

GEOLOGICAL NOTES ON PLANT FOSSIL LOCALITIES OF THE LIGORIO MÁRQUEZ FORMATION, CENTRAL PATAGONIA, CHILE

Atsushi Yabe¹, Kazuhiko Uemura², and Harufumi Nishida³

¹Fukui Prefectural Dinosaur Museum, 51-11 Terao, Muroko, Katsuyama, Fukui 911-8601, Japan
E-mail: a.yabe@dinosaur.pref.fukui.jp

²National Science Museum, Tokyo 169-0073, Japan

³Chuo University, Tokyo 112-8551, Japan

The Ligorio Márquez Formation (Suárez *et al.*, 2000), consisting of clastic terrestrial deposits with abundant plant megafossils, is exposed in the area south of Lago General Carrera (Lago Buenos Aires in Argentina) in eastern Central Patagonia of Chile (Fig. 1). There are different opinions on the stratigraphic positions of the formation: Niemeyer (1975) compared it to marine Guadal Formation of Oligo-Miocene age, but Charrier *et al.* (1979) included it in their “lower Marine sedimentary unit” from the Late Cretaceous to Paleocene. However, Uemura (in Nishida ed., 1988) suggested a possible terrestrial origin for the formation exposed in “Mina Ligorio Márquez” and mentioned its age as being Paleocene to Eocene based on plant megafossils. His opinion was supported by Suárez *et al.* (2000) who designated the Ligorio Márquez Formation. Suárez *et al.* (2000) concluded the age to be Late Paleocene to Early Eocene based on newly collected plant megafossils as well as on K-Ar ages for the overlying basalt flows.

The plant megafossil assemblage of the Ligorio Márquez Formation was surveyed first by the late Professor M. Nishida and his collaborators (Nishida ed., 1988, 1990). Although he did not provide figures and species descriptions, Uemura (1988, 1990) observed that the assemblage consists of many subtropical elements common to Paleocene-Eocene assemblages of Argentina. On the other hand, Yoshida (1990) described pollen of *Nothofagidites* and *Podocarpidites*, which are typical of temperate forest. These reports contributed to subsequent paleobotanical studies, but the marked contrast between plant mega- and microfossil compositions as well as ambiguous stratigraphic data caused confusion in discussing floristic history and paleoclimate (Suárez *et al.*, 2000; Troncoso *et al.*, 2002). This paper describes the stratigraphic succession of the Ligorio Márquez Formation as well as lithofacies of plant megafossil localities investigated by us and by Uemura (1988). We carried out a stratigraphic study and additional collection at the Ligorio Márquez Formation around the “Mina Ligorio Márquez”, a type locality of the formation, in January 2004. We also report new K-Ar dates for the overlying basalt flow. Plant fossil assemblages of the formation are reported by Okuda *et al.* (2006, this volume). Hinojosa *et al.* (2006, this volume) also provides physiognomic analysis of the plant megafossil assemblage.

Stratigraphy of the Ligorio Márquez Formation

The Ligorio Márquez Formation in the study area consists of alternating beds of quartz-rich sandstone and mudstone with a few intercalations of thin coal seams, and reaches a maximum thickness of about 55 m (Fig. 2). It overlies unconformably the Lower Cretaceous Flamencos Tuffs dated 125-128 Ma (Suárez and de la Cruz, 1997: K-Ar whole-rock age), and is overlain by basalt flows that yield K-Ar ages of the Middle Eocene (Suárez and de la Cruz, 1997; Suárez *et al.*, 2000; this study). As Suárez *et al.* (2000) described, this formation comprises three sedimentary units. The lower unit consists of dark-gray mudstone intercalated with fine- to coarse-grained sandstone with occasional granules. This unit was recognized only in the section at LM04. The middle unit consists mainly of pebbly sandstone intercalated with thin mudstone, containing well-preserved plant megafossils. The sandstone is characterized by planar cross-stratifications. The upper unit is composed of carbonaceous mudstone and intercalates a few coal seams, suggesting a marsh environment. It is also

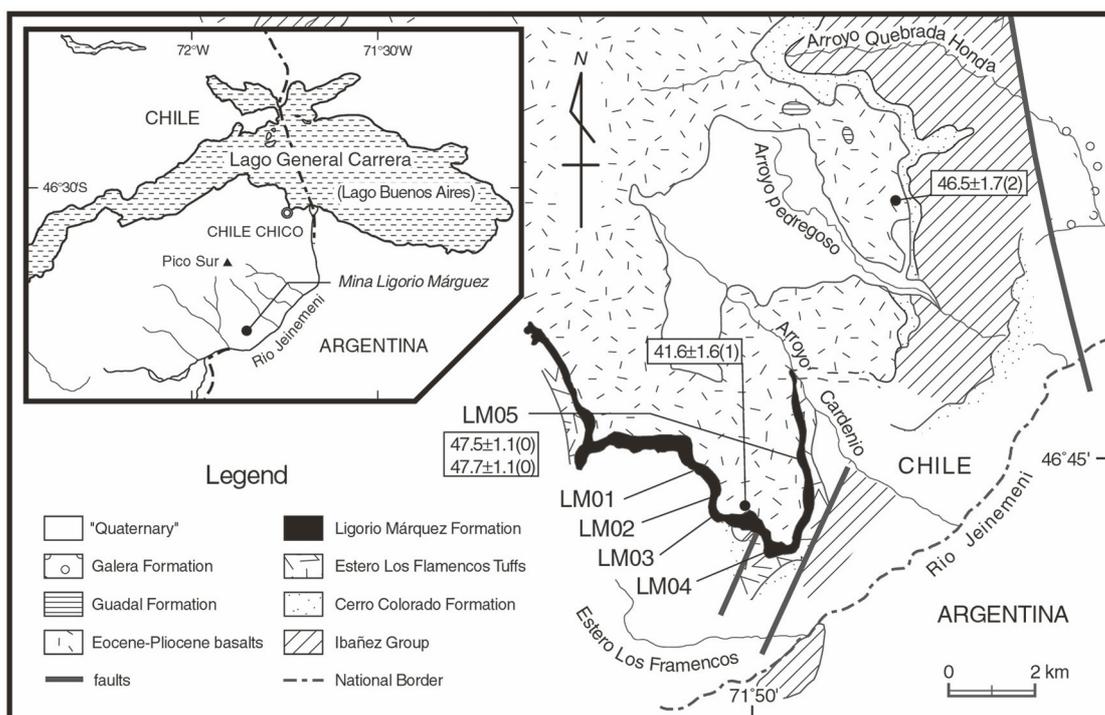


Fig. 1. Geologic map around the “Mina Ligorio Márquez”, south of Chile Chico, eastern central Patagonia, Chile (adopted from Suárez *et al.*, 2000). Numbers indicate localities of columnar sections shown in Fig. 2. Numbers in square represent K-Ar dates. 0: this study, 1: Suárez *et al.* (2000), 2: Suárez and de la Cruz (1997).

either intercalated with or overlain by cross-stratified very coarse-grained sandstone less than 1-m thick, probably representing either channel-fill or crevasse-splay deposits (Suárez *et al.*, 2000). Root traces indicative of fossil soil (paleosol) are common in the mudstone of the middle and upper units (Fig. 4-6), suggesting a terrestrial depositional environment. They were used as a key for local stratigraphic correlation (Fig. 2).

Troncoso *et al.* (2002) reported plant megafossils from the locality close to LM04 of the measured section. Plant megafossils have been reported from medium-grained sandstone at the base of a thick sandstone unit characterized by cross-stratification or root traces. The level of the locality was tentatively compared to the bottom of the middle unit. We collected well-preserved plant megafossils intensively from the middle unit at “Mina Ligorio Márquez” (LM01, GPS data: 46°45.243’S, 71°50.874’W, 1219.8 m asl), along with small reference collections at LM02 and LM04.

Descriptions of plant megafossil locality

Plant megafossil localities at LM01 are shown in Fig. 3. Locality 03 was a main locality of Uemura (1988, position based on personal communication with co-author).

There are at least two levels of plant-bearing mudstone covered by relatively ill-sorted, fine- to very coarse-grained sandstones with erosional surfaces (Fig. 4-2). They are occasionally pinched out by erosion. Mudstones are usually intercalated with fine- to very fine-grained sandstone sometimes characterized by current ripple laminations (Fig. 4-3). Carbonaceous root traces were often observed in the upper part of the mudstone (Fig. 4-4). The thickness and frequency of the sandstone changes vertically and horizontally, and may contribute to the content and degree of preservation of plant megafossils. Plant megafossils collected from localities 03 and 04 are moderately well-preserved and some yield cuticles. Abundant fossil pollen and spores were also recovered from these beds, but not from the mudstone in the upper unit (Okuda *et al.*, 2006, this volume). Judging from the geometry of each facies and facies association, thick sandstones with cross-stratifications

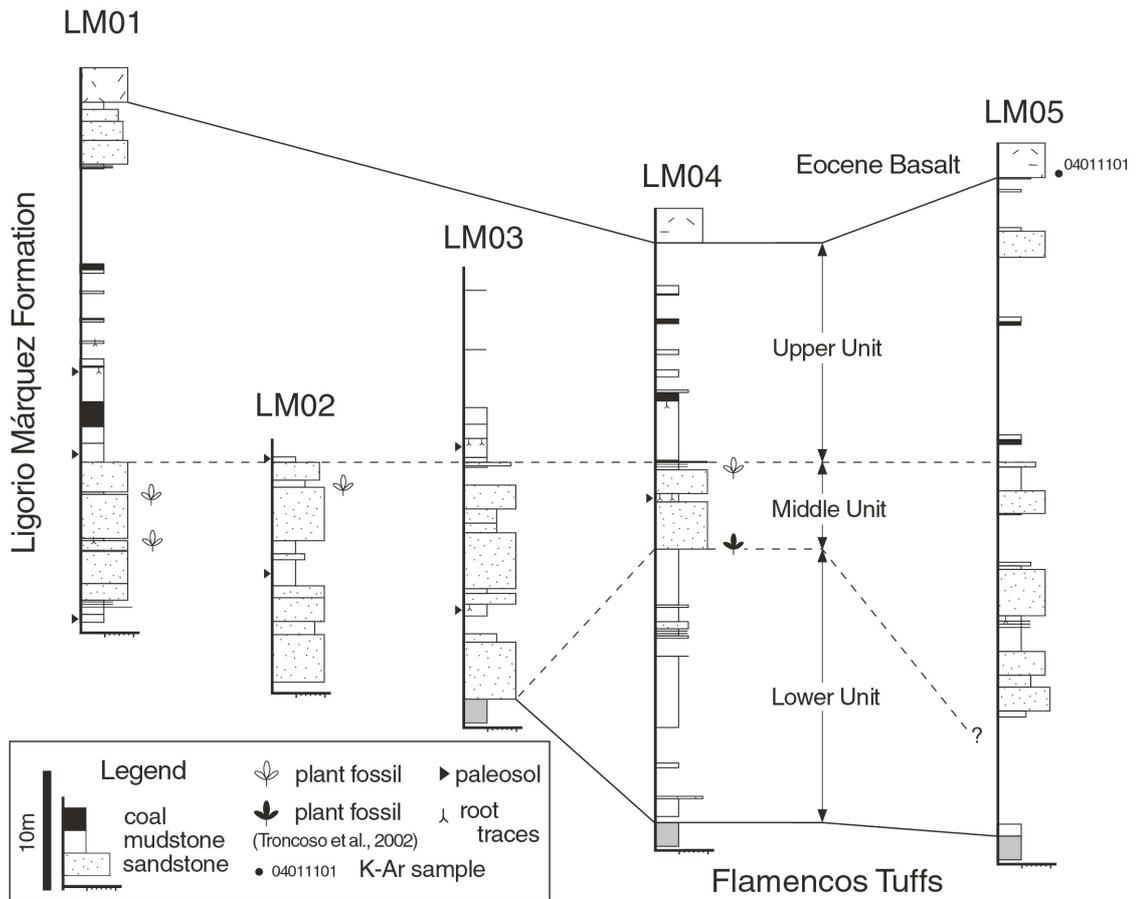


Fig. 2. Columnar sections of the Ligorio Márquez Formation.

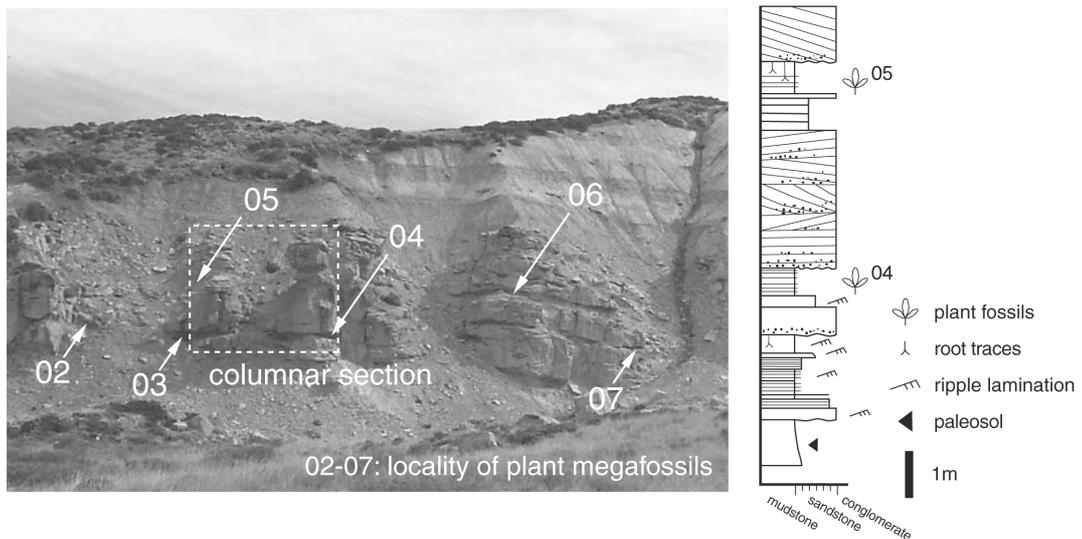
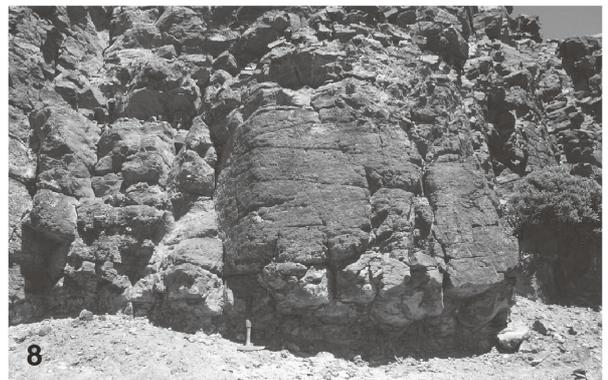
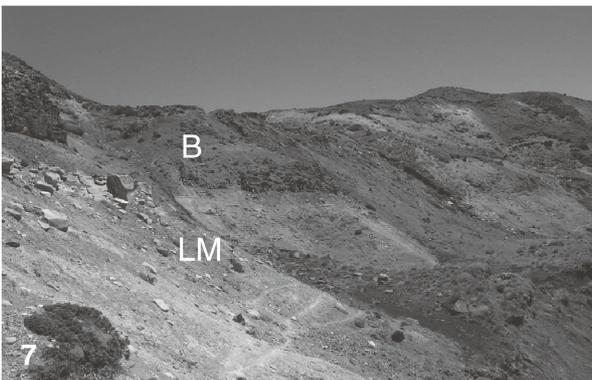
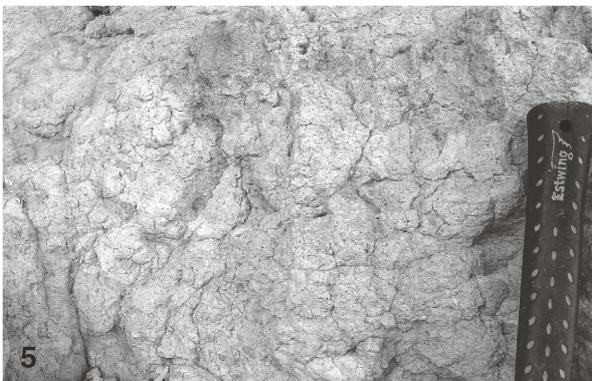
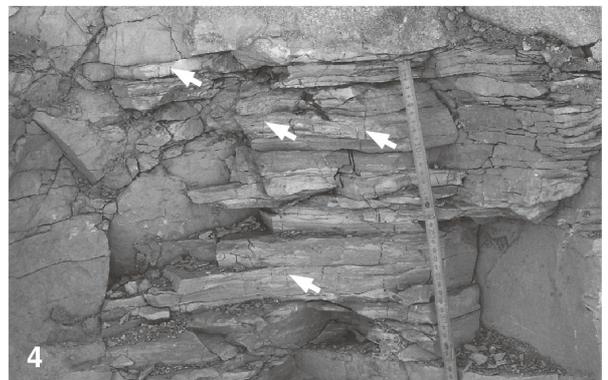


Fig. 3. Outcrop of the Ligorio Márquez Formation at LM01 (“Mina Ligorio Márquez”), showing plant megafossil localities (02-07). Position of the columnar section was shown by dotted line.



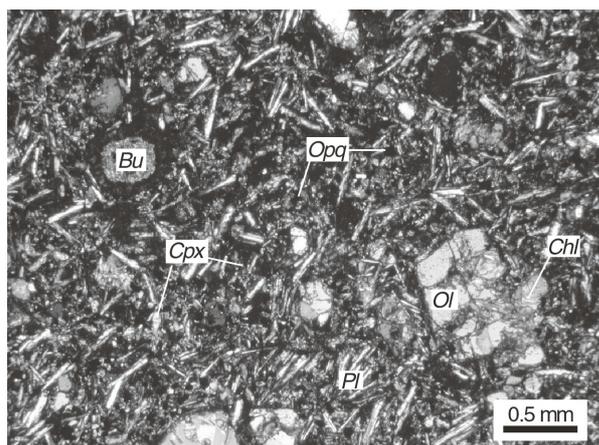


Fig. 5. Thin section photomicrograph of the basalt (no. 04011101) used for K-Ar dating (cross-polarizer view). Cpx: Clinopyroxene, Pl: Plagioclase feldspar, Ol: Olivine, Chl: Chlorite, Opa: Opaque minerals, Bu: Bubble.

were interpreted as channel-fill deposits, while plant-bearing mudstones were inferred to represent floodplain deposits.

K-Ar dating

K-Ar dating was done for a basalt flow just above the Ligorio Márquez Formation. A sample (no. 04011101) was collected at LM05 (GPS data: 46°45.031'S, 71°49.046'W), approximately 2.5 km east of the type locality where more than 10 m of thick basalt overlies alternating beds of white sandstone and mudstone of the Ligorio Márquez Formation with angular unconformity (Fig. 2; Figs. 4-7 and 4-8).

The rock is slightly altered with olivine phenocrysts partially replaced by chlorite (Fig. 5). Therefore, we decided to analyze plagioclase feldspars that appear fresh in microscopic observations. All analysis,

Table 1. K-Ar dates of basalt flow above the Ligorio Márquez Formation.

sample No.	potassium (wt. %)	rad. ^{40}Ar (10^{-8}cc STP/g)	non-rad. ^{40}Ar (%)	K-Ar age (Ma)
04011101		231.1 ± 2.4	8.6	47.5 ± 1.1
Plagioclase (# 150-200)	1.237 ± 0.025	232.1 ± 2.4	8.5	47.7 ± 1.1
				average 47.6 ± 0.78

Decay constants by Steiger & Jäger (1977) were followed: $\lambda_e = 0.581 \times 10^{-10}/\text{year}$, $\lambda_\beta = 4.962 \times 10^{-10}/\text{year}$, $^{40}\text{K}/\text{K} = 1.167 \times 10^{-4}$. An error of the average age was calculated by the following equation (Tsukui *et al.*, 1985):

$$\Delta T = 1/2 \sqrt{\Delta T_1^2 + \Delta T_2^2 + (T_1 + T_2)^2} \quad \Delta T: \text{error of average age, } \Delta T_1 \& \Delta T_2: \text{error of each analysis, } T_1 \& T_2: \text{K-Ar age of each analysis.}$$

Fig. 4. 1, Outcrop of the Ligorio Márquez Formation at LM01 (“Mina Ligorio Márquez”); 2, An example of lithofacies in the middle unit. Pebbly sandstone with cross-stratification overlies plant-bearing mudstone (equals to plant megafossil locality 03) with erosional surface. Middle unit. LM01; 3, Plant megafossil locality 04, showing dark gray mudstone frequently intercalated with white fine- to very fine-grained sandstone. Middle unit. LM01. Hammer for scale has a handle 30 cm long; 4, Plant megafossil locality 05, showing carbonaceous root traces (arrows). Middle unit. LM01; 5, Paleosol at middle unit of LM02, showing irregular joining and scattering organic matters. Handle of hammer is 3 cm wide; 6, Paleosol with abundant root traces. The bed probably corresponds with that reported by Suárez *et al.* (2000: fig. 2). Middle unit. LM04. A pen for scale is 14 cm long; 7, Upper unit of the Ligorio Márquez Formation (LM) and overlying basalt (B) at LM05; 8, Locality of a sample for K-Ar dating. LM05. Hammer handle is 30 cm long.

including preparation of material, was done at the Hiruzen Institute for Geology and Geochronology, following the same procedures described in Nagao *et al.* (1984) for K analysis and in Itaya *et al.* (1991) for Ar isotope analysis. Argon isotope analysis was performed twice on the same material to evaluate data reproducibility. The analytical results are shown in Table 1.

We obtained two new K-Ar dates of 47.5 ± 1.1 Ma and 47.7 ± 1.1 Ma. They agree well within analytical uncertainties and their average of 47.6 ± 0.78 Ma is used here as the representative age of the basalt unit.

Conclusions

The Ligorio Márquez Formation exposed approximately 25 km south of Chile Chico is a terrestrial clastic deposit consisting of fluvial channel, flood plain, and marsh deposits. Our collection of plant mega- and microfossils was made at the flood plain deposits of the middle sedimentary unit from where Uemura (1988, 1990) and Yoshida (1990) reported plant mega- and microfossils, respectively. Stratigraphically, these deposits are close to the horizon of plant megafossils reported by Troncoso *et al.* (2002). Climate deterioration has been suggested to account for the difference in composition between the plant mega- and microfossils (Suárez *et al.*, 2000; Troncoso *et al.*, 2002). However, our data suggest that it should be ascribed to either insufficient collection and/or taphonomic bias rather than climate. During our field survey in January 2004, we successfully collected some *Nothofagus* leaves (Okuda *et al.*, 2006, this volume).

Suárez *et al.* (2000) showed some K-Ar whole-rock ages for the basalt flow above the Ligorio Márquez Formation. One date of 41.6 ± 1.4 Ma was obtained from the rock immediately above the formation near LM03. This age is much younger than ours, although it is in general agreement with the K-Ar whole-rock ages of the same unit further north (57 ± 1 to 44 ± 5 Ma). The K-Ar age of 46.5 ± 1.7 Ma for the basalt approximately 6 km northeast of LM05 is also slightly younger but within the analytical uncertainties of one of our results. These data suggest that either there are at least two basalt units overlying the Ligorio Márquez Formation and all K-Ar ages represent eruption age, or that the results of K-Ar whole-rock analysis tend to be younger, owing to alteration of minerals. Assuming that our new data represent the eruption age, the Ligorio Márquez Formation can be assigned to the early Middle Eocene or older (Gradstein *et al.*, 2004).

The K-Ar ages obtained in this study are similar to that of the plant megafossil assemblage of Río Pichileufú in Argentina (e.g., Berry, 1938; $41^{\circ}7'S$) recently dated as 47.46 ± 0.05 Ma by the $^{40}\text{Ar}/^{39}\text{Ar}$ method (Wilf *et al.*, 2005). The Río Pichileufú assemblage has been considered contemporaneous with the diverse flora of Laguna del Hunco located at similar latitudes (e.g., Berry, 1925, 1938). Wilf *et al.* (2003, 2005) gave $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 52.13 ± 0.32 Ma and 51.91 ± 0.22 Ma (middle Early Eocene) for the plant-bearing beds of Laguna del Hunco. Although the plant megafossil assemblage of the Ligorio Márquez Formation shares some similarities with these classical assemblages (Uemura, 1988; Okuda *et al.*, 2006, this volume) they are distinct from each other, especially in the presence of *Nothofagus* in the former assemblage. The same observation applies to the Late Paleocene Concepción-Arauco taphoflora of Central Chile (37°S), which was also compared to the plant megafossils of the Ligorio Márquez Formation (Troncoso *et al.*, 2002). Further paleobotanical studies are needed to understand the history of floristic change in this region.

References

- Berry E W. 1925. A Miocene flora from Patagonia. *Johns Hopkins University Studies in Geology*, **6**: 183-251.
 Berry E W. 1938. Tertiary flora from the Río Pichileufú, Argentina. *Geological Society of America Special Paper*, **12**: 1-149.
 Charrier R, Linares E, Niemeyer H, Skarmeta J. 1979. K-Ar ages of basalt flows of the Meseta Buenos Aires in southern Chile and their relation to the southeast Pacific triple junction. *Geology*, **7**: 436-439.
 Gradstein F M, Ogg J G, Smith A G ed. 2004. A Geologic Time Scale 2004. Cambridge University Press, New York, 589 pp.
 Hinojosa L F, Pesce O, Yabe A, Uemura K, Nishida H. 2006. Physiognomical analysis and paleoclimate from Ligorio

- Márquez fossil floras, Ligorio Márquez Formation, 46°45'S, Chile, In: Nishida H (ed.). Post-Cretaceous floristic changes in southern Patagonia, Chile. Chuo University, Tokyo, 45-55.
- Itaya T, Nagao K, Inoue K, Honjou Y, Okada T, Ogata A. 1991. Argon isotope analysis by a newly developed mass spectrometric system for K-Ar dating. *Mineralogical Journal*, **15**: 203-221.
- Nagao K, Nishido H, Itaya T, Ogata K. 1984. An age determination by K-Ar method. *Bulletin of the Hiruzen Research Institute*, **9**: 19-38. in *Japanese*
- Niemeyer H. 1975. Geología de la región comprendida entre el lago General Carrera y el Rio Chacabuco, Provincia de Aysén, Chile. Thesis of Universidad de Chile. Santiago: Universidad de Chile.
- Nishida M ed. 1988. A Report of the Botanical Survey to Bolivia and Southern Chile (1986-87). Chiba University, Chiba, 41 pp.
- Nishida M ed. 1990. A Report of the Paleobotanical Survey to Patagonia, Chile (1989). Chiba University, Chiba, 47 pp.
- Okuda M, Nishida H, Uemura K, Yabe A. 2006. Paleocene/Eocene pollen assemblages from the Ligorio Márquez Formation, central Patagonia, XI Region, Chile, In: Nishida H (ed.). Post-Cretaceous floristic changes in southern Patagonia, Chile. Chuo University, Tokyo, 37-43.
- Steiger R H, Jager E. 1977. Subcommittee on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters*, **36**: 359-362.
- Suárez M, de la Cruz R. 1997. Cronología magmática de Aysén Sur, Chile (latitude 45°-48°30' LS). Actas Octavo Congreso Geológico Chileno, Antofagasta, Chile, II: 1543-1547.
- Suárez M, de la Cruz R, Troncoso A. 2000. Tropical/subtropical Upper Paleocene-Lower Eocene fluvial deposits in eastern central Patagonia, Chile. *Journal of South American Earth Sciences*, **13**: 527-536.
- Tsukui M, Nishido H, Nagao K. 1985. K-Ar ages of the Hiruzen Volcano Group and the Daisen Volcano. *Journal of the Geological Society of Japan*, **91**: 279-288. in *Japanese with English abstract*
- Troncoso A, Suárez M, de la Cruz R, Palma-Heldt S. 2002. Paleoflora de la Formación Ligorio Márquez (XI Región, Chile) en su localidad tipo: sistemática, edad e implicancias paleoclimáticas. *Revista Geológica de Chile*, **29**: 113-135.
- Uemura K. 1988. Geological notes on the plant megafossil localities in southern Chile. In: Nishida M (ed.). A Report of the Botanical Survey to Bolivia and Southern Chile (1986-1987). Chiba University, Chiba, 10-15.
- Uemura K. 1990. Tertiary plants from the Guadal Area in Aisen Region, Chile. In: Nishida M (ed.). A Report of the Paleobotanical Survey to Patagonia, Chile (1989). Chiba University, Chiba, 8-11, pl. 3.
- Wilf P, Cúneo N R, Johnson K R, Hicks J F, Wing S L, Obradovich J D. 2003. High plant diversity in Eocene South America: evidence from Patagonia. *Science*, **300**: 122-125.
- Wilf P, Johnson K R, Cúneo N R, Smith M E, Singer B S, Gandolfo M A. 2005. Eocene plant diversity at Laguna del Hunco and Río Pichileufú, Patagonia, Argentina. *The American Naturalist*, **165**: 634-650.
- Yoshida A. 1990. Preliminary notes on the palynological remnants from Mina Ligorio Márquez, Chile Chico, Chile. In: Nishida M (ed.). A Report of the Paleobotanical Survey to Patagonia, Chile (1989). Chiba University, Chiba, 12-15, pls. 4, 5.