Proceedings of 15th International Congress of Speleology, Kerrville, Texas, USA, 19-26 july 2009
Symposium on Karst Islands

GEOMORPHIC AND ARCHEOLOGICAL FEATURES OF COASTAL CAVES IN MADRE DE DIOS ARCHIPELAGO (PATAGONIA, CHILE)

Richard MAIRE[1-2], Bernard TOURTE[2], Stéphane JAILLET[2], Joel DESPAIN[3], Benjamin LANS[1], Franck BREHIER[2], Luc-Henri FAGE[2], Laurent MOREL[4], Marc POUILLY[5], Thibault DATRY[6], Marc MASSAULT[7], Dominique GENTY[8], Karine WAINER[8], Vincent RIDOUX[9], Willy DABIN[9], Jean-François PERNETTE[2], Marcelo AGÜERO FARIDONI[10], Maria-Jose MANNESCHI[11] and TEAMS OF ULTIMA PATAGONIA EXPEDITIONS 2000, 2006, 2008

[1] *CNRS, Lab. ADES, 12 Esplanade des Antilles, 33607, Pessac cedex, France rmaire@ades.cnrs.fr*
[2] *Association Centre-Terre, Pasquet, 33760, Escoussans, France*
[3] *National Park Service, Sequoia and Kings Canyon National Park, CA 93271, USA*
[4] *Université de Lyon1.* [5] *IRD.* [6] *Cemagref, Lyon.* [7] *Université d'Orsay.* [8] *LSCE, CEA-CNRS, Saclay.*
[9] *Université de la Rochelle.* [10] *Asociacion Chilena de Espeleologia, Santiago.* [11] *Universidad de Chile, Santiago*

Abstract

Located at 50°30' S, Madre de Dios archipelago is an outstanding natural and archeological heritage, which Chile designated a protected area in January 2008. Together with Diego de Almagro Island (51°30'S), this is the most southerly and inhospitable karst on Earth, owing to a subpolar climate with extreme rainfall (>7-8 meters/year) and strong winds ("roaring fifties"). The Upper Carboniferous and Lower Permian Tarlton Limestones (500 m thick) form part of the pre-Jurassic basement of the Andean Cordillera, the former Pacific margin of Gondwana. Along the fjords and Pacific front, cliff-side exploration with rubber dinghies has revealed three exceptional caves with: 1) archeological artifacts (Pacific Cave); 2) glacial sediments (Moraine Cave); 3) stepped beaches and whale bones (Whale Cave).

Discovered in 2006, Pacific Cave is the first archeological cave found in the Patagonian islands containing paintings from the Kawésqar culture. This marine cave, 3 m above sea level, contains thick shelly deposits (limpets), bone fragments, fireplaces with charcoal and 50 paintings. Thirty were made with red ocher (anthropomorphic figures, "sun-wheel"). Geochemical analyses with a portable X-ray analyzer (Niton) indicate about 1 to 3 % of iron. Twenty drawings were made with charcoal, and one seems to represent a galleon. Because of recent glacio-isostatic uplift (main upper horizontal shoreline at +3 m), the age of the drawings is probably between several hundred and about 3000-4000 years. The oldest known burial site is 4520 ±60 years BP in Ayayema Cave (+10 m), explored in 2000.

Moraine Cave has a 40 m large entrance situated 50 m above sea level on the west front of Guarello Island; it is filled by a 25-m-thick morainic deposit with interbedded varves. The oldest stalagmite is 9055 ±915 years BP. Three stepped horizontal wall notches at about +55 m are not yet interpreted.

Whale Cave contains a huge entrance 70 m high and 50 m wide, located on the Pacific front, but perpendicular to the swell direction. This karstic cave, 180 m long, contains several stepped pebble marine terraces at +5 m, +7 m, + 9 m, and +10.5 m, all with granite pebbles carried from the eastern part of the island by glaciers. Many whale bones (6 skulls, many vertebrae, and ribs), especially blue whale and Hyperodon, are dispersed throughout the middle and bottom parts of the cave between +7 and +11.5 m. Two ^{14}C dates indicate ages of 3200 ±100 years BP at +9 m, and 2600 ±60 years BP for another whale bone at +37 m, suggesting deposition by a tsunami. All these karst and archeological features recorded in littoral caves provide an understanding of the complex evolution of this coastal area since the last deglaciation and the origin of Kawésqar occupation.

1. Introduction

The karst areas of Madre de Dios archipelago, called the "marble glaciers," remained virtually unknown until 1995-2000 because of their remoteness and very inhospitable climate (Maire et al., 1999). Speleological research has begun both on the marble glaciers and along the coast, first in the fjords and then on the wild Pacific coast (Pernette et al., 2009). This

new type of coastal speleology with rubber dinghy allowed us to discover some major caves with significant archeology, paleontology, sedimentology and paleoenvironmental information. The Permian and Carboniferous limestones (Tarlton limestones) are located between volcano-sedimentary formations of Upper Paleozoic on South and West (Duque de York formation) and the Mesozoic granites of the Patagonian Batholith on the east. These carbonates, with many dikes, correspond to corallian paleoreefs, part of an accretionary prism of the Gondwana paleocontinent. Recent Kr-Ar dating of biotite indicates 133-140 Ma for the intrusions in limestones related to the magmatic activity of an ancient volcanic arc (Duhart et *al*., 2003). We observe some residual fragments of the old oceanic floor (Denaro Complex).

Figure 1. *Location of Madre de Dios archipelago in Southern Chile.*

Madre de Dios (50°30'S) is located on the isotherm +7°C, at the northern limit of the subpolar isothermic climate (Zamora et Santana, 1979). In Guarello meteo station, the precipitation is 7000–8000 mm/yr and the mean wind speed is 70 km/hour from the northwest. The annual thermal amplitude is weak, about 5 to 6°C. In protected places, the vegetation is characterized by the primitive magellanic forest with the genus Nothofagus inherited of Gondwana. The southern edge of Madre de Dios was almost completely covered by ice during the last cold period, except for some limestone nunataks. Glacial striations are preserved only in a few places under talus, as at Guarello. Moraines are very rare because they have been flooded by the postglacial transgression. However, erratic blocks are numerous up to altitudes of 400 m, showing a huge postglacial dissolution of 1.50 m (Maire et al., 2009).

2. Pacific Cave: the first Kawésqar paintings of the Patagonian archipelagos

Pacific Cave, located at the exit of Azul fjord, along the Pacific coast, is 25 m long, 10 m wide and 4 m high. Discovered here in 2006 were the first cave paintings of the Patagonian archipelagos. Their study is essential for a better understanding of the cultural heritage of the Kawésqar people, now almost vanished. Only a very small Kawésqar community of 17 people lives now in Puerto Eden.

The importance of shelly deposits (limpets) covering 100 m^2 suggests a frequent occupation during a long period. There are also many bones of seabirds and several fireplaces with charcoal. There are 50 painted objects, including 30 of red ocher and 20 of charcoal. The main panel is at the bottom of the cave, in the darkest part. The ocher paintings are situated at heights between 0.5 m and 4 m. Anthropomorphic figures are the most numerous (11), followed by geometric drawings like "sun wheels." According to the ethnographic grid (Emperaire, 1955), a horned anthropomorphic figure could correspond to Kawtcho, the Kawésqar divinity. The charcoal drawings are situated lower, 70 cm from the floor. Among the identifiable drawings is a "sun wheel," some anthropomorphic figures, and a sketch of boat, probably the back of a galleon. If this interpretation is correct, the picture could be 400 to 500 years old and related to the first contact with Europeans.

The outer part of the cave, near the entrance, has a few modern remnants. A date on the wall (1961?) and some recent debris

are evidence of later use of this shelter. Re-use of the site is also reflected by a series of four small red ocher drawings. The technique used appears to be smear painting and suggests a late addition. Five non-destructive analyses with a portable X-ray unit (Niton) confirmed that the red ocher paintings, at the bottom of the cave, are rich in iron oxide, Fe_2O_3 (Fe = 10,900 ± 400 to 27,000 ± 600 ppm). The charcoal paintings contain 1230 to 1630 ± 30 ppm of strontium. By comparison, the Sr content in the Tarlton limestone is 200 to 400 ± 10 ppm and in ocher 120 to 140 ± 9 ppm. All of the figures show artistic activity over a fairly long period. On the mainland, in the Pampa and Tierra del Fuego, the oldest human settlements are dated to 11,000–12,000 BP. But in the islands, the settlements are much more recent, around 6000–6500 BP, both in the Beagle Channel in the Strait of Magellan and in the Otway Sea (Legoupil, 1995).

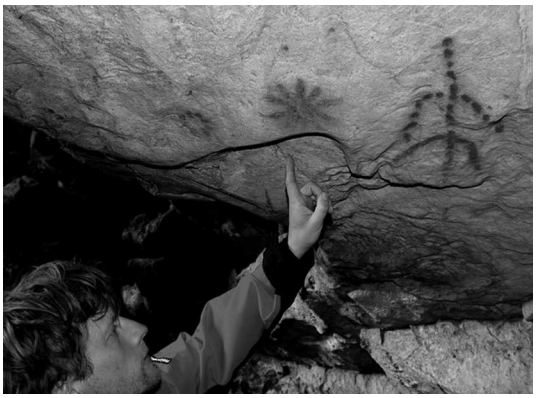

Figure 2. *Ocher paintings in Pacific cave ("sun wheel" an anthropomorphic figure) (photo L.H.Fage).*

Figure 3. *Measurement of ocher paintings with a µ-XRF portable unit (photo B.Tourte).*

Discovered in 2000, the oldest burial site of Madre de Dios is located in Ayayema Cave at +10 m; it dates from 4520 ± 60 BP (Legoupil et Sellier, 2004). Because of the marine origin of the Pacific Cave and its low altitude (+3 m), the occupation cannot be older than the last few millennia. The area was exposed above sea level by recent glacio-isostatic uplift, e.g., at Whale Cave since 3000 BP (infra §4). Indeed, the main marine notch is at about +3 m, the same altitude as the shelly deposit, but the rocky floor of the Pacific Cave is lower. Elsewhere, recent radiocarbon dating of human bones indicates 630–690 BP for a burial shelter in Barros Luco and 730–920 BP for Bahia Historica Cave in Whale Beach (2 Sigma calibration, Beta Analytic, Miami). The first anthropological examinations of bones in Barros Luco shelters show the evidence of Mongoloid features. The radiocarbon ages prove a Prehispanic occupation on the Pacific front, but very probably from land routes highlighted in 2008, for example between Seno Soplador and Whale Beach. Indeed it was highly unlikely for Kawésqar people to navigate the Pacific Ocean with their fragile canoes.

3. Moraine Cave: a record of the last deglaciation

Discovered in 2000, Moraine Cave is located at +50 m on the west coast of Guarello Island in Seno Eleuterio. The large entrance, 35 m high, is protected by the magellanic forest. The Moraine Cave is the inactive part of a karstic system whose

waters emerge today through bedrock blocks a few meters above sea level. Floods in the cave may exceed 1 m^3/sec. This system probably relates to the Three Lakes Sinkhole 1 km to the east (altitude 90 m) (Jaillet, Maire et al, 2008). The cave is formed by a main entrance hall 100 m long, 40–50 m wide and 30–40 m high. It is partially filled by a thick morainic deposit over 20 m on the left side (South). In the entrance, the vertical section shows (1) a lower unit 8 m high composed of gravel and blocks cemented by compact glacial flour; (2) an intermediate varve level 0.6 m thick; (3) an upper unit 10 m thick similar to the lower unit. It contains many limestone fragments, and also some of granite from the batholith (eastern part of Madre de Dios), as well as sandstone and conglomerate from the volcano-sedimentary formation of Duque de York.

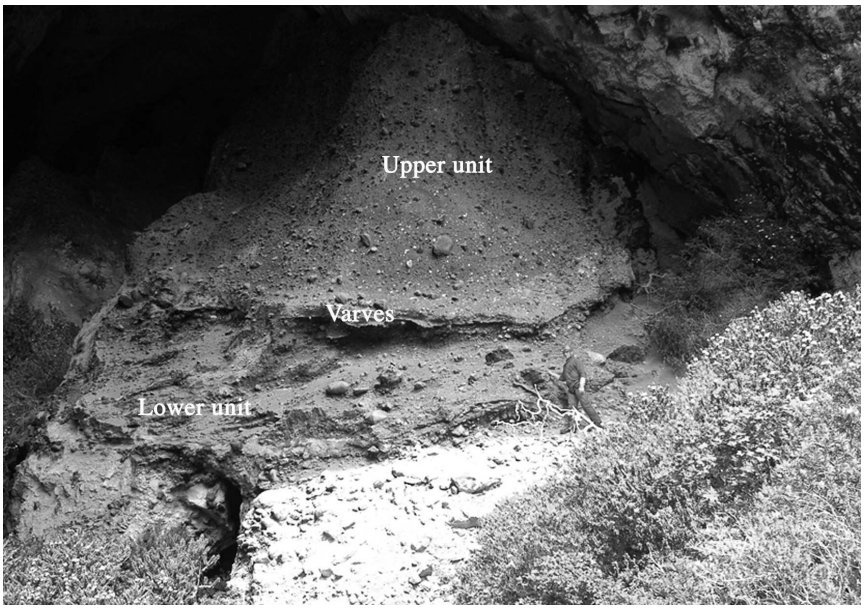

Figure 4. *The morainic deposit at the entrance of Moraine cave (phtoto R. Maire).*

A small gallery, 50 m long, was formed on the left bank between the deposit and the wall. It contains speleothems and the same intermediate level of varves. An active stalagmite 30 cm high was sampled directly on the eroded moraine edge A first U/Th dating (TIMS) made on the bottom calcite indicates an age of 9055 ± 915 yr BP (analysis K. Wainer, LSCE). It is clear that the thick moraine deposit is linked to the last glaciation, and probably to the phase of deglaciation between 20,000 and 10,000 years BP. Indeed, this deposit is related to a large glacial sinkhole located on the left bank of the Eleuterio glacier. Large eroded and broken stalactites, on the floor in the deep part of the room, are evidence for glacial floods after the subterranean morainic injection. This specific hydrology, with temporary artesian conditions, would have been responsible for a reverse hydrologic pattern in the karst system. Indeed, in the inclined dry tubes of Three Lakes Cave, the orientation of scallops is opposite to today's flow direction (Jaillet, Maire et al., 2008).

This morainic complex trapped in a cave is unique in Madre de Dios. It offers a record of the various episodes of the last deglaciation phases separated by an erosional phase and varve sedimentation, which could correspond to rapid events of Dansgaard-Oeschger type. Furthermore, on the right bank of the entrance hall, three big horizontal notches seem related to former glacial lake levels. Several types of solution notches were observed in other caves, especially in the Whale Bay area.

4. Whale Cave: a Holocene marine cemetery

Very difficult of access either by sea or land, Whale Cave is the largest cave chamber of Madre de Dios: 180 m long, 40 m wide and 30–50 m high. Opening directly along the Pacific coast, on the North side of the Whale Bay, the huge entrance 70 m high is oriented south, perpendicular to the swell direction (west to northwest). It contains a remarkable whale cemetery discovered in 2000. All the bones are scattered and are not articulated; they are situated in the middle and bottom of the room on several stacked marine terraces. Five skulls of blue whales and one of Hyperodon (determination V.Ridoux, W. Dabin) and numerous vertebrae and ribs were observed between +5 m and +11.5 m. Four terrace levels are preserved and were surveyed in 2008 with a theodolite: the +5.7 m terrace in continuity with the upper marine notch of

+5-6 m; the +7 m terrace, the most important, in the central part of the cave; the + 9 m terrace, the lowest level, showing the most important accumulation of bones; and the + 10.5 m residual terrace visible only in the northern part of the room. The fine matrix of the highest terrace (+10.5 m) is whitish because of weathered bones and guano (phosphate).

A petrographic study of cobbles was conducted on the terraces. Between 98 and 115 rock samples were examined at each of three sites: (1) outside the cave entrance and along the ocean margin (modern terrace); (2) inside the cave's large entrance room, terrace at +5.7 m amsl; and (3) deeper into the cave at +9 m. Samples varied in areal extent, as did the rock sizes and rock conditions. The ocean-margin site was 0.04 m^2 with rounded cobbles ranging from 2 to 10 cm on their long axis with no signs of recent breakage. The entrance-room site included cobbles from 4 x 4 m of cave floor, with some angular rocks and 15 broken or fractured stones. They ranged in size from 4 to 25 cm. The interior cave site (+9 m) included two sediment deposits 1.5 m apart and both approximately 3 m above an active stream. Stones were 1 to 2 cm in size with no larger ones present. Approximately 30 cobbles had been broken or fractured. All broken faces displayed a weathering rind not seen on those in the entrance room. Also of note at the interior site were banded sediments, many displaying dark coloration from organic matter.

Figure 5. *The main marine terrace (+7 m) in Whale cave (photo R. Maire).*

The petrographic results point to two different influences on the development of Whale Cave. A small stream initially formed the cave and its influence still dominates the sediments and cave development in the deep cave area. Granitic rocks are not found in the watershed of the stream and so are not present in the sediment deposit found here. The weathering rinds on the stones in this area reveal the relative antiquity of the deposits. The small size of the rocks points to the limited ability of a small stream to carry larger ones into the cave. The fine-grained and banded sediments are also likely of fluvial and not marine origin. The lower parts and the large entrance room of the cave were later inundated by marine water, which deposited more recent sediments of similar origin to the modern sediments and cobbles in the high-tide zone adjacent to the Pacific and just outside the cave entrance. Here we find granitic rocks that have been transported greater distances by wave and tide action compared to the fluvial deposits, and larger stones that must have been carried by powerful marine action.

Clear differences were also documented in the sediments of the cave. On the seacoast just outside the cave entrance and within the cave's first and largest room, small rounded cobbles include approximately 10% plutonic rocks (granite); but at the rear of the cave no granite was found – cobbles where limited only to limestone with a few pieces of volcanic rock. Outcrops of plutonic rocks are not present near the cave and would likely have been transported into the area only by glaciers and by the action of the ocean. In addition, fine sediments in the first large cave room are exclusively sand without layers or lamination. At the rear of the cave, sediments are much finer (silt or even clay-size) and are clearly laminated and layered. This evidence points to a double origin for Whale Cave – initial cave-passage development through the action of a

cave stream, and significant enlargement of the cave's large entrance room by the actions of the Pacific, which deposited the sand and granite fragments.

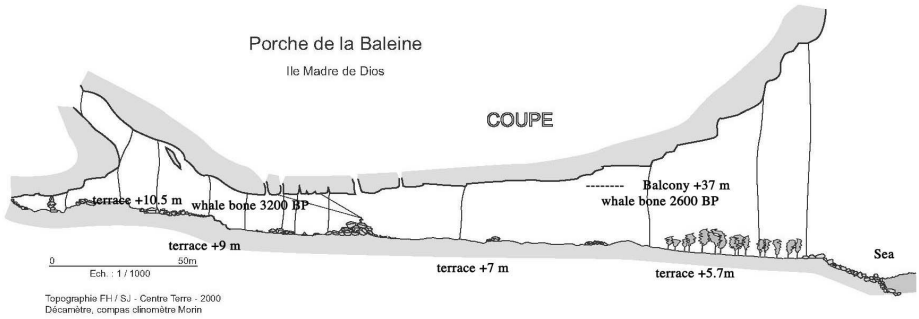

Figure 6. *Longitudinal section of Whale Cave with location of marine terraces and radiocarbon datings.*

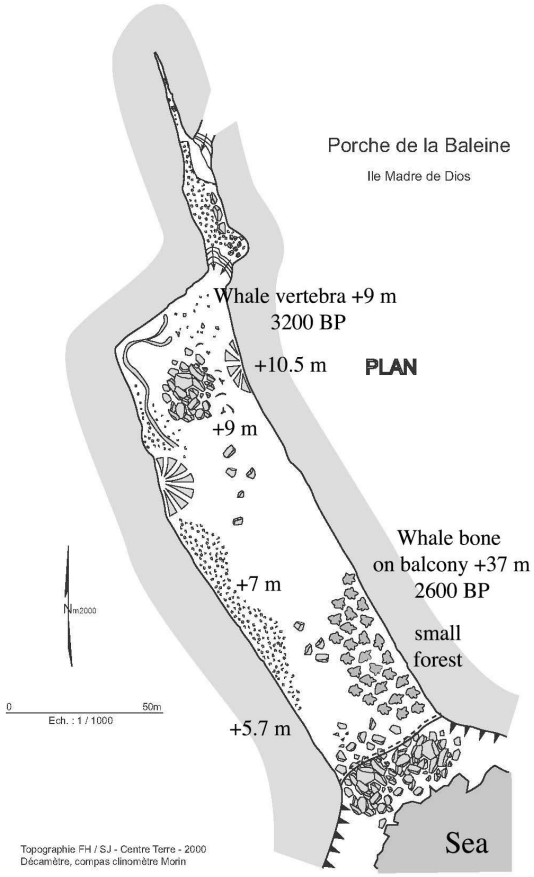

Figure 7*. Map of Whale cave (S. Jaillet).*

A first radiocarbon date was obtained from a whale vertebra in the deep area at +9 m. The age is 3200 ±100 years BP (analysis: Marc Massault, CEA/Saclay). Our first interpretation is that the whales were transported into the cave by currents, tides and waves when the cave floor was lower, before the recent glacio-isostatic uplift. The disarticulated skeletons spread over a distance of 150 m, with a clear predominance toward the bottom of the cave, showing the effect of storms. But there is another complementary explanation. During the first descent into the cave from the top of the cliff, we discovered whale vertebra and several other bones in anatomical connection, on a balcony 5 m wide situated at +37 m, as well as a few limpet shells indurated by calcite. A radiocarbon date of a piece of bone shows an age of 2600 ± 60 yr BP (analysis: M.Massault, CEA, Saclay). Because of the orientation and altitude of the cave entrance, only a tsunami can explain the presence of whale bones at +37 m. This hypothesis explains the dispersion of the bones throughout the rear of the cave, and also within a fissure between +10 m and +11.5 m. Earthquakes and tsunamis occurred along the Chilean coast during the Pleistocene.

Figure 8. *Whale vertebra in the rear of Whale Cave (terrace +9m), age 3200 ± 100 BP (photo R. Maire).*

5. Conclusions

Located at the ocean-island contact, the different types of coastal caves of Madre de Dios have preserved many records of the first human impact and environmental evolution: cave paintings, burial sites, whale bones, glacial sediments, stages of marine terraces, and old horizontal notches, all indicators impossible to have survived outside because of glacial erosion and Holocene dissolution. The relationship between these karst records and the recent glacio-isotatic uplift is one of the interesting perspectives of this research.

Aknowledgements : to Ultima Patagonia Expeditions and to Arthur Palmer for his advice and editing.

References

Duhart, P., Munoz, J, Tassinari, C.C.G., Quiroz, D. (2003) K-Ar geochronology and Sr and Nd isotopic composition of the Patagonian Batholith in the Madre de Dios archipelago (50° 30'S), Southern Chile. South American symposium on isotope geology, Salvador, CBPM-IRD, 542-544.

Despain, J., Maire, R., Jaillet, S. (2009) Morphological relationships between erratic boulders and associated bedrock limestone fins or "rock comets," Madre de Dios archipelago, Chile. Proceeding of "Karst Horizons" congress, UIS, Kerrville, Texas (this volume).

Emperaire, J. (1955) Les Nomades de la Mer. Le Serpent de Mer (ed. 2003), 344 p.

Jaillet, S., Maire, R., Brehier, F., Despain, J., et al. (2008) Englacement, eustatisme et réajustements karstiques dans l'archipel de Madre de Dios (Patagonie, Chili). Karstologia, **51**, 1-24.

Legoupil, D. (1995) Des indigènes au cap Horn: conquête d'un territoire et modèle de peuplement aux confins du continent sud-américain. Journal de la Société des Américanistes, **81**, 9-45.

Legoupil, D., et Sellier, P. (2004) La sepultura de la Cueva Ayayema (Isla Madre de Dios, Archipiélagos occidentales de Patagonia). Anales des Instituto de la Patagonia, **32**, 115-124

Maire, R., et équipe Ultima Patagonia (1999) Les « glaciers de marbre » de Patagonie, Chili. Un karst subpolaire océanique de la zone australe. Karstologia, **33**, 25-40.

Maire R., Jaillet, S., Hobléa, F. (2009) Karren in Patagonia (Chile), A natural laboratory for hydroeolian dissolution. In *Karst rock features, karren sculpturing*, Gines, A., ed., International Union of Speleology (in press).

Pernette, J.F., Tourte B., Maire R., (2009) The Centre-Terre expeditions to patagonian karst islands: a historic overview. Proceeding of "Karst Horizons" congress, UIS, Kerrville, Texas (this volume).

Zamora, E. et Santana A. (1979) Caracteristicas climaticas de la costa occidental de la Patagonia entre las latitudes 46°40' y 56°30'S. *Anales Inst. Patagonia*, Punta Arenas (Chile), **10**, 109 -154.

Figure 1. *Location of Madre de Dios archipelago in Southern Chile.*

Figure 2. *Ocher paintings in Pacific cave ("sun wheel" an anthropomorphic figure) (photo L.H.Fage).*

Figure 3. *Measurement of ocher paintings with a µ-XRF portable unit (photo B.Tourte).*

Figure 4. *The morainic deposit at the entrance of Moraine cave (phtoto R. Maire).*

Figure 5. *The main marine terrace (+7 m) in Whale cave (photo R. Maire).*

Figure 6. *Longitudinal section of Whale Cave with location of marine terraces and radiocarbon datings.*

Figure 7*. Map of Whale cave (S. Jaillet).*

Figure 8. *Whale vertebra in the rear of Whale Cave (terrace +9m), age 3200 ± 100 BP (photo R. Maire).*