AMEGHINIANA (Rev. Asoc. Paleontol. Argent.) - 46 (2): 437-442. Buenos Aires, 30-07-2009 ISSN 0002-7014

NOTA PALEONTOLÓGICA

Recognition and implications of globigerinathekids (Eocene planktic foraminifera) in coal-bearing successions of the forearc of south-central Chile (37º45'-41º50'S)

Kenneth L. FINGER[1] and Alfonso ENCINAS[2]

Introduction

Tertiary coal-bearing deposits occur at different localities along the forearc of south-central Chile (*e.g.*, Brüggen, 1950; Sernageomin, 1998). The most important and well-studied successions are those that crop out on the Arauco peninsula (~37ºS). The presence of marine intercalations containing foraminifera and molluscs has permitted these strata to be placed within the late Paleocene-Eocene interval (Tavera, 1942; Martínez-Pardo *et al.*, 1997).

South of the Arauco peninsula, between Angol and Ancud (figure 1), coal-bearing successions extend farther inland from the coastline, to the Coastal Cordillera and the Intermediate Depression. The stratigraphy and age of these strata are not well understood because their outcrops are scarce and no marine fossils have been reported from them. Most workers consider these successions as Oligo-Miocene, which is younger than those of the Arauco area (*e.g.*, Cisternas *et al.*, 1990; Sernageomin, 1998; Torres *et al.*, 2000). However, our foraminiferal study of wells drilled in these successions recognizes the presence of *Globigerinatheka*, a planktic foraminiferal genus indicative of the Eocene. The presence of foraminifera in coal-bearing strata of this area had not been reported previously. In this note, we present and discuss our findings regarding the age of these deposits.

Geologic setting

The study area is located between Angol and Ancud (37º45'-41°50'S) in the forearc of south-central Chile (figure 1). At these latitudes, Paleozoic metamorphic rocks and minor Mesozoic plutonic rocks compose the basement that is overlain by Cenozoic sedimentary and volcanic strata. The paucity of good outcrops in the area has resulted in a complicated Tertiary stratigraphy due to the naming of several formations that appear to be geographically limited and difficult to correlate (*e.g.*, Brüggen, 1950; García, 1968; Sernageomin, 1998). Cisternas and Frutos (1994) simplified the local stratigraphy by defining three genetic units: 1) a lower coal-bearing unit assigned to the Eocene or to the Oligo-Miocene (see below) and deposited in alluvial and estuarine environments (Le Roux and Elgueta, 2000); 2) a middle volcanic and volcanoclastic unit that was referred to as the Coastal Volcanic Belt (Vergara and Munizaga, 1974) and radiometrically dated as late early Oligocene to early Miocene (Cisternas and Frutos, 1994 and references therein; Sernageomin, 1998; Antinao *et al.*, 2000); and 3) an upper marine fossiliferous unit interpreted as middle to late Miocene (Martínez-Pardo and Pino, 1979; Marchant, 1990; Osorio and Elgueta, 1990) and deposited at bathyal depths (Encinas *et al.*, 2007).

Findings

We examined foraminifera from seven wells drilled by ENAP (The National Petroleum Chilean Company) in the study area (figure 1) that encountered two contrasting units characterized by very different foraminiferal faunas. The upper unit consists of interbedded siltstone and fine sandstone bearing rich and well-preserved foraminiferal assemblages typical of the regional Neogene and indicative of lower-bathyal (>2000 m) deposition (Encinas *et al.*, 2007). In contrast, the lower unit has coal intercalations and yielded foraminifera preserved as reddish brown, crystalline molds devoid of any original calcite shell (figures 2.1-2.7). The most abundant forms resemble *Globigerinatheka*, a planktic genus restricted to the late early to late Eocene

[1]University of California Museum of Paleontology, 1101 Valley Life Sciences Building, Berkeley, CA 94720-4780, USA. *kfinger@berkeley.edu*
[2]Departamento de Ciencias de la Tierra, Universidad de Concepción, Casilla 160-C, Concepción, Chile. *aencinas@udec.cl*

 AMGHB2-0002-7014/09$00.00+.50

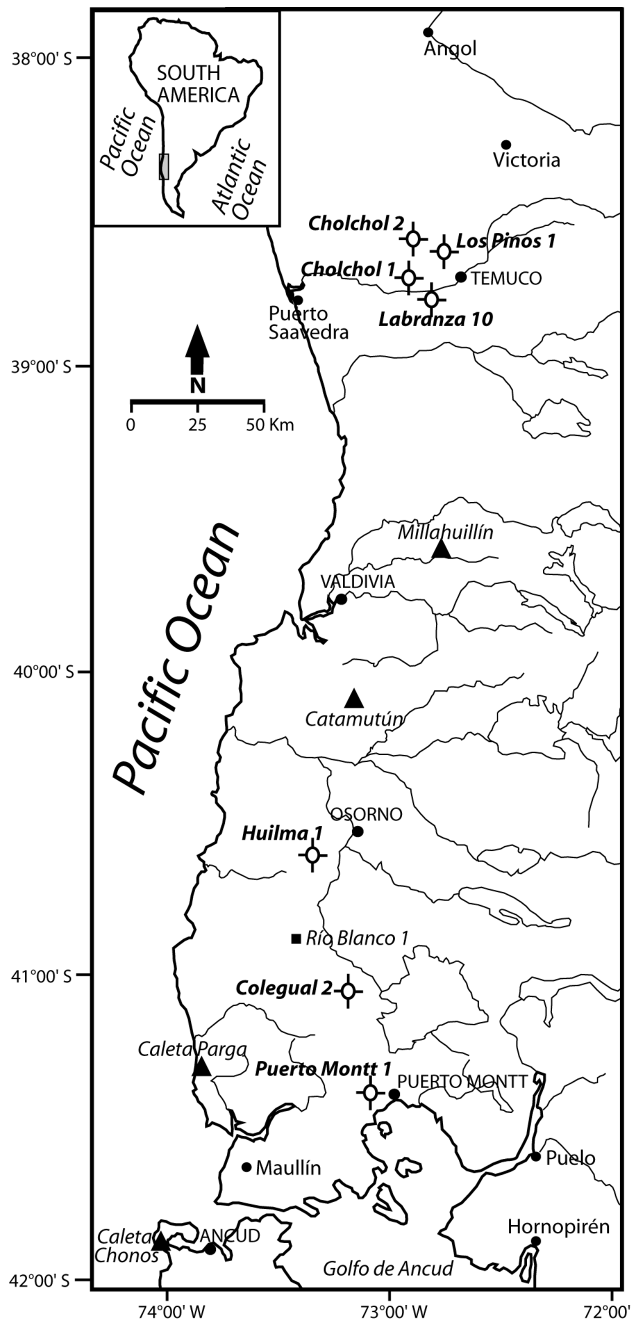

Figure 1. Map of the study area showing localities cited in the text, which includes ENAP wells that yielded the molds ascribed to *Globigerinatheka* (open circles), the Río Blanco 1 well (square), and the most important outcrops of the coal-bearing successions (triangles) / *mapa del área de estudio en el que se muestran las localidades citadas en el texto. Se incluyen los pozos de la ENAP en que se encontraron los moldes de foraminíferos asignados al género* Globigerinatheka *(círculos), el pozo Río Blanco #1 (cuadrado) y los afloramientos más importantes de las sucesiones carboníferas (triángulos).*

(Premoli-Silva *et al*., 2006). *Globigerinatheka* is one of a few closely related Eocene genera characterized by a subspherical test with supplementary apertures (figures 2.8-2.13). Although earlier chambers and supplementary apertures are barely discernable on the best of the specimens observed, we are confident that most of these internal molds are *Globigerinatheka* for the following reasons: (1) they have a subspherical shape with a low trochospire and enveloping ultimate chamber, (2) some of the better-preserved specimens show small circular depressions along their sutures that could be indicative of the supplementary apertures, (3) most of these internal molds are deeply incised to varying degrees along their short axis, reflecting where the suture with supplementary apertures separates the last two chambers in *Globigerinatheka*, (4) they dominate most of the assemblages in the lower section, which is not unusual within Eocene marine sequences, and (5) nothing resembling this form occurs in the upper section, nor was anything like it seen in the many Neogene assemblages we have examined from this region.

Foraminiferal molds illustrated in figures 2.3-2.7 are deposited in the University of California Museum of Paleontology (UCMP), Berkeley, USA. Well-preserved specimens from other localities (figures 2.8-2.12) reside in Finger's personal collection; they were picked by him from sample residues provided by the late H.M. Bolli, who also confirmed the identifications.

The presence of *Globigerinatheka* also was noted by Marchant (1990) in her study of foraminifera from exploratory wells drilled by coal-mining companies in the Catamutún area (figure 1). Marchant (1990) may have thought the *Globigerinatheka* specimens were reworked, as she interpreted the entire well section as the middle Miocene Santo Domingo Formation. Whereas she did not specify the unit or the borehole depths from which any of the foraminifera were obtained, another possibility is that the Neogene taxa are from the Santo Domingo Formation and *Globigerinatheka* is from the underlying coal-bearing Estratos de Pupunahue Formation. Rather than reworking the *Globigerinatheka* in the Neogene, it is more likely that the Neogene specimens were displaced by downhole caving. This was evident in the lower sections we studied, as the Neogene component was smaller, consisted primarily of robust specimens, and was sporadic in both presence and abundance.

Discussion

The age of the coal-bearing successions that crop out in the forearc of south-central Chile between Angol and Ancud has been debated for a long time. Previous interpretations favored either an Eocene or an Oligo-Miocene age for these deposits, but few are based on reliable data. Our recognition of *Globigerinatheka* in these strata is an important step

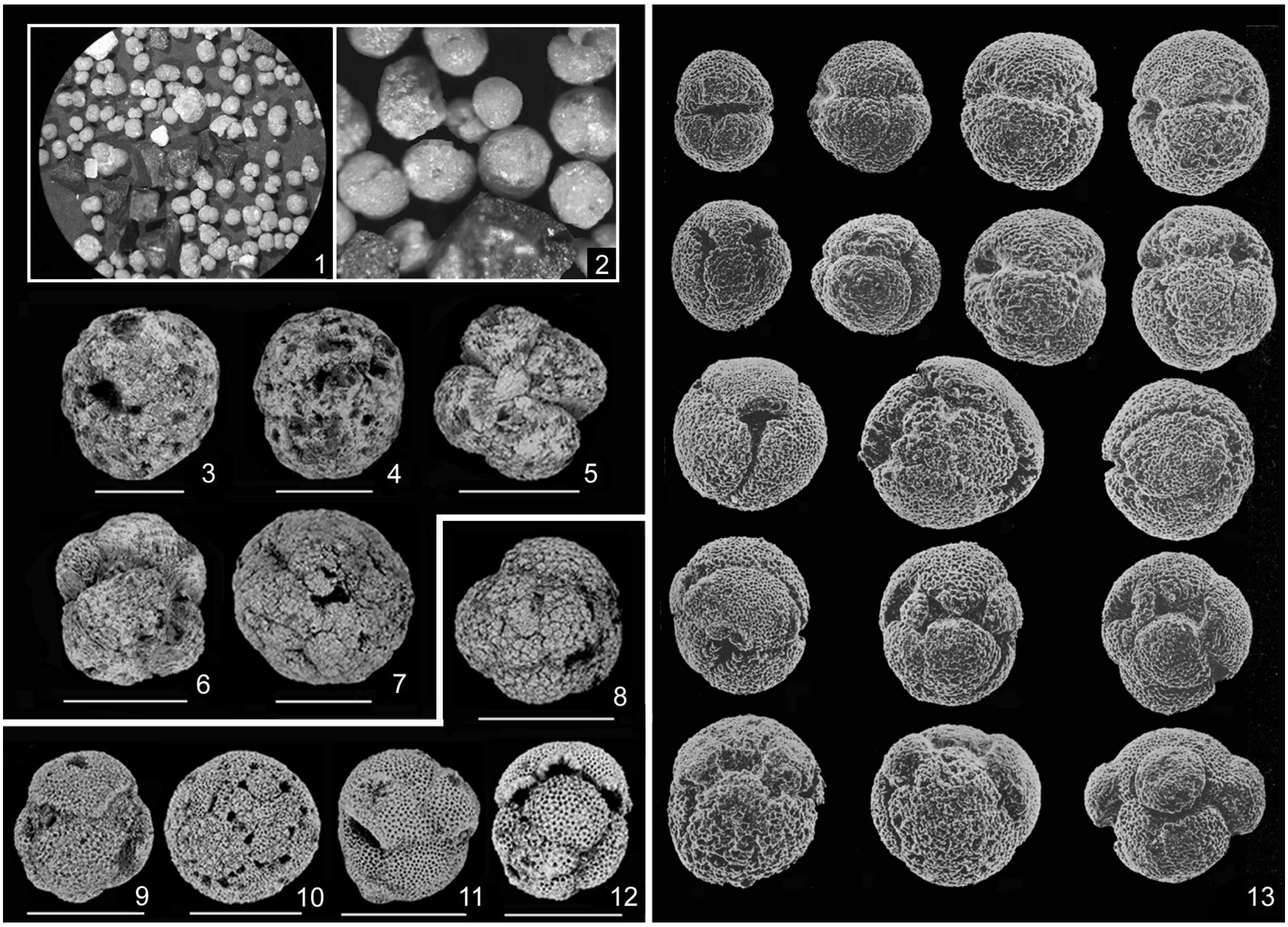

Figure 2. Comparison of the foraminiferal molds with several Eocene globigerinathekids (scale bars = 300 µm; **2.1** and **2.2** are photomicrographs, **2.3-2.13** are scanning electron micrographs [SEMs]): **2.1-2.7,** Internal molds of planktic foraminifera from ENAP well-cutting samples. **2.1, 2.2,** Processed samples (picked residues) from the coal-bearing interval in Colegual #2 (note the relative abundance of subspherical foraminiferal molds and the presence of coal fragments); **2.3-2.5,** Specimens UCMP24093, UCMP24094, and UCMP24095 from Colegual #2. **2.6,** Specimen UCMP24096 from Cholchol #2; **2.7,** Specimen UCMP24097 from Cholchol #1. **2.8-2.13,** Well-preserved Eocene specimens similar in gross morphology to the molds; picked from material provided by H. Bolli. **2.8, 2.9,** ***Globigerinatheka subconglobata*** (Shutskaya), sample loc. IT636, Italy; **2.10,** ***Orbulinoides beckmanni*** (Saito), sample loc. HMB75, Barbados; **2.11,** ***G. seminvoluta*** Keijzer, sample loc. HK408, Trinidad; **2.12,** ***G. mexicana kugleri*** Bolli, Loeblich and Tappan, sample loc HK408, Trinidad; **2.13,** Bolli's (1972, pl. 7) plate of 17 paratypes of ***G. subconglobata luterbacheri*** Bolli from the upper Eocene of Switzerland (all at same magnification) / *Comparación de los moldes de foraminíferos con varios globigerinathekidos del Eoceno (barras de escala = 300 µm;* ***2.1*** *y* ***2.2*** *son microfotografías,* ***2.3-2.13*** *son fotos de microscropio electrónico de barrido [SEM]):* ***2.1-2.7,*** *moldes internos de foraminíferos planctónicos provenientes de muestras de roca molida de pozos de ENAP.* ***2.1, 2.2,*** *muestras procesadas (residuo tras lavado del sedimento) del intervalo carbonífero del pozo Colegial #2 (nótense la relativa abundancia de moldes subesféricos de foraminíferos y la presencia de fragmentos de carbón);* ***2.3-2.5,*** *especimenes UCMP24093, UCMP24094 y UCMP24095del pozo Colegual #2.* ***2.6*** *espécimen UCMP24096 del pozo Cholchol #2.* ***2.7,*** *espécimen UCMP24097 del pozo Cholchol #1.* ***2.8-2.13,*** *foraminíferos Eocenos bien preservados similares, de manera general, a los moldes; extraídos de material proporcionado por H. Bolli.* ***2.8, 2.9,*** **Globigerinatheka subconglobata** *(Shutskaya),muestra loc. IT636, Italia;* ***2.10,*** **Orbulinoides beckmanni** *(Saito), muestra loc. HMB75, Barbados;* ***2.11,*** **G. seminvoluta** *Keijzer, muestra loc. HK408, Trinidad;* ***2.12,*** **G. mexicana kugleri** *Bolli, Loeblich y Tappan, muestra loc. HK408, Trinidad;* ***2.13,*** *lámina (tomada de Bolli, 1972, fig. 7) con fotos de 17 paratipos de* **G. subconglobata luterbacheri** *Bolli del Eoceno superior de Suiza (todas las fotos con el mismo aumento).*

toward resolving the dispute. In the following, we review previous data interpretations as well as plausible explanations for the discrepancy.

Studies in favor of an Eocene age

Troncoso and Barrera (1979) studied palynomorphs from coal-bearing strata of the Cheuquemo Formation intersected by the ENAP Rio Blanco 1 well (figure 1). Based on comparisons with pollen recorded from Mesozoic and Cenozoic successions in Argentina and Chile, they ascribed an Eocene age to the well samples analyzed. In the Temuco area farther north (figure 1), Rubio (1990) assigned the coal-bearing Temuco Formation to the Eocene-late Oligocene interval based on the age that Troncoso and Barrera (1979) proposed for correlative deposits and because the Temuco Formation is unconformably subjacent to the late Oligocene to early

Miocene Pilmahue Formation. An Eocene-early Oligocene age also is ascribed by Antinao *et al*. (2000) to the coal-bearing strata of the Caleta Chonos Formation in northern Chiloé (42°S) (figure 1). This unit is intruded by subvolcanic rocks of the late Oligocene-early Miocene volcanic complex of Ancud (Antinao *et al*., 2000).

Studies in favor of an Oligo-Miocene age

Fenner and Sylvester (1936) dated the coal-bearing succession of Millahuillín (figure 1) as Oligocene based on the presence of the marine bivalve *Panopea panis* Ihering. However, Brüggen (1950) considered their identification of the fossil erroneous and instead assigned it to the freshwater genus *Anodonta*. On the basis of lithology and coal rank, he suggested that there probably were two coal-bearing successions – one more indurated and correlated with the Paleogene coal-bearing strata of the Arauco peninsula and the other less indurated and correlated with the Miocene Navidad Formation (Brüggen, 1950). However, we believe that age assignments based on lithological induration and coal rank are unreliable. Bituminous coal of the Arauco peninsula (Wenzel, 1982) could be contemporaneous with, but may have formed under a higher sedimentary load, than subbituminous coal (Alfaro *et al*., 2000) in our study area, or the latter could correspond to an upper and therefore less-loaded interval of a continuous succession that spanned the entire Eocene.

Palma-Heldt and Alfaro (1982) studied palynomorphs from samples collected from different coal mines of the Valdivia area (figure 1) and concluded an uncertain Eocene-Miocene age. Subsequently, Cisternas *et al*. (1990) proposed an early Miocene age for the coal-bearing successions of the same area. According to these authors, pollen associations from the Paleogene of the Arauco peninsula are characteristic of a subtropical climate whereas those from the Valdivia area indicate a cold-temperate climate and are therefore younger. However, we consider that this age determination is not reliable because associations indicative of similar cold-temperate conditions have been found in middle to late Eocene successions of Argentina (Barreda and Palazzesi, 2007). Torres *et al*. (2000) studied palynomorphs from the coal-bearing successions of Caleta Parga (figure 1) that indicated an uncertain Eocene-Miocene age; however, they suggested an Oligocene-Miocene age for these strata because of the *Araucaria-Nothofagus-Podocarpus* association that Leppe *et al.* (1997) considered to be no older than Oligocene in Chile. We question this age assignment because the floral association also occurs in middle to late Eocene successions of Argentina (Barreda and Palazzesi, 2007).

U-Pb analysis of zircons extracted from an ash-layer intercalated between two coal-beds at the Catamutún mine (figure 1) yielded an age of 23.5 ± 0.5 Ma, which approximates the Oligocene/Miocene boundary (Sernageomin, 1998).

Considering the aforementioned data, only three of the age correlations warrant further consideration: the Eocene age based on the pollen (Troncoso and Barrera, 1979), the latest Oligocene-earliest Miocene radiometric age (Sernageomin, 1998), and the late early to late Eocene age based on *Globigerinatheka* in the present study. Although recent work on pollen constrains the age determined by Troncoso and Barrera (1979) to the middle-late Eocene (Troncoso, personal comm., 2007), it is based on a biostratigraphic framework for Cenozoic pollen of South America that has not been firmly established.

Several explanations for the discrepancy between the remaining two ages warrant consideration:

1. *The radiometric age is erroneous.* Unfortunately, the Catamutún mine, where the ash layer was sampled, collapsed some years ago, precluding any possibility of resampling its section to check the validity of this data. Yet, we are reluctant to disregard this date because the method employed (U-Pb in zircons) is generally reliable. However, the stratigraphic relationships of coal-bearing strata in the northern (Temuco) and southern (Caleta Chonos) parts of the study area, where they respectively underlie (Rubio, 1990) or are intruded (Antinao *et al.,* 2000) by late Oligocene to early Miocene volcanic rocks (see above), are arguments against the latest Oligocene-earliest Miocene age. It is also noteworthy that Marchant (1990) cites the presence of *Globigerinatheka* in strata of the area where the ash layer was sampled. In addition, no Oligocene marine strata have been found in other parts of the Chilean forearc (including the Arauco peninsula) where Miocene marine deposits always overlie Eocene or older rocks (*e.g.*, García, 1968; Finger *et al*., 2007).
2. *The* Globigerinatheka *specimens were reworked and redeposited into a late Oligocene-early Miocene succession.* Although reworking is a possibility that should not be discounted, the stratigraphic relations of coal-bearing strata with late Oligocene to early Miocene volcanics (see above) is an argument against this hypothesis.
3. *The specimens are misidentified.* The genera most similar in form to *Globigerinatheka* are *Porticulasphaera* and *Orbulinoides*. All three are in the same subfamily that is restricted to the middle and late Eocene, which renders their differentiation irrelevant to the crux of this study. Nevertheless, the majority of specimens appear more like some species of *Globigerinatheka*

than any other. Subspherical genera in the Oligocene and Miocene are quite different from those in the Eocene, and their internal molds would reflect that. Furthermore, we did not see any comparative taxa in the hundreds of Neogene assemblages analyzed.

4. *The studied successions are Eocene to latest Oligocene.* As cited above, this is refuted by the stratigraphic relations of coal-bearing strata with late Oligocene to early Miocene volcanic successions.

5. *There are two coal-bearing successions, one Eocene and the other late Oligocene-early Miocene.* The latter succession would have been deposited during the initial stage of development of a basin that formed in the Oligo-Miocene and culminated with marine deposition of the Santo Domingo Formation, as proposed by Elgueta *et al*. (2000) and Le Roux and Elgueta (2000). However, the presence of two different coal-bearing successions is not evident on seismic lines or in borehole data generated by ENAP in the study area (*e.g*., García, 1968; Elgueta *et al*., 2000). In addition, continuous sedimentation between the coal-bearing and the marine successions is unlikely, as Illies (1970) and Alfaro *et al*. (2000) cited the presence of a discordant contact between them. Furthermore, x-ray studies on clay minerals of the Pupunahue and Santo Domingo formations in the Valdivia area suggest that the coal-bearing successions were uplifted and eroded prior to subsidence and marine deposition in the Miocene (Méndez, 1996). The extreme contrast in preservation of foraminifera between the Miocene marine sequence and the coal-bearing succession also suggests the unconformity.

The above arguments favor an Eocene age for the coal-bearing deposits of south-central Chile. Confirmation of an Eocene age for these strata necessitates revision of the geological history interpreted for this region. For example, Muñoz *et al*., (1997) and Le Roux and Elgueta (2000) consider that deposition of the coal-bearing and marine genetic units defined by Cisternas and Frutos (1994) (see above) was temporally continuous during a late Oligocene to late Miocene interval. However, an Eocene age for the lower coal-bearing strata would imply a significant hiatus between that section and the middle to upper Miocene strata resulting from an intervening regression. Regardless of the above arguments, it remains difficult to reject the latest Oligocene-earliest Miocene radiometric age obtained by Sernageomin (1998) and additional data is needed to resolve the discrepancy between age indications.

Acknowledgments

This research was funded by Proyecto Fondecyt No. 3060051 of Conicyt and the IRD (Institut de Recherche pour le Développment). We are grateful to both institutions for supporting our research. ENAP (The Chilean National Petroleum Company) kindly allowed us access to their microfossil slides from wells drilled in the study area. We thank Dawn E. Peterson for operating the Hitachi T-1000 SEM at the University of California, Berkeley.

References

Alfaro, G., Helle, S., Kelm, U., Palma, S. and Pickel, W. 2000. Geología, geoquímica y composición maceral de los carbones de la X Región de los Lagos, Chile, con énfasis en los yacimientos de Catamutún y Mulpún. *Zentralblatt für Geologie und Paläontologie* 1: 851-869.

Antinao, J.L., Duhart, P., Clayton, J., Elgueta, S. and McDonough, M. 2000. *Mapa Geológico Nº 17, Area de Ancud-Maullín, Región de Los Lagos*. Escala 1: 100.000. Sernageomin.

Barreda, V. and Palazzesi, L. 2007. Patagonian vegetation turnovers during the Paleogene-early Neogene: origin of arid-adapted floras. *The Botanical Review* 73: 31-50.

Bolli, H.M. 1972. The genus *Globigerinatheka* Brönnimann. *Journal of Foraminiferal Research* 2: 109-136.

Brüggen, J. 1950. Fundamento de la Geología de Chile. *Instituto Geografico Militar Santiago*, 374 p.

Cisternas, M.E. and Frutos, J. 1994. Evolución tectónico-paleogeográfica de la cuenca Terciaria de los Andes del sur de Chile (37°30′-40°30′LAT.S.). *6º Congreso Geológico Chileno* (Concepción), *Actas* 1: 6-12.

Cisternas, M.E., Alfaro, G., Palma, S. and Helle, S. 1990. Marco geológico de las cuencas carboníferas de edad Terciaria del sur de Chile. *9º Congreso Geológico Argentino* (San Juan), *Actas* 1: 191-195.

Elgueta, S., McDonough, M., Le Roux, J., Urqueta, E. and Duhart, P. 2000. Estratigrafía y sedimentología de las cuencas Terciarias de la Región de Los Lagos (39-41°30′S). *Boletín de la Subdirección Nacional de Geología Sernageomin* 57: 1-50.

Encinas, A., Finger, K.L. and Buatois, L.A. 2007. Evidences of deep-marine sedimentation in the present longitudinal depression of south-central Chile (38°30′-41°30′S) during the neogene. Tectonic implications. *4º European Meeting on the Palaeontology and Stratigraphy of Latin America* (Madrid-España), *Actas*: 125-129,

Fenner, R. and Sylvester, C. 1936. [*Informe sobre los carbones situados en las provincias de Valdivia y Chiloé. Informe Caja de Fomento Minero, Santiago de Chile*, 51 pp. Unpublished.].

Finger, K.L., Nielsen, S.N., DeVries, T.J., Encinas, A. and Peterson, D.E. 2007. Paleontologic evidence for sedimentary displacement in Neogene forearc basins of central Chile. *Palaios* 22: 3-16.

García, F. 1968. Estratigrafía del Terciario de Chile central. In: G. Cecioni (ed.), *El Terciario de Chile Central*, Editorial Andrés Bello, Santiago de Chile, pp. 25-57.

Illies, H. 1970. Geología de los alrededores de Valdivia y volcanismo y tectónica en márgenes del Pacífico en Chile meridional. *Instituto de Geología y Geografía de la Universidad Austral,* Valdivia, 64 p.

Leppe, M., Ruiz, K. and Palma-Heldt, S. 1997. Chilean record of *Araucaria-Nothofagus-Podocarpus* association since Tertiary to Recent. *Noticiero de Biología* 5, p. 243.

Le Roux, J.P. and Elgueta, S. 2000. Sedimentologic development of a late Oligocene-Miocene forearc embayment, Valdivia Complex, southern Chile. *Sedimentary Geology* 130: 27-44.

Marchant, M. 1990. Foraminíferos Miocénicos de los Estratos de Pupunahue (Provincia de Valdivia: X Región): Determinación de la edad probable y paleoambiente. *2º Simposio sobre el Terciario de Chile* (Concepción): 177-188.

Martínez-Pardo and R., Pino, M. 1979. Edad, paleoecología y sedimentología del Mioceno marino de la Cuesta Santo Domingo, Provincia de Valdivia, X Región. *2º Congreso Geológico Chileno* (Arica), *Actas*: H 103-H 124.

Martínez-Pardo, R., Martínez-Guzmán, R. and Vilches-Guzman, G. 1997. El límite Paleoceno-Eoceno en la cuenca carbonífera de Arauco-Concepción, Chile central. *8º Congreso Geológico Chileno* (Antofagasta), *Actas*: 530-533.
Méndez, D.K. 1996. [*Alteraciones diagenéticas en sedimentos arcillosos de la cuenca de Pupunahue, provincia de Valdivia, X Región. Proyecto II, Departamento de Ciencias de la Tierra de la Universidad de Concepción, Concepción*, 99 pp. Unpublished.].
Muñoz, J.B., Duhart, P., Crignola, P., Farmer, G.L. and Stern, C.R. 1997. The mid-Tertiary coastal magmatic belt, south-central Chile. *8º Congreso Geológico Chileno* (Antofagasta), *Actas* 3: 1694-1698.
Osorio, R. and Elgueta, S. 1990. Evolución paleobatimétrica de la Cuenca Labranza documentada por foraminíferos. *2º Simposio sobre el Terciario de Chile* (Concepción): 225-233.
Palma-Heldt, S. and Alfaro, G. 1982. Antecedentes palinológicos preliminares para la correlación de los mantos de carbón del Terciario de la provincia de Valdivia. *3º Congreso Geológico Chileno* (Concepción), *Actas*: A207-A235.
Premoli-Silva, I., Wade, B.S. and Pearson, P.N., 2006. Taxonomy, biostratigraphy, and phylogeny of *Globigerinatheka* and *Orbulinoides*. In: P.N. Pearson, R.K. Olsson, B.T. Huber, C. Hemleben and W.A. Berggren (eds.), Atlas of Eocene Planktonic Foraminifera. *Cushman Foundation for Foraminiferal Research*, *Special Publication* 41: 169-212.
Rubio, X. 1990. Geología regional y estratigrafía del Terciario de la cuenca de Labranza, IX Región, Chile. *2º Simposio sobre el Terciario de Chile* (Concepción): 285-295.
Sernageomin, 1998. *Estudio geológico-económico de la X Región Norte*. Informe Registrado IR-15-98, Sernageomin, Santiago, 6 volúmenes, 27 mapas.
Tavera, J. 1942. Contribución al estudio de la estratigrafía y paleontología del Terciario de Arauco. *1º Congreso Panamericano de Ingeniería de Minas y Geología* (Santiago), *Anales* 2: 580-632.
Torres, C., Palma-Heldt, S. and Hanne, A. 2000. Estudio palinológico de la cuenca carbonífera de Parga, X Región, Chile. *9º Congreso Geológico Chileno* (Puerto Varas), *Actas* 1: 573-577.
Troncoso, A. and Barrera, E. 1979. Estudio palinológico de tres testigos del pozo Río Blanco N° 1 (Osorno, Chile). *2º Congreso Geológico Chileno* (Arica), *Actas* 3: H1-H14.
Vergara, M. and Munizaga, F. 1974. Age and evolution of the Upper Cainozoic andesitic volcanism in central-south Chile. *Geological Society of America Bulletin* 85: 603-606.
Wenzel, O. 1982. Estratigrafía de las series carboníferas de Arauco. *3º Congreso Geológico Chileno* (Concepción), *Actas*: F256-F279.

Recibido: 30 de junio de 2008.
Aceptado: 26 de marzo de 2009.