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

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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, Depositional 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 corresponden 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, calcisferulidos y calpionélidos. Las calizas de Polpaico serían los primeros depósitos marinos albianos paleontológicamente confirmados, dentro del sector pacífico de los Andes centrales chilano-argentinos.

Palabras claves: Microfósiles, Albiano marino, Cuenca de Santiago, Chile central, Calizas de Polpaico, Foraminíferos planctónicos y bentónicos, Algas calcáreas esqueléticas, Calcisferulidos, Calpionélidos, Ambiente de deposición, Paleogeografía.
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; Hallam et al., 1986; Riccardi, 1987; Macellari, 1988; Mpodozis and Ramos, 1990).

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 Chicas 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. Nasi4; 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 Chicas Formation (Thomas, 1958), formed by coarse red conglomerates and sandstones interbedded with lavas and limestones. According to Thomas (1958), the Las Chicas 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. Nasi3; 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

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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 Maastrichtian 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. Nas; 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 indicative 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 (Covacevich, 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-

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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-drone; 11-observed contact; 12-inferred contact; 13-observed normal fault; 14-inferred normal fault; 15-stratigraphical column, sites 1, 2, 3; 16-sinistral strike-slip fault; 17-strike and dip; 18-radiometric age.
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.
Initially 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 Tiltill limestone, 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 113 Ma, given by the plutons cutting the Las Chilcas Formation near Llaima (Rivano et al., 1986), considered to agree fairly well with recent palaeomagnetic 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 occurred at the end of the early Cretaceous (Hauterivian to Albian) (Aberg 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
- Caler as 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 corallines); Cayeuxia sp. (Erect codiaceans); Salpingoporella dinarica (Dasycladaceans); Muniera baconica Deke.; Muniera grambasti Cherchi (Charophytes).

Planktonic Foraminifera: Favusella washitensis (Carsey), Hedbergella delrioensis (Carsey); H. infracretacea (Glaessner); H. trocoida (Gandolfi); Rotalipora subticinensis (Gandolfi); Tichella bajaouensis Sigal; T. breggianensis (Gandolfi); T. praeunicinensis Sigal, T. roberti (Gandolfi).

Benthonic Foraminifera: Coskinolinella daquini Delmas and Deloffre; Sabaudia minuta (Holker); 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).
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 assignment. 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 Campanian (Andri, 1972), reinforces the herein proposed age. In fact, two calcispherulids species from the above limestones, B. conoida 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 palinochronos­ stratigraphy (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 Valanginian (Colom, 1988), probably due to regional facies development (Dellau, 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 (Colomella) (Trejo, 1980; Colom, 1988), and in the Campanian at the Rocky Mountains, U.S.A. (Eicher, 1965). It is possible, therefore, that T. carpathica, no younger than the early Valanginian in Europe, and the Aptian in the Antillean area (Colom, 1988), can be middle Albian in the Polpaico locality, coinciding with the LAD of Colomella 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 trochosphiral forms with globose chambers and round margins, suggesting a low diversity and depauperate taphoecenosis. 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
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 CO₂ 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 terrestrial 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 succession would have also been affected by local tectonic, climatic and sea-level perturbations, partially masking the above major global trends. This same succession 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 Gullisanc, 1989; Charrier and Muñoz, 1994).

The new proposed paleogeographic scenario differs from those traditionally admitted for the region, all associated with a long interior north-west/south-north embayment, limited to the west by the Chilean Coastal Range (Muñoz-Cristi, 1956; Aubou n 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.
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