Reprinted from: Nishida, H. (ed.) *Post-Cretaceous Floristic Changes in Southern Patagonia, Chile,* ChuoUniv., Tokyo, p. 37-43, (2006)

PALEOCENE/EOCENE POLLEN ASSEMBLAGES FROM THE LIGORIO MÁRQUEZ FORMATION, CENTRAL PATAGONIA, XI REGION, CHILE

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The Ligorio Márquez Formation (Suárez *et al*., 2000) in the XI region of Chile (Chilean central Patagonia) is of fluvial to backmarsh origins of the Paleogene/Eocene. This strata is no more than 60 m thick and is composed of coal seams and flood plain deposits with abundant plant fossils, which have been the focus of attention in attempting to understand the floristic and climate history of southern South America during the early Tertiary period. The purpose of this palynological research is to confirm the presence or absence of *Nothofagus* pollen and to reconstruct the palynoflora of the Ligorio Márquez Formation. The consideration of this matter originated with a preliminary pollen report (Yoshida, 1990) suggesting the presence of temperate taxa such as *Nothofagus* and Podocarpaceae, which was inconsistent with the known tropical/subtropical megaflora from the same Formation (Suárez *et al*., 2000). Yoshida's (1990) hypothesis, if he was right, would reorganise the paleofloral and/or chronological frameworks during the Tertiary period south of Chile Chico, in order to reconcile with regional supertropical climate of the Late-Paleocene/Early-Eocene derived from the so-called Cenozoic Climate Optimum (e.g. Bowen *et al*., 2004; Svensen *et al*., 2004).

Phytogeographically, central Patagonia (which includes the Mina Ligorio Márquez area) is vital to an understanding of the history of *Nothofagus* migration through the Gondowana continent. *Nothofagus* (or Nothofagaceae) first appeared during the late Cretaceous period, and expanded toward the equator through the Tertiary period. *Nothofagus* records in central Patagonia (ca. 40°S) started in the late Eocene (see Tanai, 1986; Uemura, 1990) and many of the records consisted of only fragmentary pollen evidence, requiring a combination of systematic pollen analyses and plant megafossil excavations to obtain a more reliable documentation of *Nothofagus* history.

The pollen evidence derived by Yoshida (1990) showed the presence of *Nothofagidites*, *Podocarpidites* and *Myrtaceidites* based on a total of 815 counts of sporopollen. Although Yoshida(1990) did not noted the precise sampling horizon, his material was based on rocks from the layer 2 at Mina Ligorio Márquez (Figs. 1, 2). Troncoso *et al*. (2002), however, pointed out that Yoshida's (1990) pollen and spores assemblage differ in composition and characteristic pollen species from those of their analysis, and suggested a yonger age for Yoshida's assemblage.

In order to confirm these matters, we carried out a resampling with greater stratigraphic control of the Ligorio Márquez Formation. In particular (1) multiple analyses for tens of horizons from different facies and (2) a lithological column with descriptions of sampled horizons were presented. It should also be noted that a plant megafossil excavation and age determination were performed in parallel by the co-authors (see Terada *et al*., 2006; Yabe *et al*., both in this volume), resulting in a multiproxy analytical approach.

Field description of the Ligorio Márquez Formation

The Ligorio Márquez Formation, previously termed Ligorio Márquez Beds (Suárez and de la Cruz, 1996),

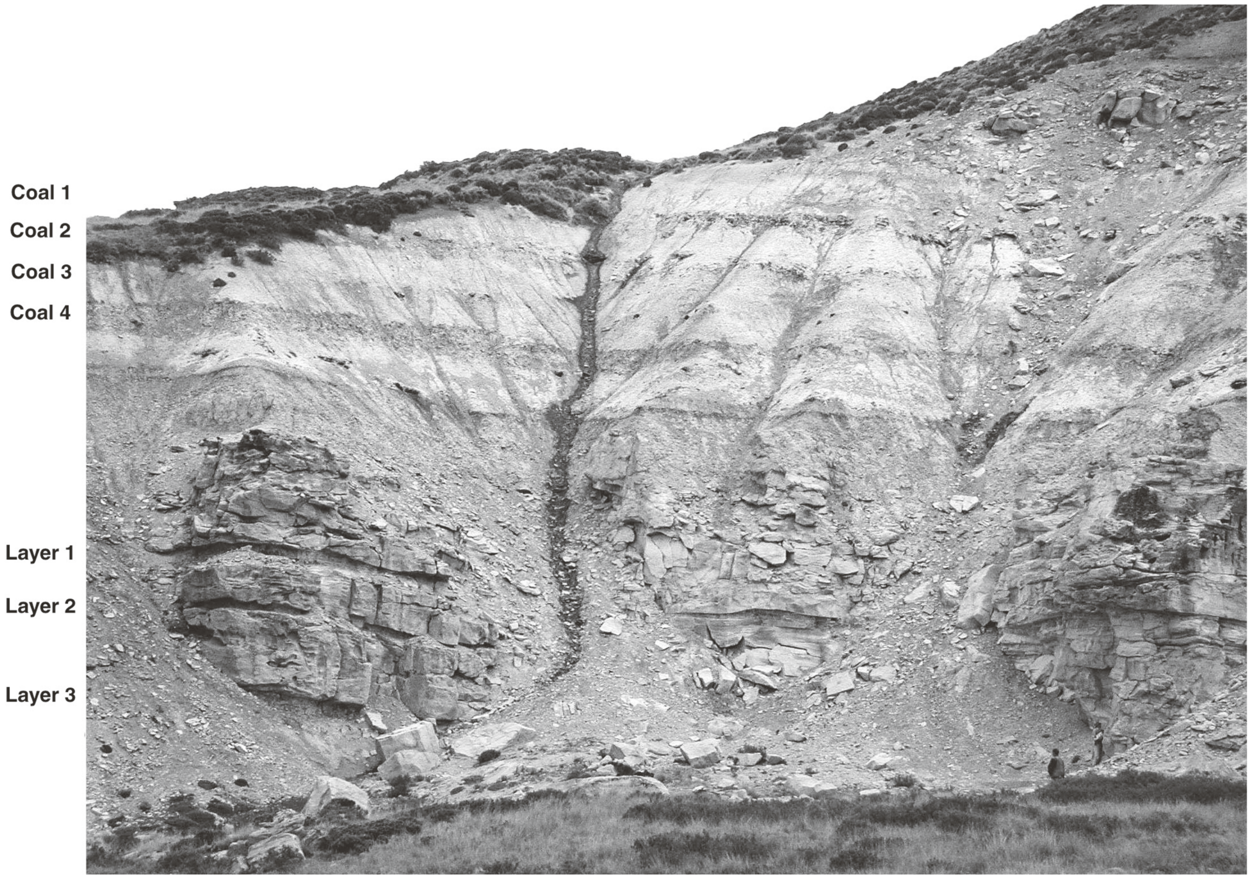

Fig. 1. Sampled section at Mina Ligorio Márquez (46°45.49'S; 71°50.54'W; 1210 m asl), south of Chile Chico, XI region, Chile.

was redefined by Suárez *et al*. (2000) with the type locality settled at Mina Ligorio Márquez (46°45'S; 71°50'W), an abandoned coal mine 25 km south of Chile Chico. This coal-bearing formation is underlain by the Flamencos Tuffs and the Cerro Colorado Formation with K-Ar (biotite) dates of 123-128 Ma (i.e. Cretaceous age), and is overlain by the San José Formation and the Posadas Basalt with K-Ar (whole rock) dates of 41-57 Ma (i.e. Early Eocene age) (see Suárez *et al*., 2000). The Lauraceae-rich megaflora of the Ligorio Màrquez Formation is different from that of the more temperate San José Formation, and would appear to be 'best compared' with the Concepción-Arauco taphoflora of the Upper Paleocene (Suárez and de la Cruz, 1996; Suárez *et al*., 2000). Coupled with the globally hot, wet climate of the early Cenozoic Optimum (see Bowen *et al*., 2004), the Upper-Paleogene and Lower-Eocene were given as estimated ages of the Ligorio Márquez Formation (Suárez *et al*., 2000).

Our reanalysis point (46°45.49'S; 71°50.54'W; 1210 m asl) appears to have been located 2.5 km northwest of the lithological column investigated by Suárez *et al*. (2000). At this reanalysis point, a fresh section 50 m in height was available owing to past coal mining activities (Fig. 1). Field investigations were carried out in January 2004. Lithologically, the sampled section consisted of four coal/shale seams alternating with siltstones in the middle part, and three layers of flood plain deposits in the lower part (Fig. 2). Plant megafossils were yielded from the flood plain deposits, instead of the coal seams. A tentative plant identification in the field showed the dominance of Lauraceae leaves associated with Cunoniaceae (*Caldculvia* sp.), Malvaceae, *Liquidambar* sp., Leguminosae, Proteaceae, Escalloniaceae, etc. An 3 cm ivory-white tuffaceous band characterized the uppermost of the three flood plain layers. Sedimentologically, parallel and/or trough cross-bedding laminations were seen in the flood plain deposits and alternating sands/silts, while the siltstones alternating with the coal seams were massive without visible sedimentary structures. In the upper part of the section, sand/silt beds were buried beneath collapsed debris, and escaped our sampling, though it can be said that no critical facies differences existed between the siltstones. The section was capped by a generally black volcanic basalt at the top. In addition, the Ligorio Márquez

Formation shows a certain lateral change in lithology, with changeable lithofacies on the scale of dozens of meters.

Materials and methods

Sediment samples for the pollen analysis were collected from 29 horizons in 5-35 m of the section (see Fig. 2). More specifically, 15 samples were collected from the coals, 7 from the silts and 7 from the flood plain deposits. Samples were 5-10 grams each, collected from unweathered section slopes, sealed in plastic bags and underwent pretreatments (pollen extraction and condensation) in a laboratory at the International Research Centre for Japanese Studies (IRCJS) in Kyoto, Japan.

The pretreatment followed the standard KOH-acetolysis method (Moore *et al*., 1991), with neither HF treatments nor oxidations to minimise pollen damages. The sediment materials were milled and bathed in 10% HCl overnight to remove calcium carbonates. After excess HCl was rinsed off, the samples were boiled in 10% KOH for 10 minutes to remove humic acids. The resulting suspension was cleaned by repeated centrifugation and decanting to remove clay-sized particles. Fossil pollen was extracted from heavier particles by heavy liquid flotation using a $ZnCl_2$ solution. The samples were finally acetolysed and mounted in 100% glycerol. More than 150-200 grains of pollen excluding spores were counted for each sample, forming the sums for relative percentage calculations. No sample with less than 100 grains was contained in our data.

The percentages of pteridophyte spores were calculated based on the total sporopollen. Pollen atlases by Heusser (1971) and Moar (1993) were referred to for pollen identification. Refer to Terada *et al*. (this volume) for more information regarding this plant megafossil research.

Description of results

Our analysis provided 7 pollen spectra from the flood plain deposits, while the coal/shale and siltstones were devoid of pollen. Theoretically, coal seams should contain fossil pollen, but in our samples large quantities of charred organic fragments hindered the detection of any pollen grains. The siltstones simply contain no pollen. By contrast, the flood plain deposits yielded abundant fossil pollen.

Photomicrographs of the major pollen types are

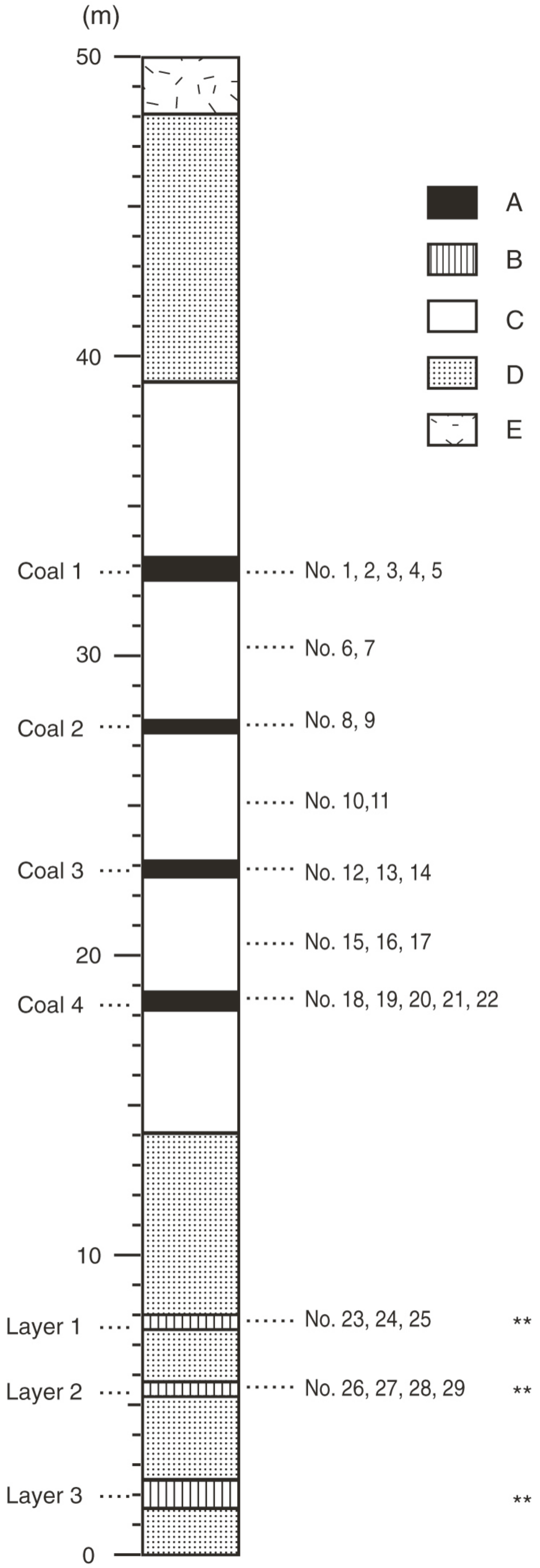

Fig. 2. Lithological column of the sampled section with palynologically analysed horizons (Nos. 1-29). Double asterisks denote the horizons of our plant megafossil excavations. Lithology: A. coal/shale; B. flood plain deposit; C. siltstone; D. sandstone; E. volcanic basalt.

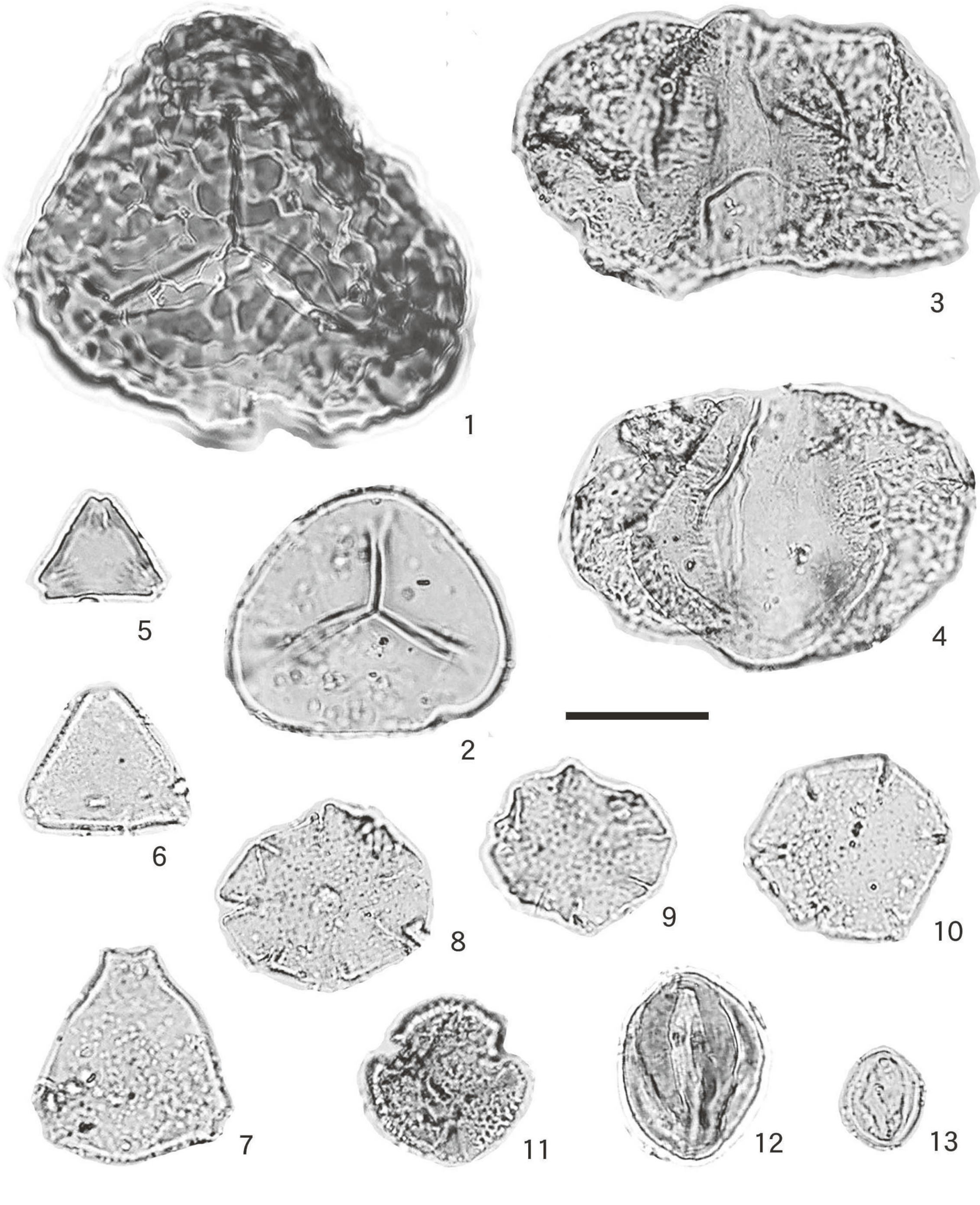

Fig. 3. Photomicrographs of representative pollen types from the Ligorio Márquez Formation, XI region, Chile. 1-2. Trilete fern; 3-4. *Podocarpidites*; 5. Tripolate (*Myrtaceidites*); 6-7. Tripolate (Proteaceae-type); 8-10. *Nothofagidites*; 11. Tricolpolate (reticulate-type); 12. Tricolpolate (*Aexitoxycon*-type); 13. Tricolpolate (*Caldculvia*-type). Scale: 20 µm.

shown in Figure 3. '*Nothofagidites*' are a single, relatively large (~30 μm) pollen type with subtle surface ornamentations. These features are reminiscent of *N. fusca*-type (Heusser, 1971; Moar, 1993), a temperate pollen type commonly derived from the modern southern-beech forests of *N. dombeyi*, *N. pumilio*, *N. betuloides*, *N. antarctica*, etc. in central Patagonia (see Okuda *et al*., 2004), whereas Yoshida (1990) suggested a *N. brassii*-type (*Brassospora*), which is found in more tropical forest in e.g. New Guinea today (Hanks and Fairbrothers, 1976; Okuda *et al*., 2002). Our data was also characterized by the presence of *Podocarpidites* and *Myrtaceidites*. The dominant taxon was the tripolate-type pollen, reminiscent of modern Proteaceae, as well as some tricolpolate pollen with a resemblance to *Aextoxycon* and *Caldculvia*. Concerning spores, various types of trilete fern characterized the total sporopollen. To allow data comparisons, our terminology follows Yoshida (1990). As a consequence, most pollen types Yoshida (1990) reported were reconfirmed here. The pollen of Lauraceae, which are dominant in the contemporaneous megaflora, is unique in so far as their vulnerable pollen structures are poorly suited to chemical treatments in the lab (Fægri and Iversen, 1989), creating no crucial disagreements between the mega- and palynofloras.

Figure 4 provides a visualization of quantitative palynological compositions from the Ligorio Márquez Formation. Here we can see that, with 50-60% of the total sum excluding spores, the dominant component is tripolate pollen and that the major associates are *Podocarpidites* and *Nothofagidites* with 10-20% in stable values. These features are shared by the seven spectra from two independent flood plain deposits, strengthening the statistical significance of the palynoflora. Irregular value changes were found only for trilete fern spores; i.e., in samples 23-24 the trilete ferns occupied 50-60% of the total sporopollen while in samples 28-29 they were 3-4%. The latter was reported by Yoshida (1990).

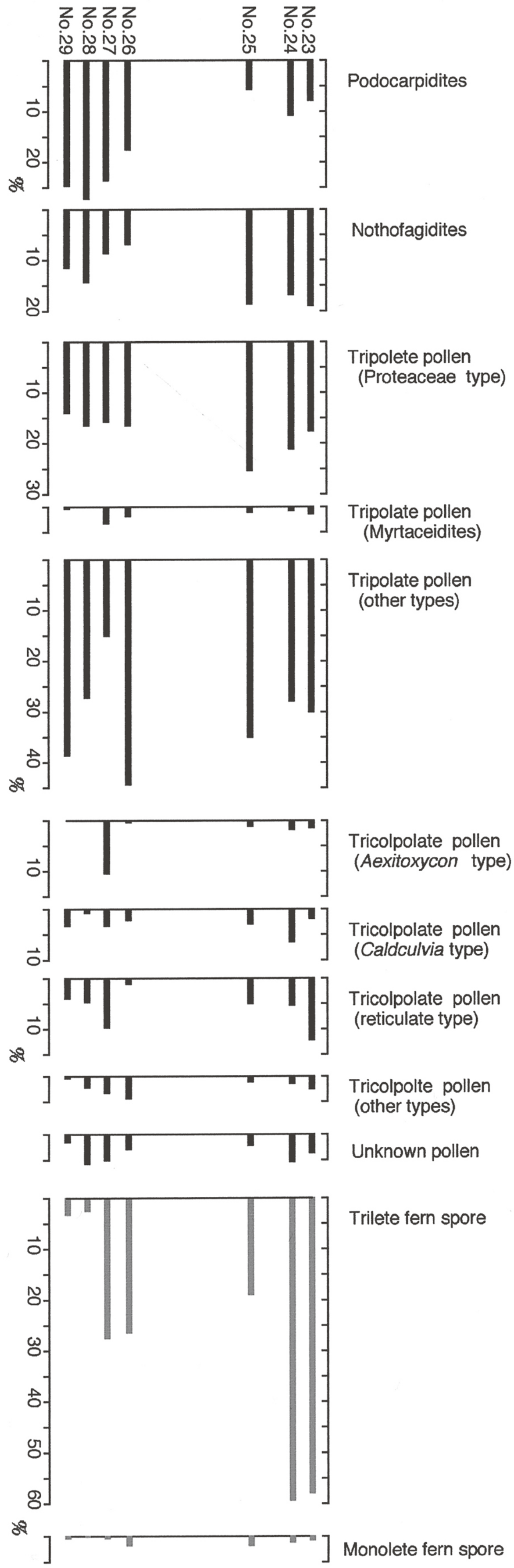

Fig. 4. Fossil pollen assemblages from the Ligorio Márquez Formation, XI region, Chile. Pollen counts of 150-320 were obtained for seven spectra. The sum for pollen percentage calculations does not contain fern spores. Pollen type terminology follows Yoshida (1990).

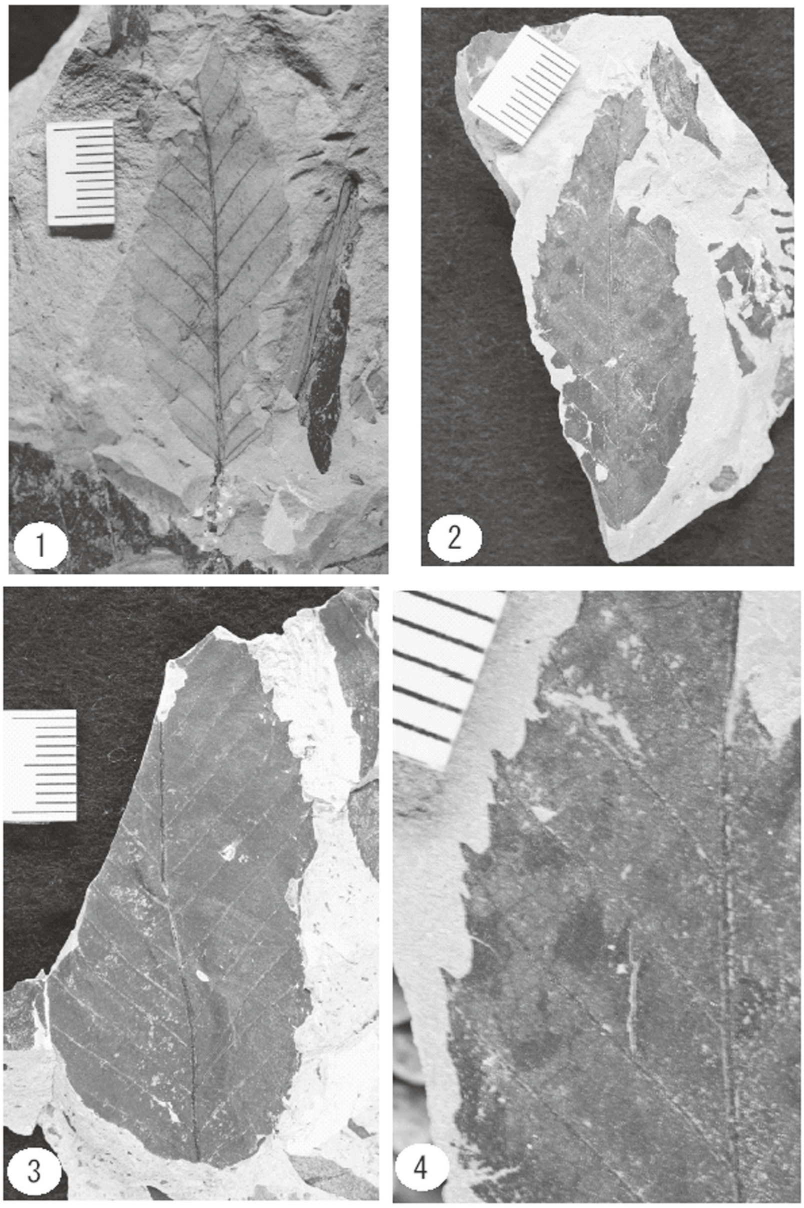

Fig. 5. Leaf remains of *Nothofagus* sp. from the layer 2 of the Ligorio Márquez Formation.
1, 2, 4. LMZ-1; 2 is the couter part of 1, and 4 is the enlargement of 2. 3. LMZ-2. Scale in mm.

In addition to the above pollen evidence, we newly found fossil leaves of *Nothofagus* from the layer 2 at Mina Ligorio Márquez (Fig. 5). These leaves, showing a resemblance to *N. subferruginea* Dúsen known from Oligocene and Miocene sediments, are rare element at this locality.

Concluding remarks

A palynological reanalysis of three different facies of the Ligorio Márquez Formation reconfirms a temperate palynoflora with abundant *Nothofagus* and Podocarpaceae pollen. A general agreement among the seven spectra from two independent sedimentary layers gives statistical significance to the composition, confirming the remarks by Yoshida (1990). These pollen spectra would appear to be in conflict with botanical evidence from the more tropical/subtropical megaflora, when we take into consideration a new K-Ar date of 47.6±0.78 Ma that is provided by Yabe *et al*. (this volume) for the basalt layer above the Ligorio Márquez Formation. Suárez *et al*. (2000) attempted to reconcile the megafossil and pollen flora by introducing an assumption. That is, if Yoshida's (1990) palynoflora was taken from the uppermost levels of the Ligorio Márquez Formation, his spectrum would correlate with a temporal climate deterioration that occurred during the early Late Paleocene and was found in the Antarctic Peninsula (Dingle *et al*., 1998). Our results do not fundamentally challenge their idea, but suggest that a somewhat younger age than discussed by Suárez *et al*. (2000) might be given to the Ligorio Márquez Formation, because our data are taken from the basal portion of the section, instead of the uppermost levels that they had assumed.

With regard to phytogeographic themes through the Tertiary period, the occurrence of *Nothofagidites* pollen and the newly found *Nothofagus* leaves in the Ligorio Márquez Formation may constitute one of the oldest fossil evidence of southern beech in central Patagonia, and contributes to an understanding of the migration history of *Nothofagus* in the southern mid-latitudes.

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