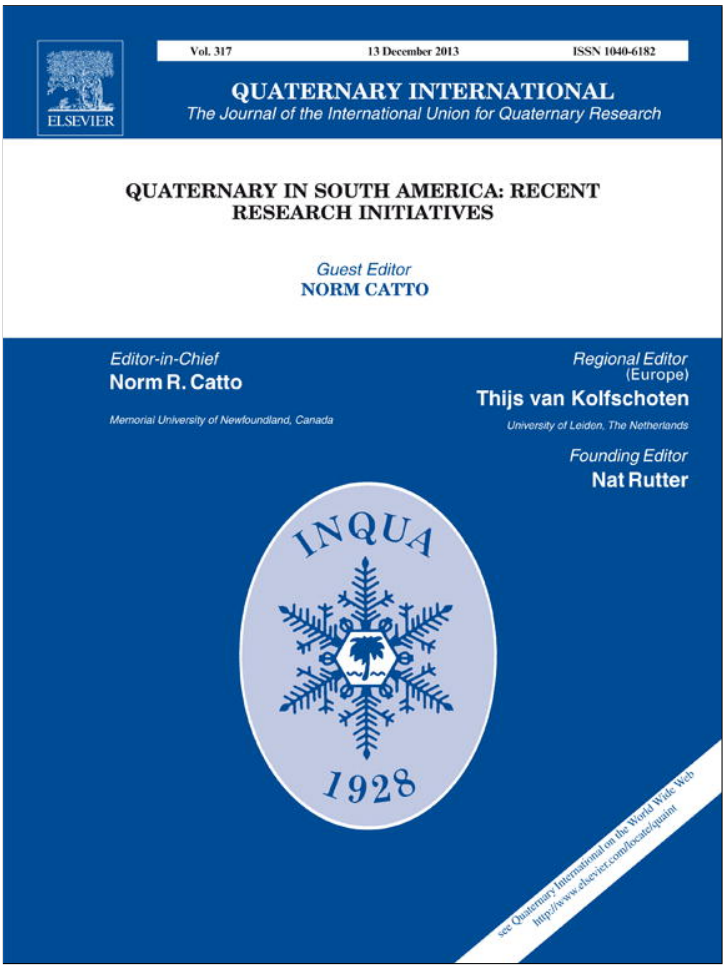

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The peopling of the Fuego-Patagonian fjords by littoral hunter–gatherers after the mid-Holocene H1 eruption of Hudson Volcano

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ABSTRACT

Early Holocene (>8500 cal BP) littoral sites are well documented along the Pacific coast of Chile north of 32°S, but they do not occur south of this latitude. It has been proposed that canoe Indians of Fuego-Patagonia, the earliest evidence for which is mid-Holocene (Punta Santa Ana; 7440 cal BP), adapted themselves to the sea from terrestrial hunter–gatherer populations already living since >13,000 cal BP in southernmost South America south of 52°S. This adaption may have taken place first in the area around Seno Otway, near the earliest maritime cultural sites, where transit to and from the interior pampas was relatively easy and forest providing trees for canoes existed. Seno Otway is also the proposed source for green obsidian, a distinctive lithic material found in many of the oldest maritime sites, including Túnel 1 and Imiwaia 1 along the Canal Beagle >300 km to the southeast. This green obsidian was previously exploited and transported long distances by terrestrial hunter–gatherers, as evidenced by its presence in the Period III (9500–7400 cal BP) levels of Pali Aike and Fell's Cave located >200 km east of Seno Otway. However, this obsidian does not occur in Period IV (after 7400 cal BP), when it and other obsidian types from distant sources are absent among the lithic tools found in these two sites. This hiatus in the long distant terrestrial transport of obsidian in southernmost Patagonia has been attributed to the catastrophic environmental effects of the H1 eruption of Hudson volcano (46°S) at ~7750 cal BP. This eruption, which was more than five time larger than the 1991 eruption of the same volcano, covered much of Tierra del Fuego with up to >20 cm of tephra, and the Seno Otway area with at least >4 cm of tephra. As well as interrupting long distance terrestrial transport of obsidian over all of southernmost Patagonia, it may have devastated for an extended time period the flora and fauna supporting the local terrestrial hunter–gatherers in this area, particularly in Tierra del Fuego, which was already isolated by the opening of the Strait of Magellan at ~9240 cal BP. Here it may have actually extinguished this culture completely. However, it was unlikely to have affected marine species. We propose that this volcanic eruption was a significant trigger to the development of the maritime population from the older terrestrial hunter–gatherers.

1. Introduction

Since the presence of canoe Indians in the Fuego-Patagonian fjords (Figs. 1 and 2) was first observed by Europeans (see Martinic, 1992), and archaeological sites preserving a distinctive littoral economy were first dated from ~7440 cal BP (Table 1 and Fig. 3; Legoupil and Fontugne, 1997; Orquera and Piana, 1999; Legoupil, 2003; San Román, 2010; Orquera et al., 2011), researchers have tried to answer the following two related questions: 1) What is the relationship between the littoral populations described in the historical record (Yaghan/Yamana around Tierra del Fuego; Alacalufe/Kaweskar in the canals further to the northwest) and the earlier pre-historic canoe Indian populations? and 2) Where did the earliest canoe Indians come from and how were they related to the terrestrial hunter–gatherers of the southernmost Patagonian pampas who are documented to have arrived in this region more than 5000 years earlier? Here we review information relevant to answering these related questions concerning the prehistory of the maritime hunter–gatherers of the southernmost Patagonian fjords and the terrestrial hunter–gatherers of the neighbouring pampas, and discuss the role of a sudden catastrophic event, the mid-Holocene (~7750 cal BP; Table 2 and Fig. 3) H1 eruption of the Hudson volcano (Stern, 1991, 2008; Naranjo and Stern, 1998), the largest eruption of any volcano during the Holocene in the southern Andes, as a possible trigger to the development of the first maritime hunter–gatherers in the fjords of Fuego-Patagonia.

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Table 1
Radiogenic Carbon ages of important archaeological sites discussed in the text.

Sample#	Context	Significance	Material	^{14}C yrs BP	cal yrs BP
Punta Santa Ana 1; the earliest littoral site in Fuego-Patagonia (site#6 in Fig. 2; San Román, 2010)					
Beta-252914	Level III	Early occupation	Guanaco bones	6330 ± 50	7260 ± 60
Beta-252913	Level II	Early occupation	Human bones	6290 ± 50	7220 ± 50
Soto-Heim 1992	Level II	Early occupation	Human bones	6540 ± 110	7440 ± 100
Ponsonby; Riesco Island site with early terrestrial and later littoral occupations (site#10 in Fig. 2; Legoupil, 2003>)					
Gif-1049	Upper level b	Marine occupation	Carbon	3720 ± 130	4095 ± 185
Gif-10138	Lower level B	Marine occupation	Terrestrial mammal bone	4565 ± 55	5210 ± 115
Gif-9567	Upper level C	Marine occupation	Terrestrial mammal bone	4430 ± 50	5080 ± 140
Gif-10784	Lower level C	Marine occupation	Carbon	5380 ± 105	6150 ± 120
Gif-10783	Drowned forest	Opening Canal Fitz Roy	Wood	7275 ± 70	8095 ± 70
Gif-10140	Upper level D	Terrestrial occupation	Carbon	6690 ± 130	7570 ± 100
GifA-95556	Lower level D	Terrestrial occupation	Sedimentary carbon	7450 ± 80	8275 ± 75
Túnel 1; Canal Beagle site with early terrestrial and later littoral occupations (site#8 in Fig. 2; Orquera and Piana, 1999)					
AC 840	Layer D	Marine occupation	Carbon	6410 ± 150	7305 ± 145
Beta 21969	Layer D	Marine occupation	Carbon	6470 ± 110	7380 ± 95
AC 674	Lower layer F	End Component 1	Carbon	6680 ± 110	7560 ± 85
Beta 2517	Lower layer f	End component 1	Carbon	6980 ± 110	7815 ± 105
AC 660	Upper layer G	End Component 1	Sedimentary carbon	6830 ± 140	7705 ± 125
Beta 6748	Upper layer G	End Component 1	Sedimentary carbon	6900 ± 70	7750 ± 70
Imiwaia 1; Canal Beagle site with early terrestrial and later littoral occupations (site# 7 in Fig. 2; Orquera and Piana, 1999)					
AA-78549	Layer R	Marine occupation	Carbon	6390 ± 50	7339 ± 55
AA-78551	Layer S	Terrestrial occupation	Carbon	7840 ± 55	8660 ± 75
Fell's Cave; terrestrial site (site#1 in Fig. 2) with obsidian-bearing (Period III) and free (Periods I, II and IV) levels (Bird, 1988)					
I-5139	Level 4, sample 4	Beginning of Period V	Carbon	685 ± 90	645 ± 70
I-5140	Level 8, sample#6	End of Period III	Carbon	6485 ± 115	7395 ± 100
I-5141	Level 8, sample#8	End of Period III	Carbon	6560 ± 115	7455 ± 100
I-5138	Level 7, sample#3	End of Period III	Carbon	6740 ± 130	7615 ± 110
I-5142	Level 10, sample 10	Beginning of Period III	Carbon	8180 ± 135	9135 ± 195
I-5143	Level 12, sample#15	End of Period II	Carbon	8480 ± 135	9455 ± 145
I-5144	Level 13, sample#18	In Period II	Carbon	9100 ± 150	10,240 ± 225
I-5145	Level 17, sample#21	In Period II	Carbon	9030 ± 230	10,140 ± 325
I-5146	level 18, sample#23	End of Period I	Carbon	10,080 ± 160	11,705 ± 305
W-915	Level 19	In Period I	Carbon	10,720 ± 300	12,520 ± 405
I-3988	Level 20	Beginning of Period I	Carbon	11,170 ± 170	13,075 ± 185

Table 2
Uncalibrated ^{14}C ages and current best average age for the mid-Holocene H1 eruption of Hudson Volcano.

General area	Location	Sample#	Lab#	^{14}C yrs BP	Reference
17 previously published ages (Stern, 2008)					
TDF	Altos de Boqueron	90-14A	GX-16596	>6575 ± 110	Stern, 1991, 1992
TDF	Río Rusphen	90-12A	GX-16594	>6625 ± 110	Stern, 1991, 1992
TDF[b]	Pen Muñoz Gamero	GC2 116 cm		>6915 ± 40	Kilian et al., 2003
TDF	Túnel 1	Layer F	AC 674	<6680 ± 210	Orquera and Piana, 1999
Aisen[b]	Cerro Teodoro	94T-65B		<6720 ± 140	Naranjo and Stern, 1998
TDF[b]	Túnel 1	Layer G	AC 660	<6830 ± 140	Orquera and Piana, 1999
Aisen[b]	Juncal Alto	94T-49G		<6840 ± 90	Naranjo and Stern, 1998
Aisen[b]	Rio Ibañez	93-43B		<6865 ± 220	Naranjo and Stern, 1998
TDF[b]	Túnel 1	Layer G	Beta 6748	<6900 ± 70	Orquera and Piana, 1999
TDF[b]	Laguna Blanca	90-04B	GX-16592	<6930 ± 120	Stern, 1991, 1992
TDF[b]	Túnel I	Layer F	Beta 2517	<6980 ± 110	Orquera and Piana, 1999
Aisen[b]	Lago Verde	94T-44D		<7010 ± 40	Naranjo and Stern, 1998
TDF[b]	Ruta 257	90-22B	GX-16541	<7015 ± 215	Stern, 1991, 1992
TDF	Rio Rusphen	90-12B	GX-16595	<7435 ± 120	Stern, 1991, 1992
TDF	Ruta 257	90-23 GB	GX-16540	<7535 ± 120	Stern, 1991, 1992
TDF	Altos de Boqueron	90-14B	GX-16597	<7550 ± 120	Stern, 1991, 1992
TDF	Pen Muñoz Gamero	GC2 144 cm		<7635 ± 40	Kilian et al., 2003
9 new ages obtained since 2008					
Isla de los Estados[b]	Galvarne Moraine	449.5 cm	LuS 6544	>6755 ± 80	Björck et al., 2012
TDF[b]	Las Cotorras	470–475 cm	AA62823	>7043 ± 47	Borromei et al., 2010
Aisen	Cochrane	312 cm depth		>7160 ± 60	A Holz pers. com., 2010
Magallanes	Straits	990 cm	OS 72978	>7480 ± 55	Aracena et al., 2013
Aisen	Cochrane			>7485 ± 60	Villa-Martínez et al., 2012
Isla de los Estados	Laguna Cascada	CAS/387	LuS 6935	>7715 ± 60	Unkel et al., 2010
Isla de Estado[b]	Galvarne Moraine	454.5 cm	LuS 9301	<6750 ± 50	Björck et al., 2012
Magallanes	Hambre lake	804–806 cm	Keck 79260	<7370 ± 20	Hermanns and Biester, 2011
Isla de los Estados	Laguna Cascada	CAS/391	LuS 6936	<7775 ± 60	Unkel et al., 2010
Best average[a]	13 samples			6890 ± 100	7750 ± 95 cal yrs BP

[a] Average of only those 13 samples within the standard deviation of this average as described in the text.
[b] Among the 13 samples included in this best average. TDF = Tierra del Fuego.

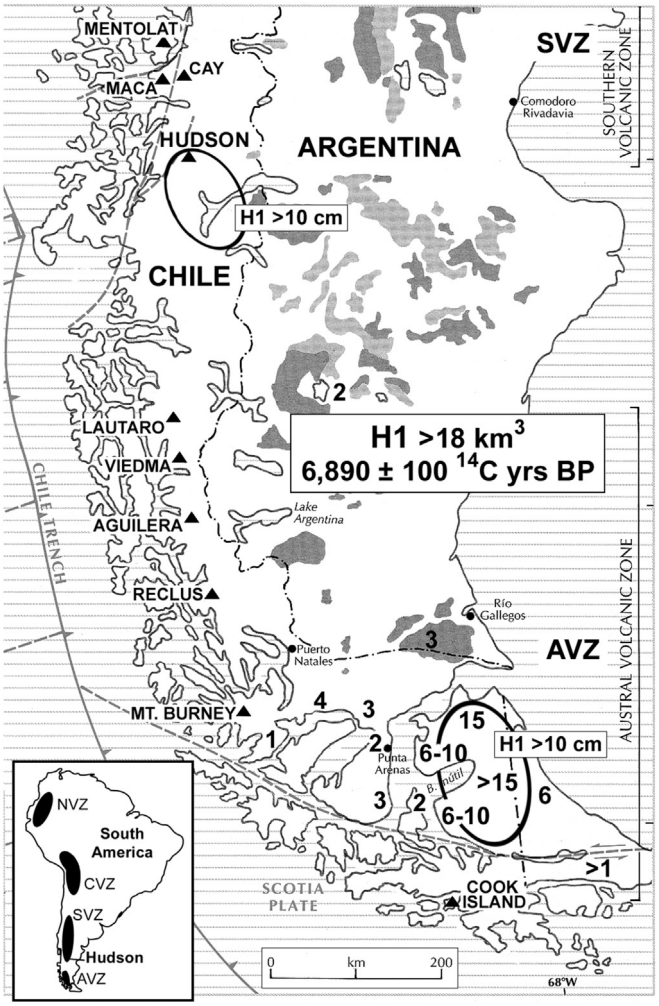

Fig. 1. Map showing the location of the Hudson volcano, H1 tephra thicknesses (in cm) in Fuego-Patagonia, and the >10 cm thick distal maximum tephra-fall isopach on Tierra del Fuego resulting from the mid-Holocene H1 eruption (7750 ± 95 cal BP; Table 2; Naranjo and Stern, 1998; Stern, 2008). Inset shows the location of the Hudson volcano at the southern end of the Southern Volcanic Zone (SVZ) of the Andes.

2. Prehistory of Fuego-Patagonia maritime hunter–gatherers

Before the marine incursion associated with the formation of the Strait of Magellan at about 9240 cal BP (Fig. 3; McCulloch et al., 2005a, 2005b; Morello et al., 2012), Fuego-Patagonia had already been inhabited by bands of terrestrial hunters who left their traces in the archaeological sites of Fell's cave (site #1 in Fig. 2; 13,075 ± 185 cal BP in Table 1) and Pali Aike (site #2 in Fig. 2; 9690 ± 562 cal BP) on the continent (Bird, 1938, 1988), and Tres Arroyos (site #3 in Fig. 2; 12,830 ± 90 cal BP) on Tierra del Fuego (Massone, 1996; Morello et al., 2012). In the early terrestrial hunter–gatherer sites of Cerro Sota cave, on the continent near Pali Aike (Bird, 1988), and Tres Arroyos cave, on Tierra del Fuego, evidence of interactions with the coast is provided by shell and/or sea lions remains found in the earliest occupational levels in association with bone remains of extinct Pleistocene terrestrial megafauna such as the Milodon (*Mylodon darwini*), native horse (*Hippidion* sp.), as well as some wild camelids and big felids (Latorre, 1998) that coexisted besides modern fauna. However, no archaeological sites of the same early ages as Fell's cave and Tres Arroyos have been found along the current coast of either the southernmost South American continent or Tierra del Fuego. The coast at >13,000 cal BP was then far away from its current location, since sea level in late glacial times was still about 120 m below modern sea level. Therefore it is possible that the evidence for the strategies of survival of the earliest littoral inhabitants are now submerged and thus hidden.

The earliest age in the region recorded from a coastal site that shows evidence of navigation and a clear littoral economy orientation is 7440 ± 100 cal BP from Punta Santa Ana (site #6 in Fig. 2; Table 1; San Román, 2010). The evidence for the use of canoes was first found nearby on Englefield Island in Seno Otway (site #5 in Fig. 2), as well as in Túnel 1 on the northern shore of the Canal Beagle (sites #7 in Fig. 2; Orquera and Piana, 1999, 2009; Orquera et al., 2011) and around Navarino Island south of Canal Beagle (Fig. 2; Legoupil and Fontugne, 1997). On Englefield Island, as in other coastal sites like Punta Santa Ana, Túnel 1 and Imiwaia 1 (site #8 in Fig. 2; Orquera, 2005; Orquera and Piana, 1999, 2009; Orquera et al., 2011), the maritime economy presents a remarkable difference with the one existing in the terrestrial hunter–gatherer sites of the Patagonian pampas region. Coastal sites, in which birds, mollusks and marine rather than terrestrial mammals were the main food sources consumed, show a very important and totally new bone industry, which includes decorated harpoons of cruciform base, wedges, needles, and beads for necklaces. The archaeological evidence from these sites registers the appearance of green obsidian as an important lithic material (Stern and Prieto, 1991; Morello et al., 2001, 2004). From those times onward, this obsidian, obtained from its supposed source located along the northern shores of Seno Otway on Riesco Island (Fig. 2), radiated outwards towards coastal sites in Tierra del Fuego and elsewhere in the southernmost fjords, as well as to the continent and inland sites on Tierra del Fuego (Oría et al., 2010), a process that has continued until recent times as demonstrated by some green obsidian arrow points in ethnographic collections assembled by European explorers and sailors (Borrero and Franco, 2001; Prieto and Cárdenas, 2002).

Although the Holocene ascent of sea-level may have covered archaeological evidence that existed previous to the moment of the maximum marine sea level (about 5–10 m over current sea level), that is to say, archaeological evidence previous to ~7440 cal B.P. (Pluet and Pirazzoli, 1991), Fuego-Patagonia underwent extensive glacial rebound as well as tectonic uplift which paralleled sea level rise both before this time and continuing on to the present (Rabassa et al., 2000; McCulloch et al., 2005a,b; Stern et al., 2011). Therefore, the lack of maritime cultural sites older than ~7440 cal BP in this region cannot simply be attributed to their being submerged. However, it should be noted that coastal sites are being attacked nowadays by the erosion that the sea causes along the coast (Prieto and Van De Maele, 1995). Bird (1980) observed this for one of the Isabel Island shell middens (site #9 in Fig. 2), in the eastern Magellan's Strait area, which "in little more than fifty years the destruction initiated already at the time of the visit of Lovisato has been almost completed. If the same conditions stay, it will not lack much so that it is not left anything of a shell midden that once was great, aside from some devices worn away by the water in the debris of Punta Silvestre. In that case the complete cycle of human occupation, destruction of the site and redeposition of the most lasting artifacts, could take place in a term of three hundred years." Therefore erosion may have destroyed some littoral sites older than 7440 cal BP.

3. Origin of the maritime people

Within the South America prehistoric framework, the appearance of maritime economies in the early Holocene has been extensively discussed by Llagostera (1992) for the Pacific coast, and Lavallée (2000) for the Atlantic coast. Along the Pacific coast in

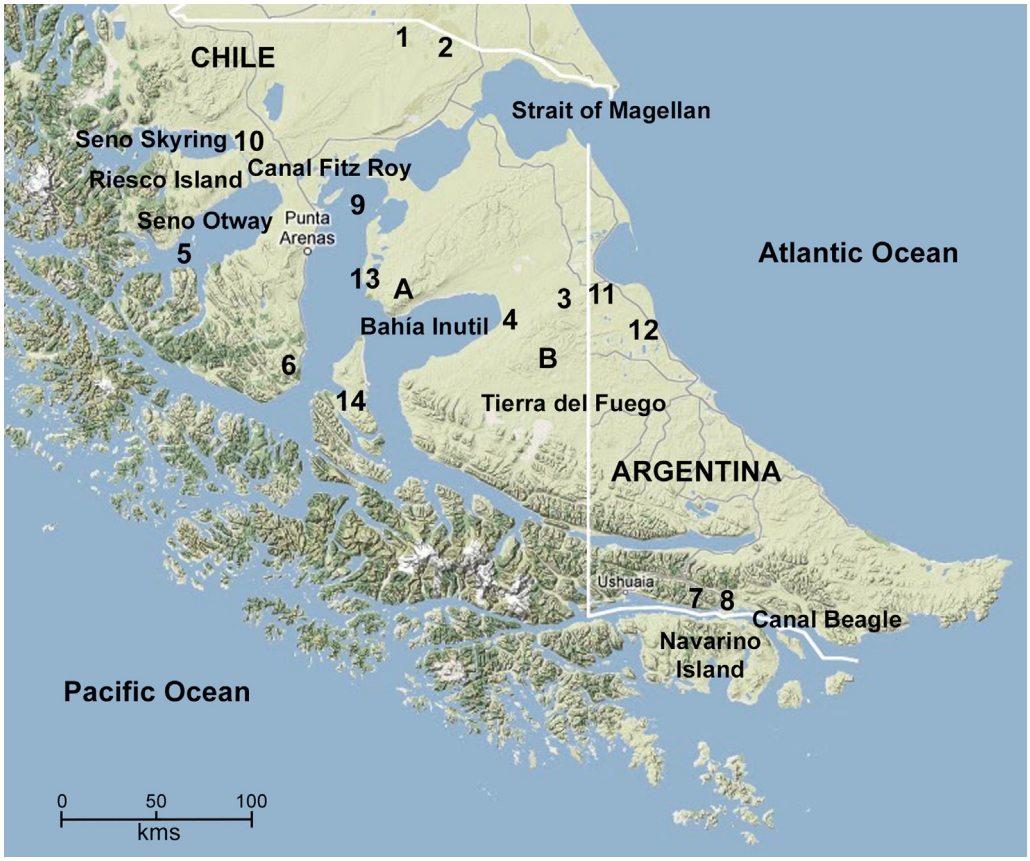

Fig. 2. Map of the location of geographic features and archeological sites in Fuego-Patagonia discussed in the text. Letters **A** and **B** indicate the locations of the photographs of H1 tephra on Tierra del Fuego shown in Fig. 5. Archaeological sites include; #1 Fell's cave; #2 Pali Aike cave; #3 Tres Arroyos (or Cerro los Onas); #4 Marazzi 1; #5 Englefield Island; #6 Punta Santa Ana; #7 Túnel 1; #8 Imiwaia 1; #9 Isabel Island; #10 Ponsonby; #11 Río Chico and Cerro Las Bandurrias; #12 Laguna Arcillosa; #13 Cabo Monmouth 20; and #14 Dawson Island.

northern and central Chile (between 23°30′ and 32°S), early maritime culture sites range in age from ~11,800 to 8500 cal BP (Mendez Melgar, 2012). In contrast, the evidence suggests that along the southernmost regions of the Pacific coast (south of 42°S; Dillehay, 1989) intensive occupation of the coast by maritime hunter–gatherers and the probable use of canoes first happened only during the mid-Holocene. The age of these southern coastal occupations are concordant with the greatest ascent of sea level, as well as with an important contemporaneous advance of the southern forests towards the east (Markgraf, 1985).

As human beings were present as early as >15,000 cal BP in Monte Verde archaeological site, located close to the coast in south-central Chile (42°S; Dillehay, 1997), and terrestrial hunter–gatherers were present in the pampas of southern Patagonia as early as >13,000 cal BP (Table 1; Bird, 1988; Massone and Prieto, 2004), two hypotheses have been raised to explain the presence of canoe people only after ~7440 cal BP in the world's southernmost end: 1) They are descendents from older maritime populations already adapted to the sea that migrated into southernmost Patagonia from the north, or 2) They adapted themselves to the sea and became maritime populations from the terrestrial hunter–gatherer population already living in the south.

The first hypothesis is expressed by Saxon (1976) as "Fuego-Patagonia was occupied by "tides" of different groups, each one of which would have developed his techniques of exploitation in some other place." In support of this hypothesis is the observation that modern ethnographic populations present noticeable phenotypic differences, with tall terrestrial hunters (Selk'nam/Ona on Tierra del Fuego; Tehuelches/Aónikenk on the continent) and shorter canoe people. However, it is certainly possible that ~7440 years was a long enough time span to transform the taller terrestrial hunters into the smaller canoe people. Furthermore it is important to note that there are no human remains previous to the sixth millenium BC in the region of southernmost Patagonia to confirm that terrestrial hunters were in fact of higher stature than either the contemporaneous or modern maritime people. Farther north, Mena et al. (2003) found ten human skeletons in Baño Nuevo cave, near Coyhaique, Chile (46°S), with dates spanning from 9970 to 9540 cal BP and a clearly terrestrial diet, and the adult skeletons show small statures, not tall ones. On the other hand, a woman skeleton from Punta Santa Ana, up to now the earliest canoe people representative (~7440 cal BP; Table 1), displays stature higher than the ones of modern canoe people (Hernández et al., 1997). Furthermore, the examination of the earliest maritime and terrestrial hunter–gatherer skeletons in southernmost Patagonia display very great variations in stature dimensions depending on the group to which they are assigned (Hernández et al., 1997; Santiago et al., 2011).

Hernández (1992), based on a study of Fuego-Patagonian skulls, also concludes that the hypothesis of two different currents of peopling that proceeded from different remote origins, one of canoe people and another one of terrestrial hunters, does not seem acceptable, and that a single origin is more probable for the two groups, followed by their later differentiation. The skull characteristics of the fuegians in general, including the maritime Yamana and Kaweskar subgroups, and terrestrial Selk'nam, show similar modifications in nasal morphology even now (Lalueza et al., 1997). Similar conclusions are derived from the analysis of other cranium-

facial features (Cocilovo and Di Rienzo, 1984-1985). Genetic studies also locate the development of both Fuegian maritime and terrestrial hunter–gatherer populations south of 41°S (Lalueza et al., 1995), since mitochondrial lineages C and D in South America are both located there (García-Bour et al., 1998), although recently some burials in the southern Patagonian region have also yielded haplotype B (Manríquez et al., 2011).

Thus, although the physical appearance of modern Fuego-Patagonia canoe people may seem to suggest that they come from somewhere else, physical anthropology and genetics do not support this argument (Hernández, 1992; García-Bour et al., 1998). Also arguing against the first hypothesis, that the earliest Fuego-Patagonian maritime groups are descendents from older maritime populations already adapted to the sea in the north, is the evidence that south of 32°S the earliest maritime archaeological sites (~7440 cal BP; Table 1) only occur in the southernmost Fuego-Patagonian region south of 52°S, and that dates for maritime sites become younger (<6800 cal BP; Ocampo and Rivas, 2004) to the north along the archipelago in Chiloé north of 44°S. Ocampo and Rivas (2004) further conclude that there were profound differences in the technology and use of resources of the maritime people in Chiloé and Fuego-Patagonia, and that it was very unlikely that the latter was derived from that developed around Chiloé, but in fact more likely the other way around, as a result of migration from south–to–north, consistent with the northward decrease in the ages of littoral sites in these two regions.

In further support of the second hypothesis, that the littoral oriented people of Fuego-Patagonia was derived from a terrestrial

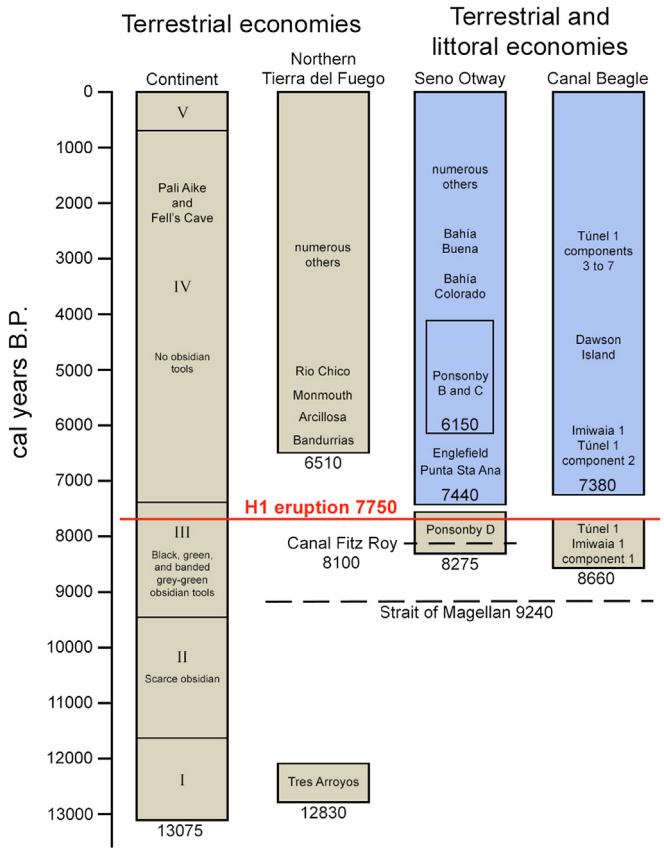

Fig. 3. Chronology of the Hudson H1 eruption (in cal BP) relative to terrestrial and littoral hunter–gatherer archaeological sites in Fuego-Patagonia (modified from Legoupil, 2003), which illustrates the close chronological correlation between the Hudson H1 eruption and the transition from terrestrial to littoral economies in both the Seno Otway area and Tierra del Fuego.

population already living in the south (south of 52°S) that adapted themselves to the sea and became maritime populations, is the fact that the earliest maritime sites in southernmost Patagonia are located in zones where the continental ice barrier present between 47 and 52°S disappears and passage towards the channels is possible from the steppe. The continental ice barrier between the steppe and the sea extends between 46°50′ and 47°50′S in the northern Patagonian ice field, and between 48° and 51°50′S in the southern Patagonian ice field, and there also exists a very inpenetrable forested geographic barrier in the zone between both these two ice fields. South of the southern Patagonian ice field the forested barrier disappears and relatively easy pathways exist, as they did in the past, between the Patagonian pampas to the inner seas of Otway and Skyring and to the south of Bahía Inutil in Tierra del Fuego (Fig. 2). In other words, the earliest archaeological sites of the canoe people in southernmost Patagonia are located precisely where ancient terrestrial hunters could first reach the fjords from the pampas.

One problem is that there are very few sites in these regions occupied by terrestrial hunters before the arrival of canoe people to these same sites. Ponsonby (site #10 in Fig. 2; 8275 ± 75 cal BP; Table 1; Legoupil, 2003) on Riesco Island between Seno Otway and Skyring, and Túnel 1 (the Old Component or Component 1; 7820 ± 100 cal BP; Table 1; Orquera and Piana, 1999, 2009; Piana and Orquera, 2009; Orquera et al., 2011) and Imiwaia 1 (Layer S: 8660 ± 75 cal BP; Table 1; Orquera and Piana, 1999, 2009) along the Canal Beagle are the only three such sites known containing evidence of terrestrial hunter–gatherers prior to marine culture occupations (Fig. 3). The latter two sites are also the only evidence that people stayed on Tierra del Fuego after the opening of the Strait of Magellan.

Ponsonby, located in the eastern extremity of Riesco Island, was first occupied by terrestrial hunter–gatherers when the Canal Fitz Roy, that now separates the island from the continent, did not exist (Fig. 3). In its earliest occupation level D (8275–7570 cal BP; Table 1), prior to the opening of Canal Fitz Roy and older than any clearly maritime sites in the region (Fig. 3), there is evidence of an intensive use of guanaco typical of terrestrial hunter–gatherers, with only an occasional exploitation of pinnipeds and cetaceans (Legoupil, 2003), and there are no cultural traits that can be assigned definitively to a maritime economy. At that time, green obsidian, obtained from an unknown source most probably located somewhere on the then Riesco Peninsula, was transported by terrestrial hunters as far east as Fell's cave and Pali Aike (Fig. 2), where it occurs in Bird's Period III occupational level (9500–7400 cal BP; Figs. 3 and 4; Table 1; Bird, 1938, 1988; Stern, 2000, 2004).

The formation of Canal Fitz Roy, at approximately 8100 cal BP (Bernard, 2003, Table 1), possibly due to glacial rebound and isolation of Seno Skyring from the sea prior to further global sea level rise, may have, as happened on Tierra del Fuego when rising sea level inundated the Strait of Magellan, left some terrestrial hunters isolated on Riesco Island, although they were possibly able to cross the few hundreds of meters that separate the island from the continent using some kind of occasional navigation craft, a precursor of a canoe, such as the one referred to by Bourne (1853) among the Patagonians during the XIX century.

In Ponsonby layers C (6150–5080 cal BP; Table 1) and B (5210–4095 cal BP; Table 1), occupied more than 1300 years after layer D, and also after the opening of Canal Fitz Roy and the isolation of Riesco Island from the continent (Fig. 3), there is clear evidence for a significant increase in the importance of consumption of marine mammal and birds, and more maritime cultural elements such as the presence of harpoons, one of which is identical to one found by Bird (1980) at Isabel Island, and also by the presence of great

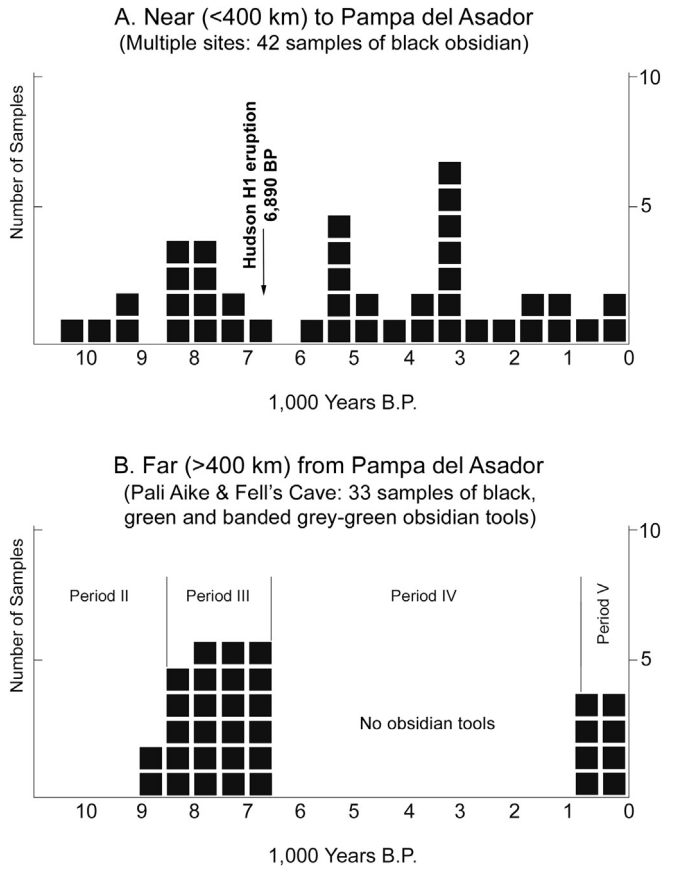

Fig. 4. Chronology of the Hudson H1 eruption (in ^{14}C BP) relative to **A**. the presence of black obsidian from Pampa del Asador in sites within 400 km of this obsidian source area, and **B**. of all obsidian tools in Fell's cave and Pali-Aike (Stern, 2000, 2004). In **A** each dark square represents a sample of black obsidian from many different sites within 400 km southeast of Pampa del Asador, with chronological context provided by archeaologists who collected these samples from these sites (Stern, 1999, 2004). In **B** each square represents a sample of either black, green or banded grey-green obsidian from either Pali Aike or Fell's cave in the collections of Bird (1938, 1988) and/or the independent excavation of Fell's cave by Emperaire et al. (1963). The figure illustrates the close temporal correlation of the H1 eruption and the haitus in long distance terrestrial transport of obsidian in the area of southernmost Patagonia affected by this event. Ages of the cultural periods in Pali Aike and Fell's cave are from Table 1 (Bird, 1988).

denticulated spears like those that are found in many other canoe sites of the region such as Dawson Island (Legoupil, 2003; Legoupil and Pigeot, 2009; Legoupil et al., 2011), as well as other maritime cultural elements such as decorative bone artifacts. Nevertheless, there are bolas and the guanaco is still the main prey. However, it is important to note that the occupation of these layers occurred well after the development of many of the nearby maritime sites in the area of Seno Otway such as Isla Englefield and Punta Santa Ana (Fig. 3). Thus Ponsonby cannot be interpreted as a site preserving the transition between terrestrial and maritime cultures, merely as originally a terrestrial hunter–gatherer site, first occupied prior to the opening of Canal Fitz Roy, and only later, after the opening of the canal and the isolation of the island, occupied by people exhibiting maritime economic and cultural elements similar to the already well establish maritime population living nearby (Fig. 3).

Túnel 1 and Imiwaia 1 also show essentially abrupt changes, after 7380 ± 95 cal BP to littoral exploitation strategies from older, >7750 ± 70 cal BP, terrestrial hunter–gatherers, without evidence of different intervening stages of this transition (Fig. 3 and Table 1; Orquera and Piana, 1999, 2009). In the Component 1 of Túnel 1 on Tierra del Fuego there is evidence that suggests the presence of terrestrial hunters whose lithic industry is atypical compared to those on the continent, specifically with regard to polished lithic wedges (Orquera and Piana, 2009). This atypical industry might be an expression of the isolation of the original settlers of Tierra del Fuego, and might be an indicator of Borrero's so called "cultural change derived from small populations occupying a new niche" (McEwan et al., 1997). Imiwaia 1 also contains some artifacts, including a tranchet, a very long leaf shaped blade and a borer that are unknown in the older Tierra del Fuego sites Tres Arroyos and Marazzi 1 occupied by terrestrial hunter–gatherers prior to the opening of the Strait of Magellan (Piana et al., 2012). However, Orquera and Piana (2009) conclude that the maritime people, who appear first in Túnel 1 at ~7380 cal BP (Fig. 3 and Table 1), ~60 years after their presence at Punta Santa Ana, do not "reflect an exploratory or experimental stage: the adaption was already well structured and adjusted to the environment over which it developed for the next millennia."

Despite the lack of evidence for sequential stages of transition between terrestrial and marine hunter–gatherers in any of the known archaeological sites of the region, we conclude that the maritime people of the Fuego-Patagonia Canals originated *in situ* from the terrestrial hunter–gatherers that had populated this region many years before. The terrestrial hunter–gatherers of southernmost South America lived in the semi-arid steppe and pampas of the Patagonian plateau, while the canoemen developed new strategies, specifically the canoe and detachable harpoons for hunting seals and sea lions, required to live within the rainy glacial fjords of the forested and ice covered southern Andean mountain chain.

Other recent review papers of Orquera (2005), Orquera and Piana (2009) and Orquera et al. (2011), which also favor the *in situ* origin for the Fuego-Patagonian canoe Indians, discuss both the possible environmental factors involved in producing this new adaptation *in situ*, and those factors involved in selecting the advantages of these variations so that they were successfully transmitted through numerous generations in the form of a distinctive economy. With respect to the adaptive advantages that allowed the newly evolved maritime economy to persist, they note the abundant availability of highly nourishing marine resources, the enhanced mobility within canoes to reduce both alimentary stress related to local food shortages, the potentially closer age spacing between surviving children compared to terrestrial hunter–gatherers that were required to carry small children on long journeys, and finally the relatively sheltered waters compared to the open sea provided by the system of fjords and canals in Fuego-Patagonia.

With respect to the possible environmental factors that produced this new littoral adaption, Orquera (2005), Orquera and Piana (2009) and Orquera et al. (2011) are more equivocal, and find no conclusive evidence of any single factor to motivate this adaption. They do note that, since the development of canoes depends on trees (*Nothofagus betuloides*) from the forest, it would seem reasonable to expect that this new adaption occurred where terrestrial groups encountered forests along the shores of the fjords, and in general the known limits for the interaction of the terrestrial groups and the canoeists seem to have been the limits of forest and steppe. Orquera and Piana (1999, 2009) and Orquera et al. (2011) therefore suggest that this transition occurred first in the area along the western shores of the Magellan Strait and the inner seas of Senos Otway and Skyring, the region where the earliest evidence for a littoral oriented economy is found at Punta Santa Ana (~7440 cal BP; Table 1; Fig. 3), and where forests were present by ~8000 cal BP and access between the steppe and forested area was relatively easy. In contrast, at the earliest canoe Indian site Túnel 1 along Canal Beagle, the forest did not occupy the area until after 6700 cal BP (Orquera and Piana, 1999). The inner sea

region of Seno Otway is also the source area of the distinctive green obsidian appearing in the earliest maritime cultural levels in Tierra del Fuego (Stern and Prieto, 1991; Morello et al., 2001, 2004).

We therefore concur with Orquera and Piana (1999, 2009) and Orquera et al. (2011) that the Seno Otway and western Strait of Magellan areas was where the early transition from terrestrial to littoral hunter–gatherers most probabaly occurred, and that following this transition the maritime economy radiated out rapidly to Tierra del Fuego more than 300 km to the south, as well as possible 1500 km north to Chiloé (Ocampo and Rivas, 2004). Long distance material exchange between Fuego-Patagonia and Chiloé has recently been demonstrated by the finding of obsidian derived from the Chaitén volcano east of Chiloé Island in archaeological sites within the Pali-Aike volcanic field and at Monte León along the Atlantic coast north of the eastern entrance to the Strait of Magellan (Stern et al., 2012).

4. Role of the mid-Holocene H1 eruption of the Hudson Volcano

The *in situ* origin of the Fuego-Patagonian littoral oriented society may have been related to some significant stimulus, a dominant cause in the sense of Estévez (2005, 2009), such as the isolation of the population of terrestrial-hunters on Tierra del Fuego Island as a result of the opening of the Strait of Magellan, or the formation of Canal Fitz Roy producing the isolation of Riesco Island, which had to have been strong incentives for trying navigation. However, the former event took place at ~9240 cal BP, well before the development of the littoral oriented economy (Fig. 3; Rabassa et al., 2000; Franco et al., 2004). The timing of the latter event was probably after around ~8100 cal BP (Bernard, 2003). Although this latter date remains uncertain, it clearly was well after the opening of the Strait of Magellan and therefore closer in age to the origin of the canoe people, the earliest evidence for which is dated in Punta Santa Ana as 7440 cal BP (Table 1).

Some other geologically sudden events (volcano eruptions, huge lake outbursts, sea level rise, etc) have had very substantive impacts as triggers for social crises and changes in prehistory (Estévez, 2005, 2009; Estévez and Vila, 2013). Here we suggest that the mid-Holocene H1 eruption of the Hudson volcano, located at 46°S (Fig. 1), may also have had a significant role as a trigger for developing littoral economic strategies ultimately involving the navigation of canoes in Fuego-Patagonia. This suggestion is based on a number of lines of evidence, including 1) the close similarity of the age of this eruption (~7750 cal BP: Table 2) and appearance of canoe people in Fuego-Patagonia (7440 cal BP; Fig. 3); 2) the significant physical impact this eruption likely had on southernmost Patagonia, particularly in the isolated area of northern Tierra del Fuego, as indicated by tephra-fall isopachs (Figs. 1 and 5); and 3) the evidence for the cultural impact of this eruption in all of southern Patagonia as indicated by an interruption in long-distance terrestrial transport of obsidian (Fig. 3; Stern, 2004), obsidian tools being absent in Period IV in both Pali-Aike and Fell's cave (Fig. 4).

Estimates for the age of the Hudson H1 eruption have evolved through time, but are increasingly well constrained. Auer (1974) referred to the grey-green tephra produced by this eruption as Tephra II, and determined an age of between 4800 and 6600 ^{14}C BP for this tephra. Stern (1991) suggested an age of 6775 ± 150 ^{14}C BP based on eight radiocarbon age dates from sites in Tierra del Fuego. Naranjo and Stern (1998) considered the age of the eruption to be 6720 ± 140 ^{14}C BP, based on what they believed to be their most reliable determination in peat. McCulloch and Davies (2001) estimated a very similar age of 6725 ± 65 ^{14}C BP for this tephra based on a statistical analysis of the available data, and Stern (2008) calculated the average of the 10 best age of 17 published conventional radiocarbon age determination to be 6850 ± 160 ^{14}C BP, or 7720 ± 140 cal BP (CALIB 5.0.2; Stuiver et al., 2006). Since then, nine new Acceleratory Mass Spectrometry ages for the Hudson H1 tephra have been published. Table 2 present all 26 available radiocarbon age dates for the Hudson H1 eruption, including the nine new AMS ages. The average of all 26 ages is 7100 ± 360 ^{14}C BP. Progressively dropping those ages that fall out of the 2 sigma uncertainty identifies first 22 ages that average 7040 ± 295 ^{14}C BP, and finally 13 best age determinations, all within analytical uncertainty of their average of 6890 ± 100 ^{14}C BP, or 7750 ± 95 cal BP (Table 2).

This age is older than the earliest dated maritime sites in Fuego-Patagonia, including Túnel 1 layer D at 7380 cal BP (Orquera and Piana, 1999, 2009), Imiwaia 1 layer R at 7340 cal BP (Piana and Orquera, 2009), and Punta Santa Ana at 7440 cal BP (Fig. 3), which allows some time for this culture to develop from the terrestrial hunter–gatherer culture through a few hundred year transitional stage, although it is worth noting that the earliest age at Punta Santa Ana, which is the oldest for any Fuego-Patagonian littoral culture site, is from level II of the excavation, and thus does not actually date the initial occupation of this site.

What is most significant, however, is that the H1 tephra, which occurs in layer F at Túnel 1, is located stratigraphically exactly between the older Túnel 1 terrestrial-hunter gather component (Component 1 of Túnel I in lower layer F and layer G), and the later younger maritime cultural remains at this site (Component 2 of Túnel I in layer D; Piana and Orquera, 2009). Sedimentological analysis showed that 60% of the light fraction of lower F layer, which is 4–6 cm thick and covers the remains of a terrestrial hunter–gatherer occupation floor, is volcanic glass of mesosilicic to acidic type (Orquera and Piana, 1987). Micromorphological analysis carried out in the Institució Milà i Fontanals of the Spanish National Research Council demonstrates that lower F layer was a primary volcanic tephra-fall deposit with almost all its mineral components and rock fragments composed of volcanic ash accumulated in a relatively rapid depositional event (M. Taulé i Delor, pers. com., 2013). Tephra color, morphology and chemistry (Stern, unpublished data) confirm that this was H1 tephra. Vegetal charcoal yielded two radiocarbon dates for lower layer F (Tables 1 and 2) of 7560 ± 85 cal BP and 7820 ± 100 cal BP, and two ages for sediment samples from the top of the underlying G layer (Tables 1 and 2) are 7705 ± 125 cal BP and 7750 ± 70 cal BP, yielding an average of 7710 cal BP for the H1 tephra in this specific site. This is essentially the same as the average of age for this eruption of 7750 cal BP derived from the average of the 13 best dates available for H1 from over a wide region of southern Patagonia (Table 2).

It is clear from this evidence that whatever the uncertainty in either or both the tephra and the site occupation ages, that the H1 eruption occurred precisely in the time span separating the early terrestrial from the later littoral oriented occupations at Túnel 1 (Fig. 3). After this eruption the terrestrial hunter–gatherers did not return to this site, and, in fact, the next appearance of terrestrial hunter–gatherers in Tierra del Fuego was along its Atlantic and northwestern coasts more than 1000 years later, after ~6700 cal BP (Fig. 3; Morello et al., 2012 and references cited therein). These people possessed a lithic tool technology typical of contemporaneous terrestrial hunter–gatherers on the continent and which lacked the atypical aspects of the lithic tools of the older terrestrial hunter–gatherers encountered in the older components of Túnel 1 and Imiwaia 1.

The H1 tephra eruption covered all of southern Patagonia (Fig. 1), and particularly the area of Tierra del Fuego (Figs. 1 and 5), with a significant thickness of fine-grained glassy tephra. Tephra isopachs indicate that the area of Tierra del Fuego represents a distal maximum of H1 tephra thickness ranging up to >20 cm. In the area of the inland seas northwest of Tierra del Fuego, tephra fall

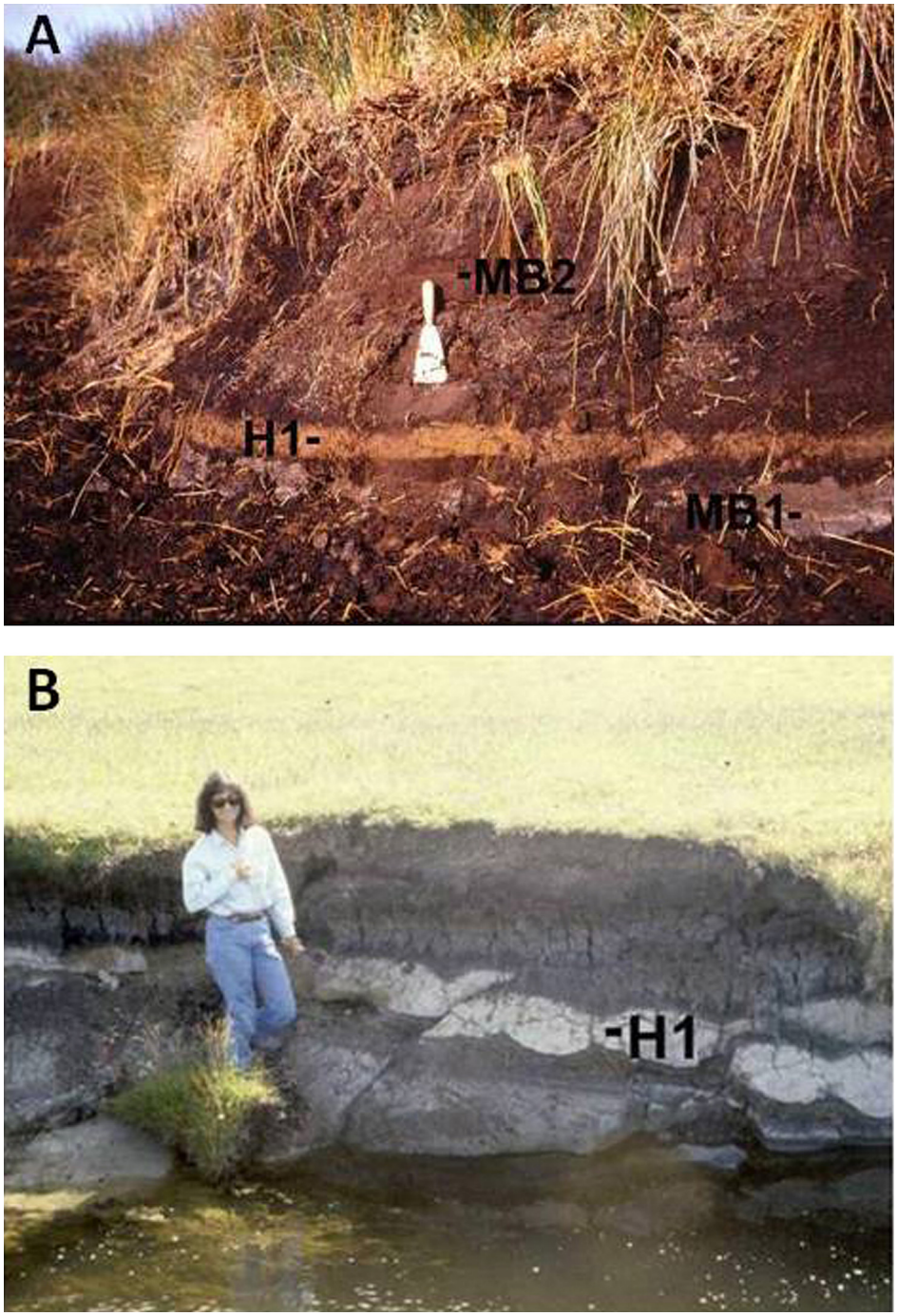

Fig. 5. Photos of the H1 tephra on Tierra del Fuego (Stern, 2008) from the mid-Holocene Hudson eruption, at **A** in Altos de Boqueron, where it is unlikely to have been either thickened or compacted, and at **B** along Río Chico where some post tephra-fall thickening, as well as soft sediment compaction and deformation, may have occurred. Locations of these sites are indicated as letters A and B, respectively, in Fig. 2.

thicknesses are less, but still >4 cm at Laguna Escondida on the north shore of Seno Skyring (Stern, 2008). Based on the area of these isopachs, Stern (1991, 2008) and Naranjo and Stern (1998) estimated the volume of the H1 eruption to be > 18 km^3, which is 4–6 time greater than estimates for the 3–4 km^3 volume of the 1991 eruption of this same volcano (Naranjo et al., 1993; Scasso et al., 1994). The mid-Holocene H1 eruption of the Hudson volcano was in fact the largest eruption yet documented of any volcano in the southern Andes during the Holocene.

The smaller 1991 eruption of the Hudson volcano lead to a significant negative impact on sheep ranching, with estimates of up to >40% of the total population of sheep killed as the result of the eruption, and cattle farming, as well as on wildlife, in the area of thickest airfall (Naranjo et al., 1993; Bitschene and Mendia, 1995), and it could be expected that the very thick layer of tephra deposited in Fuego-Patagonia as a result of the H1 eruption would have negatively impacted the terrestrial flora and fauna and the economy of the terrestrial hunter–gatherers in this region. The physical mechanisms suggested to be responsable for this impact include 1) covering of pasture and watering holes by tephra; 2) conjuntivitis and other eye alterations leading to disorientation and starvation or animals; 3) ash entering the respiratory systems of

animals leading to pulmonary hemorrhaging; 4) gastrointestinal problems caused by ingestion of ash and associated toxic chemicals adhering to ash (Sulfur and Fluorine for example); and 5) wearing down of teeth due to the abrasive nature of ash. Most of these could equally affect humans directly, but would be unlikely to affect marine mollusks or mammals, or birds.

Kilian et al. (2003, 2006) demonstrate, based on a pollen and sedimentary record in peat and lake sediment cores from the Gran Campo Nevado area at the west end of Seno Skyring (Fig. 1), that deposition of an 8–10 cm thick, fine-grained tephra layer from the Mid-Holocene explosive MB2 eruption of Mt. Burney volcano at 4260 cal BP (Stern, 2008) was followed by a long-lasting impact on the ecosystem both near and far from the volcanic center. They showed that slow release of SO_2 from vesicles of altering pumice caused long-term acidification of weakly buffered soils, resulting in nutrient depletion attributed to soil acidification, which in turn led to a decay of the evergreen and southern beech (*Nothofagus*) rain forest lasting for ~1900 years. The effects of the 4–20 cm thick mid-Holocene Hudson H1 tephra, which was two times more iron-rich (H1 FeO of >5 wt % versus MB2 FeO of 2–3 wt %) and thus probably more sulfur-rich than the Mt Burney MB2 tephra (Stern, 2008), most probably led to a similar collapse of the terrestrial, but not marine, ecosystem along all the area transitional from the rain forest to the pampas in southernmost Patagonia.

An indirect indication of significant regional disruption of the terrestrial hunter–gatherer economy as a result of the Hudson H1 eruption is suggested by an interruption in the long distance terrestrial transport of obsidian in southern Patagonia just after this event (Fig. 4; Stern, 2004). The occurrence of black obsidian from Pampa del Asador, southeast of the Hudson volcano, decreases after 7750 cal BP in archaeological sites within 400 km of this source area. Furthermore, artifacts of all types of obsidian (black from Pampa del Asador, green from Seno Otway and grey-green from Cordillera Baguales; Stern, 2000), of which 18 examples were described by Bird (1938, 1988) and 5 by Emperaire et al. (1963) in occupation levels in Fell's cave corresponding to cultural Period III (Fig. 4), are notably absent from occupation levels corresponding to Period IV, dated after 7400 cal BP in this site (Table 1; Bird, 1988). The fact that these two independent excavations both found obsidian tools concentrated in occupation levels associated with cultural Period III (Fig. 4) before ~7400 cal BP, and absent in Period IV after this time, and the seven internally consistent ages (Table 1) determined by Bird (1988) for the levels corresponding to these cultural periods in Fell's cave, demonstrates a hiatus in the long distance terrestrial transport of obsidian in southern Patagonia just after the Hudson H1 eruption (Fig. 4; Stern, 2004). The presence of green obsidian tools among those recovered from both Pali Aike and Fell's cave also provides evidence that green obsidian was exploited and widely distributed by terrestrial hunter–gatherers prior to the evolution of the littoral culture in Fuego-Patagonia, which also exploited and widely distributed this obsidian after 7440 cal BP (Stern and Prieto, 1991; Morello et al., 2001, 2004).

5. Discussion and conclusion

Volcanism has been cited extensively as a possible trigger for climatic, biological and cultural changes throughout the world (Estévez, 2005; Estévez and Vila, 2013). In Fuego-Patagonia, both Bird (1938, 1988) and Auer (1974) stressed the possible role of volcanism as a potential initiator of cultural change within the small early Patagonian populations.

One of the most significant cultural changes in Fuego-Patagonia prehistory is the appearance of littoral economic adaptations at about 7440 cal BP. Although the use of marine life along the coast of the sea as a food staple is much older, the invention of watercraft and the subsequent colonization of the Fuego-Patagonian archipelago only took place >5000 years after the first human presence in the area.

Since there is no other significant environmental trigger known for this cultural change, we propose that the explosive Hudson H1 volcanic eruption dramatically affected northern Tierra del Fuego and western Strait of Magellan populations, pushing some people to the sea in search of edible marine resources that were not affected by this eruption as much as were terrestrial resources. In contrat, Orquera (2005) states that "it would be irresponsible to propose this without concrete evidence" that this eruption provoked an ecological catastrophe causing the terrestrial resource depletion that lead to the marine adaption. We believe that 1) by analogy with the impact of the Hudson 1991 eruption (Bitschene and Mendia, 1995), and by implication of studies of the impact of the MB2 tephra fall on the ecosystem in this same general region (Kilian et al., 2003, 2006), that such an ecological catastrophe must have been caused in Tierra del Fuego by the Hudson H1 eruption; 2) the hiatus in long-distance terrestrial transport of obsidian in southernmost Patagonia after this eruption (Fig. 4) is independent evidence of the disruption of the continuity of the terrestrial hunter–gatherer culture in this region; and 3) the disappearance of the terrestrial hunter–gatherers from the coastal sites in Tierra del Fuego such as Túnel 1, which were later occupied by littoral oriented people exactly after the interval when the H1 tephra appears in these sites, are together sufficient independent lines of information to make the suggestion that the H1 eruption of the Hudson volcano may have been an important trigger in the development of the littoral people from the terrestrial hunter–gatherers a valid possibility.

In fact, the H1 eruption may have killed all the terrestrial hunter–gatherer population on Tierra del Fuego, which had been isolated since the opening of the Strait of Magellan at ~9240 cal BP, since no evidence occurs for their existence until more than 1000 years after the H1 eruption (Fig. 3), and then only along its Atlantic (Río Chico at 6680 cal BP (site #11 in Fig. 2); Cerro Las Bandurrias at 6510 cal BP (site #11 in Fig. 2) and Laguna Arcillosa 2 at 6330 cal BP (site #12 in Fig. 2)) and northwestern coasts (Marazzi 1 at 6390 cal BP (site #4 in Fig. 2) and Cabo Monmouth 20 at 6340 cal BP (site #13 in Fig. 2); Morello et al., 2012 and reference cited therein). Significantly, the tool set of these younger terrestrial hunter–gatherers were similar to those on the continent and did not contain any of the unusual features of the older terrestrial hunter–gatherers who occupied Túnel 1 and Imiwaia 1 prior to the H1 eruption. Therefore, we suggest that it was not only the littoral orientation culture, which radiated out from the Seno Otway area after ~7440 cal BP, but also a new mid-Holocene migration of terrestrial hunter–gatherers from the continent after ~6700 cal BP, that together independently repopulated a possibly totally unoccupied Tierra del Fuego inland area after the H1 event. The terrestrial hunter–gatherers may have reached there on makeshift rafts, such as the Aónikenk used to cross the Santa Cruz river, or perhaps they were helped by their maritime descendents as were the Selk'nam escaping from the Salesian Mission on Dawson Island (Morello et al., 2012 and references cited therein).

In summary, we propose that the catastrophic mid-Holocene H1 tephra-fall dramatically impacted a broad-spectrum of terrestrial hunter–gatherer subsistence economies which had maintained themselves in the region of Fuego-Patagonia for >5000 years after the vanishing of the Pleistocene megafauna. The geographic isolation of some of these people on Tierra del Fuego after ~9240 cal BP and on Riesco Island after ~8100 cal BP produced a bottleneck effect in their biological and social features (the normal phenotype, language and strategies of organization) leading some groups to continue to emphasize the exploitation of terrestrial resources,

with unique lithic tools, while others may possibly have begun to develop the techniques required to exploit littoral resources. The H1 tephra-fall produced by the mid-Holocene eruption of the Hudson volcano triggered the expansion of those groups oriented to the coastal resources, which were the least affected by this disturbance, and at least on Tierra del Fuego, may have extinguished all those small isolated populations still dedicated to a terrestrial economy.

Borrero (l994-5) suggested that the stages of peopling of Patagonia involved first exploration, then colonization, followed by effective long-term occupation. For Fuego-Patagonia in general, we suggest that this sequence should be modified to also include, after >5000 of effective long-term occupation by terrestrial hunter–gatherers beginning at >13,000 cal BP, volcanic catastrophe caused by the H1 eruption at 7750 cal BP, followed by cultural change and recolonization based on a new marine economy that than effectively occupied the Fuego-Patagonian canals for the last 7500 years. For Tierra del Fuego, the volcanic catastrophe may have cause the complete extinction of all the terrestrial hunter–gatherer inhabitants.

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