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THE VEGETATION HISTORY AND PALEOCLIMATOLOGY
FOR THE LATE QUATERNARY OF
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THE VEGETATION HISTORY AND PALEOCLIMATOLOGY FOR THE LATE QUATERNARY OF ISLA DE LOS ESTADOS, ARGENTINA

By

Warren Harvey Johns

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ABSTRACT

THE VEGETATION HISTORY AND PALEOCLIMATOLOGY FOR THE LATE QUATERNARY OF ISLA DE LOS ESTADOS, ARGENTINA

By

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Pollen has been analyzed from three cores retrieved from the peat of Isla de los Estados, just east of Isla Grande, Tierra del Fuego. The three resulting pollen diagrams indicate paleoecological and paleoclimatological trends over the past several thousand years in the southeastern-most extension of the Magellanic rain forest. Arboreal pollen is almost exclusively from the southern beech (*Nothofagus*). A computer program was devised in attempting to differentiate mathematically the two main components of the island's *Nothofagus* flora, *N. betuloides* from *N. antarctica*, based upon the relative number of apertures of the pollen grains. Four full major vegetational cycles are detected from the pollen spectrum of the 9.6-m Bahia Crossley core, and these may indicate the effects of long-term paleoclimatological and paleoecological trends upon the local flora.

ACKNOWLEDGMENTS

A debt of gratitude is owed to many individuals who have made this thesis possible. First of all, my heartfelt appreciation goes to the chairman of my thesis guidance committee, Dr. Aureal T. Cross, who took a special interest in me upon my first arrival at Michigan State University in 1975 and who has provided expert guidance and keen insights all along the way. My sincere thanks go to Dr. Ralph Taggart and Dr. C. E. Prouty, who have also provided much-needed assistance as members of my thesis guidance committee. A special note of appreciation goes to the Department of Botany for providing samples from Isla de los Estados and to Dr. Taggart for his help particularly in solving the difficult *Nothofagus* taxonomy. Valuable discussions with Dr. Harry Imshaug, Department of Botany and Plant Pathology, Michigan State University, and Dr. David Moore, Department of Botany, University of Reading, are also gratefully acknowledged. And finally, a debt of both gratitude and love goes out to my wife, who cheerfully did the painstaking job of typing the thesis and provided undying support and encouragement from start to finish.

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INTRODUCTION

Isla de los Estados (Staten Island), Argentina, is located just off the eastern tip of Tierra del Fuego at approximately 55°S, 64°W. Oriented along an east-west axis, it is just over 60 km long, a maximum of 18 km wide, and has a maximum elevation of nearly 1000 m. It is separated from Isla Grande of Tierra del Fuego by the 30-km wide Estrecho de le Maire to the west. The much wider Drake Passage separates it from the Antarctic Peninsula and South Shetland Islands to the south. The island has a very irregular coastline with numerous fjord-like bays, some of which almost bisect the island.

Botanically, the island is located at the easternmost edge of the Magellanic evergreen rain forest, which is the southernmost forest in the world. This forest extends as far south as Islas Hermite at 56°S, which is only about 800 km from the Antarctic Peninsula. Isla de los Estados itself has dense, impenetrable thickets of the southern beech, *Nothofagus*, thus making exploration of the island on foot very difficult. Expeditions to the island have discovered that the best method of collecting is landing at the many sheltered bays and making short forays into the surrounding land area.

One such expedition, R/V *Hero* Cruise 71-5, was designed to study primarily the terrestrial plant life of the island, although ostracodes and various microfauna were studied through bottom-sampling in the bays. During that expedition, October 11 to November 14, 1971, three cores of peat deposits were obtained and returned to Michigan State University for pollen analysis. The cores were from the mid-eastern, central, and far western portions of the island and can serve as a basis for the reconstruction of the vegetation history of the island since the end of the last glaciation.

The purpose of the present study is to report the results of the pollen-analytical work on these three cores and to interpret the variations in the pollen spectra in terms of paleoecological, vegetational, and paleoclimatological changes. Present-day analogs in the form of plant communities now inhabiting the island will be used to develop a reconstruction of the plant successional changes during the Postglacial period. The reconstruction will then be compared with other reconstructions for Tierra del Fuego and southern Patagonia.

CHAPTER I

SUMMARY OF PREVIOUS STUDIES ON ISLA DE LOS ESTADOS

Botanical Studies

The Tierra del Fuego area, of which Isla de los Estados is a part, was visited by the first plant collector, George Handisyd, in 1690. Since then more than 200 collectors have visited the area, and of these, 80 have published reports (Moore, 1974, 1975). The first to discover Isla de los Estados were Schouten and Le Maire, who named it Staten Island (Isla de los Estados) in 1616 after their homeland which was Holland (Imshaug, 1972). The first naturalists to visit the island landed in 1774 while Captain Cook's ship anchored off Islas Ano Nuevo on his second voyage (Imshaug, 1972). However, their collections were limited to that small group of islands which are off the north coast of Isla de los Estados.

Other collectors to Isla de los Estados followed in succession: Menzies in 1787, Foster in 1828, Hahn in 1882, and Racovitza in 1898 (Imshaug, 1972). Two collectors in the late 19th century had their reports published in national museum publications: Alboff at LaPlata, in 1896, 1897, and Spegazzini at Buenos Aires, in 1896 (Moore, 1974, 1975). The Swedish South-Polar Expedition first visited the island in 1902, and again in 1903 following the wreck of the ship <u>Antarctica</u>, and out of these expeditions emerged the classic studies on the botany of the island. As a result, a number of extensive monographs were published first by C. J. F. Skottsberg, in 1906, 1913, 1916, and 1926, and then by H. Roivainen, in 1954, most of which were in German (Moore, 1974, 1975). While minor expeditions to the island were conducted by botanists, Hicken, in 1912 and Castellanos, in 1933-1934 (Imshaug, 1972), the only major botanical expeditions comparable to that of the Swedish Expeditions early in the century were the R/V *Hero* cruises conducted within the last decade.

The R/V *Hero* Cruise 71-2 consisted of a survey of the vertebrates, arthropods, and marine biota at Isla de los Estados, and this was complemented by R/V *Hero* Cruise 71-5 whose primary goal was to survey the terrestrial plant life (Imshaug, 1972). This latter cruise in October and November, 1971, resulted in the retrieval of the three peat cores which served as the basis for this study.

Numerous botanical studies have been spawned by the expedition, most of which are still in progress. The lichens are being studied mainly by Dr. H. A. Imshaug (Michigan State University), the bryophytes by several individuals, and the vascular plants by Dr. T. R. Dudley (U.S. National Arboretum) and Dr. Garrett E. Crow (University of New Hampshire). A flora for the vascular plants is being published by Dudley and Crow (in press). Apart from the R/V *Hero* studies, a more comprehensive flora is being developed and analyzed for the entire south Patagonian and Fuegian area under the direction of Dr. David Moore (University of Reading, U.K.), while a flora representing Tierra del Fuego has already been published (Moore, 1974).

As far as I am aware, no palynological studies have been done for Late Quaternary deposits on Isla de los Estados until the time of the R/V *Hero* Cruise 71-5. Dr. Ralph Taggart (Michigan State University) has undertaken the study of the Postglacial history based on palynological analysis of the peat cores collected by that expedition. This study serves to complement Auer's series of pollen profiles developed from bog studies for central and eastern Tierra del Fuego (Auer, 1965).

Geological Studies

The geological surveys have not been nearly so numerous and extensive as the botanical surveys on Isla de los Estados. Windhausen's survey of the geology of Argentina does not refer to Isla de los Estados in the text, although his geological map (Windhausen, 1931) does depict the island as being bisected into two main lithological types:

1) a marine sedimentary sequence from Jurassic to Cretaceous (Neocomian);
2) a porphyritic sequence of Triassic age.

The earlier geological reports were sketchy and at best fragmentary, so it was not until 1943 that the first synthesis of the early reports was published by Harrington (in Spanish), together with the results of his own summer field work there in cooperation with the Argentine Navy (Harrington, 1943, cited in Dalziel, *et al*., 1974). Some of Harrington's work has appeared more recently in English (Harrington, 1956, 1962).

An even more comprehensive survey of the island was conducted by R/V *Hero* Cruise 72-2, which was a joint Argentine-United States geological venture sponsored by the U. S. Antarctic Research Program. The expedition, which took place during April and May, 1972, had the services of geologists I. W. D. Dalziel and K. F. Palmer, of the Lamont-Doherty Geological Observatory, and Argentine geologists R. Caminos,

F. Nullo, and R. Casanova, of the University of Buenos Aires. Like the botanists on a previous expedition, they found it nearly impossible to study the island extensively on foot due to the almost impenetrable tussock grass and extremely dense thickets of southern beech in the lower elevations. Landings could not be made at most points along the rocky coast, but only at the more sheltered bays and fjords. In a matter of six weeks more than 200 landings were made around the full perimeter of the island, and several hundred rock and mineral samples collected. The following geological studies have been published incorporating the data derived from the R/V Hero Cruise: a brief preliminary report of the expedition (Dalziel, 1972), a comprehensive report of the conclusions reached (Dalziel, *et al*., 1974), and other reports dealing with the whole regional geology of the southern Andes (Dalziel, 1976; Dalziel, *et al*., 1975, 1977).

Most of the island is composed of silicic volcanic rocks, such as tuffs, ignimbrites, and lavas that were deposited in a shallow marine environment with scattered volcanic islands. Overlying the volcanic sequence is a homogeneous sequence of black mudstones and shales that crop out along a narrow portion of the northernmost parts of the island and a wider area at the western end of the island, as well as on the four islands to the north of the main island. The contact between the volcanic and sedimentary sequences is conformable. The recent geological studies on the island have resulted in the following revisions of Harrington's analysis (Harrington, 1962):

1) Within the upper portion of the volcanics are often found thin units of pure black mudstones, which lithologically are indistinguishable from the mudstones of the overlying sedimentary sequence.

Harrington believed that these mudstones were all fault-bounded outliers of the overlying sequence. The most recent studies have shown that these mudstones were deposited at the same time as the volcanics and are to be considered as intercalations in the transitional contact between the volcanics and overlying mudstones and shales. There is no evidence for faulting at the contact, which is shown to be conformable.

2) Structurally, the island is an asymmetric syncline whose axis extends roughly east and west. Harrington considered one of the limbs of the fold to be overturned because sedimentary rocks underlie volcanic rocks at Puerto Roca on the north-central coast. Later geologists have interpreted these sedimentary rocks to be merely intercalations in the uppermost portion of the volcanics. However, recent studies do indicate that locally one limb of the syncline was overturned, but that appears to be only at the easternmost portion of the island.

Harrington assigned the sedimentary sequence to the Upper Jurassic on the basis of the belemnites which he assigned to the genus Belemnopsis. More recent studies have verified his interpretation. The entire volcanic and sedimentary sequences on the island are thought to be Upper Jurassic and Lower Cretaceous deposits, which correlates well with an identical sequence for the subsurface of Isla Grande of Tierra del Fuego, which has been deciphered by drilling, and with surface mapping. The macrofossils collected by the R/V Hero Cruise include, in addition to the abundant belemnites, some pelecypods (Inoceramus), some bryozoan-like fossils, and a single brachiopod; the microfossils include radiolarians and foraminifers, which, to my knowledge, have not been identified and reported as yet.

The formations described to date in Tierra del Fuego are listed in Table 1 along with their lithological and faunal characteristics and accompanying orogenic activity. The lowest identifiable formation of the Cordillera which extends to Isla de los Estados is the Yahan Formation (Jurassic). The Cretaceous formations, "Capas del Hito XIX" and Leticia, both have the pelecypod *Inoceramus*, which was reported also from Isla de los Estados, while the latter formation is characterized by an abundance of mollusks (Borrello, 1972). The latest orogenic activity would be the final uplift of the Andes in the late Pliocene, thus forming the Cordillera along the southwest edge of Tierra del Fuego which continues as the backbone of Isla de los Estados and offers the explanation for the mountainous aspect of the island (Dalziel, *et al*., 1974).

The latest series of geological studies on the island, by Dalziel and others, have largely concentrated on the structural relationships between Isla de los Estados and the Andean Cordillera to the north and the North Scotia Arc which extends to South Georgia Island. The author is not aware of studies dealing with the geomorphology or the glacial history of the island. Thus, there are many gaps in our knowledge of its geological history, especially in regards to the entire Tertiary and Quaternary epochs.

TABLE 1

GEOLOGICAL SEQUENCE FOR TIERRA DEL FUEGO[a]

Age		Group	Formation and Orogeny	Lithology	Paleontology
Tertiary	Neogene		movimiento valaquicos		
			"Magallanense"	conglomerate, beds of lignitic coal	
	Paleogene		movimiento pirenaicos		
			Rio Bueno Formation		foraminifera
			movimiento laramicos		
Cretaceous		Rio Claro Group	Leticia Formation		Comanchian mollusks
			Policarpo Formation	sandstone	mollusks
			"Capas del Hito XIX"	limestone	Albian mollusks
Jurassic			movimiento austricos (oregonianos)		
			Beauvoir Formation	orthoflysch	ammonites
			movimiento diablianos		
			Lemaire Formation		
			Yahan Formation	eugeosynclinal, ophiolites	

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[a] Data taken from Borrello (1972)

Meteorology

Meteorologically, Tierra del Fuego is known as one of the stormiest inhabitable portions of the world, being subjected to incessant winds. The dominant climatic factor that characterizes this region is the strong wind, which nearly always blows from a westerly direction and which almost never ceases, either summer or winter (Miller, 1976; Prohaska, 1976). The wind is much stronger along the coast, having a mean annual velocity of 12 m/sec at the westernmost Islas Evangelistas contrasted with a mean of 4 m/sec inland at Punta Arenas (Miller, 1976). Throughout southern Patagonia the wind often peaks in gusts 30 m/sec (Miller, 1976).

Another climatic characteristic of this region is the lack of seasonality as evidenced by a relatively small difference between January and July temperatures (see Table 2). Thunderstorms and hail are rare occurrences, while below freezing temperatures can occur any month of the year, according to the data from Ushaia due west of Isla de los Estados (Prohaska, 1976). There is no part of Tierra del Fuego with greater than 100 frost-free days out of 365 days.

A synthesis of climatic data has been collected from several sources and tabulated for twelve sites between 52^{o} and 54^{o} S latitude, one of which includes a station at the eastern tip of Isla de los Estados (Table 2). It should be noted that southward along the Argentine coast, there is a decreasing temperature difference between the January and July means (Rio Gallegos, Rio Grande, Ushaia, Isla

TABLE 2

TEMPERATURE AND PRECIPITATION DATA FOR S. CHILE, S. ARGENTINA, AND ARGENTINE ISLANDS[a]

Station	S. Lat.	W. Long.	Elev.	Mean Annual Precip.	Mean Annual Temp.[b]	Jan. Temp.[b]	July Temp.[b]	Jan.-July Difference[b]
Grupo Evangelistas, Chile	52°24'	75°06'	55 m	2569 mm	6.4	8.7	4.4	4.3
Punta Arenas, Chile	53°10'	70°54'	8 m	448 mm	6.7	11.7	2.5	9.2
San Isidro, Chile	53°47'	70°58'	20 m	864 mm	6.1	9.6	2.7	6.9
Rio Gallegos, Argentina	51°37'	69°14'	26 m	281 mm	7.1	12.9	1.3	11.6
Rio Grande, Argentina	53°48'	67°47'	9 m	379 mm	5.0	9.8	0.4	9.4
Ushaia, Argentina	54°48'	68°19'	6 m	574 mm	5.5	9.2	1.6	7.6
Bahia Douglas, Chile	55°09'	68°08'	5 m	915 mm	5.4	9.3	1.0	8.3
Isla Navarina, Chile	55°10'	67°30'	8 m	471 mm	5.8	9.5	2.2	7.3
Stanley, Falkland Islands	51°42'	57°51'	2 m	681 mm	5.5	9.4	1.9	7.5
South Georgia Island	54°16'	36°30'	3 m	1414 mm	1.6	4.6	-1.3	5.9
Isla Observatorio, Argentina	54°39'	64°08'	50 m	625 mm	5.1	8.3	1.9	6.4
Isla de los Estados, Argentina	54°23'	63°47'	12 m	1701 mm	5.7	9.2	2.6	6.6

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[a] The data tabulated here were derived from Meteorological Office, Great Britain (1958), Kalela (1941), Miller (1976), Prohaska (1976), and Wernstedt (1972).

[b] All temperatures are given in °C.

TABLE 3

CLIMATIC DATA FOR ISLA DE LOS ESTADOS AND TWO NEARBY STATIONS[a]

	Isla de los Estados (54°23' S., 63°47' W.)			Isla Observatoria, Islas Ano Nueva (54°39' S., 64°08' W.)		
MONTH	Mean Temp. (°C)	Mean Precip. (mm)	Mean Temp. (°C)	Minimum Temp. (°C)	Mean Precip. (mm)	Relative humidity (%)
Jan.	9.2	136	8.3	0	71.1	81
Feb.	8.6	182	8.3	0.6	63.5	82
Mar.	7.7	148	7.5	0	68.6	83
Apr.	6.2	157	5.6	-2.8	71.1	83.5
May	4.6	164	3.9	-5.0	50.8	83
June	3.0	172	1.7	-5.6	50.8	84
July	2.6	122	1.9	-8.3	40.6	83
Aug.	3.0	125	2.2	-6.7	38.1	82.5
Sept.	3.9	96	3.3	-7.8	33.0	81.5
Oct.	4.9	107	5.3	-3.3	33.0	81.5
Nov.	6.8	125	5.8	-4.4	48.3	79.5
Dec.	8.1	169	7.5	0	55.9	81.5
Annual	5.7	1701	5.1	-8.3	624.8	82.5

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[a] Data from Meteorological Office, Great Britain (1958), Kalela (1941), and Prohaska (1976).

TABLE 3 (cont'd)

Ushuaia, Tierra del Fuego

(54°48' S., 69°19 W.)

MONTH	Mean Daily Temp. (°C)	Daily Range in Temp. (°C)	Minimum Temp. (°C)	Mean Precip. (mm)	Relative Humidity (%)	Mean Daily Sunshine (h)	Prevailing Wind Direction	Mean Wind Speed (m/sec)
Jan.	9.2	8.5	-0.3	58	71	5.5	SW	4.7
Feb.	9.0	8.8	-4.0	50	70	5.7	SW	4.4
Mar.	7.8	8.5	-2.4	57	73	4.2	SW	3.3
Apr.	5.7	7.7	-6.3	46	75	2.8	SW	3.3
May	3.2	6.7	-12.1	48	78	2.0	SW	3.1
June	1.7	6.1	-12.6	45	80	1.0	SW	2.2
July	1.6	6.3	-11.1	47	79	1.4	SW	2.8
Aug.	2.2	6.6	-19.6	49	77	3.2	SW	3.3
Sept.	3.9	7.6	-7.2	38	73	4.8	SW	4.4
Oct.	6.2	8.5	-5.7	37	66	6.2	SW	5.0
Nov.	7.3	8.8	-3.5	50	68	6.2	SW	5.6
Dec.	8.5	8.4	-3.3	49	70	6.0	SW	5.3
Annual	5.5	7.7	-19.6	574	73	4.1	SW	3.9

de los Estados). This is an indicator of the lack of seasonality, as already noted. Also, the amount of precipitation increases to the south or southwest. Isla de los Estados lies in a band of high precipitation that extends northwestward along the pre-cordillerans through the Grupo Evangelistas Islands, which have even higher amounts of precipitation. Generally this band has greater than 2000 mm precipitation annually, and in one case (Isla Guarello, 50°23'S, 75°20'W) precipitation reaches a phenomenal 7500 mm annually; i.e., about 20 mm daily (Young, 1972).

The more detailed meteorological data for Isla de los Estados itself is given in Table 3, accompanied by data from Observatorio Island immediately to the north and from Ushuaia to the west on Isla Grande.

Palynology, Paleoecology, Paleoclimatology

No published reports of the palynology of Isla de los Estados have appeared in readily accessible journals dealing with the Mesozoic, Tertiary, or Quaternary. Micropaleontological studies on the Mesozoic samples collected by R/V *Hero* Cruise 72-2 have concentrated on the foraminifera and radiolarians, not on the pollen and spores.

From nearby Isla Grande of Tierra del Fuego, several Late Quaternary palynological studies have been generated (Auer, 1958, 1960, 1966; D'Antoni, 1980; Markgraf, 1977; Markgraf and D'Antoni, 1977), while an occasional palynological study of recent material from Tierra del Fuego has appeared in the literature, as for example the genera *Lebetanthus* (Arroyo, 1975) and *Vicia* (Moore and Scotter, 1976). There has been very little information on the paleoclimatology of Isla de los Estados with regards to either the Mesozoic (U. Jurassic - L. Cretaceous) or the Late Quaternary. The present study attempts to begin filling the information vacuum for the Late Quaternary by first reconstructing the vegetation history since the last Glacial, then by deducing paleoecological inferences and finally paleoclimatological inferences whenever possible from the information available.

CHAPTER II

METHODS AND TECHNIQUES

Collection of the Samples

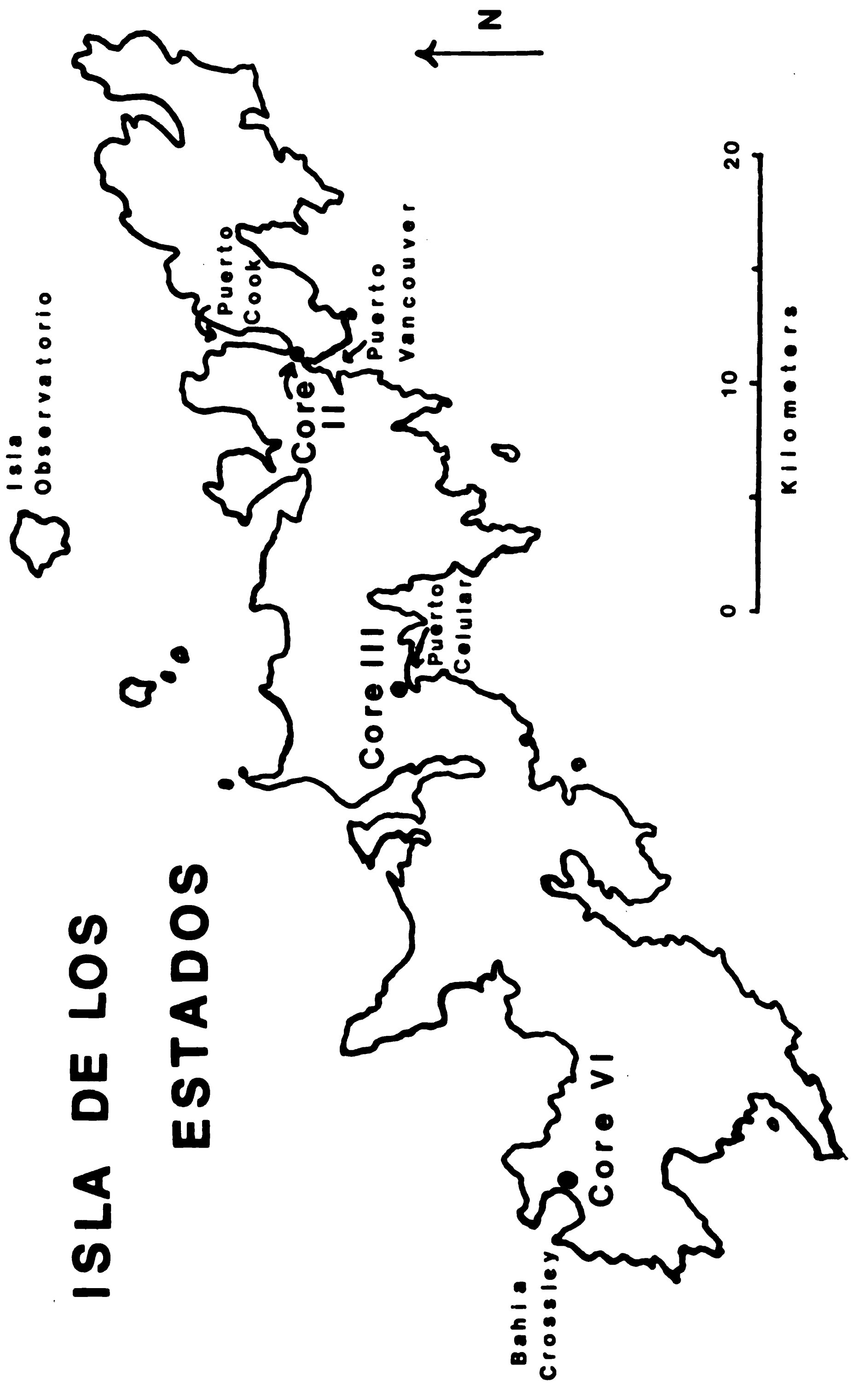
Three cores composed of peat were obtained by Michigan State University from the R/V Hero Cruise 71-5, which was funded by the Office of Polar Programs, National Science Foundation, while three other cores have been sent elsewhere.

On 29 October, 1971 Core II was collected from a boggy heath located on the narrow isthmus separating Puerto Cook from Puerto Vancouver near the center of the island's eastern sector (Figure 1). Its collectors were Dr. Karl Ohlsson and Dr. Garrett Crow, at that time graduate students from Michigan State University. The specific location of this 4.51 m core was about 100 m from the north shore of Puerto Vancouver. Core I (not studied) was collected at the same locality.

Core III was obtained by Dr. Henry Imshaug and Mr. Karl Ohlsson, of Michigan State University, on 1 November, 1971 from a boggy heath. Its location was in a valley between the first two hills northeast of a stream mouth at the head of Puerto Celular (also known as Punta Delgado), near the center of the island (Figure 1). In drilling the core, the collectors occasionally encountered water pockets, and at the bottom they struck a rock (or bedrock) 3.05 m below the surface. The last core section contained white rocky material which appears to have been derived from the Jurassic porphyritic bedrock. Cores IV and V were also collected at the same locality, but they were not analyzed.

FIGURE 1

MAP OF ISLA DE LOS ESTADOS



On 11 November, 1971 Karl Ohlsson and Garrett Crow obtained Core VI from a Marsippospermum meadow on the east end of Bahia Crossley about one-quarter mile (.4 km) inland from Bahia Teniente Palet and about fifty meters from the farthest dune from the shore (Figure 1). The corer could be driven no further than 9.63 m, and the bottom section of the core had some granular material indicating the possible presence of bedrock just below. Certain short sections of the core contained only water or watery peat. Core VI differs from the others in that it is in the area of underlying Jurassic-Cretaceous sedimentary deposits composed of shales and black muds (Figure 1). All cores were obtained with a Davis peat sampler by alternating between two holes six inches (15 cm) apart and bringing the peat to the surface in one-foot (.3 m) sections. The cores were immediately frozen, and the three cores described above, out of a total of six cores taken on the expedition, were sent to Michigan State University wrapped in aluminum foil. The present author was not part of the scientific team which superintended the collection of the cores.

Preparation and Mounting Techniques

When the frozen cores reached Michigan State University, one-inch (2.5 cm) segments were cut out from the larger one-foot (.3 m) lengths, and a sample was removed from the center of each segment using a 9 mm cork borer. Each slug was extruded into the sample vials and the remaining segment inserted back into the core, re-wrapped, and returned to the freezer. According to the field notes, Core II was to contain fifteen one-foot lengths, but only fourteen were located in the laboratory. All other cores were complete, except for the fact that the first one-foot (.3 m) section from each drill site was not collected, and the second one-foot (.3 m) section of Core VI came to the surface empty.

The individual peat samples were prepared using a standard processing procedure for peat samples as outlined in Appendix A. The samples were processed by several experienced students[1] in the Michigan State University Palynology and Paleobotany Laboratory, under the direction of Dr. Aureal T. Cross and Dr. Ralph E. Taggart, and records of the sample preparation were duly registered in the log books kept permanently in the laboratory. The processing consisted basically of boiling the peat samples in 5% KOH in order to free the pollen from the matrix. The mounting consisted of placing two drops of melted glycerin jelly with residue on a coverslip, placing the slide on the cover slip, and then on a slide warming tray to cause it to spread evenly. Since the glycerin jelly mount is sensitive to air and moisture, it had to be sealed off by a thin band of fingernail polish around the outside edge of the cover slip.

Identification of the Palynomorphs

The main reference tools utilized in the identification of the palynomorphs were Pollen and Spores of Chile by Calvin J. Heusser (1971) and Pollen Flora of Argentina by Vera Markgraf and Hector L. D'Antoni (1978). Both of these works have keys to aid in the identification of unknowns in addition to photographs displaying the pollen and spores in

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[1] The author did not participate in the laboratory processing and mounting of the samples, although he has had experience in the preparation of similar samples.

equatorial and polar views as well as at high and median focus for detecting diagnostic exine elements.

Because Heusser (1971) described nearly 700 pollen and spore types and Markgraf and D'Antoni (1978) nearly 400, it was advisable to narrow down the potential palynoflora for Isla de los Estados to those plants found growing today on the island or elsewhere in Tierra del Fuego. For that purpose the "Index to the Flora of Isla de los Estados" by Dudley and Crow (unpubl. ms.) served as a framework into which the pollen and spore flora could be incorporated. However, the peat samples contain taxa which are not found represented on the island today, either due to long-distance transport of pollen (such as Ephedra) or to possible fluctuations in the phytogeographical range of certain taxa. Thus it was necessary to widen the scope of potential taxa that could be represented to include those whose range today extends south of the Strait of Magellan. The "Cataloga de las Plantas Vasculares Nativas de Tierra del Fuego" by D. M. Moore (1974) has proved most useful in that respect as well as "The Alpine Flora of Tierra del Fuego" by D. M. Moore (1975). Most of the genera listed by Moore are illustrated in either Heusser's or Markgraf and D'Antoni's reference works cited above.

For the identification of those genera not illustrated in the above two works use was made of the modern reference collection consisting of mounted slides in the Michigan State University Paleobotany and Palynology Laboratory, which has pollen from many species representing most families of flowering plants of North and South America. Generally less than two percent of the palynomorphs had to be placed in the "unknown" category. This category also includes those which were unidentifiable because of poor preservation or because of their being partially obscured from view by detritus. Viewed as a whole, the actual number of rare or exotic palynomorphs which could not be identified was less than one percent of the total. Additional aids in the further identification of the unknowns have been Erdtman's Pollen Morphology and Plant Taxonomy (Erdtman, 1966); Pollen Flora of Taiwan (Huang, 1972); Key to the Quaternary Pollen and Spores of the Great Lakes Region (McAndrews, Berti, and Norris, 1973); and Pollen Analysis (Moore and Webb, 1978).

All identification was done on one of two similar Leitz Ortholux microscropes (serial numbers GG2669 and 591962), using the 54 X and 95 X objectives requiring oil immersion for observance of maximum detail.

Counting Techniques

Generally a total of 200 pollen grains and spores were counted from each sample, though occasionally the count was increased to 250 or 300. In a few cases the count was between 100 and 200 due to a low pollen density in the residue. Any exceptions to the 200 count are noted on the pollen diagrams. The count excluded spores, cysts, or other entities from non-vascular plants, such as dinoflagellates, miscellaneous algae, fungi, and bryophytes, although bryophyte and dinoflagellate percentages based upon total pollen are recorded on the diagrams.

As one measure of insuring the validity of the counts, the selection of the microscope stage coordinates to be used in counting was done in a random fashion. First, the coverslip area was divided into four rectangular quadrants which extended the full width; then, the exact horizontal coordinate to be covered in each traverse was selected from a "random numbers table". When the count reached 50 in one quadrant, then a traverse in the next quadrant was selected until all four quadrants were covered and the count totaled 200. Any palynomorph whose geometric center passed outside of the counting zone was automatically excluded from the total count.

Due to the dominance of the flora by Nothofagus, an attempt was made to count the Nothofagus pollen in every sample, the exceptions being those samples whose pollen density was too low for counting. In the pollen diagrams where there is no information other than the Nothofagus percentages for a given sample it means that the total pollen and spores were counted, but not identified. In a few cases any unusual or important taxa observed in the count are noted on the diagrams with a plus (+) symbol. Pollen frequencies on the diagrams are relative, i.e., they are computed in terms of percentages of the total count, and not in terms of the absolute concentration of pollen in each sample.

Photographic Techniques

Photographs of selected pollen and spores were taken on a Leitz Orthomat camera and microscope unit located in the Michigan State University Paleobotany and Palynology Laboratory. All photographs were taken under the two highest magnifications using oil immersion, unless the palynomorph was too large for the field of view, such as some specimens of Armeria. Kodak Panatomic-X film was used. This was developed using normal darkroom procedures. Representative pollen and spores are illustrated in Plates 1 - 5 at 1000 X magnification, unless otherwise noted.

CHAPTER III

RESULTS

The results of this study are summarized in three pollen and spore diagrams (Figures 2-4), which are in terms of a relative pollen frequency based on the total pollen and spores. Seventy taxonomic groups are represented in total on the three diagrams. However, the total palynoflora for Isla de los Estados would be even higher if certain of the groups, such as the Ericaceae-type and the Compositae, were broken down into their constituent and identifiable genera. For example, Mutisia (Plate 3, Figure 3-10) of the family Compositae is a component of the total flora, but does not appear on the pollen diagrams. Nassauvia (Plate 3, Figures 3-11, 3-12, 3-13) of the Compositae makes a somewhat frequent and regular appearance in the flora, but its presence also is not noted on the diagrams. The pollen sum excludes the spores or cysts of non-vascular plants, although the relative frequencies for the dinoflagellates and bryophytes do appear on the diagrams.

Core II

The Core II diagram representing Puerto Cook-Puerto Vancouver in the eastern sector is comprised of approximately 45 clearly identifiable taxonomic types obtained from 14 samples. The sample with the highest diversity is Pb9731 at the base of the core, while the three samples with low diversity are Pb9694, Pb9701, and Pb9712. Low diversity does not appear to be connected with low relative percentages for arboreal pollen frequencies. Diversity is high in samples Pb9724 and Pb9731 where the

FIGURE 2

POLLEN DIAGRAM FROM THE PEAT DEPOSITS OF THE PUERTO VANCOUVER-PUERTO COOK ISTHMUS, ISLA DE LOS ESTADOS, ARGENTINA

Samples with only *Nothofagus* frequencies given are based upon a pollen sum which includes total unidentified pollen and spores and excludes entities of non-vascular plants.

Figure 2. Pollen Diagram from the Peat of Puerto Vancouver, Isla de los Estados

FIGURE 3

POLLEN DIAGRAM FROM THE PEAT DEPOSITS NEAR PUERTO CELULAR, ISLA DE LOS ESTADOS, ARGENTINA

Samples with only *Nothofagus* frequencies given are based upon a pollen sum which includes total unidentified pollen and spores and excludes entities of non-vascular plants.

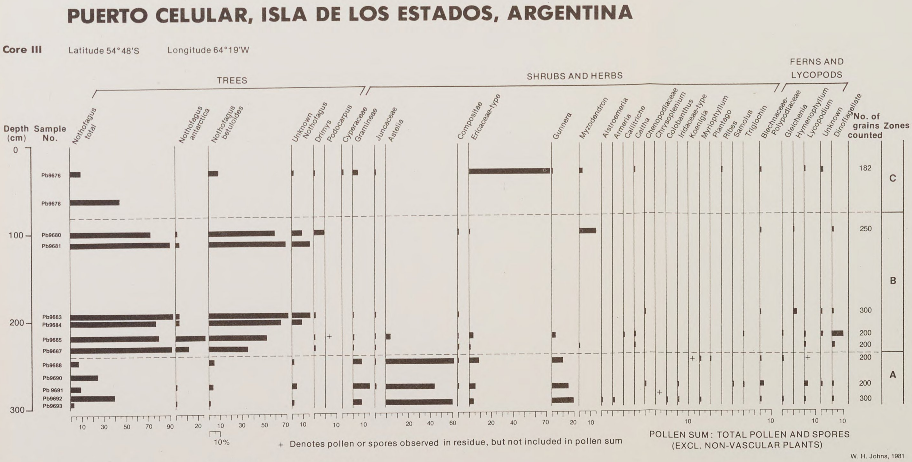


Figure 3. Pollen Diagram from the Peat of Puerto Celular, Isla de los Estados

FIGURE 4

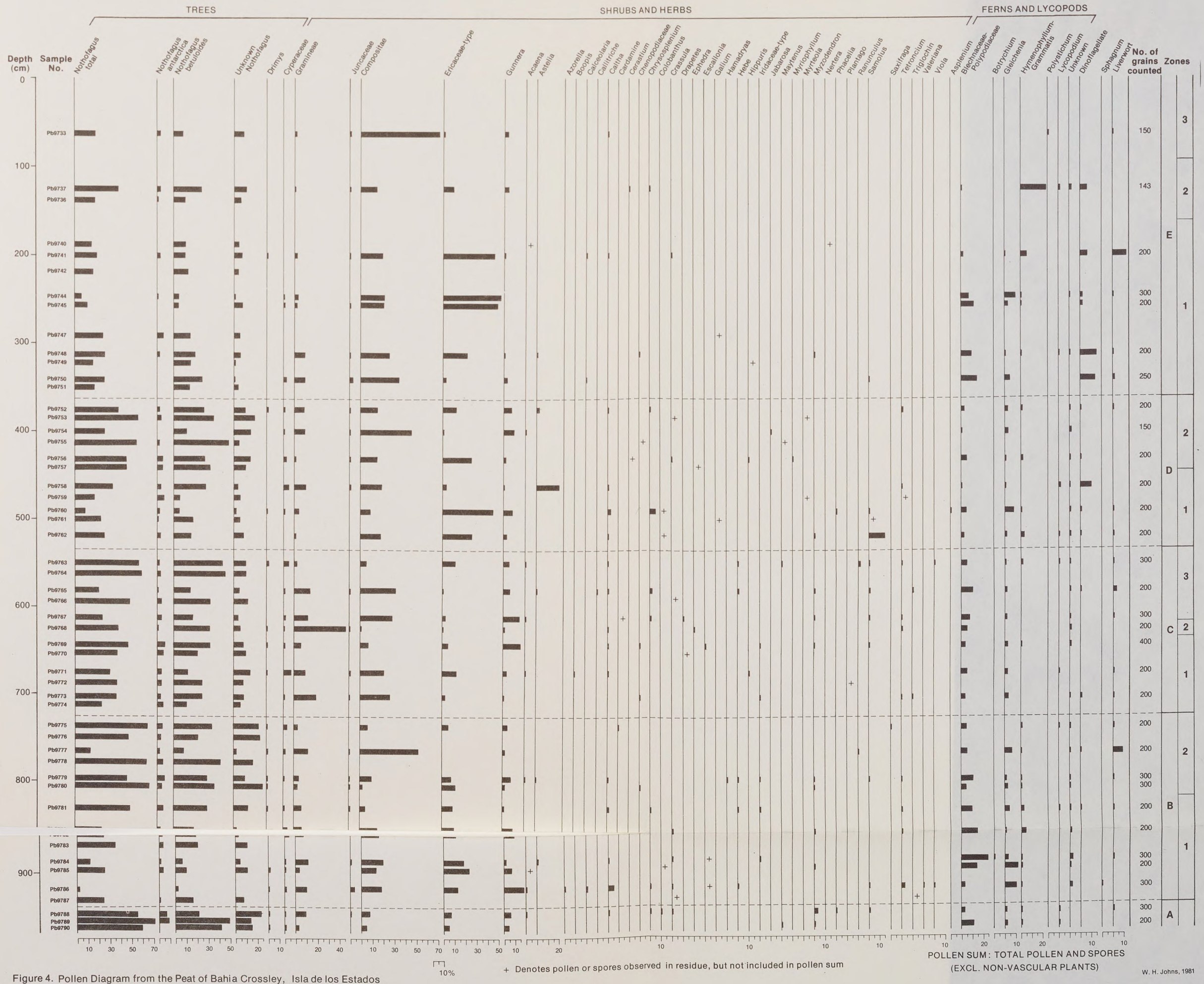
POLLEN DIAGRAM FROM THE PEAT DEPOSITS EAST OF BAHIA CROSSLEY,

ISLA DE LOS ESTADOS, ARGENTINA

Samples with only *Nothofagus* frequencies given are based upon a pollen sum which includes total unidentified pollen and spores and excludes entities of non-vascular plants.

BAHIA CROSSLEY, ISLA DE LOS ESTADOS, ARGENTINA

Core VI Latitude 54°48'S Longitude 64°42'W



+ Denotes pollen or spores observed in residue, but not included in pollen sum

POLLEN SUM: TOTAL POLLEN AND SPORES
(EXCL. NON-VASCULAR PLANTS)

W. H. Johns, 1981

Figure 4. Pollen Diagram from the Peat of Bahia Crossley, Isla de los Estados

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arboreal pollen is only 2% and 0 respectively.

The major pollen contributors fall into ten taxonomic groups, all of which have relative percentages equal to or greater than 10% at some point in the core. Four other taxa have percentages ranging from 2% to 9% in at least one sample, while the remaining taxa all contribute less than 2% to the total pollen influx. Consistently, the greatest contributor is *Nothofagus*, which dominates the interval from 3.6 m to 1.0 m. Second in importance are the pterophytes, followed by Compositae, Empetraceae (including some Ericaceae and Epacridaceae), Gramineae and *Gunnera*, all of which are found in every sample. Consideration should be given to what I have called the ephemeral dominants, those taxonomic groups which achieve dominance only temporarily and then wane to insignificance or disappear entirely from the record. The two ephemeral dominants are Cyperaceae and *Astelia*, both of which reach maxima of greater than 50% prior to the time when *Nothofagus* begins to become dominant. Pterophytes clearly dominate only in sample Pb9712, although they are important contributors elsewhere. The Compositae achieve a clear dominance in Pb9709 and a lesser role in Pb9701. The only significant maxima in the Ericaceae-type pollen, which includes Empetraceae, are in zone D, where peaks occur in samples Pb9701 and Pb9694, the latter one being its point of greatest dominance.

A description of the pollen zones is briefly summarized here, while the interpretation will follow in the next chapter. Zone A of Core II is characterized by unusually low *Nothofagus* percentages of 0 - 6%. It is subdivided into A-1 where the Cyperaceae are clearly dominant, A-2 where Cyperaceae, the Ericaceae-type, and Blechnaceae-Polypodiaceae are the chief contributors, and A-3 where *Astelia* is dominant. In zone B *Nothofagus* has values that generally exceed 40% and at one point reaches 83%, thus dominating all other taxa. Zone C begins with *Nothofagus* just under 25%. It is subdivided into C-1 in which the Pterophyta are preeminent, C-2 in which the Compositae are slightly dominant, and C-3 in which *Nothofagus* rises to a peak of 83% again. The youngest and longest of the zones is D, which is subdivided into D-1 with a strong *Nothofagus* dominance accompanied by a rise in the Ericaceae-type pollen, D-2 with a *Nothofagus*-*Gunnera* association, and D-3 with another rise in Ericaceae-type pollen. Zone D-2 has also a peak of the ephemeral dominant, *Astelia*, which attains 18% relative frequency.

In noting over-all trends in Core II between competing or conjoined taxa, it is found that the trend of *Nothofagus* is usually the inverse of Pterophyta, and the trends of the Compositae and Ericaceae-Empetraceae are more often in tandem than in competition.

Core III

The shortest of the three cores, Core III, which was obtained near the geographical center of the island, has eight samples that provide the framework for the diagram (Figure 3). Diversity of the total flora appears to be roughly proportional to the number of samples surveyed; thus, Core III has a total flora of about 30 identifiable taxa, compared to 45 for Core II. Diversity is not always related to arboreal pollen frequency, because the three samples, Pb9685, Pb9691, and Pb9693, having the highest diversity with at least 13 taxa contain contrasting high and low *Nothofagus* percentages. In spite of its low diversity, Core II contains four taxa not reported from the other two cores, *Alstroemeriaceae*, *Armeria*, *Koenigia*, and *Podocarpus*.

Like Core II to the east, Core III has the ephemeral dominant, Astelia, at the base of the core, but unlike Core II Cyperaceae cannot be considered in that category. However, Ericaceae-Empetraceae appear to have become an ephemeral dominant in the upper portion of the core.

Core III can be readily divided into the following three major zones: zone A characterized by values of Astelia from 43% to 62%, zone B where Nothofagus clearly dominates with 71% to 91% of the total pollen, and zone C where Ericaceae-Empetraceae are dominant with a peak of 71%. To further define any specific trends among the individual taxa is not possible until more samples are available.

Core VI

Core VI, has a length of 9.6 m, which is twice the length of Core II. This was collected from the western end of Isla de los Estados at the eastern end of Bahia Crossley. The pollen diagram (Figure 4) shows a total diversity of about 50 distinguishable taxonomic types based on 45 samples, which suggests that the increase in diversity is due to a larger number of samples than the previous two cores. The individual samples also have a higher diversity than the average for individual samples of Cores II and III, the one exception being Pb9731 in Core II with the highest diversity of any sample studied. Diversity does not appear to be linked with changes in arboreal pollen percentages. For example, high diversity occurs in sample Pb9786 where the arboreal pollen (AP) content drops to its lowest percentage occurrence in the entire core, 2.6%. High diversity occurs also in samples Pb9769 and Pb9779 where total arboreal pollen reaches 48.5% and 47.3% respectively. Diversity is also quite high in Pb9763 where the arboreal Drimys attains its highest percentage and where total arboreal pollen stands at 58%.

The major pollen contributors fall into nine taxonomic groups, (*Nothofagus*, Gramineae, Compositae, Ericaceae-type, *Gunnera*, *Astelia*, Blechnaceae-Polypodiaceae, *Gleichenia*, and *Hymenophyllum-Grammatis*). Of these, *Astelia* and *Hymenophyllum-Grammatis* should be considered as ephemeral dominants, each of them having a single peak. Three taxa contribute from 5% to 10% pollen at most to the total spectra, and the most stable and persistent of these are the Cyperaceae. One taxon, *Samolus*, peaks at 15% in Pb9762, although it attains less than 2% frequency in all other samples. Approximately thirty-five taxa contribute less than 5% of the pollen, and by far most of these contribute less than 2%. Besides these thirty-five minor contributors, there are other minor contributors not listed separately, such as *Lebetanthus*, which has been included with the Ericaceae-type pollen on the basis of its similar tetrad structure.

The over-all trends can be best described in terms of the pollen zonation summarized in Table 4. Five major zones can be recognized, the boundaries of which have been determined by the *Nothofagus* maxima, or peak values. Boundaries occur just above the maxima at Pb9788, Pb9775, Pb9763, and Pb9752 as also denoted in Figure 4. Four full zones (B-E) of *Nothofagus* cycles can be identified in Core VI, in which the repeating pattern is a gradual increase of *Nothofagus* relative frequencies to maximum values followed by an abrupt decline. Each zone boundary is determined by this abrupt *Nothofagus* decline.

Zone A is the shortest of the five zones because presumably it may be only the upper portion of a *Nothofagus* cycle. It is assumed that if the pollen spectrum could be extended by retrieval of further peat samples below sample Pb9790 at the base of Core VI, it would depict

TABLE 4

POLLEN ZONATION FOR CORE VI, BAHIA CROSSLEY

	Zone E	E-3		Compositae
1 m				
		E-2		*Nothofagus* - *Hymenophyllum*
2 m				
3 m		E-1		Ericaceae-type dominant (some Compositae, *Nothofagus*, and Pterophyta)
4 m	Zone D	D-2	c.	*Nothofagus*
			b.	*Compositae*
			a.	Ericaceae-type
		D-1	b.	*Astelia*
5 m			a.	*Ericaceae-type*
	Zone C	C-3	b.	*Nothofagus*
			a.	*Compositae*
6 m		C-2		Gramineae - *Nothofagus*
		C-1		*Nothofagus* - Compositae
7 m				
	Zone B	B-2	c.	*Nothofagus*
8 m			b.	*Compositae*
			a.	*Nothofagus*
9 m		B-1		Pterophyta - Ericaceae-type (with some *Gunnera*, Compositae, rising *Nothofagus*)
	A	A		*Nothofagus* dominance

a gradual increase of *Nothofagus* percentages toward Pb9790. At least a *Nothofagus* forest would not be apt to appear suddenly as a mature forest in the pollen record. In zone A *Nothofagus* reaches a relative frequency of 71%, which is the highest for any sample in Core VI.

Zone B is characterized by a steady increase of *Nothofagus* relative percentages from almost a complete absence of *Nothofagus* pollen. Sample Pb9786, which is second from the base of zone A, has a relative frequency of 2%, which is the lowest for *Nothofagus* in Core VI. The top portion of this zone has a strong Compositae maximum followed immediately above by a *Nothofagus* maximum.

Zone C begins with a *Nothofagus*-Compositae association which is interrupted by a sharp, but brief, influx of Gramineae. The top portion of this zone returns to an almost identical *Nothofagus*-Compositae association that appeared previously. Zone C concludes with the rise of *Nothofagus* to another maximum and the waning of Compositae.

Zone D begins with the rise of Ericaceae-type pollen to its first dominance in Core VI, followed by the relatively rapid rise of the ephemeral dominant, *Astelia*. The remainder of zone D is characterized by the presence of *Nothofagus* at relative frequencies from 26% to 57% accompanied by another influx of Ericaceae-type pollen, after which a notable Compositae maximum occurs. The end of zone D is marked by a *Nothofagus* maximum of about 40%.

Zone E begins with a lengthy and apparently stable period when the Ericaceae-type dominate. It is followed by a time when a *Nothofagus-Hymenophyllum* association is dominant, the only example in Core VI when *Hymenophyllum* makes a strong appearance. This zone ends with the Compositae reaching their highest peak in the core with over 70% of total pollen and spores.

The over-all trends can be summarized as follows:

1) *Nothofagus* fluctuating in cycles from maxima to minima, characterized by a gradual rise to maximum values and a relatively rapid decline to minimum values,
2) Gramineae being fairly stable at values revolving around 10% except for sharp pulse to 46.5% in zone C-2,
3) Compositae usually fluctuating in an inverse relationship to *Nothofagus*,
4) The Ericaceae-Empetraceae, *Gunnera*, and Pterophyta sometimes paralleling the trends of each other as in zone B, but sometimes trending in opposite directions as in zone E.

More than passing notice should be given to the fact that three of four Compositae maxima (Pb9754, Pb9765-7, and Pb9777) all occur just prior to *Nothofagus* maxima (Pb9752, Pb9763 and Pb9775), providing added evidence for the cyclical nature of the zones. The larger questions of why this occurs and what implications it might have in terms of possible climatic cycles or vegetational succession will be dealt with in the next chapter.

Comparisons between the Three Cores

The over-all trends of the *Nothofagus* percentages can be shown to roughly parallel one another in Cores II and VI if we assume the base of Core II correlates with the 9.3 m level of Core VI represented by sample Pb9787. (This must remain an assumption until such time that radiocarbon dates become available to test its validity.) Zone A of Core II then correlates with zone B-1 of Core VI; zone B of Core II with zones B-2 through C-3 of Core VI; zone C of Core II correlates with zone D of Core VI; and finally zone D of the former correlates with zone E of the latter on the basis of the Ericaceae-Empetraceae maximum values in both.

Core III correlates with Core II best, which may be explained on the basis that both are much closer to each other geographically than Cores III and VI. Zone A in both cores seems to correlate well, especially in view of the fact that the ephemeral dominant, Astelia, is found in both while it is not found in zone A of Core VI. Zone B of Core III seems to correspond to zones B and C of Core II, but due to a gap the correlation cannot be defined in any detail. Zone C of Core III correlates with zone D of Core II, since the Ericaceae-Empetraceae reach their peak in each of the two zones.

In addition to the over-all trends of Nothofagus, the strongest basis for correlation among the three cores is the Ericaceae-Empetraceae maximum in zone D of Core II, zone C of Core III and zone E of Core VI. Whether this peak (which is composed mainly of Empetrum of Empetraceae) is synchronous in all three cores needs to be substantiated by radiocarbon dating, but this study will treat the matter as a working hypothesis, which can be tested by some other lines of evidence.

The Astelia peak in the mid-section of Core VI (Pb9758) is not considered to be correlative or synchronous with greater Astelia peaks at the base of Cores II and III because the other pollen data contemporaneous with that peak do not correlate. Nothofagus in Pb9758 stands at 34% while at the base of Core III it is less than 10% and at the base of Core II it is 2% or less. Thus, Core VI has no Astelia peak which can be synchronized readily with that of either Core II or Core III.

The Cyperaceae maximum at the base of Core II has no counterparts in the other cores. A sharp Gramineae peak in Core VI at sample Pb9768 may correspond to a small Gramineae peak at Pb9712 in Core II; only radiocarbon dates could help determine whether they are correlative at this time. This further underscores the fact that the final determinant in palynological and stratigraphic correlation of the three Isla de los Estados peat deposits will be radiocarbon dating; thus, any cross-correlations proposed should be considered as tentative.

CHAPTER IV

DISCUSSION

Towards a Paleoecological Interpretation

The key to the reconstruction and interpretation of some of the plant communities of the recent past is the usage of modern-day analogs, preferably from the same geographical locality as the cores. Fortunately, extensive studies have been done and are yet in progress in analyzing the present-day plant communities and their constituents for Isla de los Estados (Crow, 1975).

The forested areas of Isla de los Estados represent an extension of the southernmost forest in the world, the Magellanic evergreen forest, which follows a narrow belt of high precipitation along the pre-cordillera of the southwestern coast of South America (Young, 1972). To the east of the cordillera, which is the southern extension of the Andes, the precipitation levels fall off dramatically, as for example at Punta Arenas, where the mean annual precipitation is one-sixth that of the Grupo Evangelistas of the rain forest belt of the outer islands, even though Punta Arenas lies just a few kilometers from the rain forest. In addition to having high rainfall, the rain forest is characterized by very low differences between summer and winter mean temperatures, thus having a lack of seasonality, while just to the east of the cordillera there is a more pronounced seasonality. Extremely low sub-freezing winter temperatures are not recorded along the rain forest belt (which includes Isla de los Estados), but they do occur on the eastern (leeward) side of the cordillera. This is reflected in the fact that most precipitation comes in the form of rain rather than snow, even in winter. The Grupo Evangelistas record a mean annual number of days with snowfall as 20.3, while 289 days have precipitation greater than 1 mm (Miller, 1976). Isla Observatoria just a few miles north of Isla de los Estados records 249 days per year with appreciable precipitation, and probably would have a comparable snowfall profile (Meteorological Office, Great Britain, 1958).

While there are up-to-date phytogeographical maps available for a pictorial summary of the vegetation formations of southern Patagonia (Arroyo, 1975; Young, 1972, Heusser and Streeter, 1980), the author has chosen to give a verbal summary based on two recent summaries, the one for all of southern Patagonia (Moore, 1978) and the other for Isla de los Estados (Dudley and Crow, unpub. mss.). These recent studies are erected on the foundation laid by C. J. F. Skottsberg, whose exhaustive treatment of the Magellanic region remains untranslated from the German (Skottsberg, 1916, cited in Moore, 1978).

The major vegetation zones, which roughly parallel one another and parallel the coast, are largely determined by the topography and the unique climate. The topography is characterized by the southern extension of the Andes along a narrow belt just east of the outer islands of the Magallanes, and, in the southern portion, the cordillera itself drops below sea level to form the inner islands with rugged shorelines and an intricate system of fjord-like inlets and channels. Geologically, the cordillera is an anticlinal fold slightly overturned to the northeast which was formed during the main Andean uplift in mid-Cretaceous times resulting in a slaty cleavage axial, that is, planar to the fold (Dalziel *et al.*, 1974; Palmer and Dalziel, 1973). The axial-plane cleavage has been cut by granite intrusions occurring in post-Albian and pre-Coniacian time of the Cretaceous. In Tierra del Fuego the batholith forms the core of the Cordillera Darwin, while to the west the outer islands are composed of basement schists of possible Paleozoic age. The mechanism for uplift is the collision of the westward moving South American plate with the Antarctic plate. To the east and north of the uplifted areas Isla Grande of Tierra del Fuego consists of a low, flat-lying plain containing post-orogenic Upper Cretaceous sediments as well as Tertiary sediments.

Climatologically, the outer islands are subjected to constant rains, high humidity, strong incessant westerly winds, and comparatively moderate temperature fluctuations about the mean, both diurnally and annually. The moisture-laden winds rise as they cross the cordillera and thus heavy precipitation results, which feeds the glaciers in the high elevations. (The author is not aware of any reported existing glaciers in Isla de los Estados, however.) To the northeast of the cordillera, a rain shadow is formed with a steep rainfall gradient in just a few miles, which has a profound effect on the vegetation.

The major vegetational belts, as classified by Skottsberg (1916) and as summarized in Moore (1968, 1975, 1978, 1979) and Young (1972), are as follows:

1) *Magellanic moorland*. Due to the exceptionally strong winds, high rainfall and the poor drainage on the Andean diorites of the batholith, only a plant community of dwarf heath shrubs, cushion plants, sedges, and bryophytes can thrive. *Nothofagus* is found mainly in the

sheltered coves. At various localities *Astelia*, *Caltha*, *Acaena*, *Empetrum*, *Myrteola*, *Oreobolus*, and *Marsippospermum* can each be dominant or co-dominant depending on local variables.

2) *Evergreen forest*. In a belt where the annual rainfall is between 800 mm and 4000 mm *Nothofagus betuloides* assumes greater importance as the precipitation rises, although it is intermingled with *Nothofagus pumilio* in a mixed evergreen-deciduous forest when the precipitation is just above 800 mm. The evergreen rain forest is unique in that it is dominated by a single tree species, *Nothofagus betuloides*, an evergreen member of the southern beeches. This dominance is illustrated on the pollen diagrams by relative percentages often above 50% and even up to 92% for *Nothofagus*, largely that of *Nothofagus betuloides* (Figures 2 - 4, especially Figure 3). The other member of the evergreen forest, *Drimys winteri*, fills a lesser role in the understory of Isla de los Estados and is a minor contributor to the total pollen spectrum, although in the northern reaches of the rain forest it occupies the overstory and can become locally dominant (Young, 1972).

The evergreen forest extends from sea level to about 350 m, while it tends to favor sheltered valleys and coves as it enters higher elevations until at its upper limit it forms a "krumholz" of twisted, dwarf scrub. Besides *Nothofagus* and *Drimys* other constituents of the forest are the tree fern *Blechnum magellanicum*, the shrub *Lebetanthus*, and the epiphytic filmy ferns *Hymenophyllum*, *Grammatis*, and *Serpyllopsis*.

3) *Alpine vegetation*. Just above the "krumholz" of *Nothofagus antarctica* the alpine vegetation in Tierra del Fuego begins. Timberline generally lies between 550 and 600 m, although on the large mountains it may occur as high as 700 m. Three main factors, exposure to wind, the

presence of water, and the type of substrate, determine the nature of the alpine vegetation. It is composed of the following four structural variants:

a) The *cushion heath*, which can occur at elevations well below timberline, is characterized above timberline by cushions of *Bolax* often over a meter high as well as by *Abrotanella*, *Azorella*, *Caltha*, *Colobanthus*, *Drapetes*, and *Plantago*. At increasingly higher elevations the cushions become more scattered and *Bolax* loses its dominance, until at the upper elevation limit of vegetation scattered cushions of mostly *Saxifragella* are present accompanied rarely by *Azorella* or *Cerastium*.

b) The *dwarf shrub heath* often interdigitates with the cushion heath and shares most of the plant species found in the cushion heath. But along the edges of rock screes as well as on other well-drained sites a well-defined shrub heath develops, which is dominated by *Empetrum* and to a lesser extent by *Pernettya* and *Myrteola*. Species not shared by the two associations are *Cystopteris fragilis* and *Senecio darwinii*, which are primarily found in the dwarf shrub heath when becoming members of the alpine community.

c) The *feldmark* is located on large sections of rolling or gently sloping ground littered with talus deposits. Most alpine plants have a difficult time becoming established here, but it does provide the unique habitat required by *Nassauvia lagascae* var. *globosa* and *Nastanthus spathulatus*, which are found nowhere else in Tierra del Fuego, and for *Usnea*, which often blankets the feldmark.

d) The *alpine meadow* flora is concentrated in areas where there are permanent streams and seepage areas often derived from permanent snow banks or glaciers. The rich and varied flora is composed of some of the same genera found in the other alpine associations, such as *Abrotanella*, *Caltha*, and *Plantago*, but it also includes some others not mentioned as characteristic of the first three associations: *Acaena*, *Gunnera*, *Hierochloe*, *Lagenophora*, *Ourisia*, *Oxalis*, *Poa*, *Primula*, *Tapeinia*, and *Viola*. If the stream bank is composed of coarse soil, then *Cardamine*, *Epilobium*, *Hamadryas*, and *Nassauvia* are likely to occur. Poorly-drained areas flanking the streams may support a variety of grasses and sedges (e.g., *Carex*, *Carpha*, *Schoenus*, and *Uncinia* of Cyperaceae).

4) *Transitional forest*. As delineated by Young (1972), this occurs at the transition from the evergreen to the deciduous forest in an eastward direction from the cordillera. Outwardly the transitional and the evergreen forest resemble one another because of their dominance by *Nothofagus betuloides*, but the eastern edge of the true evergreen forest is demarcated by the disappearance of the shrubs, *Philesia* and *Tepualia*, as well as the epiphyte *Hymenophyllum pectinatus* and the ground-dwelling *Blechnum magellanicum* and *Gleichenia quadripartita*. Lacking these understory elements, the transition forest is characterized by pure stands of *Nothofagus betuloides* of sometimes sizable proportions and by little undergrowth and no vascular epiphytes.

5) *Magellanic deciduous forest*. This occurs as a narrow belt between the eastern edge of the transition forest and the western fringe of the steppe and sometimes penetrates into the steppe in isolated copses along valleys. It is dominated by the summer-green beeches, *Nothofagus pumilio* primarily and *Nothofagus antarctica* secondarily, in a belt circumscribed by a mean annual precipitation from 400 to 800 mm

at altitudes from sea level to 600 m. At higher elevations as well as higher latitudes *Nothofagus antarctica* becomes increasingly dominant because of its greater adaptive ability. Along the forest borders and in clearings a shrub community of *Escallonia*, *Pernettya*, and *Ribes* may develop in the moister habitats, and one occupied by *Berberis*, *Chiliotrichium*, and *Embothrium* may be found in the drier sites.

6) *Patagonian steppe*. The grass steppe occurs consistently east of the cordillera and is dominated by the grasses, *Festuca* and *Stipa*. Other graminoids associated with the community are *Bromus* and *Poa*. Non-graminoid members are most often *Acaena*, *Calceolaria*, *Hypochoeris*, *Relbunium*, *Verbena*, and *Vicia*. In wetter sites such graminoids as *Alopecurus*, *Carex*, *Deschampsia*, *Juncus*, and *Phleum* are found, and a dwarf shrub heath dominated by *Empetrum* is found on the shallow acid soils.

Five of the six major vegetation types as outlined for southern Patagonia occur on Isla de los Estados, the Patagonian steppe being totally absent. The reason for its absence is readily apparent when one examines the rainfall data. To the north Rio Gallegos and Rio Grande, Argentine, have annual precipitation levels of 281 mm and 379 mm respectively (Chapter I, Table 2), and both are located in the Patagonian steppe. The high precipitation levels of Isla de los Estados do not allow for the development of steppe.

Seven vegetation formations have been recognized on Isla de los Estados, according to the work of Dudley and Crow (unpub. ms.). In addition to the first five described above for all of southern Patagonia, these authors include a littoral vegetation and a maritime tussock formation. The littoral vegetation has elements of the meadow flora and the Magellanic moorland, while the maritime tussock formation consists of a single dominant species, Poa flabellata, that forms large tussocks on the high bluffs and headlands along the coast. The scrub formation described by these authors appears to be the "krumholz" of the evergreen and deciduous Nothofagus forests at the higher elevations, thus it can be considered as a subunit of either the evergreen or the deciduous Magellanic forest.

The seven major vegetation formations on Isla de los Estados described by Dudley and Crow (unpub. ms.) have been schematized by the author in tabular form (Table 5). The representative flora has been given for each formation and in some cases for each subunit of the formation. They are listed by their generic names only, since it is usually impossible to carry their identification to the species level when studying them palynologically. These modern-day vegetation reconstructions will be used as the groundwork for reconstructing the plant communities of the past by utilizing the information collected from a pollen-analysis of the three peat cores.

Interpretative Problems and Possible Solutions

Before a reconstruction of the plant communities for the post-glacial period can proceed, consideration must be given to the major gaps that exist between the present and the past and to the difficulties involved in bridging those gaps. As long as those difficulties are kept in mind, then the temptation to stretch the pollen data further than is legitimate will be avoided. The investigator will not extract more information than is available in the pollen data, and the reconstruction of the vegetation history over the past several thousand years will not

TABLE 5

VEGETATION FORMATIONS OF ISLA DE LOS ESTADOS[a]

1. *Littoral vegetation*

   a. Supratidal cushion plants - taking root in soil-filled cracks of the rocky shoreline

   Colobanthus - two species
   Crassula
   Plantago
   Poa

   b. Peaty surface just above rocky shoreline

   Apium
   Cotula
   Gunnera
   Ranunculus
   Senecio - two species

   c. Cliff face plants - overlooking the sea

   Azorella
   Colobanthus
   Cotula
   Crassula
   Ourisia
   Senecio

   d. Shoreline shrub zone - occuring in sheltered bays

   Escallonia - Dominant
   Hebe
   Ribes

   e. Sandy beaches

   Acaena
   Apium
   Caltha
   Cardamine
   Hierochloe
   Juncus
   Senecio

2. *Maritime tussock formation* - headlands and high bluffs overlooking the ocean

   Poa flabellata - single dominant species, known as tussock grass; it forms clumps that often crowd out most other species

   Occasionally the following are found:

   Apium
   Blechnum
   Cardamine
   Senecio

TABLE 5 (cont'd)

3. *Evergreen forest formation*

   a. True Magellanic evergreen rain forest - southern and eastern portion of the island

   Nothofagus betuloides - overwhelmingly dominant
   Drimys winteri - other arboreal representative
   Berberis
   Blechnum
   Grammatis
   Gunnera
   Hymenophyllum - 2 species
   Lebetanthus
   Luzuriaga
   Senecio
   Serpyllopsis

   b. Magellanic evergreen transitional forest - northwestern portion of the island

   Nothofagus
   Drimys
   Few plants growing on forest floor

4. *Scrub formation*

   a. *Nothofagus antarctica* association (deciduous forest)

   Pure stands of dwarfed *N. antarctica* with little undergrowth

   b. *Nothofagus betuloides* - *Marsippospermum grandiflorum* association

   N. betuloides - predominant, forming impenetrable thicket
   M. grandiflorum - dominant ground cover
   Berberis
   Chiliotrichium
   Hymenophyllum
   Pernettya

5. *Meadow formation*

   Marsippospermum grandiflorum - singularly dominant, giving the appearance of a grass meadow

   Asplenium
   Berberis
   Chiliotrichium
   Drimys
   Galium
   Gunnera
   Hymenophyllum
   Nothofagus
   Pernettya
   Ranunculus
   Senecio

TABLE 5 (cont'd)

6. *Magellanic moorland formation* - composed of many subunits

a. *Empetrum rubrum* association - most predominant subunit

Dominated by:
Empetrum
Marsippospermum
Pernettya

Others that are present, but usually scattered in distribution:
Berberis
Blechnum - 2 species
Chiliotrichium
Drimys
Gunnera
Luzuriaga
Nothofagus
Rubus

b. *Caltha* association

Caltha - 2 species dominant
Astelia
Drapetes
Gaimardia
Gaultheria
Gunnera
Nanodea
Perezia
Pernettya
Tribeles

c. *Astelia pumila* association - high elevations

A. *pumila* - almost pure stands formed
Abrotanella
Azorella
Bolax
Caltha - 2 species
Drosera
Gaimardia
Gleichenia
Nothofagus
Oreobolus

7. *Alpine formation* - 450 m and below, lower limits variable

Abrotanella
Azorella - 2 species
Bolax
Caltha
Drapetes
Empetrum
Hymenophyllum
Nothofagus
Oreobolus
Pernettya
Poa
Senecio
Viola

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[a] Summary of the vegetation of Isla de los Estados adapted from an unpublished manuscript by T. R. Dudley of the U. S. National Arboretum, and G. E. Crow of the University of New Hampshire. This is similar to, but an expansion of, the material found in Crow (1975).

be more precise than the precision limits inherent in palynology. Following are the major interpretative problems (or gaps) and their possible solutions (i.e., the ways in which the gaps can be bridged).

The lack of surface samples. One of the most important links in spanning the gulf between the vegetation of the present and the pollen of the past is the analysis of the pollen contained in surface samples from the site under study. The advantage of surface sampling is that it can be more readily determined which of the living plant taxa are over-represented, which are under-represented, and which are represented not at all in the pollen flora (a problem which will be analyzed separately below). No surface samples were collected and sent on to Michigan State University from the three coring sites. Another method for detecting the modern pollen flora is to set up aeropalynological stations and process the pollen from mostly anemophilous plants collected on oiled microscope slides over periods of time. Since the stations must be in operation at all seasons of the year in which flowers are in bloom, it would hardly be expected that such stations would be set up during the short R/V *Hero* cruise. It would be advantageous for future cruises or botanical expeditions to the island to collect aeropalynological samples, or at least to collect samples from the surface of the substrate.

The problem of representation. If a plant ecologist were to analyze each constituent member of the community according to its relative contribution to the total plant biomass of the community, and a palynologist were to analyze the modern sediments in order to determine the relative contribution of each pollen and spore taxon to the total palynoflora, and comparisons were made of the two sets of data in terms of relative percentages, one would find discrepancies in varying degrees between most of the taxa. The problem is that of under-representation and over-representation (or even non-representation) between the living flora and the pollen flora. If the magnitude of the differences is known between the two, then it is possible to re-interpret the pollen diagram, so that values more representative of the actual composition of the plant community would be given. The pioneer study along such lines is now in progress for Argentine Patagonia. Markgraf, D'Antoni and Ager (unpub. ms.) are relating the pollen flora from surface samples with the existing vegetation patterns representative of the desert regions of northern Argentina and the temperate forest and steppe regions of southern Argentina as far south as Tierra del Fuego. A similar study should be done for Isla de los Estados, but it will not be feasible until such time as surface samples become available.

However, some generalized judgments can be made on representation based upon available descriptions of the vegetation surrounding the three coring sites. Berberis is represented at the sites of Cores II and VI as an important constituent of the flora, but no Berberis pollen grains were found in Core II and almost none were found in Core VI. This seems to be a case of under-representation. Another example is Pernettya, which is reported today from the vicinity of Cores III and VI, but was rarely encountered in the cores themselves. The most outstanding example of under-representation is that of Marsippospermum which is the major component of the heath around Core III and the meadow around Core VI's site. Only two or three palynomorphs which could be attributed to Marsippospermum were located in these cores. However, there may be another problem involved here, that of preservation.

Another factor in non-representation or under-representation is that non-anemophilous plants are at a distinct disadvantage compared with anemophilous plants because they can only be represented in the pollen record if the core penetrated the spot where the parent plant once grew and where the pollen fell on the peat. Such is the case with *Armeria*, which was found only in sample Pb9693 at the base of Core III. *Armeria* should be much better represented in the pollen record based upon its wide range today in a variety of habitats from alpine (Moore, 1975) to oceanic islands (Moore, 1968). It grows today in the vicinity of Core II, but its pollen has not been detected in that core, the reason being that *Armeria* is self-pollinated, not wind-pollinated (Moore and Yates, 1974).

The problem of preservation. A certain member of the plant community may make a sizable contribution to the modern pollen spectrum, but due to the biochemical composition of the exine or due to the nature of the substrate, its pollen may become corroded or entirely destroyed over a period of time. All of the Juncaceae, of which *Marsippospermum* is a member, seem to be characterized by a low durability factor (i.e., poor preservability) perhaps due to the thinness of the exine compared to the size of the pollen grain, or to its susceptibility to corrosion in the weakly acidic peats. However, peat is considered to be an excellent preserving medium for spores and pollen grains, especially for Postglacial palynomorphs.

The problem of exotic pollen. Occasionally pollen grains appear in the pollen record here which represent plants now known to grow at considerable distance from the coring site. The answer to this problem is not that its range once extended much wider than at present. Evidence from other cores shows that its Postglacial range has differed little from today's range. The probable explanation is that long-distance transport is involved. Pollen of anemophilous plants is often lofted into the air currents of the upper atmosphere or sometimes storms carry the pollen far beyond their usual ranges. Ephedra has been found in just two samples of Core VI (Figure 4), but it is not currently growing anywhere on the island today. The nearest source area is the Patagonian steppe of Tierra del Fuego. Thus Ephedra pollen probably was transported to the island by the prevailing westerlies, and has been detected only in the core at the western tip of the island. It is reported in the pollen record from several samples at the La Mision site, which is located just north of Rio Grande of eastern Tierra del Fuego, but it is never found in significant numbers (Markgraf, 1977).

One would expect the exotic pollen of Podocarpus to have been found in several samples from Isla de los Estados, since it is found in the majority of samples from the 9.2-m La Mision core approximately 225 km to the northwest, sometimes occurring in surprising numbers, i.e., more than 10% of total pollen (Markgraf, 1977). It also has been transported more than half way across the Atlantic to Tristan de Cunha on the mid-Atlantic ridge and appears on the pollen record there (Hafsten, 1960). However, only one grain of Podocarpus pollen has been identified in the Isla de los Estados samples, being found in Core III from the center of the island. This unmistakable example of Podocarpus has been illustrated (Plate 1, Figure 1-15) and has been noted on the Core III diagram (Figure 2). The reason for its scarcity is simply that the prevailing winds there are south-westerly, while it would take north-westerly winds to bring in Podocarpus, which now grows north of the Magellanic Straits (Moore, 1974).

The problem of pollen taxonomy. Pollen and spore taxonomy does not reach the degree of exactness as does the taxonomy of the parent plant, for the simple reason that the taxonomist is dealing with a much smaller portion of the plant with an extremely small number of diagnostic features compared to the whole-plant taxonomy. Very seldom can the palynomorph be identified down to the level of the species. Thus when an attempt is made to determine paleoecological associations, a generic identification only cannot provide the information an identification on the species level could. Some genera like Senecio, Acaena, and Azorella contain species which vary from alpine representatives to those that favor wet sites to those that tolerate drier sites; therefore, their presence in the pollen record does not facilitate the making of precise paleoecological and paleoclimatological interpretations.

Some palynomorphs cannot be safely identified below the level of the family, such as Chenopodiaceae and Gramineae, thus making paleoecological interpretations even less certain. Many of the genera within Compositae, Cyperaceae, and Juncaceae are difficult to differentiate. Therefore, they have been lumped together in their respective families. Three heath families, Empetraceae, Epacridaceae and Ericaceae, have very similar pollen usually occurring as tetrads, so these have been considered as one taxonomic group on the pollen diagrams, the Ericaceae-type. Yet the individual genera may have differing paleo-environmental requirements, e.g., Lebetanthus of Epacridaceae is usually associated with the Nothofagus forests and Empetrum of Empetraceae with the Magellanic moorland heaths. Members of the Polypodiaceae cannot usually be safely distinguished, and there is possible confusion with the Gleichenaceae, so these facts must be kept in mind when analyzing the pollen diagrams.

In order to differentiate the Magellanic evergreen forest from the deciduous forest palynologically it would be advantageous to be able to clearly separate taxonomically the pollen of _Nothofagus betuloides_ from that of _N. antarctica_, the two major components of these forests respectively, but it is not possible to positively differentiate between the two on the basis of the morphology of the grains. Heusser (1971) suggests that the palynologist can separate _Nothofagus_ into only the two groups, the Dombeyi and Obliqua types. He states, "Identification below the type level does not appear workable" (Heusser, 1971, p. 35). Unfortunately, _N. betuloides_ and _N. antarctica_ both fall within the same Dombeyi type. However, an attempt will be made below to separate the two species of _Nothofagus_ in a general fashion based upon the differing ratios of the number of apertures.

In spite of these taxonomic difficulties, it is still possible to extract a substantial amount of information from the pollen record in making paleoecological and paleoclimatic reconstructions.

A Possible Solution to Identification of Nothofagus Pollen

The problem of the further identification of the stephanoaperaturate _Nothofagus_ pollen beyond the two types, Dombeyi and Obliqua, may find its solution in the possibility that each _Nothofagus_ species has a different ratio of aperture numbers. According to Heusser (1971, pp. 35, 36) _N. antarctica_ has 5 to 7 apertures distributed in the following way: 5-3%, 6-50% and 7-47%, in contrast to _N. betuloides_ which has 4 to 7 apertures distributed as follows: 4-3%, 5-67%, 6-29%

and 7-1%. If one were to have a predominance of 5-aperturate *Nothofagus* grains in a given sample accompanied by a scattering of 4-aperturate types, then one would conclude that *N. betuloides* is the dominant species represented in the count. Conversely, a predominance of 6- and 7-aperturate *Nothofagus* almost to the exclusion of 5-aperturate types would tend to confirm the identification of these as *N. antarctica*. But the matter is not so clear-cut, because there is generally a mixture of the two species, as indicated by contemporary floras, and the two species occur in undetermined proportions in the flora.

Besides *N. betuloides* and *N. antarctica*, the only other species of *Nothofagus* currently growing on the island is *N. pumilio*. The samples examined rarely contained *N. pumilio* pollen which can be readily identified by its more rotund appearance and its staining properties. (It stains a deeper red color, possibly due to the susceptibility of the exine to absorb safranin dye more easily.) For the purposes of our *Nothofagus* differentiation, the possible effects of *N. pumilio* can be ignored because of its negligible contribution (less than 2% of total *Nothofagus*).

Dr. Ralph E. Taggart suggested that it would be possible to differentiate the *Nothofagus* species mathematically based upon an analysis of the numbers of apertures for all *Nothofagus* grains in a given sample. He devised a computer program (Appendix B) for differentiating *N. betuloides* from *N. antarctica*, and the following step by step sequence is a description of the procedure.

The first step is to obtain an aperture count for all *Nothofagus* present. Generally the *Nothofagus* count had to be extended beyond those identified in the minimum count of 200 pollen and spores.

Occasionally more than 1000 pollen and spores had to be counted in order to increase the *Nothofagus* count to a statistically significant level in a sample.

The second step is to determine the statistical probability for a given *Nothofagus* pollen grain to be assignable to *N. antarctica*. This may be accomplished only on the basis assuming that aperture ratios in this species has remained unchanged during Postglacial time. The aperture ratios given by Heusser, 5-3%, 6-50%, 7-47%, for *N. antarctica*, and 4-3%, 5-67%, 6-29%, 7-1% for *N. betuloides*, indicate that for a given 7-aperturate pollen grain, the probability is 50 times greater that it is *N. antarctica* rather than *N. betuloides*. This means that if fifty 7-aperturate pollen grains are counted in a given sample, only one of those is to be attributed to *N. betuloides*. For all practical purposes the effect of *N. betuloides* upon the 7-aperturate count is negligible. The formula for obtaining the total *N. antarctica* (TA) is found by simply taking the total 7-aperturate *Nothofagus* count (T7) of a given sample and dividing by 47%.

$$TA = T7/.47 \qquad \text{(Equation 1)}$$

The third step is to determine the contribution of *N. betuloides* to the total count. This can be accomplished by analyzing statistically the 5-aperturate count with the assumption that the ratios given by Heusser hold true throughout Postglacial time. For a given number of 5-aperturate pollen grains the probability for the occurrence of *N. betuloides* is 67:3, based upon Heusser's ratios. Here the contribution of *N. antarctica* is slightly above the negligible level, and thus must be computed. The total *N. betuloides* pollen (TB) is calculated on the basis of the total 5-aperturate count (T5) divided by 67%, after which the contribution of N. antarctica is subtracted.

$$TB = T5/.67 - (TA \times .03) \qquad \text{(Equation 2)}$$

The total N. antarctica (TA) has been derived from the previous formula and is multiplied by 3% to obtain the relative contribution of N. antarctica in the 5-aperturate count, due to the fact that 97% of N. antarctica do not have five apertures.

The fourth step is to determine how many of the Nothofagus pollen grains cannot be attributed to either N. antarctica or N. betuloides in the total Nothofagus count (TN). The total unknown Nothofagus (UN) is derived from the total Nothofagus (TN) less the total N. antarctica and total N. betuloides.

$$UN = TN - (TA + TB) \qquad \text{(Equation 3)}$$

The figures for TA and TB are obtained easily by the previous two equations, and TN has been accurately tallied during the counting of samples, being composed of all Nothofagus grains in a given sample having an available aperture count. (Grains not counted in TN are those which were partly blocked from view or which were folded.) Thus the total of unknown Nothofagus (UN) can be easily derived.

To facilitate the calculations of the three equations, the equations were incorporated into a computer program (Radio Shack TM Level II BASIC) for use on a Radio Shack TRS-80 Model I Microcomputer. The computer program used in the calculations is found in Appendix B, and the aperture data obtained from the Nothofagus counts is located in Appendices C, D, and E. Much appreciation goes to Dr. Ralph Taggart, of the Department of Botany and Plant Pathology, for writing the computer program. The results provided by the computer tabulation are found in Figures 2, 3, and 4 of Chapter III, where the relative contributions of *N. antarctica*, *N. betuloides*, and unknown *Nothofagus* to the total *Nothofagus* count are given.

An examination of the profiles from the three cores indicates that *N. betuloides* is clearly dominant over *N. antarctica*. With only three exceptions, Pb9685, Pb9687, Pb9721, from among more than 100 samples, the percentages for *N. antarctica* are less than 10%. (It should be noted that the percentages given on the diagrams are based upon total pollen and spores, not total *Nothofagus* pollen.) This is in contrast to *N. betuloides* which reaches 50% of total pollen and spores, or higher, in several samples. This disproportion between the two *Nothofagus* species throughout the Postglacial period is confirmed by the analysis of leaf and fruit macrofossils from the Mylodon Cave, Ultima Esperanza, southern Chile, covering the Postglacial period (Moore, 1978). A series of four radiocarbon dates starting with 12,496 B.P. gives the chronology of the dung deposits from the extinct ground sloth, *Mylodon*, accompanied by a sequence of leaf litter deposits. Although Ultima Esperanza is more than 400 km north of Isla de los Estados and lies just outside the Magellanic rain-forest belt, the cave deposits do indicate episodes of forestation with a mixed *Nothofagus* evergreen-deciduous forest. During these episodes of forestation *N. betuloides* was clearly the dominant species on the basis of the presence of many more times the amount of plant remains than *N. antarctica*. The latter reaches a small peak at mid-point in the interval between 7803 and 5643 B.P., and an even smaller peak in the layer dated to 2556 B.P. *N. pumilio* usually fluctuates at levels midway between the peaks of *N. betuloides* and *N. antarctica*.

The over-all patterns of variation of *Nothofagus* percentages for Isla de los Estados do not correlate well with the profile at the La Mision (Cabo Domingo) site as studied by Auer (1965, 1974). In contrast with Ultima Esperanza and Isla de los Estados, the La Mision diagram generally ascribes the lowest percentages to *N. betuloides*, while the higher percentages alternate between *N. antarctica* and *N. pumilio*. Auer's data may differ because he uses totally different aperture percentages than does Heusser (Auer, Salmi and Salminen, 1955, cf. Heusser, 1971).

One obvious result of the computer analysis of the *Nothofagus* aperture data is that the "unknown" *Nothofagus* percentage in certain samples is at higher levels than is desirable. As noted above, the "unknowns" cannot all be attributed to *N. pumilio*, because one can visually distinguish that pollen species from the other two *Nothofagus* usually present. The "unknowns" would have to be attributed to *N. betuloides*, *N. antarctica*, or to another species of *Nothofagus* not extant on the island today. If the pore distribution has remained relatively constant throughout the Postglacial period, and if no other *Nothofagus* species has made a detectable contribution to the pollen influx, then it is more likely that most of the "unknowns" are attributable to *N. betuloides* because of the apparently greater contribution of *N. betuloides* over *N. antarctica* according to the computer analysis.

However, the high levels for the "unknown" *Nothofagus* percentages do call into question the accuracy of equations 1, 2, and 3 used for the derivation of the *N. antarctica* and *N. betuloides* percentages. It is thought that the equation for *N. antarctica* is fairly accurate because it allows for low percentages of *N. antarctica* in comparison with *N. betuloides*, which accords with the fact that a relatively low number of 7-aperturate grains are found in the samples. Yet the number of 5-aperturate grains does not conform with Heusser's percentages for N. betuloides, suggesting that 67% have five apertures. In Core VI the totals for the aperture counts along with their respective percentages relative to total Nothofagus are as follows:

Four	Five	Six	Seven	Eight	Nine	Unidentified
106	2199	2081	221	9	1	336
2.3%	47.6%	45.1%	4.8%	0.2%		

This represents the totals for the data found in Appendix E.

The number of Nothofagus with five apertures is less than 50%. If nearly all of these are attributable to N. betuloides, then we have evidence that Heusser's ratios derived from Chilean material may not always apply. Unfortunately we have had no opportunity for analyzing the pollen from living trees on Isla de los Estados to determine whether the aperture percentages for N. betuloides should be modified slightly, or whether the figures given by Heusser for Chile hold true for the Island. It is possible that there has been some phenotypic variation at differing geographical sites for palynomorphs within a given Nothofagus species.

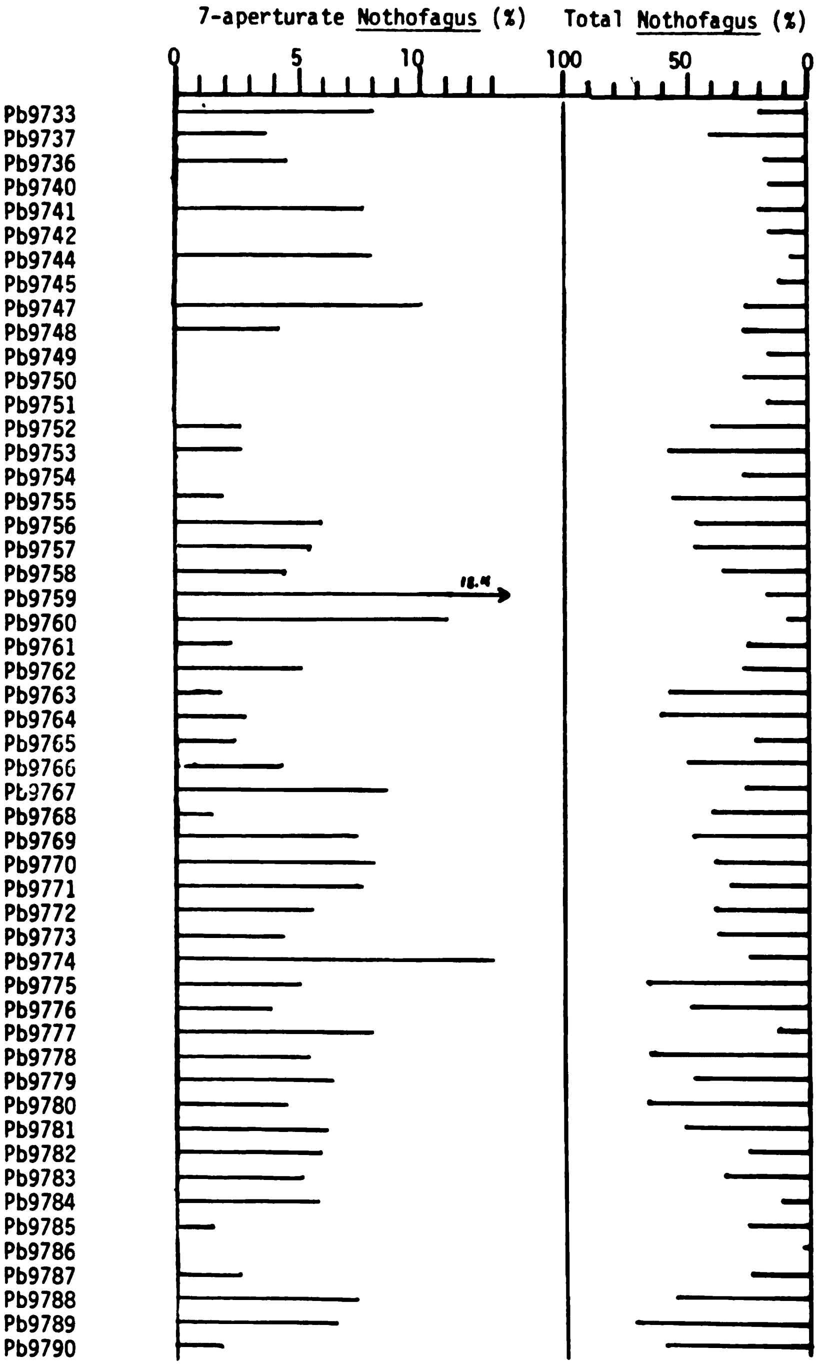
There are two means whereby we can test the accuracy of aperture studies of fossil pollen and its application to taxonomic identification. The first is to use the resultant data as a means of prediction. We have determined the relative proportions of N. betuloides and N. antarctica in our samples, especially in Core VI. We should then be able to predict how many of the total number of pollen grains should have a certain number of apertures. For example, the data from Heusser would suggest that 3% of the total N. betuloides should have four apertures. This means that of the total *Nothofagus* in Core VI attributed to *N. betuloides* (4149 in all) approximately 124 should have four apertures. The actual total as given above is 106, which is within the limits of statistical uncertainty. Thus the percentages given for 4-aperturate *N. betuloides* by Heusser can be validated throughout the last several thousand years in the Bahia Crossley deposit.

A second means of testing the validity of the equations is to compare the *N. antarctica* percentages with those of total *Nothofagus*. This can be best accomplished by analyzing the relative percentages of 7-aperturate pollen with respect to total *Nothofagus*. As noted previously most of the grains with 7 apertures can be attributed to *N. antarctica*. A comparison between 7-aperture percentages in Core VI with total *Nothofagus* percentages appears in Figure 5. I have reduced the total *Nothofagus* to one-tenth the scale for the 7-aperturates. It should be noted that the percentages for the 7-aperturates is based upon total *Nothofagus*, while the percentages for total *Nothofagus* is relative to total pollen and spores. The reason for this is that total *Nothofagus* is a function of the paleoclimate, probably basically the result of temperature changes. An increase in tree pollen, in this case *Nothofagus*, can be correlated with an increase in temperature.

A close comparison of the 7-aperturate percentages with total *Nothofagus* indicates that there is an inverse relationship. I have reversed the direction of the 7-aperturate percentages in order to accentuate this relationship in Figure 5. The inverse correlation between the two sets of data is reasonable from a paleoclimatological and paleoecological standpoint. Whenever there is a drastic decrease

FIGURE 5

NOTHOFAGUS ANTARCTICA PERCENTAGES
COMPARED TO
TOTAL *NOTHOFAGUS* PERCENTAGES IN CORE VI



in mean temperature, as indicated by a drop in total *Nothofagus*, then *N. antarctica* has an ecological advantage over *N. betuloides*. The former is the hardier of the two and grows at higher elevations today, sometimes forming low mats of "krumholz" near tree-line in the Magellanic region. Also, it is deciduous, while its rival, *N. betuloides*, is evergreen. A rise in mean temperature, as indicated by a rise in the total *Nothofagus* percentages, gives an advantage to *N. betuloides*, especially if the winters are warmer. The validity of equation 1, which proposes a means of isolating *N. antarctica* as the major constituent of the 7-aperturate pollen, is thus substantiated by the inverse relationship between 7-aperturate pollen percentages and total *Nothofagus* pollen. It is possible, therefore, to distinguish the *Nothofagus* pollen of Isla de los Estados on the basis of a mathematical analysis of aperture counts.

Paleoecological Interpretation for Core II (Puerto Cook-Puerto Vancouver)

For the paleoecological reconstruction, modern analogs will be used based on the seven vegetation formations for the island analyzed by Dudley and Crow (unpub. ms.). These formations are the littoral vegetation, maritime tussock, evergreen forest, scrub, meadow, Magellanic moorland, and alpine. Also, useful will be a detailed vegetation analysis for the Falkland Islands (Moore, 1968), which has a similar climatic regime, and which has many of the same plant formations, such as the maritime tussock, the heaths, and the littoral vegetation. The Falklands have a total of 163 species of native vascular plants, compared to 170 for Isla de los Estados, but an important difference is the absence of arboreal species on the Falkland Islands, which are located 520 km east of the Strait of Magellan between the latitudes of 50°00'S and 52°30'S.

The vegetation history at the Puerto Vancouver-Puerto Cook isthmus, the site for Core II, begins with two distinctive, but somewhat dissimilar, heaths found in zone A, and these are also characterized by the virtual absence of *Nothofagus*. The pollen diagram (Figure 2) shows first a strongly dominant Cyperaceae heath (zone A-1) and then a strongly dominant *Astelia* heath (zone A-3) separated by a transition zone (A-2) comprised of Cyperaceae, Ericaceae-Empetraceae, Blechnaceae-Polypodiaceae, none of which achieve strong dominance. The Cyperaceae of zone A-1 is best paralleled by the wetter subunits of the *Cortaderia* heath (pampas grass) association of the Falklands where *Carex* and *Oreobolus* may be co-dominant. At the beginning of the zone, Gramineae is second in importance to Cyperaceae, and *Uncinia* may be the major contributor to the Cyperaceae total, which parallels the condition on the West Falkland Islands.

Zone A-3 is analogous to the *Astelia pumila* association of the Magellanic moorland formation in view of the fact that it contributes 60% of the pollen sum and that the *Nothofagus* forest must have been greatly limited. In that association *Astelia* is said to form dense mats composed of almost pure stands of *Astelia*. It favors highly mineral soils, especially soils freshly exposed through erosion (D. M. Moore, personal communication). The two heaths of zone A, which are characterized by strong dominants, thus parallel the Magellanic heathland of the modern vegetation.

Sample Pb9731 of zone A-1 has two special characteristics: first it has the highest diversity for any sample in the three cores, and second it has no *Nothofagus* pollen represented. Except for sample Pb9730 which was taken just above it, no other sample out of more than 100 samples examined has a total absence of *Nothofagus*. To account for this noteworthy absence, one could suggest that either there had been no forests prior to that time due to the effects of the last glaciation, or that forests had indeed existed just prior, but they had been decimated and removed from the pollen record by either a single factor or a combination of factors.

First, in consideration of the hypothesis of a deforestation having occurred at the time of deposition of the two lowest samples of Core II (Pb9730 and Pb9731), the main evidence hinges upon the correlation of zone A here with the lowest portion (Pb9786) of zone B in Core VI, at which point *Nothofagus* values are at their minimum for any sample in the Bahia Crossley core, being only 2% of the pollen sum (Figures 2 and 4). In Bahia Crossley this is clearly a case of deforestation, because the preceding zone A has evidence of heavy forestation. If samples Pb9730 and Pb9731 of Core II correlate with sample Pb9786 of Core VI, then for consistency sake one would have to argue that deforestation accounts for the lack of *Nothofagus* at the base of Core II. In other words, at that point in time the eastern portion of Isla de los Estados would have to be characterized by a lack of the Magellanic forests, while the western portion must have had scattered individuals or clumps of *Nothofagus*. The central portion of the island would also have to be characterized as having had very low numbers of *Nothofagus* if the base of Core II is correlative with the base of Core III (Figures 2 and 3).

Another suggestion to account for the lack of *Nothofagus* pollen at the base of Core II is that this zone depicts a flora that indicates either Lateglacial or early Postglacial conditions. As noted earlier, sample Pb9731 in this zone has the highest diversity of any sample out of more than 100 examined in three cores. With 23 taxa represented, it has 60% of taxa found in all the samples analyzed in Core II. In comparison with the three next highest samples in diversity, Pb9691, Pb9693, and Pb9786, each of which 45% of the total taxa found in their respective cores, there is no doubt that sample Pb9731 has the highest diversity. The logical explanation is that this represents a pioneer community that has entered the island relatively soon after deglaciation when competition would have been at a minimum.

Paleotemperature inferences from the pollen data of Alerce, Chile (41°25'S, 72°52'W) indicate that between 11,300 B.P. and 9410 B.P. the mean January (summer) temperature was as low as 6°C below today's mean, which was the lowest at that site for any time in the Postglacial (Heusser and Streeter, 1980). A temperature 6°C lower than today's for Isla de los Estados would result in a mean annual temperature slightly below the freezing point (Table 3), preventing development of forests.

If the correlation of zone A in Core II with the 11,000 - 10,000 B.P. period of minimum temperatures inferred from the Alerce, Chile record is valid, then it could likewise be characterized as a period of higher precipitation than today's levels. Inferences from the pollen data at Alerce suggest that the mean annual precipitation for that site at 10,500 B.P. was more than twice the value of today's annual mean of 1933 mm (Heusser, 1974; Heusser and Streeter, 1980). The large concentration of Cyperaceae pollen at the base of Core II would likewise support a hypothesis of increased mean precipitation. To suggest that correlation is possible between Puerto Vancouver and Alerce, Chile far to the north is based on the fact that both locales today support coastal rain forests with similar climatic regimes, the Alerce site being in the Valdivian rain forest and Puerto Vancouver being in the Magellanic rain forest.

Also if our zone correlates with the time frame of 9410 - 11,300 B.P., we would expect lower sea levels than today's levels when the Postglacial eustatic response of sea level to ice melting is taken into account. The pollen profile for A-1 does not match that which would be expected for littoral vegetation. For example, two of the important littoral taxa, Colobanthus and Crassula, are not represented in this zone, although they are represented elsewhere in the core. It suggests that the shoreline was further away from the Core II site than it is today, and makes much less plausible the idea that the deforestation then was due to damage by salt spray. The marine dinoflagellate evidence for this core (Figure 2) tends to fit the hypothesis of a lower sea level because there are no dinoflagellates represented in either zone A-1 or A-2, while they are represented further up in the core. These dinoflagellates, which will be discussed later in more detail, may be carried in sea spray into the peat as a result of high wind and waves during a storm. However, the dinoflagellate evidence for a lower sea level is not conclusive because there are other samples in Core II without dinoflagellates. Nevertheless, the absence of marine dinoflagellates in zone A-1 does indicate that storm damage was not responsible for the deforestation.

The question should be asked, Can zone A be classified as Lateglacial, while zone B is to be placed at the beginning of the Postglacial? A final answer cannot be reached until radiocarbon determinations become available, but tentatively the answer is negative. This zone possibly can be correlated with the basal portion of the La Mision diagram (Markgraf, 1977), taken from a core in the Patagonian steppe 225 km northwest of the western tip of Isla de los Estados. Both cores have high percentages of Cyperaceae near the base followed by a great increase in Nothofagus. This basal zone is dated at 8490 ± 400 and 9300 ± 180 years B.P. by ^{14}C; thus, it would be considered Postglacial. Another evidence that zone A is Postglacial is that a high percentage of the minor taxa (those having less than 2% of the total pollen count) are non-alpine in affinity. The following taxa reported in zone A are not found listed as regularly occurring alpine species for Tierra del Fuego (Moore, 1975): Boopis, Chloreae, Chrysosplenium, Hebe, Jabarosa, Littorella, Pratia, Samolus, and Triglochin. One would expect that mostly alpine species would be represented if this were an assemblage that arrived soon after de-glaciation of the region. The tentative correlation of zone A with Heusser's Alerce core would perhaps place it slightly earlier than the basal portion of the La Mision diagram. Whichever is the case, zone A would be early in the Postglacial period.

In summary a clear understanding of zone A in Core II is crucial because it offers the key to correlation with other Postglacial pollen profiles, both at Isla de los Estados and at sites of higher latitudes in the southern part of the continent. The high taxonomic diversity and the low relative frequency for arboreal pollen offer important clues to long-term climatic fluctuations having unique local effects.

The upper three zones of Core II are generally characterized by a substantial contribution of Nothofagus pollen. Zone B can be described best as Magellanic rain forest probably dominated by Nothofagus betuloides in the lowlands and along the lower slopes and represented by *N. antarctica* probably on the upper slopes. At one point (Pb9721) *Caltha* must have flourished in the lowlands, probably indicating very moist conditions there. It would be difficult to distinguish edaphic factors from long-term climatic trends at this point.

The transition from zone B to zone C is marked by the rise of the Blechnaceae-Polypodiaceae and Gramineae and the decline of *Nothofagus*. Zone C-1 may be described as a Gramineae-fern association due to the fact that the ferns achieve a relative frequency of more than 40% of the total pollen and spores. Some of these ferns are represented by the tree fern, *Blechnum*, which would occupy the forests, but others such as *Gleichenia* and some Polypodiaceae would occupy the meadows and open slopes. Zone C-2 can be characterized as a Compositae-fern association, although ferns are of relatively less importance than in zone C-1. Zone C-3 is described as a Magellanic rain forest, or more accurately as a Magellanic evergreen forest, due to the apparent prevalence of *N. betuloides* over *N. antarctica*. This subzone is quite similar to the subzones located at the tops of each of the major zones in Core VI, and is known for its lack of diversity among the understory constituents. Some of the total diversity is contributed by the littoral elements, *Crassula*, *Gunnera*, and *Senecio* (which comprises a portion of the Compositae) in zone C-3.

Zone D begins with a Magellanic evergreen forest in D-1, which is not as dominant as the one in C-3 followed by a decline in forestation in zones D-2 and D-3. This subzone of D-2 is of interest because it was possibly a time when *Gunnera* occupied the lowlands and *Astelia* the open patches in the *Nothofagus* forests on the slopes. An

Ericaceae-type heath association, which is almost entirely composed of *Empetrum*, develops in the open places of the forest, as seen in D-1, and much more extensively in D-3 as the *Nothofagus* forests decline. This latter subzone is similar to the flora today at Puerto Vancouver. Field notes accompanying the cores indicate that the isthmus is a boggy heath dominated by *Empetrum* and accompanied by *Marsippospermum*, *Astelia*, and *Chiliotrichium*. Of these only *Marsippospermum* is not represented in zone D-3, apparently due to the low durability of its pollen. The area today also has scattered individuals of *Nothofagus betuloides* at the lower elevations and stands of *N. antarctica* at the higher elevations, while the less prominent members of the community are *Berberis*, *Caltha*, *Drimys*, *Gunnera*, and *Myrteola*. Of these latter only *Gunnera* has been detected in the pollen record.

Paleoecological Interpretation for Core III (Puerto Celular)

The vegetational history for Core III in general parallels that of Core II, one reason being that the two sites are only 16 km apart and another being that they have similar terrain. Both cores have an *Astelia* association of the Magellanic heath formation in zone A of each respective core. However, the Cyperaceae association at the base of Core II is absent from Core III, but it may be due to the possibility that the sampling of Core III did not continue deep enough or that the organic accumulation began at a later time. The *Astelia* heath in Core III was maintained over a longer period of time than in Core II based upon the fact that *Astelia* peaks are found throughout approximately 50 cm of the core.

Modern analogs can help clarify the pollen profile for zone A.

Herbarium notes (Michigan State University Herbarium, Isla de los Estados collection) indicate that tussock grass (*Poa flabellata*) grows today at approximately 100 m altitude on a hill overlooking Puerto Celular, and this association is intermixed with *Astelia*, *Caltha*, and *Empetrum*. It is possible that the maritime tussock formation is represented in zone A. In regards to *Astelia pumila*, herbarium notes (Michigan State University Herbarium) state the following: "Very common, dominant plant of a dense heath, forming acres and acres of uniform height, dense sheets on very steep (50° to 70° grade) and wet hillsides of Mte. Celina in Puerto Celular." The altitude there is said to be approximately 1000 ft. (300 m). Perhaps what is pictured in zone A is an extensive growth of *Astelia* on the lower slopes in a mat-like cushion heath, where normally *Nothofagus* would be growing. There may have been periodic replacement of these *Astelia* heaths with *Nothofagus*, followed by the reestablishment of *Astelia* on portions of the slopes.

Herbarium notes (Michigan State University Herbarium) also shed light on *Armeria maritima* which has been described as growing on a very rocky area along the beach at the base of the sea cliffs of Puerto Vancouver. In Puerto Celular it is possible that *Armeria* was a pioneer species growing on the rocky substrate of the valley where Core III was retrieved. The coring device struck rock at the base of the peat, and *Armeria* occurs in the pollen record with several grains counted in the lowest sample (Pb9693) of the core. More conclusive evidence that *Armeria* once grew at the core site is the fact that it is *not* anemophilous (Moore and Yates, 1974) and that it is not likely that stream transport would deposit its pollen at the coring site. A small hill separates the coring site from a stream emptying into the head of Puerto Celular nearby.

Zone B is characterized by relative frequencies of Nothofagus pollen greater than any other zone in the three cores. It is an extensive development of the Magellanic evergreen forest, which appears to be dominated by N. betuloides. At the base of the zone a sizable influx of N. antarctica pollen seems to have occurred perhaps indicating that the "krumholz" scrub was at a lower altitude at that time. Since then it appears to have shifted to higher altitudes, thus raising the altitude of the N. antarctica forest and making it less likely that its pollen would reach the core site. The top of zone B has the development of what may be considered as the Magellanic evergreen transitional forest (Dudley and Crow, unpub. ms.), which is located today at the northwest corner of the island and which consists of Nothofagus, Drimys and a few plants growing on the forest floor. The pollen of the arborescent Drimys winteri achieves the highest relative frequency for any sample in the core at Pb9680. In addition the Nothofagus parasitic plant, Myzodendron, reaches here a much higher relative frequency than in any other sample, and this also accords with the suggestion of heavy forestation. In addition only a small number of plants must have covered the forest floor, mainly a few Compositae, Empetrum, and ferns.

Zone C appears to have a development of an Empetrum heath which can be designated as Magellanic moorland formation and which may be linked with similar developments in the uppermost portions of the other two cores. Zone C is generally similar to the modern flora, the main difference being that I have characterized it as an Empetrum heath in contrast with the modern habitat which has been described as a boggy Marsippospermum heath. The lack of durability for Juncaceae pollen would account for this basic difference, although some Juncaceae pollen is found in zone C. Field notes accompanying the core describe the present vegetation as being composed of abundant Empetrum, some Pernettya, and an occasional Chiliotrichium. The hillsides today contain Astelia, Blechnum, Caltha, Drimys (occasionally), Myrteola, Nothofagus betuloides, and Pernettya. N. antarctica has not been described from the modern flora at that site, and it is interesting that N. antarctica is absent from zone C, although it appears to be present in all the other samples of Core III.

Paleoecological Interpretation for Core VI (Bahia Crossley)

The longest of the three cores, Core VI, preserves the most detailed account of the Postglacial vegetational and paleoecological changes for Isla de los Estados. From the pollen record it is not always possible to separate the local or edaphic factors from the regional or paleoclimatic factors that account for the changing flora. In fact, most changes in the pollen spectrum are due to both local and regional factors interacting with one another in a very complex fashion.

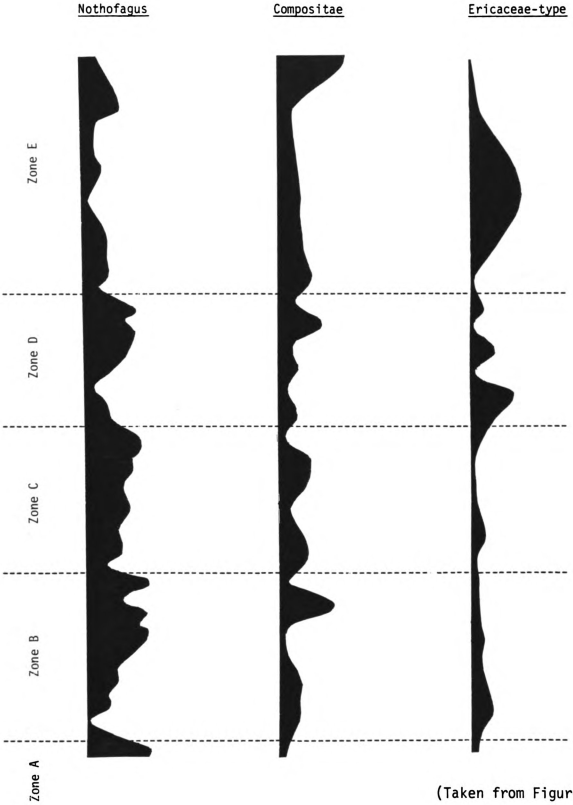
Local or edaphic changes in the pollen spectrum can be detected on occasion when the relative frequency for one taxon changes dramatically while concurrently the frequencies of most of the other taxa do not shift dramatically. The closest example of this is in sample Pb9768 where the Gramineae are dominant. Although Gunnera, Compositae, and the Ericaceae-type pollen also decline somewhat, the remaining taxa remain relatively stable. It is possible that there was extensive dune formation at that time between the coring site and Bahia Crossley, which are approximately 0.4 km apart, and that these dunes were covered with Gramineae. According to the herbarium notes of the Isla de los Estados collection (Michigan State University Herbarium), *Hierochloe redolens* is the "dominant grass of the sand dunes" of the island, so it may have been the major constituent of the Gramineae peak. Today the dunes extend to approximately 50 m from the coring site. Another possibility is that extensive stands of tussock grass (*Poa flabellata*) developed on the headlands overlooking Bahia Crossley. Unfortunately it is impossible to differentiate *Hierochloe* pollen from *Poa*.

Another example of a more localized change in the pollen spectrum is the influx of *Astelia* in sample Pb9758. Possibly there may have developed a break in the *Nothofagus* forests on the slopes opening the way for the growth of *Astelia* mats. It is also possible that extensive wind damage, erosion, or storm activity may have developed these forest openings. Dinoflagellate cysts reach their highest concentration of any sample up to that point in the core, and this could be indicative of intensive storm activity. On the other hand, that part of the world is noted for its almost continuous storminess, so other factors could have been involved.

The long-term paleoclimatic trends in Core VI are dominated by four major climatic cycles which are reflected in four major cycles of pollen sequences. The four uppermost pollen zones define the limits of the four pollen sequences. It appears that three taxa, *Nothofagus*, Compositae, and the Ericaceae-type are involved in the four major pollen cycles, and these are diagramed in Figure 6. Each zone boundary

FIGURE 6

FOUR MAJOR VEGETATIONAL CYCLES IN CORE VI



(Taken from Figure 4)

is defined as the transition from relatively high *Nothofagus* percentages to relatively low percentages. For the duration of each zone *Nothofagus* gradually increases from minimum values to maximum. The transition from maximum back to minimum values is relatively rapid when contrasted with the gradual increase to a maximum. Zone A does not show a gradual increase in *Nothofagus* because the sampling ended at its base, but it is presumed if the sampling zone could have been extended to a lower level it might indicate a decrease in *Nothofagus* values below the present sample levels.

The Compositae and Ericaceae-Empetraceae cycles are out of phase with one another and with those of *Nothofagus*, but the length of each cycle is of approximately the same duration as the length of the corresponding *Nothofagus* cycle. The peak for each Compositae cycle is reached below the peak for each *Nothofagus* cycle. On the other hand the peak for each Ericaceae-Empetraceae cycle, although not having as great an amplitude, occurs above the corresponding peak of the *Nothofagus* cycle. It becomes immediately clear that we can infer from the pollen data of Core VI four major successional cycles. The succession follows the order of *Nothofagus*, Ericaceae-Empetraceae, and Compositae, this sequence being repeated at least four times during the Postglacial period. The following table designating the zone or subzone where each peak occurs illustrates the successional nature of these cycles as shown in Figures 4 and 6:

	Nothofagus	Ericaceae-type	Compositae
Zone	A	B-1	B-2
	B-2	C-1	C-3
	C-3	D-1	D-2
	D-2	E-1	E-2

The four vegetational cycles can be described in terms of the major plant formations found on the island today. At the tops of zones B,C, and D *Nothofagus* reaches a maximum development, and this can be characterized as Magellanic evergreen forest. The main constituent of this forest appears to have been *N. betuloides* accompanied by a relatively small proportion of *Drimys winteri*. According to the computer analysis of *Nothofagus*, *N. antarctica* maintains an amazingly consistent pattern of relatively low percentages of total pollen, usually between 2% and 8%. This would seem to indicate that *N. antarctica* probably has existed in its usual stands of scrub at higher elevations continuously over a large portion of the Postglacial period. This also corresponds to the modern vegetation summary for the habitat surrounding the core site. *N. antarctica* is said to exist today on the higher slopes with a few scattered individuals along a nearby stream. *Drimys winteri* also has very few representatives in the valley, but it becomes more abundant on the lower hillsides. Today some scrub *N. betuloides* occupies the meadow and the stream side, and an abundance of this evergreen southern beech occurs on all the surrounding slopes. It would seem that during the maximum development of the evergreen forest, *N. betuloides* must have spread more extensively into the meadows surrounding the core site more so than its present destination.

The second component of the vegetational cycles, the Ericaceae-Empetraceae, can be correlated best with the *Empetrum* association of the Magellanic moorland formation. This stands in contrast to the present-day picture because the field notes accompanying the core do not mention the presence of *Empetrum*. The third and fourth cycles of the *Empetrum* heath development are noted for their higher relative frequencies of pollen than do the first two. The last cycle is especially significant in terms of the extent of heath development both spatially and temporally. It must have been a strong dominant over the other vegetation formations for a considerable period of time due to its representation in more than a meter of the core. The four Ericaceae-types, *Empetrum*, *Gaultheria*, *Lebetanthus*, and *Pernettya*, have been identified in the pollen record here, and all appear to be members of this heath, which must have occupied the meadow as well as the slopes.

The third component of the vegetational cycles, the Compositae, achieve a peak that is usually quite dominant prior to the time when *Nothofagus* reaches it maximum. In the modern flora the composites *Chiliotrichium diffusum* and *Senecio smithi* are listed as being present. It is difficult to assign this part of the cycle to any particular vegetation formation because the composites are so numerous and diverse in their ecological requirements that one would not want to limit them to any one habitat. One that possibly would fit the pollen profile is the meadow formation, which is dominated by *Marsippospermum*. Both *Chiliotrichium* and *Senecio* are members of this formation, which is the dominant formation around the core sight today.

The question can be asked, At what point does the present-day surface intersect the climatic and vegetational cycles? Definitely the modern vegetation does not represent the Ericaceae-Empetraceae heath formation because *Empetrum* does not appear to be a member of the modern flora. Also the highest sample in the core (Pb9733) has less than 2% of that type of pollen. The *Nothofagus* forest does not seem to have reached its maximum development, otherwise sample Pb9733 should have much more *Nothofagus* pollen than it does have. In addition, the unforested meadow around the core site today would allow for a much more extensive development of the Nothofagus forests. The evidence is strongest that the present flora represents an intersection with the maximum development of the Compositae portion of the cycle. As already noted, the Compositae achieve their greatest dominance in sample Pb9733. Unfortunately, no samples higher in the core than that are available for analysis.

The larger question and more speculative one is this, Can we use these inferred paleoclimatic and paleoecological cycles as a means of prediction? It lies outside the scope of this study to answer that question because it would depend on many contingencies, the main one being whether the cycles are repetitive in the same order of succession. Another is the question of the duration of the cycles, especially the question of how variable are the lengths of the cycles.

The Compositae and Ericaceae-Empetraceae components of the cycles usually fluctuate in an inverse relationship to one another. This can be noted by a careful comparison of the adjacent columns for each on the diagrams (Figures 4 and 6). The question should be raised as to whether they are competing taxa. The Ericaceae-Empetraceae do not always compete with the Compositae for the same ecospace, for the maximum development of the former do not always result in the decline of the latter. However, competition may be in the other direction, the Compositae competing for the ecospace of the Ericaceae-Empetraceae. It should be noted that whenever the Compositae reach their maximum development the Ericaceae-Empetraceae decline to very low percentages, or in the case of one sample (Pb9777) the latter disappears from the record entirely. The competition between these two taxonomic groups may help to explain in the future the nature of these paleoclimatic cycles.

Synthesis

In making over-all comparisons between the paleoecological interpretations of the three cores, one prominent feature is the development of heavily dominant Empetrum heaths as indicated in the top portion of all three cores. From this it can be concluded that during a period of several centuries, or perhaps longer, Isla de los Estados was blanketed by a major vegetational formation in the lower elevations, that of a Magellanic heath with a dominant Ericaceae-type association. This same phenomenon has occurred across Tierra del Fuego as depicted on Auer's pollen diagrams for southern Patagonia (Auer, 1958). The pollen diagram from La Mision shows an Empetrum peat at 3.0 m in the 9.2 m core and the continued presence of Empetrum (Markgraf, 1977). However, its values are much lower than those on Isla de los Estados, rising to just over 5% relative frequency at its maximum. Even though the La Mision site cannot be characterized as having an Empetrum heath due to its classification as Patagonian steppe formation, it does indicate that conditions were more favorable for the growth of Empetrum at the 3 m level than perhaps at any other point in the Postglacial period. The pollen diagrams from Isla de los Estados and other parts of Tierra del Fuego can be justifiably used to determine certain paleoclimatic trends during the Late Quaternary.

For Isla de los Estados a climatic factor readily derived from the pollen profiles is that of temperature. The arboreal pollen percentages of the three cores are thought to be directly correlated with temperature changes. There appears to be a cyclicity of fluctuations from high to low AP percentages, which could not be explained on any other climatic basis, such as, storm damage or precipitation changes. As already noted previously, the arboreal pollen percentages, which are composed basically of Nothofagus with an occasional 1% or 2% of Drimys, correlate well with the varying fluctuations between N. antarctica and N. betuloides.

If the arboreal pollen percentages, which are essentially the Nothofagus percentages, are temperature-dependent, then we should expect to find a degree of correlation with the other temperature curves for southern South America. Unfortunately most of the pollen diagrams for this part of the world have not been translated into temperature curves. Auer (1974) interpreted his diagrams more in terms of sea level fluctuations than in terms of temperature changes. Markgraf (1977), in reinterpreting Auer's La Mision diagram on the basis of sampling again the entire section, found in the pollen record evidences of humidity as well as temperature changes, although her study does not report a temperature curve. In northern South America some of the Late Quaternary pollen diagrams have been interpreted in terms of vegetational zones changing altitudinally, lake levels fluctuating synchronously with zone shifts, and sea levels fluctuating, all of which are related to temperature changes (Van der Hammen, 1974a, 1974b).

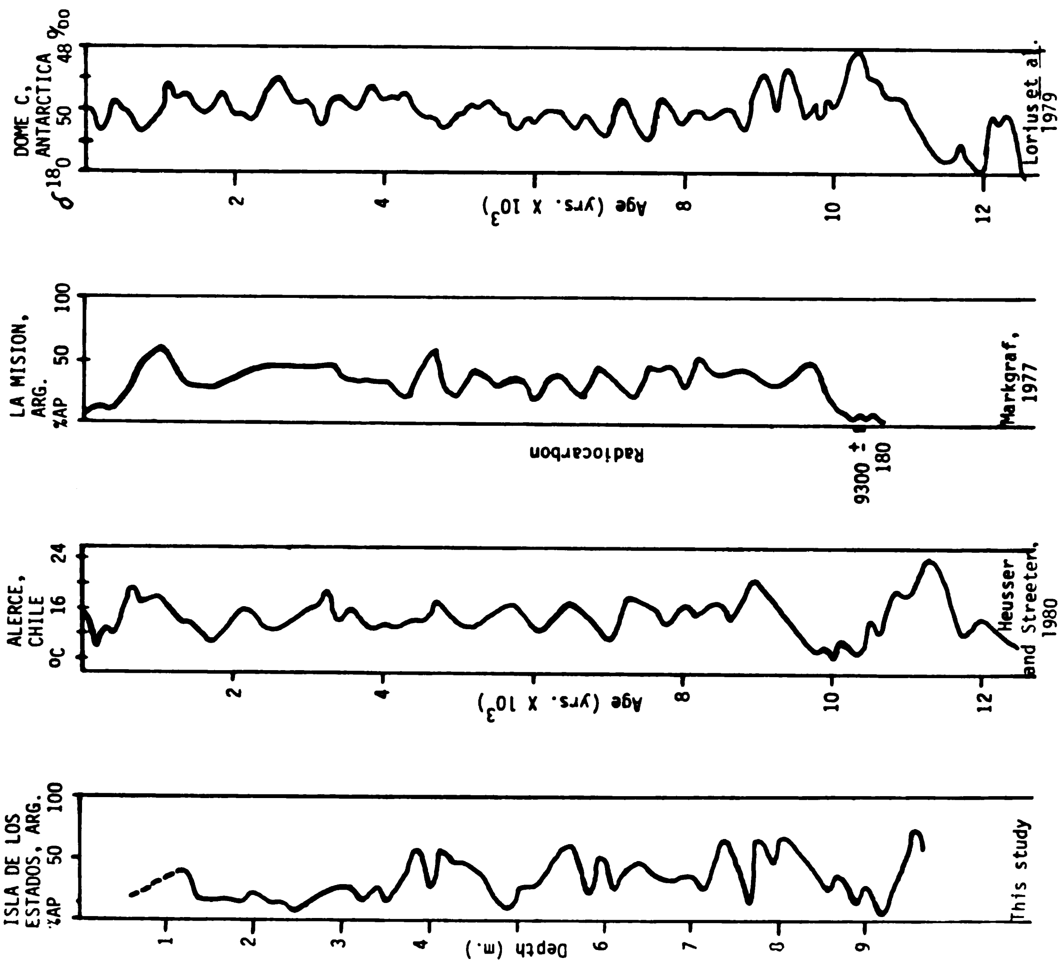
The best and most detailed temperature curve for the Late Quaternary of southern South America has been produced by Heusser and Streeter (1980), covering the last 16,000 years. They first derived a set of regression equations from modern pollen rain in various parts of Chile by which pollen data can be directly correlated with mean January (summer) temperature. Then they applied these equations to the pollen data found in a radiocarbon-dated core obtained from the lake bottom at Alerce, Chile. The temperature curve for the Postglacial time at Alerce, Chile, describes an overall pattern having similar ties with the arboreal pollen curve at Bahia Crossley, Isla de los Estados, Argentina (Figure 7). Unfortunately, we do not have radiocarbon dates for a more precise comparison with the Chilean data.

In addition to the temperature curve, Heusser and Streeter (1980) prepared a precipitation curve described as mean annual precipitation for the Alerce area. With some exceptions the precipitation curve is the inverse of the temperature curve. A comparison between the precipitation curve of Alerce with the arboreal pollen curve at Bahia Crossley indicates that the Nothofagus fluctuations of Isla de los Estados should be viewed indeed as directly correlated with temperature, not precipitation changes.

The Isla de los Estados temperature curve also has been compared with the re-interpreted La Mision diagram (Markgraf, 1977; D'Antoni, 1980). Figure 7 suggests that the two curves are not as closely parallel to each other as the Bahia Crossley and Alerce diagrams are. This at first appears strange in view of the fact that the first two are separated by only about one degree latitude, while the Bahia Crossley and Alerce sites are separated by 13^{o} latitude. The apparent anomaly of how two widely separated geographical areas could have closer pollen and temperature patterns than two geographically close sites is clarified by an examination of the present climatic

FIGURE 7

COMPARISON OF THE LATE QUATERNARY PALEOTEMPERATURE TRENDS IN THE HIGH LATITUDES OF THE SOUTHERN HEMISPHERE



regimes in each. Alerce and Bahia Crossley are both in areas of high precipitation and relatively moderate differences between summer and winter mean temperatures, thus they support a rain-forest vegetation. The main differences are that the former lies in the Valdivian rain forest and has a higher mean temperature, and the latter is found in the Magellanic rain forest. The precipitation for Alerce today is 1933 mm annually (Heusser, 1974), while for Isla de los Estados it is 1701 mm annually (Table 3). This stands in contrast with La Mision, which today lies outside of the Magellanic rain forest and which has an annual precipitation of less than 500 mm (Markgraf, 1977). It lies within the vegetation province known as Patagonian steppe. It appears, then, that the Nothofagus curve from La Mision diagram may be a reflection as much of precipitation changes as of temperature. Once the mean annual precipitation in the past exceeded 800 mm, then enough moisture would be present for a Nothofagus forest to begin to develop. When precipitation levels dropped to that of the present level, Patagonian steppe would be the natural result. The Nothofagus curve of La Mision would not be expected to closely parallel that of Isla de los Estados.

Besides temperature data derived from the Nothofagus curve of the Bahia Crossley core, it is possible to derive precipitation data. It appears that the percentage changes in the Ericaceae-like taxa (Empetraceae, Epacridaceae, Ericaceae) are dependent upon precipitation changes. The dominant species in the southern oceanic wet-heathlands is Empetrum rubrum (Moore, 1979), and the dominant Ericaceae-type pollen in all three cores is Empetrum rubrum, the only species of Empetrum in the Magellanic region. The precipitation in the heathland or

Magellanic moorland varies in annual values from 5000 mm on Isla Wellington, Chile, to 600 mm on the Falkland Islands (Moore, 1979). Although many factors, such as cloud cover, soil run-off, exposure to prevailing winds, can be responsible for variations in heathland composition, one major factor in the development of the heathland is precipitation.

Besides temperature and precipitation, another important climatic factor which has had an effect on the vegetation history of Isla de los Estados is that of wind. As mentioned earlier, the wind is a major factor in the formation of the Nothofagus "krumholz". Generally the effects of wind would be nearly impossible to detect from an analysis of the pollen profiles, but the three Isla de los Estados cores offer the unusual possibility of ascertaining the wind effects by means of marine dinoflagellates, which are found almost continuously throughout the core samples. They are roughly in two different sizes and are illustrated in Plate 6 (Figures 6-13, 6-14, and 6-15). The smaller sized dinoflagellates definitely outnumber the larger ones, possibly due to the fact that the wind would have transported the smaller ones greater distances and due in part to smaller forms being in near shore waters.

Most likely the marine dinoflagellates have been transported to the three core sites by means of wind rather than by flooding of the peat deposits. There is no evidence of marine transgressions as there is for the La Mision site to the northwest on Isla Grande (Auer, 1974; Markgraf, 1977). As wind squalls would pick up moisture from the ocean surface or as the wind would scatter the salt spray created from the wave action on the rocky shore, dinoflagellates could easily have been carried in the sea water droplets and deposited at their present location inland. It is theorized that an increase in their relative numbers may indicate an increase in storm or wind activity. All three core sites are in sheltered areas at the end of narrow bays, so the presence of dinoflagellates becomes all the more remarkable and attests to the force of the wind. The isthmus between Puerto Vancouver and Puerto Cook has the lowest relative percentages, and zones D and E of Core VI at Bahia Crossley have the highest. Bahia Crossley has an exposure only to the northwest, Puerto Celular has an exposure only to the south or southeast, and Puerto Vancouver-Puerto Cook has an exposure both to the north and to the south.

Ultimately it may be possible to compare the temperature profile of Isla de los Estados with those which are being obtained from Antarctic ice cores by means of oxygen isotope ratios (Johnsen, et al., 1972; Robin, 1977; Lorius, et al., 1979). With the present technology, the ice cores cannot be dated with radiocarbon, and their ages have to be estimated using complex methods. The only ice-core climatic record which has been correlated with the radiocarbon time scale is the one obtained from Dome C, which is nearly 2000 km from the South Pole in the direction opposite to that of South America (Lorius, et al., 1979). The resulting temperature curve from Dome C can be compared with the pollen curve from Bahia Crossley (Figure 7), but much more work needs to be done at both sites before any cross-correlations are attempted. It may be possible that the Antarctic oxygen isotope studies will help to clarify the enigmas surrounding the four major paleoecological cycles in the Bahia Crossley pollen diagram.

Future studies of the Late Quaternary palynology of Isla de los Estados should concentrate on tying the vegetation history firmly with the radiocarbon time scale, converting the pollen profiles into temperature and precipitation values, correlating surface samples and present-day pollen rain with the pollen data, correlating variations in aperture numbers of *Nothofagus* pollen from fossil samples with those from living *Nothofagus*, determining the cause and the timing for the four major paleoclimatic cycles as inferred from the Postglacial pollen record, constructing the fluctuations of vegetation patterns throughout the island within the larger context of vegetation changes for all of southern South America, and testing the feasibility of correlating paleoclimatic pattern changes between southern South America and Antarctica.

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APPENDICES

APPENDIX A

PROCESSING AND MOUNTING TECHNIQUES

(1) Place approximately 50 ml of 5% KOH in a small glass beaker and add the peat sample.

(2) Heat the KOH to the boiling point in a water bath and stir peat mixture into the KOH using a glass stirring rod to break up and disperse the peat mass. Allow the sample to boil very gently for several minutes until the peat is completely dispersed. The KOH solution should be dark brown.

(3) Pour the contents of the beaker through a fine screen and collect the filtrate and fine residue in a second beaker. Carefully wash the residue remaining on the screen, using a wash bottle, to extract additional fine material. Discard the coarse material remaining on the screen.

(4) Transfer the contents of the second beaker into 90 ml glass centrifuge tubes and centrifuge at 1550 RPM for 5 minutes.

(5) Alternately wash with distilled water and centrifuge the contents of the tube 3 times.

(6) After the third wash in distilled water transfer the contents of the tube into a sample vial using a small amount of distilled water.

(7) Spin down the contents of the vial using a clinical style centrifuge for 2 minutes.

(8) Remove excess water using the aspirator and add 3 drops of safranin O stain. Shake the vial to mix the contents and allow to stand for 20 minutes.

APPENDIX A (cont'd)

(9) Fill the vial with water, mix thoroughly and centrifuge for 2 minutes. Aspirate the supernatant liquid. Repeat this process until the supernantant liquid shows no trace of stain.

(10) Add an amount of melted glycerin jelly appropriate to the volume of residue; shake the vial to mix the contents, cap securely and store.

Mounting residue on microscope slides:

(1) Place the vial containing the residues in hot water bath until the glycerin jelly will flow easily.

(2) Put two drops of the residue on glass cover slip 22 mm round or square. Use No. 1 or No. 1½ thickness glass (11-17 micrometers).

(3) Center a properly labeled standard 25 x 75 mm microscope slide on the cover slip and turn over assembled slide to an upright position.

(4) Place the mounted sample on a warming table to cause the glycerin jelly to spread evenly.

(5) Seal the sample permanently by applying clear enamel (such as fingernail polish) around the edges of the cover slip.

APPENDIX B

COMPUTER PROGRAM FOR DIFFERENTIATING NOTHOFAGUS SPECIES

Radio Shack TM Level II BASIC for the TRS-80 Model 1 Microcomputer

```
10 CLS:PRINT"NOTHOFAGUS IDENTIFICATION PROGRAM"
20 PRINT"ISLA DE LOS ESTADOS POLLEN STUDY"
30 PRINT
40 INPUT"SAMPLE NUMBER";S$
50 INPUT"TOTAL POLLEN";TP
60 INPUT"TOTAL NOTHOFAGUS";TN
70 INPUT"TOTAL 7 PORED NOTHOFAGUS";T7
80 INPUT"TOTAL 5 PORED NOTHOFAGUS";T5
90 CLS
100 LPRINT".":LPRINT".":LPRINT"SAMPLE: ";S$
110 A7=.47
120 A5=.03
130 B5=.67
140 TA=T7/A7:TA=INT(TA)
150 T5=T5-(T5*A5)
160 TB=T5/B5:TB=INT(TB)
170 IF (TA+TB)>TN THEN TB=TN-TA:TX=0:GOTO200
180 IF (TA+TB)=TN THEN TX=0:GOTO200
190 TX=TN-(TA+TB)
200 LPRINT"TAXON","TOTAL","PERCENT"
210 LPRINT"N. ANTARCTICA",TA,(TA/TP)*100
220 LPRINT"N. BETULOIDES",TB,(TB/TP)*100
230 LPRINT"UNK. NOTHOFAGUS",TX,(TX/TP)*100
240 LPRINT"ALL NOTHOFAGUS",TN,(TN/TP)*100
250 CLS
260 INPUT"ANOTHER SAMPLE (Y/N)";R$
270 IF R$="Y" THEN CLS:GOTO 40
280 IF R$="N" THEN END
290 CLS:GOTO 260
```

APPENDIX C

NOTHOFAGUS APERTURE COUNT--CORE II

Pb Sample Number	Number of apertures: 4	5	6	7	8	Total Nothofagus	Total Pollen
9694		10	10			20	100
9695	3	25	23			51	200
9696		9	2	1		12	100
9698		58	60	7		125	200
9699	2	28	16	1		47	90
9700		15	15	1		31	100
9701	5	33	28	1		67	200
9702	2	23	14			39	100
9705	3	55	37	3		98	200
9706	1	48	34			83	100
9707		76	74	3		153	200
9708	1	28	31	1		61	100
9709	1	26	15	1		43	200
9710	2	14	13			29	100
9711		18	26	1		45	100
9712	1	24	23	1		49	200
9715	2[a]	46	54	4		106	200
9716		24	28	1		53	100
9717	2	17	12	1	1	33	100
9718	7	60	61	7		135	200
9719	1	29	43			73	100

---

[a] Includes one Nothofagus grain with three apertures.

APPENDIX C (cont'd)

Pb Sample Number	Number of apertures: 4	5	6	7	8	Total *Nothofagus*	Total Pollen
9720	1	24	57	1		83	100
9721	5	70	87	18	3[b]	183	300
9722		19	37	2		58	100
9723	2	15		1		44	100
9724			3		1	4	200
9725			3			3	150
9726		3	3			6	100
9727		1	1			2	150
9728		1	1			2	84
9731						0	250

---

[b] Includes one grain with nine apertures.

APPENDIX D

NOTHOFAGUS APERTURE COUNT--CORE III

Pb Sample Number	Number of apertures: 4	5	6	7	8	Total Nothofagus	Total Pollen
9676	1	10	7			18	182
9680	4	106	66	2		178	250
9681		48	40	2		90	100
9683		150	172	6		278	300
9685		41	25	13		79	200
9687		49	122	11		182	200
9688		7	7			14	200
9691		6	10	1		17	200
9693		3	3	1		7	200

APPENDIX E

NOTHOFAGUS APERTURE COUNT--CORE VI

Pb Sample Number	Number of apertures: 4	5	6	7	8	UN[a]	TN[b]	Total Pollen
9733		9	14	2		3	28	150
9736	1	9	11	1			22	124
9737	2	25	26	2		1	56	142
9740	1	12	9			1	23	150
9741		14	22	3		1	40	200
9742		17	11			3	31	188
9744	1	18	16	3		1	39	600
9745		6	12			5	23	200
9747	3	15	14	4		2	38	150
9748	1	27	18	2		6	54	200
9749		22	12				34	200
9750	3	45	17			3	68	250
9751	1	20	11			3	35	200
9752	4	38	34	2		1	79	200
9753	2	51	54	3		5	115	200
9754	2	13	22			3	40	150
9755	1	35	19	1			56	100
9756	5	78	90	9	2[c]	5	189	400

---

[a] UN refers to unknown *Nothofagus*, i.e. *Nothofagus* whose precise aperture count is unavailable.

[b] TN refers to total *Nothofagus*, including the UN count.

[c] Includes one grain with nine apertures.

APPENDIX E (cont'd)

Pb Sample Number	Number of apertures:					UN[a]	TN[b]	Total Pollen
	4	5	6	7	8			
9757		46	41	5		2	94	200
9758	1	39	25	3			68	200
9759	1	12	27	9		3	52	300
9760	3	11	10	3			27	300
9761	3	48	39	2		3	95	400
9762	5	67	76	8		7	163	600
9763	6	123	93	4		4	230	400
9764	7	97	69	5		4	182	300
9765	3	22	15	1		2	43	200
9766		46	43	4		7	100	200
9767	1	36	26	6		7	76	300
9768	1	45	26	1		5	78	200
9769	9	92	63	13		15	192	400
9770	2	30	36	6		3	77	200
9771		26	49	6		14	95	300
9772	2	36	29	4		5	76	200
9773	3	36	27	3	1	5	75	200
9774	2	17	21	6		2	48	200
9775	2	54	38	5		33	132	200
9776	3	31	42	3		18	97	200
9777		13	10	2		2	27	200
9778	1	59	47	5	1	17	130	200
9779	2	62	68	9			141	300

APPENDIX E (cont'd)

Pb Sample Number	Number of apertures: 4	5	6	7	8	UN[a]	TN[b]	Total Pollen
9780	4	128	143	10	3	50	338	500
9781	1	43	49	6		2	101	200
9782	3	102	71	11		5	192	800
9783	2	57	70	7		3	139	400
9784	4	56	77	8	1	8	154	1300
9785	1	43	82	10	2	12	150	600
9786		14	2				16	700
9787	4	56	51	3		6	120	500
9788		43	84	10		19	156	300
9789	2	68	45	8		19	142	200
9790	1	87	75	3		11	177	300
TOTAL	106	2199	2081	221	10	336	4953	

PLATES

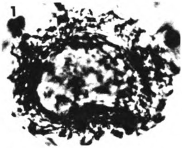
PLATE 1

Figure		Coordinates
	PTERIDOPHYTA	
1	Aspidiaceae: *Polystichum* sp.	Pb9726 V+7.7 X H+10.6
2	Gleicheniaceae: *Gleichenia* sp.	Pb9699 V-4.9 X H+20.4
3	Hymenophyllaceae: *Hymenophyllum* sp.	Pb9762 V+6.9 X H+19.2
4	Hymenophyllaceae: *Hymenophyllum* sp.	Pb9719 V+2.4 X H+15.4
5	Lycopodiaceae: *Lycopodium magellanicum*	Pb9730 V+2.1 X H+11.5
6	Lycopodiaceae: *Lycopodium magellanicum*	Pb9730 V+2.1 X H+11.5
7	Lycopodiaceae: *Lycopodium fuegianum*	Pb9691 V-4.8 X H+20.0
8	Lycopodiaceae: *Lycopodium fuegianum*	Pb9691 V-4.8 X H+20.0
9	Lycopodiaceae: *Lycopodium* sp.	Pb9715 V-4.5 X H+23.1
10	Ophioglossaceae: *Botrychium* sp.	Pb9784 V-9.7 X H+23.1
11	Polypodiaceae	Pb9711 V+4.9 X H+7.0
12	Polypodiaceae	Pb9739 V+5.8 X H+5.0
13	Polypodiaceae: *Blechnum* sp.	Pb9724 V-9.4 X H+23.8
14	Polypodiaceae: *Blechnum* sp.	Pb9691 V-5.8 X H+27.8
15	Podocarpaceae: *Podocarpus* sp.	Pb9685 V-6.3 X H+24.4
16	Ephedraceae: *Ephedra* sp.	Pb9757 V-2.9 X H+17.3
17	Alstroemeriaceae: cf. *Alstroemeria haemantha*	Pb9693 V-8.9 X H+22.3

All illustrations 1000X. Coordinates given in terms of mm of horizontal (H) or vertical (V) movement in an upward (+) or downward (-) direction from reference point.

PLATE 1

1



3

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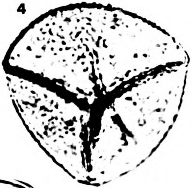


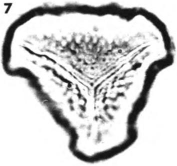
5

6

11

2

7



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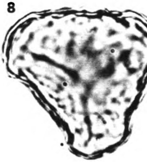

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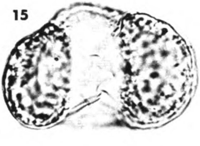

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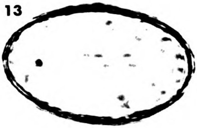

17

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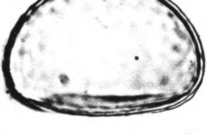

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PLATE 2

ANGIOSPERMAE, MONOCOTYLEDONAE

Figure		Coordinates
1	Centrolepidaceae: *Gaimardia australis*	Pb9731 V-6.5 X H+5.6
2	Centrolepidaceae: *Gaimardia australis*	Pb9731 V-6.5 X H+5.6
3	Cyperaceae: cf. *Carex* sp.	Pb9753 V-1.4 X H+11.3
4	Cyperaceae: cf. *Cyperus* sp.	Pb9691 V+7.4 X H+14.2
5	Cyperaceae: cf. *Scirpus* sp.	Pb9771 V-6.7 X H+22.3
6	Cyperaceae: cf. *Uncinia* sp.	Pb9731 V-5.6 X H+7.1
7	Gramineae	Pb9693 V+6.2 X H+11.1
8	Gramineae	Pb9721 V+4.8 X H+16.2
9	Gramineae	Pb9771 V+0.6 X H+4.8
10	Iridaceae: *Tapeinia* sp.	Pb9731 V+4.3 X H+16.1
11	Juncaceae: *Marsippospermum* sp.	Pb9731 V+4.7 X H+18.4
12	Juncaceae: *Patosia* sp.	Pb9691 V-2.1 X H+27.1
13	Juncaginaceae: *Tetroncium magellanicum*	Pb9709 V-5.9 X H+11.3
14	Juncaginaceae: *Triglochin* sp.	Pb9685 V-4.5 X H+10.3
15	Liliaceae: *Astelia pumila*	Pb9691 V+0.9 X H+22.3
16	Liliaceae: *Astelia pumila*	Pb9724 V+2.2 X H+19.7
17	Orchidaceae: cf. *Chloraea magellanica*	Pb9731 V+4.6 X H+14.1

ANGIOSPERMAE, DICOTYLEDONAE

Figure		Coordinates
18	Callitrichaceae: *Callitriche* sp.	Pb9685 V+11.0 X H+18.7
19	Calyceraceae: *Boopis*, cf. *B. gracilis*	Pb9731 V+4.7 X H+15.9
20	Caryophyllaceae: *Colobanthus* sp.	Pb9727 V-6.6 X H+24.4
21	Caryophyllaceae: *Cerastium* sp.	Pb9737 V-5.4 X H+7.7
22	Caryophyllaceae: *Cerastium* sp.	Pb9737 V-5.4 X H+7.7
23	Caryophyllaceae: *Spergularia marina*	Pb9730 V-1.1 X H+21.5
24	Celastraceae: *Maytenus disticha*	Pb9755 V-6.1 X H+12.4
25	Celastraceae: *Maytenus disticha*	Pb9755 V-6.1 X H+12.4

All illustrations 1000X. Coordinates given in terms of mm of horizontal (H) or vertical (V) movement in an upward (+) or downward (-) direction from reference point.

PLATE 2

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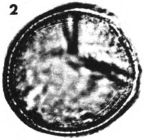

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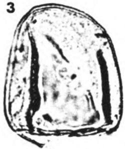

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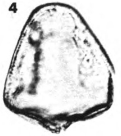

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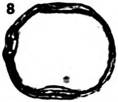

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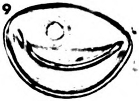

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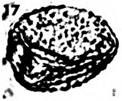

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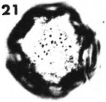

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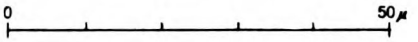

PLATE 3

Figure		Coordinates
	ANGIOSPERMAE, DICOTYLEDONAE	
1	Chenopodiaceae: cf. *Suaeda* sp.	Pb9755 V+1.1 X H+7.5
2	Chenopodiaceae: cf. *Suaeda* sp.	Pb9755 V+1.1 X H+7.5
3	Compositae: cf. *Adenocaulon* sp.	Pb9749 V+4.1 X H+8.9
4	Compositae: *Ambrosia* sp.	Pb9690 V+8.5 X H+11.2
5	Compositae: *Ambrosia* sp.	Pb9690 V+8.5 X H+11.2
6	Compositae: cf. *Baccharis* sp. or *Gutierrezia* sp.	Pb9706 V-7.9 X H+21.4
7	Compositae: cf. *Chiliotrichium* sp. or *Cotula* sp.	Pb9765 V+1.7 X H+9.2
8	Compositae: cf. *Chiliotrichium* sp. or *Cotula* sp.	Pb9765 V+1.7 X H+9.2
9	Compositae: cf. *Hypochoeris* sp. or *Senecio* sp.	Pb9785 V-2.5 X H+20.3
10	Compositae: *Mutisia* sp.	Pb9721 V-7.2 X H+26.2
11	Compositae: *Nassauvia* sp.	Pb9724 V-6.6 X H+14.3
12	Compositae: *Nassauvia* sp.	Pb9786 V-3.1 X H+17.3
13	Compositae: *Nassauvia* sp.	Pb9786 V-3.1 X H+17.3
14	Compositae	Pb9731 V+6.0 X H+9.1
15	Compositae	Pb9731 V+6.0 X H+9.1
16	Compositae	Pb9733 V-2.7 X H+8.5
17	Crassulaceae: *Crassula moschata*	Pb9711 V-10.1 X H+13.0
18	Crassulaceae: *Crassula moschata*	Pb9695 V+7.5 X H+21.4
19	Cruciferae: *Cardamine* sp.	Pb9767 V+5.1 X H+23.2
20	Cruciferae: *Draba magellanica*	Pb9700 V+7.8 X H+21.4
21	Cruciferae: *Draba magellanica*	Pb9700 V+7.8 X H+21.4
22	Droseraceae: *Drosera uniflora*	Pb9721 V-6.1 X H+9.9
23	Empetraceae: *Empetrum rubrum*	Pb9784 V-3.4 X H+7.1
24	Empetraceae: *Empetrum rubrum*	Pb9695 V+4.0 X H+23.7
25	Empetraceae: cf. *Empetrum rubrum*	Pb9730 V-9.0 X H+18.3
26	Ericaceae: *Gaultheria antarctica*	Pb9771 V+7.6 X H+3.8
27	Epacridaceae: *Lebetanthus myrsinites*	Pb9691 V-6.5 X H+13.0
28	Ericaceae: *Pernettya* sp.	Pb9737 V-5.6 X H+6.1
29	Escalloniaceae: *Escallonia* sp.	Pb9751 V-7.7 X H+27.0

All illustrations 1000X. Coordinates given in terms of mm of horizontal (H) or vertical (V) movement in an upward (+) or downward (-) direction from reference point.

PLATE 3

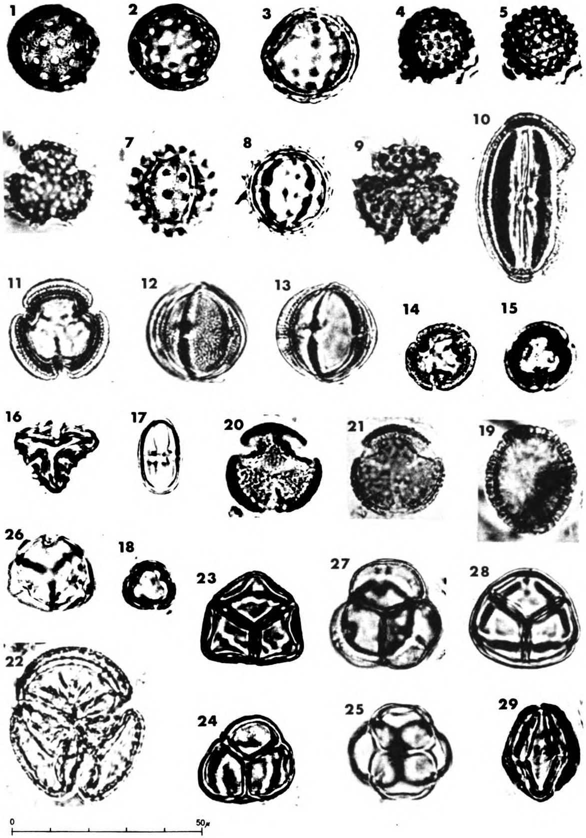
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PLATE 4

Figure		Coordinates
	ANGIOSPERMAE, DICOTYLEDONAE	
1	Euphorbiaceae: *Euphorbia* cf. *E. portulacoides*	Pb9717 V-6.9 X H+25.3
2	Fagaceae: *Nothofagus betuloides*	Pb9719 V+2.3 X H+13.1
3	Fagaceae: *Nothofagus antarctica*	Pb9724 V+1.5 X H+6.7
4	Fagaceae: *Nothofagus obliqua*	Pb9719 V+3.3 X H+15.4
5	Fagaceae: *Nothofagus pumilio*	Pb9691 V-2.0 X H+17.8
6	Gunneraceae: cf. *Gunnera lobata*	Pb9762 V-0.2 X H+10.5
7	Gunneraceae: *Gunnera magellanica*	Pb9786 V-1.4 X H+21.8
8	Gunneraceae: *Gunnera magellanica*	Pb9691 V-2.5 X H+9.8
9	Gunneraceae: *Gunnera magellanica*	Pb9691 V-2.5 X H+9.8
10	Gunneraceae: *Gunnera magellanica*	Pb9786 V-3.3 X H+14.4
11	Gunneraceae: *Gunnera magellanica*	Pb9721 V+0.1 X H+23.9
12	Haloragaceae: *Myriophyllum* cf. *M. elatinoides*	Pb9693 V+6.1 X H+27.8
13	Leguminosae: *Adesmia* sp.	Pb9694 V+5.7 X H+22.1
14	Lentibulariaceae: *Pinguicula antarctica*	Pb9761 V-6.2 X H+15.4
15	Plumbaginaceae: *Armeria maritima* (750X)	Pb9693 V+3.1 X H+26.0
16	Plumbaginaceae: *Armeria maritima* (750X)	Pb9693 V+3.1 X H+26.0

All illustrations are 1000 magnification, except for Figures 15 and 16 which are 750 magnification. Coordinates given in terms of mm of horizontal (H) or vertical (V) movement in an upward (+) or downward (-) direction from reference point.

PLATE 4

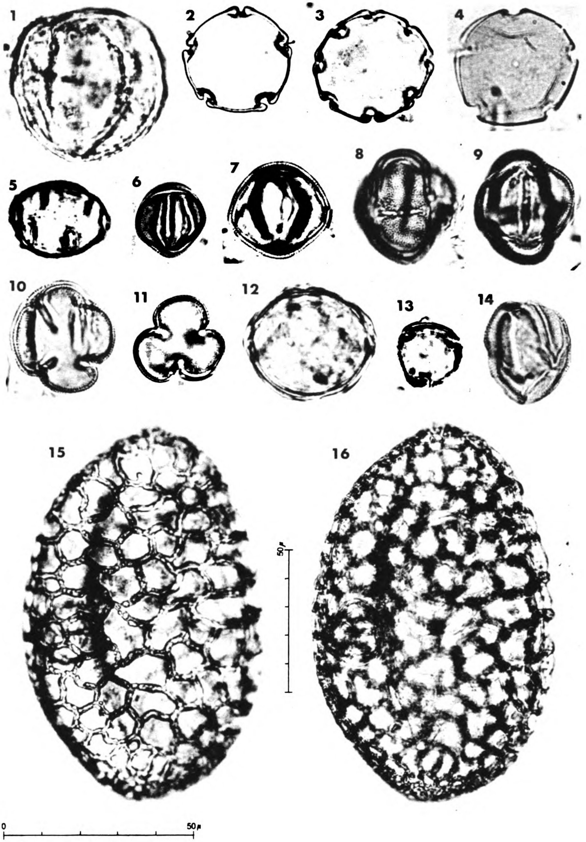

PLATE 5

Figure		Coordinates
	ANGIOSPERMAE, DICOTYLEDONAE	
1	Lobeliaceae: *Pratia repens*	Pb9724 V+9.9 X H+12.5
2	Myrtaceae: *Myrteola nummularia*	Pb9724 V-3.1 X H+5.5
3	Myrtaceae: *Myrteola nummularia*	Pb9724 V-6.3 X H+19.3
4	Myrtaceae: cf. *Amomyrtus* sp.	Pb9699 V-2.4 X H+19.0
5	Myzodendronaceae: *Myzodendron* sp.	Pb9788 V+6.3 X H+13.4
6	Plantaginaceae: *Littorella australis*	Pb9731 V+6.0 X H+13.0
7	Plantaginaceae: *Plantago* sp.	Pb9731 V-0.9 X H+5.5
8	Polygonaceae: *Koenigia islandica*	Pb9688 V-2.8 X H+8.5
9	Primulaceae: *Samolus spathulatus*	Pb9761 V-8.6 X H+25.1
10	Ranunculaceae: *Caltha* sp.	Pb9721 V+4.4 X H+26.0
11	Ranunculaceae: *Caltha* sp.	Pb9722 V+1.3 X H+14.3
12	Ranunculaceae: *Hamadryas* sp.	Pb9779 V-1.4 X H+14.0
13	Rosaceae: *Acaena* sp.	Pb9786 V+1.0 X H+23.7
14	Rosaceae: *Acaena* sp.	Pb9692 V+1.3 X H+17.3
15	Rubiaceae: *Nertera depressa*	Pb9740 V+3.5 X H+9.3
16	Rubiaceae: *Nertera depressa*	Pb9740 V+3.5 X H+9.3
17	Saxifragaceae: *Chrysosplenium macranthum*	Pb9692 V+2.4 X H+18.7
18	Saxifragaceae: *Chrysosplenium macranthum*	Pb9731 V+2.7 X H+17.7
19	Saxifragaceae: *Chrysosplenium macranthum*	Pb9731 V+2.7 X H+17.7
20	Saxifragaceae: *Ribes magellanicum*	Pb9727 V+6.4 X H+18.6
21	Scrophulariaceae: *Calceolaria* sp.	Pb9741 V+9.7 X H+7.3
22	Scrophulariaceae: *Hebe elliptica*	Pb9786 V+0.4 X H+16.2
23	Solanaceae: *Jabarosa* sp., cf. *J. magellanica*	Pb9724 V-8.0 X H+11.4
24	Thymelaeaceae: *Drapetes muscosa*	Pb9712 V+5.5 X H+20.8
25	Thymelaeaceae: *Drapetes muscosa*	Pb9712 V+5.5 X H+20.8
26	Umbelliferae: *Azorella* sp.	Pb9731 V-3.5 X H+8.9
27	Umbelliferae: *Azorella* sp.	Pb9731 V-4.7 X H+12.4
28	Valerianaceae: *Valeriana* sp., cf. *V. carnosa*	Pb9738 V-4.1 X H+10.5
29	Violaceae: *Viola* sp.	Pb9698 V+3.3 X H+5.0
30	Winteraceae: *Drimys winteri*	Pb9681 V-6.7 X H+14.1
	UNKNOWNS	
31	Unknown A, cf. *Calceolaria* or *Weinmannia*	Pb9692 V+1.8 X H+18.5
32	Unknown B, cf. *Tropaeoleum*	Pb9685 V-3.5 X H+10.7
33	Unknown C	Pb9691 V-1.4 X H+14.3
34	Unknown D, cf. *Asclepiadaceae*	Pb9767 V-8.5 X H+24.5

All illustrations 1000X.

PLATE 5

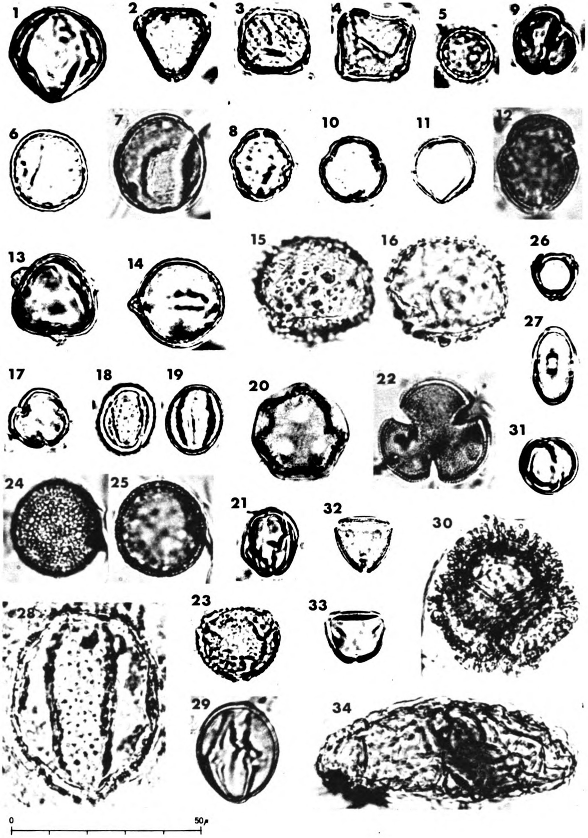
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PLATE 6

MISCELLANEOUS AND UNKNOWNS

Figure		Coordinates
1	Unknown E, cf. *Araucaria*	Pb9729 V+6.2 X H+25.1
2	Unknown F	Pb9780 V-7.3 X H+8.8
3	Unknown G	Pb9690 V-3.1 X H+17.8
4	Unknown H, cf. *Cupressus sempervirens*	Pb9730 V+6.2 X H+10.9
5	Unknown I	Pb9745 V-4.7 X H+21.3
6	Unknown J, cf. *Cyperaceae*	Pb9731 V+7.3 X H+13.4
7	Unknown K	Pb9691 V-2.0 X H+17.5
8	Unknown K	Pb9691 V-2.0 X H+17.5
9	Unknown L	Pb9749 V-1.7 X H+18.0
10	Unknown M, cf. *Hippuris vulgaris*	Pb9692 V+1.6 X H+17.6
11	Unknown N	Pb9691 V+1.9 X H+8.7
12	Sphagnaceae, *Sphagnum* sp.	Pb9786 V-9.4 X H+10.7
13	Marine dinoflagellate	Pb9692 V-4.9 X H+14.9
14	Marine dinoflagellate	Pb9691 V-3.3 X H+19.0
15	Marine dinoflagellate	Pb9685 V-1.7 X H+27.1
16	Hepaticales	Pb9770 V-1.9 X H+8.2

All illustrations 1000X. Coordinates given in terms of mm of horizontal (H) or vertical (V) movement in an upward (+) or downward (-) direction from reference point.

PLATE 6

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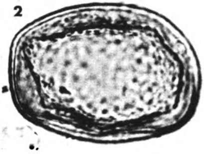

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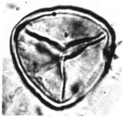

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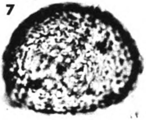

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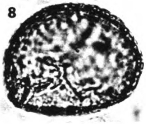

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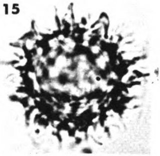

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