Revista Chilena de Historia Natural
*62:* 61-74, 1989

# Climate of the Chilean channels between 11,000 to 10,000 yr B.P. based on fossil beetle and pollen analyses

## Clima de los canales australes de Chile entre 11.000 y 10.000 años A.P. basado en análisis de polen y coleópteros fósiles

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### ABSTRACT

The Témpano Sur site in the Chilean Channels is located about 1 km from the margin of Glaciar Témpano, an outlet glacier of the South Patagonian icefield (48°44'S, 74°02'W). The lowermost peat bed from a section of interbedded peats and sands has lower and upper dates of 11,190 and 10,130 yr B.P., respectively. Analyses of fossil beetles and pollen indicate independently that a brief episode of pioneer vegetation followed glacial recession. This was replaced by a mosaic of *Nothofagus betuloides* woodland stands and patches of moorland, similar to the Magellanic Moorland vegetation of the present day. Thus, climatic conditions which permitted this development between 11,000 and 10,000 yr B.P. must have been similar to those presently existing in the Chilean Channels. This interpretation contradicts claims for the existence of a significant cooling in the climate of southern South America between 11,000 and 10,000 yr B.P. equivalent in timing to the Younger Dryas Stade of northwestern Europe.

Key words: Lateglacial paleoclimate, palynology, coleoptera, Chilean Channels.

### RESUMEN

El sitio Témpano Sur se encuentra localizado un km al oeste del Glaciar Témpano, un brazo glaciar que desciende del Hielo Patagónico Sur. La turba basal de una secuencia estratigráfica compuesta de varias capas sobrepuestas de turba y arena, ha sido fechada entre 11.190 y 10.130 años A.P. (antes del presente). El análisis de coleópteros y polen fosil indican, en forma independiente, que luego de la regresión del brazo glaciar, se inicia un episodio breve de recolonización, que se completa con el desarrollo del bosque de *Nothofagus betuloides* y vegetación de tundra magallánica. Así, las condiciones climáticas que permitieron el desarrollo de este tipo de vegetación habrían sido semejantes a las actuales. Esta interpretación contradice el reciente postulado para la América del Sur de una etapa fría que se desarrollaría entre 11.000 y 10.000 años A.P. y que sería equivalente al *Younger Dryas* de Europa.

Palabras claves: Paleoclima tardiglacial, palinología, Coleoptera, región de los canales chilenos.

### INTRODUCTION

The strongest evidence for the existence of a cold episode in southern South America coeval with the emphatically cold Younger Dryas Stade of the North Atlantic is based on palynological studies in the Chilean lake region between latitudes 39° and 42°S (Heusser 1966, 1974, 1984, Heusser and Streeter 1980), and also in Tierra del Fuego (Heusser and Rabassa 1987). Not all pollen records, however, from the Chilean lake region (Heusser 1981) nor from Chiloe Island (Villagran 1985, 1988) document an environmental change at that time. The beetle fauna, based on studies of fossil assemblages from the Rio Caunahue section at 40°S 08'W also does not show any evidence of a past major climatic change (Ashworth and Hoganson 1984, 1987, Hoganson and Ashworth 1982). Likewise, no evidence for an environmental reversal during the interval 10,000-11,000 yr B.P. is reflected in pollen profiles from the Argentinian lake region at 41°S (Markgraf 1983, 1984). Earlier, Mercer (1976) pointed out that the lower temperatures and increased precipitation proposed by Heusser (1974, 1984) would have caused a glacial readvance. To date there is no evidence from the

(Received 15 December 1988. Accepted 20 June 1989).

glacial geology of the region in support of such an advance. The lack of any supporting evidence from glacial geology or of ambiguous evidence from the fossil biota of the region for a climatic change led to the conclusion that changes in the Alerce pollen profile might not represent a regional climatic change (Ashworth and Hoganson 1984). The suggestion was made that the disruption in the vegetation at Alerce could have had a local cause such as water level changes, or an eruption of a nearby volcano. To further pursue this question, cooperative studies in glacial geology, palynology, and paleoentomology were undertaken with John Mercer in the Chilean Channels adjacent to the South Patagonian icefield. Records from this southern region in vicinity of extensive, active glaciers were expected to be even more sensitive to paleoclimatic changes than those from the mid-latitudes lowlands.

## Chilean Channels

### *Geology*

The Chilean channels adjacent to the South Patagonian icefield between 48°30'S and 51°50'S is an archipelago of rugged mountainous islands with elevations up to 1 500 m. The entire region has been glaciated with the possible exception of a narrow coastal strip north of 49°S. At the last glacial maximum in southern South America, ca. 19,500 yr B.P. (Mercer, 1976), the fiords adjacent to the South Patagonian icefield and main channels such as the Canal Messier are assumed to have been filled with glacial ice.

Glaciar Témpano, in the region of the site (Fig. 1), a major outlet glacier of the South Patagonian icefield was within its 1968 borders by 11,000 yr B.P. and remained there until 5,500 yr B.P. By 4,100 yr B.P. the glacier had advanced westward to its Neoglacial maximum. Glaciar Témpano then receded and from 3,100 yr B.P. to recent centuries was in a shrunken state. The latest readvance, almost to the early Neoglacial limit, culminated between A.D. 1760 and 1945. Since 1945 the glacier margin has receded 5 km (Mercer, pers. comm.).

### *Climate*

The region has an oceanic climate in which both winters and summers are cool and wet, and lack seasonality. The rainfall according to Almeyda and Saez (1958) is highest at some distance inland from the coast. At Isla Guarello, 50°23'S, a phenomenal average annual precipitation of 7346 mm has been recorded. Further inland at Puerto Eden the average annual rainfall recorded was 3032 mm. The mean monthly temperature range of the coldest to the warmest months at Puerto Eden is 2.8° to 11.6°C respectively. The mean annual temperature of the region is about 7°C.

### *Vegetation*

At low elevations, in sheltered locations bordering the canals the vegetation is typically a dense forest of *Nothofagus betuloides, Pilgerodendron uvifera, Podocarpus nubigena, Drimys winteri*, and *Pseudopanax laetevirens*. Above 200 m open moorlands persist but patches of *Nothofagus antarctica* woodland exist to the limit of vegetation growth. Characteristic moorland taxa of poorly drained surfaces are the dwarf conifer *Dacrydium fonckii,* and the cushion plants such as *Astelia, Azorella* and *Donatia fascicularis.* On better drained soils *Empetrum rubrum* is common. A clearly defined tree line marked by an elfin forest and an alpine tundra was not observed in the Channels. Bare rock, snow and ice prevail at elevations above 900 m. The floristics of the different plant communities and their ecology have been described in detail by Pisano (1977, 1983). The ecology of the *Nothofagus* species, described by McQueen (1976) and Young (1972) provided information on the growth characteristics of the forest.

### *Beetle fauna*

The beetle fauna of the Chilean Channels includes some groups such as the migadopine carabids that are restricted in distribution to southernmost South America (Darlington 1965, Kuschel 1960). The fauna, however, shares most of its species

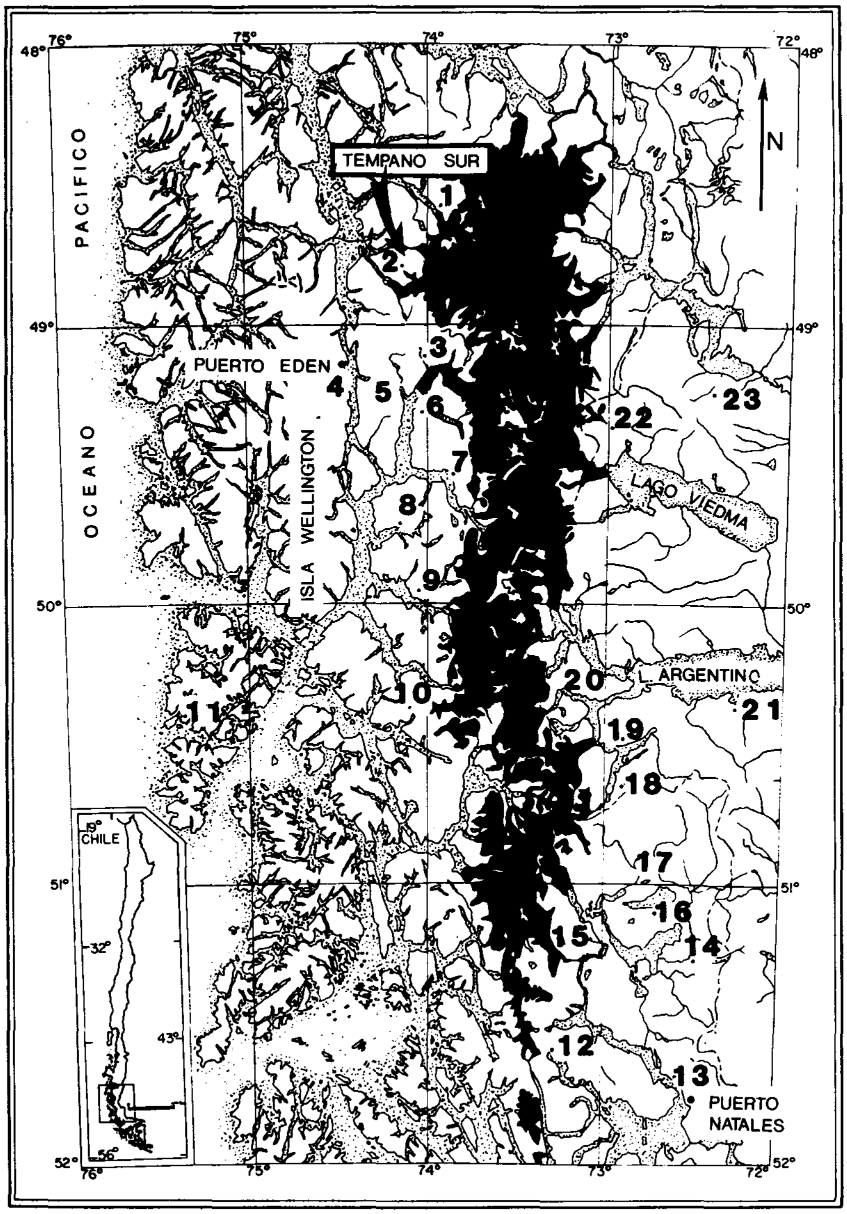

*Fig. 1:* Locations at which the existing beetle fauna was sampled in the Chilean Channels (1985 and 1986) and in Argentinian Patagonia (1982). The dark-shaded area is the South Patagonian icefield. 1. Glaciar Bernardo; 2. Glaciar Témpano; 3. Glaciar Bruggen; 4. Puerto Edén; 5. Bahía Elizabeth; 6. Fiordo Exmouth; 7. Fiordo Falcon; 8. Fiordo Ringdove; 9. Fiordo Penguin; 10. Fiordo Guillardi; 11. Isla Guarello; 12. Fiordo Worseley; 13. Puerto Natales; 14. Cerro Castillo; 15. Río Pingo; 16. Lago Pehoe; 17. Laguna Azul; 18. Brazo Sur, Lago Argentino; 19. Glaciar Moreno; 20. Lago Roca; 21. Estancia Bon Accord; 22. Río Fitzroy; 23. Lago San Martín.

Sitios de colecta de coleópteros en los canales chilenos (1985 y 1986) y en la Patagonia Argentina (1982). El area sombreada corresponde al área ocupada por el Hielo Patagónico Sur. 1. Glaciar Bernardo; 2. Glaciar Témpano; 3. Glaciar Bruggen; 4. Puerto Edén; 5. Bahía Elizabeth; 6. Fiordo Exmouth; 7. Fiordo Falcon; 8. Fiordo Ringdove; 9. Fiordo Penguin; 10. Fiordo Guillardi; 11. Isla Guarello; 12. Fiordo Worseley; 13. Puerto Natales; 14. Cerro Castillo; 15. Río Pingo; 16. Lago Pehoe; 17. Laguna Azul; 18. Brazo Sur, Lago Argentino; 19. Glaciar Moreno; 20. Lago Roca; 21. Estancia Bon Accord; 22. Río Fitzroy; 23. Lago San Martín.

with the lake region to the north. Compared to the fauna of the lake region, however, that of the Channels is species poor reflecting a harsher climate (Fig. 2A). The pattern of species diversity for the endemic ground beetle *Ceroglossus,* for example, is typical. In the lake region *Ceroglossus* is represented by four species whereas in the Channels it is represented by a single species. Most genera in the Channels are represented by single species.

Collections of the existing fauna of the Channels were made from various habitats and various locations (Fig. 1) during field studies in 1985 and 1986. A plot of the distribution of species by the gross characteristics of the vegetation illustrates that the majority of species are adapted to forest habitats (Fig. 2B). Several species, however, are restricted to the barren and sparsely vegetated zones adjacent to the glaciers.

## The Témpano Sur site

The Témpano Sur site at 48°44'S 74°02'W, was located by John Mercer in 1968 (Fig. 3). At that time the site was about 1 km east of the calving terminal of the Glaciar Témpano (Mercer, 1970). Presently the site is about 1 km west of the terminal.

The Témpano Sur section is located in a linear, presently inactive, meltwater channel on the south side of the Témpano fiord about 1 km west of the present margin of the ice (Fig. 3). Downstream from the channel narrows to a gorge with vertical bedrock walls 15 m high. The accumulation of organic sediments in the channel in the past probably resulted when water ponded behind a rock fall dam to form a small lake. Spalling of large blocks of the well-jointed diorite from the walls of the gorge into the channel is an active process.

A vertical section was excavated from the overgrown cutbank on the south side of the channel on January 30, 1985. The section consisted of interbedded sandy peats and sands overlying a dark gray (10YR 4/1) clay. The clay, probably representing lacustrine deposition of rock flour, accumulated on a gravel with sub-rounded

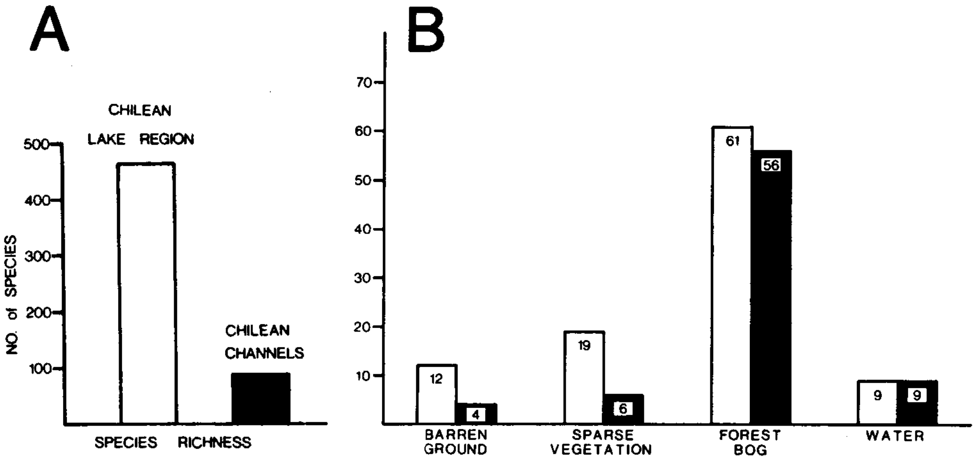

*Fig. 2A:* Comparison of the numbers of beetle species in the Chilean lake region and Chilean Channels faunas.

**Comparación entre el número de especies de Coleoptera en la región de los lagos y los canales chilenos.**

*Fig. 2B:* Distribution of beetle species in the Chilean Channels and southern Patagonia (see Fig. 1) by physiognomic categories. White columns; total number of species. Black columns: numbers of species restricted to the category.

**Distribución en categorías fisionómicas de Coleoptera en los canales chilenos y en la Patagonia argentina. En blanco: número total de especies; en negro: número de especies correspondientes a las categorías fisionómicas.**

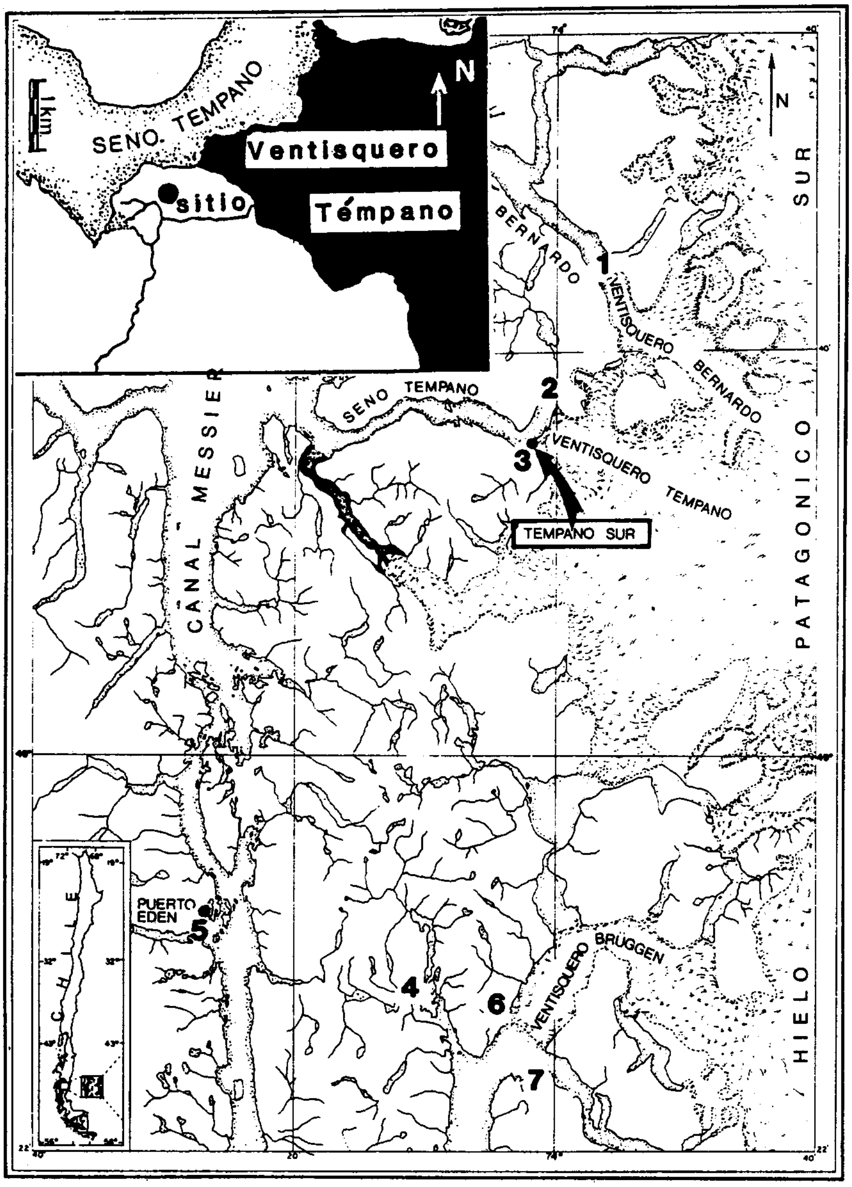

*Fig. 3:* Location of the Témpano Sur site in the Chilean Channels and of collection sites for existing beetle fauna (see also Fig. 1). 1. Glaciar Bernardo; 2. Témpano Norte; 3. Témpano Sur; 4. Bahia Elizabeth; 5. Puerto Eden; 6. Glaciar Bruggen; 7. Fiordo Exmouth.

**Ubicación del sitio Témpano Sur en los canales y de los sitios de colecta de la fauna actual de coleópteros (ver Fig. 1): 1. Glaciar Bernardo, 2. Témpano Norte; 3. Témpano Sur; 4. Bahía Elizabeth; 5. Puerto Edén; 6. Glaciar Bruggen; 7. Fiordo Exmouth.**

and sub-angular clasts of igneous and metamorphic lithologies. The lower peat changes from a dark brown (7.5YR 2/2) moss peat with twigs and leaves at the base to a black (5YR 2.5/YR) woody peat at the top. Clay laminae and sand lenses occur throughout the peat. Wood from the base of the lower peat collected in 1968 was dated at 11,100 ± 170 yr B.P. (I-3825) and that collected in 1985 dated at 11,100 ± 80 yr B.P. (Beta-12597). Wood from the top of the lower peat had an age of 10,130 ± 140 yr B.P. (Beta 14496).

A column of sediment was collected for pollen analysis through the lower peat and the clay. Bulk samples of about 10 kg size were collected at each 12 cm interval from adjoining parts of the section for fossil beetle analysis.

## METHODS

### *Preparation and identification of fossil beetles*

More than a thousand well-preserved disarticulated skeletal parts of insects were removed from the lower peat samples employing a kerosene flotation technique. The procedures followed those described by Ashworth (1979). The fossils were mounted on micropaleontological slides and are stored in the Quaternary Entomology Laboratory at North Dakota State University. The skeletal fragments are mostly the elytra, pronota, and heads of Coleoptera (beetles) (Fig. 4). However, cephalothoraces of oribatid mites, head capsules of chironomid midges, and puparia of flies were also recorded. The fossils were identified by comparing them directly to identified specimens of extant species. Reference specimens were difficult to locate because few collections have been made in the remote Channels. Charles Darwin's specimens in the British Museum of Natural History, Philip Darlington's specimens in the Museum of Comparative Zoology, Harvard University, and Guillermo Kuschel's specimens in the New Zealand Arthropod Collection were especially useful for identification purposes. Some of the fossils represent undescribed species (Fig. 5) and some may be new discoveries. The species which could be identified are listed in Table 1.

### *Preparation of pollen samples*

Samples were taken volumetrically (1.8 ml vol) and treated according to standard techniques with hydrofluoric acid to remove silicates, and with acetolysis mixture to reduce organic matter (Faegri and Iversen 1975). Fern spore tablets were added to the samples as tracers before treatment to calculate pollen concentration per volume of sample. In view of several noticeable changes in sediment composition in the analyzed section, ranging from silty clays to sand to different peat types, and only two bracketing radiocarbon dates, a constant sedimentation rate cannot be assumed for the interval in question. Indeed, the values of total pollen concentration of the analyzed samples differ substantially for the different sediment types from less than 10,000 pollen/1.8 ml volumen in the clays to 80,000 grains/1.8 ml volume in the *Sphagnum* peat to over 300,000 pollen/1.8 ml volume in the moss peat (Fig. 6). Such differences cannot represent changes in pollen production alone, but more likely reflect different sediment deposition or growth rates. Therefore, calculation of pollen influx did not seem warranted.

Except for the lowermost level (74 cm depth) that yielded a low pollen count, all other levels had excellent pollen preservation and yielded statistically significant pollen counts. Pollen taxa are given in percent of total pollen, based on the sum of all arboreal and non-arboreal components. The arboreal component in the assemblages is represented by *Nothofagus betuloides, Pilgerodendron,* Myrtaceae, and traces of *Drimys, Pseudopanax,* and *Griselinia.* The non-arboreal component is represented by *Dacrydium, Empetrum,* Gramineae, Cyperaceae, Compositae (Tubuliflorae, Liguliflorae, and Mutisieae), and herbaceous taxa: *Astelia, Gunnera,* Ranunculaceae, Umbelliferae, Caryophyllaceae, *Acaena, Plantago,* etc. Taxa excluded from the pollen sum and calculated out-of-the sum, are fern spores (*Polypodium, Hymenophyllum*), moss spores (*Sphagnum*), clubmoss spores (*Lycopodium magellanicum*), and pollen of water plants (*Potamogeton, Ruppia*), and algae (*Pediastrum*).

## RESULTS

### *Paleoenvironmental interpretation based on beetles*

The habitats of the beetle species are listed in Table 1. Both aquatic and terrestrial species are represented in the Témpano Sur fossil assemblage. Several types of water beetles inhabited the bog in which the peat formed. Predaceous species were represented by the dytiscids *Liodessus delfini,*

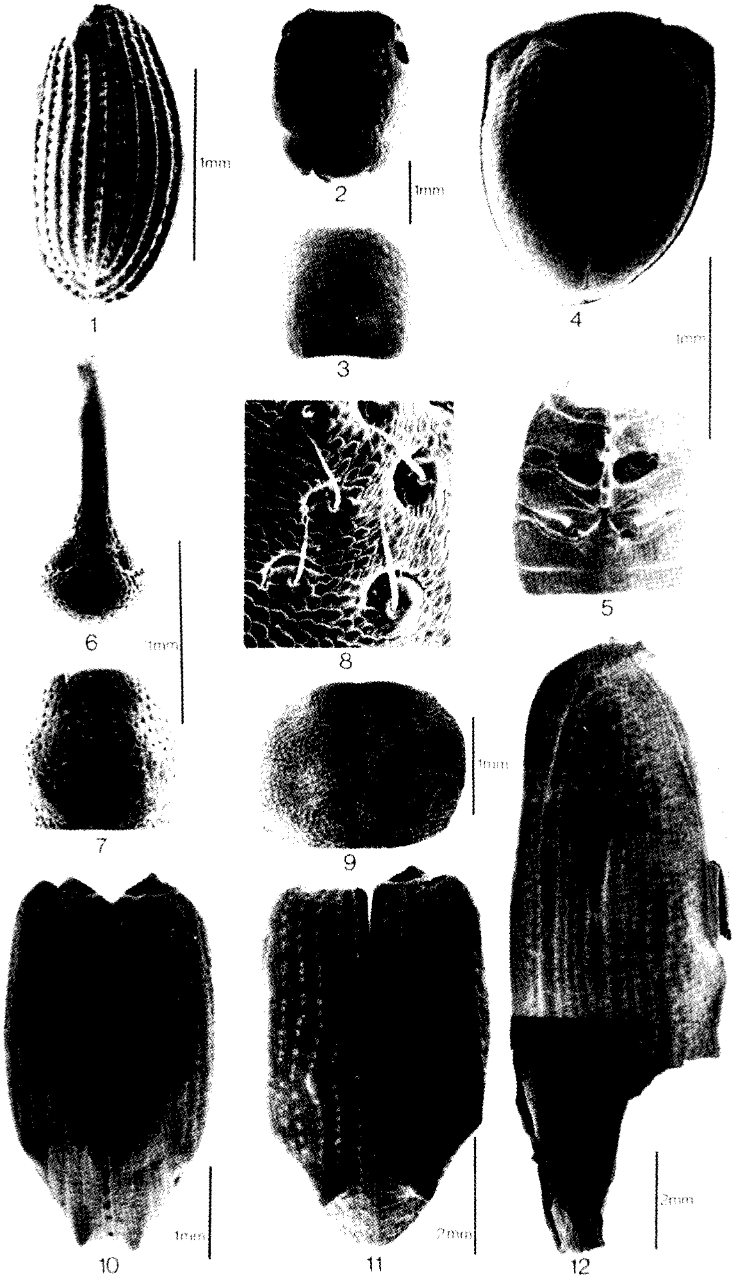

*Fig. 4:* Scanning electron micrographs of selected beetle fossils from the Témpano Sur site. 1. Left Elytron of *Apion fuegianum;* 2. Head of *Baryopsis brevipennis;* 3. Pronotum of *Baryopsis brevipennis;* 4. Elytra of *Neocamiarus* sp.; 5. Sternites of *Neocamiarus* sp.; 6. Head of Cryptorhynchinae sp. indet.; 7. Pronotum of Cryptorhynchinae sp. indet.; 8. Setae on the pronotum of Crypthorhynchinae sp. indet.; 9. Pronotum of *Listroderes rugipennis;* 10. Elytra of *Listroderes* sp. A; 11. Elytra of *Listroderes lugens;* 12. Right of elytron of *Ceroglossus suturalis.*

Microfotografías de algunas especies de coleópteros fósiles de Témpano Sur. 1. Elitro izquierdo de *Apion fuegianum*; 2. Cabeza de *Baryopsis brevipennis*; 3. Pronoto de *Baryopsis brevipennis*; 4. Elitros de *Neocamiarus* sp. 5. Esternitos de *Neocamiarus* sp. 6. Cabeza de *Cryptorhynchinae* sp. indet.; 7. Pronoto de *Cryptorhynchinae* sp. indet.; 8. Setas del pronoto de *Cryptorhynchinae* sp. indet.; 9. Pronoto de *Listroderes rugipennis*, 10. Elitros de *Listroderes* sp.; 11. Elitros de *Listroderes lugens*; 12. Elitro derecho de *Ceroglossus suturalis.*

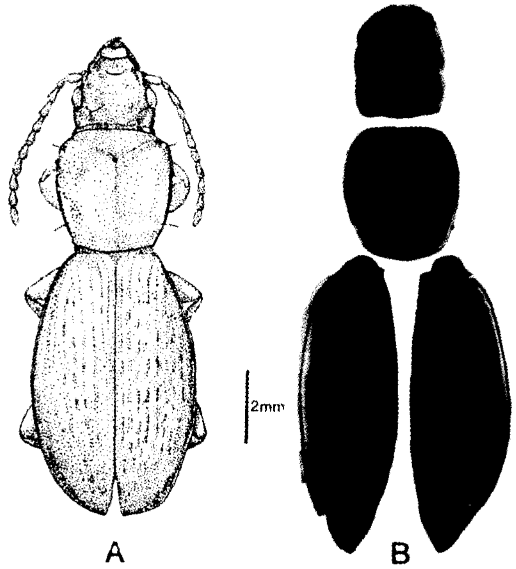

*Fig. 5: Cascellius* sp. A, an undescribed species from the Chilean Channels. (A) Drawing of a modern specimen of the species discovered in P.J. Darlington's notes at the Museum of Comparative Zoology, Harvard University. (B) Scanning electron micrographs of fossil parts from the lower peat at the Témpano Sur section.

Especie no descrita de *Cascellius* de los Canales. (A) Dibujo de un ejemplar moderno encontrado en las notas de P.J. Darlington en el Museo de Zooología Comparativa de la Universidad de Harvard. (B) Microfotografía de las partes fósiles encontradas en la turba basal de Témpano Sur.

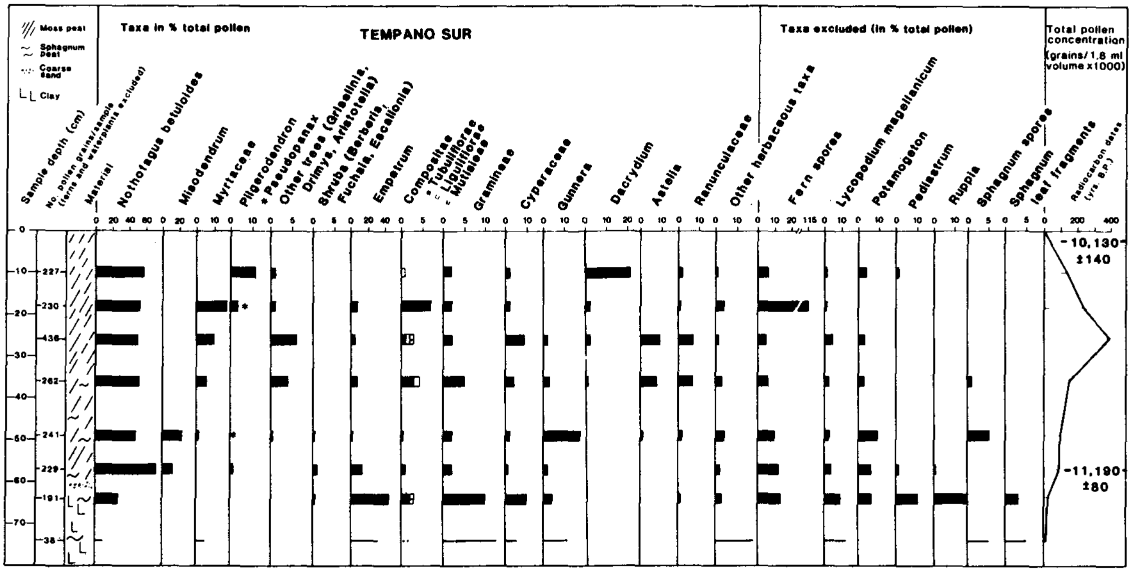

*Fig. 6:* Pollen diagram of the Témpano Sur section. Lowest sample (74 cm) yielded a statistically low pollen count.

Diagrama polínico de Témpano Sur. La muestra basal (74 cm de profundidad) no tenía suficiente polen para cálculos estadísticos.

## TABLE 1

Stratigraphic distribution of Coleoptera species in the Témpano Sur Section. Skeletal parts: H=head(s); P=pronotum(a); LE=left elytron(a); RE=right elytron(a). Habitat: W=woodland; M=moorland; A=aquatic; P=pioneer; U=undefined.

Distribución estratigráfica de Coleoptera en la sección Témpano Sur. Partes esqueletarias: H=cabeza(s), P=pronoto(a); LE=élitro(a) izquierdo; RE=élitro(a) derecho. Hábitat W=bosque abierto; M=turbera; A=acuático; P=pionero; U=no definido.

| Coleoptera taxa | Skeletal Parts | | | | Stratigraphic distribution | | | | | | | Habitat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Top | Peat | | | | Base-Clay | | |
| | H | P | LE | RE | 0 | 12 | 24 | 36 | 48 | 60 | 72 | |
| CARABIDAE | | | | | | | | | | | | |
| *Ceroglossus suturalis* (Fab.) | + | | + | + | 1 | | 2 | 1 | 1 | | | W |
| *Cascellius aenoniger* Waterh. | + | + | + | + | 4 | 1 | | | | | | W |
| *Cascellius hyadesi* Fairm. | + | | + | + | 1 | 1 | | | | | | W |
| *Cascellius* sp. A | + | + | + | + | 4 | 3 | 3 | 8 | 4 | | | W |
| *Bembidiomorphum convexum* Champ. | | + | + | + | – | | 7 | | | | | M |
| *Trechisibus* sp. | | | + | | – | | | | | 1 | | A |
| *Agonum* sp. | + | + | + | + | – | 3 | 12 | 6 | 1 | | | A |
| DYTISCIDAE | | | | | | | | | | | | |
| *Lancetes* sp. | | | + | | – | | | | 1 | | | A |
| *Rhantus signatus* (Fab.) | + | | | | 1 | | | | | | | A |
| *Liodessus delfini* (Regimb.) | | + | + | + | 2 | | 12 | 9 | | | | A |
| HYDROPHILIDAE | | | | | | | | | | | | |
| *Enochrus fulvipes* (Sol.) | + | + | + | + | 1 | 1 | 35 | 46 | 7 | | | A |
| LEIODIDAE | | | | | | | | | | | | |
| *Neocamiarus* sp. | | + | + | + | 16 | 1 | | | | | | W |
| SCYDMAENIDAE | | | | | | | | | | | | |
| *Euconnus* sp. | | | + | + | | | 2 | 1 | 1 | | | W |
| STAPHYLINIDAE | | | | | | | | | | | | |
| *Baryopsis brevipennis* Fairm. and Germ. | + | + | | | 2 | 1 | | | | | | W |
| *Paederinae* sp. indet | + | | | | 29 | | 1 | 1 | 2 | | | W |
| *Philonthini* sp. indet | + | | | + | | | 1 | | 2 | | | W |
| *Aleocharinae* spp. indet | | + | + | + | 3 | | 1 | 4 | 5 | 1 | | U |
| PSELAPHIDAE | | | | | | | | | | | | |
| Spp. indet | | + | + | + | 10 | 3 | 31 | 4 | 3 | | | W |
| BYRRHIDAE | | | | | | | | | | | | |
| Sp. indet | + | + | + | + | 5 | 1 | | 1 | | | | M |
| MELANDRYIDAE | | | | | | | | | | | | |
| *Orchesia* sp. | | + | + | + | | | | 6 | 14 | 1 | | W |
| CURCULIONIDAE | | | | | | | | | | | | |
| *Dasydema* sp. | + | | | | | | | 2 | | | | W |
| *Listroderes lugens* Germ. | + | + | + | + | | | 1 | 1 | 5 | | | P |
| *Listroderes rugipennis* Blanch. | | + | + | + | | | | | 1 | | | P |
| *Listroderes* sp. A. | + | + | + | + | 7 | | | | 1 | | | M |
| *Listroderes* sp. B. | + | + | + | + | 1 | | 2 | | | | | M |
| *Rhopalomerus tenuirostris* Blanch. | | | | + | 2 | | | | | | | W |
| *Aegorhinus vitulus* (Fab.) | | | + | | | | | 1 | 1 | | | W |
| *Apion fuegianum* Enderl. | + | | + | + | | | 2 | 2 | 8 | | | W |
| *Cryptorhynchinae* sp. indet | + | + | + | + | 10 | | | 1 | 3 | | | W |

*Rhantus signatus,* and *Lancetes* sp. Presently these species occur in a range of shallow aquatic habitats from vegetation-free to moss-choked pools. The most abundant water beetle in the fossil assemblage, the hydrophilid *Enochrus fulvipes,* inhabits the submerged mosses on the margins of shallow pools. The ground beetle *Agonum* sp. also represented by numerous fossils, is a very hydrophilous species restricted in its occurence to water-saturated moss on the margins of shallow pools.

The terrestrial species provide information about the nature of the environment that bordered the bog between 11,000 to 10,000 yr B.P. Several of these species are obligate woodland inhabitants. The large (25 mm long), flightless, predaceous ground beetle *Ceroglossus suturalis* lives primarily in woodland habitats. Of 93 specimens collected during the study of the existing fauna only two did not come from forested habitats. The broscine carabids of the genus *Cascellius,* represented by three species in the Témpano Sur assemblage, are also obligate forest inhabitants. The staphylinid, *Baryopsis brevipennis* was not collected in the study of the modern fauna but on Isla Chiloé it is restricted to the moist leaf litter of dense rain forest. The paederine staphylinids and pselaphids, both represented by abundant fossils, are abundant in the leaf litter and moss of *Nothofagus betuloides* forests.

Several of the species represented as fossils are planticolous. The melandryid *Orchesia* probably inhabits vegetation for the cover it provides. Several weevils feed directly on the rain forest vegetation. Some, such as the weevil *Rhopalomeris tenuirostris,* appear to feed on several plants while others, such as *Apion fuegianum* and *Aegorhinus vitulus* feed exclusively on *Nothofagus.* Some of the species represented by fossils are inhabitants of open environments. These species have stratigraphically restricted distributions in the Témpano Sur section. Very few specimens were retrieved from the basal clay but one of them, the small ground beetle *Trechisibus* sp., occurs on sparsely vegetated outwash plains and moraines adjacent to meltwater streams. Weevils of the genus *Listroderes* typically occur in non-woodland habitats. Fossils of the *Listroderes* in the Témpano Sur section are concentrated in the basal peat layer (48-60 cm) and in the uppermost peat layer (0-12 cm). In the modern faunal survey *Listoderes lugens* was collected in grasses in an area of *Berberis* shrubs. A single specimen, however was collected on the fern *Blechnum magellanicum* in a patch of dense forest on Isla Guarello. Specimens of *Listroderes rugipennis,* fossils of which occur only in the basal peat layer, were collected only on the sparsely vegetated moraines adjacent to glacier margins. *Listroderes* sp. A was not collected during the modern faunal survey but G. Kuschel collected specimens of this species in moorland ground mats and litter between 600-800 m elevation on Isla Wellington and on Mount Jervis across the bay from Puerto Eden. A single specimen of the undescribed cryptorhynchine weevil was also collected by Kuschel in litter at 850 m, near the limit of vegetation growth on the mountains at Puerto Eden.

The environment indicated by the fossil beetle assemblages is that an initially sparsely vegetated environment was rapidly colonized by trees. For most of the interval betweel 11,000 to 10,000 yr B.P. the site consisted of a bog surrounded by a *Nothofagus betuloides* woodland. The truncation of the peat by sand deposition implies a significant environmental change. The appearance of moorland species in the uppermost peat layer further implies that this depositional change was accompanied by harsher climatic conditions that were not supportive of woodland growth.

### *Paleoenvironmental interpretation based on pollen*

Judging from the succession of algae, waterplants, mosses, and ferns between 11,000 and 10,000 yr B.P. it seems likely that the local environment represents a hydrosere, i.e. a succession from a small pond to a peat bog. The lowermost samples (64 cm, 57 cm and 49 cm) contain taxa representative of open water (*Potamogeton, Pediastrum*), as well as *Sphagnum,* growing probably along the pond's margin.

Assemblages in the overlying levels (36 cm and 26 cm) contain much less *Potamogeton,* but instead cushion bog plants (*Astelia*) and herbaceous, wetland plants (Ranunculaceae), indicating that a bog had developed. The uppermost levels (18 cm and 10 cm) with initially high percentages of fern spores, followed by increases in *Pilgerodendron* and *Dacrydium* suggest that at that stage the bog surface has become sufficiently dry to allow trees and shrubs to grow.

An enigmatic aspect in the oldest samples from Témpano Sur concerns the abundance of *Ruppia* pollen. *Ruppia* today grows in brackish to marine environments, although Moore (1983) reports *Ruppia filifolia* also from one freshwater lake in Tierra del Fuego. *Rupia* pollen neither transports well, nor preserves well in sediments, thus should represent a local source. The absence of marine or brackish diatoms from these samples and presence of freshwater plants and algae (*Potamogeton, Pediastrum*) does not suggest a marine environment.

In interpreting the pollen assemblages in terms of regional vegetation, the samples older than 11,000 yr B.P. from silty clay material (74 cm and 64 cm) suggest a treeless pioneer vegetation, based on the dominance of *Empetrum,* Gramineae, Cyperaceae, herbaceous taxa, *Lycopodium magellanicum* and *Gunnera,* and less than 30% of *Nothofagus betuloides* (Fig. 6).

Between 11,000 and 10,000 yr B.P., *Nothofagus betuloides* percentages increases to 50% and 70%, suggesting that trees were locally present and dominant, especially in the two lowermost levels (58 cm and 49 cm). This is supported by the abundance of *Misodendrum* pollen. *Misodendrum,* a mistletoe on *Nothofagus* is known to disperse only locally (Markgraf *et al.* 1981) and thus can be used as an indicator for the local growth of trees. Because of relatively low levels of other, non-arboreal taxa in these lower levels and continuing high levels of *Gunnera*, it seems likely that the high amounts of *Nothofagus betuloides* represent the next stage of colonization. As with *Nothofagus dombeyi, Nothofagus betuloides* is known to preferentially colonize disturbed terrain (Veblen *et al.* 1977), once the climate is suitable.

In the following levels (from 36 cm upwards), *Misodendrum* disappears, other tree taxa (*Griselinia, Drimys, Maytenus, Aristotelia*) appear and non-arboreal and shrub pollen reach relatively higher levels. This suggests that the typical modern *Nothofagus betuloides* woodland had become established locally. The high levels of *Astelia,* and Myrtaceae (probably *Myrteola*) indicate that Magellanic Moorland communities expanded as well, resulting in an environment, similar in type to the modern mosaic of rainforest and moorland.

In summary, the pollen data imply that following initial deglaciation prior to 11,000 yr B.P. a pioneer vegetation colonized the site to be replaced shortly after by a mosaic of *Nothofagus betuloides* woodland and moorland vegetation similar to the modern vegetation. This suggests that climate between 11,000 and 10,000 yr B.P. must have been similar to today, both in terms of temperature and precipitation. Part of the pollen and spore assemblage changes during this 1000 year long interval represent a succession of the local environment, ranging from a pond, to a highly wet, to an ultimately well drained bog, where shrubs and tress could grow.

## DISCUSSION

The details of the local environment of the site provided by the fossil beetle analysis complements the interpretation of the vegetation over a larger area provided by the pollen analysis. The results of both analyses are in agreement that between 11,000 to 10,000 yr B.P. the site was the location of a well developed mosaic of *Nothofagus* woodland and moorland.

Woodland stands, in the harsh climate of the Chilean Channels, develop only in the most favorable locations and due to the slow growth of the tree species require several hundreds of years to develop. The development of woodland stands in ice-marginal positions such as that of the Témpano Sur site depends on environmental stability that is controlled by advances and retreats of the glacier margin (Fig.

7). Advances and retreats of the glacier margin during the recent centuries have destabilized the environment with the result that extensive woodlands are not present at the site. The border of more continuous woodland is about 1 km to the west. The vegetation of the site is presently a cushion plant moorland with *Dacrydium fonckii* and occasional, stunted trees of *Pilgerodendron uvifera*. *Nothofagus betuloides* grows as isolated specimens in the vicinity of the site but only in the shelter of the bedrock channels. The woodland stands that were present at the site between 11,000 to 10,000 yr B.P. implies an environmental stability that could only have resulted if the glacier margin was at least as far to the east of the site as it is presently.

In summary, the lithology and paleontology of the Témpano Sur sections suggests the following series of events.

1. Retreat of the glaciar in the Témpano Fiord shortly before 11,000 yr B.P. to a position near the present margin or further to the east. The gravel in the base of the Témpano Sur section was deposited at this time.
2. Ponding of meltwater and the deposition of clay in a small lake. The margins at

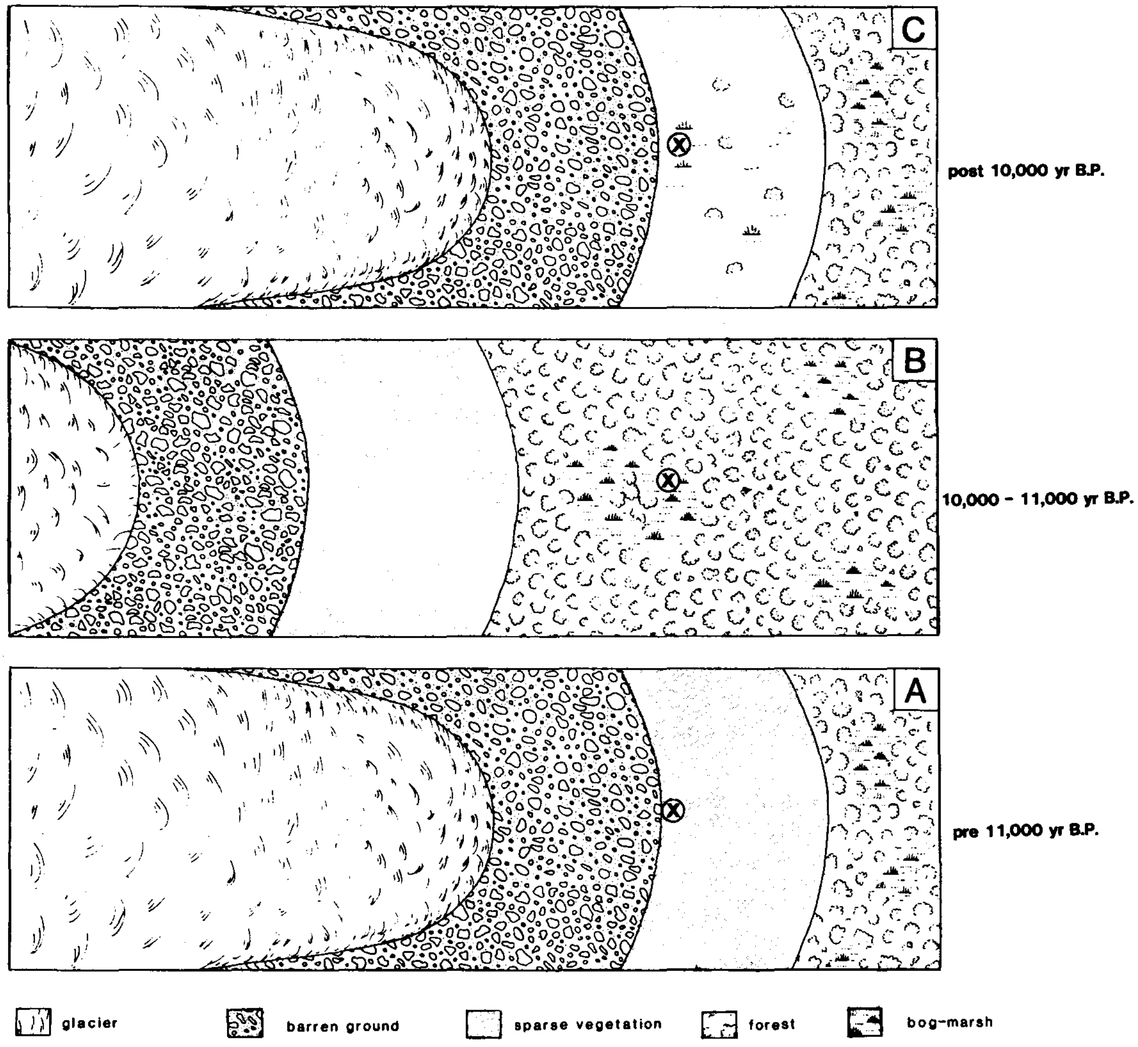

*Fig. 7:* Generalized relationship of glacier margin to different habitats pre-11,000 yr B.P. (A), 11,000 to 10,000 yr B.P. (B), and post-10,000 yr B.P. (C), as inferred from beetle and pollen analyses of Témpano Sur section.

Diagramas paleoambientales de Témpano Sur interpretados según el análisis de coleópteros y polen fósil. (A) Anterior a 11.000 años A.P. (B) Entre 11.000 y 10.000 años A.P. (C) Posterior a 10.000 años A.P.

this time were sparsely vegetated (Fig. 7A).

3. Rapid development of woodland stands in a mosaic with moorland cushion bogs, as the environment stabilized (Fig. 7B).
4. After 10,000 yr B.P. the glacier advanced causing reactivation of the meltwater channel and deposition of sand (Fig. 7C).

## CONCLUSION

The objective of our study was to test the proposition that the summer climate of southern South America was significantly colder (5° to 8°C) and wetter between 11,000 to 10,000 yr B.P. than it is presently. Such a paleoclimate, proposed originally for the Chilean lake district, would have been expected to have caused even more severe environmental changes in the higher latitudes, especially manifested by glacial advances. Glaciar Témpano would have advanced to a position west of the Témpano Sur site, and if the site itself was not under ice, the biota preserved in the peats would have been that of barren or sparsely vegetated terrain.

The geological and paleontological evidence from the Témpano Sur section does not support such a scenario. The climate that supported a mosaic of *Nothofagus* woodland and Magellanic Moorland communities at Témpano Sur between 11,000 and 10,000 yr B.P. could not have been any more severe than that of the present day.

## ACKNOWLEDGMENTS

We are grateful to John Mercer for stimulating our interests in this project. John died of cancer on July 3, 1987. He was a great scholar of Quaternary studies in South America and his participation will be greatly missed.

We thank the following people for the help they provided with various aspects of the project. Mario Arnello, Antonio Horvart, and Patricio Silva of the Proyecto Nacional Chile Futuro, arranged the logistics of the 1985 and 1986 field seasons. The officers and crew of the Chilean Navy launch "Villarrica" provided safe transport in dangerous waters. Mark Mabin of the Byrd Polar Research Centre helped to excavate the section. Mike Gunderson, an undergraduate of North Dakota State University, participated in all the collecting activities of the 1985 field season and prepared the fossil beetles for analysis. Dr. Guillermo Kuschel, Department of Scientific and Industrial Research, New Zealand, identified several of the weevil species. We appreciate editorial comments and help from Dr. J. Armesto and Dr. C. Villagrán. The National Science Foundation funded the project through grant No. EAR 8418149 to Mercer and Ashworth, and through grant No. DPP 8613980 to Markgraf.

## LITERATURE CITED

ALMEYDA AE & SF SAEZ (1958) Recopilación de datos climáticos de Chile y mapas sinópticos respectivos. Ministerio de Agricultura, Santiago, Chile: 1-195.

ASHWORTH AC (1979) Quaternary Coleoptera studies in North America: past and present. In: Erwin TL, Ball GE, Whitehead R (eds): Carabid Beetles. Dr W Junk, The Hague: 395-404.

ASHWORTH AC & HOGANSON JW (1984) Testing the Late Quaternary climatic record of southern Chile with evidence from fossil Coleoptera. In: Vogel JC (ed): Late Cainozoic Palaeoclimates of the Southern Hemisphere. Balkema, Rotterdam.

ASHWORTH AC & JW HOGANSON (1987) Coleoptera bioassociations along a elevational gradient in the Lake Region of southern Chile, and comments on the postglacial development of the fauna. Annals Entomological Society America 80: 865-895.

DARLINGTON PJ (1965) Biogeography of the southern end of the world. Harvard University Press, Cambridge.

FAEGRI K & K IVERSEN (1975) Textbook of Pollen Analysis. Hafner, New York.

KUSCHEL G (1960) Terrestrial zoology in southern Chile. Proceedings Royal Society, B 152: 540-550.

HEUSSER CJ (1966) Late Pleistocene pollen diagrams from the Province of Llanquihue, southern Chile. Proceedings American Philosophical Society 110: 269-305.

HEUSSER CJ (1974) Vegetation and climate of the southern Chilean Lake Region during and since the last interglaciation. Quaternary Research 4: 290-315.

HEUSSER CJ (1981) Palynology of the last interglacial-glacial cycle in midlatitudes of southern Chile. Quaternary Research 16: 293-321.

HEUSSER CJ (1984) Late-Glacial-Holocene climate of the Lake District of Chile. Quaternary Research 22: 77-90.

HEUSSER CJ & RABASSA J (1987) Cold climatic episode of Younger Dryas age in Tierra del Fuego. Nature 328: 609-611.

HEUSSER CJ & STREETER SS (1980) A temperature and precipitation record of the past 16 000 years in southern Chile. Science 210: 1345-1347.

HOGANSON JW & ASHWORTH AC (1982) The Late-glacial climate of the Chilean Lake Region implied by fossil beetles. Proceedings Third North American Paleontological Convention 1: 251-256.

MARKGRAF V (1983) Late and postglacial vegetational and climatic changes in subantarctic, temperate, and arid environments in Argentina. Palynology 7: 43-70.

MARKGRAF V (1984) Late Pleistocene and Holocene vegetation history of temperate Argentina: Lago Morenito, Bariloche. Dissertationes Botanicae 72: 235-254.

MARKGRAF V, D'ANTONI HL & AGER TA (1981) Modern pollen dispersal in Argentina. Palynology 5: 43-63.

MCQUEEN DR (1976) The ecology of *Nothofagus* and associated vegetation in South America. Tuatara 22: 38-68.

MERCER JH (1970) Variations of some South American glaciers since the Late-Glacial: II. American Journal of Science 269. 1-25.

MERCER JH (1976) Glacial history of southernmost South America. Quaternary Research 6: 125-166.

MOORE DM (1983) Flora of Tierra del Fuego. Nelson A, publ. England.

PISANO E (1977) Fitogeografía de Fuego-Patagonia chilena. Anales Instituto de la Patagonia 8: 121-250.

PISANO E (1983) The Magellanic tundra complex. In. Gore AJP (ed): Mires: Swamp, Bog, and Moor. Ecosystems of the World 4B. Elsevier, Amsterdam: 295-329.

VEBLEN TT, DH ASHTON, FM SCHLEGEL & AT VEBLEN (1977) Distribution and dominance of species in the understorey of a mixed evergreen-deciduous *Nothofagus* forest in south-central Chile. Journal Ecology 65: 815-830.

VILLAGRAN C (1985) Análisis palinológico de los cambios vegetacionales durante el Tardiglacial y Postglacial en Chiloé, Chile. Revista Chilena de Historia Natural 58: 57-69.

VILLAGRAN C (1988) Expansion of Magellanic Moorland during the Late Pleistocene: palynological evidence from northern Isla de Chiloe, Chile. Quaternary Research 30: 304-314.

YOUNG SB (1972) Subantarctic rain forest of Magellanic Chile: distribution, composition, and age and growth rate studies of common forest trees. In: Llana GA (ed): Antarctic Terrestrial Biology. American Geophysical Union Antarctic Research Series 20: 307-332.