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Paleoecology of Late Quaternary Deposits in Chiloé Continental, Chile

Paleoecología de los depósitos del Cuaternario tardío en Chiloé Continental, Chile

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ABSTRACT

Two stratigraphic records of the late Quaternary vegetation and paleoenvironmental setting of Chiloé Continental, heretofore unstudied, are from (1) a 7.2 – m deposit of mire peat at Cuesta Moraga (43°25's), dated at 12,310 yr B.P. and interrupted by multiple tephra layers, resting on glacial drift, and (2) a 3 – m road cut near Chaitén (42°54'S), 75 km north of Cuesta Moraga, containing a peat bed with wood, dated 11,850 yr B.P., underlying a thick tephra layer and overlying drift. Records are of fossil pollen, spores, and matrix macroremains, loss on ignition, lithology, and radiocarbon chronology. There is throughout in the data no indication of fire in predominantly *Nothofagus* forest communities, which during the late-glacial at Chaitén contained, among other tree species, *Drimys, Pseudopanax,* and *Podocarpus.* At Cuesta Moraga, where the forest was relatively open and continued to be open during the Holocene, late-glacial ground cover of *Empetrum, Gunnera,* and polypodiaceous ferns was supplanted on the mire largely by minerotrophic Cyperaceae until about 8,000 yr B.P.; later, especially after 5,000 yr B.P., ombrotrophic cushion plants, notably *Astelia, Donatia,* and *Tetroncium,* with *Dacrydium,* proliferated on the surface of the mire. The sequence reflects a paleoenvironment, less humid during an early minerotrophic phase and cooler and wetter during a subsequent ombrotrophic phase, influenced, in addition, by tectonism, as inferred by eight episodes of volcanic activity.

Key words: Fossil pollen, vegetation, paleoclimate, volcanism.

RESUMEN

Dos registros estatigráficos que dan cuenta de la vegetación y el paleoambiente de Chiloé Continental a fines del Cuaternario se obtuvieron de (1) un depósito de 7,2 m de turba en Cuesta Moraga (43°25'S), fechado en 12.310 años AP e interrumpido por múltiples capas de tefra sobrepuestas al sedimento glacial, y (2) un corte de camino de 3 m cerca de Chaitén (42°54'S), 75 km al norte de Cuesta Moraga, que contenía una turba con restos de madera, fechada en 11.850 años AP, sobre una gruesa capa de tefra y sedimento glacial. Se presentan registros de polen, esporas y macrofósiles de la matriz, pérdidas por ignición, litología y cronología de radiocarbono. Los datos no revelan ningún indicio de fuego en bosques dominados por *Nothofagus*, los cuales durante el Tardiglacial contenían, entre otras especies arbóreas, *Drimys, Pseudopanax* y *Podocarpus.* En Cuesta Moraga, donde el bosque era relativamente abierto antes y durante el Holoceno, la cubierta vegetal del Tardiglacial compuesta de *Empetrum, Gunnera*, y Polypodiaceas fue suplantada en los sectores anegados por Ciperaceas, fundamentalmente minerotróficas, hasta los 8.000 años AP. Más tarde, cerca de los 5.000 años AP., plantas ombrotróficas en cojín, notablemente *Astelia* y *Donatia*, junto a *Tetrocium* y *Dacrydium*, proliferaron en la superficie. Esta secuencia refleja un paleoambiente menos húmedo durante la fase minerotrófica temprana, y uno más frío y más húmedo durante la fase ombrotrófica subsecuente, bajo la influencia adicional del tectonismo, indicado por ocho episodios de actividad volcánica.

Palabras claves: Polen fósil, vegetación, paleoclima, vulcanismo.

INTRODUCTION

Few paleoecological data bear on the Quaternary vegetation of southern Chile in extensive sectors lying between the lake district of Llanquihue and Tierra del Fuego in Magallanes (Heusser 1987a). For hundreds of kilometers along the Andean Pacific slope, the history of vegetation over past millennia since the last ice age is virtually unknown. Studies on Isla Grande de Chiloé (Heusser & Flint 1977, Villagrán 1988a, 1988b, 1990, Heusser 1990a) and in the Chilean channels-Patagonia (Auer 1933, 1958, Heusser 1960, 1964, 1972, 1987b, Ashworth & Markgraf 1989)

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contribute to the bulk of the literature. This paucity of data precludes attempts to interpret the regional Quaternary phytogeography, involving extinction of species, survival of plants in ice-free refugia, centers of distribution, successional sequences, and migration patterns of species during and since the last ice age. It also limits interpretations of climate and other environmental factors, including fire, volcanism, tectonic activity, and changes in land-sea relations, as well as paleo-Indian invasion of the deglaciated landscape.

Problems of accessibility and the generally inhospitable conditions for field work in much of the region account in large measure for the slow pace of research apparent from the literature. However, construction of the Carretera Austral (Fig. 1), which has been a formidable engineering undertaking (Hauser 1983), has opened up for study, beginning in 1982, large parts of undisturbed terrain in Chiloé Continental and the Province of Aisén. This access accounts for the collection of paleoecological data from stratigraphic sections of two Quaternary deposits, one from a mire at Cuesta Moraga and the other from an exposure near Chaitén (Fig. 1). Results, which enlarge upon the vegetation history of the sector of Chiloé Continental, heretofore unstudied, are presented in this paper.

The mire at Cuesta Moraga is noteworthy because of its unusual plant cover and history of species representative of Magellanic Moorland, the vegetation type distributed on the outer archipelagos in the far south of Chile and localized on the upland of Isla Grande de Chiloé and several places some distance north in the Cordillera de la Costa. The mire is also remarkable for its multiple tephra layers, which, in conjunction with the radiocarbon chronology, are a record of the incidence of volcanic activity and tectonism in this part of the Andes.

Chiloé Continental

The Cordillera de los Andes, the main feature of Chiloé Continental (42°14'-45°15'S), consists of older plutonic granite and diorite with younger volcanic rock (Servicio Nacional de Geología y Minería 1982). The principal summits at altitudes of < 2,500 m. (Fig. 1) are identified by the volcanoes, Michinmávida (2,470 m), Corcovado (2,300 m), Yanteles (2,050 m), and Melimoyu (2,400 m). During the last glacial maximum, the Andes at this latitude were covered by an ice cap from which glaciers spread westward, forming a piedmont lobe that at about 20,000 yr B.P. occupied much of Isla Grande de Chiloé. Later, after an interval of recession, the lobe readvanced around 14,500-15,000 yr B.P., and ultimately, beginning before 13,000 yr B.P., wasted rapidly (Mercer 1984, Heusser 1990a).

Chiloé Continental, situated in the belt of southern westerly winds, is crossed by a continuous succession of storms, which contribute to heavy, year-long precipitation, high humidity, and extended cloudiness, characterizing a cool temperate climate (Miller 1976, Prohaska 1976). Annual precipitation averages between 4,000 and 5,000 mm with mean temperatures in January close to 14°C and in July about 6°C. Conditions are optimum for the growth of dense evergreen rain forest, which differentiates latitudinally and altitudinally.

Valdivian forest in the northern part of the region is at < 300 m altitude, and North Patagonian forest in the southern part generally reaches 400-700 m; slopes up to 1,000-1,200 m are increasingly open, occupied mainly by Subantarctic forest (Reiche 1907, Schmithüsen 1960, Oberdorfer 1960). Valdivian arboreal species are typically *Nothofagus dombeyi* and *Eucryphia cordifolia* in association with *Laurelia philippiana* and *Weinmannia trichosperma*. With the exception of *Eucryphia*, these species are also constituents of the North Patagonian forest, which is characterized by *Nothofagus betuloides*, *N. nitida*, *Drimys winteri*, and *Pilgerodendron uviferum*. Distributed throughout are the podocarps, *Podocarpus nubigena* and *Saxe-gothaea conspicua*. Subantarctic forest communities, broken by steep rocky slopes, mires, and subandean tundra, are dominated by *Nothofagus pumilio*.

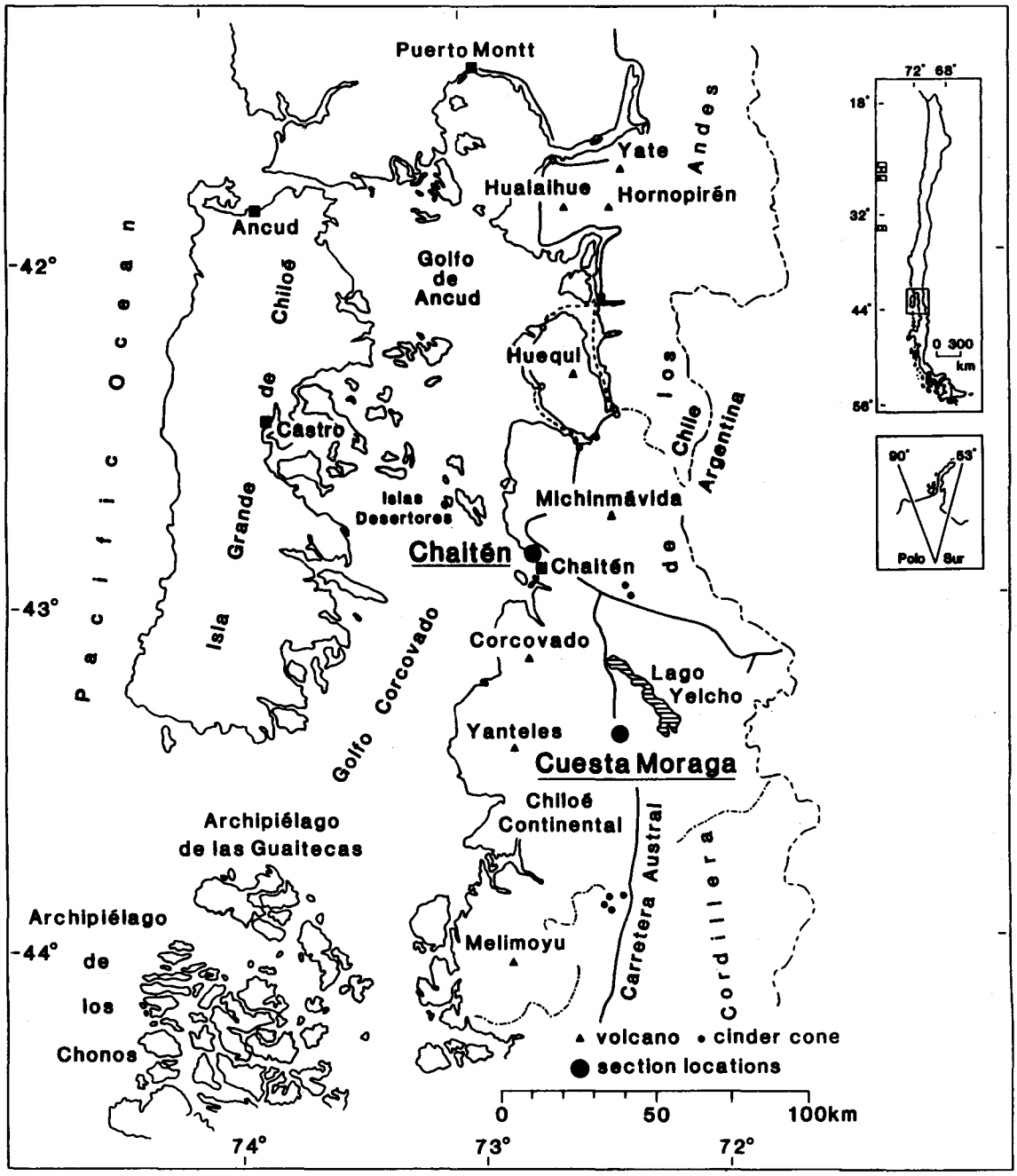


Fig. 1: Late Quaternary section locations in Chiloé Continental at Cuesta Moraga and Chaitén shown in relation to the Carretera Austral, volcanoes, sites of cinder cones, and other physical features discussed in the text.

Ubicación geográfica de las secciones correspondientes al Cuaternario tardío en Chiloé Continental, Cuesta Moraga y Chaitén, en relación con la Carretera Austral, volcanes, sitios de cono volcánico (lapilli) y otras características fisiográficas discutidas en el texto.

MATERIALS AND METHODS

Field studies

At Cuesta Moraga, samples at 10-cm stratigraphic intervals were taken from a 7.0-m peat section and at 1-cm intervals from an underlying 5-cm thick peat layer resting on glacial drift, not penetrated by coring, exposed in an adjacent road cut. The site at Cuesta Moraga (43°25'S, 72°23'W) is a soligenous mire, located at approximately 700 m in altitude, about 75 km south of Chaitén (Fig. 1). Covering an estimated 1 ha on the west side of the Carretera Austral, the mire is part of an extensive moorland complex, spread downslope to the east, at the upper limit of North Patagonian forest. The surface, sloping gently to the north, is partially covered by Magellanic Moorland cushion plants, principally, *Donatia fascicularis, Astelia pumila, Oreobolus obtusangulus,* and a variety of mire species, including *Myrteola nummularia, Drosera uniflora. Marsippospermum grandiflorum, Carex* spp., and *Sphagnum* spp. Bordering the mire and forming colonies on its surface are patches of low *Dacrydium fonckii, Pilgerodendron uviferum,* and *Nothofagus betuloides.*

Samples of a second section (Fig. 1), collected at 1-cm intervals, are from a 5-cm thick peat bed. The bed, resting between a thick tephra layer and overlying drift, is exposed 4 km north of Chaitén (42°54'S, 72°44'W), along the east side of the Carretera Austral, at an altitude of 60 m. Forest nearby contains elements of both Valdivian and North Patagonian forest types.

Laboratory studies

Laboratory processing of samples, involving potassium hydroxide deflocculation, washing with sodium pyrophosphate, hydrofluoric acid treatment, and acetolysis, followed the technique for the concentration of fossil pollen and spores outlined by Heusser & Stock (1984). Identifications under the microscope were made through use of a reference collection and descriptions of species in the Chilean flora (Heusser 1971, Villagrán 1980). Frequencies (%) of pollen taxa are from sums of 300 grains; spore frequencies are calculated from amounts of > 300 total pollen and spores.

Because mire and forest taxa together form a broad, natural ecotone at Cuesta Moraga, representative pollen derived from each of these formations is treated together in the frequency calculations, as shown diagrammed from total pollen sums (Fig. 2). Thus, relative amounts of pollen from site-derived mire species, for example, *Pilgerodendron uviferum, Dacrydium fonckii, Tetroncium magellanicum, Marsippospermum,* Cyperaceae, *Astelia pumila, Empetrum rubrum,* and *Donatia fascicularis,* can be compared with the dominant *Nothofagus dombeyi* type among minor forest species. In practice, mire species are often excluded from pollen sums; however, in view of the fact that at Cuesta Moraga their proportions are formidable, in addition to constituting a natural tension zone with the forest, this procedure was not followed.

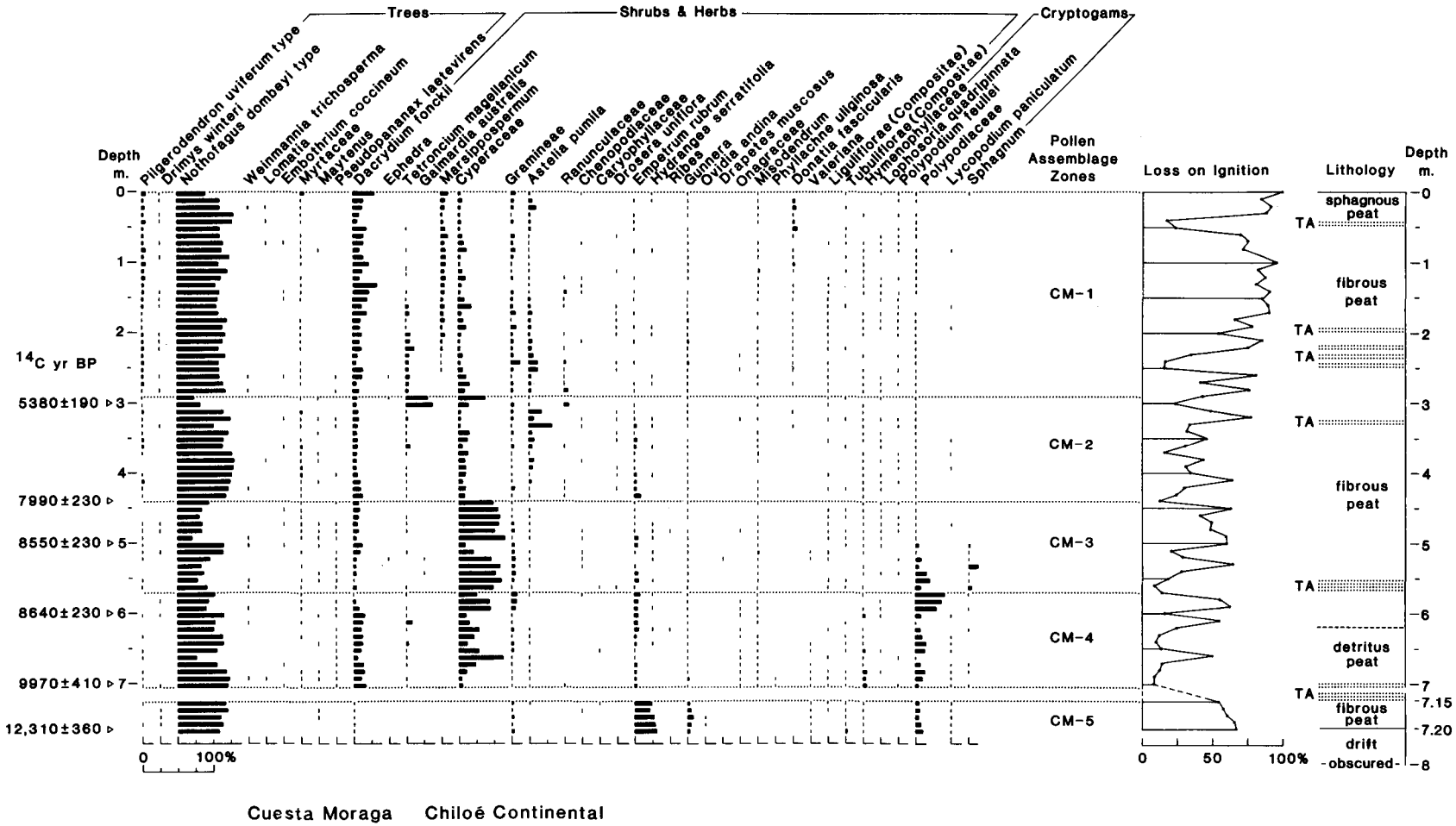
Sediments from both sections were examined and described, using the following criteria: matrix macroremains and color (Munsell Color Charts 1975), facies changes, tephra layers, charcoal, and in the case of Cuesta Moraga, loss on ignition (Aaby 1986). Radiocarbon dates (RL and GX laboratory determinations, samples ± 5 cm at core section levels and basal 1 cm in exposures) served to establish the chronostratigraphy; at Cuesta Moraga, no age determinations were made above a depth of 3 m because of possible contamination by modern roots.

Plant nomenclature for vascular plants follows Marticorena and Quezada (1985).

RESULTS

Cuesta Moraga

The section of the mire at Cuesta Moraga (Fig. 2) consists of reddish brown (5YR 4/4) *Sphagnum* at the surface, underlain by dark reddish brown (5YR 3/3) *Sphagnum* peat, increasingly decomposed at



Cuesta Moraga Chiloé Continental

Fig. 2: Diagram of pollen and spore frequency (trees, shrubs, and herbs, and cryptogams), lithology (TA, tephra layers), loss on ignition, and radiocarbon chronology, subdivided by pollen assemblage zones, of the section at Cuesta Moraga. Diagram is a composite section of a mire and adjacent underlying deposit exposed in a road cut. Note change of scale below. Analyses by CJH.

Diagrama de frecuencias de polen y esporas (árboles, arbustos, hierbas, croptógamas), litología (TA, capas de tefra), pérdidas por ignición y cronología radiocarbónica, de acuerdo a las zonas polínicas de la sección Cuesta Moraga. El diagrama es una sección compuesta de una vega y un depósito subyacente expuesto en un corte de camino. Note el cambio de escala abajo. Análisis por CJH.

depth (0-0.4 m); predominantly decomposed, dark reddish brown (5YR 3/2 - 5YR 2.5/2) fibrous peat (0.4-3.2 m); dark reddish brown (5YR 2.5/2) fibrous peat containing variable sphagnous remains, detritus, and quantities of clastics (mostly sand and small pebbles) at depth (3.2-6.2 m); dark reddish brown (5YR 2.5/2) detritus peat with clastics (6.2-7.0 m); and dark brown fibrous peat (7.5YR 3/2) overlying drift (7.0-7.2 m). Eight tephra layers (ash/lapilli), characterized as dark yellowish brown (10YR 4/4), occur at depths of 0.4-0.5, 1.9-2.0, 2.27-2.49 (3 levels), 3.25-3.26, and 5.5-5.7 m; a black tephra (7.5YR N2/), consisting predominantly of lapilli, is bedded at 7.0-7.15 m. Percent loss on ignition overall decreases with depth, as quantities of clastics increase, and in the presence of tephra layers in the section. Loss-on-ignition values in the upper part of the section reach > 75% in contrast with < 25% in the lower part. The lower section at nearly all levels has abundant ash and lapilli, probably the result of reworking of tephra downslope. Charcoal in the section is virtually absent.

Pollen and spore stratigraphy covering the past approximately 12,300 yr is divided into five pollen assemblage zones (Fig. 2, Table 1). The dominant arboreal taxon, apparently derived from the leading species in forest communities bordering the mire, is *Nothofagus dombeyi*-type (Heusser 1971), which reaches maximum proportions and fluctuates least in zones CM-1 and CM-5; remaining arboreal components amount to no more than a few per cent. Of the mire vegetation, *Dacrydium* is throughout consistently present with greater representation in zones CM-1 and CM-4; cushion plant types *Astella* and *Donatia*, along with *Marsippospermum*, are much in evidence in upper zones CM-1 and CM-2; and Cyperaceae are featured at depth in zone CM-3 and, along with the Polypodiaceae, in zone CM-4. Distinctive are *Empetrum* and *Gunnera* in zone CM-5. Plants of subantarctic affinity in the fossil record besides *Dacrydium*, *Astelia*, and *Donatia*, although not observed growing on the surface of the mire, are *Gaimardia australis*, *Drosera uniflora*, *Drapetes muscosus*, and *Phyllachne uliginosa*.

Chaitén

The measured section at Chaitén (Fig. 3) is made up of highly organic soil containing wood (0-0.7 m); a tephra layer consisting of grayish brown (10YR 5/2) lapilli and ash, grading below to black (10YR 2/1) lapilli (0.7-1.5 m); dark brown (5YR 3/2) detritus peat with wood (1.5-1.55 m); and a drift sequence of brown (10YR 5/3) diamicton (1.55-1.95 m), gray (10YR 5/1) diamicton (1.95-2.4 m), and indurated gray (10YR 6/1) till, obscured below road level (2.4-3.0 m). Based on a radiocarbon date of wood (JH Mercer, personal communication, 1984), the age of the peat is 11,850 yt B.P.; a date of 10,880 yr B.P. for the peat may be only slightly younger than the age of the wood, given the large statistical errors in the radiocarbon dates. No evidence of charcoal was observed in samples of the peat.

Pollen in the section (Fig. 3, Table 2) is predominantly of *Nothofagus dombeyi* type. Zone CH-1 contains, in addition, notable amounts of *Drimys* (15%), Ericaceae (10%), Hymenophyllaceae (18%), *Blechnum* (15%), and Polypodiaceae (60%); in zone CH-2, which covers the increase of *Nothofagus* to a maximum 85%, *Pseudopanax* and *Podocarpus* are of importance. Of significance at all levels in the section is *Huperzia selago*, a lycopod distributed today mostly in Tierra del Fuego. During the late Pleistocene, *Huperzia* ranged northward from outside the limit of glaciation to the Province of Osorno in the lake district (Heusser 1991).

DISCUSSION

Deglaciation of Isla Grande de Chiloé and Chiloé Continental took place rapidly following the last glacial maximum. Glaciers began to recede before 13,000 yr B.P. on Isla Grande and had begun to melt in the Andean cordillera before 12,300 yr B.P. (Mercer 1984, Heusser

TABLE 1

Pollen assemblage and age stratigraphic data for Cuesta Moraga.
Conjuntos polínicos y edad estratigráfica para Cuesta Moraga.

Pollen assemblage zone	Pollen assemblage	Age (^{14}C yr B.P.)
CM-1 (0-2.9 m)	*Nothofagus-Dacrydium-Donatia-Astelia-Marsippospermum*	
		ca 5,000
CM-2 (2.9-4.4 m)	*Nothofagus-Astelia*	5,380 ± 190 (3.0 m, RL-1922)
		ca 8,000
CM-3 (4.4-5.7 m)	*Nothofagus*-Cyperaceae	7,990 ± 230 (4.4 m, RL-1923) 8,550 ± 230 (5.0 m, RL-1924)
		ca 8,600
CM-4 (5.7-7.0 m)	*Nothofagus-Dacrydium*-Cyperaceae-Polypodiaceae	8,640 ± 230 (6.0 m, RL-1925)
		ca 10,000
CM-5 (7.0-7.2 m)	*Nothofagus-Empetrum-Gunnera*-Polypodiaceae	9,970 ± 410 (7.0 m, RL-1926)
		ca 12,300
		12,310 ± 360 (7.2 m, RL-1892)

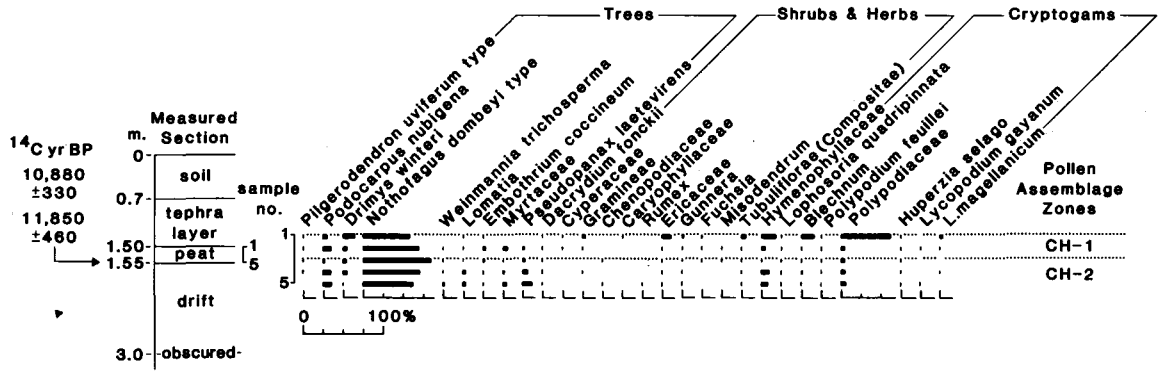


Fig. 3: Diagram of pollen and spore frequency (trees, shrubs and herbs, and cryptogams) and radiocarbon ages of peat horizon, subidivided by pollen assemblage zones, in the measured section of the road cut near Chaitén. Note scale change at depth. Analyses by CJH.

Diagrama de frecuencias de polen y esporas (árboles, arbustos, hierbas, criptógamas), litología (TA, capas de tefra), y cronología radiocarbónica del horizonte de turba de un corte de camino cerca de Chaitén de acuerdo a las zonas polínicas. Note el cambio de escala abajo. Análisis por CJH.

TABLE 2

Pollen assemblage and age stratigraphic data for Chaitén.
Conjuntos polínicos y edad estratigráfica para Chaitén.

Pollen assemblage zone	Pollen assemblage	Age (^{14}C yr B.P.)
CH-1 (150-152 cm)	*Nothofagus-Drimys-* Ericaceae-Polypodiaceae	
CH-2 (152-155 cm)	*Nothofagus-Pseudopanax*	ca 11,850
		11,850 ± 460 (wood) (155 cm, GX-9982) 10,880 ± 330 (peat) (155 cm, RL-1891)

1990a). As climate became more favorable for the development of vegetation in Chiloé Continental, a variety of plants invaded the landscape. At Cuesta Moraga, climate during the late-glacial supported *Nothofagus* in numbers sufficient to produce > 60% of the pollen sum (Fig. 2). Arboreal communities were apparently open, however, with a ground cover characterized by *Empetrum, Gunnera,* and polypodiaceous ferns. At Chaitén (Fig. 3), amounts of *Nothofagus* pollen were also considerable, between 58 and 85%, accompanied by large quantities of insect pollinated *Pseudopanax* and *Drimys,* at 12% and 15%, respectively. This pollen assemblage suggests a proximal pollen source under a cool-temperate, humid climate. Plants at these sites typify successional communities developing today on glacial outwash and recessional moraines in different parts of the southern Andes (Skottsberg 1916, Lawrence & Lawrence 1959, Heusser 1964, Anliot 1965, Pisano 1978, Veblen *et al.* 1989).

At approximately 10,000 yr B.P., following deposition of a 15-cm thick, late-glacial tephra layer, *Dacrydium fonckii* began to proliferate at Cuesta Moraga along with the arrival of other Magellanic Moorland species, *Tetroncium magellanicum, Astelia pumila,* and *Phyllachne uliginosa.* Vegetation on the surface of the mire in the early Holocene (10,000-8,000 yr B.P.) appears to have been predominantly "grass-like (graminoid)" (*sensu* Moore 1983 in his classification of Magellanic Moorland), consisting of cyperaceous species but including cushion plants. It was during the interval that reworking locally of the late-glacial tephra layer and a second tephra dated at about 8,600 yr B.P. caused quantities of ash/lapilli to occur dispersed in the lower part of the mire deposit. Light-adapted Polypodiaceae in the early Holocene at Cuesta Moraga suggest that *Nothofagus* forest communities nearby were relatively open.

Sources from which Magellanic Moorland plants spread to Chiloé Continental were unglaciated refugia on Isla Grande de Chiloé and, to the north, in the Cordillera de la Costa (Villagrán 1988b, Heusser 1982, 1990a). Species in Isla Grande refugia included *Dacrydium, Tetroncium, Gaimardia, Astelia, Drosera, Drapetes, Phyllachne, Donatia,* and *Huperzia.* Refugia located farther north along the unglaciated flanks of the Andes are also conceivable sources; however, moorland species of the kinds found at Cuesta Moraga are not in evidence along this possible pathway at present or earlier in the Holocene (Villagrán 1980). Migration from Isla Grande via

the Islas Desertores (Fig. 1), which form a closely-spaced archipelago between Golfo de Ancud and Golfo Corcovado, is favored as a direct route of some 170 km. When sea levels were lower than at present during the late-glacial, the islands were closely linked and favorably disposed for migration.

At about 8,000 yr B.P., percentages of Cyperaceae drop sharply at Cuesta Moraga (Fig. 2) and later on do not regain supremacy. The Cyperaceae appear to have been supported edaphically by high levels of divalent cations in a minerotrophic setting. Their abrupt decrease is perhaps attributable to a drop in the availability of mineral nutrients from tephra and other sources in the surroundings, which was brought on by alteration of slope drainage under a contrasting set of climatic conditions. Pollen contributed by mire species after 8,000 yr B.P. is increasingly from *Astelia* and *Tetroncium,* and after about 5,000 yr B.P. from *Dacrydium, Pilgerodendron* type, *Donatia,* and *Marsippospermum.* The mire after 8,000 yr B.P. appears to have been subject to higher levels of atmospheric moisture and have undergone ombrotrophication. This is inferred not only by floristic alteration at the mire surface but also by increased organic matter deposition shown by loss on ignition measurements. In the minerotrophic phase during the first 2,000 years of record, when larger amounts of ash/lapilli were being added to the deposit, the sedimentation rate averaged 1.30 mm yr^{-1}; later, in the ombrotrophic phase, the rate was 0.55 mm yr^{-1}. These changes at Cuesta Moraga are consistent with regional climatic trends in southern Chile, which overall show lower precipitation with higher summer temperatures in the early Holocene and increased precipitation under colder conditions during episodes in the late Holocene (Heusser and Streeter 1980).

The almost exclusive domination among forest taxa by *Nothofagus* throughout the 12,300 years of record is remarkable. The range of conditions required to maintain *Nothofagus* was evidently never exceeded during climatic regimes of the late-glacial and Holocene. Upslope/downslope or meridional migration of forest species inferred by changing late Quaternary climate is not apparent at Cuesta Moraga. This is possibly because the zone of *Nothofagus*-dominated forest was not occupied by invaders in any number or for sufficiently long intervals to be recorded in the pollen record. Temperature and precipitation changes, which influenced forest composition over the time of record in other parts of Chile, appear to have had a less dramatic effect on the makeup of forests in this part of Chiloé Continental.

The late-glacial - Holocene vegetation history of Isla Grande de Chiloé (Villagrán 1985, 1988a), by comparison, includes the expansion of North Patagonian - Subantarctic forest under cool and wet conditions (12,500-9,500 yr B.P.), followed by the invasion of Valdivian forest elements as climate became warmer and drier (9,500-5,000 yr B.P.), and, afterward, by a return of North Patagonian - Valdivian forest species, inferring wetter climate with temperatures fluctuating above and below modern levels (5,000-0 yr B.P.). Comparable paleoecological changes are shown by studies made at lower latitudes in the Cordillera Pelada (40°10'S), where less humid conditions, intensified between 9,000 and 6,500 yr B.P., restricted the spread of ombrotrophic cushion bogs and associated Magellanic Moorland species until after about 4,000 yr B.P. (Heusser 1982). In the northern lake district at Rucañancu (39° 33'S), the montane podocarp *Prumnopitys andina* prevailed during the colder late-glacial, to be replaced under a warming, drying trend by Myrtaceae, *Aextoxicon punctatum,* and grass until about 8,000 yr B.P., followed successively by *Nothofagus obliqua* type until about 7,000 yr B.P. and by *N. dombeyi* type later to the present, in keeping with the development of cooler, more humid climate (Heusser 1984).

In semi-arid, subtropical central Chile at Laguna Tagua Tagua (34°30'S), the pollen record reveals a more extensive low latitude and low altitude distribution of the podocarp *Prumnopitys andina* and of *Nothofagus dombeyi* type during the late-glacial (Heusser 1990b). Climate in effect,

as at higher latitudes, was colder with year-long precipitation in contrast to the winter-wet, summer-dry, Mediterranean climate that prevailed in the Holocene. Only within the last approximately 2,500 yr has the increase of grass with some *N. dombeyi* type implied a shift toward higher levels of humidity. Climatic trends evident at Laguna Tagua Tagua also appear in pollen data from studies made at Quereo (31°55'S) and Quintero (32°47'S) on the coast of central Chile (Villagrán & Varela 1990), where late-glacial swamp, aquatic, and arboreal taxa do not reappear until the late Holocene, when climate again was more humid after 3,000 yr B.P.

Additional pollen records from the Southern Andes in Tierra del Fuego and the region of the Chilean channels consistently follow the broad pattern of vegetational and climatic change apparent at Cuesta Moraga and the lower latitudes of Chile. In southern Tierra del Fuego (54° 52-56'S), *Nothofagus* expanded to form open woodland as climate became warmer after 10,000 yr B.P., while structurally closed forest communities of *Nothofagus* did not develop there until conditions were cooler and wetter after about 5,000 yr B.P.; before 10,000 yr B.P., vegetation was mostly treeless, made up essentially by tundra (Heusser 1989a, 1989b, 1990c, Rabassa *et al.* 1990). In the Chilean channels at Témpano Sur (48°44'S), a late-glacial pollen sequence shows *Nothofagus* prevalent in this sector at approximately 11,000 yr B.P. (Ashworth & Markgraf 1989). At Puerto Edén (49°08'S), where a Holocene sequence begins at 9,670 yr B.P., *Nothofagus* was dominant during the early millennia, followed after 4,720 yr B.P. by the spread of Magellanic Moorland, when climate apparently became increasingly wetter, as reflected by increases of both *Dacrydium fonckii* and *Podocarpus nubigena* (Heusser 1972).

At both Cuesta Moraga and Chaitén, fire has not been a factor causing forest disturbance, as in other parts of the Andean cordillera (Heusser 1987b). On the other hand, *Nothofagus*, considered opportunistic, according to Veblen *et al.* (1980), may have been sustained as a result of volcanic eruptions and tectonism that have been recurrent in Chiloé Continental. Volcanism at Cuesta Moraga is recorded by at least eight tephra layers, three dated between 12,310 and 9,970, 8,640 and 8,550, and 7,990 and 5,380 yr B.P. and five additional over the past 5,000 years. Sources of the ash/lapilli are probably the nearest active volcanoes: Yanteles, Corcovado, and Michinmávida. These volcanoes and cinder cones (Fig. 1), which are formed locally from fissural emissions, along the Liquiñe-Ofqui fault (Servicio Nacional de Geología y Minería 1982), occupy part of the southern volcanic zone, the result of subduction of the oceanic Nazca plate below continental South America (Stern 1990).

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