreasing in degree upward persists up to 2000 m above the base of the ultramafic allochthon.

The Peridotite Nappe is crosscut by a wide variety of dykes and sills emplaced between 55 Ma and 47 Ma (early Eocene; Cluzel et al., 2006, 2016), which are absent in the underlying Poya Terrane. These intrusive rocks comprise medium to coarse-grained rocks (sills and dykes), the compositions of which vary from ultramafic (pyroxenite and hornblende) to mafic (hornblende-gabbro, diorite), and felsic (leucogabbro, leucodiorite and granite) and minor dolerite dykes. Dolerite dykes crosscut all levels of the Peridotite Nappe, including the gabbro cumulates, while the other dykes and sills are restricted to the ultramafic part of the allochthon. Boudinaged dykes are present in the serpentinite sole as well. Some dykes are strongly foliated, isoclinally folded or mylonitized as a consequence of syntectonic intrusion in shear fractures. With only a few exceptions, the original composition of the dykes (geochemical and mineralogical) is surprisingly well preserved in spite of widespread serpentinitisation of the host rock; however, some of them display secondary parageneses due to post-magmatic recrystallisation. In the latter, amphibolitisation is common with hornblende or tremolite depending upon initial composition, temperature and fluid/rock ratio. A few metasomatised dykes display high Ca-Sr and low SiO₂ contents and can be termed rodingites (Python et al., 2007, 2011) and contain secondary hydro-grossular, pink zoisite, prehnite, and clinochlore.

4.2. Poya Terrane

The Poya Terrane (or Poya Nappe) (Cluzel et al., 1997, 2001, 2017) is a composite litho-tectonic unit made of two contrasting sub-units: i) Poya Terrane Basalts (PTB), which consist of massive and pillow basalts associated with Campanian to lower Eocene red, green, gray or whitish abyssal argillite and minor pink micrite

(Aitchison et al., 1995, Cluzel et al., 2001), the PTB comprise N-MORB, E-MORB, BABB and OIB-type basalts (Cluzel et al., 2001, Eissen et al., 1998), and ii) the Kone Facies (KF, Carroué 1972), which consist of Coniacian-Santonian yellowish sandstone, turbidites with minor dark red or dark grey argillite on top, intruded by 10m to 100m thick early Eocene (~55 Ma) E-MORB sills, referred to as Kone Facies Dolerites (KFD); (Cluzel et al., 2017) (Figure 1).

The structure of PTB consists of upright fault-bounded slices a few 10 ms thick and a few 100 ms long. The top of the unit is constrained by the almost horizontal basal thrust of the Peridotite Nappe. At the base, the PTB rest upon parautochthonous basement units through a shallow dipping thrust, which sharply truncates the basalt slices, giving the unit a broad synform structure. The PTB was scraped off the uppermost oceanic crust of the lower plate during the subduction of the South Loyalty Basin. The tectonic slices were first accreted to the fore-arc region of the Loyalty Arc then thrust over the leading edge of the New Caledonia Ridge. When it reached the margin, the PTB dragged large parts of the passive margin turbidites of the Kone Facies and the whole set was thrust upon autochthonous/parautochthonous rocks of the New Caledonia Ridge. Meanwhile, portions of the Poya Terrane (PTB and KF) were dragged down into the subduction zone and recrystallized into blueschists; as a consequence, discontinuous slivers of metamorphosed Poya Terrane rocks crop out along the east coast of New Caledonia (Hienghène region) on the northern side of the Mt. Panié anticlinorium, cored by Pouebo Eclogite Mélange (or Pouebo Terrane, see below).

4.3. Lenticular serpentinite bodies ("fils serpentineux" of Routhier, 1951)

Upright serpentinite slices are widespread; they are randomly distributed within the substrate of the Peridotite Nappe, while not always clearly connected with the serpentinite sole so far. These strongly sheared serpentinite bodies, a few 100s m to a few kms long and a few 10s to a few 100s m wide, contain rare blocks (phacoids) of serpentinitised peridotite and fragmented/boudinaged lower Eocene dykes (Cluzel et al., 2006, 2016). Such serpentinite slices are scarce in Poya Terrane Basalts except in the northern part of the terrane between Kaala and Tiebaghi massifs where they pass northeastward into the sedimentary substrate. These serpentinite slices are difficult to distinguish from the similar serpentinite lenses widespread in the pre-Late Cretaceous basement, especially in the Boghen Terrane, a greenschist-blueschist facies subduction complex composed of *ca* 25% serpentinites (Cluzel & Meffre, 2002; Maurizot et al., 2020a). However, pre-Late Cretaceous serpentinites apparently never contain supra-subduction dykes and may be distinguished on this basis.

Some deeply rooted serpentinite lenses are overlain by gently synformal peridotite bodies (Peak Ougne, Ouehat summit); (Figure 2 & 3).

5. The Eocene HP-LT belt of northern New Caledonia

The metamorphic belt extends over 225 km along the northeastern coast of New Caledonia from Baaba Island in the far north to Houailou (Figure 1). It has been extensively studied in its northern part along the Koumac-Ouegoa-Amos transect but remains largely underexplored between Amos Pass and Mt Panié. Four main lithotectonic units may be distinguished on the basis of lithology and metamorphic grade: (1) Montagnes

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3 1 Blanches Nappe, (2) Diahot-Mt Panié Terrane, (3) Pouebo Terrane (or Mélange) and (4) Intermediate Mélange
4 2 units. The metamorphic grade increases along a SW-NE section from subgreenschist facies (anchizone); (250°C;
5 3 0.3 GPa); (Potel et al., 2006) to eclogite facies (620°C; 2.4 GPa) (Clarke et al., 1997; Fitzhebert et al., 2003;
6 4 Vitale-Brovarone & Agard, 2013) over a distance of *ca* 20 km. Such a steep increase implies that “isograds”
7 5 across strike are actually fault/thrust boundaries between sliced units of different yet NE-ward increasing
8 6 metamorphic grade (Vitale Brovarone & Agard, 2013). Abrupt changes in strain facies (style and intensity of
9 7 ductile deformation) are generally associated with these boundaries, which may be or not, underlined by
10 8 serpentinite or mélange slices. In contrast, the metamorphic grade gently decreases southeastward (along
11 9 strike).

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18 11 5.1. Parautochthonous low grade unit : Montagnes Blanches Nappe
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20 13 This collective term (Maurizot 2011) refers to a complex set of tectonic sub-units several km in size, and
21 14 smaller tectonic slices of Late Cretaceous to Eocene sedimentary rocks forming the parautochthonous
22 15 substrate of the Poya Terrane. This unit has no known basement and was possibly detached from the
23 16 underlying (autochthonous ?) sequence at the boundary between Maastrichtian siltstones and Paleocene black
24 17 cherts (Maurizot, 2011); however, this scheme does not fully fit with the observed complexity of this unit,
25 18 which locally (Bourail region) contains tectonic slices scraped from the “basement” terranes (Permian
26 19 greywackes, Boghen metabasalts, serpentinite, etc). Due to facies similarity, it is difficult to precisely locate the
27 20 boundary between this unit and the Diahot-Panié Terrane (see below). Based upon illite crystallinity, illite–
28 21 muscovite b cell dimension, reflectance and Raman spectrometry of organic material, a maximum temperature
29 22 of 250°C at a pressure of 0.3 GPa was estimated (Potel et al., 2006).

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36 23 5.2. Diahot-Panié Terrane
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38 25 This metamorphic unit has about the same lithology as the autochthonous/parautochthonous sedimentary
39 26 cover except for the Late Cretaceous part, which displays distinctive features. Compared to the proximal
40 27 Formation a charbon, it displays more distal and deep water characteristics, and is composed of two members
41 28 that record the Late Cretaceous rifting of the Gondwana margin. The Tendo Formation is composed of sandy
42 29 and silty turbidites and minor poorly sorted conglomerates with cobbles up to 1.5 m of probable mass-flow
43 30 origin. The Pilou Formation is formed of monotonous black shales (slates) associated with volcanic and
44 31 volcanoclastic rocks and polymetallic sulfide ores. Due to ductile thrusting, isoclinal folding and the lack of
45 32 marker horizons, the original thickness of this unit remains unknown. Near Colnet Peak, Albian blueschist facies
46 33 metagreywackes closely associated with Late Cretaceous metasediments (Cluzel et al., 2010) represent the pre-
47 34 Late Cretaceous basement terranes; the poorly studied rest of the Diahot-Panié Terrane remains
48 35 stratigraphically uncorrelated. In spite of the apparently low grade metamorphism of carbonaceous schists due
49 36 to complete retrogression during exhumation, it appears that the Diahot-Panié Terrane reached eclogite facies
50 37 peak conditions (1.7 GPa; 500°C) recorded in some Late Cretaceous mafic metavolcanic rocks (Fitzherbert et al.,
51 38 2003, 2005). The tectonic structure of the terrane consists of two parts: to the west, along the western bank of
52 39 Diahot Valley, isoclinal folds associated with upright foliation define narrow linear ribbons of various
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lithologies; in contrast, the Pam Peninsula and in a general fashion the Mt Panié-Colnet Massif delineates a broad foliation anticlinorium cored by the Pouebo Terrane and limited to the NE by the linear boundary of the Loyalty Basin. The stretching lineation associated with the regional foliation has an average N70E trend (Cluzel et al., 1995) oblique to the average N130E strike of the HP-LT belt.

5.3. Intermediate Mélange units

Mélange lenses, a few 100 ms to a few kms wide and several kms long, occur within metamorphosed metasedimentary units, but are absent in the low-grade westernmost units (Montagnes Blanches Nappe). Blocks in these mélange slices are basalt, red chert, dolerite, leuco-gabbro/diorite, and granite with the same metamorphic grade as the neighbouring rocks. The serpentinite matrix of the mélange clearly differs from the serpentinite sole of the Peridotite Nappe because they exhibit metamorphic recrystallization marked by the northeast-ward increasing development of talc, chlorite and tremolite. These mélange slices are referred to as “intermediate” because they display features (see paragraph 6 below) transitional between that of serpentinite slices derived from the Peridotite Nappe and that of the Pouebo Terrane.

5.4. Pouebo Terrane

The Pouebo Terrane (Cluzel et al., 1994, 2001) is a typical tectonic mélange (e.g. Festa et al., 2010 and references therein) composed of cm- to km-size blocks (Figure 4a & 4c) enclosed in a (meta)serpentinite matrix. The best outcrops of the terrane are exposed along the provincial road on the northern slope of Amoss Pass. Most blocks are mafic and contain mineral assemblages typical of the blueschist facies (garnet, lawsonite, glaucophane) with sparse eclogite remnants and retrograde/reaction rims a few cm to 1 m thick, composed of actinolite, chlorite, magnetite and talc. Contorted blocks of well-foliated retrograde albite schist/gneiss and incompletely retrograded blueschist (Figure 4b) are enclosed in the serpentinite. Their foliation is crosscut at right angle by that of serpentinite matrix, a feature that suggests incorporation of these blocks in the mélange at least partly during the exhumation of eclogite-facies rocks. Locally (e.g., Balade Beach); (Figure 1), a metamorphosed (although weakly deformed) polygenic cobble conglomerate is composed of mafic elements and a few felsic rocks up to 1 m in size (Figure 4e & 4f). Outcrop conditions do not allow the observation of relationship between this peculiar facies and the rest of the unit; however, it most probably represents one single block embedded in the mélange.

Although a large part of the Pouebo Terrane is only exposed in remote and rugged areas surrounding Mt Panié, and thus is poorly known, it seems that the amount of serpentinite matrix decreases along strike from NW to SE. Metasedimentary elements increase up to 50% in the Hienghène region where blocks of Maastrichtian black cherts are mixed with mafic blocks. In the south-easternmost known exposure of the Pouebo Mélange, at Anse Ponandu (4.5 km to the SSE of Touho village); (Figure 1), the mélange contains mafic (E-MORB); (Cluzel et al., 2001, this study) and metasedimentary rocks, which include meta-conglomerate blocks identical to those of Late Cretaceous Tendo Formation (see 5.2 above) apparently without serpentinite matrix.

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6. Nature and origin of blocks in intermediate mélange units

Elongated mélange lenses crop out discontinuously within the meta-sedimentary rocks of the HP-LT belt (Figure 2); in the following paragraph they will be described from SW to NE, i.e. at increasing metamorphic grade across strike.

6.1. Mamelons Verts Unit

A 6 km long – 1 km wide lens of serpentinite-rich mélange crops out immediately to the north of the main road from Koumac to Poum (Figure 2, loc. 1). Overall, this unit forms a tight synform oriented NW-SE, which thins out laterally and rests against isoclinally folded and steeply dipping (70°NE on av.) Maastrichtian-Paleocene chert and micrite. The mélange is composed of strongly foliated phacoid-bearing serpentinite. Metamorphic recrystallization (i.e. talc occurrence) is not evident on outcrop. Serpentinite foliation is parallel to that of the surrounding rocks. Blocks of various nature, 10 cm to several 10s m in size, represent approximately ¼ of the mélange volume. Undeformed serpentinitised harzburgite blocks/porphyroclasts are found throughout the unit. The other blocks are gabbro, dolerite, basalt and red chert, which most probably represent elements of oceanic crust, and occasionally dark-blue (chlorite ?) schists. Some mafic rocks have a negative slope on multi-elements spiderdiagrams, display strong Nb and Ta and to a lesser extent, Ti negative anomalies. They are intermediate between IAT (island-arc tholeiite) and IAB (island-arc basalt) and thus similar to the subduction-related rocks of the Haute Néhoué Unit (see below) and display the same positive anomaly in Zr and Hf (Figure 7a). Others are more depleted in incompatible elements and display a positive slope with almost unnoticeable Zr-Hf anomalies and may be related to IAT series. Blocks of leucogabbro, which very much resemble the Lower Eocene dykes of the Peridotite Nappe are found throughout the unit. Clasts of dark-blue(chlorite?) schist-have not been formally correlated; however, they do resemble the Late Cretaceous low grade metasediments of the Pilou Formation.

6.2. Ougne-Ouehat Unit

The Ougne (Uny) and Ouehat (Mwaida) mountain peaks are located in a sparsely populated area 11 km to the NW of the main road from Koumac to Ouegoa (Figure 2, loc. 2). They are the highest of a series of hills, at 200 to 300 m elevation, which belong to a double belt of mélange, capped by peridotite klippe. The base of the klippe and the serpentinite sole (10-20m thick), which underlies them, are folded (dip < 45°) and define a series of open synclines. Beneath the peridotites, the serpentinites interleaved with mélange lenses, are deeply rooted within tightly folded Late Cretaceous to Eocene metasediments and extend laterally for more than 15 km. The composition of the blocks in mélange lenses displays much diversity (granite, leucogabbro, diorite, red chert, basalt, dolerite). Dolerites display EMORB geochemical features (Figure 8), while felsic rocks (granite and leucodiorite) are typically subduction-related (IAB) (Figure 7f & 8) and similar to rocks of the Haute Nehoue Unit (see below).

Despite their diversity, the felsic blocks sampled in the mélange yielded very similar U-Pb zircon ages (leucodiorite #POugn 1: 54.02 ± 0.46 Ma; granite #Ouehat 1: 54.12 ± 0.47 Ma; diorite #Ouehat 5 : 53.4 ± 0.9 Ma) (Figure 10), and are coeval with the Lower Eocene dykes of the Peridotite Nappe.

6.3. Haute Nehoue Unit

This small unit *ca* 1 km-wide is located at the northwestern end of an 11 km-long NW-SE trending serpentinite sliver (Figure 2, loc. 3). It is mainly composed of a coherent set of mafic and intermediate rocks discontinuously surrounded by serpentinites. The *mélange* lens is in faulted contact in the south with isoclinally folded Late Cretaceous black cherts and Paleocene micrite, and to the north with Late Cretaceous black cherts. It is composed of remarkably fresh although metamorphosed greenish pillow lavas and parallel fine to medium-grained felsic dykes (Figure 5a) without obvious tectonic deformation. Geochemical characterisation based upon “immobile” trace elements ratios (Zr/TiO₂, Nb/Y); (Winchester & Floyd 1977) delineate one single fractionation trend from basalt-andesite to dacite (diorite) composition (Figure 6). Chondrite-normalized REE patterns display prominent LREE enrichment and flat HREE patterns (not shown). Rare earth and incompatible trace elements extended patterns, and Hf-Th-Ta ratios indicate compositions intermediate between island-arc tholeiites (IAT) and island-arc basalts (IAB) (Figure 7a & 8). Parallel REE and trace elements patterns and similar plots on the Hf/3-Th-Ta triangular diagram (Wood, 1980); (Figure 8) confirm that they form one single differentiation suite. The most evolved dyke (medium-grained diorite #NHE10) has yielded a U-Pb zircon age of 54.7 ± 0.8 Ma (Figure 10a), which owing to the geochemical similarity, most probably represents the age of the whole sequence.

This subduction-related unit is bounded to the southwest by dolerite of E-MORB affinity (sample#NHE3, flat REE pattern, Hf/Th= 6.7, Th/Ta=1.0); however, the boundary is masked by river alluvium. To the northeast, the sequence has a (block/faulted ?) boundary with pillow lavas of BABB composition (sample#NHE6, LREE-depleted pattern, Hf/Th= 19.8, Th/Ta=0.9, (Nb/La)_n=0.56).

At 2.5 km to the southeast along strike, upright foliated serpentinites contain boudinaged blocks of serpentinitised harzburgite, basalt and leucogabbro. Foliation and stretching lineation in serpentinites (S1: N130E-70NE; L1: N70E) are similar to that found in surrounding schists and likely result from the same tectonic event.

6.4. Arama Unit

The main road from Koumac to Arama village crosscuts at Arama Pass a *mélange* lens 500 m wide and 2.5 km long with a NNE-SSW strike (Figure 2, loc. 4). The *mélange* contains blocks of metamorphosed pillow basalt, red chert, metadolerite and granitoid in a matrix of talc-bearing meta-serpentinite. The local occurrence of glaucophane-garnet-bearing mafic blocks (Routhier 1953; this study) and the widespread development of talc in the serpentinite matrix would suggest that the metamorphic grade in *mélange* is higher than that of the surrounding schists. However, retrograde recrystallisation in the presence of excess water has erased all traces of high-grade parageneses (blueschist or eclogite) in metasediments (carbonaceous schists) of the Diahot Terrane; in contrast, they are well preserved in the associated metamorphosed mafic rocks (Fitzherbert et al., 2005). The nearby meta-basalts and meta-andesites of the Diahot schists (Pilou Formation) display the same blueschist facies assemblages and therefore have the same metamorphic grade. The occurrence of oceanic basalt features (pillows, red cherts) as well as NMORB and EMORB geochemical composition of mafic blocks allow correlation with Poya Terrane rocks. The granitoid block enclosed in meta-serpentinite (sample # ARM 9)

(Figure 5b) has geochemical affinities intermediate between IAT and IAB-series (LREE enrichment, negative Nb and Ta anomalies, $Hf/Th = 2.9$, $Th/Ta = 4.4$); (Figure 8) and resemble felsic rocks of the Haute Nehoué unit.

At the northwest entry of Arama Village, a talc-rich lens of serpentinite mélange, 2 km long, crops out with a N-S strike. It looks very similar to the Pouebo eclogitic mélange and contains blocks of glaucophane-bearing metabasalt a few cm to several m wide enclosed in the talc-rich metaserpentinite matrix. In addition to mafic blocks of EMORB and OIB affinity, one light blue medium grain rock of IAT/IAB affinity (sample #ARM 8 geochemically similar to #ARM 9). Along the border of one large mafic block, a thin band of breccia is composed of angular cm- to dm-size clasts of various lithologies, which include metabasalt identical to that of the large block, (Late Cretaceous ?) grey schist and white fine-grain limestone similar to the Paleocene-lower Eocene micrite (Figure 5c & 5d); however, this is the only known occurrence of such facies in this unit. The rock features of this outcrop means that the polygenic breccia and the basalt block were associated before being enclosed in the serpentinite matrix.

6.5. Baviolet Unit

A large serpentinite slice 3 x 11 km oriented WNW-ESE is located half-way between Kaala-Gomen and the Mt Panié (Figure 2, loc. 5). The main serpentinite unit contains tectonic lenses of schistose Late Cretaceous microconglomerate (Tondo Fm.) and rare mélange lenses. The unit rests at shallow angles ($<30^\circ$) upon moderately metamorphosed Late Cretaceous schists. It is overlain by several shallow-dipping non-foliated (but serpentinitised) peridotite lenses 50 to 500 m wide. Downwards and laterally, it extends over ca 40 km into several narrower (ca. 50 m thick) and steeper slices of foliated serpentinite. Due to the difficult access and tropical weathering, mélange lenses were not sampled; however, a deformed felsic dyke, 20 m thick, which crops out along the main track crossing the Central Range from Hienghene to Gomen at 3.8 km to the ENE of Baviolet Summit could be sampled (sample #HCLN 8). It contains rare micropegmatoid pockets, hornblende lenses, and ultramylonite bands orthogonally crosscut by tension cracks filled with quartz-albite, albite-tremolite or tremolite only, denoting ductile deformation at about the same metamorphic grade as the enclosing metasediments. Its extreme depletion in incompatible elements (Figure 7f) makes it an unusual magmatic rock, while its modal composition of Ca-plagioclase (~45 wt%) and diopside (~25 wt%) makes it similar to some metasomatised Ca-rich rodingites. The Zr content below the detection limit of standard ICP-MS analysis (1.5 ppm), is too low for crystallizing zircons large enough to be extracted; however, REE pattern shows a positive Eu anomaly due to plagioclase, which also characteristically appears in some Lower Eocene dykes of the Peridotite Nappe (Cluzel et al, 2006); (Figure 9).

7. Nature and origin of blocks in the Pouebo Terrane

Due to tropical weathering and rugged topography, outcrops of the Pouebo Mélange are restricted to the shoreline, creek valleys (mostly waterfalls) and a few road sides; as a consequence mafic boulders, which are resistant to weathering and erosion were probably oversampled compared to other lithologies (e.g., felsic rocks, serpentinitised peridotite, ...).

7.1 Sedimentary rocks

The volumetrically minor metasedimentary blocks are metamorphosed abyssal argillites similar to that of the Poya Terrane and rocks from the Late Cretaceous to Paleocene sedimentary cover (siltstone, chert, limestone); (Maurizot et al., 2020c). Detrital zircon populations from metasandstones and siltstones show features similar to Late Cretaceous sediments (Pirard & Spandler, 2017),. Because of a prominent Santonian-Campanian detrital zircon population (88-77Ma) the protolith of these rocks was likely derived from the distal Diahot Terrane or merely from passive margin turbidites of the Kone Facies (Poya Terrane) rather than from the proximal Formation a charbon, in which this population is minor (Cluzel et al., 2011, 2017).

7.1 Ultramafic rocks.

In addition to the well-foliated meta-serpentinite matrix, rare blocks of ultramafic rocks a few metres wide have partly or totally escaped shearing deformation (Figure 4b & 4d), most of them are composed of massive talc- and chlorite-bearing meta-serpentinite (Spandler et al., 2008). Almost pure steatite with minor tremolite (soapstone) appears in foliated and unfoliated bodies. However, larger ultramafic blocks such as the Pwa Radèn Block (Yambé) approximately 1 x 1 km, have preserved their original composition except at their limits, which are surrounded by meta-serpentinite and mélange lenses that record the same metamorphic grade as the host rocks of the Pouébo Terrane. Specifically, olivine reappearance from metamorphosed serpentinite and eclogite-facies assemblages in associated mafic rocks from melange lenses suggest burial at $T < 500^{\circ}\text{C}$ and $P < 1.6$ GPa (Fitzherbert et al, 2004). Although no direct correlation exists with the Peridotite Nappe, this small unit has been interpreted as a preserved slab /mantle-wedge boundary dragged into the subduction at 50-60 km depth before its exhumation with Pouebo Terrane (Fitzherbert et al., 2004). It is worth noting that serpentinisation in these rocks predates the eclogite-facies peak metamorphism recorded by zircon overgrowths at 44 Ma (Spandler et al., 2006); and thus, has been developed more than 10 Ma before obduction.

7.2 Mafic rocks.

Despite apparent similarity, mafic blocks a few cm to 1 km in size (Figure 4a, 4b & 4c), mostly of basalt or basalt-andesite composition, display multiple magmatic affinities as suggested by incompatible trace element ratios. Four groups may be defined (numbered into brackets, refer to Figure 7 & 8):

- (1) LREE-depleted rocks with almost flat patterns, with a weak Nb negative anomaly, no Ta anomaly (Figure 7b), they plot in the MORB field of Wood's ternary plot (Figure 8) and thus can be termed BABB..
- (2) LREE undepleted rocks with a moderate negative slope, a very weak negative Eu anomaly and no Ta anomaly (Figure 7c), they plot in the low Hf/Th and low Hf/Ta part of the MORB field of Wood's ternary plot (Figure 8) and can be qualified of enriched (or undepleted) MORB (EMORB).
- (3) Alkaline rocks, which display strong negative slope on REE and trace-elements expanded patterns, no Nb-Ta anomalies (Figure 7d) and plot in the field of OIB-series on Wood's ternary plot (Figure 8).

(4) Subduction-related rocks showing a continuous range of composition with variable negative slope on expanded patterns, well defined Nb and Ta negative anomalies (Figure 7e). These rocks plot within the IAB/IAT domain on Wood’s diagram (Figure 8).

It is worth noting that the types 1, 2 and 3 are closely similar to Poya Terrane Basalts (Cluzel et al, 2001) and for the type 2, EMORB dolerites of the Kone Facies (Cluzel et al., 2017); (Figure 8); in contrast, the type 4; i.e., clearly subduction-related, was never found in the Poya Terrane.

7.3 Uncorrelated rocks

A few depleted to ultra-depleted rocks (Figure 7f) do not fit into the categories outlined above, they are generally termed felsic in the field; however, their white colour may also be due to abundant light-coloured amphibole and occurrences of massive anthophyllite and tremolite are not rare. Massive anthophyllite has incompatible elements contents below the detection limit and in contrast, is rich in compatible elements (Cr, Ni, Co); it probably comes from the reaction of serpentinite and mélange rocks during HP-LT metamorphism. Some Ca-rich rocks with supra-subduction signatures are depleted in incompatible elements but do not display high contents in Cr, Ni and Co. They are close to “rodingite” composition And thus very similar to rodingite-like dykes that crosscut the Peridotite Nappe (Cluzel et al 2006); (Figure 9) and some rocks of this type from the Pouebo Terrane yielded magmatic zircons dated at 55.7 ± 0.4 Ma (Spandler, 2006); (Figure 10), and thus are coeval to the lower Eocene supra-subduction dyke system of the Peridotite Nappe.

8. Discussion

The samples with BABB, EMORB and OIB affinities (types 1, 2 and 3) are geochemically similar to the basalts and dolerites of the Poya Terrane (Cluzel et al., 2001, 2017; Spandler et al., 2006); (Figure 8). In addition, the few available U-Pb radiochronological data from inherited zircon cores (Spandler et al., 2006; Pirard & Spandler, 2017) suggest that these mafic blocks have the same Late Cretaceous-Paleocene age as Poya Terrane rocks and that the latter are the most probable protoliths of parts of the mélange. EMORB dolerite sills of the Kone Facies, which yielded U-Pb zircon ages of ~55 Ma (Cluzel et al., 2017), are the best candidates for the largest mafic blocks of the mélange.

The occurrence of low-temperature mineral exsolution (thortveitite, yttrialite, and xenotime) at the boundary of the inherited magmatic core and the metamorphic zircon rims of some eclogites (sample #3007) allowed Spandler et al. (2004b) to suggest the occurrence of seafloor alteration before eclogite-facies metamorphism and thus a PTB protolith; i.e. originated from the lower plate of the subduction system. However, magmatic zircons cores at 55 Ma (Spandler et al., 2004a) younger than PTB and above all, unusual whole-rock composition compared with PTB (MORB-type oceanic crust of the lower plate), i.e. negative Nb-Ta anomalies (Figure 7f) slightly U-shaped REE patterns with prominent positive Eu anomaly (Figure 9), suggest a different interpretation. Supra-subduction dykes with a similar REE pattern and positive Eu anomaly are not unusual in the Peridotite Nappe, they have been emplaced at ~55-53 Ma (Figure 9) and were interpreted as slab melts derived from gabbro cumulates (Cluzel et al., 2006). These dykes may display evidence for (hydrothermal) alteration (see paragraph 4.1 above), which could account for the low temperature alteration

of magmatic zircon cores. Thus, at variance with the interpretation of Spandler et al. (2004b), these rocks could belong to the upper plate as well.

In contrast with mafic rocks of tholeiitic or alkaline composition, which closely fit with the composition of PTB (Figure 8), felsic rocks, which are extremely rare in the Poya Terrane and mafic blocks with supra-subduction zone geochemical features (type 4) had not been correlated yet. In addition, the available U-Pb ages for these rocks (55-54 Ma); (Spandler et al., 2006; Pirard & Spandler, 2017; this study); (Figure 9) are younger than that of PTB (Campanian-Eocene; i.e., 84-56 Ma), slightly postdate subduction inception (~56 Ma) and fit with the age range of the dykes of Peridotite Nappe.

The basalt-andesite pillow lavas and diorite dykes of the Haute Nehoue Unit and Ouehat-Ougne Peaks occur within the Intermediate Mélange and are (tectonically) associated with EMORB and BABB likely derived from PTB. They have no equivalent in the Poya Terrane (lower plate) and clearly differ from IAT dolerites of the Peridotite Nappe (upper plate), which are much more depleted (Figure 7a). They are also older (55-54 Ma vs. 50-47 Ma). It is suggested that they represent a small supra-subduction basin formed immediately after subduction inception and most likely resulting from incipient fore-arc extension.

The occurrence in the mélange of Lower Eocene mafic rocks with IAB/IAT (supra-subduction) affinity and thus derived from the upper plate is worth noting because they contrast with EMORB sills of the Kone Facies Dolerites (Poya Terrane), which come from the lower plate and have exactly the same U-Pb zircon age of ~55Ma.

Soon after subduction inception, depleted basalts termed fore-arc basalts (FAB) generally appear in the fore-arc region, this is the case in the IBM arc system (Hickey-Vargas et al., 2018). In contrast, the earliest magmas that appear above the Eocene subduction in New Caledonia are enriched in incompatible elements and strongly differ from FAB. The IBM subduction involved old Pacific lithosphere and was cold, while the Eocene subduction in New Caledonia initiated near the ridge and was hot; therefore, a different behaviour may be expected.

A comparison of IAB/IAT (type 2) and EMORBs (type 4) of the Pouebo Terrane (as well as EMORBs of the Poya Terrane); (Figure 7) shows some similarity. Their incompatible elements contents are similar and except Nb-Ta and to some extent Zr-Hf, the extended patterns are similar with the same negative slope (Figure 7c & 7e). Negative Nb and Ta anomalies and positive Zr and Hf anomalies are apparently overprinted on geochemical features coming from the melting of similar undepleted MORB-type sources (EMORB). Lower Eocene EMORB dolerite sills (KFD) were interpreted to form a laccolith associated with the transcurrent reactivation of the ancient Late Cretaceous passive margin due to the obliquity of the new trench with respect to the northern Norfolk Ridge (Cluzel et al., 2017). Thus, as a working hypothesis, some of the rocks with supra-subduction affinity, especially those found in the Intermediate Mélange, were possibly issued from a fertile mantle source of similar nature, which was pinched on top of the subduction zone and variably metasomatised by fluids released by the subducted slab. It is worth noting that strongly depleted IAT dolerites similar to those of the Peridotite Nappe (50-47 Ma) (Figure 7a) are absent in Pouebo Terrane and Intermediate Mélange as well. This undepleted supra-subduction melt source was very short-lived because no rock of this type younger than 55 Ma was found. Some of the felsic dykes of the Peridotite Nappe (54-52 Ma) share some features with

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the IAB-IAT of the Pouebo Terrane; however, they are more enriched in LILE and depleted in HFSE (Figure 7e). Compared to the Peridotite Nappe, Pouebo Terrane contains “normal” calc-alkaline rocks, while the former is dominantly crosscut by younger slab melts and ultra-depleted island-arc tholeiites.

A better characterisation of melt sources through isotope geochemistry is obviously needed; however, it is beyond the scope of this article. Melt sources in the fore-arc region seem to be increasingly depleted through time and a tentative chronology of these short-lived events may be established: (1) undepleted IAB from Haute Nehoue Unit (55 Ma); (2) IAB-IAT from the Pouebo Terrane (54 Ma); (3) depleted IAB-IAT from the Peridotite Nappe (54-52 Ma); and (4) ultra-depleted IAT from the Peridotite Nappe (50-47 Ma).

Rocks in mélange units clearly display a double provenance (Table 1). A large amount of mafic rocks similar to Poya Terrane Basalts come from the off scraping of the lower plate as already stated (Cluzel et al., 2001; Spandler et al., 2006); however, fore-arc rocks, which do not exist in the lower plate have been dragged into the subduction zone, and mixed with lower plate rocks and serpentinite. A different origin is needed for the supra-subduction dykes, which were injected first in the serpentinised mantle wedge before getting mixed with other mélange components.

9. Conclusion

On the basis of previously published interpretations (Cluzel et al., 2001, 2012, 2017) and the new data presented in this article, fore-arc magmatism, subduction erosion and *mélange* formation may be tentatively integrated in a comprehensive geodynamic model. The marginal basin formed to the east of the Norfolk Ridge during the Late Cretaceous-Paleocene (Figure 11a) started to close near the ridge at the end of Paleocene and resulted in a hot subduction recorded first by the HT-LP metamorphic sole. Hydration of the melting zone dragged in the subduction zone possibly generated the earliest supra-subduction magmas erupted in a transient fore-arc basin (Figure 11b). Forced shallow-dipping subduction dragged the leading edge of the upper plate (fore-arc crust and mantle); meanwhile, the uppermost oceanic crust of the lower plate (Poya Terrane Basalts) was scraped off, accreted and partly dragged into the subduction zone (Figure 11c). At ca 50 Ma the IBM (VTK) subduction started with an opposite vergence while the New Caledonia subduction zone was still active and consumed the Australian Plate. The progressively cooling subduction zone was progressively steepening and allowed the formation of gabbro-norite melts (Figure 11d) and finally formation of the Loyalty Arc. Finally, the subduction zone was progressively jammed by the arrival of the Norfolk Ridge, which resulted in obduction at the end of the Eocene (Figure 11d). It is worth noting that conceptual cross sections of Figure 11 cannot fully represent the tectonic evolution of the area, which partly occurred in a transcurrent regime. This point will be addressed in a forthcoming article.

The components of *mélanges* involved in the Eocene HP-LT metamorphic belt of New Caledonia not only come from the lower plate as previously established, but also involve major elements from the upper plate. Lower plate elements are dominantly derived from the Poya Terrane; i.e., basalts and red cherts. Scarce metasediments were also derived from the ancient passive margin (Late Cretaceous turbidites) and the sedimentary cover of the Norfolk Ridge (e.g., micritic limestone, black chert). The occurrence of polygenic breccia blocks in the *mélange* suggests that lower plate components, which include collapse breccia, have been scraped off from the base of the accreted material in front of the fore-arc region (Figure 11c).

Upper plate elements come from the serpentinised mantle rocks of the hanging wall characterized by various supra-subduction rocks, all emplaced within a very short time interval (55 Ma to 54 Ma). Among the multiple magmatic events recorded in *mélange* units some were coeval to basin formation in the upper plate, as suggested by the occurrence of andesitic pillow lavas. These lavas erupted very shortly (<1 Ma) after subduction inception, and the coeval magmatic activity ceased immediately, a fact which suggests that parts of the fore-arc region were dragged very early into the subduction zone and tectonically mixed with other components (Figure 11c). In spite of major similitudes (e.g., metaserpentinite matrix, occurrence of oceanic rocks derived from the Poya Terrane), there are significant differences between Intermediate *Mélange* and Pouébo Terrane; especially, un-depleted supra-subduction rocks (andesite-dacite series) such as Haute Nehoué rocks, and strongly fractionated supra-subduction rocks similar to the dykes of the Peridotite Nappe are apparently lacking in the Pouébo Terrane. In contrast, “normal” supra-subduction rocks, which are widespread in the Pouébo Terrane do not appear in the Intermediate *Mélange* and in the Peridotite Nappe as well. This and a slightly different timing suggest that supra-subduction components come from different places/depths of the fore-arc region.

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- The evidence discussed above suggests that:
- Mélange units of the HP-LT metamorphic complex of northern New Caledonia represents exhumed and sliced elements of the Eocene subduction zone.
 - Formation of these units resulted from subduction erosion of the footwall/lower plate (oceanic crust of the South Loyalty Basin) and the hanging wall/upper plate (fore-arc mantle of the Loyalty Basin).
 - The lower plate components were accreted first in the fore-arc region and thereafter eroded from the base of the accretion complex.
 - The mélange process occurred at least partly during exhumation.
 - The bulk of the serpentinite sole was formed largely (>10 My) before obduction at the end of the Eocene and owing to the upward decrease of serpentinitisation in the Peridotite Nappe, was mostly related to subduction. The development of porphyroclastic mylonites of the tectonic sole, was overprinted on this ancient serpentinite wedge and occurred during obduction,

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1 Figure captions

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3 Figure 2: Geological sketch map of melange units of northern New Caledonia. ABCD: location of the cross
4 section line of Figure 3. Circled numbers refer to the locations cited in the text.

5 Figure 3: Simplified cross section (for location see Figure 2). Vertical magnification x2.2; values in GPa indicate
6 the maximum pressure (depth) attained during prograde HP-LT metamorphism. The double bar shows the
7 attitude of the regional foliation S1 or Sn in the areas of multiple deformation and transposed foliation.

8 Figure 4: Outcrop pictures of the Pouebo Terrane. 4a: large mafic boulder near the top of Pouebo Terrane,
9 Ouaième Mouth, 10 km northwest of Hienghène Village. 4b: roadside on the northern slope of Amoss Pass,
10 serpentinous melange composed of blocks of weakly or non-foliated talc-rich serpentinite (underlined in
11 green), mafic eclogites (underlined in blue) and contorted retrograde albite schist/gneiss (underlined in white)
12 enclosed in well foliated serpentinite. 4c: lensoids of mafic rocks (same outcrop as 2b). 4d: moderately foliated
13 talc-rich serpentinite (same outcrop as 2b). 4e and 4f: eclogite-facies conglomerate-like polygenic breccia,
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18 breccia composed of angular mafic clasts of the same composition and white micrite, seaside track north of
19 Arama Village. 5d: detailed view of polygenic breccia.

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1 Figure 11: Tentative model of accretion and subduction erosion during the period immediately following
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11 pull-apart extension of great help for the exhumation of the HP-LT terrane.

Unit	age	Rock typology	provenance
Intermediate Melange	90 - 55 Ma	BABB/NMORB EMORB OIB	Poya Terrane (lower plate)
	> 84 – 56 Ma	Cretaceous Paleocene sediments	Norfolk/New Caledonia Ridge (lower plate)
	55 - 54 Ma	“enriched” IAB	Fore-arc region (upper plate)
Pouebo Melange	90 – 55 Ma	BABB/NMORB EMORB OIB	Poya Terrane (lower plate)
	> 84 – 56 Ma	Cretaceous Paleocene sediments	Norfolk/New Caledonia Ridge (lower plate)
	55 - 54 Ma	IAB/IAT	Fore-arc region (upper plate)
	<44 Ma (?)	Retrograde shear zones	

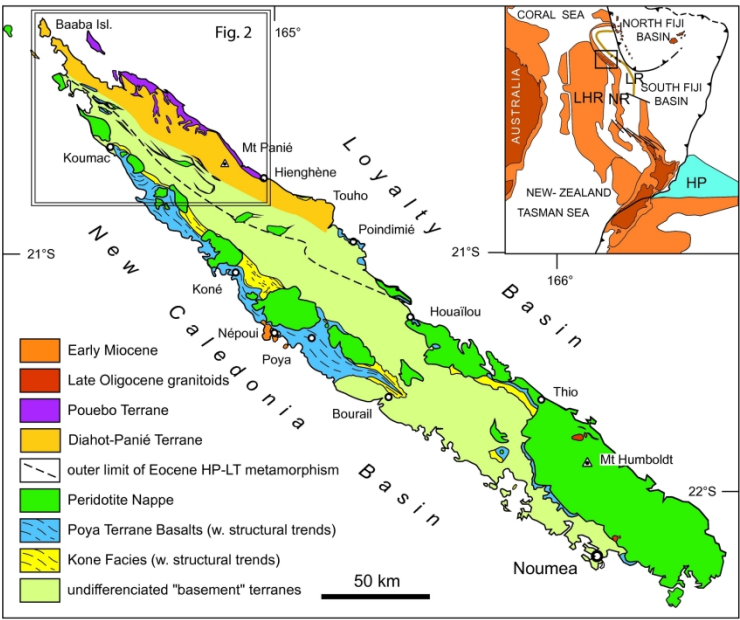


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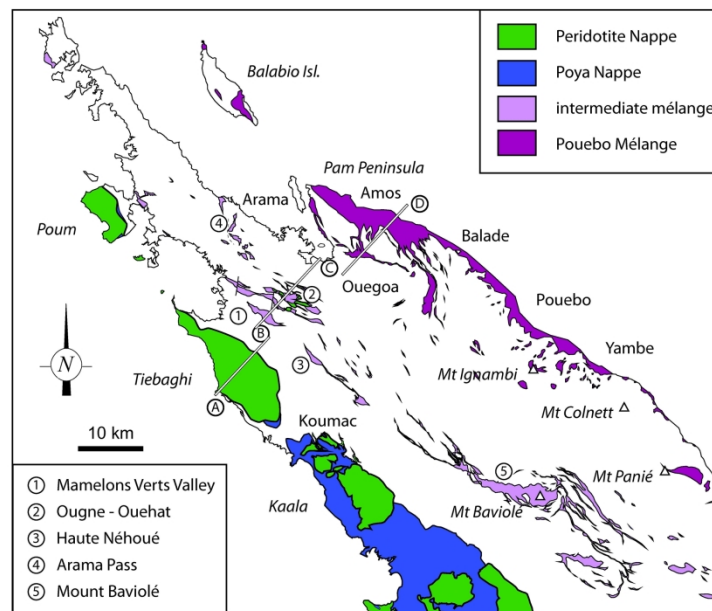


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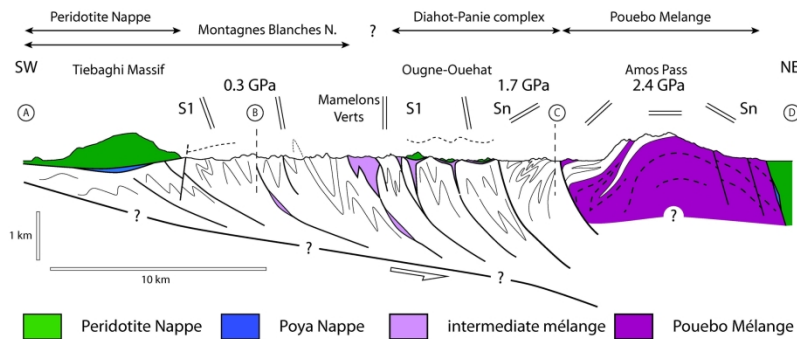


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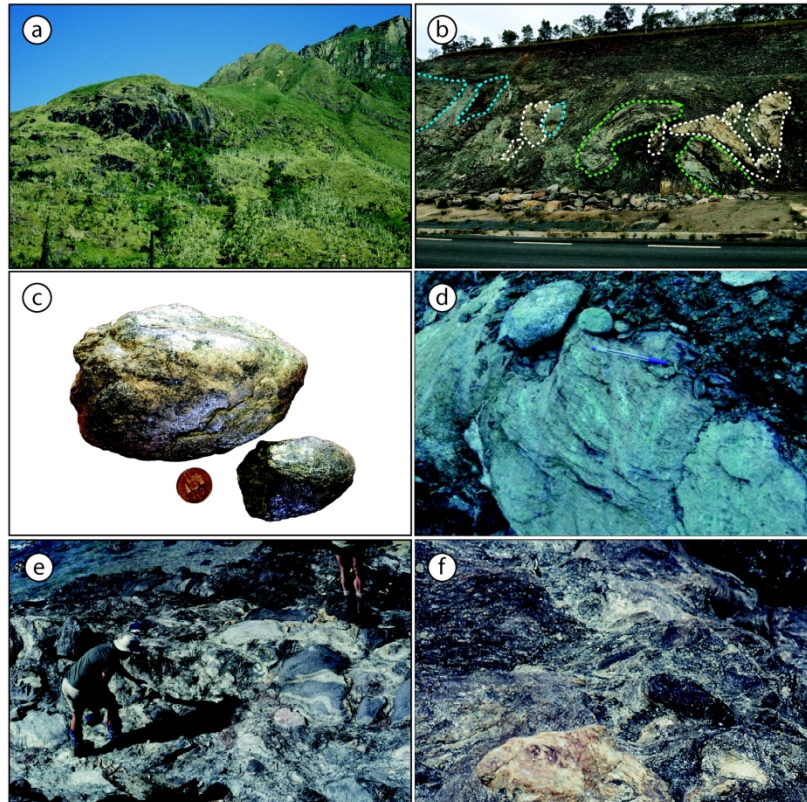


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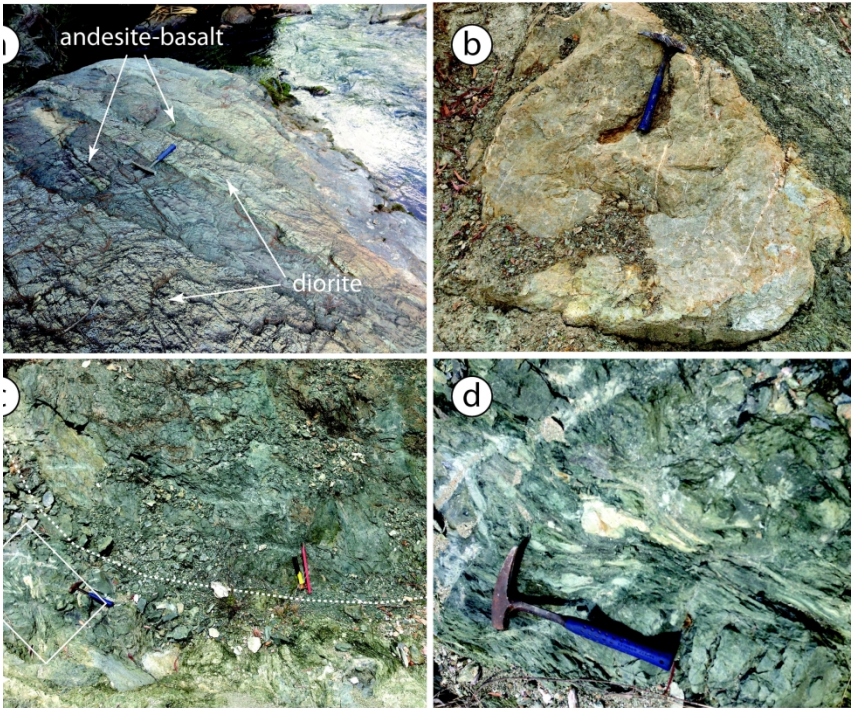


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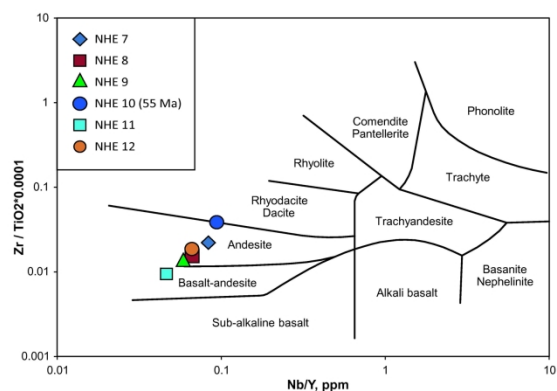


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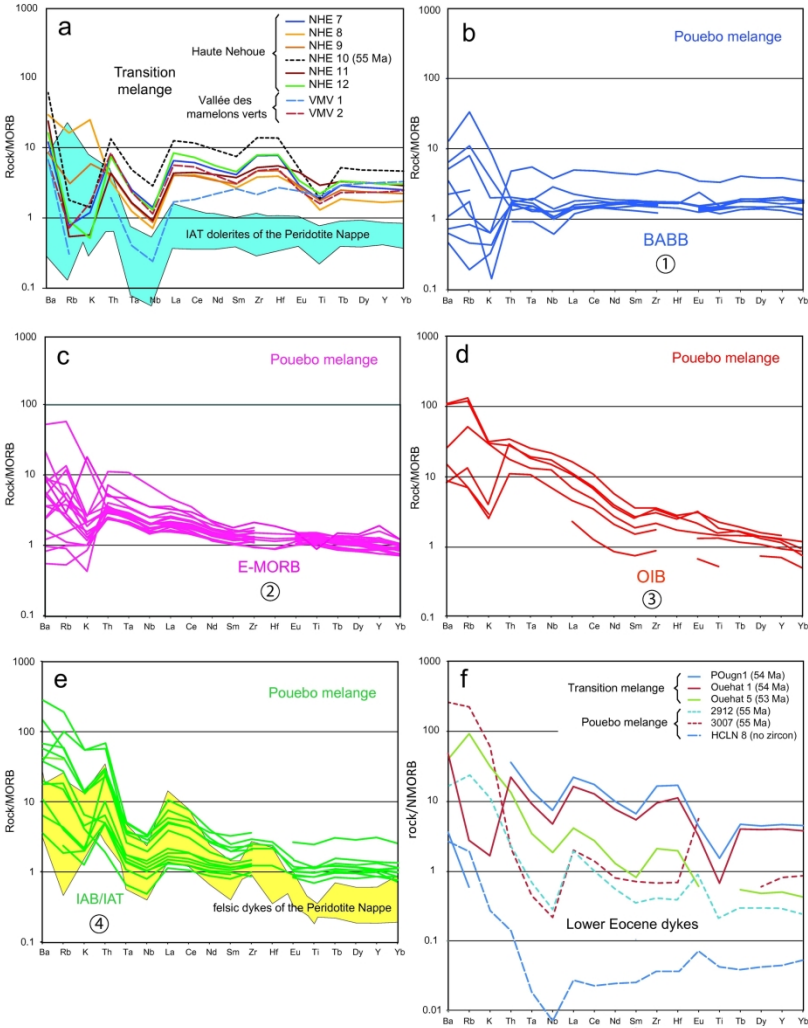


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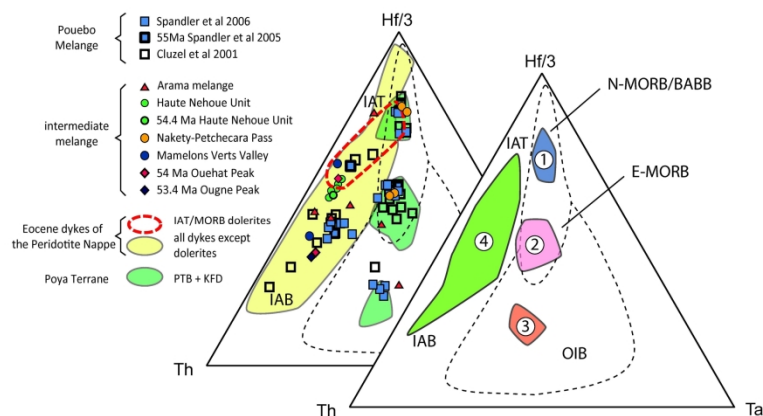


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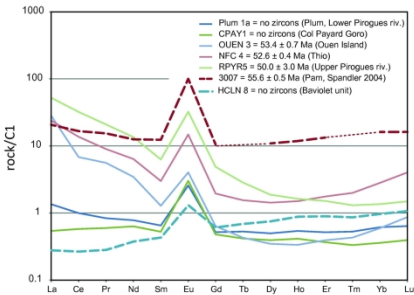


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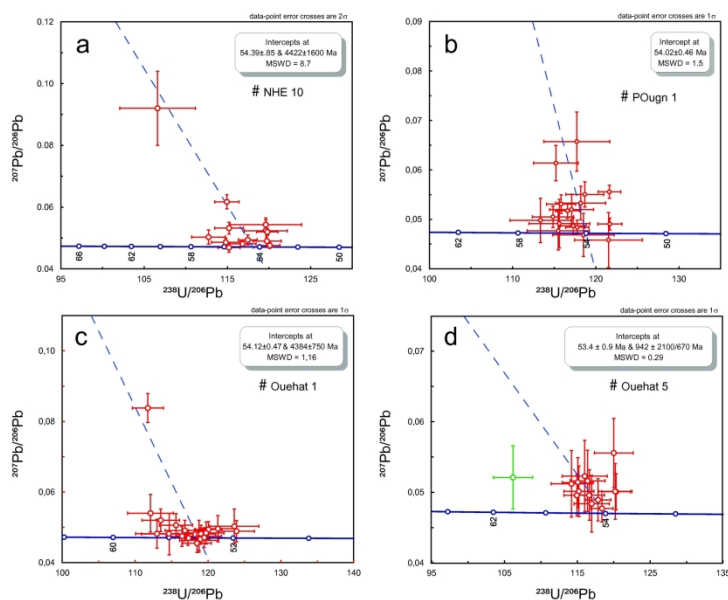


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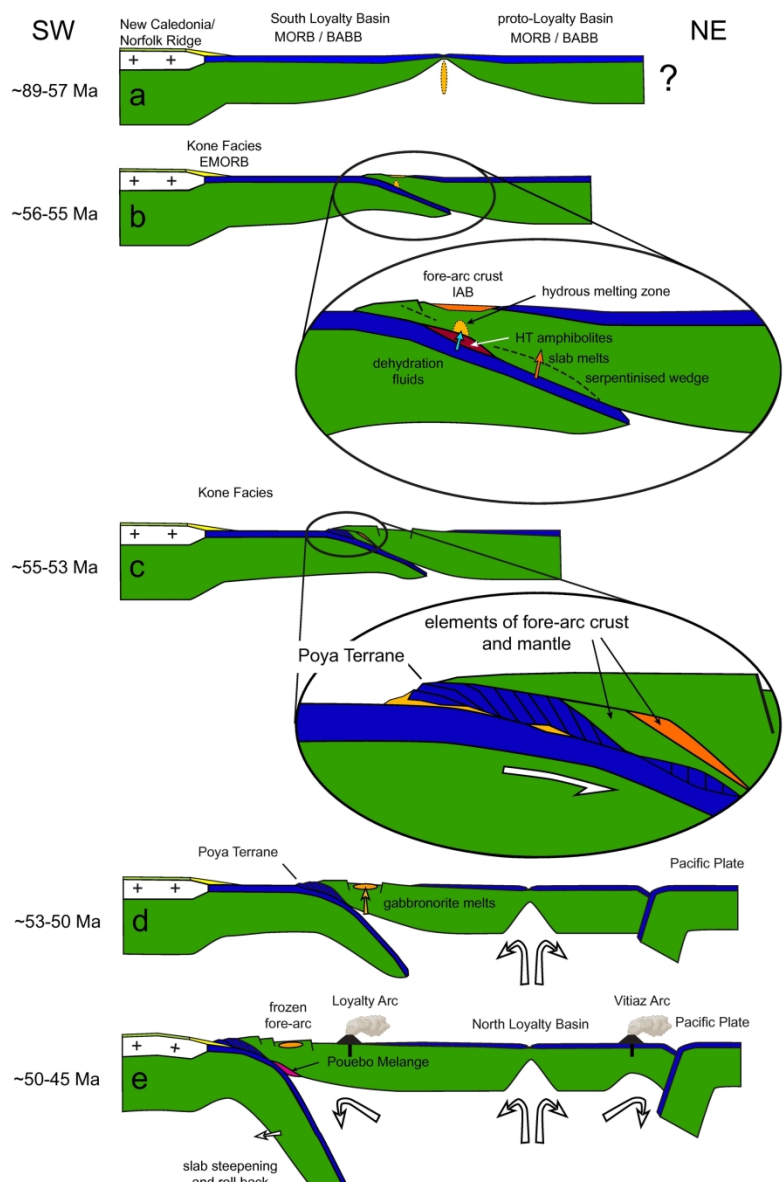


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