Senonian–Paleocene charophyte succession of the Peruvian Andes

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Received 10 March 1993 and accepted 10 August 1993

A synthesis of the available sedimentological and stratigraphic data on the Late Cretaceous and Paleocene deposits of the Peruvian Andes permits determination of the age-range of the succession and stratigraphic range of the main charophyte species. Feistiella ovalis may appear in the late Santonian(?). It persists up to the middle(?) Campanian, where it is associated with Platychara perlata, which still occurs in the late Campanian. Feistiella gildemekteri and Platychara grawzbastii are commonly found in association with Amblyoschara peruviana. In other parts of Peru, these species occur together with Amblyoschara rolli, A. bagudiana, Feistiella costata and Saponanella aff. maslovi, strongly supporting a pre-Tertiary, mainly Maastrichtian age. Early Paleocene species are only local and poorly known. The Nitellopsis supraplaiza–Maedleriella association seems to characterize a late time-span of the Paleocene, though a possible extension into the Eocene cannot be ruled out.

KEY WORDS: charophytes; stratigraphy; Late Cretaceous; Paleocene; Andes; correlations.

1. Introduction

By Senonian times the western part of the central Andean margin was becoming progressively emergent, whereas widespread, fine-grained continental to very shallow marine sediments were laid down in the eastern regions (Figure 1). These deposits mainly contain vertebrate remains (fishes, dinosaurs, reptiles and mammals), palaeofloras (charophytes and palynomorphs) and some poorly known molluscs. In order to determine the stratigraphy of these beds, detailed study and exhaustive sampling of some well-exposed sections of southern Peru have been undertaken. The recognition in the field of good correlations between the sedimentary sequences of southern Peru and Bolivia, and the determination of precisely located palaeontological samples allow us to propose a correlation chart, which in turn permits us to constrain the age of each sequence and that of their fossil content.

In Peru detailed works on the charophyte associations and succession were carried out in the eastern Amazonian Basin (Oriente, Figure 1), and led to the definition of a charophyte biozonation (Koch & Blissenbach, 1960; Rivera, 1961; Fyfe, 1963; Gutierrez, 1975, 1982). The age of these zones was constrained by palynological studies of the Cretaceous beds (Müller & Aliaga, 1981). In contrast, excepting Newell (1949) and Peck & Reker (1947), numerous charophytes have been collected in the Peruvian Andes (Figure 1) without having been located on a stratigraphic column (Kalafatovich, 1957; Grambast et al.,

1 Contribution to ISE94-050.
Figure 1. Senonian–Paleocene palaeogeography of the Peruvian margin and location of the main localities cited in the text. 1, Allochthonous terranes; 2, emergent areas subjected to erosion; 3, Andean area of Senonian–Paleocene sedimentation; 4, Oriente (widespread Senonian–Paleocene deposits).

1967; Marocco, 1978; Mégard, 1978; Ramirez, pers. comm.) and the age of these species was not precisely known (Mourier et al., 1988; Feist et al., 1989).

The aim of this paper is to synthesize the currently available data on the vertical distribution of some charophyte species collected mainly in the Andes of southern Peru, and to discuss and state their stratigraphic range.

2. Stratigraphic framework

Available data and methodology
Details of the new palaeontological and stratigraphical data have been published elsewhere (Mourier et al., 1988; Jaillard & Sempere, 1989; Gayet et al., 1991; Naeser et al., 1991; Jaillard et al., 1993). Accordingly, we only present the adopted stratigraphic framework based on biostratigraphic and sequential correlations (Figure 2).

Several sedimentary sequences have been recognized in the Senonian–Paleocene series of southern Peru. The sequences begin with detrital, sandy
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Review of the Senonian–Paleocene sequences of southern Peru

The Senonian red beds of the Peruvian Andes overlie platform limestones, the age of which is well established only in northern Peru (Benavides, 1956). In southern Peru comparable rocks (Arcurquina Formation; Benavides, 1962;...
Ayavacas Formation; Newell, 1949) and marine red-coloured sandstones (upper Cotacucho Group; Newell, 1949) have been correlated with the Turonian sequence (Jaillard & Sempere, 1989).

The first megasequence (Figures 2 and 3). In southern Peru, the first megasequence consists of evaporite-bearing red shales containing thin and local marine beds in its lower part (Chilcane Formation and lower part of the Vilquechico Group). For its stratigraphic relationships, the marine layer is correlated with the early Coniacian transgression dated in northern and eastern Peru by a rich ammonite association (Benavides, 1956; Ducloz & Rivera, 1956). It can be correlated with the Aroifilla Formation of Bolivia (Jaillard & Sempere, 1989; Sempere, 1994). Near Cuzco, the lower part of the Senonian section yielded Feistiella ovalis (Carlotto, 1992). However, the presence of reverse faults has led us to suspect tectonic duplications.

The second megasequence (Figures 2 and 3). This includes two minor sequences. The first begins with a few tens of metres of marine limestones, which yielded Tissotia steinmanni in the Arequipa area (Vicente, 1981) and marine fishes, molluscs and foraminifera elsewhere (Middle Vilquechico and Middle Yuncaypata Formations) (Figure 3). This marine layer is correlated with the major early Santonian transgression of northern Peru (Kummel, 1948; Benavides, 1956; Mourier et al., 1988). In the Vilquechico section, Peckisphaera sp. A, Amblyochara sp. A and F. ovalis indicate a Late Cretaceous age for the upper part of the sequence (Jaillard et al., 1993). It correlates with the lower member of the Chaunaca Formation of Bolivia (Jaillard & Sempere, 1989; Sempere, 1994).

The base of the second minor sequence is marked by a persistent, very thin black layer, which locally has yielded marine molluscs and selachians (Jaillard et al., 1993). The upper part of the sequence contains F. ovalis and Platychara perlata (Jaillard et al., 1993). However, in the Cuzco section, Feistiella gildemeisteri and Platychara grambastii seem to appear in the last few metres of the megasequence (Carlotto, 1992). The lower marine bed is correlated with the transgression locally known in northern Peru, dated by mid Campanian ammonites (Mourier et al., 1988). It corresponds to the upper member of the Bolivian Chaunaca Formation (Jaillard & Sempere, 1989; Sempere, 1994).

The third megasequence (Figures 2 and 3). This comprises three minor sequences. The first consists of mainly sandstone deposits, the lower part of which are interbedded with shales and limestones of marine or lacustrine origin according to locality. In Cuzco, the latter yielded F. gildemeisteri and P. grambastii (upper part of the Yuncaypata Formation; Carlotto, 1992). In the Peruvian Oriente the coeval sandstones contain a palynological assemblage of late Senonian, possibly Campanian age (Vivian Formation; Seminario & Guizado, 1976; Müller & Aliaga, 1981).

In eastern Peru and on the northeastern Peruvian Altiplano, the second sequence begins with black shales and limestones representing a major marine transgression (upper part of the Vilquechico Group; Jaillard et al., 1993). In the Cuzco area, this sequence has been removed (Carlotto, 1992). Maastrichtian palynological assemblages have been determined in equivalent sequences in the Oriente of Peru (Cachiyacu and Huchpayacu Formations; Müller & Aliaga, 1981) and in Bolivia (middle Member of the El Molino Formation; Sempere et al., 1987 Gayet et al., 1991; Sempere, 1994).
The third sequence is marked by green-coloured lacustrine deposits in eastern areas and by light green to white-coloured fluvial sandstones in the southwest. In Vilquechico, it contains *F. gildemeisteri* and *P. grambastii* (Jaillard et al., 1993). The correlative Casa Blanca Formation of the Peruvian Oriente is considered to be late Maastrichtian on the basis of palynological studies (Müller & Aliaga, 1981).

*The fourth megasequence.* This is probably limited by important sedimentary or erosive gaps and possibly comprises two minor sequences separated by another sedimentary gap (Figure 2).

In the north-Peruvian Oriente, the lower part of the Yahuarango Formation is characterized by the *Feistiella costata—Sphaerochara* association, presently ascribed to the early Paleocene (Gutierrez, 1982). [The generic assignment to *Sphaerochara* by Rivera (1961) would need to be confirmed; the quality of her illustrations does not allow this.] This flora is lacking in the Andean realm, probably because of a widespread latest Maastrichtian(?)—early Paleocene.
sedimentary gap. For instance, in the Cuzco area, a fluvial to lacustrine, locally brackish, detrital sequence which yielded Paleocene charophytes (see below) unconformably overlies the first or second sequence of the Maastrichtian Yuncaypata Formation. Similarly, the Santa Lucia Formation of Bolivia, dated by middle to late Danian vertebrate associations (Gayet et al., 1991), locally unconformably overlies the third, the second or even the first member of the Maastrichtian El Molino Formation (Sempere, pers. comm.).

In the Oriente of central Peru, the ‘Sphaerochara’–F. costata zone (Sol 1 Formation) is stratigraphically separated from that succeeding it (Sol 3 Formation) by a 10–40 m thick bed of indurated, non-calcareous shales containing abundant iron concretions and kaolinite (Sol 2 Formation), which coincides with a sharp palaeontological break (Koch & Blissenblach, 1960). This layer could represent a palaeosol reflecting an important intra-Paleocene sedimentary gap, and separating two sedimentary sequences.

In the Vilquechico area, only a few metres of probable Paleocene deposits are preserved below the conglomeratic Muñani Formation of probable Eocene age (Figure 3) (Jaillard et al., 1993). In the Bagua region, a 100-m-thick series of conglomeratic sandstones of late Paleocene age disconformably overlies the Maastrichtian beds (Naeser et al., 1991). Finally, in the western part of the Oriente of Ecuador, the Eocene conglomerates of the Tiyuyacu Formation disconformably overlie the Maastrichtian Tena Formation (Faucher et al., 1971). These observations indicate that an important phase of erosion during the late Paleocene preceded the major sedimentary disconformity of latest Paleocene to early Eocene age that reflects the Inca I tectonic phase (54–49 Ma; Noble et al., 1990; Naeser et al., 1991).

3. Occurrence and age of the charophytes of Peru

Mid–Late Cretaceous (≈ Late Santonian–Late Campanian)

Feistiella ovalis has been found in the lower part of the Yuncaypata Formation near Cuzco. However, owing to the presence of numerous reverse faults, this layer could pertain to the second Senonian megasequence. Feistiella ovalis is certainly present in the upper part of the first sequence of the second megasequence (Figures 3 and 4). It was reported from unspecified beds of the Yuncaypata Formation (Kalafatovich, 1957; Grambast in Marocco, 1978; Peck, 1977, in Ramirez, pers. comm.). Newell (1949) found it in association with Platychara perlata (Peck & Reker, 1947) in the upper minor sequence of the second megasequence. This species is common in the south-Peruvian Andes but is unknown so far in the Oriente, possibly because of the large-scale Campanian sedimentary gap. Its provisional age assignment is late Santonian(?)–late Campanian.

In the Vilquechico area Peckisphaera sp. A and Amblyochara sp. A occur in probable early to middle Campanian beds (Figure 3). Peckisphaera sp. A seems to be rather scarce in the Andean realm since it is only mentioned in the Rio Suches outcrops of Bolivia (Jaillard et al., 1993).

Platychara perlata is commonly found in the upper part of the second minor sequence of the second megasequence, of middle to latest Campanian age (Jaillard et al., 1993). It was reported from the same layers by Peck & Reker (1947) and Newell (1949), and from unspecified beds of the Yuncaypata
Formation by Kalafatovich (1957). The genus *Platychara* ranges from the late Campanian up to the early Paleocene (Grambast-Fessard, 1980; Feist & Colombo, 1983).

Although our observations in southern Peru suggest that *F. ovalis* becomes extinct a little above the first occurrence of *P. perlata*, the presence of the two species in nearby layers can be considered as indicating the middle to late Campanian interval (Figure 4).

Late–Late Cretaceous (Late Campanian?–Late Maastrichtian)

*Feistiella gildemneisteri* is known throughout the third megasequence of southern Peru (Grambast et al., 1967; Carlotto, 1992; Jaillard et al., 1993; Ramirez, pers. comm.). In Cuzco, its apparent occurrence in the uppermost part of the second megasequence is most probably because of reverse faulting (Figure 3). This widespread species is reported from the Maastrichtian Areniscas de Azúcar, Cachiyacu, Huchpayacu and Casa Blanca Formations of the Peruvian Oriente (Koch & Blissenbach, 1960; Fyfe, 1963; Gutierrez, 1982). It has been noted in undated beds of the Andes of central Peru (Grambast in Mégard, 1978) and of northwestern Bolivia (Rio Suches; Jaillard et al., 1993), and is also very common in the El Molino Formation of Bolivia (Sempere et al., 1987; Jaillard et al., 1993). Its probable age is thus latest Campanian to late Maastrichtian (Figure 4).

*Platychara grambastii* is another widespread species which occurs in association with *F. gildemneisteri* and seems to characterize the same interval (Figures 3 and 4). It has been reported from the El Molino Formation of Bolivia (Jaillard et al., 1993). However, it is unknown so far in the Oriente region (Gutierrez, 1982). The genus *Platychara* is known in Late Cretaceous and early Paleocene beds of western Europe (Grambast-Fessard, 1980) and North America (Peck & Forrester, 1979).

*Amblyochara peruiana* was described in Peru from fossiliferous layers at Laguna Umayo-Sillustani (Grambast et al., 1967), at Bagua (Mourier et al., 1988) and in the Maastrichtian Tena Formation of Ecuador (Bristow & Hoffstetter, 1977) (Figure 4). It is also very common in the El Molino Formation of Bolivia (Sempere et al., 1987; Jaillard et al., 1993). The genus *Amblyochara* is

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### Figure 4. Stratigraphic range of the main charophyte species in the Peruvian Andes; comparisons with the Peruvian Oriente and the Bolivian Andes. Black lines, well-located samples; shaded lines, unspecified stratigraphic layers.
well known from Albian to Maastrichtian beds of western Europe (Feist & Freytet, 1983; Philip, 1984), and also from the early Paleocene (Feist, 1979).

The \( F. \) **gildemeisteri**–**P. grambastii** assemblage, frequently associated with \( A. \) **peruviana**, seems to characterize the third Senonian megasequence of southern Peru and Bolivia and, locally, the top of that preceding it (Figure 4).

In the Cuzco area this assemblage is associated with 'Chara' **cylindrata** and **Tectochara** sp. (Grambast, 1963, in Ramirez, pers. comm.). In the Bolivian Andes, this three-fold assemblage is associated with **Platychara** sp. (Jaillard et al., 1993), **Amblyochara** sp., **Platychara** cf. **cruciana** and 'Peckichara' **compressa** (fide Sempere et al., 1987). Further north (rio Suches), \( F. \) **gildemeisteri** occurs together with **Lamprothamnium** sp. and **Peckisphaera** sp. B (Jaillard et al., 1993). 'Peckichara' **compressa**, reported in the Bolivian Oriente (Peck in Perry, 1963) has been placed in synonymy with **Platychara compressa** (Peck & Forester, 1979).

In the Peruvian Oriente, \( F. \) **gildemeisteri** occurs together with **Saportanella rivae**, 'Tolympella' **biacuta**, 'Chara' **cylindrata** and 'Brevichara' **orientensis** (Koch & Blissenbach, 1960; Gutierrez, 1982). According to the illustration of Rivera (1961, pl. 1, fig. 5), **Brevichara orientensis** is likely to correspond to a species of **Platychara**. Within this zone, **Amblyochara rolli** is only present in the lower part, while **F. costata** appears in the upper part (Gutierrez, 1982) (Figure 4). In unspecified layers of the central Andes of Peru, \( F. \) cf. **gildemeisteri** occurs together with **Amblyochara** sp. (Grambast in Mégard, 1978). In another area of the same region, Grambast identified **Amblyochara** sp., **A. rolli**, **Porochara** sp., **Saportanella** sp. and **S. aff. maslovi** (unpublished report of the French Institute of Petroleum, 1969, cited by Mégard, 1978). In Bagua, **A. peruviana** is associated with **A. begudiana** and **F. costata** (Mourier et al., 1988). Finally, in the Maastrichtian Tena Formation of the Ecuadorian Oriente **A. cf. peruviana** is associated with \( F. \) cf. **costata** and **Rhabadochara** sp. (Grambast in Faucher et al., 1971; Bristow & Hoffstetter, 1977).

Though species of **Platychara** are known from Paleocene beds (Peck & Forester, 1979; Gram bast-Fessard, 1980; Feist & Colombo, 1983), the presence in the \( F. \) **gildemeisteri**–**P. grambastii** assemblage of specimens of the Cretaceous genera **Saportanella**, **Amblyochara** and **Feistiella**, and the lack of the common Paleocene and Eocene genera **Maedleriella** and **Nitellopsis**, strongly supports a Late Cretaceous age. Moreover, **A. begudiana** and **S. maslovi** are common in the Upper Cretaceous beds of southern France (Babinot & Freytet, 1983; Feist & Colombo, 1983) that correlate with the late Campanian to late Maastrichtian (Philip, 1984; Galbrun et al., 1991). Because of the known range of these species and of the stratigraphic relationships, the \( F. \) **gildemeisteri**–**P. grambastii** (±**A. peruviana**) assemblage is ascribed to the Maastrichtian stage, with a possible extension into the late Campanian. Their presence in the earliest Paleocene proposed by Gayet et al. (1991) cannot be ruled out, but is considered as not sufficiently well documented to be taken into account as yet.

**Early Paleocene(?)**

The lower part of the Yahuarango Formation of the north-Peruvian Oriente is characterized by the occurrence of **F. costata**, **Sphaerochara unguarahuensis** and **S. hauroensis** (Gutierrez, 1982). This association was considered to be probably Cretaceous by Koch & Blissenbach (1960, Sol 1 Formation) and is presently ascribed to the early Paleocene (**Sphaerochara** Zone; Gutierrez, 1982). According to the range of these genera a Late Cretaceous age cannot be ruled out.
This flora is lacking in the Andean realm, probably because of a widespread sedimentary gap (see above).

**Late Paleocene and Eocene (?)**

In the Peruvian Oriente, the Sol 3 Formation and the upper part of the Yahuarango Formation are characterized by the presence of *Nitellopsis supraplana*, *N. supraplana sulcata*, *Maedleriella monolifera*, *Nodosochara conincaensis* and the disappearance of *Feistiella costata* (Koch & Blissenbach, 1960; Musacchio, 1981; Gutierrez, 1975, 1982) (Figure 4). In southern Peru, *N. supraplana* is reported from the base of the Chilca Formation of the Sicuani region (Mourier et al., 1988) and of the Cuzco area, where it unconformably overlies the Yuncaypata Formation (Carlotto, 1992). From unspecified beds of the Andes of central Peru, Mégard (1968, 1978) collected *Nitellopsis*, *Harrisichara* and *Nodosochara* of Eocene age (determined by Grambast). In the Bagua area, the lower part of the Sambimera Formation yielded *N. supraplana* associated with *Maedleriella* sp. B and *'Chara strobilocarpa'* (Mourier et al., 1988). The Sambimera Formation overlies a volcanic tuff of late Paleocene to early Eocene age (54.2 ± 6.4 Ma, Naeser et al., 1991) (Figure 2).

Although it is certainly of Tertiary age, the age of the *N. supraplana*–*Maedleriella* assemblage is not precisely established so far. The genera *Maedleriella* and *Nitellopsis* range from Maastrichtian to late middle Eocene, and from early Tertiary to Recent, respectively. *Nitellopsis supraplana* is generally considered as a Paleocene marker (Feist & Colombo, 1983), and Gutierrez (1982) ascribed this association to the upper Paleocene. If accepted, the lacustrine *N. supraplana*–bearing lower part of the Sambimera Formation would correlate with the late Paleocene Sol 3 Formation, rather than with the Eocene Pozo Formation as assumed by Naeser et al. (1991). The 6.4 Ma analytical uncertainty for the absolute age of the Bagua tuff does not exclude a late Paleocene age for the lower part of the Sambimera Formation. Whatever the case, it is likely that the lacustrine late Paleocene Sol 3 Formation and the brackish Eocene Pozo Formation have been locally confused; further studies are necessary to precisely determine the age of these beds.

4. **Palaeobiogeographic remarks**

Although the palaeontological record is far from complete enough to allow definite conclusions, some remarks can be made about the palaeogeographic distribution of the main charophyte species represented within and outside of South America.

*Feistiella gildemeisteri* is present throughout the Andes of southern Peru and Bolivia and in the Peruvian Oriente, but has not been reported so far in the north-Peruvian Andes or Ecuador. Conversely, *F. costata* is present in the Andes of northern Peru, and in Ecuador and the Peruvian Oriente, but absent in southern Peru and Bolivia. Similarly, representatives of *Amblyochara* are more common in northern Peru and Ecuador than further south. Though they are very common in the Andes, *P. grambastii* or other species of the genus *Platychara* seem to be very scarce in the Oriente.

*Amblyochara begudiana*, *P. compressa*, *S. maslovi* and *N. supraplana* have wide geographic distributions and allow useful stratigraphic correlations between the South American formations and the rest of the world. On the other hand,
although they permit reliable regional correlations, species such as *A. peruviana*, *F. gildemeisteri* and *P. grambastii* seem to be restricted to the South American continent.

Finally, the presence of *Lamprothamnium* in the Paleocene beds of Cuzco and in the Maastrichtian outcrop of Rio Suches suggests a brackish habitat and the proximity of the sea-shore.

5. Conclusions
Sequential and biostratigraphic correlations of the Senonian and Paleocene deposits of the Peruvian Andes have allowed the precise determination of the stratigraphic range of some charophyte species. With our present day state of knowledge, four charophyte assemblages apparently follow one another from Santonian until late Paleocene times.

*Feistiella ovalis* seems to appear as early as the late Santonian. Species of *Amblyochara* and *Peckisphaera* are recorded from probable late Santonian to early Campanian beds. *Platychara perlata* first occurs in mid-Campanian beds, and is not present in Maastrichtian deposits. Thus, the *F. ovalis–P. perlata* association could be of middle to latest Campanian age.

The *F. gildemeisteri–P. grambastii* assemblage, frequently associated with *A. peruviana*, is better documented and seems to characterize mainly the Maastrichtian, with a possible extension into the late Campanian. It often occurs together with *F. costata* and other representatives of the *Amblyochara*, *Platychara* and *Saportanella* genera.

The *Sphaerochara–F. costata* association of the Peruvian Oriente has not been found as yet in the Peruvian Andes, thus suggesting a large-scale sedimentary gap of part of the early Paleocene (and latest Maastrichtian?) deposits.

The *N. supraplana–Maedleriella* association can be provisionally considered as indicating a late phase of the Paleocene. However, it is not yet clear whether it is restricted to the Paleocene or extends into the Eocene.

References


**Appendix**

List of the quoted taxa with author attributions and dates.

*Amblyochara* sp. A Feist & Grambast-Fessard in Jaillard et al., 1993

*Amblyochara begudiana* Grambast, 1962

*Amblyochara peruviana* Grambast in Grambast et al., 1967

*Amblyochara rolli* (Koch & Blissenbach) Grambast in Grambast et al., 1967

*Brevichara orientalis* Rivera, 1961

*Chara cylindrica* Koch & Blissenbach, 1960

‘Chara strobilocarpa’ Reid & Groves, 1921; quoted by Peck & Reker, 1947

*Feistiella costata* (Koch & Blissenbach) nov. comb.

*Porohara costata* Feist, in Mourier et al., 1988

*P. gildemeisteri* ssp. *costata* Koch & Blissenbach, 1960

*Feistiella gildemeisteri* (Koch & Blissenbach) Feist & Grambast-Fessard, in Jaillard et al., 1993

*Feistiella gildemeisteri solensis* (Gutierrez) nov. comb.

*Pororhara costata* Feist, in Mourier et al., 1988

*P. gildemeisteri* ssp. *costata* Koch & Blissenbach, 1960

*Maedleriella* sp. *costata* Koch & Blissenbach, 1960

*Maedleriella monoliforme* (Peck & Reker) Grambast, 1957

*Nitellopsis supraplana* (Peck & Reker) Grambast & Soulié-Mäsche, 1972

*Peckisphaera* sp. A Feist & Grambast-Fessard in Jaillard et al., 1993

*Platychara grambastii* Peck & Forester, 1979

*Platychara perlata* (Peck & Reker) Grambast in Grambast et al., 1967

*Saipontanella maslovii* Grambast, 1962

*Saipontanella rivae* Gutierrez, 1975

*Sphaerocchara* spp. is mentioned by Rivera (1961) and Gutierrez (1975, 1982)