Distribution of Drift Pumice as an Indicator for Pollutant Distribution and Sediment Transport in New Caledonia

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Abstract

In 2008 and 2010, felsic drift pumice was collected from a total of 40 beaches around the main island of New Caledonia, Southwest Pacific. This island is enclosed by a barrier reef lagoon whose 2008 designation as a UNESCO World Heritage Site brought attention to the ongoing environmental degradation caused by a century of open cast nickel mining. This type of mining is notorious for producing voluminous fine grained waste sediment that clogs rivers and bays, and may compromise the lush biodiversity of the lagoon. This study examines the use of exotic drift pumice as a visual marker of sediment transport in and around the lagoon. The frequent, voluminous pumice eruptions in the Southwest Pacific provide ample source material that is somewhat durable, highly transportable in water, and easy to collect and analyze. Geochemical and mineralogical analyses were used to identify the source of the pumice in order to map the transport vector across the open ocean and into the lagoon. Pumice characteristics (abundance, angularity, and maximum clast size) were used in conjunction with beach parameters (width, composition, distance from the reef, etc.) to identify at risk coastal areas exhibiting elevated fluvial input in conjunction with reduced marine influence.

Keywords: Beach pumice; Sediment transport, coastal pollution, New Caledonia, Caledonia, lagoon currents

Introduction

New Caledonia (35°S 165°W) (Figure 1) is a ~350 km long by 50 km wide island nation located in the Southwest Pacific, approximately 1500 km away from Australia and New Zealand. The main island is enclosed by a nearly continuous barrier reef creating a lagoon of over 20,000 km2 in area. The barrier reef generally grows 14 to 25 km from the coast, but can reach distances of 100 km along the axis of elongation. In 2008 the lagoon was designated a UNESCO World Heritage Site [1]. This honor brought attention to the plight of the lagoon, which has been suffering from the detrimental effects of nearly a century of open cast mining. Although nickel mining reached its peak in the 1960s to 1970s, the industry still accounts for

a significant portion of the New Caledonian economy. The environmental impacts of open cast mining include acid mine drainage, destruction of littoral and coastal habitats, rapid shallowing of bays and reduced coral productivity in the presence of chronically elevated concentrations of suspended sediment [2-5]. However, the full extent of environmental degradation is unknown, as there has only been one comprehensive catalog of the effects of mining on the rivers and coastline of New Caledonia [5] More recent studies of the lagoon ecosystem have focused on the southwestern part of the lagoon surrounding the population center of Nouméa [6-9].
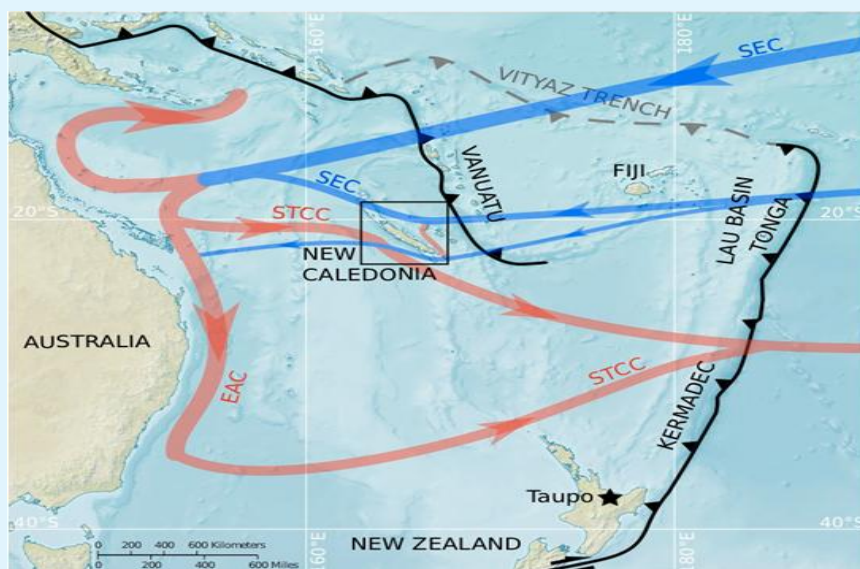
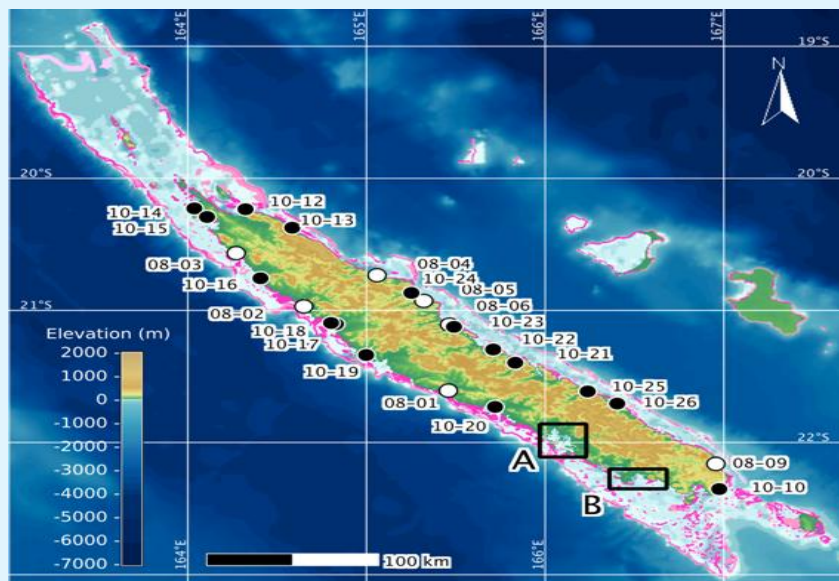Figure 1: Combined bathymetric and topographic map of the Southwest Pacific Ocean modified from (CIA, 2009.)

Figure 2: Map of Grande Terre, New Caledonia (after General Bathymetric Chart of the Oceans, 2010), with detailed insets of (A) the Baie de St. Vincent and (B) the Nouméan peninsula and Mt. Dore (after DTSI, 2009, 2010). Coral reefs (after Andréfouët et al., 2005) in dark pink shallow, pink (intermediate depth) , and light pink (deep). Circles represent sampling locations from 2008 (white) and 2010 (black). Legend shows elevation in meters above means sea level.

Black star marks the location of Taupo Volcanic Zone, New Zealand. Black box marks the) boundaries of Figure 2. Black and grey lines represent modern and relict tectonic margins, respectively (Colored lines represent

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generalized ocean currents, with arrows pointing toward the flow [10]) direction after [11-14]. Ocean currents: EAC, East Australian Current; SEC, South Equatorial Current; STCC, South Tropical Counter Current.

Smaller studies have also been carried out on the east coast and in the extreme north and south [6,15,16].

Our study used land based data collection methods to map the distribution of long shore and fluvial sediments around the island perimeter. The field study included two sample collection periods during which exotic drift pumice was collected from a total of 40 distinct locations. Samples were collected from 9 beaches in July 2008 and 33 beaches in July 2010 (Figure 2). Petrographic and geochemical compositions of the pumice samples were consistent with two recent eruptions in the Central Tonga arc.

A basic drift trajectory was mapped from the proposed source, while assuming the pumice generally followed major ocean currents [17-18]. The dominant ocean current from the equator to approximately 20°S is the SEC, which flows east to west and could potentially be enriched in pumice from Tonga, the Lau Basin, or Vanuatu prior to reaching New Caledonia [18-20]. At the eastern New Caledonian coast, the SEC bifurcates, with the North Jet recombining with the main body of the SEC and the South Jet wrapping around the southern terminus of New Caledonia to flow northward up the west coast before continuing west toward Australia [21,14]. Upon reaching the Australian coast, the SEC bifurcates again, with the south, flowing arm transitioning into the Eastern Australian Current [22]. East flowing off shoots of the EAC combines to form the South Tropical Counter Current (STCC), which breaks against the northwestern coast of New Caledonia, but would likely be poor in pumice until passing the Kermadec is lands and New Zealand further to the east [22,13]. Hence, ocean currents potentially rich in pumice were shown to have access to nearly the entire New Caledonian coastline except for the deeper bays and a stretch of the coastline in the northwest, which was serviced by pumice poor waters coming from Australia.

The intensity of longshore waves imported from the open ocean directly corresponded to pumice abundance, allowing the energy distribution of these waves, which are critical to flushing sediment from nearshore areas, to be mapped using land based data collection methods [23]. A simplified model comparing pumice abundance to other beach parameters (width, composition, etc.) can then be used to determine whether fluvial sediments are polluting nearshore areas or being exported to the lagoon. The

results were compared to previously published energy distribution maps created from a highly.

Complex three dimensional hydrodynamic box model of the southwestern lagoon developed by the French-government [7,24,9].

Materials and Methods

Detailed field observations were recorded at all of the beaches centered around descriptions of the beach in terms of the width of the beach along its profile, the size distribution of beach sediments, the amount of subaerial sediments and pumice in the beach backshore, and the landform acting as the landward boundary. Beach widths were measured from the low tide line, including exposed bedrock but not (ephemeral) sand bars, to the upper limit of wave activity at the base of vegetation, cliffs, or a seawall. The width of the beach was initially described as narrow (<5 m), intermediate (5 to 40 m), or wide (>40 m), and later quantified using a combination of site photographs and satellite images.

Satellite images were al so used to quantify the width of the lagoon from the beach to the outer barrier reef, as well as to verify the presence of fluvial sediments, as indicated by brown discoloration of nearshore waters traceable to a nearby fluvial source. Beach compositions encountered in the field included clay to silt sized mud, fine to very coarse sand, very fine pebble gravel to coarse cobble gravel, and bedrock or boulder gravel. The last two size categories were combined due to similar rarity of pumice.

Pumice samples were collected with a bias toward large clasts, so only the sieve diameter, in φ, of the largest sample was recorded for each location. Pumice abundances were rated as follows: (1) very abundant meant there was a pumiceous ridge deposit, (2) abundant meant there was a pumiceous strand line or the volumetric equivalent, (3) rare meant >10 minutes were required to fill the sample bag to an acceptable level, and (4) very rare meant only one sample was encountered. Beaches without any pumice were not encountered.
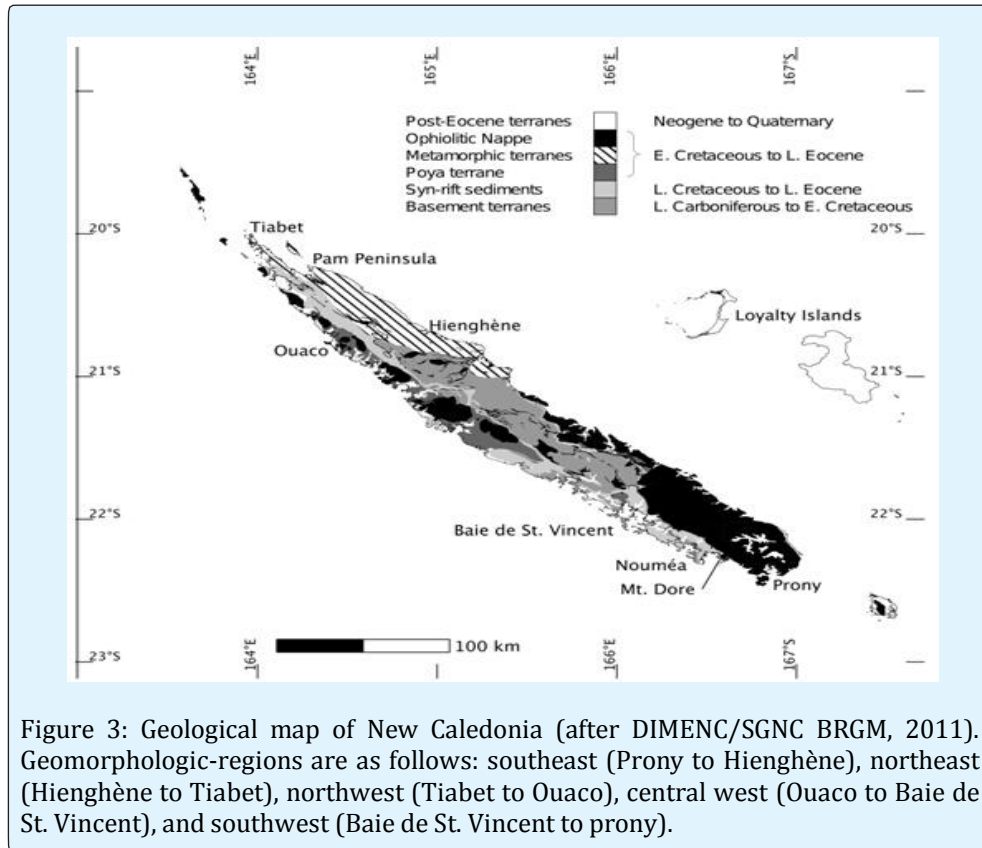
Results

Coastal Geomorphology

The geology exposed along the coast strongly influences the ruggedness of the coastal topography but the shape of the coastline itself is controlled by the intensity of waves entering the lagoon through gaps in the barrier reef [9,25]. Together, the continental geology and

the continuity and proximity of the barrier reef define at least five distinct coastal regions, including the southeast, northeast, northwest, central west, and southwest coasts (Figure 3) [5].

Figure 3: Geological map of New Caledonia (after DIMENC/SGNC BRGM, 2011). Geomorphologic-regions are as follows: southeast (Prony to Hienghène), northeast (Hienghène to Tiabet), northwest (Tiabet to Ouaco), central west (Ouaco to Baie de St. Vincent), and southwest (Baie de St. Vincent to prony).

The southeast coast of New Caledonia from Prony to Hienghène features cliffs broken by intermittent river deltas and drowned valleys [5]. Sand and gravel beaches become more numerous along the sedimentary basement terranes and the low-grade metamorphics of the Diahot terrane north of the Ophiolitic Nappe. The barrier reef grows close to shore and is generally linear but very discontinuous.

Along the northeast coast, from Hienghène to Tiabet, the highgrade metamorphics of the Daihot and Pouébo terranes produce cliffs that transition northward into gentle slopes covered by extensive mangrove forests [5]. The barrier reef grows close to shore in a nearly continuous linear to piecewise arcuate manner, with a second, sub parallel reef fringing the coast. A broad gap in the reef adjacent to the Pam peninsula funnels high energy waves from the open ocean into the lagoon [14].

The northwest coast, from Tiabet to Ouaco, is regularly disrupted by steep ultramafic klippes, between which Pleistocene sediments and Poya terrane volcanics form gentle slopes with beaches of highly variable composition [5]. The barrier reef grows an intermediate distance from the coast and is linear and fairly continuous, broken intermittently by wide channels.

The central west coast, from Ouaco to just south of the Baie de St. Vincent, features numerous small to large bays carved into the Poya and sedimentary basement terranes. The bays harbor mangrove forests and intermittent beaches of variable composition [5]. The barrier reef grows close to the shore in a piecewise arcuate manner with extensive fringing reefs growing inside the lagoon.

The southwest coast, from the Baie de St. Vincent to Prony, is generally hilly, with broad bays broken intermittently by branching peninsulas [5]. North of Mt. Dore, heterogeneous syn-rift l. sediments form two competing coastal morphologies, with broad, mangrove forested bays carved into terrigenous sediments are periodically broken by outcrops of flysch forming branching peninsulas that enclose small bays lined with sandy beaches. South of Mt. Dore, the Ophiolitic Nappe produces gently sloping gravelly beaches. The barrier

reef, while generally linear and continuous, encloses a allowing high energy waves from the open ocean to enter the lagoon unchecked. These waves are channeled around the Nouméa and bypass the deep bays on either side of the peninsula [11,26,27]. North of Nouméa, the, waves quickly lose energy and transition into the low energy wind wave characteristic of the lagoon.

Pumice Distribution and Beach Morphology

Beach and pumice characteristics are summarized in Table. Pumice deposits were universally stranded above the daily high tide line, which occurred anywhere along the beach profile depending on the beach geometry and

funnel-shaped lagoon that opens to the southwest, morphology. Abundant pumice most often occurred at the traditional berm type beach, which was also the most common beach morphology, probably due to preferential, selection for voluminous backshore sediments in the absence of dunes. However, the "berms" were generally no larger than small ridges and sometimes limited to simple strand lines. True dunes were restricted to localized climbing dunes whose convex profiles were sometimes imitated by local topography (Figure 4-Figure 6).

S.No	Location		Lagoon Width (km)	θ$_s$* (days)	Beach Composition					Strand Type	Beach width (m)	Boundary Landform
	Latitude (S°)	Longitude (°E)			Fluvial input†	Mud	Sand	Gravel	Bedrock			
SoutheastCoast‡												
10-Oct	22°21'00.26"	166°58'21.27"	8	N.D.**	N	••	•••	•		Line	15	Dunes
26-Oct	21°42'19.57"	166°24'00.02"	9	N.D.	N		•••	••		Perched.	4	Love cliff
25-Oct	21°36'47.37"	166°14'14.15"	12	N.D.	N		•••	••		Ridge	10	Hill
21-Oct	21°23'45.05"	165°49'51.05"	16	N.D.	Y			•••		Perched.	80	LOW cliff
22-Oct	21°17'44.20"	165°42'29.01"	16	N.D.	N			••	••••	Perched.	3	Cliff
23-Oct	21°07'25.31"	165°29'16.32"	16	N.D.	Y		••••			Line	20	Hill
24-Oct	20°51'53.46"	165°15'01.42"	10	N.D.	Y	••••	••			Perched.	3	Cliff
Northeast coast												
13-Oct	20°22'25.64"	164°34'59.42"	6	N.D.	Y		•••	••		Ridge	40	Hill
12-Oct	20°13'56.24"	164°19'23.27"	14	N.D.	P	•••		••		Ridge	5	Hill
Northwest coast												
14-Oct	20°13'39.37"	164°02'07.92"	17	N.D.	P			•••	••	Ridge	20	Hill
15-Oct	20°17'28.25"	164°06'24.54"	20	N.D.	Y	•••	••			Line	50	Dunes
16-Oct	20°45'22.90"	164°24'23.39"	14	N.D.	Y	••		•••		Line	15	Seawall
Central West Coast												
Open Coast												
18-Oct	21°05'37.20"	164°48'01.99"	11	N.D.	N		••		•••	Line	5	Hill
17-Oct	21°06'07.68"	164°49'40.70"	13	N.D.	Y	•	•••	••		Ridge	5	Hill
19-Oct	21°20'08.70"	164°59'49.83"	9	N.D.	P			••	•••	Ridge	15	Hill
20-Oct	21°43'43.67"	165°43'5.39"	12	N.D.	N			••	•••	Ridge	25	Hill
Baie de St. Vincent												
27-Oct	21°57'14.34"	166°00'18.65"	9	4	Y		•••	••		Line	5	Dunes

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Date	Latitude	Longitude			†						Type		Feature
28-Oct	21°57'18.61"	166°00'32.77"	9	4	Y			•••	••		Ridge	20	Hill
29-Oct	21°56'23.50"	166°00'21.09"	11	10	Y	••	•	•••	••		Ridge	60	Hill
31-Oct	21°54.29.12"	166°03'55.05"	17	10	N			••	•••		Ridge	10	Cliff
30-Oct	21°54'46.58"	166°04'38.21"	18	8	N		•••	••			Ridge	5	Hill
Oct-33	21°57'19.84"	166°08'21.26"	20	10	Y	••		•••			Ridge	25	Hill
Oct-32	21°57'34.15"	166°08'25.40"	20	10	Y			•••			Ridge	20	Seawall
Southwest coast													
Nouméan peninsula													
6-Oct	22°15'37.05"	166°23'21.75"	18	8	N			•••	••		Line	15	Dunes
1-Oct	22°17'44.73'	166°26'14.95"	18	8	N		•••	••			Ridge	10	Hill
2-Oct	22°18'12.73"	166°26'11.74"	18	8	N		•••				Line	10	Seawall
3-Oct	22°18'12.14"	166°26'14.79"	18	8	N		•••				Ridge	5	Hill
4-Oct	22°18'11.62"	166°26'42.67"	18	8	N		•••				Perched	5	Hill
5-Oct	22°15'58.99"	166°23'19.16"	23	15	Y	•••	••				Perched	170	Seawall
Boulari-Pirogues Bay													
7-Oct	22°15'33.92"	166°33'23.48"	29	15	Y		••	•••			Perched	3	Cliff
8-Oct	22°16'15.65"	166°33'35.31"	29	15	N		•••		••		Line	30	Cliff
9-Oct	22°1624.58"	166°34'16.81"	29	20	N			•••			Perched	10	Hill
11-Oct	22°17'47.21"	166°39'30.72"	32	20	Y			•••			Ridge	15	Hill

Table 1: Geomorphological Characteristics of Sample Locations and Pumice Samples from the 2010 Field Study in New Caledonia.

*θ_s is the surface sigma export time in days as shown in Figure 5A of Jouon et al. (2006).
†The presence of fluvial sediments as determined by satellite photos. Y = yes, N = no. P = possibly.
‡Coastal regions as follows: Southeast = Prony to Hienghene, Northeast = Hienghene to Pourn peninsula. Northwest = Pourn peninsula to Ouaco, Central west = Ouaco to Baie de St. Vincent. Southwest = Baie de St. Vincent to Prony.
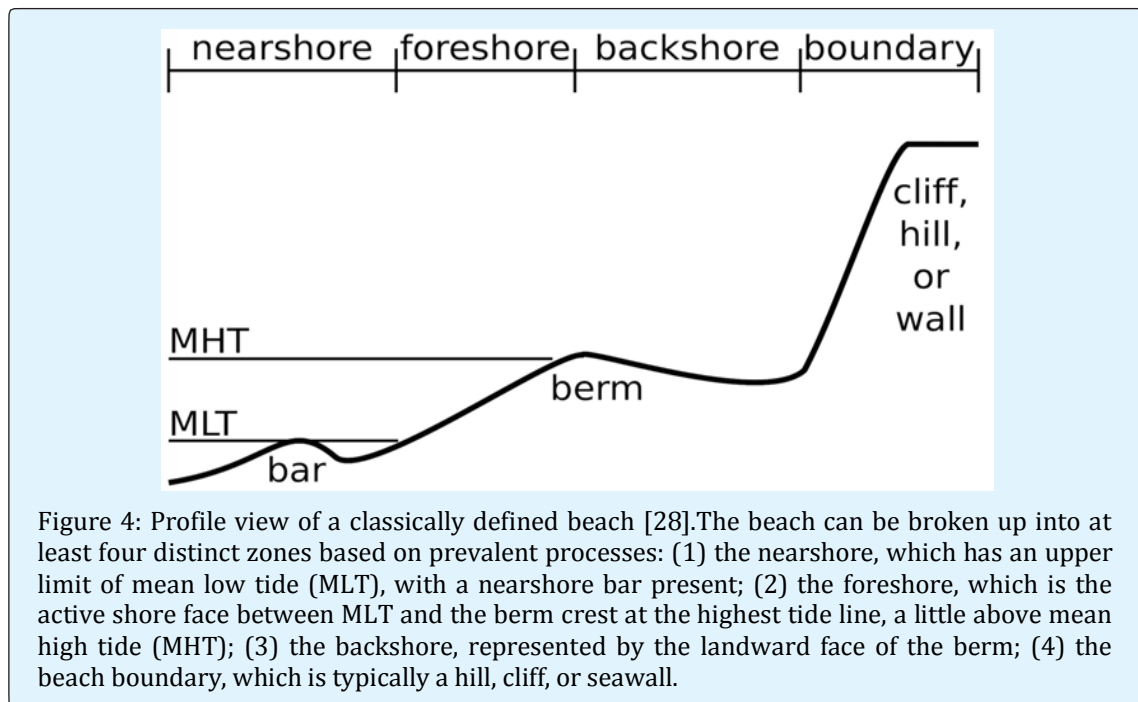** N.D. = not determined.

Pumice Abundance	Maximum clast size (phi††)	Average Rounding	Geographical location
Abundant	-7	Slightly angular	Karma Tera Ecolodge, Port Boise
Rare	-5	Angular	Campground at Plage de Port Bouquet
Abundant	-6	Slightly rounded	St. Philippe II Beach
Rare	-5	Angular	Village park. Kouaoua
Rare	-5	Slightly rounded	Beach 250 m in north of Poro
Abundant	-5	Slightly angular	RPN3 at Moneo River
Rare	-5	Slightly rounded	RPN3 at Tiwalca River
Very abundant	-7	Well rounded	Plage de St, Mathieu, Pouebo
Abundant	-6	Slightly rounded	Route de Pam, 10 km west of the north junction with RPN7
Rare	-5	Slightly angular	Pier at Poum village
Rare	N.D.	N.D.	Malabou Beach Hotel, Poum
Very rare	-7	Very angular	Depot de Mineral. Gomen, Baie de Gomen
Abundant	-5	Slightly angular	Pier at west end of Route de Foui, Komi
Abundant	-5	Round	Plage de Foue, Kane

Abundant	-7	Slightly angular	Nipoui Pier
Abundant	-6	Slightly rounded	Bale de Teremba
Abundant	-6	Slightly rounded	Bourake campground
Abundant	-6	Slightly angular	Bourake headland
Abundant	-7	Slightly rounded	Residential area 2 km north of Bourake campground
Rare	-6	Slightly rounded	Ouenghi Marina, Port Ouenghi
Very abundant	-6	Slightly rounded	End of southernmost street crossing Ave de Port Ouenghi
Rare	-4	Slightly rounded	Quai de Tomo
Rare	-5	Slightly rounded	End of the dirt road going north from Quai de Tomo
Rare	-6	Round	Kuendu Beach, Noumea
Very abundant	-6	Slightly rounded	Plage de Bale des Citrons, Noumea
Abundant	-5	Slightly rounded	Plage de I'Anse Vata, west of Fun Beach Bar.. Noumea
Abundant	-6	Round	Plage de I'Anse Vata, east of Fun Beach Bar.. Noumea
Abundant	-6	Round	Plage de I'Anse Vata at Route de I'Anse Vata, Noumea
Abundant	-7	Round	Plage de Magenta, Noumea
Rare	-5	Slightly rounded	West end of Rue de Pointe d'Och, north of Vallon Dore on RP2
Abundant	-6	Slightly rounded	Promenade de Vallon Dore 500 rn west of Rue de Panorama
Rare	-5	Well rounded	RP2 at Rue des Poinsettias, Vallon Dore
Rare	-5	Slightly angular	Bale des Pirogues, 500 m west of Rue des Duillets on RP1

Table 1: Continued.
†† Phi in cm: -4 phi=0.8 to 1.6 cm, -5 phi=1.6 to 3.2 cm, -6 phi=3.2 to 6.4 cm, -7 phi=6.4 to 12.8 cm.

Figure 4: Profile view of a classically defined beach [28].The beach can be broken up into at least four distinct zones based on prevalent processes: (1) the nearshore, which has an upper limit of mean low tide (MLT), with a nearshore bar present; (2) the foreshore, which is the active shore face between MLT and the berm crest at the highest tide line, a little above mean high tide (MHT); (3) the backshore, represented by the landward face of the berm; (4) the beach boundary, which is typically a hill, cliff, or seawall.

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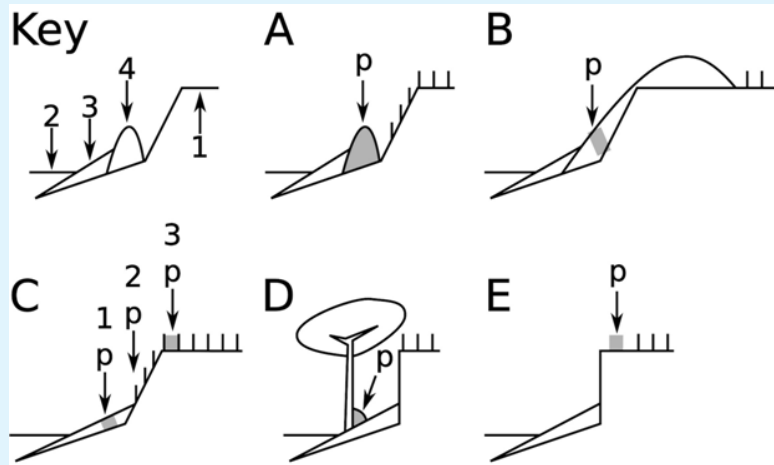
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Figure 5: Profile view of New Caledonian beach morphotypes [29,30]. Key: (1) underlying geology forming a beach platform backed by a hill or cliff, (2) sea level as represented by mean low tide, (3) intertidal beach sediments, and (4) subaerial backshore sediment deposit (ridge, berm, or dune). Grey shading represents pumice deposit, marked by the letter "p" with an arrow pointing toward the deposit. (A) Beach with ridge or berm; landward boundary is a hill, cliff, or seawall; pumice occurs in the backshore deposit. (B) Beach with climbing dunes; pumice occurs in strandlines in the upper foreshore or lower backshore. (C) Bermless beach; landward boundary is hill or cliff; pumice occurs in strandlines located in one of three (1) in the backshore, (2) trapped in grass at the base of the landward hill, (3) trapped in the grass at the top of the low (<1 m tall) landward cliff. (D) Bermless beach with tall cliff; pumice occurs in small sediment deposits trapped behind trees in the foreshore. (E) Bermless beach with low seawall; pumice occurs in strandlines perched above seawall.

Figure 6a: Profile view of the headland about 500 m east of the Bouraké Campground looking north toward the Baie de St. Vincent (location 10-28). This is a bedrock beach with a small ridge deposit at the base of a larger berm like deposit in the backshore, backed by agrassy hill.

Figure 6b: Profile view looking west along a semiprivate beach in the residential area adjacent to Port Ouenghi (location 10-30). A small ridge typical of New Caledonian "berm" type beaches is visible in the backshore.

Figure 6c: View of the Kanua Tera Ecolodge beach looking west toward Port Boisé (location 10-10). This beach is a nearly ideal example of climbing dunes. The foreshore backshore boundary occurs somewhere between the wet foreshore sediments adjacent to the active swash zone and the unconsolidated sediments of the upper backshore, which begins just above the black strand line.

Pumice abundances ranged from very abundant to very rare, but pumice was abundant on average. The angularity of collected samples ranged from very angular to well rounded, with an average of slightly rounded. The maximum size of collected samples ranged from medium pebbles (4φ) to small cobbles (7φ), with an average of very coarse pebbles (6φ). Abundant pumice tended to be of average size (6 φ) and angularity (slightly rounded). Rare pumice tended to be slightly smaller than average (5φ), with bimodal angularity (angular or slightly rounded).

Abundant to very abundant pumice occurred in every coastal region except the northwest, where pumice was always rare to very rare (10-14 to 16). Otherwise, pumice abundance was loosely tied to the width of the lagoon, the size distribution of beach sediments, and beach morphology. Abundant pumice tended to occur at berm type beaches on the open coast, where the lagoon was narrower, typically at either slightly embayed sandy to muddy beaches (Figure 6b) or intermediate width bedrock beaches along bay headlands (Figure 6a). Rare pumice tended to occur well inside the deepest bays, such as in the Baie de St. Vincent (10-30 to 33), the Dumbéa (10-06) and Boulari Pirogues (10-07 to 09, 10-11) bays adjacent to the Nouméan peninsula, and the rias (10-21) and estuaries (10-24) of the east coast. However, even the deepest days, anomalously abundant pumice occurred at localized sandy beaches (10-08, 10-30). Narrow, cliffed beaches had rare pumice regardless of reef proximity, probably because pumice could only be found in perched strand deposits on top of low (<1 m) cliffs (Figure: 5C3, 30; 10-21, 10-26), or trapped behind obstructions in the upper foreshore (Figure 5D, 24; 10-07, 10-22, 10-24). In contrast, narrow beaches without cliffs tended to have pumice abundances consistent with regional values, as pumice could become stranded at any elevation on grass covered hills above the backshore (Figure 5C2; 10-04, 10-09).

Beach Sediments and Morphology

The size distribution of beach sediments was somewhat indicative of the amount of wave energy available to a beach, e.g. gravel tended to occur on the open coast or along bay headlands, sand tended to accumulate in shallow bays on the open coast, and mud tended to occur deep inside bays. However, the presence of fluvial sediments tended to increase the proportion of either gravel or mud, such as at tidal lagoons hosting mangrove forests (Figure 7a) or estuarine mud flats (Figure 7b).

Figure 7a: View of a tidal lagoon located approximately 1.5 km north of the Bouraké Campground, looking northeast toward the Baie de St. Vincent (location 10 29). The outer mangroves are located on the crest of a berm like deposit that would be drowned at high tide. Water enters the lagoon where the mangroves thin, to the right of the photo. The inner mangroves mark the landward beach boundary. There are numerous strand lines of organic detritus in the upper backshore. Near the landward boundary of the beach, a small ridge (not pictured) contains pumice.

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Figure 7b: View of the extensive mudflats at Magenta Bay, looking northeast (location 1005). The mudflats act as a predominantly subaqueous backshore with an abbreviated foreshore exposed at low tide. The area behind the low storm wall (<1 m) periodically acts as a perched sub aerial backshore. Pumice was found in a strand line above the wall.

Bedrock beaches occurred anywhere the sediment outflow exceeded sediment inflow, such as on bay headlands and deep inside bays, far from both long shore and fluvial sediment sources. However, some of the beaches listed as being predominantly bedrock were actually sand or gravel beaches fronted by beach rock (Figure 7c) or mud beaches augmented by artificial boulder gravel. This distinction is important because artificial boulder gravel occurred without regard to wave energy, but the presence of boulder gravel often significantly reduced the size of the supratidal depositional area. At some of these beaches, pumice deposits only occurred in localized gullies (10-02, 10-16), on the leeward side of jetties, or on top of short seawalls.

Figure 7c: Profile view of the beach at Poum, looking southeast from the pier (location 10-14). This beach has developed beach rock in the foreshore. The backshore contains unconsolidated sediments.

Discussion

On the macro scale, pumice abundance was directly related to the width of the lagoon adjacent to the beach. However, this relationship did not continue into the meso scale. For example, there were localized sandy beaches in the deeper bays with anomalously abundant pumice, and there were also narrow, cliffed beaches on the open coast with anomalously rare pumice. Furthermore, pumice was always rare to very rare in the northwest, regardless of other factors.

A simple explanation is that on the macro scale, lagoon width was directly proportional to longshore wave energy, which in turn was inversely proportional to the distance from the barrier reef [7,24]. However, on the meso scale, bathymetric and topographic irregularities created fluctuations in the wave energy distribution that were reflected in the pumice distribution [11,8,24]. Modeled the energy distribution of surface currents in the New Caledonian lagoon from the Baie de St. Vincent south. Wave energies were reported in terms of the surface water export time, θ, which is the number of days needed to replace an initial volume of surface water in the lagoon with new water from the open ocean.

Pumice was abundant wherever θ was below a threshold value that varied by region. Specifically, in the Baie de St. Vincent, pumice was abundant wherever θ was less than 8 days, which increased to 15 days in the bays surrounding the Nouméa peninsula. Only two beaches in the modeled area did not conform to this model (10-06, 10-29), possibly due to unmodeled complexities in water flow at the micro scale in structurally controlled bays [30]. In Boulari Bay and the Baie de St. Vincent, two sandy beaches that were previously described as having anomalously abundant pumice (10-08, 10-30) actually corresponded to localized energy highs where θ dropped below the regional threshold values. Additionally, in one of these high energy areas, there was a narrow, cliffed beach with rare pumice (10-07), similar to ones on the open coast, supporting the idea that pumice was rare at these beaches not because of a low θ but because there was no supratidal depositional area.

Extrapolating to the rest of the island perimeter, pumice should have been abundant wherever θ was below the regional threshold value, provided there were no topographical restriction ns to pumice deposition. However, since the beach characteristics observed in the northwest did not deviate significantly from other beaches around the island, there must have been some other, unidentified factor involved in pumice distribution.

Since most of the beaches around the island were supplied pumice by long shore waves derived from the SEC, it could be that pumice was universally rare in the northwest because of a lack of pumice in long shore waves derived from the STCC.

In addition to supplying pumice, long shore waves provided the dominant means of removing sediment from a beach, as well as supplying sand produced by sorting during long shore drift [28]. Sandy beaches were typically of intermediate width (5 to 40 m) and had abundant pumice, suggesting that long shore sediments only accumulated where θ was below the regional threshold (e.g on the open coast).

Where long shore input lagged behind removal, either due to low θ (e.g. deep in bays) or headland bypass, beaches were composed of bare bedrock or locally derived gravels. Conversely, beaches near fluvial point-sources became dominated by fluvial mud or gravel that could potentially overwhelm long shore sediment removal, increasing beach widths to well above the 40m attained by sand beaches.

Taking narrow (0 to 5 m) to intermediate (5 to 40 m) width beaches as "healthy", it becomes apparent that of the beaches with fluvial sediments, "healthy" beaches tended to be located on the open coast (i.e. θ < threshold value, pumice abundant unless restricted by topography; 10-12, 10-17, 10-19, 10-23, 10-27 to 28). If embayed, "healthy" beaches were either somewhat removed from the dominant fluvial source (i.e. θ > threshold value, pumice rare; 10-11, 10-32 to 33), or situated within a localized energy high (10-07, 10-24). Conversely, "unhealthy" beaches (i.e. those wider than 40 m) tended to be situated very near the river mouth (10-21) or in secondary depositional areas downstream, such as mangrove swamps (not sampled), tidal lagoons (10-29), or mudflats (10-05). However, for "healthy" beaches with low θ values and either abundant pumice or rare pumice with cliffs in the backshore, further research would be needed to determine the volume of sediment bypassing each beach as well as to determine the ultimate destination of the sediment, such as a secondary depositional area downstream, or out to the lagoon, where elevated turbidity could affect corals.

Conclusion

The pumice samples collected in 2008 and 2010 from beaches around New Caledonia were of fairly uniform geochemistry and were shown to be from two recent eruptions in Central Tonga. The 2008 samples were dominantly from a 2006 eruption of Metis Shoal, but the

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2010 samples were dominantly from a 2001eruption of an unnamed volcano. From 2008 to 2010, the Metis Shoal samples were likely removed from beaches by storms, exposing older pumice at higher elevations as the dominant pumice deposits. This natural attenuation of pumice by high energy waves caused pumice abundances to naturally mimic wave energies, providing a land based method of measuring wave intensities.

On a macro scale, pumice abundance corresponded inversely with the width of the lagoon from the barrier reef to the beach. However, this relationship broke down on the meso scale, where bathymetric and topographic irregularities altered the wave energy distribution. On the meso scale, pumice abundance no New Caledonia drift pumice: implications for sediment transport 10 longer corresponded to lagoon width, but continued to correspond directly to wave energy. Furthermore, this relationship continued into the micro scale, to a resolution not attained by a published energy distribution map by Jouon et al. (2006) [24].

By using beach width as an indicator of the presence and extent of hyper sedimentation in the near shore area, pumice abundance can be used to determine whether sedimentation is restricted to the area immediately surrounding the beach, or whether sediment bypass might be contributing to hyper sedimentation downstream. This application could be useful for determining where to search for the places worst hit by mining or urban waste.

Acknowledgements

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