Coastal occupations in Tierra del Fuego, southernmost South America: a geoarchaeological study of a Late Holocene hunter-gatherer context

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Abstract (200)

In the present work, we focus on Marazzi 2 Site, a Late Holocene short-lived-redundant occupation of terrestrial hunter-gatherer from the southeastern coast of Inútil Bay, northwestern steppe of Tierra del Fuego, Chile. Our aim is to understand the geomorphology, stratigraphy, formation processes and pedogenesis in relation to the human occupation for the last ~3000 years. For this porpoise, we integrate geomorphology, soil micromorphology, mineralogical analysis, geochemical data and magnetic susceptibility data, as well as the micro- and macro-frequency distribution of the

archaeological material. Through all these lines of evidence we discuss three moments in the interplay between geomorphology, soil development and human occupation. First, a very low intensity of human occupation (beginning before 900 BC) was located at the river floodplain which was associated with a lack of or very weak pedogenesis. Second, multiple human occupations related to a shell midden formation on a low river terrace exhibited a weak upper horizon development but abundant coatings indicative of wetter conditions. Third, there was a second peak in human occupation intensity, but with relative less emphasis on marine resource use, which was related to stronger soil development along the present river terrace.
Keywords: Hunter-gatherers; Formation processes; Micromorphology; Magnetic Susceptibility; Geochemistry; Occupation history.

1. Introduction

The Island of Tierra del Fuego presents two main phytogeographical regions: the northern steppe plains and the southern mixed/evergreen and deciduous forest (Figure 1). The transition (ecotone) between these vegetation zones is characterized by woodland (Tuhkanen et al. 1989-90). Climatically, in a regional context, the island can be viewed as a transition between arid Patagonia and humid sub-antarctic climates, with a high oceanic influence which causes a very weak seasonality. Due to the presence of the Andean chain to the west, westerly winds produce a remarkable rain shadow which goes from less than 300 mm to more than 3000 mm per year in the northeast and southwest, respectively. Westerlies produce little consequence to the temperature regime (Markgraf, 1993; Collantes et al., 1999).

The northern steppe environments of Tierra del Fuego (Figure 1) have been peopled from ~8500 BC when the island was still connected with the continent (Massone, 2004; McCulloch et al., 2005). However, the first Late Pleistocene archaeological evidence is confined to one site and does not have temporal continuity throughout the Early Holocene. Only after ~4000 BC did the human occupation record of the steppe re-appear and spread along the plains and ecotones, increasing sharply during the last 2000 years (Borrero, 2008; Morello et al., 2012a). Broadly, these populations were terrestrial hunter-gatherers concentrated on exploiting *Lama guanicoe* (guanaco), among other terrestrial smaller mammals as prey. However, we also know that they made complementary use of maritime food, including fish, pinnipeds, marine birds, cetaceans and molluscs (Borrero, 2008).

On the other hand, the oldest record from the southern humid forest environment is around 5800 BC (Piana et al., 2011). In contrast with the northern plains, the archaeological evidence trend does not reveal an occupation gap between the first record and the rest. The frequency of occupation events also shows a remarkable peak in the last 2000 years. Archaeological evidence from this region describes marine hunter-gatherer groups inhabiting the coasts of the Beagle channel, focusing their subsistence and technology mainly on sea mammals and molluscs (Orquera & Piana, 1999). This way of life was not exclusive to the main island as there are also abundant archaeological sites in the southwestern archipelagos (Figure 1), such as on the Brunswick peninsula, Englefield, and Dawson and Navarino islands (Morello et al., 2012b; San Román, 2013; Legoupil et al., 2011; Ocampo & Rivas, 2004; respectively).

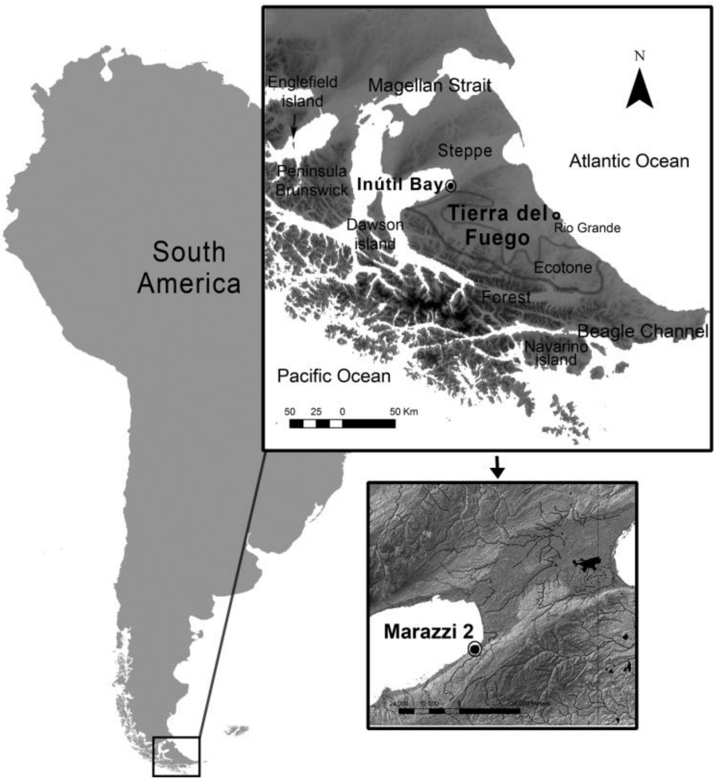


Figure 1. Marazzi 2 Site location (S53° 31.508´ W69° 21.661´) and some geographical references named in the text. Vegetation zones are based on Tuhkanen et al. (1989-90).

When the first Europeans arrived to these territories in the XVI century, they noticed the presence of some different native groups (Gusinde 1982). As it is illustrated in Figure 2, historical and ethographical records indicate three major groups: a) Selk´nam, terrestrial hunter-gatherers of the northern steppe and non-littoral forest; b) Yámana, maritime hunter-gatherers of the Beagle Channel and islands to the south; and c) Kawésqar or Alakaluf, maritime hunter-gatherers of the western islands. In addition, the Haush were a little-known group that seems to have combined elements of both Yámana and Selk´nam lifeways (Yesner et al., 2003). As

Selk´nam, Aónikenk groups were terrestrial hunters distributed in the southern continental Patagonia (Martinic, 1995). Western and southern coasts of the Island were superposition areas for Selk'nam, Kawésqar/ Alacaluf and Yámana. Interestingly, this ethnographical picture coincides well with the archaeological record.

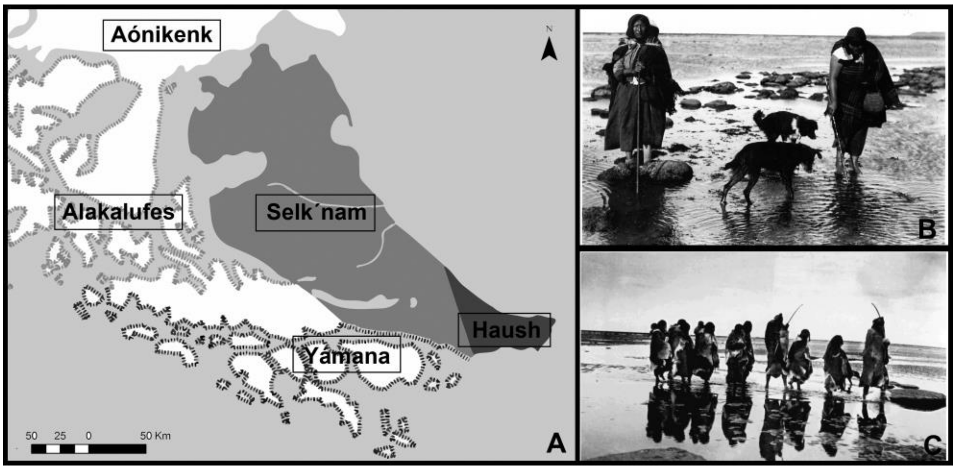


Figure 2. A- Etnographic map taken and modified from Lothrop (1928). B, C- Selk´nam groups from the northern steppe of Tierra del Fuego, Rio Grande, Atlantic coast, Argentina. Pictures taken by Alberto De Agostini (A) in 1923 and by Charles Furlong (B) in 1908 (Alvarado et al., 2007:152, 202).

In the present work, we focus on Marazzi 2 Site, which is located along the southeastern coast of Inútil Bay of the northwestern steppe of Tierra del Fuego (Figure 1). From a geoarchaeological perspective, our aim is to understand the geomorphology, stratigraphy, formation processes and pedogenesis in relation to the human occupation for the last ~3000 years. This specific set of aims all contribute to the understanding of the landscape evolution and to a broader question concerning the nature of littoral occupations of terrestrial hunter-gatherers.

2. Marazzi 2 area

Marazzi 2 Site is situated in an extensive archaeological locality (~100 km^2) along the southeastern coast of Inútil Bay (Figure 1) which comprises isolated finds and more than 30 archaeological material concentrations. Marazzi 2 Site is one of those concentrations, which along with Marazzi 1 Site (dated around 3500 BC) constitute the more interesting human activity areas in the locality (Massone et al., 1997; Morello et al., 1999).

The archaeological record of Marazzi 2 Site extends over an area of ~6000 m^2 along the coast. Both fauna remains and stone artifacts suggest a short-lived-redundant coastal occupation of terrestrial hunter-gatherer groups dated between ~AD 1000 and ~900 BC in the Late Holocene (Massone et al., 2003, 2007; Morello et al., 2004). This interpretation fits well with a broader spatial scale pattern of the island which, despite of some potential methodological and taphonomical biases, indicates a more intensive and multi-purpose use of the Magellan Strait coasts versus the briefly logistic sites found inland (Borrero, 1986; Borrero et al., 2006).

The profile analyzed in this work has been subject to previous excavations which rendered information concerning ~1.5 m of continuous archaeological deposits (Massone et al., 2003, 2007; Morello et al., 2004; Arroyo-Kalin et al., 2007; Calás & Lucero, 2009). This unit is situated on a 2/3 masl fluvial terrace of the Torcido River (Figure 3) and constitutes one of the longest human related sedimentation record in northern and central Tierra del Fuego.

The area has a mean annual temperature of ~6°C, rainfall is around 300 mm per year and westerly winds, more intense in summer, reach an average of ~40 km/h. These conditions result in a semi-arid cold steppe environment established from ~7500 BC (McCulloch et al., 2000). Colluvial and aeolian material accumulated from terminal moraine deposits and the westerly winds, respectively, provide the two main sediment sources for the site. Important erosion features dominate the western and northern coast, related to the ~4000 BC marine transgression (McCulloch & Bentley, 1998).

Regional studies of the late Holocene Torcido River floodplain and terrace where the site sits suggest that those deposits only began to accumulate from after ~2000 BC (Brambati, 2000). At the site, soil profiles are very weakly developed, with an A-AC-C soil profile (or Mollisol) often beneath aeolian and colluvial sediments on which there is an incipient pedogenesis of an A-C profile (or Entisol) (Frederiksen, 1988; Soil Survey Staff, 2010). This sequence was observed in other northern regions of the Island (Favier Dubois, 2003). In the excavation unit under investigation, this profile development cannot be easily distinguished from the superimposed cultural deposit.

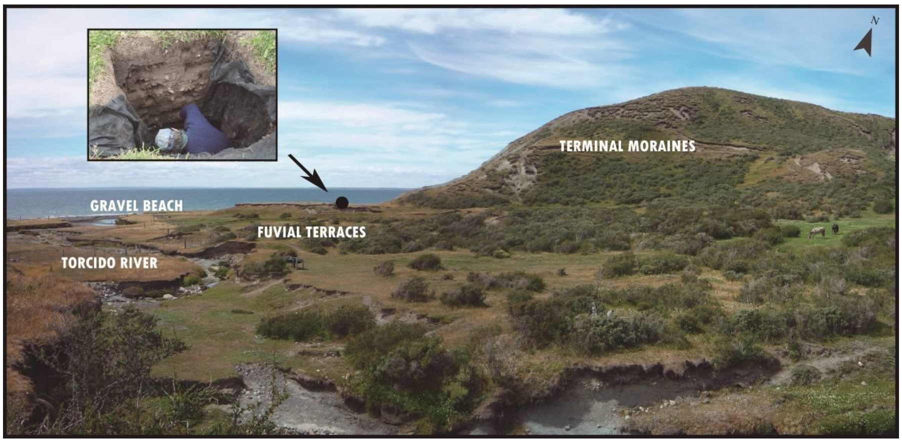


Figure 3. Geomorphological context of Marazzi 2 Site and closer view of the western profile of the excavation unit discussed in this work.

3. Material and methods

Soil micromorphology (description of soils and related materials in their undisturbed state at a microscopic level) was used following standard guidelines (Bullock et al., 1985; Courty et al., 1989; French, 2003; Stoops, 2003; Stoops et al., 2010). Mineralogy analysis was done by counting minerals at five equidistant spots (10x) along the micromorphological slide, as a sampling strategy. The mineral frequency at these five spots was averaging to obtain totals per sample. The appearance of certain amorphous minerals was estimated semi-quantitatively. For the present study, six micromorphological samples were collected (Figure 5), air-dried, impregnated with polyester resin mounted on a glass slide and polished to generate a thin section of 25-30 µm thick to analyze at different magnifications with a petrographic polarizing microscope. The slide preparations were made in the McBurney Geoarchaeological Laboratory, Division of Archaeology, University of Cambridge, UK.

In addition, nine sets of sedimentological samples were taken at 10 cm intervals along the same profile (Figure 5) in order to measure the following parameters.

1. Magnetic susceptibility. It quantifies the response of a material to an external magnetic field and gives an indication of *in situ* burning and old land surfaces (Clark, 2000).The instrument used was an AGICO (Advance Geoscience Instrument Company – Czech Republic) susceptibility metre model MFK1-FA (Department of Geology, University of Buenos Aires). Before measuring, dried samples were ground in an agate mortar. Three different frequencies (~1000 Hz, 4000 Hz and 16000 Hz at 200 A/m maximum amplitude of magnetic field) were run and the susceptibility values were normalised to mass. The frequency-dependent susceptibility ($X_{FD(1, 16)}$) parameter was chosen to measure the susceptibility difference between two frequencies: 1000 Hz and 16000 Hz (Dearing, 1999; Hrouda, 2011). Results above 5% by mean are considered significant and have a high probability of having superparamagnetic grains (magnetite) in the sample. The threshold of 5% is considered a significant since 12% has been the highest value recorded in local rocks (Qingsong et al., 2005).

2. Total inorganic and organic carbon (TIC-TOC). It was processed by loss-on-ignition (Avery & Bascomb, 1974). After reaching a constant weight in a 40°C oven for ~3 hours, samples were burnt at 550°C for 14 hours. The weight difference was used as an indirect indicator of organic matter content (IDEAN, University of Buenos Aires).

3. Percentage of $CaCO_3$.The laboratory procedure involved the use of acid base titration with HCl as titrant (Department of Geology, University of Buenos Aires).

4. pH. It was measured with a hand-held pH meter (SANXIN model PHS-3D-02) by dissolving the sediments in distilled water at room temperature using a 1:2.5 volumetric mixture of soil and distilled water (Avery & Bascomb, 1974).

5. Finally, soil texture was determined by feel and ascribed a color with the Munsell Soil Color chart. The quantity and diversity of the archaeological record observed in the micromorphological thin sections was taken as an indicator of the intensity and nature of human occupation. Data yielded by the micromorphological analysis was also compared with the vertical density distribution of artefacts registered by other research teams during the previous excavations (Morello et al., 2004; Arroyo-Kalin et al., 2007; Massone et al., 2007).

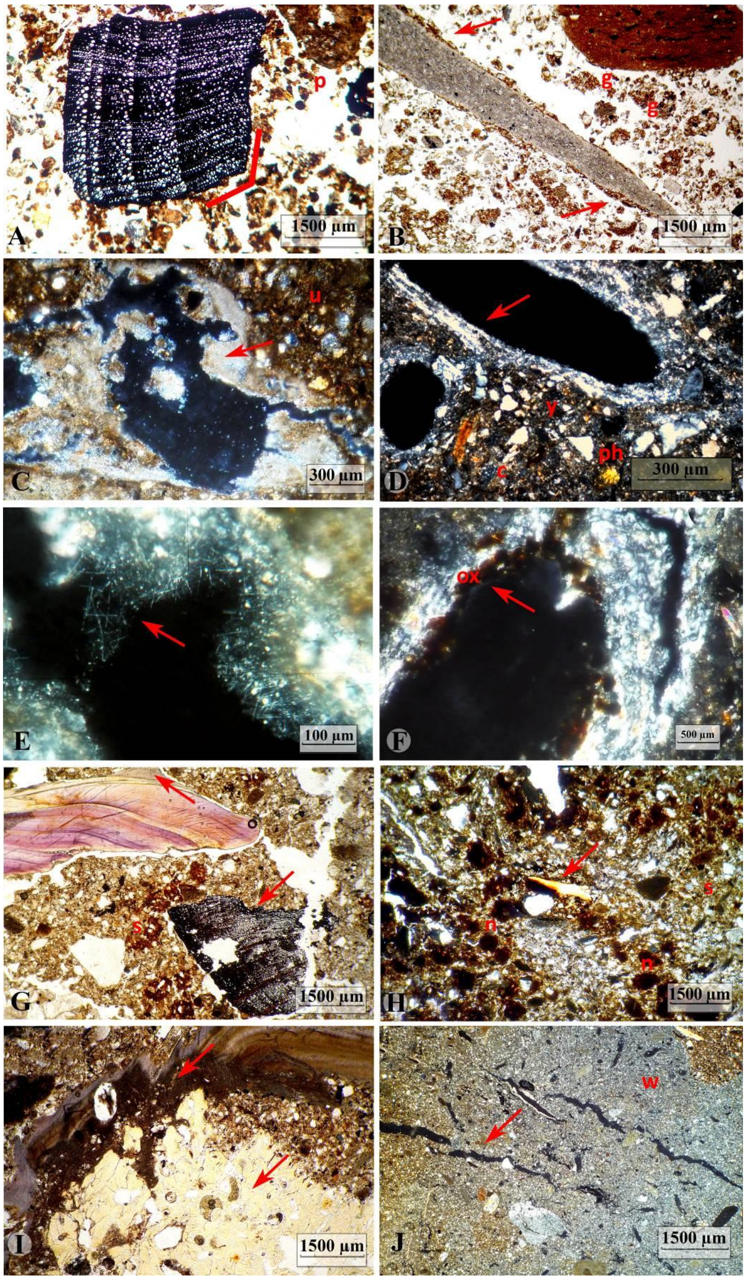
The interplay of these line of evidences contributed to the understanding of processes such as pedogenesis (bioturbation and diagenesis) and morphogenesis (aeolian and colluvial inputs), along with the possible human modification of soils and sediments at Marazzi 2 Site.

4. Results

Figure 5 displays the western profile understudy (Figure 3). Macroscopically, from bottom to top, the stratigraphy is characterized by grey silty loam sediment (125-110 cm), with a massive structure. This sediment becomes highly mottled and with calcareous precipitation (shell mollusc weathering) (110-100/90 cm). Up to 100/90 cm the excavation unit is partially flooded by the groundwater. The archaeological material is rare and consists of whole and broken shell molluscs. Above, the sediment is more compact (100/90-70/60 cm) and corresponds to a grey silty clay loam with calcareous precipitation, less mottling than beneath and massive structure. There are also more fine roots. From 70/60 cm there is a clear change in a compaction and color which goes from grey to dark/ very dark grayish brown. Here, the archaeological material (bones, shells, charcoal and stone artifacts) it reaches its highest density, up to 50/40 cm depth. The texture is a silty clay loam followed by a sandy loam (in both cases with abundant gravel), and the structure looks more crumbly than the fabric underneath. From here to the top, the archaeological material in the profile is rare, the structure remains crumbly or granular, the texture is a sandy loam and the colour becomes slightly darker, especially in the last 10 cm where the presence of roots is very high. For all the layers and/or horizons, contacts are more or less diffused.

4.1. Micromorphology

Figure 4 illustrates some micromorphological features of the six slides (for a full description, see Table A, Appendix). Samples show a channel/vughy microstructure from the bottom up to ~60 cm, and a granular/crumby one up-profile (Figure 4B). The coarse/fine ratio (defined by a 50 µm limit) records a predominance of fines (60-70%), with a small shift to coarser particles upwards. The groundmass related distribution is always porphyric (Figure 4D) and the b-fabric is undifferentiated (Figure 4C), except between ~85-100 cm where it is observed as a crystallitic b-fabric (Figure 4D). Well sorted samples are only observed from the bottom up to ~100 cm (Figure 4H), and the orientation of the particles varies along the sequence with a lack of trend (random in most of the cases, vertical in two samples and horizontal in one). Broadly speaking, the gravel component of the samples is sub-rounded to rounded, while the finer fraction is mainly sub-angular. The organic matter (tissue remains, fine organic material, punctuations, fungi spores, algae, etc.; Figure 4E) is very degraded at the bottom (Stage E sensu Blazejewski et al., 2005) and along the profile it never goes beyond 25%, distributed randomly (humified material is more abundant up-profile) (Table 2).



A
p
1500 µm
B
g
g
1500 µm
C
u
300 µm
D
y
c
ph
300 µm
E
100 µm
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s
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I
1500 µm
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w
1500 µm

Figure 4. Photomicrographs (PPL: plane polarized light/ XPL: cross polarized light): A- well preserved sub-angular charcoal fragment within a pellety fabric (p) (sample #1, 28-41 cm, PPL). B- dirty coatings around a microflake embedded in a highly porous pellety microstructure (sample #2, 44-55 cm, PPL). C- calcitic ash partially filling voids in an undifferentiated b-fabric (u) (sample #3, 63-75.5 cm, XPL). D- laminated coatings in channels and vesicles within an open porphyric related distribution (y) and a crystalltic b-fabric (c) (sample #4, 86-99 cm, XPL). E- fibrous crystals in voids of the same coatings mention in D (sample #4, 86-99 cm, XPL). F- same coating -D and E- combined with iron oxides (ox) (sample #4, 86-99 cm, XPL). G- well preserved shell fragments, with organic matter replaced by iron, iron nodules and stains (s) (sample #5, 101-113 cm, PPL). H- angular fragment of burnt bone, well defined iron nodules (n) and stains (s) (sample #6, 112-124 cm, PPL). I- dissolution processes on shell and bone (sample #6, 112-124 cm, PPL). J- well sorted fine deposit (w) and horizontally oriented channels (sample #6; 112-124 cm, XPL) (see Table A, Appendix).

Concerning the pedofeatures, iron nodules and iron stains are very abundant between 116-85 cm (Figure 4G and H). Also at lower levels, depletion features such as $CaCO_3$ dissolution (Figure 4G), biological degrading and minerals/rocks weathering are more frequent. Coatings are absent up to ~100 cm and rare upwards (i.e. dirty clay coatings in voids and on particles) (Figure 4B). Between ~85-60 cm there are very abundant first order interference color coatings and hypo-coatings, filling partially and sometimes totally chambers/ vesicles and root channels (Figure 4D, E and F). They present a low relief in PPL and, assuming that there is only one mineral type, its crystallization pattern has two different expressions: as amorphous patches and a needle-like form (Figure 4E). The latter grows towards the center of the void or channel, suggesting an *in situ* crystallization. There are also some “plates” (that could be the other section of the needle-like mineral) oriented parallel to the void wall and also forming “bridges” or “chains” across the voids, confirming the *in situ* growth of this mineral. In some spots, these coatings and hypocoatings look laminated and combined with carbonates and iron (Figure 4F). All these properties could suggest that this mineral is a type of clay, probably kaolite ($Al_2Si_2O_5(OH)_4$) (see below), though it is difficult to determine clay types with a petrographic microscope so more detailed studies should carry on.

Bioturbation (seen in the presence of rooting, passage features, excremental material, granular structures, unsorted deposits and lack of bedding) increases upwards. Finally, pellety fabrics and phosphatic nodules (<50 µm) are ubiquitous pedofeatures throughout.

The mineralogy (Table 1) is mainly represented by authigenic amorphous and nodules of iron oxides, quartz crystals and lithics. In less frequency, there are opaque minerals, such as plagioclase, amphibole, feldspar and some others. Considering the distinctive composition along the profile, there is a low peak in the quartz frequency at the bottom and a moderate increment of lithics towards the top. Carbonates are concentrated between 100-60 cm, opaque minerals and iron oxide between 125-60 cm and clay (illuviated and as a feldspar weathering product) between 100-60 cm. Finally, phytoliths are present, although in low frequency, throughout the profile. This low frequency could be taphonomic because phytoliths can be dissolved in a pH range of 4-8 (though in a high rate water flow through the sediment) (Fraysse et al., 2009; Karkanas 2010).

MINERAL	#1 28-41	#2 44-55	#3 63-75.5	#4 86-99	#5 101-113	#6 112-124	TOTAL %	σ
quartz	52.15	45.96	49.57	47.59	47.49	58.02	50.18	4.45
lithic	34.97	26.71	28.21	12.05	25.70	15.57	23.90	8.57
opaques	0	0	14.53	13.86	7.26	0.47	6.02	6.91
plagioclase	6.75	3.11	2.56	8.43	4.47	9.43	5.70	2.82
amphibole	3.68	6.83	2.56	9.64	5.03	4.72	5.41	2.51
feldespar	0.61	11.18	0	4.82	4.47	7.08	4.69	4.16
pyroxene	0.61	2.48	0.85	1.81	1.12	2.83	1.62	0.90
epidote	0.61	2.48	0.85	0	2.79	0.94	1.28	1.11
glauconite	0	0.62	0.85	1.81	0.56	0	0.64	0.67
zircon	0	0.62	0	0	0.56	0.47	0.28	0.31
apatite	0.61	0	0	0	0.56	0.47	0.27	0.30

oxides	x	x	x	xx	xxx	xxxx	-	-
clay	x	x	xxx	xxxx	xx*	xx	-	-
carbonate	-	x	xx	xxxx	x	x	-	-
sericite	x	-	-	-	-	x	-	-
zeolite				X				
chlorite	x	-	-	-	-	-	-	-
phytoliths (opal)	xx	xx	x	x	x	x	-	-

Table 1. Relative frequency of mineral appearance in the thin sections (#1, #2, #3... and their depth in cm). Lithics include sedimentary, metamorphic and igneous rocks. Due to the colour (orangish, reddish), iron oxides are likely to be limonite, goethite and/or hematite. Carbonates are mainly represented by calcitic ash and the shell weathering. x = rare; xx = occasional; xxx = frequent; xxxx = abundant. * = inaccurate.

Table 2 presents the archaeological evidence recorded in the micromophological thin sections. The higher and more diverse archaeological material concentration is between ~100-30 cm depth, with a peak between ~80-60 cm. A dominant presence of molluscs is recorded from ~113 to 85 cm. Consistently, these data match well with the macroscopic density distribution recorded by other excavations (Morello et al., 2004; Massone et al., 2007) carried out in the same unit and another one done one metre away (Table 3).

Thin section depth (cm)	Bone fragments	Stone artifacts	Shell fragments	Charcoal	Ash	Organic matter
#1: 28-41	xx*	xx	xx	xx		xxx
#2: 44-55	xx*	x	x	xx		xx
#3: 63-75.5	xxx*		xx		xxxx	x
#4: 86-99	xx		xxx		xx	xxx
#5: 101-113	x*		xxxx			xx
#6: 112-124	xx*		xx			xx

Table 2. Semi-quantitative estimation of the archaeological material recorded through micromorphological analysis. Ordinal scale: x= rare; xx = occasional; xxx = frequent; xxxx = abundant. * = “burnt”.

Depth (cm)	**Terrestrial fauna (NISP/m^3)**	**Marine fauna (NISP/m^3)**	**Mollusc density (MNI/m^3)**
0-30	1919.9	40.4	90400
30-60	1778.1	24.5	274595
60-90	2366.5	116.3	908000
90-120	941.5	92.8	422500
120-150	19.4	0	0

Table 3. Calculation of the density of fauna remains from archaeological excavations (based on Morello et al., 2004; Massone et al., 2007; Calás & Lucero, 2009).

4.2. Magnetic susceptibility and geochemistry

Magnetic susceptibility results are shown in Figure 5/Table 4, and indicate two distinctive trends. On one hand, from 120 to 70 cm, there are low values ranged between 0.001-0.007 m^3/kg. In contrast, from 70 to 30 cm, values range between 0.014-0.018 m^3/kg, showing a significant incremental change in the magnetic susceptibility values.

The $X_{FD(1, 16)}$ that could be related with the presence of superparamagnetic magnetite grains (Dearing, 1999; Hrouda, 2011) shows approximately a zone of values around 2% between 120-90 cm and another zone around 5% between 90-30 cm. Therefore, the $X_{FD(1, 16)}$ indicates a good agreement with the variation of bulk susceptibility values mentioned above.

Concerning the other parameters, Figure 5/Table 4 indicates that, with some oscillations, carbon percentage (TIC-TOC) increases upwards. This incremental rise is smooth from the bottom to ~70/60 cm and sharper upwards. The percentage of $CaCO_3$ is very low at 120/110 cm, increasing and remaining rather constant up to 70/60 cm. From this depth to the top of the profile, values decrease remarkably. The acidity level of the sequence is alkaline (maximum pH of 8.28), except at the bottom of the profile where the pH is neutral to weakly calcareous (pH of 6.7).

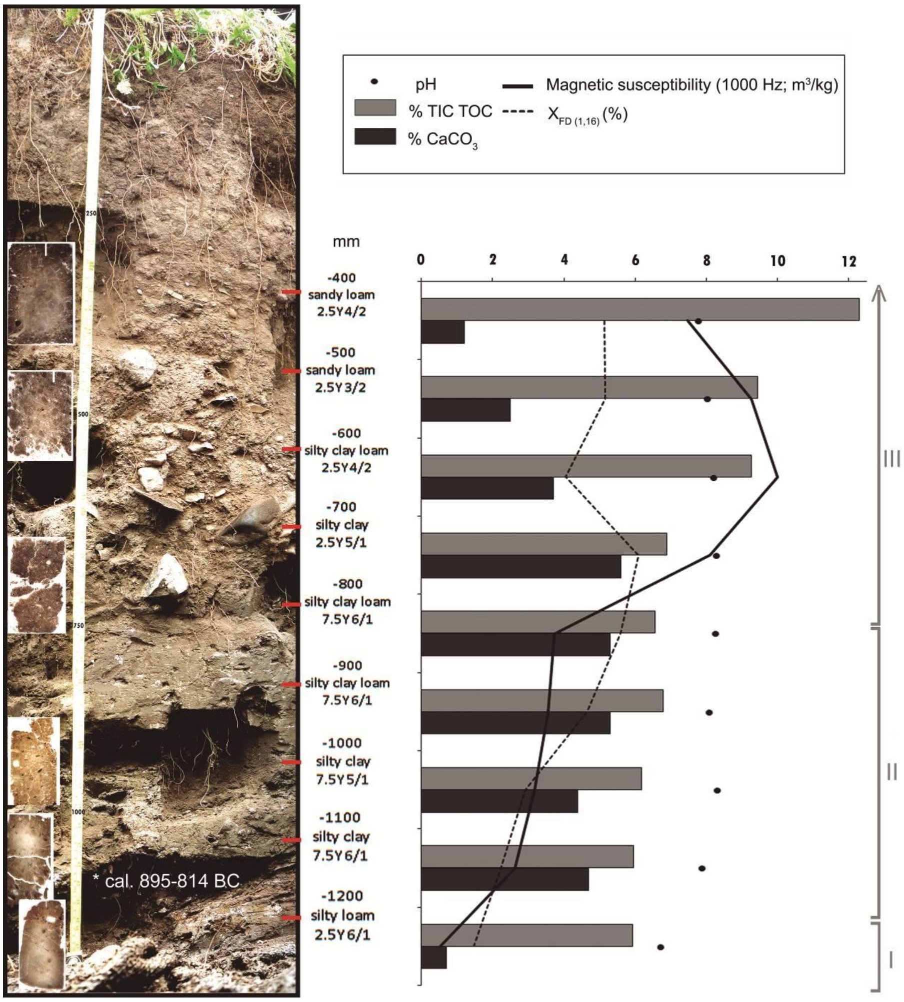

Figure 5. The western profile of Marazzi 2 Site (124 cm), indicating the micromorphological and sediment sample depths and geochemical and magnetic susceptibility results. Magnetic susceptibility values are normalized and multiplied by 10. I, II, and III are the "moments" proposed in the discussion section. Charcoal material for the radiocarbon determination (2745+-40 BP –Ua 21140- / 895-814 cal. BC (OxCal 4.2 - SHCal13 curve, Bronk Ramsey, 2009) was collected from

other profile of the same excavation **at a depth of ??? in moment (Please specify for correlation)** (Morello et al., 2004).

Depth (cm) and corresponding thin section (#...)	pH	TIC TIC (%)	$CaCO_3$ (%)	Magnetic Susceptibility	
				At 1000 Hz (m^3/kg)	*X_{FD}=100(X_{LF} - X_{HF})/X_{LF} (%)
-40 (#1)	7.74	12.307	1.2	0.0136	5.1429
-50 (#2)	8.01	9.438	2.5	0.0168	5.1670
-60 (#2)	8.19	9.275	3.7	0.0182	4.0355
-70 (#3)	8.25	6.881	5.6	0.0147	6.0876
-80 (#3)	8.23	6.556	5.3	0.0068	5.5959
-90 (#4)	8.06	6.793	5.3	0.0064	4.6665
-100 (#4)	8.28	6.170	4.4	0.0058	2.9139
-1100 (#5)	7.85	5.951	4.7	0.0047	2.2276
-1200 (#6)	6.7	5.935	0.7	0.0010	1.4685

Table 4. Geochemical and magnetic susceptibility results. *Frequency-dependent susceptibility parameter, where X_{LF} and X_{HF} are the susceptibility at low (1000 Hz) and high (16000 Hz) frequencies.

5. Discussion

Through the integration of the different lines of evidence presented above, we summarize and discuss three moments (Figure 5) in the interplay between geomorphology, soil development and human occupation. We also examine the formation processes which may have affected the archaeological record.

5.1. First moment: the floodplain

Considering the present geomorphological position of the excavation unit on a high river terrace (Figure 3), the well-sorted fine deposits within horizontal channels located in the deeper micromophological thin section (at 116-124 cm) could be understood as a floodplain deposit

(Figure 4J). The peak of well sorted quartz crystals (Table 1 and Table A) and relatively less lithics (gravel size) present could be understood as more intense aeolian action and/or less colluvial additions.

In relation to the archaeological record, the above thin section presents a higher density of **fabric ??** (Table 2 and 3), so one could expect that the material was placed at this level and therefore migrated downwards **(explain this).** Nonetheless, as bone remains show at least two different stages of weathering, it is also likely that some of the material (the more weathered) corresponds to an older context, for example to the floodplain. The presence of fine bedding recorded in the micromorphology analysis would also support this to some extent, or at least the idea of a non-disturbed sector within this deposit. Indeed, the relatively lower archaeological concentration than above could also be explained by a taphonomic bias, as bone is stable with pH above 8.1 and below 7 will dissolve depending on the water flow (Berna et al., 2004). Low percentages of $CaCO_3$, an acid pH, a high frequent of iron oxides and the low magnetic susceptibility values (Maher, 1998; Orgeira et al., 2000) also confirm the presence of water and, therefore, the high chemical weathering context of this level. These conditions have not allowed good soil development to occur.

5.2. Second moment: the shell midden

Groundwater table oscillation was registered through the presence of mottling (i.e. iron nodules, stains, organic matter replacements, etc.) recorded from ~116 to 85 cm (Figure 4H). Geomorphologically, this level is already related with a (probably low) fluvial terrace formed by a combination of colluvial and aeolian processes which are indicated through the micromorphological and mineralogical analysis in the presence of well-sorted fine quartz, a higher quantity of gravels (lithics) than below (moderately oriented) and bedding.

A third important source of material comes from the human occupation itself, mainly represented by molluscs. Consistently, the percentage of $CaCO_3$ is higher between ~110-70 cm (Figure 5).

Despite of the presence of mollusks all along the profile, the higher proportion of them in this level could be understood as a sparse shell midden deposit, even though its density and thickness is much lower than others well known shell middens found in the western Patagonian archipelagos (Legoupil et al., 2011; Morello et al., 2012b; San Román, 2013) and southern Tierra del Fuego (Balbo et al., 2010; Orquera et al., 2011; Villagrán et al., 2011; among others). Well preserved molluscs (Figure 4G) could suggest low migration processes. It represents a first moment of intense human occupation.

The micromorphological analysis shows abundant coatings and hypo-coatings which could be related to a B horizon at ~100-85 cm. Interestingly, these type of coatings probably composed of kaolinite or any other silica-rich clay are not registered in any other level of the profile, nor in present in any deeper horizon, suggesting a higher relative input of water at this point. Studies carried out in the northern of Tierra del Fuego indicate the presence of palaesols around AD 1500 (Orgeira et al., 2012) and AD 1200/1300 (Favier Dubois, 2003), also recorded around AD 1300 in limnological works done in the southern part of the continent (Haberzettle et al., 2005, 2006; Mancini 2007). Previously, pollen records of the northern steppe plains point to wetter condition between AD ~500-800 (Heusser, 1993). In sum, those abundant coatings could be the result of a rise in humidity during the last 3000 years, though episodic increases in precipitation could also produce these pedofeatures.

The low increment of magnetic susceptibility from 0.001 to 0.0064 m^3/kg and the rise of the $X_{FD(1,16)}$ from ~1.6% to ~4.6% (Figure 5/Table 4) could be caused by secondary minerals generated by bacterial activity, soil formation and burning that promote the development of superparamagnetic particles (Dearing, 1999; Dalan & Banarjee, 1998).

5.3. Third moment: the pedogenesis

From ~80 cm to the top of the profile, there is a sequence of topsoils whose limits are difficult to define macro- and microscopically. This sequence can also be explained by the formation of one or more aggradational A horizons, a frequent feature in soils developed on slopes which receive a constant addition of colluvial material (Selby, 1993).

Despite the continuous accumulation of the archaeological material to the site profile, the most intense human occupation seems to be placed between ~80-60 cm (Table 2 and 3). This archaeological scenario contrasts both qualitatively and quantitatively with the deposit underneath. Microscopically, there is a sensitive reduction in the presence of molluscs, and a higher quantity of bone fragments. Macroscopic quantification also yields a remarkable change towards the presence of guanaco *vs.* molluscs (Calás & Lucero, 2009). Table 2 shows a shift from dense archaeological materials with emphasis in shells molluscs, towards high densities with abundance in archaeological bone, organic matter and fire evidence (i.e. charcoal, ash; Figure 4A and C).

Since pedogenesis is more remarkable in these levels, bioturbation alerts us to potential biases in the vertical distribution of the archaeological material. This fact is illustrated by the presence of different bone fragments with distinctive weathering stages, as well as colluvial material, passage features, granular microstructures, lack of beddings and pellety or excremental fabrics. Granular/crumby microstructures are probably a consequence of burrowing animals such as *Ctenomys sp*., whose bones and probable macro-features were also recorded in the archaeological excavations (Morello et al., 2004; Massone et al., 2007). However, at the same time, the abundant presence of ash registered in the micromorphological sample number 3 (between ~80-60 cm, Figure 4C) could constitute an indicator of some well preserved sectors in the profile (Ismail-Meyer & Huber, 2013).

The archaeological material observed around 40/30 cm depth is likely a “stone-line” phenomenon, well recorded in the region (e.g. Favier Dubois, 2009). Soil biota such as earthworms can generate a biomechanical sorting by burrowing and mounding, which tends to displace larger objects downward and smaller objects upward (e.g. Balek, 2002). This means that at least some of the material found around 30 cm depth could have been actually deposited on the ground surface and buried by this phenomenon.

The archaeological contrast between this moment and the second one also coincides with a sharp change in the magnetic susceptibility (Figure 5/ Table 4). This property shows a substantive increment at 70-60 cm, coinciding with the second mayor archaeological density and the beginning of a well developed A horizon. Both the presence of anthropogenic ash (Figure 4C) and pedogenetic processes could contribute to that magnetic susceptibility enhancement (Dearing, 1999; for a local discussion Orgeira et al., 2012). A possible combustion source at this level could have contributed to the *in situ* mineral crystallization seen in the first order interference colour coatings (Figure 4D, E and F).

These results are relevant as local studies of magnetic susceptibility in archaeological context did not record any magnetic enhancement associated with anthropogenic deposits located near the Atlantic coast of northern Tierra del Fuego (Orgeira et al., 2000). In that area, the low intensity of human occupation may explain this lack of magnetic signature. Even though the archaeological sites of the Magellan Strait coast, such as Marazzi 2 Site, correspond to the same populations which inhabited the Atlantic coasts, it has recorded a regional pattern with a higher intensity of human occupation along the Magellan Strait *vs*. the Atlantic coasts (Borrero et al., 2006).

6. Summary and conclusions

During the last 3000 years the interplay between geomorphology, pedogenesis and human populations has transformed the soils and sediments at Marazzi 2 Site. Considering the co-evolution of these different systems we can summarize the following scenarios:

1. Before 900BC there was a very low intensity of human occupation located on the Torcido River floodplain. This is associated with a lack of or very weak pedogenesis evidence. Some taphonomic

issues (such as the water table contact and the neutral to weakly calcareous pH) suggest a possible bias in the quantity of surviving archaeological material, though part of the material could come from the level above.

2- Subsequent multiple occupations were related to shell midden formation with a high density of archaeological remains located on a low river terrace exhibiting a weakly developed upper horizon and abundant coatings probably related with wetter conditions.

3- Then there is a second peak in human occupation intensity above, but with a relative less emphasis on marine resources. This is related to stronger soil development along the present river terrace. The proportion of aquatic resources becomes lower towards the top of the profile (Figure 5).

Thus, the geoarchaeological work at Marazzi 2 Site shows that during the Late Holocene this sector of the coast was visited repeatedly under different natural environments and with distinctive purposes at least in term of consumption. Even with the use of microscopic techniques, no discontinuity in the deposit was observed which indicates “human abandonment” (after Balbo et al., 2010).

The geoarchaeological and archaeological studies at Marazzi Site 2 support the regional pattern recorded elsewhere in northern Tierra del Fuego. As already demonstrated by stable isotope data, lithic provenence analysis and fauna remains, the highly mobile populations of northern Tierra del Fuego had a complementary use of coast and inland environments, although with a dominance of guanaco as the main subsistence resource (Borrero, 1986; Yesner et al., 2003; Barberena, 2004; Borrero et al., 2006; Borrazzo, 2012).

Methodologically, we would finally like to highlight the importance of integrating different techniques which comprise multiple spatial scale analyses (Dincauze 2000), including the study of the geomorphology of the site, the macroscopic profile descriptions, micromorphological and mineralogical information, and geochemical data and magnetic properties. In the present work, all these data were relevant to understanding the archaeological scenario which, in turn, helps to understand the transformation of that natural setting.

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Appendix

Commented [I1]: It goes horizontally

	Microstructure	Groundmass (c/f ratio$_{50\mu m}$)	Coarse fraction	Pedofeatures
#1 top	Granular/crumby m. (bigger granules than below. *c.* 20 mm). Porosity: 20-25%. Frequent channels (1 mm width). vughs (500-1000 µm) and simple packing voids.	40/60. R. distribution: open porphyric. b-fabric: undiff. (organic micromass).	More gravel than below (up to *c.* 10 mm). rounded/ subrounded. sub-vertical oriented. Subangular small size particles. Randomly oriented. Poorly sorted. **Anthropogenic components**: Shells (more and bigger than below. Echinoderms. Bones (some highly weathered and others smaller but better preserved and burnt –same as below-)- Microflake. Charcoal. **Organic matter**: 15-20%. Preservation stages B. C and D (sensu Blazejewski et al.. 2005). Tissue remains (up to 5 mm). cells. organic fine material. punctuations and fungi spores.	Phosphatic nodules. Clay dirty coatings. Pellety fabric. Passage features.
#2	Granular/crumby m. (<15 mm). Porosity: 35-40%. Frequent vughs and chambers.	40/60. R. distribution: double space porphyric. b-fabric: undiff. (organic micromass).	Less gravel than below. rounded/ subrounded. Subangular small size particles. Moderately vertical oriented deposit. Poorly sorted. **Anthropogenic components**: shells (less. smaller and more fragmented than below; some patially dissolved. Echinoderms. Bones fragments (some highly weather and some other smaller pieces well preserved and burnt. Microflake (15 mm). Charcoal. **Organic matter**: 8-12%. Stages B. C and D. Tissue remains replaced by iron oxydes. Organic fine material. abundant fungis spores and punctuations. Algae.	Few phosphatic and iron nodules. Clay dirty coatings. Pellety fabric. Passage features.
#3	Vughy m. (*c.* 2 mm). Porosity: 25-30%. Frequent channels (*c.* 1mm) and chambers.	40/60. R. distribution: double space porphyric. b-fabric: undiff. (organic micromass).	More abundant and bigger gravel than below (up to 5 mm). mainly subrounded. Subangular small size particles. Massive deposit. Randomly oriented. Poorly sorted. **Anthropogenic components:** shells. vertical oriented (less. smaller. more fragmented but well preserved than below. up to 10 mm). Few cases of partially dissolved shells. Echinoderms. Bone fragments. very frequent. some partially dissolved (from 500 µm to 7 mm) and others burnt (2.5mm). Abundant calcitic ash filling voids. with punctuation and superimposed iron. **Organic matter:** 5-10%. Stages A. B and C. Tissue remains (in some cases replaced by iron oxydes). cells. organic fine material. punctuations.	Few clay dirty and first interference color coatings (as underneath). Abundant calcitc ash coatings. Few phosphatic nodules (100 µm). Frequent amorphous iron. Pellety fabric. high biological degrading. Bone interperization.
#4	Channel/vughy m. Porosity: 20-25%. Root channels (*c.* 800 µm) more abundant at the bottom. Vughs (> 500 µm). Chambers (*c.* 500-1000 µm)	30/70. R. distribution: open porphyric. b-fabric: crystalitic and undiff. (organic micromass).	Less gravel than below and above. rounded. Subangular small size particles. Horizontal orientation. Poorly sorted. **Anthropogenic components**: shells (less than below). Echinoderms. Bone fragments (up to 5 mm). **Organic matter**: 15-20%. (Stage B. C and D). Some well preserved tissue remains. organic fine material. cells. punctuations.	Iron nodules -REDOX-. Very Abundant first order interference color coatings and hypocoatings (see full description in the text above). Some CaCO3 and iron coatings. Rare dirty clay coatings. CaCO3 dissolution. Pellety fabric. Beddings.

#5	Vughy m. (*c.* 700 µm). Porosity: 20-25%	30/70 - 40/60. R. distribution: open porphyric. b-fabric: undiff. (organic micromass).	More gravel than below and above. (up to 10 mm) rounded/ subrounded. Subangular small size particles. Well sorted deposit (but less than below). **Anthropogenic components**: abundant shells (better preservation. more quantity and less fragmented that below. moderate vertical oriented). Echinoderms. A burnt rounded piece of bone. **Organic matter**: 10-15%. Tissue remains. Stage B. C and D. Algae.	Iron nodules. organic matter replaced by iron. stainings -REDOX-. Phsphatic nodules. Manganese precipitation. CaCO3 dissolution forming coatings. Mineral weathering. Pellety fabric. High bioturbation. Few first order interference color coatings (same as above).
#6	Channel m. Porosity: 10-15%. Root channels (*c.* 800µm). Horizontal and vertical orientation in the middle and bottom of the sample. respectively. Vughs (<1mm).	first half 40/60; second half 30/70. R. distribution: open space porphyric. b-fabric: undiff. (organic micromass).	Less gravel than above. subrounded. Randomly orientated. Subangular small size particles. Well sorted. **Anthropogenic components:** abundant shells (but less than above). mainly dissolved and fragmented. Frequent angular bones. some highly weathered and others burnt. **Organic matter**: 10-12%. Tissue remains. cells. fine organic material. puctuations. Highly degraded; Stage E. The humified organic material looks horizontal oriented.	Iron nodules (concentrated on the top). stainings -REDOX-. Phosphatic nodules. Manganese precipitation. $CaCO_3$ dissolution. Beddings. Rock weathering.

Table A. Main features of the micromorphological description. Note: “m.” = microstructure; “undiff.” = undifferentiated; “R.” = Related.