

Sedimentology, palaeontology, biostratigraphy and correlation of the Late Cretaceous Vilquechico Group of southern Peru

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Detailed analysis of the Late Cretaceous Vilquechico Group (formerly Vilquechico Formation) of the Southern Andes allows the recognition of three major sedimentary sequences, defining Lower, Middle and Upper Vilquechico lithologic formations (LVF, MVM and UVF respectively). Some of them (MVM and UVF) include in turn minor sedimentary sequences. In addition to dinosaur trackways, they contain a marine fauna (selachians, actinopterygians, molluscs) in their transgressive basal parts, and lacustrine fossils (charophytes, ostracods, gastropods) in their regressive continental upper parts. Two charophyte biozones characterize the MVM and the UVF respectively. The lithologic and sedimentary features of the major sequences, as well as their palaeontological contents allow large-scale correlations with other Andean series. Such correlations permit us to tentatively ascribe the unfossiliferous LVF to the Coniacian–early Santonian (?) time-span, and the MVM to the Santonian–late Campanian interval. The UVF is of latest Campanian–late Maastrichtian age. As a consequence, the assumed correlations between the Vilquechico Group and some of the vertebrate-bearing Andean localities are revised.

L'étude détaillée du Groupe Vilquechico (antérieurement défini comme Formation Vilquechico) du Crétacé supérieur des Andes sud Péruviennes révèle l'existence de trois séquences sédimentaires majeures, définissant des formations lithologiques appelées inférieure, médiane et supérieure (LVF, MVM et UVF respectivement). Certaines d'entre elles (MVM et UVF) peuvent être subdivisées en séquences mineures ou membres. Outre des traces de dinosaures, elles contiennent des faunes marines (sélaciens, actinoptérygiens, mollusques) dans leurs parties basales transgressives, et des fossiles lacustres (charophytes, ostracodes, gastéropodes) dans leurs parties supérieures continentales régressives. Deux biozones distinctes de charophytes caractérisent respectivement la MVM et la UVF. Les caractéristiques sédimentologiques et lithologiques des séquences majeures, ainsi que leurs contenus paléontologiques respectifs permettent des corrélations à grande échelle avec d'autres séries andines. Ces corrélations permettent, à titre d'hypothèse, d'attribuer la LVF azoïque au Coniacien-Santonien inférieur (?) et la MVM à l'intervalle Santonien inférieur (?)-Campanien supérieur, tandis que la UVF serait d'âge Campanien terminal-Maastrichtien supérieur. En conséquence, les corrélations supposées de certains gisements andins à vertébrés avec le Groupe Vilquechico sont réexaminées.

El estudio detallado del Grupo Vilquechico (anteriormente definido como Formación Vilquechico) del Cretácico superior del Sur del Perú evidencia la presencia de tres secuencias sedimentarias mayores, definiendo así Formaciones litológicas inferior, mediana y superior (LVF, MVM y UVF, respectivamente). Dos de ellas (MVM y UVF) pueden ser sub-divididas en secuencias menores o miembros. Además de huellas de dinosaurios, las secuencias mayores contienen faunas marinas (selacios, actinopterygianos, moluscos) en su base transgresiva, y fósiles lacustres (carófitas, ostrácodos, gasterópodos) en su parte superior continental regresiva. Dos biozonas de carófitas distintas caracterizan la MVM y la UVF respectivamente. Las características sedimentológicas y litológicas de las secuencias mayores, así como sus contenidos paleontológicos respectivos permiten correlaciones a gran escala con otras series andinas. Dichas correlaciones permiten tentativamente atribuir la LVF azoica al Coniaciano-Santoniano inferior (?), la MVM al intervalo Santoniano inferior (?)-Campaniano tardío, mientras que la UVF sería de edad Campaniano terminal-Maastrichtiano superior. En consecuencia, las correlaciones supuestas de ciertos yacimientos andinos de vertebrados con dicho Grupo son reexaminadas.

KEY WORDS: Sedimentology, palaeontology, biostratigraphy, correlation, Late Cretaceous, Vilquechico Group, Peru.

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1. Introduction

1.1. Geological setting (E. Jaillard)

During the Cretaceous period the central Andean active margin was divisible into several NW-trending geographic zones, parallel to the subduction trench. In Peru, the following can be recognized from the southwest to the northeast (Audebaud *et al.*, 1973; Mégard, 1978; Jaillard & Sempéré, 1989; 1989; Fig. 1):

—A coastal zone, which comprises mainly pre-Cretaceous rocks, associated with volcanic products.

—A western domain (West Peruvian Trough, Arequipa Trough), where there is a thick, nearly continuous record of marine sedimentation during Mesozoic times (Benavides, 1962; Vicente, 1981; Vicente *et al.*, 1982).

—An axial cordillera (Marañón geanticline, Santa Lucia axis), which acted as a swell during most of the Mesozoic and received only a limited amount of sedimentation during the Cretaceous (Wilson, 1963; Mégard, 1978; Batty & Jaillard, 1989);

—An eastern domain (Oriente, Putina Basin) in-filled by mainly terrigenous, Triassic to Quaternary sediments (Kummel, 1948; Koch & Blissenbach, 1962; Seminario & Guizado, 1976).

In southern Peru and Bolivia, the present-day structural zones are oblique with respect to the palaeogeographic domains. Hence, the "Altiplano" area comprises the axial cordillera in Peru, and a great part of the eastern domain in Bolivia. In northern Peru and Ecuador, the present-day coastal zone is made up of allochthonous, mainly oceanic terranes (Figure 1).

In the central Andes, Cretaceous sedimentation began with the accumulation of widespread fluvial to deltaic sands of Valanginian to Aptian age (Benavides, 1956; Moulin, 1989). The late Aptian to early Albian transgression then triggered the development of a widespread carbonate platform which recorded the successive stages of the Late Cretaceous transgression (Benavides, 1956; Jaillard, 1987). According to location, the western domain emerged between early Coniacian and middle Campanian times (Jaillard & Sempéré, 1989), as a result of the beginning of the Andean orogeny ("Peruvian phase" of Steinmann, 1929; Mégard, 1978).

When present, the latest Cretaceous deposits of the central Andes are made up of shallow marine to continental red beds which conformably or unconformably overlie Turonian to Santonian marine deposits (Benavides, 1956, 1962; Wilson, 1963; Mégard, 1978; Dalmayrac *et al.*, 1980; Vicente, 1981; Mourier *et al.*, 1988). The Late Cretaceous and early Tertiary red beds are as yet poorly dated. However, precise dating of these deposits is important for geological and palaeontological inferences.

1.2. Geological problems (E. Jaillard)

The Cretaceous stratigraphy of the Altiplano and Putina basins has been subject to conflicting interpretations (Figure 2). According to Newell (1949), the Cretaceous deposits of southern Peru comprise two successive sandstone-shale sequences. The first sequence (sandstones of the Huanané Formation—limestones and red shales of the Moho Group) was assigned an early to early Late Cretaceous age, whereas the upper sequence (sandstones of the Cotacucho Group—shales of the Vilquechico Formation) was ascribed to the late Late Cretaceous. However, Audebaud *et al.* (1976), Laubacher (1978) and Dalmayrac *et al.* (1980) proposed that the two sequences were separated by an important reverse fault, and that they were thus

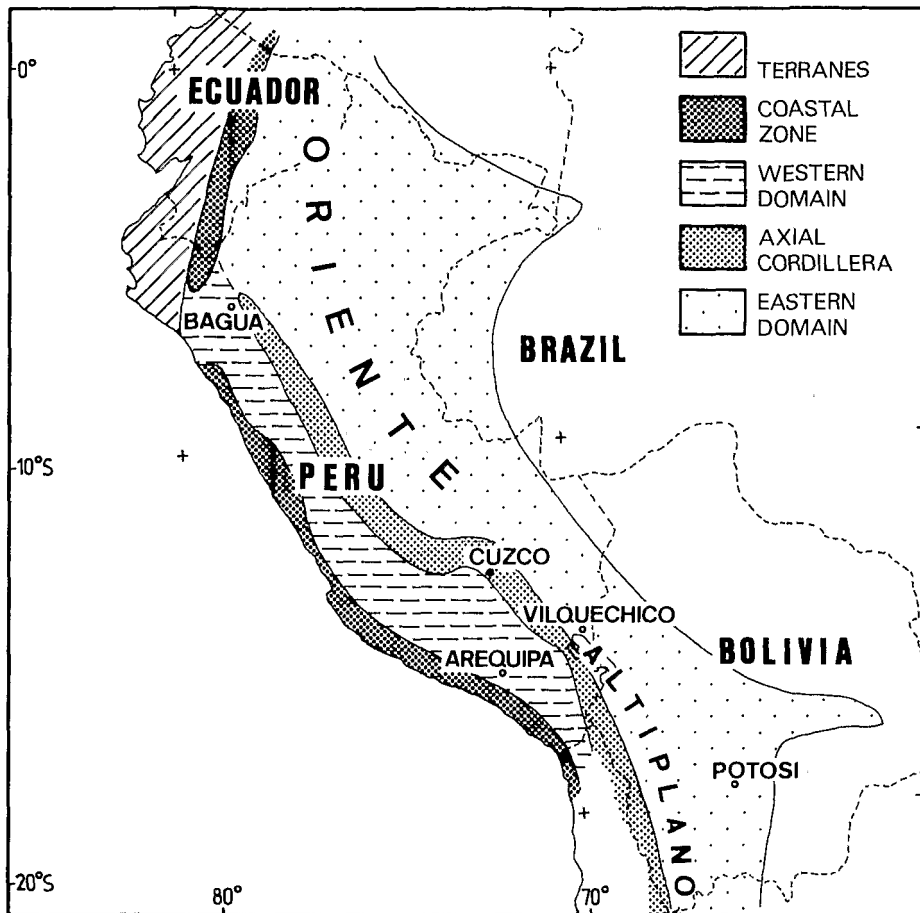


Figure 1. Palaeogeographic sketch of the Central Andes during the Cretaceous showing the main localities cited in the text.

laterally equivalent sequences, both of Early to Late Cretaceous age (Figure 2), deposited in two distinct basins (the Altiplano and Putina Basins respectively). More recently, Ellison (1985), Palacios & Ellison (1986) and Klinck *et al.* (1986) have returned to the idea that the two sequences are stratigraphically superposed (Figure 2).

The widespread Late Cretaceous regression is interpreted to be the result of the Peruvian tectonic phase, which is thought to represent the beginning of the Andean orogeny (Steinmann, 1929; Mégar, 1978). However, the emergence of the central Andean margin appears to be widely diachronous (Jaillard & Sempéré, 1989), and the successive sedimentary and tectonic events are so far only poorly known.

1.3. Palaeontological problems (B. Sigé)

The age of the Vilquechico Formation is critical for the debate regarding the Cretaceous/Tertiary boundary crisis.

In the local section of Laguna Umayo, less than 100 km southwest from Vilquechico, a fossil assemblage including mammal remains was recovered in the late 1960s (Grambast *et al.*, 1967). According to the geological setting and available

	ALTIPLANO	
Late K	MUÑANI	
Late K	VILQUECHICO	
	COTA-	_____
	CUCHO	HUATASANE
Middle K	M	_____
	O	AYAVACAS
Early K	HUANCANE	
Early K	MUNI	
Late J	SIPIN	

NEWELL 1949

	ALTIPLANO	
	SOUTHERN	NORTHERN
Early T		MUÑANI
Late K		VILQUECHICO
	M	_____
Middle K	O	_____
	H	AYAVACAS
Early K	O	_____
		HUATASANE
Early K	HUANCANE	
Early K	MUNI	
Late J	SIPIN	

AUDEBAUD et al. 1976

	ALTIPLANO	
	SOUTHERN	NORTHERN
T/K	PUNO?	MUÑANI
Late K	-----	VILQUECHICO
		COTACUCHO
		MOHO
Middle K		HUATASANE
		HUANCANE
Early K	AYAVACAS	MUNI
	ANGOSTURA	CHUPA
SIPIN		

KLINCK et al. 1986

Figure 2. Main interpretations of south Peruvian Cretaceous stratigraphy.

biostratigraphic data, especially the charophyte assemblage, the fossil-bearing level has been correlated with the regional Vilquechico Formation. The Laguna Umayo mammals have thus been described (Thaler in Grambast *et al.*, 1967; Sigé, 1968, 1971, 1972) and were initially generally accepted as Late Cretaceous forms, representatives of the oldest known mammalian fauna from South America (e.g. Clemens *et al.*, 1979).

About fifteen years later in central-western Bolivia, the mammalian fauna of Tiupampa was discovered in a local section attributed to the regional El Molino Formation (Marshall *et al.*, 1983a). According to the geological context and the fossil record, the latter is assumed to be Late Cretaceous in age, and correlatable with the south Peruvian Vilquechico Formation (e.g. Martinez, 1980). The Tiupampa mammalian fauna has been described or commented on in various papers, and was still very recently considered as representative of the South American Late Cretaceous fauna, and the dawn of the South American mammals (Marshall & de Muizon, 1988; Marshall, 1989).

However, some authors (Van Valen & Sloan, 1977; Sloan *et al.*, 1986; Sloan, 1987, Bonaparte, 1990; and, more extensively Van Valen, 1988) have questioned the alleged Late Cretaceous age of the Laguna Umayo and Tiupampa mammals. Judging from the advanced evolutionary stage of some taxa, they have favoured a Palaeocene age for these faunas. Van Valen (1988) undertook a critical revision of the dating for these formations and local sections which led him to question the data—and therefore the biostratigraphic value—of the many fields of research concerned. The data provided by fossils well-represented in the Andean formations, either marine (notably the selachians) or continental (notably the charophytes), were thus questioned. Finally, these views led Van Valen (1988) to assume that the dinosaurs, documented in these rocks by eggshells at Laguna Umayo and by footprints in the El Molino Formation, would represent early Tertiary survivors of the worldwide Cretaceous/Tertiary extinction crisis. Other similar early Palaeocene dinosaur occurrences are alleged by Van Valen (1988) and Sloan *et al.* (1986) in other parts of the world. However, several of Van Valen's assertions concerning the selachians have been shown to be unfounded (Cappetta, 1990).

At the same time, other mammals have been discovered and described from the presumed Campanian Los Alamos Formation (Northern Patagonia, Argentina), providing evidence of a very diversified Late Cretaceous fauna (*vide* Bonaparte, 1990). Clearly, they belong to various non-tribosphenic mammalian groups, and represent a faunal stratum more archaic and geologically older in its general distribution than that of the tribosphenic therian groups, the latter having become dominant since Late Cretaceous. This Patagonian fauna shares no taxa at ordinal level with the Tiupampa and Laguna Umayo faunas. This high taxonomic degree of difference has been put forward as evidence for a chronological gap longer than the one accepted between the Campanian and the Maastrichtian, i.e. of a younger, Palaeocene age, for the alleged Maastrichtian faunas.

Palaeontological discussions dealing with the faunas of the local sections of Laguna Umayo and Tiupampa thus brought the age of the Vilquechico and El Molino regional Formations into question. There have been two recent important contributions to this discussion. First, the stratigraphic position of the Tiupampa mammal-bearing level has been reappraised (Sempéré, pers. comm.), and second, the Mesozoic and Palaeocene vertebrates of Bolivia have been extensively reviewed (Gayet *et al.*, 1991), the latter work taking the former into account. The Tiupampa levels are now considered to belong to the Palaeocene Santa Lucia

Formation, not the El Molino Formation. The first two members of the El Molino Formation are dated as Maastrichtian, and the third is attributed to the earliest Palaeocene although there is no palaeontological evidence for this, specific fossil markers being lacking.

2. Sedimentology (E. Jaillard)

Newell (1949) defined the Cotacucho Group as including in its upper part a 185 m-thick, shaly unit ("unit o"). However, subsequent workers considered that this unit belonged to the Vilquechico Formation (e.g. Audebaud *et al.*, 1976; Laubacher, 1978; Klinck *et al.*, 1986), a view which we follow in this paper because it is more useful for mapping and stratigraphic matters. The so-defined, 850 m-thick Vilquechico Formation consists mainly of green-grey or red-purple shales and marls interbedded with thin, dark to grey-coloured limestone beds, and with yellow to brownish sandstones.

The Vilquechico Formation was ascribed to the Late Cretaceous by Newell (1949) on the basis of the presence of the charophytes *Feistiella* (= *Porochara*) *ovalis*, and *Platychara perlata* (Peck & Reker, 1947). More recently, Dávila & Ponce de León (1971) mentioned the fish species *Gasterocheupea branisae* and the selachian species *Pucapristis branisi*. According to these data, the Vilquechico Formation is regarded as Campanian-Maastrichtian in age.

At the Vilquechico locality, the Vilquechico Formation can be divided into three transgressive-regressive major sedimentary sequences that constitute three well-defined lithological units (Figure 3). We propose to consider the latter as Formations, the Vilquechico Formation of Newell (1949) becoming the Vilquechico Group.

2.1. The Lower Vilquechico Formation (LVF, first major sequence, 150 m, unit "o" of the Cotacucho Group of Newell, 1949)

This overlies the shallow marine sandstones of the top of the Cotacucho Group. Poor outcrops of crushed rocks indicate a possible faulted contact between the two units. It begins with 50 m of red marls and subordinate shales. Near the base, thin beds of rippled sandstones are common. In the middle part, green or grey-coloured, thin-bedded muddy limestones exhibit thin horizontal laminations, frequently disturbed by desiccation features. One of the calcareous beds is a marly, green-coloured oyster coquina which reveals that marine incursions sporadically occurred. The number of limestone beds decreases upwards. The lower part of the LVF is interpreted as having been deposited in tidal to very shallow marine environments (Figure 3).

The upper part of the LVF is made up of dominantly red shales with subordinate marls, intercalated with very thin beds of fine-grained sandstones and of centimetre-thick, white-coloured chalky limestone beds. The amount of limestone beds decreases upwards, whereas the sandstone ratio slightly increases. Dominant sedimentological features are thin parallel laminae and desiccation cracks. Fibrous, secondary gypsum is locally abundant. These sediments are interpreted as representing continental, partly lacustrine environments. The paucity of detrital material and the lack of fluvial channels indicate a very flat topography and a quiet tectonic setting, thus suggesting a coastal pediment-playa environment (Figure 3).

2.2. *The Middle Vilquechico Formation* (MVF, second major sequence, 310 m, units "a" to "d" of the Vilquechico Formation of Newell, 1949)

This comprises two minor sedimentary sequences, that can be considered as members.

The first minor sequence (lower member of the MVF): This is composed of three informal units (Figure 3). It begins with a 10 m-thick, yellow-coloured, thinning-upward, non-channelized sandstone bed (unit "a" of Newell, 1949), which exhibits dominantly flat-bedding and trough cross-bedding near the base, and small ripples, evaporitic pseudomorphs, and burrows toward the top. Measurements indicate WNW-ward palaeocurrents. At Vilquechico, this sandy unit might represent shoreline deposits. Some 35 km to the north, near the village of Putina, this unit consists of typical fluvial deposits with WSW-ward palaeocurrents which grade upwards into tidal sands.

The basal sandstones are overlain by a 35 m-thick series of dark-coloured limestone beds intercalated with black shales (unit "b" of Newell, 1949). They contain bivalves and fish remains, and exhibit abundant laminations and thin layers of fibrous secondary gypsum. Towards the top, desiccation cracks are present. These features indicate a restricted shallow marine depositional environment (Figure 3).

A 220 m-thick series of variegated shales and marls (unit "c" and part of unit "d" of Newell, 1949) follows. In the green to grey-coloured lower part, desiccation cracks and thin layers of secondary gypsum are frequent, and dark-coloured limestone intercalations contain bivalves and gastropods. In the dominantly red-coloured upper part, the number of gypsum layers decreases but evaporitic nodules are common, and intercalations of parallel-laminated or rippled, burrowed siltstones and fine-grained sandstones contain plant fragments and charophyte oogonia. This variegated series is interpreted as having been deposited at first in a littoral, and then in a continental, partly lacustrine, environment. As a whole, the first minor sequence of the MVF constitutes a typical transgressive sedimentary sequence (Figure 3).

The second minor sequence (upper member of the MVF; 45 m, upper part of the unit "d" of Newell, 1949): This begins with a few metres of dark-coloured limestones which contain a marine fauna (selachian and molluscs). It continues with greenish, charophyte-bearing marls and limestones, and ends with red-coloured marls, silts and shales, thus expressing a marine to continental and lacustrine evolution (Figure 3). The presence of both lacustrine plants and marine fauna at the base of the sequence reveals mixed shallow and fresh-water influences, suggesting the presence of an epicontinental, partly brackish sea-way.

From the upper part of the MVF (unit "d" of Newell, 1949), *Platychara perlata* and *Feistiella* (= *Porochara*) *ovalis* were identified (Peck & Reker, 1947; Newell, 1949). In the last 100 m of the unit, the amount of sandstone beds decreases, and the shales are affected by numerous small-scale sedimentary dykes in-filled by silts or sands, which exhibit a preferential N-S to NNE-SSW trend.

2.3. *The Upper Vilquechico Formation* (UVF, third major sequence, 380 m, units "e" to "g" of the Vilquechico Formation of Newell, 1949)

This comprises three transgressive-regressive minor sedimentary sequences that can be regarded as members (Figure 3).

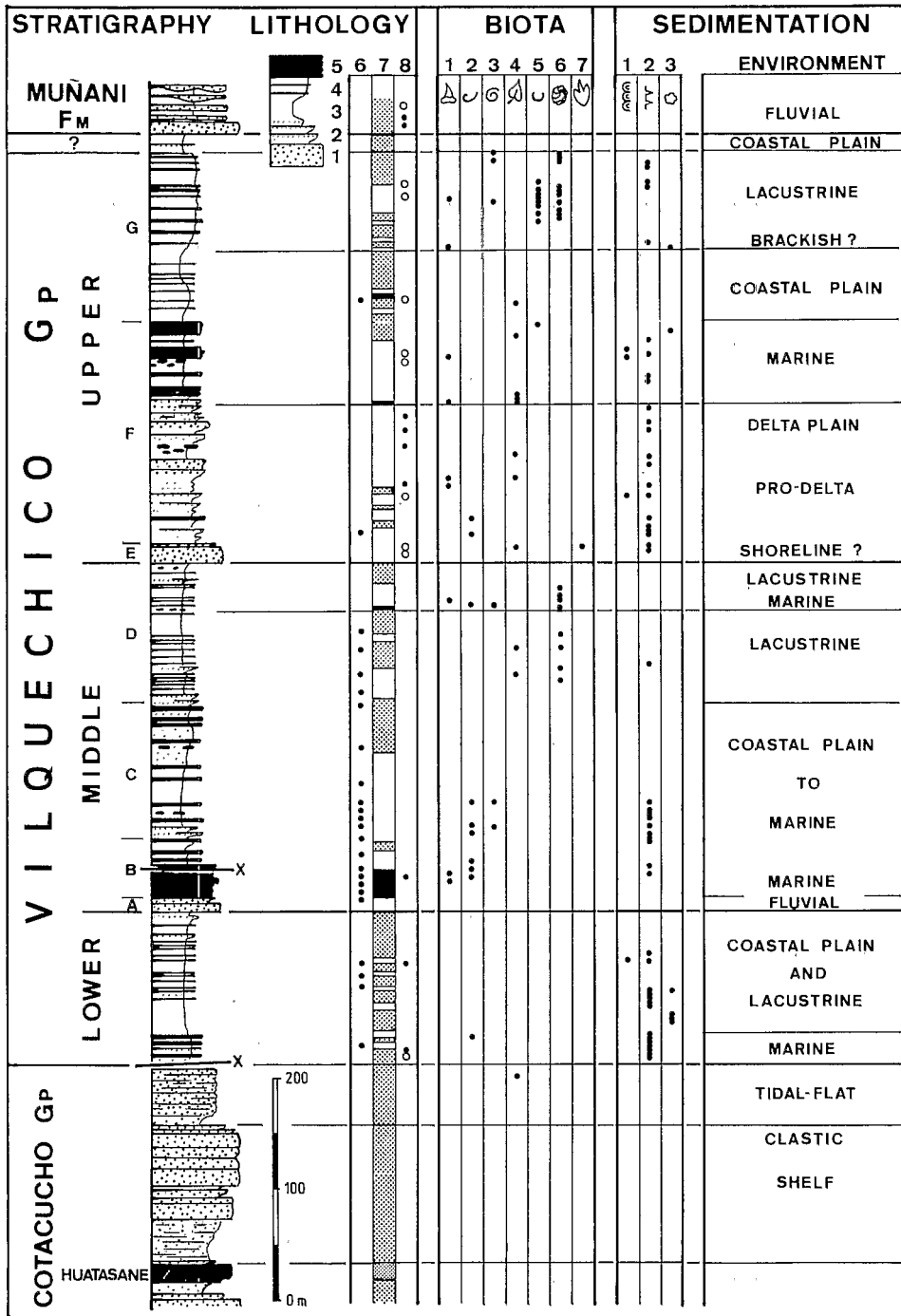


Figure 3. Lithostratigraphy and sedimentological interpretations of the Vilquechico Group near the village of Vilquechico. *Lithology*: 1, sandstones; 2, sandstones and shales; 3, shales; 4, marls and thin-bedded limestones; 5, limestones; 6, gypsum veins; 7, colour: white areas—yellow to greenish; dotted areas—pink, red or purple; black—dark grey to black; 8, black spots—iron nodules; open circles—pyrite. *Biota*: 1, fish teeth; 2, bivalves; 3, gastropods; 4, plant fragments; 5, ostracods; 6, charophyte oogonia; 7, dinosaur trackways. *Sedimentation*: 1, algal structures; 2, desiccation structures; 3, pedogenetic concretions.

The first minor sequence (lower member of the UVF): This is 145 m thick and begins with a 15 m-thick layer of massive, Fe-rich yellow sandstones (unit "e" of Newell, 1949), which exhibits scarce parallel- or cross-bedding, and abundant bioturbations. Its upper surface shows desiccation features, dinosaurian tracks, plant remains and bone fragments. It could represent fluvial sandy facies. 35 km further north, east of Putina, it unconformably overlies the MVF, and exhibits a N to NE direction of transport.

This is followed by about 130 m of dominantly grey to green, or brownish-coloured siltstones and fine-grained sandstones, intercalated with shales (part of unit "f" of Newell, 1949). In the lower part, some thin-bedded limestones contain bivalves, remnants of fish and algal crusts and balls, thus indicating restricted, shallow marine to brackish conditions (prodelta or estuarine). In the upper part, the fossils consist mainly of wood fragments or leaf remains. Dominant sedimentary features are desiccation cracks, horizontal laminations, current ripples, worm trails and rill-marks, strongly suggesting delta plain deposition. Hence, the first minor sequence of the UVF was probably deposited in a mixed, deltaic-shallow marine environment, and might represent a progradational deltaic sequence (Figure 3).

The abundance of sandy material suggests that the topography was more variable than during the deposition of the preceding sequence. Scarce small-scale clastic dykes possess a ENE–WSW mean orientation.

The second minor sequence (middle member of the UVF, 140 m, upper part of unit "f" and base of unit "g" of Newell, 1949): This begins with dark-coloured limestone beds or nodules alternating with brown to green-coloured siltstones and clays. Limestone beds often contain selachian and fish teeth, algal structures and desiccation features that suggest a shallow marine, probably restricted environment. The shales then become red, and the presence of ostracods, leaf fragments and calcareous pedogenetic concretions indicate a transition to continental deposits (Figure 3). These latter are made up of purple to red-coloured shales, with a few intercalations of thin, dark-coloured limestone beds. The second sequence thus displays a typical regressive trend.

The third minor sequence (upper member of the UVF, upper part of the unit "g" of Newell, 1949): This is made of marls and limestones which contrast markedly with the underlying shales. It begins with a 20 m-thick series of red and green-coloured marls interbedded with marine selachian-bearing limestones. This is overlain by a 70 m-thick horizon of green and red-coloured, lacustrine marls and limestones which contain very abundant charophyte oogonia, ostracod or gastropod coquinas, and scarce fish remains (Figure 3). Desiccation cracks and bioturbation are common. At the top, the marls and shales become red, and the fossils disappear. The upper member of the UVF is thus interpreted as having been deposited firstly in a shallow and restricted marine environment, and then in mainly lacustrine conditions evolving towards continental facies. As for the preceding minor sequence, the scarcity of detrital material suggests a very flat topography and a quiescent tectonic regime.

A fourth minor sequence or a new major one?: Below the overlying, coarse-grained Muñani Formation, a 15 m-thick series of red-purple, non-calcareous and non-fossiliferous shales is interpreted as continental deposits, and seems to indicate a significant regression. It could represent either the beginning of a new minor sequence of the UVF, or the lower part of a new major sequence. The reduced

thickness does not allow detailed analysis, but comparisons with neighbouring series support the second interpretation (see below).

2.4. The Muñani Formation

The Vilquechico Group and the overlying red shales are sharply overlain by the fluvial coarse-grained sandstones and shales of the Muñani Formation (Figure 3). For its stratigraphic relations, the Muñani Formation is usually considered as Eocene (Audebaud *et al.*, 1976; Mourier *et al.*, 1988). At Vilquechico palaeocurrents indicate southward transport. The shaly intervals of the Muñani Formation contain N-S to NNE-SSE-trending clastic dykes.

In summary, the Vilquechico Group as described here reflect mixed marine-continental sedimentation in a flat, stable domain. However, a tectonic event seems to be indicated at the base of the UVF by both the presence of a notable amount of sandy material and local unconformities. The N-S to NNE-SSW-trending clastic dykes of the MVF, UVF and the Muñani Formation express a mild N-S to NNE-SSW compressional strain and an E-W to WNW-ESE-trending extension, resulting from either the palaeoslope geometry, or more probably, the palaeotectonic regime.

The Vilquechico Group comprises three major transgressive-regressive sedimentary sequences (or formations), some of which are composed of minor but well-defined sedimentary sequences (or members) (Figure 3). Such well-defined sedimentary sequences and discontinuities are powerful tools to support or improve the biostratigraphic correlations.

3. Marine molluscs (J. P. Lefranc)

3.1. *Bivalvia*

Family Cardiidae; Genus *Granocardium*; subgenus *Ethmocardium*
Granocardium (Ethmocardium) whitei Dall, 1900.

Description

Material: about 30 imprints and several internal moulds (USTL Coll. VI 26-1 to 30).

Occurrence: Vilquechico Group, Middle Vilquechico Formation, Vilquechico locality, southern Peru (sample Vi 26, collector E. J. 1988).

Measurements: six well preserved specimens (VI 26-1 to 6) have been measured; two vertically fossilized specimens (VI 26-7 & 8) give an appreciation of the thickness (Table 1).

Table 1. Parameters of the studied specimens of *Granocardium (Ethmocardium) whitei*.

Specimens VI 26	1	2	3	4	5	6	7	8
Length	0.87	0.85	0.79	0.95	0.82	0.82		
Height	0.85	0.82	0.76	0.91	0.78	—		
Thickness	—	—	—	—	—	—	0.37	0.35

Specific characters: small bivalves, with a thin shell of almost suborbicular or quadrate shape, equivalve, slightly inequilateral. The length (anteroposterior diameter) is always slightly larger than the height (umboventral diameter); most of the specimens are between 0.7 and 0.9 cm high; two specimens reach 1 cm. Hinge disposition not clear, except in some specimens in which lateral teeth are partially preserved. Beak not large but rather prominent on the top part of the shell. Sculpture on the valves consists of thin radial ribs; ribs and furrows are 45 or 55 in number according to whether they are counted near the beak or near the pallial margin. Each rib, of rounded profile, is transversely marked by numerous notches and granulations concentrically disposed, resulting from successive disruptions in growth.

Affinities

The small size of the shell, its quadrate shape, the abundance of radial ribs reaching 50 in number, and notches on the ribs in concentric lines, are all characteristic of the subgenus *Ethmocardium*. Despite the fact that this subgenus is regarded by several authors as being only represented in the Upper Cretaceous of North America and of the Pacific realm, the Peruvian specimens here studied must be referred to *Ethmocardium*, and especially to the subgenotypic species *Cardium speciosum* Meek & Hayden. This was later redescribed by Dall (1900) under the valid name *Cardium whitei* on the basis of specimens collected from Upper Cretaceous beds in Montana, USA. Four other Late Cretaceous cardiid species bear some resemblance to the Peruvian fossils, as follows.

Cardium becksi (Müller 1847) comes from the lower Senonian chalk of Aachen (Germany) and has been reported subsequently from other German localities (Frech, 1887; Holzapfel, 1889). Several fossils from the *Exogyra overwegi* layers of early Maastrichtian age and various Senonian formations outcropping in the Libyan Desert of Egypt were referred to this German species (Quaas, 1901). Pervinquièrre (1912) suggested that *C. becksi* occurred in the Maastrichtian *Cardita beaumonti* beds of the Tunisian-Libyan border near Ghadames. *Cardium becksi* is a small fossil, high rather than large, and it has only 25 or 30 ribs, separated by very narrow furrows.

The species *Cardium ottoi* (Geinitz 1843) occurs in the upper Turonian and lower Senonian of Gossau (Austria). It was synonymized by Zittel (1865) with *Cardium incomptum* from the Trichinopoli Formation of India (Forbes, 1845). The external shape of this fossil is very similar to the Peruvian shells but the number of ribs it bears only reaches 20. Rather different is *Cardium ottoi* var. *africanum* described by Schneegans (1943) from the Turonian of Niger; its oblique shape renders the specific attribution doubtful.

Collected in the Upper Cretaceous beds of the Mungo River, Cameroon, *Granocardium* (*G.*) *kruschi* Riedel, 1932 has about 50 ribs on each valve. The ribs are adorned with numerous tubercles, justifying its attribution to the subgenus *Granocardium*. The size of *G. (G.) kruschi* is usually between 4.5 and 5 cm in height, and it is possible to find young or dwarf specimens with measurements comparable to those of the Peruvian fossils. Nevertheless, the tubercles on the ribs are present from the commencement of growth of the shell, as shown on Riedel's figures.

3.2. *Gastropoda*

Family Epitoniidae; Genus *Epitonium*
Epitonium cf. *jasmundi* Wanner, 1901

Table 2. Parameters of the studied specimens of *Epitonium* cf. *jasmundi*.

Specimens VI 26	31	32	33	34
Length of the fragment	0.19	0.35	0.17	—
Diameter of the fragment	0.07	0.17	0.12	0.11
Apical angle	22°	18°	—	—

Description

Material: one incomplete specimen (VI 26–31) presenting the first whorls with characteristic sculpture; one imprint of a longitudinal section, nearly complete, showing the last whorl with characteristic sculpture (VI 26–32); two oblique sections of whorls (VI 26–33 & 34).

Occurrence: Vilquechico Group, Middle Vilquechico Formation, Vilquechico locality, southern Peru (sample Vi 26, collector E. J. 1988).

Measurements: the material being incomplete, measurements (in cm) are given only as an indication of dimensions (Table 2).

Specific characters: very small-sized gastropod of turriculate shape, comprising seven whorls at least; whorls rounded, separated by an impressed suture and narrow furrow, clearly obvious on the last whorl. Aperture not preserved. Sculpture consisting of transverse or collabral riblets or costae (estimated to be about 12 or 14 on the last whorl) feebly inclined forward in the apertural part of the whorl. Spiral cords absent or not preserved.

Affinities

Epitoniid gastropods have not often been described from Upper Cretaceous formations, especially in North and South America. The genus *Epitonium* seems to be more common in Asia, Europe and Africa. *Epitonium jasmundi* was reported by Wanner (1901) from the Libyan Desert of Egypt, where it was collected a little above the *Exogyra overwegi* beds (early Maastrichtian). Except for its 37° apical angle and its larger size, the Egyptian *E. jasmundi* is closely comparable to the Peruvian species: the number of whorls, number of costae, rounded shape of the whorls and impressed suture are all similar.

Among the epitoniid species described from Africa, *Acrilla desertorum* (Wanner) was collected in the Maastrichtian beds of the Libyan Desert of Egypt (Quaas, 1901, p. 243, pl. 32, fig. 29), the Far South of Tunisia (Pervinquièrre, 1912, p. 62, pl. 3, figs 16–18), Morocco (Salvan, 1954, p. 146, pl. 9, figs 9–10), and Senegal (Tessier, 1952, p. 372, pl. 31, figs 1–4). This species is characterized by its cancellate sculpture, produced by very thin and numerous transverse riblets crossed by two or three spiral cords. From the same Maastrichtian formations of the Libyan Desert of Egypt, Wanner (1901) described the species *Scalaria calamistrata* and *S. labrosa*. Both are very obtuse and thick forms: the first has numerous thin transverse riblets; the second, rare and large costae.

Scalaria? varicostata was described by Riedel from the Upper Cretaceous of Cameroon (1932, p. 82, fig. 20; pl. 17, fig. 8; pl. 33, fig. 6). This turriculate, elongate shell, with spiral and transverse sculpture, is probably not an epitoniid. *Scalaria goryi* (Lartet, 1872, p. 44, pl. 10, fig. 6–7; Blanckenhorn, 1927, p. 139; pl. 2, fig. 31–32) from the Senonian beds of Palestine, is short, thick, and has a cancellate sculpture.

Age and environmental indications

As previously reported, *Granocardium* is restricted to Cretaceous formations, and the subgenus *Ethmocardium* to the Upper Cretaceous. The association *Granocardium* (*Ethmocardium*) *whitei*—*Epitonium* cf. *jasmundi* strongly supports a Senonian age for the Middle Vilquechico Formation.

These marine bivalves and gastropods are exposed on the top surface of a dark grey limestone bed, iron-rich, dolomitic, heavy and recrystallized. The shells are small, with an iron film covering external and internal surfaces. These elements suggest a confined and anoxic marine environment, where the conditions of life were difficult and reduced to scattered areas of monospecific or poorly diversified species.

4. Fish remains (H. Cappetta)

The following fish remains have been recovered from the section (Figure 6).

4.1. Middle Vilquechico Formation

Vi 18 layer: Actinopterygian fragments (VI 18-1 to 6).

Ptychotrygon sp.: this genus is represented by one incomplete tooth (USTL VI 18-1) lacking a root, and by several fragments (VI 18-2 to 4). The crown is high and globular with a salient apron and an almost circular and deep lingual hollow. The scarcity and poor state of preservation do not allow a specific identification.

Rhinobatid?: two fragmentary teeth (VI 18-5 & 6) are doubtfully assigned to this family.

Vi 27 layer: *Schizorhiza stromeri*: rostral teeth (VI 27-1 to 3).

4.2. Upper Vilquechico Formation

Vi 32 layer: Actinopterygian tooth (VI 32-1).

Vi 35 layer: *Pucapristis branisi*: this species is represented by a fragmentary rostral tooth (VI 35-1).

Vi 38 layer: Actinopterygian fragments (VI 38-1 to 3).

Vi 41 layer: *Dasyatis* sp. Some teeth (VI 41-1 to 9, more or less complete, show a cuspidate crown and are morphologically rather close to a species (*Dasyatis* nov. sp. 3) recently discovered in Bolivia (Cappetta, 1991; Gayet *et al.*, 1991; see below).

Actinopterygian fragments (VI 41-10 to 12).

Vi 47 layer: Actinopterygian fragments (VI 47-1 to 6).

Age and environmental indications

Ptychotrygon, found at the base of the Middle Vilquechico Formation, is here recorded for the first time in South America. For the Middle Vilquechico Formation, and for the base of the second sequence of the Upper Vilquechico Formation, the occurrence of sclerorhynchid remains (*Pucapristis*, *Schizorhiza*) provides an upper age limit, this group not continuing beyond the end of the Maastrichtian. *Schizorhiza stromeri* is mainly abundant in Maastrichtian deposits, but occurs as early as the mid-Campanian in the Celendín Formation of northern Peru (Cappetta in Mourier *et al.*, 1988).

The *Dasyatis* sp., collected at the base of the upper member of the UVF (Vi 41 layer), is similar to *Dasyatis* nov. sp. 3, referred to above, occurring in the Middle El Molino Member, at Rancho Hojada (Quebrada Taxisca), southern Bolivia. At this locality the sequence is considered to be Maastrichtian on lithologic grounds (Gayet

et al., 1991). The same species also occurs at the base of the Upper El Molino Member, in the Bolivian Torotoro area (sample from E. Jaillard, 1990), together with an indeterminate myliobatiform with grinding-type dentition. In this case, the batoid association does not enable an age determination to be made. It must be emphasized that the association with *Dasyatis* sp. (= *Dasyatis* nov. sp. 3 of Bolivia), in Peru as well as in Bolivia, contains dasyatids of modern aspect, very different from the other dasyatid species previously described from Bolivia (Cappetta, 1975). These faunas contain no other selachian taxa, and are completely lacking sclerorhynchids.

In the Vilquechico section, the occurrence of *Ptychotrygon* sp. and a somewhat questionable rhinobatid indicates marine conditions for the base of the MVF. The genus *Schizorhiza*, well known elsewhere from marine deposits, suggests a similar environment for the upper part of the MVF.

5. Tracks of large reptiles (P. Ellenberger)

The Vilquechico Group yields reptilian footprints in the basal part of the Upper Vilquechico Formation (Figure 3). They have been discovered on the top surface of the thick, yellow to pink-coloured sandstone bed which marks the base of the UVF, in the type section, two kilometres northwest of the village of Vilquechico. The layer contains three distinct types of tracks (Figures 4, 5).

The present study was carried out thanks to partial surveys and a series of photographs taken on the spot by E. Jaillard. Other types of observations such as map quadrating, moulding, photographs under slanting light and/or stereophotography would be helpful in further study.

5.1. Previous work

Lower Cretaceous tracksites in South America: Until recently, Peru remained one of the few major South American countries for which detailed studies of dinosaurian footprints were lacking. However, dinosaurian tracks have been noted to occur in the Lower Cretaceous of northern Peru (Trotter, 1964) and in the Vilquechico area (Jaillard pers. comm., 1989). In other South American countries, only the Lower Cretaceous has been really productive: in Chile, the Berriasian tracksite of Colchagua (n° 15 in the record of Leonardi, 1989); in Brazil, the mostly pre-Aptian tracksites of Paraná, Antenor Navarro, Sousa, Piranhas, Ceará (n° 12–13, 16–31, 32–33, *ibid.*); in Argentina, the Neocomian tracksite of San Luis (n° 12, *ibid.*). Owing to their older age, these footprints are presumed to not correspond to those newly discovered at Vilquechico.

Upper Cretaceous tracksites: The following data have to be considered:

(1) The two Upper Cretaceous tracksites of Neuquén (El Chocón, Argentina). The former (Leonardi's record n° 34, late Senonian) shows an isolated Coelurosaurian footprint. The latter (n° 35, same age?) shows several trackways attributable to Carnosauria, and in addition a set of two large footprints attributed to Ornithopoda. Detailed data remain unpublished (Leonardi, 1989).

(2) The Upper Cretaceous tracksite of Salta (Quebrada de la Escalera, Argentina), 200 km to the north (n° 36, Maastrichtian age, Yacoraite Formation). Here, the main type of track has been attributed by Alonso (1980) to an hadrosaurid, and described by him under the name *Hadrosaurichnus australis*. Associated with this is a claw-equipped tridactyl, theropod-like carnosaurian (Alonso & Marquillas, 1986, fig. 6, track 3; Leonardi, 1989). The neighbouring tracksite of Quebrada Tapón is

particularly notable for containing ichnites in a fine-grained yellowish to greenish sandstone of the Yacoraita Formation, only 10 m below the red sandstones of the Palaeocene Mealla Formation (Alonso, 1989). Here a great typical carnosaur (Pes 40 × 38 cm, *Salfitichnus mentoor*) occurs. Associated with it are a small neornithe bird (galliforme?, *Yacoraitichnus avis*), and two rather incomplete isolated footprints which possibly belong to the atypical hadrosaurians *Taponichnus donottoi* and *Telosichnus saltensis*.

(3) The Upper Cretaceous tracksites in central Bolivia, at Torotoro (Department of Potosí) and at Parotani (Department of Cochabamba). These are both Maastrichtian in age (Leonardi's records 37 and 38 respectively). In the former site, the yellow to red sandstones have revealed an astonishing gathering of theropods ("60 parallel carnosaur trackways"). The whole is associated with quadrupedal ornithischians (ceratopsians?, *Ligabueichnium bolivianum* Leonardi, 1984). Many other partial trackways (carnosaurs) are associated at that site with 8 sauropod trackways ("6 adults and 2 young ones"; Leonardi, 1984; Branisa, 1968). Such a gathering does not match the Vilquechico ichnofauna. The palaeoenvironment was probably different. In the latter site (Parotani), there were only 6 trackways of poor quality (carnosaurs?), now destroyed by recent landslips (Leonardi, 1981).

(4) Tracksites recently described by Noblet *et al.* (1987; Noblet *et al.*, in press) from the uppermost Cretaceous of Peru, in the same area as those previously mentioned by Gregory (1916). They are of interest for two reasons: (1) their stratigraphical position in the 6000 m-thick Senonian to Palaeocene "Red Beds" succession (footprints level is located at *c.* 4000 m high up in the sequence); (2) their relative geographical proximity, 200 to 300 km to the northwest of Vilquechico. At Sicuani, the Languí site shows a 2 m²-slab with three types of footprints: (i) a tiny unnamed coelurosaurian-like foot, with digits II-III-IV being very divergent (Pes 10 cm); (ii) a small ornithopod rather similar with *Sinoichmites* Kuhn, 1958 (Pes 11 cm); (iii) a rather large, unnamed tridactyl foot with a long median digit, possibly a carnosaur (Pes 22 cm) (Noblet *et al.*, in press, fig. B). At Cuzco, the modest K'Ayra ichnological site (Noblet *et al.*, in press) has revealed an isolated tridactyl-like, unnamed footprint, possibly mesaxonian (Pes 13 cm). Considering its spatulate digits, with a unique pad, as well as the broad and spread out plantar sole, with the starting point at the fourth digit, this footprint looks like a typical quadrupedal ornithischian, with the sort of "stubby" ceratopsid-like four-toed foot that *Monoclonius* had in the Late Cretaceous (*vide* Romer, 1956, p. 400; Moraes, 1924). Still near Cuzco, the second tracksite, at Paruro, on a 25 m²-slab comprises more than six distinct tracks belonging to three different animals: (i) an unknown biped walking on a narrow track, its legs tracing long and deep streaks in the mud (theropod?, Noblet *et al.*, in press, figure 3C); (ii) a very tiny dinosaur leaving, in its two trackways, only three parallel prints of its fingers. Noblet *et al.* think that it might be compared with *Atreipus* of Olsen & Baird (1986); (iii) a larger ornithischian which left three complete tracks. These tracks do not display strong similarities with those of Vilquechico, but interesting is the track at top of figure 3C in Noblet *et al.*, with its exceptionally shuffling gait, to which we refer below.

5.2. The new tracksite of Vilquechico

Systematics

Class Reptilia; Order Saurischia; Suborder Coelurosauria
Family? Ornithomimidae Marsh, 1890

Ichnological genus *Ornithomimipus* Sternberg, 1926

Ornithomimipus jaillardi sp. nov. (Track A, Figures 4, 5)

Diagnosis: For generic diagnosis see Haubold (1971, p. 475); specific diagnosis: narrow foot with a large median digit, an interdigital tissue or membrane, a light gate, and a heart-like plantar sole (Figure 5). Smaller than *O. angustus*, and a foot a bit less narrow.

Derivatio nominis: As a token of esteem to Etienne Jaillard.

Holotype: Material *in situ*, Vilquechico, southern Peru (basal level of UVF). Stride with three successive steps in hyporelief.

Paratype: Also *in situ*, a complete trackway of 4 steps depicted on the spot (figures and stereophotos).

State of preservation: Very good. Deambulation on a still plastic soil in process of stabilization.

Parameters

(1) Pes. Elongated, narrow, functionally tridactyl, typically digitigrade. Front part penetrating deep into the soil in contrast to the rear part, and to such an extent that the long median digit, extended forward, has edges of impression tending to meet on the surface (Figure 5).

Measurements made on the reconstruction of the skeleton (in cm). Length: 19 to 22; digits from the digitometatarsal articulation: II = 8; III = 16; IV = 10. No mark of hallux (I). Digits II-III-IV remaining close to one another: total divarication II-IV = 40°. The median III is strongly projected forward (as for late coelurosaurians): length beyond the line joining the tips of the two lateral digits = 8. Digit III showing a slight distal incurvation inwards (=15°). Width: 15; between tips of digits II and IV: 12 to 14. Pads of phalanxes not apparent. Claws appear to be blunt. Thick membrane or interdigital tissue. Phalanx formula type: (1)-2-3-4-0.

(2) Manus. Not visible.

(3) Track. Track curving gently to the right (Figure 4). Stride: 125 to 127 cm (steps 62.5 to 63.5 cm). Ped. angulatio: 170° to 175°. Width of track: 2 to 8 cm. Progress made by means of large steps on a very narrow track.

Discussion and systematic classification: Such a narrow foot, with a long median digit, as well as the nature of the plantar sole, the light gate, the membrane or interdigital tissue, recall the whole coelurosaurian group, as from the Triassic age (e.g. *Masitisauropus exiguus*, Stormberg-type 68c) (Ellenberger, 1974, p. 100, and pl. P). However, in view of the presumed age and all the characteristics described above, it is necessary to consider the ornithomimids (cf. Romer, 1956, p. 398). In South America, none of the previously described coelurosaurian tracks possesses the parameters of this small coelurosaur from Vilquechico. The Sicuani sample is too small (10 cm), with a median digit III much shorter and the lateral digits spread out.

In North America, the Edmonton Formation in Alberta has provided the only published track which could be closely compared with the Vilquechico coelurosaurian from a generic point of view, namely *Ornithomimipus angustus* Sternberg, 1926 (Haubold, 1971, p. 74). The latter is, however, of greater size (*i.e.* double: 39 × 30 cm) and its three digits II-III-IV are much closer to each other than in the Vilquechico specimen. The genus denomination *Ornithomimipus* is therefore retained, and pending a better inventory, we attribute to the new type the species name *O. jaillardi* sp. nov.

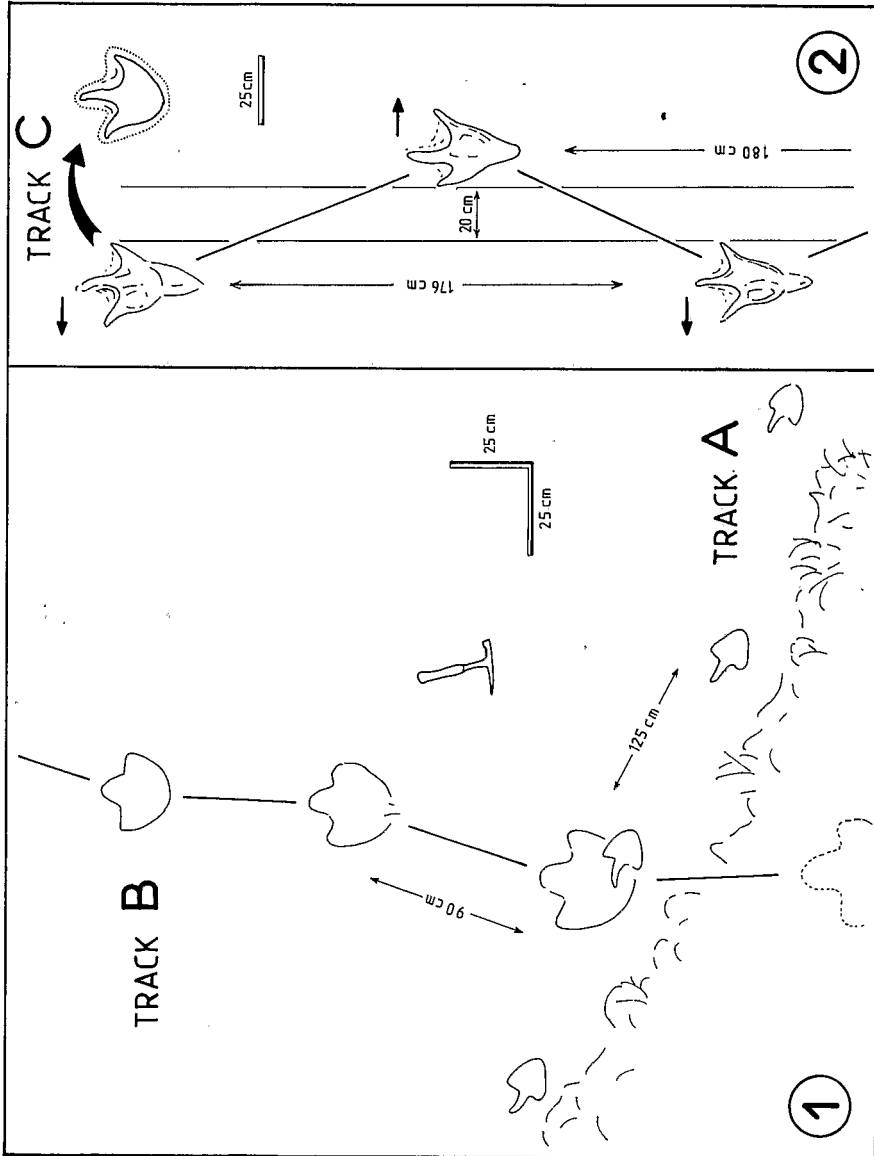


Figure 4. Dinosaur tracks of the lower UVF at Vilquechico, Peru: general views from photographs. 1. The principal slab, slightly slanting view: Track A, *Ornithomimipus jaillardii* sp. nov., and Track B, *Hadrosaurichnus titicacaensis* sp. nov. 2. Track C: *Incertae sedis*. Note the swinging displacement of this kind of track, which reflects progress across a slippery surface.

Suborder Ornithopoda; Family Hadrosauridae Cope, 1869

Ichnological genus: *Hadrosaurichnus* Alonso, 1980

Hadrosaurichnus titicacaensis sp. nov. (Track B, Figures 4, 5).

Diagnosis: For generic diagnosis see Alonso (1980); specific diagnosis: smaller than *H. australis*, with median digit III comparatively shorter, lateral digits II and IV even more divergent, gate a bit shorter, width of track a bit less.

Derivatio nominis: From Lake Titicaca, a few kilometres south of Vilquechico.

Holotype: Material *in situ*, Vilquechico, southern Peru (basal level of UVF). A complete trackway of at least 5 steps depicted on the spot (figures and stereophotos).

State of preservation: Good. Deambulation on a still plastic soil, but slightly hardened at the start. This track crosses the preceding one at right angles and appears to be somewhat more recent as shown by the superposition of the first of the three steps. We associate with this track the neighbouring track B', of similar aspect, but 3/5 smaller.

Parameters

(1) Pes. Deeply spread out in width; tridactyl without any digitigrady; impression of digits and foot sole everywhere constant in the soil, as in the case of semi-plantigrades (Figure 5).

Measurements after reconstruction of the skeleton (in cm): Length of the foot on the soil: 25; 30 with the heel (track B': 15). Digits from the digitometatarsal articulation: II = 12, III = 17, IV = 13; and from the heel (basipod): 20, 25, 21 (track B': 7, 10, 8 respectively, for the digits alone). No hallux impression. The three very short digits are particularly spread out: total divarication II-IV: 60°. The median III extends forward only 8 cm further than the tips of the lateral toes (track B': 5); slight incurving towards the interior (=10°). Width of the foot at the level of the tips of the digits II and IV: 23. Total width: 25 (track B': 15 cm). Interdigital tissue probably firm. The claws are very blunt and have the apparent form of a hoof, as in the case of the Hadrosaurians.

(2) Manus. Not visible.

(3) Track. Stride 180 cm (step approximately 90 cm, Figure 4). Ped. angulatio: c. 166°. Width of track: 12 to 13 cm. Progress is made in plantigrade fashion and with a slight swing.

Discussion and systematic classification: All the features observed, as well as the likely reconstruction of the skeleton of the foot indicate the presence of a two legged ornithischian and, within the group of ornithopods, preference goes to hadrosaurians because of: the shortening of the autopod, especially the spectacular shortening of digit III; the spreading of lateral digits II and IV; and the large rounded nails which terminate the three digits II, III and IV. These features are found in the case of the anatosaurids where, however, the foot including the phalanxes is even more telescoped (*vide* Romer, 1956, p. 400).

From the ichnological point of view, there are parallels mainly within America. There is the indeterminate "hadrosaurid" footprint of larger size discovered by Langston (*in* Haubold, 1971) in the Late Cretaceous of the St Mary River in South Alberta, which he considered to possibly belong to *Corythosaurus* or *Hypacrosaurus* (?) (Haubold, 1971, p. 87, 89), and the unnamed footprints discovered by Noblet *et al.* (1987) in the "Red Beds" at Langui (Sicuaní) (Figure 5; light dotted line superimposition), or their parallel medium-sized ornithischian tracks at Paruro

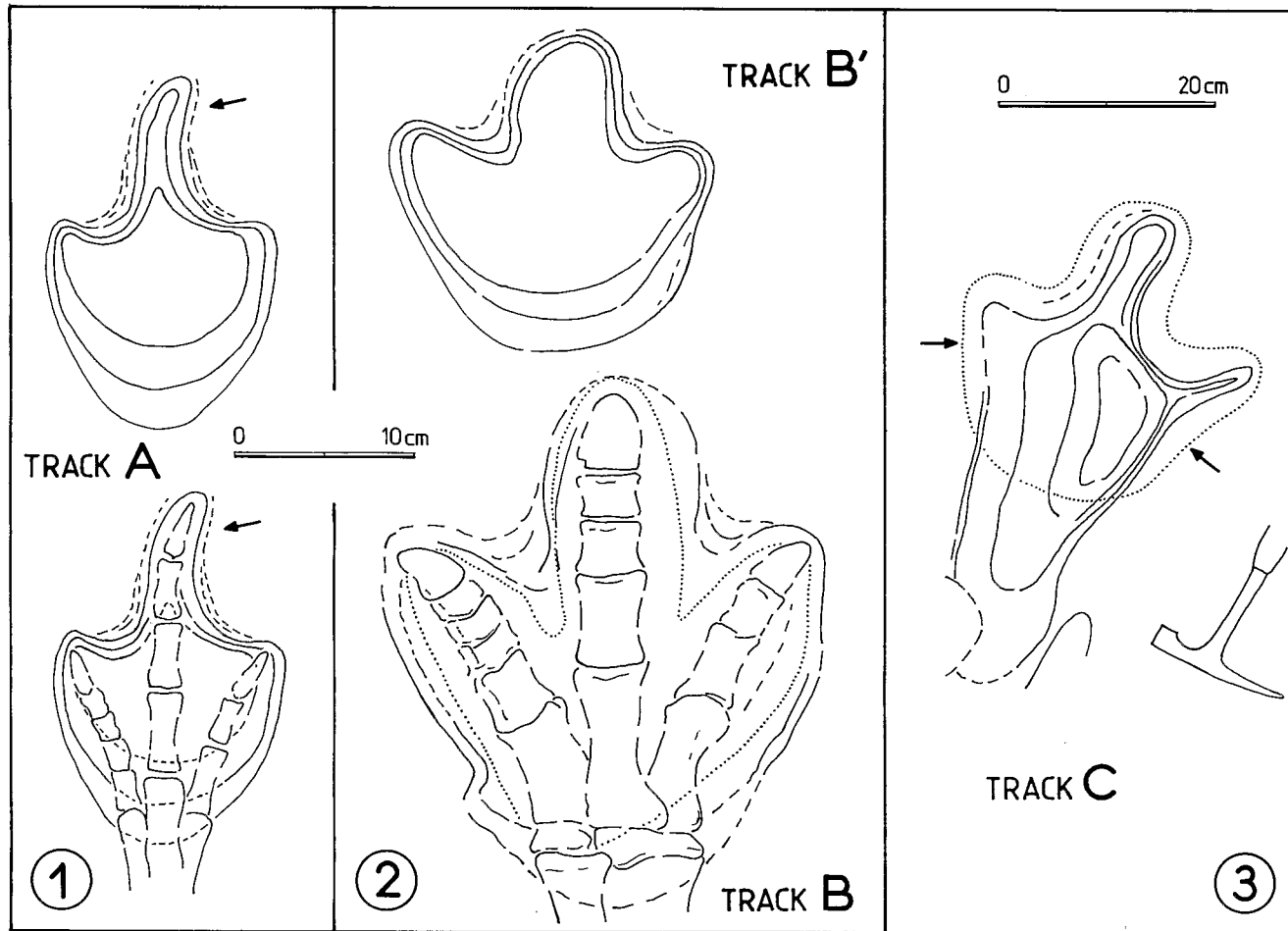


Figure 5. Dinosaur tracks of the lower UVF at Vilquechico, Peru: footprints and reconstructions. 1. Track A, *Ornithomimipus jaillardii* sp. nov., fourth step of the track (Holotype), after stereophotos (above), and approximate reconstruction of the skeleton (below). 2. Track B, *Hadrosaurichmus titicacaensis* sp. nov., a footprint of the larger size; third step in the main track (holotype), with approximate reconstruction of the skeleton. Light dotted line: superposition of one of the Cuzco-Sicuaní footprints, same scale. Track B': *Hadrosaurichmus titicacaensis* sp. nov., a footprint of the smaller size (isolated step). 3. Track C, *Incertae sedis*, the second step of the track, after a photograph. Note the intense shrinking of the soil, and the deepening of the track along its external edge because of the muddy conditions.

(Cuzco). Seemingly much closer are the hadrosaurid footprints in a large gathering described by Alonso (1980) at Salta (Argentina), and referred to as *Hadrosaurichnus australis*. But as noted above, the Vilquechico specimen differs from *H. australis* in the following five ways: the foot is smaller (30×25 v. 37×28); the digits are more spread out (divarication 60° v. 54°); median digit II is shorter and less projected beyond lateral ones (5 cm v. 6 cm); lesser gate (180 cm instead of 198); the width of the track is narrower (13 cm instead of 23).

While keeping the generic denomination *Hadrosaurichnus*, we propose, therefore, a new species, *H. titicacaensis* sp. nov., for this type of track.

Incertae sedis (Track C, Figures 4, 5)

State of preservation: Complete tridactyl track with at least four consecutive steps. It is rather difficult to describe this track, which was apparently made while the soil was soft and viscous. The mud bilaterally closed up on the footprints of each of the three toes forwards. Behind, a large trail of the foot in the mud makes any accurate description difficult. The effort made by the biped has enlarged the track and caused the foot to be deported toward the exterior as is customary for the deambulation of bipeds on slippery material.

Parameters

(1) Pes. Comparing the various footprints of the track, the following can be deduced. Length of the foot: 30 cm. Beyond such narrowing of the digitiprints due to the viscosity (see Figure 5), the parameters are similar to those of track B, i.e. the relative length of the digits, the slight projection of the median III (8 to 9 cm only with respect to the tips of II and IV), angle of divarication II-IV greater than 60° , and up to 70 – 80° . As a result, width of the foot: 28 cm.

(2) Manus. Not visible.

(3) Track. The strides are almost identical to those of track B (176–180 cm). Step: 88–90 cm. Width of track slightly larger, 40 to 50 cm, with a greater swing because of the mud. Deambulation in a way to be compared with one of the Paruro (Cuzco) tracks, which Noblet *et al.* (in press, figure 3B) consider to have been made by an animal that was possibly "sick or very old".

Discussion and systematic classification: In spite of appearances, it is tempting to consider that we are dealing here with a close neighbour of one responsible for the track B, i.e. an ornithopod (possibly hadrosaurian?). However, another field study might lead to a change of opinion.

Conclusion

The Vilquechico tracks A and B demonstrate the simultaneous existence, in this part of the Andes towards the end of the Cretaceous period, of both saurischian and ornithischian dinosaur footprints. The Cuzco and Sicuani tracks (Noblet *et al.*, in press) increase the interest with the occurrence there also of such big dinosaurs, one of them being compared with track B of this work.

6. Charophytes (M. Feist and N. Grambast-Fessard)

Two distinct charophyte-bearing horizons have been encountered in the Vilquechico Group. The first is located in the upper part of the Middle Vilquechico Formation

(samples Vi 21 to Vi 29), which had formerly been sampled by Newell (Peck & Reker, 1947; Newell, 1949). The second (samples Vi 43 to Vi 51) is located in the lacustrine part of the third minor sequence of the Upper Vilquechico Formation, near the top of the Group.

6.1. *The first Charophyte zone (Vi 21 to Vi 29)*

Vi 21: Feistiella ovalis comb. nov. = *Porochara ovalis* (Fritsche) Grambast, 1967 = *Chara ovalis* Fritsche, 1924 in Peck & Reker, 1947, p. 3, figs 7–11.

These specimens, which are rather big ($1000\text{--}1075 \times 800\text{--}875 \mu\text{m}$) and regularly ovoid in shape (Figure 6a), are identical to the material from the locality of Peck & Reker (1947) (sample 60, collected in the Moho Gp, 4 km SE of Moho, 15 km SE of the Vilquechico locality). Musacchio (1972) described for this species a simple basal plate which characterizes the genus *Feistiella* Schudack.

Vi 22: Feistiella ovalis: rare. *Peckisphaera* sp. A: gyrogonites nearly spherical with flat summit, spiral cells irregular to slightly nodular. Dimensions: $750\text{--}825 \times 750\text{--}800 \mu\text{m}$; $n = 7\text{--}8$ (Figure 6h). These specimens differ from those of *Peckisphaera portezueloensis* Musacchio, 1973 (Neuquén Group, Late Cretaceous, Argentina) in being somewhat larger, more regularly spherical and with the spiral cells having an irregular surface.

Vi 24: Amblyochara sp. A: gyrogonites ovoidal with flat or slightly depressed summit and tapering base with a small basal funnel, and concave spiral cells. Dimensions: $1150\text{--}1425 \times 1150\text{--}1325 \mu\text{m}$; $n = 9\text{--}11$ (Figure 6f, g). These specimens are close to *Amblyochara peruviana* Grambast, 1967 (Sillustani = Laguna Umayo, 20 km NW of Puno), but larger and with a generally wider outline.

Vi 25: oospores of Porocharaceae. The extraction of the fossils provides only internal moulds, the spiral cells being destroyed. These remains have neither systematic nor stratigraphic significance.

Vi 27: Platychara perlata (Peck & Reker) Grambast, 1967 = *Chara perlata* Peck & Reker, 1947 (pp. 3, 4, figs 19–21). The specimens are poorly preserved and uncommon. Dimensions: $800\text{--}840 \times 1040\text{--}1080 \mu\text{m}$; ISI = 75–80 (Figure 6e).

Vi 28, Vi 29: Charophyta, gyrogonites impossible to extract and identify.

6.2. *The second charophyte zone (Vi 43 to Vi 51)*

Vi 43: Feistiella gildemeisteri comb. nov. = *Porochara gildemeisteri* Koch & Blissenbach, 1960 (p. 65, fig. 15-1; pl. 1, fig. 7). This species, characterized by the narrowing outline of the upper half of the gyrogonite, possesses a single basal plate and, thus, must be assigned to the genus *Feistiella* Schudack.

Vi 49: Feistiella gildemeisteri comb. nov. *Platychara grambastii* Peck & Forester, 1979. Dimensions: $475\text{--}650 \times 750\text{--}975 \mu\text{m}$; ISI = 60–77.

Vi 50: Platychara grambastii Peck & Forester, 1979. Dimensions: $625 \times 825\text{--}975 \mu\text{m}$; ISI = 64–75 (Figure 6d).

Vi 51: Feistiella gildemeisteri comb. nov.

6.3. *Systematic note*

Peck & Reker (1947) first described specimens of *Platychara* from the Vilquechico Group under the name *Chara perlata* = *Platychara perlata* (Peck & Reker) Grambast. A new, enlarged description of this species was given by Peck & Forester (1979) who included specimens from Mexico. It thus appears that gyrogonites from

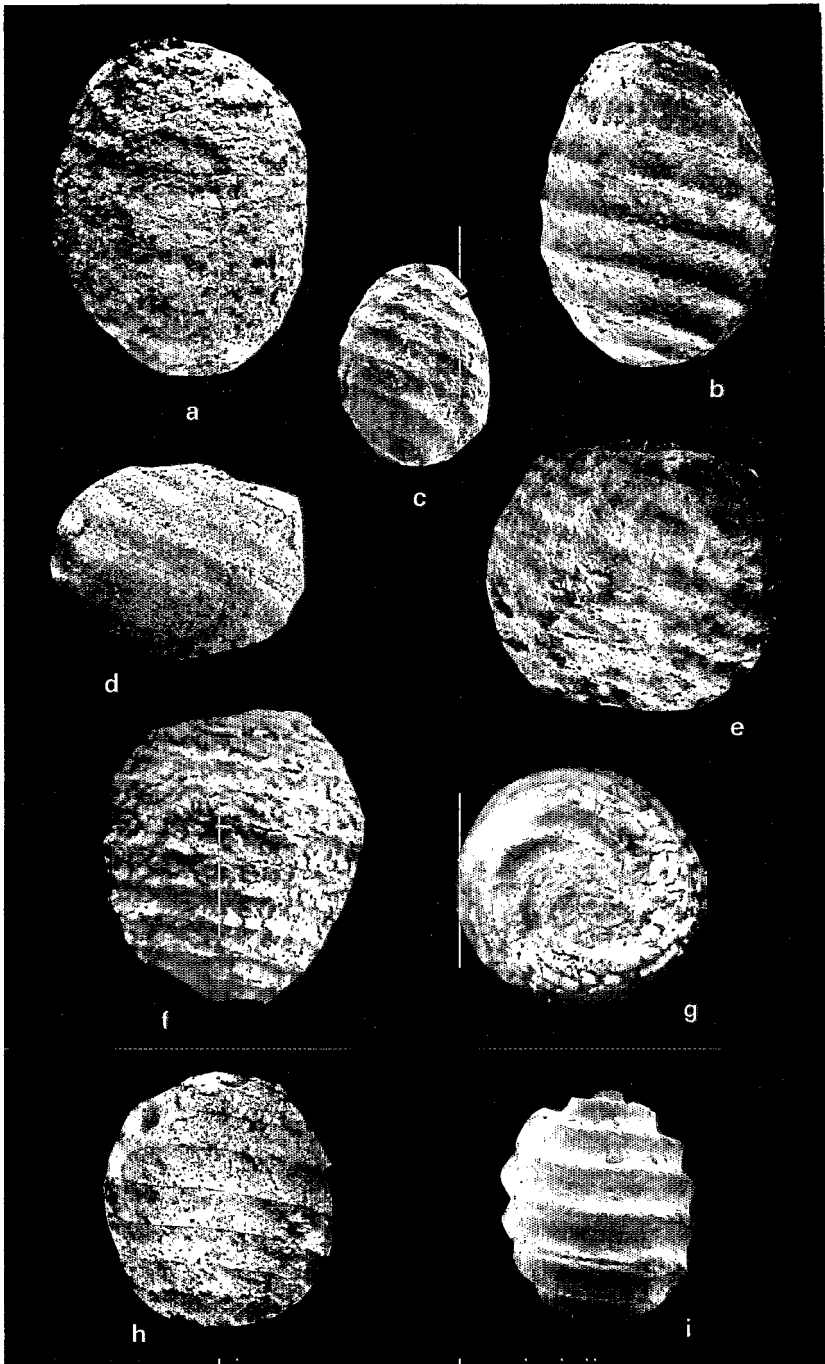


Figure 6. Some Late Cretaceous charophytes from Andean sections. a, *Feistiella ovalis* (Fritzche) comb. nov. Feist & Grambast-Fessard, C 1203-1, $\times 40$, Vilquechico Vi 21; b, *Feistiella gildemeisteri* (Koch & Blissenbach) comb. nov. Feist & Grambast-Fessard, C 1190-1, $\times 40$, Cuzco 2, c, *Feistiella gildemeisteri*, forma minor, C 1196-1, $\times 40$, Cuzco 8; d, *Platychara grambastii* Peck & Forester, C 1210-1, $\times 40$, Vilquechico Vi 50; e, *Platychara perlata* (Peck & Reker) Grambast, C 1207-1, $\times 40$, Vilquechico Vi 27; f, g, *Amblyochara* sp. A, lateral and apical view, C 1205-1 and 2, $\times 27$, Vilquechico Vi 24; h, *Peckisphaera* sp. A, C 1204-1, $\times 40$, Vilquechico Vi 22; i, *Feistiella costata* (Koch & Blissenbach) Feist, CF 2744-1, $\times 43$, Fundo el Triunfo. All specimens housed in the USTL collections.

Vi 27 should be assigned to this species, as they are somewhat larger and less flattened ($ISI = 75-92$) than *P. grambastii*, this last character being apparently the most significant.

The specimens from Vi 49 and Vi 50 belong to the species *P. grambastii* Peck & Forester, 1979, established on material from Jamaica. They agree quite well with the Jamaican specimens studied by Kumar & Grambast-Fessard (1984) with respect of their size and flatness ($ISI = 60-77$). The basal tip is, however, less marked than that reported by Peck & Forester (1979). The existing variations concern the size of the gyrogonites, which are larger in Vi 50 ($625 \times 825-975 \mu\text{m}$) than in Vi 49 ($475-625 \times 700-875 \mu\text{m}$).

6.4. Stratigraphic remarks

As regards the Charophyte flora, two different zones are recognized in the Vilquechico Group. In the first (Vi 21 to Vi 29), the presence of *Feistiella ovalis* comb. nov. is significant. This species was first recorded from the Moho Group (bed f), a few kilometers SE of the Vilquechico village, by Peck & Reker (1947). It is mentioned by Musacchio (1972) as occurring at Tres Cruces (Yacoraite Fm., Argentina). This zone also contains *Platychara perlata*. The genus *Platychara*, most frequent in Mesozoic rocks, is also present in the Palaeocene (Grambast-Fessard, 1980). It is necessary to mention the report by Peck & Forester (1979) of *Platychara perlata?* in Palaeocene-Montian sediments from Argentina (Roca Fm., Prov. Rio Negro) with doubtful species assignment. Musacchio & Moroni (1983) described "*Platychara perlata*" from the El Carrizo Formation (Prov. Rio Negro, Argentina) which they ascribe to the Palaeocene, according to other fossil species present in the same association (Charophyta and Ostracoda).

The second charophyte zone (Vi 43 to Vi 51) is characterized by the presence of *Feistiella gildemeisteri* comb. nov. This is missing in the first zone. It also contains *Platychara grambastii*. *F. gildemeisteri* is a widely distributed species which has been recovered from numerous South American localities. The various layers providing this species have generally been assigned to the Late Cretaceous (see Mourier *et al.*, 1988). Germundson (1965) mentions *P. gildemeisteri* in layers ascribed to "earliest Palaeocene" in Alberta (Canada), but a re-examination of these specimens in the collections of the University of Missouri reveals that they differ from typical *F. gildemeisteri*, and can no longer be assigned to this species.

Though a Late Cretaceous age is most probable for the two charophyte zones of the Vilquechico Group, an early Palaeocene extension cannot be excluded for the younger of the two. However, it must be emphasized that no Palaeocene markers have been found so far in the group. In the same way, species collected in the Bagua area from layers dated between 54.2 ± 6.4 and 28.7 ± 3.7 to 30.0 ± 3.1 Ma by the fission-track method, and attributed to the early to middle Eocene (Naeser *et al.*, 1991), are absent from the Vilquechico and Cuzco localities.

In conclusion, the charophytes permit the distinction of two biozones: zone 1 with *Feistiella ovalis* and *Platychara perlata*; zone 2 with *Feistiella gildemeisteri* and *Platychara grambastii*. A third zone might be characterized by *Feistiella costata* (Koch & Blissenbach) Feist, a species which occurs in association with different Late Cretaceous taxa (Feist in Mourier *et al.*, 1988). In the section of the Oriente of Peru studied by Koch & Blissenbach (1960), this third zone is located above those which contain *F. gildemeisteri*. In the Bagua Formation, the *F. costata* zone is identifiable below the Tertiary beds dated by *Nitellopsis supraplana* and associated species (Mourier *et al.*, 1988).

Both zones 1 and 2 are to be considered as Late Cretaceous, although some taxa in zone 2 could extend into the lower Tertiary. A more accurate assignment to precise stages within this period may be deduced from the comparison of the sections discussed below.

6.5. Other revised South American charophyte floras

The following determinations are all based on material from different collectors in the Grambast (C) and Feist (CF) collections held at USTL, Montpellier.

1. *Fundo el Triunfo*. Fundo el Triunfo Formation, Bagua region, northern Peru (Feist in Mourier *et al.*, 1988): CF 2744. *Amblyochara peruviana*, *Amblyochara begudiana*, *Feistiella costata* (Figure 6 i).
2. *Cuzco*. Upper part of the Yuncaypata Formation, southern Peru (G. Carlier's settlement): C 1190 to 1197. *Feistiella gildemeisteri*, fairly numerous; depending on the horizon concerned, large specimens (Figure 6 b) are sometimes associated with less calcified, much smaller forms (*forma minor*) (Figure 6 c), *Platychara grambastii* (Cuzco 7).
3. *Sillustani*. (= Laguna Umayo locality of subsequent authors). Umayo Formation, Puno region, southern Peru (Grambast *et al.*, 1967): C 801. *Feistiella gildemeisteri* and *forma minor*, *Amblyochara peruviana*.
4. *Airamponne*. Vilquechico Formation?, Putina region, southern Peru: C 803. *Porochara* sp. B. Gyrogonite with a more regular ovoid outline.
5. *Rio Suches*. Northwestern Bolivia (G. Laubacher's settlement): CF 2816. *Feistiella gildemeisteri*, *Lamprothamnium* sp., *Peckisphaera* sp. B. The latter specimens are identical to the forms present in the lower part of the Willow Creek Formation, Late Cretaceous, Oldman River Bridge, Alberta (Canada) (specimen KG 61.10.32, US Geological Survey, Denver), referred to by Germundson (1965) as *Amblyochara*.
6. *Panduro*. Road to Torotoro, Bolivia: C 1200. *Feistiella gildemeisteri*, *Amblyochara peruviana*, *Platychara grambastii*, rare.
7. *Maragua*. El Molino Formation, Sucre region, Bolivia: C 1198. The present state of knowledge makes it possible to improve on Grambast's identifications (in Branisa *et al.*, 1969): *Feistiella gildemeisteri*, *forma minor* (mentioned as *Porochara* sp.), *Platychara grambastii* (instead of *P. cf. perlata*), *Amblyochara peruviana*.
8. *Chaunnaca*. Cuesta de la Majada, Sucre region, Bolivia: C, 1202. *Feistiella gildemeisteri*, *Platychara grambastii*, *Amblyochara peruviana*, large specimens, *Platychara perlata*? or *P. compressa*? (a few large gyrogonites with convex spirals and apical prominent rosette).

It is concluded from these observations that the presence of *Feistiella gildemeisteri* in most of these localities suggests a correlation with the second charophyte zone of the Vilquechico Group.

7. Biostratigraphic appraisal (B. Sigé)

The present study of the stratotypic Vilquechico Group at Vilquechico has provided new records of four different groups of fossils (Figure 7), molluscs, actinopterygian and selachian fishes as marine organisms, lacustrine algal plants (charophytes) and terrestrial dinosaurian reptiles. The following appraisal is presented according to the stratigraphical succession described.

The Lower Vilquechico Formation (LVF) did not yield fossils. Its age can be assumed only through speculative interpolations and correlations.

The Middle Vilquechico Formation (MVF) contains many marine and lacustrine fossiliferous layers. Near the base, bed Vi 18 provided selachian teeth (*Ptychotrygon* sp. and rhinobatid?) devoid of precise stratigraphic value. In the upper part, layers Vi 21, 22, 24, 25, 27, 28 and 29 are rich in charophyte gyrogonites, among which *Feistiella ovalis*, *Platychara perlata*, *Amblyochara* sp. A, and *Peckichara* sp. A have been identified. This association represents the first of the two charophyte zones defined in the Vilquechico Group. The previous identifications of the two first species by Peck & Reker (1947) from the same layers and section (Newell, 1949) are corroborated. The genus *Platychara* is known up to the Palaeocene, but the rare Palaeocene reports of the *P. perlata* are questionable, and *F. ovalis* is an unequivocal Late Cretaceous marker. Therefore, the age indication of the first charophyte zone association is the Late Cretaceous.

The marine bed Vi 26, intercalated within the charophyte-bearing beds of the upper part of the MVF, contains the bivalve *Granocardium* (*Ethmocardium*) *whitei* and the gastropod *Epitonium* cf. *jasmundi*. The age indication of these molluscs is "Senonian". Layer Vi 27 of the upper part of the MVF yielded tooth material of the batoid selachian *Schizorhiza stromeri*. This ubiquitous taxon is mainly Maastrichtian, and unknown from Tertiary deposits.

In summary, the marine and continental fossils from the upper part of the MVF have significant stratigraphical value, and their age indications are consistent with each other. The most precise indication is provided by *Schizorhiza stromeri*, which is mainly known as a Maastrichtian species. It has, however, recently been reported from the mid-Campanian upper Celendín Formation of northern Peru, where it was previously referred to as Neoselachian *incertae sedis* (Cappetta in Mourier *et al.*, 1988; Cappetta, 1991). A mid-Campanian to Maastrichtian age can be thus proposed for the upper part of the MVF.

The Upper Vilquechico Formation (UVF), in common with the MVF, contains several marine and continental fossiliferous beds. In the first minor sequence, the surface of the thick basal sandstone bed bears footprints of at least two large-sized terrestrial dinosaur species. Since dinosaurs have not yet been proved to be convincing Palaeocene markers in Andean formations, the most probable age indication of these fossils is Mesozoic. The marine fish from layer Vi 32 do not allow any improvement on this determination.

In the second minor sequence, layers Vi 35 and Vi 38, have yielded tooth material of marine actinopterygian and selachian fishes. The batoid selachian *Pucapristis branisi* from Vi 35 indicates the top of the Maastrichtian as an upper limit.

In the third sequence of the UVF, beds Vi 43, 49, 50 and 51 are rich in lacustrine charophyte remains, among which *Feistiella gildemeisteri* and *Platychara grambastii* are identified. This association is diagnostic of the second charophyte zone recognized in the Vilquechico Group. It was not previously reported from the local section. The age indication is Late Cretaceous. From layers Vi 41 and Vi 47 teeth of marine actinopterygian and the selachian *Dasyatis* sp. have been identified. The latter is recorded as *Dasyatis* sp. 3 in the Middle El Molino Bolivian fauna of Quebrada Taxisca (Rancho Hoyada) (Cappetta, 1991).

In summary, although a Palaeocene extension of some charophyte taxa cannot be definitely ruled out, their occurrence along with the selachians and dinosaurs found in this formation is consistent with a Late Cretaceous, probable latest Campanian to late Maastrichtian age determination for the UVF.

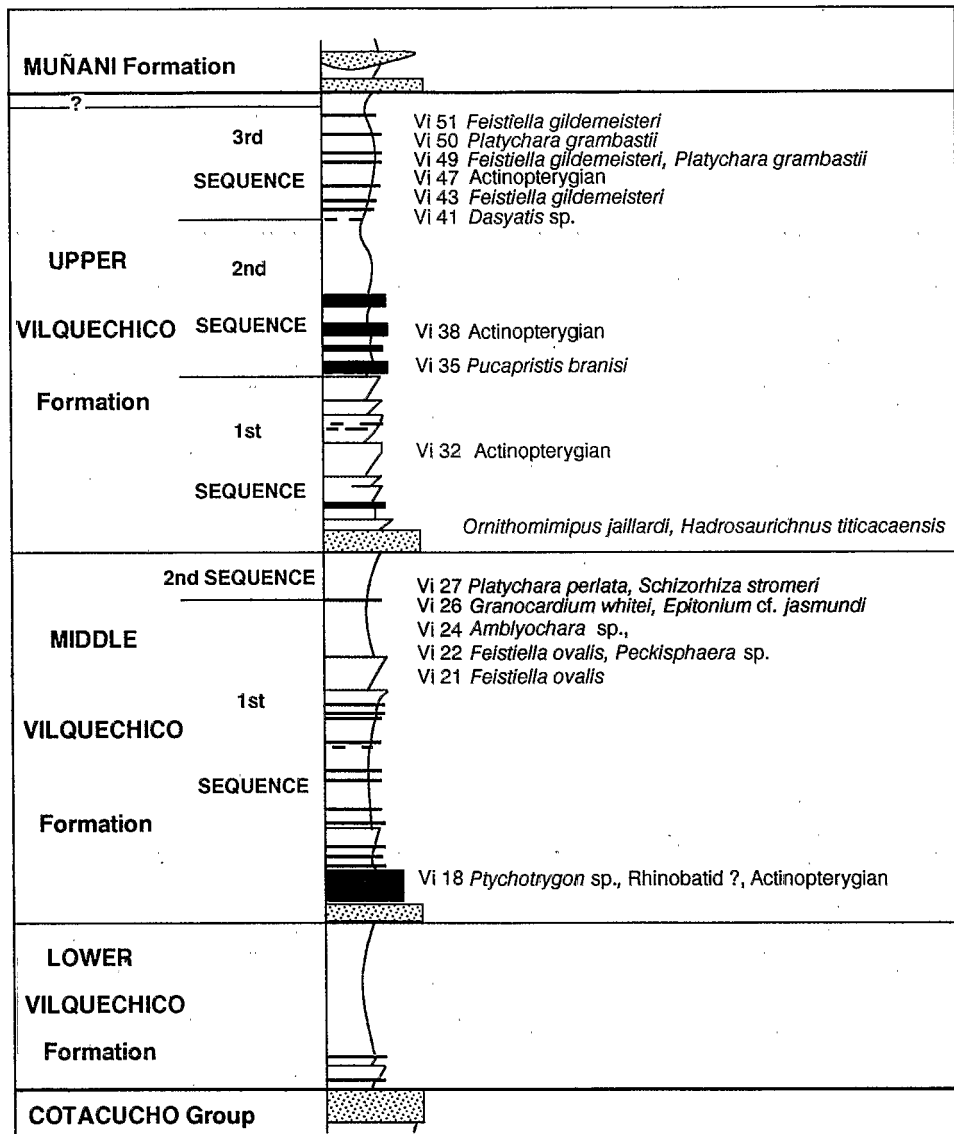


Figure 7. Location of the samples (numbers prefixed Vi) and the fossil record.

8. Sedimentological, lithostratigraphic and biostratigraphic correlations

(E. Jaillard & B. Sigé).

Sedimentological and lithostratigraphic correlations are useful throughout the eastern Andean sedimentary domains, which includes the Vilquechico region. Biostratigraphic data are necessary to support the correlations of the major sedimentary discontinuities through the western Andean domain, because the Andean orogeny created a very variable sedimentary pattern.

8.1. Correlations with the eastern domains

8.1.1. *The Peruvian Northern Altiplano* (Moho area, Figure 8: section 1). In this area Newell (1949) defined a thick red shale sequence as the Moho Group. In its lower

part, the Group contains limestone intercalations (Ayavacas Formation, unit "b" of the Moho Group of Newell, 1949), which yielded middle Albian to late Cenomanian ammonites (Lisson, 1924; Cabrera & Petersen, 1934; Newell, 1949). According to Newell's (1949) description and E. Jaillard's observations, the rest of the Moho Group can be divided into three major sedimentary sequences.

The first (unit "c" of Newell, 1949) is composed of undated variegated shales. The second comprises, from base to top, thick sandstones (unit "d"), green shales alternating with thin-bedded limestones (unit "e"), and red shales (unit "f"). Near the top of this sequence, oyster-like bivalves and the charophyte *Feistiella* (= *Porochara*) *ovalis* (Peck & Reker, 1947) have been found (Newell, 1949). This sequence can be therefore correlated with the MVF on its lithological and palaeontological similarity. The third sequence of the upper part of the Moho Group comprises basal sandstones (unit "g"), green shales (unit "h"), and red shales and sands capped by a thin dolomitic bed (unit "i" and "j", *ibid.*). The lithological succession makes a correlation with the UVF very probable. Although not precisely located in the section, the occurrence of *Schizorhiza* cf. *stromeri* (Klinck *et al.*, 1986, p. 51) indicates a mid-Campanian to Maastrichtian age for part of the Moho Group.

8.1.2. The Peruvian North West Altiplano (Nuñoa area). East of Cuzco, near the Nuñoa and Ocongate localities, continental red shales interbedded with dark-coloured marine marls and limestones (Hanchipacha Formation; Audebaud, 1967, 1973) have yielded charophytes, bivalves, ostracods and an aptychus, and are correlatable with the Vilquechico Group (Audebaud *et al.*, 1976). They are conformably overlain by a 1000 m thick series of purple shales and thin-bedded sandstones (Chilca Formation; Audebaud, 1973) containing charophyte oogonia of Palaeocene to early Eocene age (*Nitellopsis* (*Tectochara*) *supraplana*, Feist in Mourier *et al.*, 1988). The 15 m-thick series of purple shales overlying the Vilquechico Group in the Vilquechico section seems to be equivalent to the Chilca Formation. In the Nuñoa area, the latter is overlain by the coarser-grained sandstones and shales of the Muñani Formation (Audebaud, 1973; Audebaud *et al.*, 1976). The very reduced thickness of the Chilca Formation of the Vilquechico section suggests a sedimentary or erosional gap encompassing most of the Palaeocene.

8.1.3. The Rio Suches outcrops. In northwestern Bolivia, near Huarachani and close to the Peruvian border, an isolated outcrop of black shales yielded marine fish remains (*Brychaetus* sp.), a dyrosaurid crocodile (Argollo *et al.*, 1987), and the charophyte species *Feistiella gildemeisteri*, *Lamprothamnium* sp. and *Peckisphaera* sp. B (Feist & Grambast-Fessard, this work). Although a Palaeocene age had been proposed for these rocks (Argollo *et al.*, 1987), it must be emphasized that no marine deposits of this age are so far known in the Andean basins. Thus, as supported by the charophyte association, a correlation of the Rio Suches beds with the UVF is more probable. A convergent view is that of Gayet *et al.* (1991).

8.1.4. The Bolivian Andes (Potosí Basin, Figure 8: section 3). In Bolivia, Sempéré *et al.* (1988) recognized four main sedimentary sequences within the Late Cretaceous deposits (see also Jaillard & Sempéré, 1989). The first includes red shales and subordinate sandstones capped by Cenomanian and Turonian limestones (Miraflores Formation, Branisa *et al.*, 1966), and can be correlated with the Ayavacas Formation of the Peruvian Altiplano. The second comprises lacustrine, evaporite-bearing red shales (Aroifilla Formation), including local basaltic flows of Santonian age (85 ± 1 Ma, McBride *et al.*, 1983). Its stratigraphic position and depositional

environment can be tentatively correlated with unit "c" of the Moho Group, and with the LVF. The third sequence (Chaunaca Formation) begins with dark-coloured intertidal limestones which yielded a Santonian to early Campanian palynological assemblage (Pérez, 1987), and continues with continental red shales. Near the top, a limestone intercalation marks a second, minor transgressive stage. This sequence can be correlated with the MVF since it records the same sedimentary evolution.

The last transgressive–regressive sequence (El Molino Formation, Sempéré *et al.*, 1987; Sempéré, pers. comm. 1990) consists of three minor sedimentary successions regarded as members. The first comprises, from base to top: massive sandstones, oolitic limestones with marine fish, and marls, stromatolites and sandy deposits. The second begins with marine green marls and oolitic limestones, and ends with red shales and marls. The third member consists of green to dark marls and limestones. These sequences display a sedimentary evolution identical to that of the UVF. The El Molino Formation has an extended fossil record, including charophytes (*Feistiella gildemeisteri*, *Platychara grambastii*, *Amblyochara peruviana*: Grambast in Branisa *et al.*, 1969, revised by Feist & Grambast-Fessard, this work), molluscs (*Melania potoensis*), selachians (*Pucapristis branisi*, *Ischyrrhiza hartenbergeri*, *Schizorhiza* aff. *stromeri*, *Dasyatis branisai*, *D. schaefferi*, *D. molinoensis*, *D. sp.* 1, 2, 3, *Pucabatis hoffstetteri*, *Pucabatis* sp.: Cappetta, 1975; 1991), actinopterygians, and other fishes and lower vertebrates (among which *Coelodus toncoensis*, *Lepidotes* sp., *Lepisosteus* sp., *Gasteroclupea branisai*, *Enchodus* sp.,? *Apateodus*, *Molinichtys inopinatus*, *Hoplias* sp., *Roxochelys* cf. *vilavilensis*, *Crocodylia* indet., *Dyrosauridae* indet., *Coelurosauria* indet., *Sauropoda* indet., *Ornithopoda* indet., *Ligabueichnium bolivianum*: Gayet *et al.*, 1991; Leonardi, 1989). Several of these fossils (charophytes, some selachians and actinopterygians, dinosaurs) indicate a late Campanian to Maastrichtian age. Moreover, a palynological association from the second sequence of the El Molino Formation indicates a Maastrichtian age (Pérez in Sempéré *et al.*, 1987). However, as for the UVF, no typical Cretaceous fossils (sclerorhynchids or dinosaurs) are known so far in the third El Molino member (Gayet *et al.*, 1991). Because of its lithological features and sedimentary evolution, as well as its biostratigraphy, the El Molino Formation can be definitely considered as a lateral equivalent of the UVF, and the three members recognized in each formation seem to be exactly equivalent.

The El Molino Formation is conformably overlain by red-purple continental shales and sands of the thick Santa Lucia Formation of Palaeocene age (Sempéré, pers. comm.). According to sedimentological comparisons, the last 15 m of the Vilquechico section could represent a reduced, most probably eroded equivalent of the Santa Lucia Formation.

8.1.5. The Eastern Basin of Peru (Oriente, Figure 8: section 4). In the Oriente Basin of Peru, the lowermost continental red beds (Areniscas de Azúcar Group of Koch & Blissenbach, 1960, 1962) generally overly ammonite-bearing marine marls of Santonian age (upper Chonta Formation, Kummel, 1948; Seminario & Guizado, 1976). The section begins with a conspicuous 100 m-thick sandstone bed which has yielded Campanian palynomorphs (Vivian Formation, Seminario & Guizado, 1976). The overlying black shales and limestones contain brackish to marine foraminifera (Cachiyacu Formation, Seminario & Guizado, 1976) and is dated by Maastrichtian palynomorphs (Müller & Aliaga, 1981). The upper part of the series is composed of continental red shales (Huchpayacu Formation) locally grading into sandy shales (Casa Blanca Formation, Seminario & Guizado, 1976). In spite of the presence of

the Palaeocene spore species *Foveotrilites margaritae*, the latter unit contains a palynological assemblage which characterizes the Maastrichtian Stage (*Tricornites elongatus*, *Crassitricolporites brasiliensis*, *Buttinia andreevi* and *Aquilapollenites senegalensis*; Müller & Aliaga, 1981). The charophyte species *Feistiella gildemeisteri*, *Feistiella costata*, *Chara cylindrata* and *Tolypella biacuta* were reported from the Huchpayacu Formation (Koch & Blissenbach, 1962; Fyfe, 1963), and are regarded as Maastrichtian in age (Guttierrez, 1982). According to its sedimentological and lithological features as well as to its charophyte record, this formation correlates well with the UVF.

The Areniscas de Azúcar Group is overlain by the Yahuarango Formation, the lower part of which still contains the species *Feistiella costata*, together with some *Sphaerochara* species. It is ascribed to the early Palaeocene on the basis of the palynological data (Müller & Aliaga, 1981; Guttierrez, 1982). Its upper part contains a charophyte association among which *Nitellopsis* (= *Tectochara*) *supraplana* provides a good early Tertiary marker (Koch & Blissenbach, 1962; Fyfe, 1963; Feist in Mourier *et al.*, 1988; Feist *et al.*, 1989).

8.1.6. *The Eastern Basin of Ecuador* (Oriente, Figure 8: section 5). In this area, ammonite-bearing marine marls of Santonian age are overlain by sandstones, marine shales and limestones and then continental red shales (Tena Formation, Tschopp, 1953; Bristow & Hoffstetter, 1977). The lithological succession is similar to that of the Areniscas de Azúcar Group and of the UVF. The Tena Formation contains Maastrichtian marine foraminifera (*Globotruncana* cf. *lapparenti* and *Siphogenerinoides* aff. *cretacea*, determined by J. Sigal in Bristow & Hoffstetter, 1977); undetermined fish teeth, and Late Cretaceous charophytes (*Feistiella* cf. *costata*, *Amblyochara* cf. *peruviana* and *Rhabdochara* sp.; Bristow & Hoffstetter, 1977).

The charophyte association is not comparable with those of the Vilquechico Group, but it has affinities with that of the Fundo el Triunfo Formation of the Bagua area of northern Peru (see below), thus suggesting changes related to the latitude and/or climate. However, the Tena Formation seems to be lithologically and sedimentologically equivalent to the UVF.

8.2. Correlations with the western domains

8.2.1. *The Southern Altiplano of Peru* (Puno area, Figure 8: section 6). A few kilometres northwest of Puno, on the north side of Laguna Umayo (= Sillustani locality of Grambast *et al.*, 1967), red shales and marls with sandy and thin microconglomeratic intercalations have yielded various continental vertebrate remains, among which mammals and dinosaurs are documented by teeth and eggshell material respectively (Thaler in Grambast *et al.*, 1967; Sigé, 1968, 1971, 1972; Kerourio & Sigé, 1984). No marine molluscs or selachians were found there. The charophyte species associated with the vertebrates (same locality and layer) are *Feistiella gildemeisteri*, *forma minor*, and *Amblyochara peruviana* (Feist & Grambast-Fessard, this paper). On the charophyte evidence, the Laguna Umayo fossiliferous beds were dated as Late Cretaceous, and correlated with the Vilquechico Group (the type locality of which lies about 75 km NE). More recently, an early Tertiary age of the Laguna Umayo vertebrate-bearing beds was alleged on indirect mammalian evidence (Van Valen, 1988). In order to avoid further confusion, the proper name Umayo Formation is given to the fossiliferous unit of Laguna Umayo locality (Laubacher & Marocco, 1990). The Umayo Formation can be

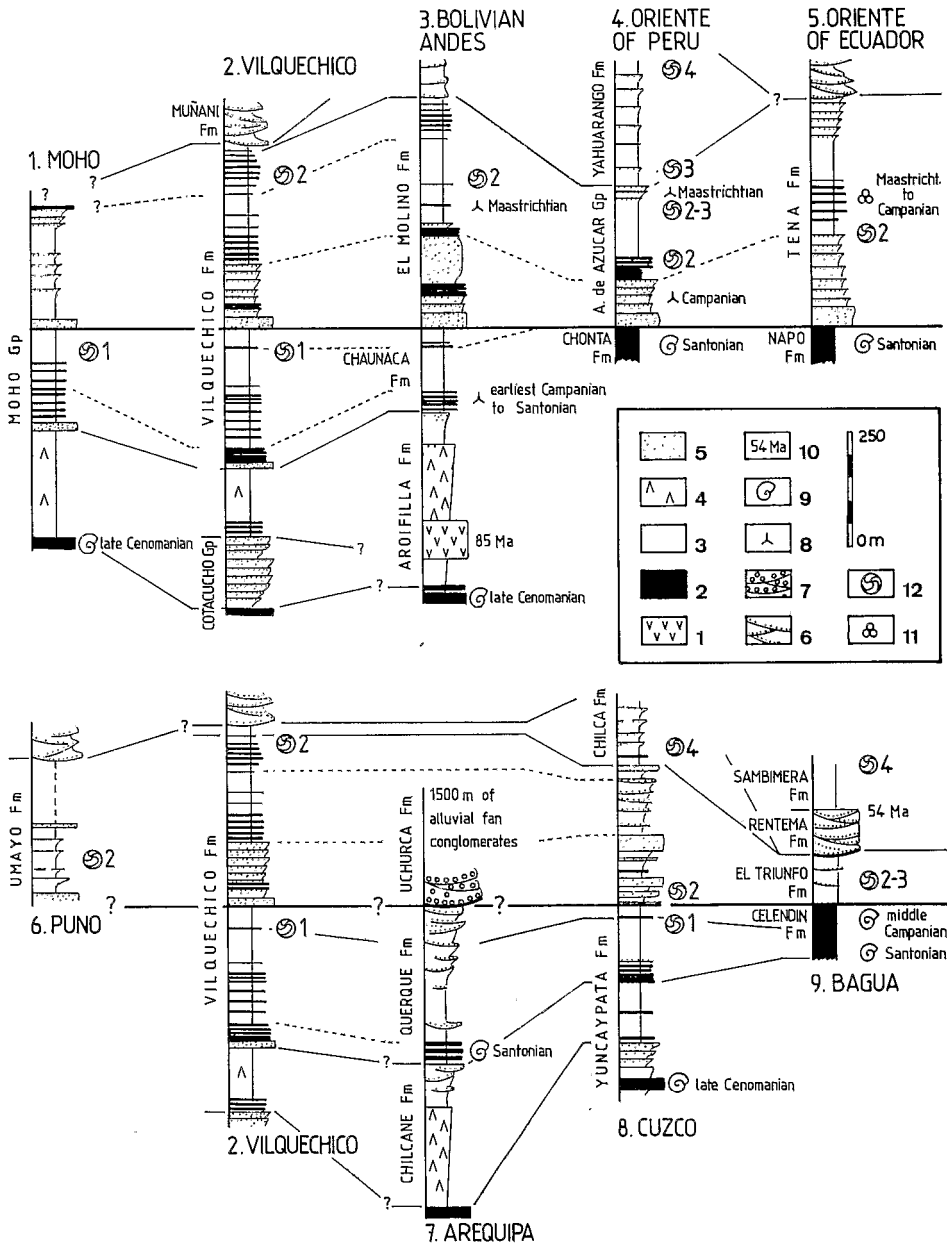


Figure 8. Comparisons and proposed correlations of some Late Cretaceous successions in the Central Andes. *Lithology*: 1, volcanic flows; 2, marls and limestones; 3, shales; 4, evaporites; 5, sandstones; 6, cross-bedding; 7, conglomerates; *Stratigraphy*: 8, palynological data; 9, charophytes; 10, ammonites; 11, radiometric data; 12, foraminifers.

correlated with the Vilquechico Group according to their revised charophyte assemblages. A closer correlation may be with the Upper Vilquechico Formation.

8.2.2. *The Arequipa area* (Figure 8: section 7). In the Arequipa area, the Turonian limestones of the Arcurquina Formation (Benavides, 1962) are overlain by three

shales (Chilcane Formation) that grade upwards into fluvial shales and sandstones. It has been correlated with the Bolivian Aroifilla Formation (Jaillard & Sempéré, 1989). The second sequence (Querque Formation or Omoye Formation) begins with shallow marine limestones dated by the Santonian ammonite *Tissotia steinmanni* (Hosttas, 1967; Vicente, 1981). It ends with a coarsening-upward series of lacustrine marls followed by fluvial sandstones. This transgressive–regressive sequence can be tentatively correlated with the MVF. The third sequence consists of undated, coarse-grained, alluvial fan conglomerates which disconformably overlie the Querque Formation, and express the beginning of the Andean tectonic deformations in this area. Although no palaeontological evidence can support this assumption, such a tectonic event might have been recorded by the sandy base of the UVF.

8.2.3. *The Cuzco area* (Figure 8: section 8). In the Cuzco area, Cenomanian limestones (lower part of the Yuncaypata Formation; Kalafatovich, 1957) are capped by red shales of unknown age which could correlate with the first minor sequence of the MVF. The middle minor sequence of the MVF would then be represented by green shales and black limestones, overlain by evaporite-bearing red shales. At the top, black shales yielded charophyte specimens determined as *Platychara perlata* and *Feistiella ovalis* (Kalafatovich, 1957; Carlotto *et al.*, 1990), thus indicating a correlation with the upper member of the MVF. The overlying sandstones yielded *Feistiella gildemeisteri* and *Platychara grambastii* (collected by G. Carlier, Feist & Grambast-Fessard, this work), that suggest a correlation with the third member of the UVF. The overlying red shales and fine-grained conglomerates are currently the subject of further study.

Further south, there is a 4500 m-thick series of coarse-grained, fluvial red beds which was deposited during part of the late Senonian period (Córdova, 1986; Noblet *et al.*, 1987; López & Córdova, 1988): they contain dinosaurian footprints 4000 metres above the base (*vide* Ellenberger, this paper). The detrital sedimentation of the lower member of the UVF is probably related to the tectonic development of such a subsident basin.

8.2.4. *The North-Peruvian Andes* (Bagua area, Figure 8: section 9). The Bagua area is the only known Andean locality where marine, ammonite-bearing mid-Campanian beds (Bengtson, *in* Mourier *et al.*, 1988) overlie the marine marls of early Santonian age (Benavides, 1956). From the mid-Campanian marine beds, selachian remains previously referred to as Neoselachian *incertae sedis* (Cappetta *in* Mourier *et al.*, 1988) are now identified as *Schizorhiza stromeri* (Cappetta, this work); this suggests a correlation with the upper part of the MVF.

Red beds (Fundo el Triunfo Formation) overlie the mid-Campanian marine shales and marls. These have yielded the charophytes *Amblyochara peruviana*, *A. begudiana* and *Feistiella costata*, dinosaurian bones, and selachian teeth (*Pucabatis* cf. *hoffstetteri*, Triakidae and Sclerorhynchidae), which together indicate a late Campanian to Maastrichtian age (Mourier *et al.*, 1988). The Fundo el Triunfo Formation thus would be equivalent to part of the UVF.

It is disconformably overlain by fluvial conglomeratic sandstones associated with volcanic ashes dated as 54 Ma (*c.* Palaeocene-Eocene boundary, Naeser *et al.*, 1991), and then by lacustrine deposits which have yielded *Nitellopsis supraplana*, *Maecleriella* sp. and *Chara strobilocarpa* of Eocene age (Feist *in* Mourier *et al.*, 1988).

8.2.5. *The Andes of Central Peru*. In Central Peru, the Santonian marine Celendín Formation is overlain by thick red beds which have yielded *Porochara* sp., *Feistiella*

cf. *gildemeisteri*, *Amblyochara* sp., *A. rolli*, *Saportanella* gr. *maslovi* (Grambast in Mégard, 1978). Although no correlations can be made because of the lack of detailed sedimentological studies, a Late Cretaceous age for part of these red beds is suggested by the charophyte association and local occurrence of probable Late Cretaceous foraminifera (Mabire, 1961).

9. General stratigraphic framework (E. Jaillard)

If the proposed correlations are accepted, they define, as a working hypothesis, a coherent stratigraphical and sequential framework (Figure 9), based on the stratigraphic data from various Andean stratigraphic sections (Figure 8).

9.1. The Lower Vilquechico Formation (LVF)

The base of the LVF marks the beginning of red bed sedimentation in the Altiplano area. In the southern Central Andes, this usually occurs near the Turonian–Coniacian boundary (Jaillard & Sempéré, 1989). However, in most areas, the presumed Coniacian red beds overlie Turonian shelf limestones, whereas at Vilquechico, the LVF is underlain by the undated sandy unit of the upper Cotacucho Group. This sandy unit can represent either an equivalent of the widespread Turonian carbonate shelf, or an equivalent of the sandy base of the Aroifilla Formation of Bolivia (Sempéré *et al.*, 1988). In any case, the existence of a possible fault at the very base of the LVF makes any precise determination difficult. Since this sequence comprises Santonian basaltic flows in Bolivia, the LVF can be tentatively ascribed to the Coniacian–early Santonian time-span.

9.2. The Middle Vilquechico Formation (MVF)

The marine limestones of the lower part of the MVF is of Santonian age according to the palynological data from Bolivia, and the ammonite from the Arequipa region. Furthermore, such a well-defined marine transgression might be represented by the early (?) Santonian open marine marls and limestones of the Celendín, upper Chonta and upper Napo Formations of central and northern Peru, and of Ecuador.

The second marine transgression of the MVF (base of the second minor sequence) seems also to be a widespread event, since it is known throughout the Bolivian Altiplano (upper Chaunaca Formation) and in the Cuzco area. We propose that it could correlate with the ammonite-bearing mid-Campanian marine horizon of the uppermost Celendín Formation of the Bagua area, since both layers contain comparable selachian species. If correct, the MVF would be of early Santonian to middle or late Campanian age.

9.3. The Upper Vilquechico Formation (UVF)

The basal discontinuity of the UVF can be considered as close to the Campanian–Maastrichtian boundary, since it overlies the middle Campanian marine transgression, and underlies the Maastrichtian marine levels of the El Molino Formation of Bolivia and the Cachiyacu Formation of the Peruvian Oriente. The first member of the UVF probably contains the Campanian–Maastrichtian boundary. However, a late Campanian age for the whole first member of the UVF cannot be ruled out (Guttierrez, 1982). The second member and its equivalent of the El Molino Formation contain dinosaur tracks and sclerorhynchid selachians that indicate a Maastrichtian age. This is supported by the palynomorph composition of the

	ALTIPLANO	
	SOUTHERN	NORTHERN
EOCENE	?	
PALEOCENE	?	
MAASTRICHTIAN	UMAYO	3° Seq
	M j to g	Upper 2° Seq
—?—	VILQUECHICO	1° Seq
CAMPANIAN		Middle 2° Seq
SANTONIAN		1° Seq
CONIACIAN	O f to d	Lower
TURONIAN	G b	COTACUCHO Gp
	P a	
		AYAVACAS

Figure 9. Proposed stratigraphic framework for the Altiplano of southern Peru; cf. Figure 2.

Cachiyacu Formation of the Peruvian Oriente (Müller & Aliaga, 1981). The third member of the UVF and of the El Molino Formation did not yield unequivocally Cretaceous fossils. However, the charophyte assemblage and *Dasyatis* sp. 3, as well as the palynological data from the equivalent Huchpayacu and Casa Blanca Formations of the Peruvian Oriente strongly support a late Maastrichtian age. The UVF can therefore be ascribed to the latest Campanian–late Maastrichtian interval.

A Palaeocene age is probable for the uppermost 15 m of the Vilquechico section, which on sedimentological grounds seems to be equivalent to the Palaeocene Santa Lucia Formation of Bolivia, and to the Chilca Formation of the Nuñoa area, east of Cuzco.

10. Palaeontological discussion (B. Sigé)

Some of the Laguna Umayo mammals have provoked stratigraphical objections to a Cretaceous age for the Vilquechico Group which require a more explicit discussion. *Perutherium altiplanense* Thaler, 1967 has been considered as too advanced an ungulate in regard to a Late Cretaceous age (e.g. Bonaparte, 1990). This progressive stage of *Perutherium* is conceived relative to the evolutionary gradation of the ungulates in the early Tertiary of North America. Clearly this cannot be regarded as a universal standard (Marshall, 1989), unless any effect of endemic evolution in an isolated continent is devised. *Perutherium* has been interpreted as a primitive notoungulate (Marshall *et al.*, 1983b), and accepted as such by Sloan (1987: 183) and Van Valen (1988). The occurrence of notoungulates in the North American and Asian Palaeocene is too restricted to provide any Laurasian evolutionary standard. *Perutherium* seems to be older than the already much

diversified middle Palaeocene notoungulates from Brazil, Argentina and Bolivia. The occurrence of the small marsupial *Peradectes austrinum* (Sigé, 1971), described from Laguna Umayo, is alleged at Tiupampa on the basis of a single upper molar (Marshall & de Muizon, 1988). This specimen, although seemingly congeneric, does not support the specific identity because some of the characters (larger size, ectoflexus and styler cusp C less marked for a M3 or 4/, centrocrista more rectodont than predilambodont) are inappropriate, a view shared by de Muizon (1991). It is not, therefore, of value for correlation. An ancestral position for *P. austrinum* with respect to the Tiupampa species seems more probable, hence favouring an older age for the Peruvian species.

The mammalian fauna of the presumed Campanian Los Alamos Formation of Northern Patagonia (Bonaparte, 1990) is regarded as evidence to update the first known South American faunas with marsupials and placentals. This is based on their mutually exclusive composition at a high taxonomic (ordinal) level. The diversified Los Alamos fauna completely lacks tribosphenic forms, whereas younger faunas lack non-tribosphenic groups (except xenarthran, which could have their origin within the gondwanatherians; Bonaparte, 1990). On the one hand, the age of the Los Alamos Formation is not constrained by that of the underlying formations, and so it could be somewhat older than currently presumed. On the other, the chronological gap between a presumed Campanian fauna and a presumed Maastrichtian fauna could be 10 Ma or even more. This seems to be quite enough time to enable a drastic turnover and subsequent endemic evolution of the mammalian fauna to take place. Such a major change seems, in any case, to have occurred on this continent! Moreover, the difference in latitude between Patagonia and southern Peru should not be overlooked, since the southern Los Alamos mammals could represent a geographically restricted assemblage, with forms derived from a Mesozoic gondwanan fauna.

Finally, it is worth noting that in Laguna Umayo the fossil-bearing level so far studied (LU 3) belongs to the lower part of the local section (Sigé, 1972). It is overlain by nearly 300 m of red clays with thin sandstone and tuff intercalations that are apparently conformably capped by black and grey andesitic pyroclastic breccias and tuffs which crop out in the isthmus of the Sillustani peninsula. Another vertebrate (including mammals)-bearing level, lithologically similar to LU 3, and situated about 250 m above, has been recognized and distinguished under the name Chulpas. Its fauna is currently being studied, but it has not yet provided any biostratigraphically conclusive data (Crochet & Sigé, 1993). Therefore the age of the red clay overlying the LU 3 level of the Laguna Umayo section cannot be precisely stated, and a partial extension in the Palaeocene cannot be ruled out.

11. Conclusions

The Vilquechico Group can be divided into three major sedimentary sequences, which constitute lithological formations named as the Lower, Middle, and Upper Vilquechico Formations (LVF, MVF, UVF) respectively. Some of these sequences can be subdivided into minor sequences. The sequences seem to be identifiable throughout most of the eastern areas of the Central Andes. The Vilquechico Group contains numerous fossils such as dinosaurs, fishes, molluscs, ostracods and charophytes. Both palaeontological and sedimentological data permit regional stratigraphic correlations that lead to a revised, although still hypothetical, stratigraphical framework for the Late Cretaceous Andean formations.

The undated LVF can be tentatively ascribed to the Coniacian–early Santonian interval. The MVF is considered to represent sedimentation that began in the early Santonian, and continued through most of the Campanian. Finally, the UVF might encompass latest Campanian times but is mostly of Maastrichtian age.

Two charophyte associations representing biozones can be defined. On present evidence they are probably middle Campanian and late Campanian–Maastrichtian in age respectively.

The Vilquechico Group, which has long been considered to be restricted in age to late Campanian–Maastrichtian, in fact most probably comprises Coniacian to middle Campanian beds. Therefore, as shown by Audebaud *et al.* (1976), it constitutes a partial lateral equivalent of the Moho Group of the Peruvian Altiplano, since the latter overlies Cenomanian or Turonian limestones and has yielded charophytes (Newell, 1949) and selachians (Klinck *et al.*, 1986), both of mid-Campanian to Maastrichtian age (this work). The hypothesis of the stratigraphic superposition of the Vilquechico Group upon the Moho Group (Newell, 1949; Ellison, 1985; Palacios & Ellison, 1986; Klinck *et al.*, 1986) must definitely be rejected.

The Umayo Formation of the outskirts of Puno can be considered as a partial lateral equivalent of the UVF, as suggested by the dinosaurian eggshells and the charophytes.

The third major sedimentary sequence of the Vilquechico Group (UVF) correlates exactly with both the El Molino Formation of Bolivia, and the Areniscas de Azucar and Tena Formations of the Peruvian and Ecuadorian Oriente. This reflects both a widespread marine transgression and a very uniform and stable eastern sedimentary domain. A significant tectonic event is recorded by the Vilquechico Group at the base of the UVF. It seems to be roughly synchronous with the creation of the Cuzco-Sicuani red bed basin, and with the fanglomerate deposits of the Arequipa area (Uchurca Formation). Its age can thus be considered to be close to the Campanian–Maastrichtian boundary.

A Palaeocene sedimentary or erosional gap is suggested by the sharp contact between the Eocene Muñani Formation and the very thin red shales correlated with the Palaeocene Chilca Formation.

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