

## FINAL REPORT PROGRAM LEFE

Program LEFE/ action(s) Océan- Atmosphère	Project Title SEPORa (South-Est Pacific Ocean Reservoir Age) Estimation des âges 14C du réservoir océanique dans le sud-est Pacifique depuis la dernier maximum glaciaire	Years 2017 – 2018
<p>PI <b>Giuseppe SIANI</b> , Geoscience Paris-Saclay, <a href="mailto:giuseppe.siani@universite-paris-saclay.fr">giuseppe.siani@universite-paris-saclay.fr</a></p> <p>Participating Laboratories : Laboratoire des Sciences du Climat et de l'Environnement Gif-sur-Yvette</p>	<p>Other funding sources : ECOSud-Conycit (Integrated Action project between France and Chile; 2016-2018) "Impact of circulation changes and melting of Patagonian caps on CO2 regulation atmospheric by the Southern Ocean "This project makes it possible to finance the fieldtrip missions of French researchers In Chile.</p>	
<p><b>Context:</b> The Southern Ocean (SO) and its circulation plays a key role in the global climate system. Indeed, a key element of thermohaline circulation is the return path of water masses from the deep ocean to the surface via the dynamics of upwellings controlled by the latitudinal position and the intensity of the westerly winds as well as the amount of heat and carbon transferred from the deeper to the surface ocean reservoir and atmosphere.</p> <p><b>Objectives:</b> <u>The project Sepora</u> aims to provide new perspectives on the chronology, duration and mechanisms governing the climate changes in the SO since the last deglaciation. The temporal framework is constrained by tephrochronology, a powerful tool for stratigraphic and chronological correlation of marine and terrestrial climatic events to control the possible existence of synchronous or asynchronous events on a regional and inter-hemispheric scale. To do this, a prerequisite to synchronize the marine and continental archives is the quantification of the <math>^{14}\text{C}</math> ages of the surface ocean reservoir (<math>R_{\text{surf}}</math>, i.e. the <math>^{14}\text{C}</math> age difference between the sea surface and the atmosphere).</p> <p>As part of this project we aim to understand what is the ascent depth of the SO upwellings cell all along the Southeast Pacific (SEP) to understand whether the mixing depth gradually increases to reach the entire water column at the end of deglaciation and to what latitude. Hence, the starting point was the establishment of precise age models of marine climate records over the SEP sector of the SO by a latitudinal mapping of the surface ocean <math>^{14}\text{C}</math> reservoir ages (<math>R_{\text{surf}}</math>). We have initially provided a study of tephrochronology on two marine cores from the SEP at <math>41^\circ\text{S}</math> which is proving to be the best method to independently estimate the <math>R_{\text{surf}}</math> of the oceanic reservoir (i.e. Siani et al., 2013, <i>Nature Communication</i>). Subsequently, we undertook a tephrochronological study of a sedimentary lake sequence (Lago Castor) further south (<math>45^\circ\text{S}</math>) with the aim to providing more chronological control points for continental climate records in the Aysén region.</p> <p><b>Main results:</b> A detailed tephrostratigraphy study supported by AMS <math>^{14}\text{C}</math> dating, oxygen stable isotope (<math>\delta^{18}\text{O}</math>) and geochemical analyses has been carried out from two deep-sea cores MD07-3100 and MD07-3098 collected offshore the Los Lagos region (<math>41^\circ\text{S}</math>), close to the main Andean volcanic centres of the Southern Volcanic Zone. Counting of glass shards from 150 and 135 samples on the detrital fraction along the core MD07-3100 and MD07-3098 revealing the occurrence of sixteen and ten ash layers respectively over the last 20 ka BP (Figure 1). The joint analysis of major and traces elements by laser ablation on LA-ICPMS-HR on "mono volcanic glass-shards from marine and continental sites (Laguna El Trebol among the others) has made it possible to find the sources of the eruptions associated with marine tephra from the cores and attributed to the volcanoes of the Puyehue /Cordon Caulle complex, Hudson and for the majority Michinmahuida. We were also able to provide the first estimates of <math>R_{\text{surf}}</math> at <math>41^\circ\text{S}</math> in the SEP with the discrimination of the ignimbrite of Amarillo at the Early Holocene (<math>R_{\text{surf}} = 990 \pm 70</math> years, in Haddam et al., 2018). A more accomplished article on the reconstruction of volcanic events by marine tephrochronology in the SVZ during the last 20 ka is being drafted and will be submitted in June 2020. We focused later on the Lago Castor, located at the latitude of <math>45^\circ\text{S}</math> in the southern part of the Andean Southern Volcanic Zone (SVZ). The nearest active volcanoes are Cay, Maca, Hudson and Mentolat. Tephra along the 15 meter lake core were identified at naked eye revealing the occurrence of 49 events covering the last 20 ka BP (Figure 2). Major element analyses have allowed to confidently correlate 31 events to the Mount Hudson, greatly extending the activity of this volcano since the last deglaciation, and 7 to Mentolat. Finally, we tentatively attributed 11 events to the Maca/Cay volcano complex. This study also allowed to obtain a new <math>R_{\text{surf}}</math> estimate of <math>1320 \pm 120</math> years at the beginning of the last deglaciation in the marine core MD07-3088 (Haddam et al., 2018). This value is calculated from the comparison between the TL6 tephra at 870 cm (<math>14,970 \pm 80</math> 14C yr, in Carel et al., 2011, JVGR) and the H0 tephra, found in the Castor lake and in sediments recovered in several lakes of the Aysen region, attributed to the Hudson volcano (average age for this eruption at <math>13,650 \pm 90</math> 14C yr). This result confirms previous sea-surface reservoir <math>^{14}\text{C}</math> age estimation of <math>1320 \pm 95</math> yr at <math>46^\circ\text{S}</math> for the first part of the last deglaciation. These preliminary results relating to the <math>R_{\text{surf}}</math> estimates are necessary to provide new temporal constraints on i) the ventilation time of intermediate and deep ocean waters and ii) understanding the climatic mechanisms controlling ocean circulation in this region and on a larger scale on the carbon cycle since the late glacial period. In this regard, a study on the evolution of the radiocarbon ventilation time of intermediate and deep water masses in the South-East Pacific is being carried out as part of the doctoral thesis by Consuelo Martínez Fontaine. The first results were published in the journal</p>		

Paleoceanography and Paleoclimatology (Martinez Fontaine et al., 2019). In addition, the inferred robust age models for cores located at 41°S and 46°S in the SEP allowed us to reconstruct both ventilation and depth expansion of the water masses within bathyal depths (~1500 – ~2500 m), inferring the lower depth limit variations of the Antarctic Intermediate Water (AAIW) since ~22 kyr cal. BP. These results will be published in the review Paleoceanography and Paleoclimatology (Haddam et al., accepted)

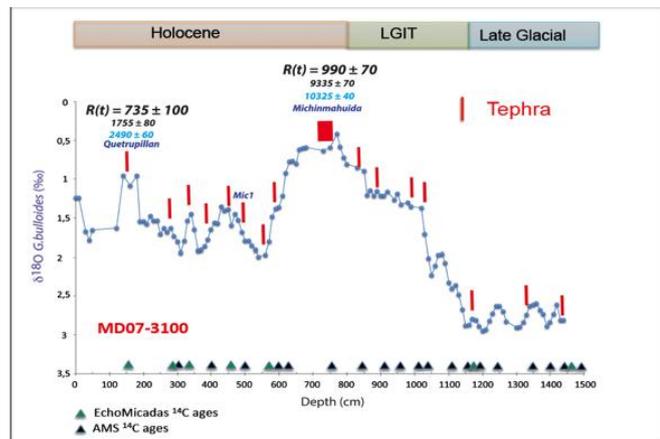


Figure 1

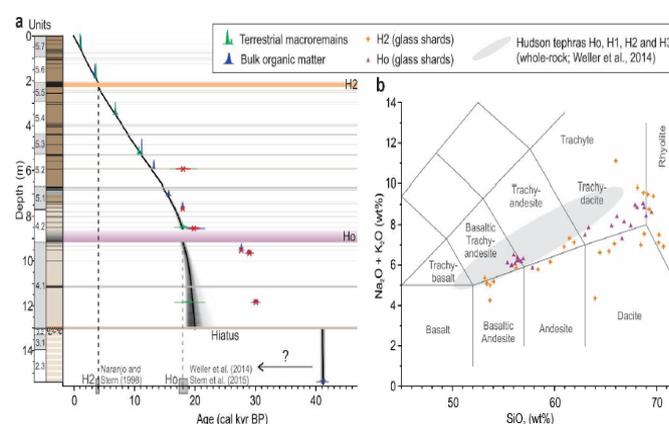


Figure 2

**Figure 1:** Estimated reservoir  $^{14}\text{C}$  ages  $R(t)$  of the surface ocean for core MD07-3100. The figure shows the variation of the  $\delta^{18}\text{O}$  on the planktonic foraminifera *G. bulloides* vs. depth (cm). The red lines correspond to the tephra identified in the core, the triangles the AMS  $^{14}\text{C}$  datum points. The  $^{14}\text{C}$  ages reported in black relate to continental tephra, whereas the  $^{14}\text{C}$  ages in light blue correspond to marine tephra. **Figure 2:** (a) units, lithology and age model based on 20  $^{14}\text{C}$  ages and deposition of 49 tephra layers (grey rectangles, purple (Ho) and orange (H2) rectangle) and 3 turbidites (brown rectangles). The resulting ages of Ho and H2 are projected on the age axis and fall within the range of published ages for these tephras (grey rectangles). (b)  $\text{Na}_2\text{O} + \text{K}_2\text{O}/\text{SiO}_2$  TAS plot of glass shards from H2 (purple triangles) and Ho (orange diamonds) tephras, compared to published data from all major Hudson eruptions (grey area).

#### Future of the project :

Solid research perspectives are to be expected in the short term, in particular within the framework of a recent oceanographic mission organized by the International Ocean Discovery Program Expedition 383 DYNAPACC (Dynamics of the Pacific Antarctic Circumpolar Current) which took place between the May and July 2019 in the southern sector of the Atlantic and East Pacific. Long sedimentary series will transpose to the Plio / Pleistocene scale the understanding of the functioning of the Southern Ocean and thus explore the Dynamics of the Pacific Antarctic Circumpolar Current as well the climatic mechanisms driving the evolution of atmospheric  $\text{CO}_2$ .

#### Publications dans le cadre du projet SEPORA :

- Haddam N.A. , G. Siani, E. Michel, J. Kaiser, F. Lamy, S. Duchamp-Alphonse, J. Hefter, P. Braconnot, F. Dewilde, G. Isgüder, N. Tisnerat-Laborde, F. Thil, N. Durand, C. Kissel (2018). Changes in latitudinal sea-surface temperature gradients along the South Chilean margin since the last Glacial. *Quaternary Science Reviews* 194 : 62-76. doi.org/10.1016/j.quascirev.2018.06.023.
- Haddam, N. A., E. Michel, G. Siani, L. Licari, F. Dewilde. (2020, accepted MS) Ventilation and expansion of intermediate and deep waters the Southeast Pacific during the last termination. *Paleoceanography & Paleoclimatology*.
- Martínez-Fontaine C., R. De Pol-Holz, E. Michel, G. Siani, D. Reyes-Macaya, G. Martínez-Méndez, T. DeVries, L. Stott, J. Southon, M. Mohtadi and D. Hebbeln (2019). Ventilation of the deep ocean carbon reservoir during the last deglaciation : Results from the Southeast Pacific. *Paleoceanography & Paleoclimatology* 34 (12) 2080-2097. https://doi.org/10.1029/2019PA003613
- Wils, K., Van Daele, M., Lastras, G., Kissel, C., Lamy, F., Siani G. (2017). Holocene Event Record of Aysén Fjord (Chilean Patagonia): an Interplay of Volcanic Eruptions, Crustal and Megathrust Earthquakes. *Journal of Geophysical Research: Solid Earth*, 122. https://doi.org/10.1002/2017JB014573.

**Conférences : Participation à 11 conférences** internationales entre 2017 et 2019 dont 2 en tant qu' « invited Speaker »

**Siani G.** Conférence *The dynamics of the climate in the last glacial-interglacial cycle*, Bologna-Italy, June 17th-18th 2019.

**Siani G.** Workshop *Postglacial marine productivity reconstructions*, Punta Arenas-Chile 14-16 november 2018