Middle Albian marine planktonic microfossils from the Santiago basin, central Chile: their depositional and paleogeographic meaning

Rubén Martínez-Pardo

Antonio Gallego

Rodolfo Martínez-Guzmán

Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Casilla 13518, Correo 21, Santiago, Chile

ABSTRACT

Limestones from the Polpaico locality, within the Santiago basin, on the east side of Central Chile's Coastal Range, originally considered as intermontane lake deposits, with no conclusive paleontological information, and assumed to be Cenomanian-Turonian in age, are marine and essentially middle Albian according to thin section planktonic microfossil studies. They would correspond to an open carbonate shelf transgressive environment, not deeper than 100 m, characterized by warm-temperate waters (*ca.* 15-17°C annual average), affected by anoxic conditions and related to a broad marginal basin directly connected to the Pacific Ocean and to the Neuquén basin. Determined taxa include skeletal calcareous algae, planktonic and benthonic foraminifera, calcispherulid and calpionellid species. The Polpaico limestones would be the first Albian marine deposits paleontologically supported within the Pacific side of the Chilean-Argentinean Central Andes.

Key words: Microfossils, Marine Albian, Santiago basin, Central Chile, Polpaico limestones, Planktonic and benthonic foraminifera, Skeletal calcareous algae, Calcispherulids, Calpionellids, Depositonal setting, Paleogeography.

RESUMEN

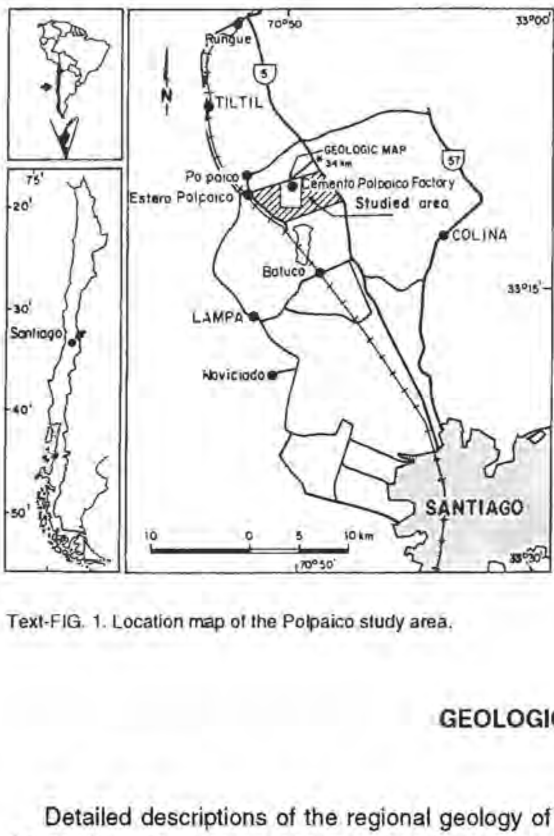
Microfósiles planctónicos marinos del Albiano medio de la cuenca de Santiago en Chile central: su significado deposicional y paleogeográfico. Las calizas presentes en la localidad de Polpaico, dentro de la cuenca de Santiago, en el borde oriental de la Cordillera de la Costa de Chile central, originalmente interpretadas como depósitos lacustres intermontanos de edad cenomaniana-turoniana y sin evidencia paleontológica definida, son marinas y básicamente del Albiano medio, según microfósiles planctónicos estudiados en secciones delgadas. Ellas corresponderían a un ambiente de plataforma carbonatada transgresivo, de no más de 100 m de profundidad, de aguas templado-cálidas (*ca.* 15-17°C promedio anual), afectado por condiciones anóxicas e integrado a una amplia cuenca marginal directamente conectada con el Océano Pacífico y con la cuenca de Neuquén. Los taxa determinados incluyen especies de algas calcáreas esqueléticas, foraminíferos planctónicos y bentónicos, calcisferúlidos y calpionélidos. Las calizas de Polpaico serían los primeros depósitos marinos albianos paleontológicamente confirmados, dentro del sector pacífico de los Andes centrales chileno-argentinos.

Palabras claves: Microfósiles, Albiano marino, Cuenca de Santiago, Chile central, Calizas de Polpaico, Foraminíferos planctónicos y bentónicos , Algas calcáreas esqueléticas, Calcisferúlidos, Calpionélidos, Ambiente de deposición, Paleogeografía.

Revista Geológica de Chile, Vol. 21, No. 2, p. 173-187, 5 Figs., 1 Plate, December 1994.

INTRODUCTION

Marine Albian deposits have been recognized on the Pacific margin of South America between Venezuela and southern Perú and in the Magallanes basin, but have not been strictly confirmed in the Chilean-Argentinean Central Andes (Leanza and Castellaro, 1955; C. Nasi[1]; Hallam *et al.*, 1986; Riccardi, 1987; Macellari, 1988; Mpodozis and Ramos, 1990).



Text-FIG. 1. Location map of the Polpaico study area.

New micropaleontological information provided in this work makes it possible to assign an Albian age and a true marine origin to the limestones cropping out in the Polpaico locality, 37 km northwest of the city of Santiago, within the Santiago basin and on the eastern side of the present Coastal Range (Brüggen, 1950; (text-Fig. 1). Traditionally assigned to the Las Chilcas Formation (Thomas, 1958), but without conclusive paleontological information, these calcareous strata had heretofore been regarded as lacustrine or lagoonal in origin (Herm, 1965, 1967; Vergara and Drake, 1979; Corvalán and Vergara, 1980), and Cenomanian-Turonian (Thomas, 1958), Santonian-Coniacian (Riccardi, 1987), Campanian-Maastrichtian (Corvalán and Vergara, 1980), Hauterivian-Albian (Mpodozis and Ramos, 1990), and Barremian or older in age (prior to 118 Ma) (Rivano *et al.*, 1986), basically according to the assumed dates of their enclosing formation.

The aim of this contribution is to provide taxonomic information about some specific microfossil groups recognized through thin-section studies in the Polpaico limestones, including their chronostratigraphic, paleoenvironmental and paleogeographic meaning. In addition, to show that micropaleontological studies can be basic for the new models that the terminal early Cretaceous paleogeography and geohistory of the Chilean-Argentinean Central Andes are already requiring.

GEOLOGICAL SETTING

Detailed descriptions of the regional geology of the study area are presented and can be revised elsewhere (Thomas, 1958; Godoy, 1982; C. Nasi[1], 1984; González, 1987). Therefore, only the local sequence and the main unsolved regional geologic problems will be presented herein.

The Polpaico limestones are emplaced in the Las Chilcas Formation (Thomas, 1958), formed by coarse red conglomerates and sandstones interbedded with lavas and limestones. According to Thomas (1958), the Las Chilcas Formation conformably overlies the Veta Negra Formation, mainly composed of flood basalts with intercalations of continental sediments and some assumed marine carbonate beds (Nasi and Thiele, 1982) and is, in turn, unconformably overlain by the Lo Valle Formation of continental volcanoclastic characteristics. The ages and the contact relationships of the above formations are highly controversial at present (Corvalán and Vergara, 1980; Nasi and Thiele, 1982; Godoy, 1982; C. Nasi[1]; Charrier, 1986; Rivano *et al.*, 1986; Martínez-Pardo and González, 1988; Beck *et al.*, 1990).

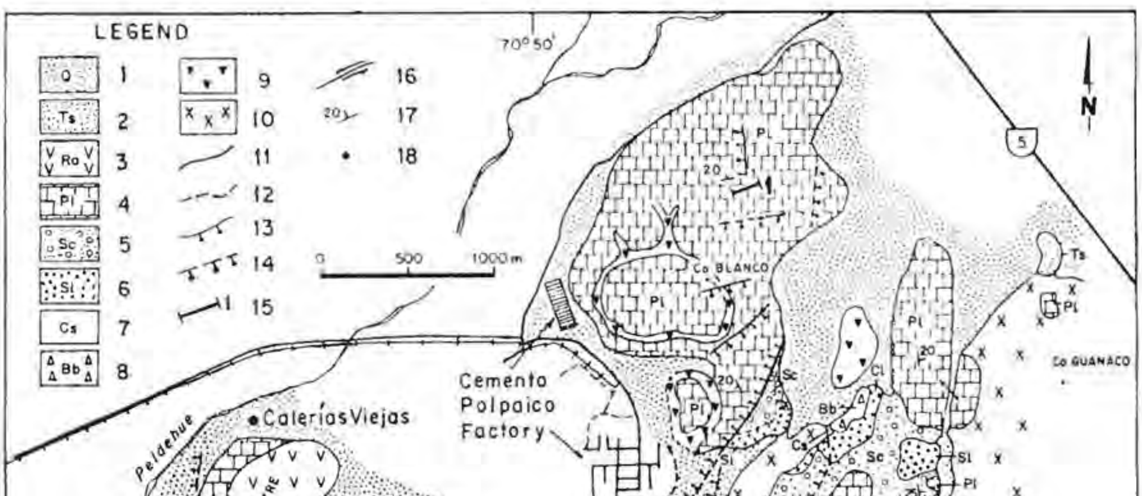
The above lithologic units would represent a transition stage between marine and continental domains, associated to the ensialic 'aborted' marginal basin developed in Central Chile during Hauterivian to Albian

[1] 1984. Geología de la Cordillera de la Costa de Chile central. *In* Seminario Actualización de la Geología de Chile. *Servicio Nacional de Geología y Minería* (Inédito), parte L, p. 1-17. Santiago.

times (Åberg *et al.*, 1984; Mpodozis and Ramos, 1990). According to Beck *et al.* (1990), the combined stratigraphy of the Lo Prado, Veta Negra and Las Chilcas formations suggests an early Cretaceous continental arc environment including the Lo Valle Formation *(sic)*. To other authors, on the contrary, that continental intra-arc environment would be late Cretaceous for the Las Chilcas Formation, and connected to the Campanian to Maastrictian fore-arc marginal deposits exposed in the Algarrobo locality, representing the Quiriquina transgression in the coastal side of the study area (Corvalán and Vergara, 1980; C. Nasi[1]; Macellari, 1988; Yrigoyen, 1991).

The published record of the micro-scaphopods of the genus *Dentalium* in the Polpaico limestones, at the base of Cerro Blanco Site, supposed to be indicatives of a brackish lagoonal environment (Corvalán and Vergara, 1980), has not been confirmed till now. It is not excluded that they may represent small vegetal stem debris (Covacecich, personal communication, 1990).

The stratigraphic sequence cropping out at the Polpaico locality contains a maximum of 90 m of limestones and volcanoclastic sedimentary rocks with intercalated sandstones. The four members recognized in this work, all conformable with each other, are those shown in text-figures 2 and 3a (Gallego, 1994). Within the type locality, on the north side of the Cerro Mesa (text-Fig. 3a), the sequence begins with 8 m of conglomeratic sandstones yielding poorly preserved plant remains (Member I), succeeded by nearly 30 m of fine to coarse laminated sandstones with calcareous interbeds near the top (Member II). Next, there are 12 m of sandstones and paraconglomerates with abun-



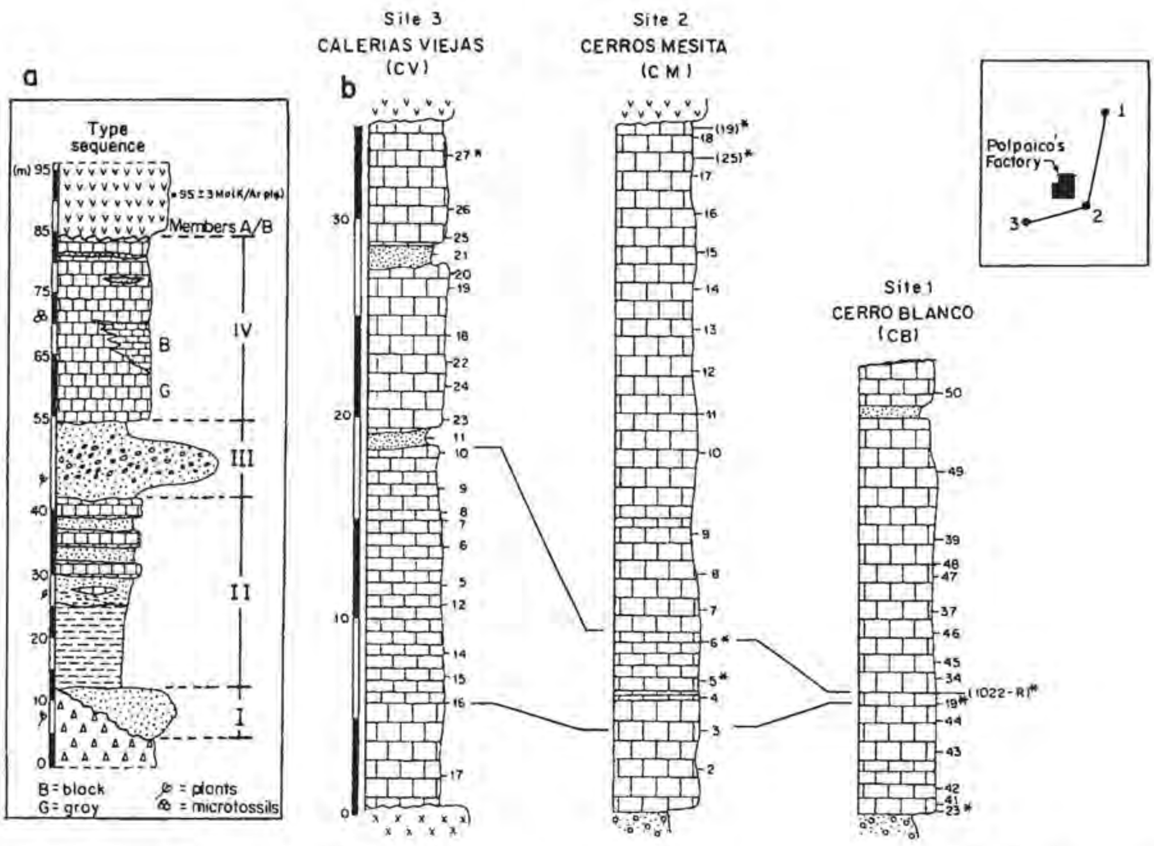
Text-FIG. 2. Geological map of the Polpaico area (After Gallego, 1994. 1- Quaternary; 2- tuff and sandstone; 3- red andesite; 4- Polpaico limestones (Member IV); 5- sandy conglomerate (Member III); 6- silty-sand and limestone (Member II); 7- coarse sandstone (Member I); 8- basal breccia; 9-green basalt; 10- diorite; 11- observed contact; 12- inferred contact; 13- observed normal fault; 14- inferred normal fault; 15- stratigraphical columns, sites 1, 2, 3; 16- sinistral strike-slip fault; 17- strike and dip; 18- radiometric age.

dant reworked silicified trunks into the basal beds (Member III). It ends with about 30 m of cream-colored limestones with thin intercalations of pumice-rich red sandstones at the top, which grade laterally to black and gray limestones towards the southwest (Member IV). The whole sequence rests with erosional unconformity on andesitic breccia lavas and is overlain, also with an erosional unconformity, by a red andesitic lava flow or sill (95±3 Ma, K-Ar, plagioclase) (Gallego, 1994). In addition, close to the southern border of the study area, this same succesion is intruded by granodioritic stocks (92±3 Ma, K-Ar, plagioclase), dikes and veins (Gallego,1994).

The Polpaico limestones coincide with Member IV, and include five calcareous microfacies associations, which mostly represent marine mudstones and wackestones with frequent mixed planktonic and continental bioclasts, but only occasional benthonic skeletal debris. These microfacies associations would indicate transitional, marginal, and inner-to-outer shelf depositional settings (Gallego, 1994).

To the authors, on the basis of present-day information, the most significant and yet unsolved geologic problems within the study area would be the following:

- The exact stratigraphic position of the Polpaico limestones within the Las Chilcas Formation.



Text-FIG.3. Generalizec sequence and studied calcareous columns from the Polpaico area (after Gallego, 1994). 3a- type sequence, northern side of Cerro Mesa: I- coarse sandstone Member; II- silty-sand and limestone Member; III- sandy conglomerate Member; IV- Polpaico limestone Member. 3b- location of the Polpaico limestones (Member IV) profiles, including number and stratigraphic position of the samples. Asterisks mark those containing the photographed microfossils on plate 1. Sample 1202-R (Rivano, 1982, SERNAGEOMIN), positioned according to its microfosssil content. Legend for lithology as in text-figure 2.

Initialy assigned to the lower part of the above unit on field grounds (Thomas, 1958), they have been moved later on, without any informed stratigraphic evidence, to the top of the same formation (Corvalán and Vergara, 1980).

- The unknown areal extent of the Polpaico limestones supposed to cover, as a synchronous horizon, most of the interior side of the present Coastal Range, from Santiago in the south to La Ligua in the north (Corvalán and Vergara, 1980). In fact, the Tiltil limestones, exposed 10 km to the northeast of Polpaico type locality, are probably Miocene in age (Martínez-Pardo and González, 1988).
- The two-opposing ages formally admitted for the top of the Las Chilcas Formation by most Chilean geologists over the years. Accepting its supposed upper lateral intertonguing with the Lo Valle Formation (Thomas, 1958; Godoy, 1982, 1986; Beck *et al.*, 1990), and the minimum radiometric ages of 64-70.5 Ma of the second one (Drake *et al.*, 1976), the Las Chilcas Formation and the Polpaico limestones would be as young as 64 Ma, and Maastrichtian (Kent and Gradstein, 1985), or slightly older in age at its higher part, as postulated by Corvalán and Vergara (1980). On the other hand, according to the radiometric age of 118 Ma, given by the plutons cutting the Las Chilcas Formation near Llaillay (Rivano *et al.*, 1986), considered to agree fairly well with recent paleomagnetic studies within the area (Beck *et al.*, 1990), this same unit would instead be older than 118 Ma, therefore Barremian or earlier (Kent and Gradstein, 1985).
- The genetic and time relationship between the Las Chilcas Formation and the progressive closure and thrusting of the 'aborted' Central Chile marginal back-arc basin supposed to have occured at the end of the early Cretaceous (Hauterivian to Albian) (Åberg *et al.*, 1984; Mpodozis and Ramos, 1990). This major regional tectonic event would be coincidental with the change from a 'Mariana type' to 'Chilean-type' subduction along the oceanic margin of Central Andes (Coira *et al.*, 1982), and related to the onset of the active drift of the South American continent following its separation from Africa around 90-100 Ma ago (Reyment and Dingle, 1987).
- The clear evidence of an important sedimentary discontinuity over the Las Chilcas Formation, probably connected either to the global sea-level fall of the late Albian-earliest Cenomanian, or to the interregional unconformity recognized at about 98 Ma (Vail *et al.*, 1977; Haq *et al.*,1987). This sedimentary break, already postulated by Klohn (1956) and Martínez-Pardo and González (1988), has not yet been considered by any author in Chile (Charrier, 1986), except for a very recent and brief reference by Charrier and Muñoz (1994). It would correspond, however, to the Miranic Diastrophic Phase (*ca.* 98 Ma) of Central Andes (Stipanicic and Rodrigo, 1970; Ramos, 1988), probably coincident with the former Albian to Senonian Orogenic Phase of Charrier and Vicente (1972), according to this study.

SAMPLE DATA

The Polpaico limestones samples investigated in this opportunity are from three stratigraphic columns within the study area (text-Fig. 3). The geographic location of the columns and the key letter abbreviations for them are as follow:

- Cerro Blanco Site (CB)
- Cerro Mesita Site (CM) and
- Caleras Viejas Site (CV)

Sample positions on each stratigraphic column and their corresponding number are shown in text-figure 3b, after Gallego (1994). Megascopic and microscopic descriptions of these, including their corresponding thin sections, can also be revised in Gallego (1994). Sample 1202-R (collected by S. Rivano, SERNAGEOMIN, 1982), is from the Cerro Blanco locality, and would be close to sample CB-19 of the lower part of that column, according to its microfossil content.

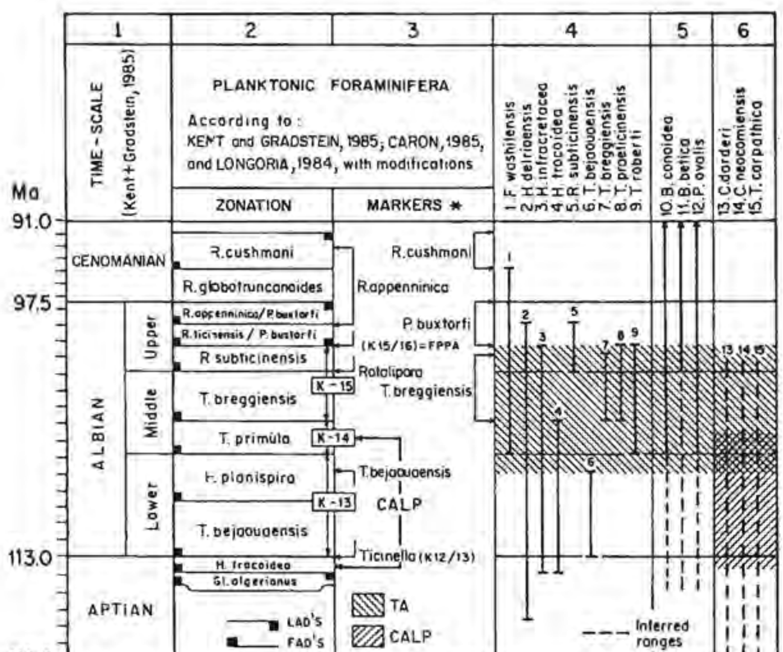
MICROPALEONTOLOGY

No isolated microfossils were recovered from the Polpaico limestones in this study, and the occurring recorded taxa mostly represent selected determinations based on 120 thin-sections. The conclusive admitted species are:

Skeletal calcareous algae: *Lithophyllum* sp., *Lithoporella* sp. (Crustose corallites); *Cayeuxia* sp. (Erect codiaceans); *Salpingoporella dinarica* Radoicic (Dasycladaceans); *Muniera baconica* Deeke; *M. grambasti* Cherchi (Charophytes).
Planktonic Foraminifera: *Favusella washitensis* (Carsey), *Hedbergella delrioensis* (Carsey); *H. infracretacea* (Glaessner); *H. trocoidea* (Gandolfi); *Rotalipora subticinensis* (Gandolfi); *Ticinella bejaouaensis* Sigal; *T. breggiensis* (Gandolfi); *T. praeticinensis* Sigal, *T. roberti* (Gandolfi).
Benthonic Foraminifera: *Coskinolinella daquini* Delmas and Deloffre; *Sabaudia minuta* (Hofker); *Trocholina lenticularis* Henson.
Calcispherulids: *Bonetocardiella conoidea* (Bonet); *B. betica* (Azema); *Pithonella ovalis* (Kaufmann).
Calpionellids: *Calpionellites coronata* Trejo; *C. darderi* Colom; *C. neocomiensis* Colom; *Tintinopsella carpathica* (Murgeanu and Filipescu).

BIOCHRONOSTRATIGRAPHY

According to planktonic foraminifera, the Polpaico limestones are basically middle Albian in age (text-Fig.4). Specifically, they would cover the time span bracketed between the upper part of *H. planispira* Zone (terminal lower Albian), and the top of *R. subticinensis* Zone (early upper Albian). This time interval is approximately equivalent to that encompassed by the Albian planktonic zones K-13 (upper part), K-14 and K-15 of Mexico (Longoria, 1984), and close to the initial part of the *F. washitensis* Zone, marking the middle to late Albian along the eastern continental margin of Brazil (Viviers, 1985).



* Datum planes

Text-FIG. 4. Biochronostratigraphy of the middle Albian Polpaico limestones. 1- Albian time-scale and numeral ages; 2, 3- standard planktonic foraminiferal zonation and datum planes; 4, 5, 6- whole stratigraphic ranges of planktonic foraminifera, calcispherulids and calpionellids species herein recorded; K15/K16 FPPA Datum: first evolutionary appearance of acute periphery and single keeled species in planktonic foraminifera; (K-15), (K-14) and (K-13): Albian planktonic foraminiferal zones from the Gulf of Mexico region; TA: tentative age of Polpaico limestones; CALP: first and last appearance of Albian Calpionellids in the Caribbean region (genus *Colomiella*).

These two zones occur just about on, but below the First Planktonic Periphery Acute Datum (FPPA Datum) (Bandy, 1967; Wonders, 1980; Caron, 1985; Leckie, 1989) (text-Fig. 4).

The conspicuous absence of periphery acute species among the investigated planktonic foraminifera, suggesting that the whole assemblage is close and previous to the FPPA Datum (=K15/K16 Datum) (text-Fig. 4), supports the above age asignment. The occasional, but reliable occurrence in the Polpaico limestones of calcispherulids (*Bonetocardiella* and *Pithonella*), known from the late Aptian up to the Santonian-Maastrichtian as a group (Krasheninnikow *et al.*, 1986), but specially significant between middle Albian and Cenomanian (Andri, 1972), reinforces the herein proposed age. In fact, two calcispherulids species from the above limestones, *B. conoidea* and *P. ovalis*, are restricted to middle Albian and close to, but prior to the FPPA Datum in northeastern Brazil (Dias-Brito, 1985), as corroborated by palinochronostratigraphy (Regali *et al.*, 1985). The non-recognition among the Polpaico limestones' calcispherulids of the genus *Stomiosphaera*, recorded as frequent in several Tithonian-Neocomian limestones from Central Chile (Herm, 1965, 1967), supports a similar conclusion.

The occasional occurrence of calpionellids (*Tintinopsella* and *Calpionellites*) in some gray and black filament-rich mudstones and wakestones of the Polpaico limestones, points in the same direction, even though they are not in agreement with the LAD's assigned to this whole group in the Western Mediterranean Province (Remane, 1969, 1985). There is strong evidence at present, however, that calpionellids became extinct at different times throughout the world after the early Valangin an (Colom, 1988), probably due to regional facies development (Delfau, 1986). As a matter of fact, it occurred during the early Valanginian at the Mediterranean Tethys (Remane, 1985); within the middle Albian in the Antillean Tethys *(Colomiella)* (Trejo, 1980; Colom, 1988), and in the Cenomanian at the Rocky Mounta ns, U.S.A. (Eicher, 1965). It is possible, therefore, that *T. carpathica*, no younger than the early Valanginiar in Europe, and the Aptian in the Antillean area (Colom, 1988), can be middle Albian in the Polpaico loca ity, coinciding with the LAD of *Colomiella* in Mexico (Longoria, 1984), an age limit probably valid for all the calpionellids recognized within the study area.

The minimal early upper Albian age postulated in this opportunity for the Polpaico limestones, 100 Ma according to recent calibration of the FPPA Datum by Kent and Gradstein (1985), is also corroborated by two radiometric dates. The first one, 95±3 Ma, K-Ar-plagioclase, corresponds to the base of the red andesitic lava flow or sill unconformably overlying the Polpaico limestones (text-Fig. 3a). The second, 92±3 Ma, K-Ar-plagioclase, is from the dioritic stock intruding the complete sequence in the southern portion of the study area, including the red andesitic lava flow or sill capping it off (Gallego, 1994); (text-Fig. 2).

DEPOSITIONAL SETTING AND PALEOGEOGRAPHY

Most of the explosive morphologic changes experienced by planktonic foraminifera and other pelagic microfossils during the middle to late Albian, as admitted at present, were the product of the unusually dynamic paleoceanographic, paleoclimatic and paleogeographic conditions prevailing during that period (Tappan and Loeblich, 1973; Douglas and Savin, 1978; Wonders, 1980; Vincent and Berger, 1981; Caron and Homewood, 1983; Leckie, 1987, 1989). It is valid, therefore, based on the above relationships, to use the morphologic characteristics of the Polpaico planktonic foraminifera, to infer the main physicochemical environmental parameters producing their specific morphologic features and, by extension, the probable depositional setting of the limestones themselves.

As previously noted, the planktonic foraminifera from the Polpaico limestones are mostly smallish trochospiral forms with globose chambers and round margins, suggesting a low diversity and depauperate taphoceoenosis. By analogy with similar modern morphotypes, they would have been shallow dwellers taxa, not deeper than 100 m, restricted to the photic zone, above the thermocline, proper to marginal shelf-seas and related to near-surface warm-temperate anoxic waters of low density and reduced depth thermal gradients (Douglas and Savin, 1978; Hart, 1980; Wonders, 1980; Caron and Homewood, 1983; Leckie, 1989). In present tropical non-anoxic waters 100-200 m deep, usually coupled with a strong thermocline piercing into the photic zone, the

Text- FIG. 5. Latest early Cretaceous paleogeography of Chilean-Argentinean central Andes; **stippled border:** suggested outline of the marginal basin providing the Polpaico limestones deposition in the west, directly open to the Pacific Ocean, and connected with the Neuquén basin to the east; **arrows:** dominant sedimentary input (adapted from Rosenfeld, 1987 and Macellari, 1988).

trochospiral planktonic foraminiferal morphotypes are, on the contrary, larger and with compressed chambers and acute or single keeled margins, as it first occurred just above the FPPA Datum, during the late Albian second episode of planktonic foraminifera morphologic diversification (Longoria, 1984; Caron, 1985; Leckie, 1989). These last morphotypes have not been recognized in the Polpaico limestones as yet.

The accepted major events contributing to produce the above special morphologic characteristics among the planktonic foraminifera, would be the following:

- A long term rise of the global sea level beginning at the middle Aptian and lasting up to the Cretaceous/Tertiary boundary, which reached a first significant peak in the latest Albian. This major high sea level would have created shallow to intermediate shelf-seas and marginal basins not deeper than 100 m close to, but below the FPPA Datum, and truly deep waters, under 200 m, just over it (Vail *et al.*, 1977; Haq *et al.*, 1987).
- An overall increase of global mean annual temperature of the sea, around 15-17°C prior to the FPPA Datum, with a peak of about 28-30°C immediately over it, and a reduced equator-to-pole gradient close to 10°C during both steps. These temperatures also suggest unusually equable warm climatic conditions during that time (Barron, 1983; Barron and Washington, 1982; Axelrod, 1984). Through the production of low latitude warm saline waters, the above temperature changes would have modified the density structure of the upper sea levels, reinforcing the dynamic and ecological instability of the photic zone (Brass *et al.*, 1982; Widle and Berry, 1982; Marshall, 1988), and triggering the morphologic diversification of the planktonic foraminifera (Leckie, 1989).
- A widespread period of intensive terrigenous organic carbon burial, from the latest Aptian up to the FPPA Datum. Associated to anoxic global conditions, and representing cyclical 'black shale' and carbonate deposition on epicontinental seas, this event is frequently individualized as Oceanic Anoxic Event 1 (OAE-1) (Scholle and Arthur, 1980). It would be responsible for the world-wide marked low diversity and depauperate character of most early to middle Albian shelf-seas planktonic foraminiferal assemblages, as it is evident in the Polpaico limestones, almost devoid of benthonic forams and plenty of organic carbon at different levels.
- The high CO_2 atmospheric levels derived from the

increased rates of sea-floor spreading and plate margin volcanism and plutonism occurred during the middle and upper Albian (Schlanger *et al.*, 1981; Barron and Washington, 1985), in connection with the opening of the South Atlantic Ocean (Reyment and Dingle, 1987). These high CO_2 levels would have been much influential on terrestial vegetation, the evolution of flowering plants, the weathering ratios, and on the delivery of nutrients to the marine realm, increasing gross marine primary productivity and the planktonic foraminiferal diversity (Leckie, 1989).

According to the above analysis and to the planktonic foraminiferal data herein recorded, the middle Albian limestones from Polpaico are marine and related to an equable warm-temperate climate, with a mean annual temperature of *ca.* 15-17°C and low bathymetric and longitudinal thermal gradients, probably under 10°C. Within the studied stratigraphic sequence, they would be indicative of a marginal open transgressive carbonate shelf platform environment, not deeper than 100 m, and with abundant buried terrigenous carbon and oxygen deficient. This same succesion would have also been affected by local tectonic, climatic and sea-level perturbations, partially masking the above major global trends. The complex carbonate-clastic depositional cyclicity recognized in the whole Polpaico sequence, where the clastic intervals would indicate sea level regressive deposits, and carbonate intervals transgressive ones (Gallego, 1994), supports these additional modifications. The whole study sequence would correspond to the terminal stage of the major marine transgressive cycle developed within the Andean basin from the early Jurassic to the late Albian (Macellari, 1988), recently defined as Patagonides cycle (Ramos, 1980).

The paleogeographic scenario associated to the above limestones suggests a gentle-sloped inner shelf platform, directly open to the Pacific circulation and representing a wide marginal marine basin far-reaching to the east during the mid Albian (text-Fig. 5). This wide embayment, probably related to the ensialic 'aborted' one postulated for central Chile during the late early Cretaceous (Mpodozis and Ramos, 1990), would have also reached the Neuquén basin (Ramos, 1988), clearly disconnected from the Pacific margin by an 'stationary' magmatic arc only after the late Cretaceous onset according to this study, not earlier as usually admitted at present. (Macellari, 1988; Ramos, 1988; Legarreta and Gulisano, 1989; Charrier and Muñoz, 1994).

The new proposed paleogeographic scenario differs from those traditionally admitted for the region, all asociated with a long interior north-west/south-north embayment, limited to the west by the Chilean Coastal Range (Muñoz-Cristi, 1956; Aubouin and Borello, 1970; Hallam *et al.*, 1986; Macellari, 1988), in the broad and direct connection now admitted between the postulated basin and the Pacific Ocean up to the late Albian. According to this new model, and accepting as valid the occurrence of the latest early Cretaceous 'aborted' marginal basin of central Chile (Mpodozis and Ramos, 1990), to produce this new scenario it would be sufficient to extend the meridional limit of the above basin some degrees southward, probably down to 40°S from its present 33°S admitted location (Mpodozis and Ramos, 1990) (text-Fig. 5).

One of the advantages of this new proposed model, would be to explain the close correlations shown by the major global paleoceanographic and anoxic events across the western margin of South America and the Neuquén basin during the Albian, usually questioned and discredited nowadays (Hallam *et al.*, 1986; Macellari, 1988).

CONCLUSIONS

- The micropaleontological evidence presented in this opportunity confirms the occurrence of mid Albian marine deposits within the Santiago basin, in Central Chile.
- These deposits would be part of the Pacific transgressive sequence associated to the terminal part of the Patagonides tectonic cycle, also reaching the Neuquén basin.
- The evaluation on paleogeographic, paleoceanographic and paleoenvironmental terms of the new micropaleontological data, would be critical for the traditional models actually admitted for the terminal Lower Cretaceous geohistory of the Chilean-Argentinean Central Andes.

ACKNOWLEDGEMENTS

The authors want to thank Cemento Polpaico S.A. for their technical and financial support to the present study, as well as to all those colleagues who contributed with their ideas and observations to improve it. Constructive review of the manuscript by J. Corvalán, V. Covacevich, E. Godoy and E. Pérez (SERNAGEOMIN), and S. Elgueta (Departamento de Geología, Universidad de Chile), is gratefully acknowledged. Research project initially supported by the Fondo Nacional de Ciencia y Tecnología de Chile (FONDECYT), Grant No. 569-88.

REFERENCES

Åberg, G.; Aguirre, L.; Levi, B.; Nyström, J. 1984. Spreading subsidence and generation of ensialic marginal basin: An example from the Early Cretaceous of Central Chile. *In* Marginal basin geology (Kokelaar, B.P.; Howells, M.; editors). *Geological Society of London, Special Publication*, No. 16, p. 185-193.

Andri, E. 1972. Mise au point et donnés nouvelles sur la famille des *Calcisphaerulidae* Bonnet 1956; Les genres *Bonetocardiella, Pithonella, Calcisphaerula* et *Stomiosphaera*. *Revue de Micropaleontologie*, Vol. 15, No. 1, p. 12-34.

Aubouin, J.; Borrello, A.V. 1970. Regard sur la géologie de la Cordillère des Andes: relais tectoniques et cycles orogeniques superposés: le Nord argentin. *Societé Géologique de France, Bulletin*, Vol. 12, No. 7, p. 246-260.

Axelrod, D.I. 1984. An interpretation of Cretaceous and Tertiary biota in polar regions. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol. 45, No. 2, p. 105-147.

Bandy, O.L. 1967. Cretaceous planktonic foraminiferal zonation. *Micropaleontology*, Vol. 13, No. 1, p. 1-31.

Barron, E.J. 1983. A warm, equable Cretaceous: the nature of the problem. *Earth-Sciences Reviews*, Vol. 19, p. 305-338.

Barron, E.J.; Washington, W.M. 1982. Cretaceous climate: a comparison of atmospheric simulations with the geologic record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol. 40, Nos. 1-3, p. 103-133.

Barron, E.J.; Washington, W.M. 1985. Warm Cretaceous climates: high atmospheric CO_2 as a plausible mechanism. *In* The carbon Cycle and Atmospheric CO_2; natural variations Archean to Present (Sundquist, E.T.; Broecker, W.S.; editors) *Geophysical Monograph*, No. 32, p. 546-553.

Beck, Jr., M.E.; Burmester, R.F.; Garcia, A.; Rivano, S. 1990. Paleomagnetic results from Cretaceous rocks in the Llaillay-San Felipe-Putaendo region: implications for block rotations in the Andean forearc. *Revista Geológica de Chile*, Vol. 17, No. 2, p. 115-130.

Brass, G.W.; Southam, J.R.; Peterson, W.H. 1982. Warm saline bottom water in the ancient ocean. *Nature*, Vol. 296, p. 620-623.

Brüggen, J. 1950. Fundamentos de la Geología de Chile. *Instituto Geográfico Militar*, 374 p. Santiago.

Caron, M. 1985. Cretaceous planktic foraminifera. *In* Plankton Stratigraphy (Bolli, H.; Saunders, J.B.; Nielsen, K.P.; editors). *Cambridge University Press*, p. 17-86.

Caron, M.; Homewood, P. 1983. Evolution of early planktic foraminifera. *Marine Micropaleontology*, Vol. 7, No. 6, p. 453-463.

Charrier, R. 1986. Estratigrafía, evolución tectónica y significado de las discordancias de los Andes chilenos entre 32°S durante el Mesozoico y Cenozoico. *In* Geología y recursos minerales de Chile (Frutos, J.; Oyarzún, R.; Pincheira, M.; editores). *Geología y recursos minerales de Chile, Universidad de Concepción*, p. 101-133.

Charrier, R.; Vicente, J.C. 1972. Liminary and geocyncline Andes; Major orogenic phases and synchronical evolution of the central and austral sectors of the southern Andes. *Conferencia sobre problemas de la tierra sólida*, Vol. 2, p. 451-470. Buenos Aires.

Charrier, R.; Muñoz, N. 1994. Jurassic Cretaceous Palaeogeographic evolution of the Chilean Andes at 23°-24°S Latitude and 34°-35°S Latitude: A comparative analysis. *In* Tectonics of the Southern Central Andes (Reutter, K.J.; Scheuber, E.; Wigger, P.; editors). *Springer-Verlag*, p. 233-242.

Coira, B.; Davidson, J.; Mpodozis, C.; Ramos, V. 1982. Tectonic and magmatic evolution of the Andes of northern Argentina and Chile. *Earth-Sciences Reviews*, Vol. 18, Nos. 3-4, p. 303-332.

Colom, G. 1988. Una revisión del grupo de los Tintínidos (infusorios Oligótricos Loricados). La evolución de sus especies en los mares paleozoicos y secundarios. *Revista Española de Paleontología*, Vol. 3, p. 71-104.

Corvalán, J.; Vergara, M. 1980. Presencia de fósiles marinos en las Calizas de Polpaico: implicaciones paleoecológicas y paleogeográficas. *Revista Geológica de Chile*, No. 10, p. 75-83.

Delfaud, J. 1986. Organisation scalaire des évenements sédimentaires majeurs autour de la Mésogée durant le Jurassique et le Crétacé: Consequences pour les associations biologiques. *Centres de Recherches Exploration-Production, Elf-Aquitaine, Bulletin,* Vol. 10, No. 2, p. 509-535.

Dias-Brito, D. 1985. Calcisphaerulidae do Albiano da Bacia de Campos-Río de Janeiro-Brasil: investigaçoes taxonomicas, bioestratigraficas e paleoambientais Collection papers. *Congreso Brasilero Paleontológico, No. 8 (Río de Janeiro, 1983), Ministerio de Minas e Energia, Departamento Nacional de Productos Mineros, Servicio Geológico, No. 27, Sección Paleontología y Estratigrafía,* No. 2, p. 195-305.

Douglas, R.G.; Savin, S.M. 1978. Oxygen isotopic evidence for the depth stratification of Tertiary and Cretaceous planktonic foraminifera. *Marine Micropaleontology,* Vol. 3, No. 2, p. 175-196.

Drake, R.; Curtis, G.; Vergara, M. 1976. Potassium-Argon dating of igneous activity in the Central Chilean Andes, latitude 33°S. *Journal of Volcanology and Geothermal Research,* Vol. 1, No. 3, p. 285-295.

Eicher, D.L. 1965. Cretaceous Tintinnids from the Western Interior of the United States. *Micropaleontology,* Vol. No. 4, p. 449-456.

Gallego, A. 1994. Paleoambiente y mecanismo de depositación de la secuencia sedimentaria que aflora en el sector de Polpaico, Región Metropolitana, Chile. Memoria de Título (Inédito), *Universidad de Chile, Departamento de Geología,* 476 p.

Godoy, E. 1982. Geología del área de Montenegro-Cuesta de Chacabuco, el «problema» de la Formación Lo Valle, Región Metropolitana, Chile. *In Congreso Geológico Chileno, No. 3, Actas,* Vol. 1(A), p. 124-146.

Godoy, E. 1986. Los intrusivos hipabisales miocénicos del Cordón Chacabuco: ¿un caso de fraccionamiento de hornblenda? *Comunicaciones,* No. 37, p. 49-64.

González, E. 1987. Prospección y evaluación de yacimientos de caolín, cuarzo y caliza en el sector de Tiltil, Región Metropolitana. Memoria de Título (Inédito), *Universidad de Chile, Departamento de Geología,* 114 p.

Hallam, A.; Biró, L.; Pérez, E. 1986. Facies analysis of the Lo Valdés Formation (Tithonian-Hauterivian) of High Cordillera of Central Chile, and the palaeogeographic evolution of the Andean Basin. *Geological Magazine,* Vol. 123, No. 4, p. 425-435.

Haq, B.U.; Hardenbol, J.; Vail., P.R. 1987. Chronology of fluctuating sea levels since the Triassic. *Science,* Vol. 235, p. 1156-1167.

Hart, M.B. 1980. A water depth model for the evolution of the planktonic Foraminiferida. *Nature,* Vol. 286, No. 5770, p. 252-254.

Herm, D. 1965. Microfacies de algunos sedimentos calcáreos del Jurásico y Cretácico Inferior de Chile Central (Cordillera de la Costa y Cordillera de los Andes). *Sociedad Geológica de Chile,* No. 11, p. 13-17.

Herm, D. 1967. Zur Mikrofazies kalkiger Sedimenteinschaltungen in Vulkaniten der andinen Geosynklinale Mittelchiles. *Geologische Rundschau,* Vol. 56, p. 657-699.

Kent, D.V.; Gradstein, F.M. 1985. A Cretaceous and Jurassic geochronology. *Geological Society of America, Bulletin,* Vol. 96, p. 1419-1427.

Krasheninnikov, V.A.; Basov, I.A. 1986. Late Mesozoic and Cenozoic stratigraphy and geological history of the South Atlantic high latitudes. *In* Global stratigraphic correlation of Mesozoic-Cenozoic seciments of oceans and continents. *Palaeogeography, Palaeoclimatology, Palaeoecology,* Vol. 55, No. 2-4, p. 145-188.

Klohn, C. 1956. Estado actual del estudio de la «Formación Porfirítica». *Revista Minerales,* No. 55, p. 41-60.

Leanza, A.F.; Castellaro, H. 1955. Algunos fósiles cretácicos de Chile. *Revista de la Asociación Geológica Argentina,* Vol. 5, No. 3, p. 159-262.

Leckie, R.M. 1987. Palaeoecology of mid-cretaceous planktonic foraminifera: A comparison of open ocean and epicontinental assemblages. *Micropaleontology,* Vol. 33, No. 2, p. 164-176.

Leckie, R.M. 1989. A paleoceanographic model for the early evolutionary history of planktonic foraminifera. *Palaeogeography, Palaeoclimatology, Palaeoecology,* Vol. 73, p. 107-138.

Legarreta L.; Gulisano, C. 1989. Análisis estratigráfico secuencial de la Cuenca Neuquina (Triásico superior-Terciario inferior). *In* Cuencas Sedimentarias Argentinas (Chebli, G.; Spalletti, L.; editores). *Universidad de Tucumán, Serie de Correlaciones Geológicas,* No. 6, p. 221-243.

Longoria, J.F. 1984. Cretaceous biochronology from the Gulf of Mexico region based on planktonic microfossils. *Micropaleontology,* Vol. 30, No. 3, p. 225-242.

Macellari, C.E. 1988. Cretaceous paleogeography and depositional cycles of western South America. *Journal of South American Earth Sciences,* Vol. 1, No. 4, p. 373-418.

Marshall, J. 1988. Submarine salt lenses. *Nature,* Vol. 333, p. 594-595.

Martínez-Pardo, R.; González, E. 1988. Sobre la ocurrencia de depósitos calcáreos neógenos en el extremo NW de la Cuenca de Santiago, Chile central. *In Congreso Latino-Americano Geológico, No. 7, Anales,* Vol. 1, p. 507-528. Belém, Pará, Brasil.

Mpodozis, C.; Ramos, V. 1990. The Andes of Chile and Argentina. *In* Geology of the Andes and its relation to hydrocarbon and mineral Resources (Ericksen, G.E.; Cañas, M.T.; Reinemund, J.A.; editors). *Earth Sciences Series, Circum-Pacific Council Energy Mineral Resources,* Vol. 11, p. 59-90.

Muñoz-Cristi, J. 1956. Chile. *In* Handbook of South American Geology (Jenks, W.; editor). *Geological Society of America, Memoir,* No. 65, p. 189-214.

Nasi, C.; Thiele, R. 1982. Estratigrafía del Jurásico y Cretácico de la Cordillera de la Costa, al sur de Río Maipo, entre Melipilla y Laguna de Aculeo (Chile Central). *Revista Geológica de Chile,* No. 16, p. 81-99.

Ramos, V. 1988. The tectonics of the Central Andes; 30° to 33°S latitude. *Geological Society of America, Special Paper*, No. 2·8, p. 31-54.

Regali, M.S.P.; Uesugui, N.; Lima, E. 1985. Palinoestratigrafia e paleoambiente da Bacia de Barreirinhas, Maranhão, Brasil. Collection papers. *In Congreso Brasilero de Paleontología, No. 8* (Río de Janeiro, 1983), *Ministerio de Minas e Energía, Serie Geológica, Departamento Nacional de Productos Mineros, Serie Geología*, No. 27, *Sección Paleontología y Estratigrafía*, No. 2, p. 461-470.

Remane, J. 1969. Les possibilités actuelles pour une utilisation stratigraphique des Calpionelles (Protozoa incertae sedis, Ciliata?). *In International Conference on Planktonic microfossils, No. 1, Proceedings*, Vol. 2, p. 559-573. The Netherlands.

Remane, J. 1985. Calpionellids. *In* Plankton Stratigraphy (Bolli, H.M.; Saunders, J.; Perch-Nielsen. K.; editors). *Cambridge University Press*, p. 555-572.

Reyment, R.; Dingle, R. 1987. Palaeogeography of Africa during the Cretaceous period. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol. 59, Nos. 1-3, p. 142-152.

Riccardi, A.C. 1987. Cretaceous paleogeography of southern South America. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol. 59, No. 1-3, p. 169-195.

Rivano, S.; Sepúlveda, P.; Boric, R.; Hervé, F.; Puig, G. 1986. Antecedentes radiométricos para una edad cretácica inferior de la Formación Las Chilcas. *Revista Geológica de Chile*, No. 27, p. 27-32.

Rosenfeld, U. 1987. La Cuenca de Neuquén. Análisis de una cuenca sedimentaria mesozoica en el sector austral de Sudamérica 1975-1985. *In* Investigaciones Alemanas Recientes en Latinoamérica: Geología (Miller, H.; editor). *Instituto de Colaboración Científica*, p. 70-78. Tubingen, Alemania.

Schlanger, S.O.; Jenkyns, H.C.; Premoli Silva, I. 1981. Volcanism and vertical tectonics in the Pacific basin related to global Cretaceous transgressions. *Earth Planetary Science Letters*, Vol. 52, p. 435-449.

Scholle, P.A.; Arthur, M.A. 1980. Carbon isotope fluctuations in Cretaceous pelagic limestones: potencial stratigraphic and petroleum exploration tool. *The American Association of Petroleum Geologist, Bulletin*, Vol. 64, p. 67-87.

Stipanicic, P.; Rodrigo, F. 1970. El diastrofismo eo y mesocretácico en Argentina y Chile, con referencias a los movimientos jurásicos de la Patagonia. *Cuartas Jornadas Geológicas Argentinas, Actas*, Vol. 2, p. 334-352.

Tappan, H.; Loeblich, Jr., A.R. 1973. Evolution of the oceanic plankton. *Earth Sciences Reviews*, Vol. 9, p. 207-240.

Thomas, H. 1958. Geología de la Cordillera de la Costa entre el Valle de la Ligua y la Cuesta de Barriga. *Instituto de Investigaciones Geológicas, Boletín*, No. 2, p. 1-86.

Trejo, M. 1980. Distribución estratigráfica de los tintínidos mesozoicos mexicanos. *Revista del Instituto Mexicano del Petróleo*, Vol. 12, No. 4, p. 4-13.

Vail, P.R.; Mitchum, Jr., R.M.; Thompson, S. III. 1977. Seismic stratigraphy and global changes of sea level, Part 4, Global Cycles of Relative Changes of sea level. *In* Seismic Stratigraphy; applications to hydrocarbon exploration (Payton, C.P.; editor). *American Association of Petroleum Geologists, Memoir*, No. 26, p. 83-97.

Vergara, M.; Drake, R. 1979. Edades K-Ar en secuencias volcánicas continentales Postneocomianas de Chile Central; su depositación en cuencas intermontanas restringidas. *Asociación Geológica Argentina, Revista*, Vol. 34, No. 1, p. 42-52.

Vincent, E.; Berger, W.H. 1981. Planktonic foraminifera and their use in paleoceanography. *In* The oceanic lithosphere, in the collection The sea; ideas and observations on progress in the study of the seas (Emiliani, C.; editor). *John Wiley and Sons*, Vol. 7, p. 1025-1119.

Viviers, M.C. 1985. Caracteristicas bioestratigraficas dos sedimentos albo-cenomanianos da Bacia do Ceará, Relaçoes com outras bacias brasileiras e africanas. Collection papers. *In Congreso Brasilero de Paleontología, No. 8 (Río de Janeiro, 1983), Ministerio de Minas e Energía, Departamento Nacional de Productos Mineros, Serie Geológica*, No. 27, *Sección Paleontologia e Estratigrafia*, No. 2, p. 529-538.

Widle, P.; Berry, W.B.N. 1982. Progressive ventilation of the oceans: potential for return to anoxic conditions in the post-Paleozoic. *In* Nature and Origin of Cretaceous Carbon-Rich Facies (Schlanger, S.O.; Cita, M.B.; editors). *Academic Press*, p. 209-224. New York.

Wonders, A.A.H. 1980. Middle and late Cretaceous planktonic foraminifera of the western Mediterranean area. *Utrecht Micropaleontological Bulletin*, Vol. 24, p. 1-157.

Yrigoyen, M. 1991. Notas explicativas del mapa de recursos energéticos de la región circum-pacífica, cuadrante sureste. *United States Department of the Interior, United States Geological Survey*, 59 p.

Manuscript received: September 13, 1993; accepted: September 27, 1994.

PLATE 1

PLATE 1

(Thin-section microfossils of Polpaico limestones. Numbers in parenthesis following the key sample abbrevation, indicate the selected slides used for photography)

Figures

1, 21 — ***Ticinella breggiensis*** (Gandolfi)

1. Transverse tangential thin-section: 400. CB-23(16).
21. Oblique tangential thin-section: X250, CM-6(10).

2 — ***Favusella washintensis*** (Carsey)
Equatorial thin-section: X 158, CM-6 (10).

3, 18 — ***Tintinopsella carpathica*** (Murgeaunu and Filipescu).
Longitudinal thin-sections:
3. X 98, CM-19S (7).
18. X 126, CM-6 (10).

4, 7 — ***Ticinella bejaouaensis*** Sigal
Subaxial tangential thin-sections:
4. X 400, 1202-R (27).
7. X 250, 1202-R (27).

5, 16, 17, 22, 23 — ***Ticinella roberti*** (Gandolfi)
Axial thin-sections:
5. X 250, CM-19(19); 16. - X 250, CB-19(19).
17. X 400, 1202-R(27); 22.- X 400, MC-19(24); 23. X 400, CB-19(24).

6, 8, 25 — ***Rotalipora subticinensis*** (Gandolfi)
Axial thin-sections:
6. X 250, CV-27(1); 8. X 250, CM-25(9); 25.- X 250, CB-19(19).

9 — ***Calpionellites darderi*** Colom
Longitudinal oblique thin-section: X 250, CM-6(10).

10 — ***Ticinella praeticinensis*** Sigal
Subaxial tangential thin-section: X 250, CV-27(11).

11, 12 — ***Calpionellites coronata*** Trejo
Longitudinal oblique thin-sections:
11. X 156, CM-6(10).
12. X 98, CB-50(25).

13, 15 — ***Bonetocardiella conoidea*** (Bonet)
Longitudinal thin-sections:
13. X 250, CV-9(23).
15. X 250, CV-9(23).

14 — ***Calpionellites neocomiensis*** Colom
Longitudinal oblique thin-section: X 126, CM-6(10).

19 — ***Bonetocardiella betica*** (Azema)
Longitudinal section: X 250, CV-9 (23).

20 — ***Pithonella ovalis*** (Kaufmann)
Longitudinal section: X 250, 1202-R(27).

24 — ***Hedbergella trocoidea*** (Gandolfi)
Axial thin section: X 250, CM-5(4).

PLATE 1