CRETACEOUS SEQUENCE STRATIGRAPHY OF PERU AND BOLIVIA

Etienne JAILLARD, Institut Français d' Etudes Andines, Casilla 18-1217, Lima 18, PERU.
Present address:Institut Dolomieu, 15 rue Maurice-Gignoux, 38031 Grenoble Cedex, FRANCE.
Thierry SEMPERE, ORSTOM-YPFB,CC 4875, Santa Cruz, BOLIVIA.

Abstract : The "Cretaceous" (in fact Latest Jurassic - Paleocene) history of the Peru - Bolivia Andes has developed in an active margin setting for about 90 Ma. An evolving variegated paleogeography, including marginal basin, external back-arc and fractured cratonic areas, can be reconstructed. In Peru, sedimentation was grossly characterized by mainly deltaic siliciclastic deposits during the Latest Jurassic - Early Aptian interval, carbonate shelves till Campanian times, and continental red beds later on. Only Cenomanian and Santonian marine transgressions reached the Bolivian territory, where continental facies had deposited since Latest Jurassic times, till a major transgression covered it during the Late Campanian - Early Paleocene interval.

Numerous sedimentary discontinuities are observed and paleontologically dated, but only a few of them extend throughout the study area, impeding the definition of a unique sequence stratigraphy for all regions. However, an eastward and southeastward "migration" of discontinuities through time is evidenced, and this enlightens the intimate conjugation of eustatic and tectonic processes in the Cretaceous evolution of the Peru - Bolivia Andes.

I. INTRODUCTION

During Cretaceous times, the central Andes were submitted to the subduction of the oceanic Phoenix plate beneath the western edge of the South American continental plate (James, 1971; Audebaud et al., 1973; Mégard, 1984, 1987). Since Late Cretaceous times, the South American western margin has undergone important deformations. The complex Andean mountain belt edificated mostly during Cenozoic times. Though the structure of the Andes of Peru and Bolivia is still poorly understood, two major structural belts can be distinguished (Sempere et al., 1989), which roughly correspond to distinctive paleogeographic domains.

The western domain is restricted to western Peru and comprises from W to E: (a) a coastal zone within which intracontinental marginal basins and subsequent post-Albian continental magmatic arcs developed; (b) a westward-sloping marine shelf (West Peruvian Shelf = WPS) which was bounded eastwards by highs with reduced sedimentation (Marañón and Santa Lucía swells). In northwesternmost Peru, the Lancones and Talara basins individualized in Albian and Campanian times respectively.

The eastern domain includes from W to E: (a) the Peruvian Altiplano and the Bolivian Andes; (b) the Ecuadorian-Peruvian eastern basin (Oriente); and (c) the mostly emerged Precambrian Guianese and Brazilian shields.

Though the Cretaceous stratigraphy of the central Andes is still only approximately known, stratigraphic syntheses have been attempted by Myers (1974, 1980), Rivera et al. (1975) and Guevara (1980) for the coastal zone; by Benavides (1956), Wilson (1963), Mégard (1978), Vicente (1981) and Jaillard (1987) for the WPS; by Newell (1949), Audebaud et al. (1976) and Laubacher and Marocco (1989) for the Peruvian Altiplano; Kummel (1948), Tschopp (1953), Koch and Blissenbach (1960), Reyes (1972), Cherroni (1977) and Sempere et al. (1987, 1988) have dealt with the Oriente and Bolivia. In the Peruvian Altiplano, Klinck et al. (1986) proposed new stratigraphic interpretations that have not been confirmed by our field work, and will not been taken into account in this paper.

This paper is a preliminary attempt to synthetize the present knowledge concerning the age and nature of the major discontinuities recognized in the central Andes, in order to precise the sequence stratigraphy proposed by Jaillard (1987, 1989), Sempere et al. (1987, 1988), Macellari (1988) and Marocco (1989). Concluding remarks shortly deal with some tectonic and geodynamic interpretations, which will be developed in a forthcoming work.

Synthetized stratigraphic data for each megasequence are presented in appendix, together with additional references. In order to be as objective as possible, we have included in these tables all the paleontological determinations reported from the stratigraphic units, without discussing them. Thus local contradictions may appear, illustrating the difficulties met in establishing such a stratigraphic framework. However, revisions of Latest Cretaceous-Earliest Tertiary stratigraphy are still under way (e.g. Sempere et al., 1987; Mourier et al., 1988; Feist et al., 1989), and new data will be presented in forthcoming papers (Sempere, 1989; Jaillard et al., in progress).

II. METHODS AND NOMENCLATURE

In this paper, we use sedimentary discontinuity surfaces as base tools to define sedimentary events that we arbitrarily admit to be "instantaneous" and synchronous in first approximation, though possible cases of diachronism and sedimentary gap will be discussed too.

Each discontinuity is referred to by the letter "k" followed by a one-digit (major discontinuities) or two-digit (discontinuity of lesser importance) number. Five major discontinuity surfaces are thus termed k 0, k 1 (= k 10), k 2 (= k 20), k 4 (= k 40) and k 5 (= k 50). The Middle to Late Cenomanian period (k 3 epoch) comprises three important discontinuities which closely succeed in time, and are termed k 3A, k 3B and k 3C (= k 30). k0 and k5 actually bound the "Cretaceous" supersequence.

Minor intercalated discontinuities are identified by an additional digit (for example, k 21 and k 22 intercalate between k 2 and k 3A).

We call "sequence" a sedimentary unit limited by two discontinuities, which will be identified by the letter "K" followed by the index numbers of the two bounding discontinuities (for instance, K 1-2 is the megasequence bounded by k 1 and k 2; K 21-22 is the sequence defined by k 21 and k 22).

A discontinuity defined in a particular locality is not usually recognized in all the study area (i.e. Peru and Bolivia) but only over a domain that we term "influence area" of the discontinuity. For instance, in part of the Potosí basin (Bolivia), the sedimentary succession between k 0 and k 3B is apparently continuous, and this region therefore does not belong to the influence area of k 1, k 2 and k 3A.

In this paper we use the time-scale of Haq et al. (1987). We use the following conventions: Gp = Group; Fm = Formation; Mb = Member.

III. AGE AND NATURE OF THE DISCONTINUITIES AND SEQUENCES.

<u>III.1. The K 0-1 Sequence</u> (Kimmeridgian ? - Latest Berriasian).

Because of the scarcity of the outcrops, the presence of tectonic décollements and the difficult diagnosis of the fauna, the age of this sequence is still poorly constrained, and stratigraphic data will be exposed with some details before discussing possible correlations. The k0 surface has been defined by Sempere et al. (1988) in Bolivia, where coarse, often conglomeratic deposits (Condo Fm) unconformably overlie Paleozoic or Mesozoic rocks. This sharp unconformity has been related by these authors to the Kimmeridgian "Araucan" tectonic event of Chile and Argentina (Stipanicic and Rodrigo, 1969), because of its association with numerous tensional features (see also Martinez and Vargas, 1988). The basal conglomerates vertically and laterally pass to alluvial sandstones and red beds, paleogeographically controlled by tensional structures.

In the Peruvian Altiplano, similar conglomerates of alluvial-fan origin (Chupa Fm, Ellison, 1985; Klinck et al., 1986) are overlain by shallow marine to lagoonal carbonate deposits (Sipin Fm), followed by intertidal red shales and sandstones (Muni Fm) of Late Jurassic to Early Cretaceous age (Newell, 1949). These three units are affected by tensional synsedimentary tectonics, which obscure their stratigraphic relationships.

In the southern WPS, shallow marine clastics (Labra Fm, Benavides, 1962; Vicente et al., 1982) sharply overlie Callovian to Early Oxfordian black shales (Vicente, 1985), with local disconformity (Yanca Fm of Olchauski, 1980), and grade upward into Early Tithonian lagoon-barrier deposits (Gramadal Fm, Chavez, 1982; Batty and Jaillard, 1989). The latter usually disconformably underlie the k 1 discontinuity. Nevertheless, Late Tithonian black shales and sands are locally known (Tiabaya outcrops, Geyer, 1983).

In the central WPS and in the coastal area, similar Early Tithonian carbonate deposits are known (Jaguay Fm, Ruegg, 1961; Caldas, 1979), and Berriasian black shales underlie the k 1 discontinuity (Bellido, 1956; Puente Piedra Fm, Rivera et al., 1975; Wiedmann, 1981). In the Lima area, the Latest Berriasian black shales postdate the functioning of a marginal basin (Atherton et al., 1985).

In the northern WPS, lagoonal deposits of probable Early Tithonian age (Simbal Fm, Jaillard and Jacay, 1989) are sharply overlain by a thick aggradational sequence including proximal turbidites, slope deposits, and basinal black shales of Late Tithonian and Berriasian age (part of the Chicama Gp, Wiedmann, 1981; Geyer, 1983; Jaillard and Jacay, 1989). Another discontinuity precedes the deposition of a fining-upward deltaic sequence (Tinajones Fm), partly eroded beneath k 1.

In summary k 0 can be tentatively correlated with the basal contact of the Labra Fm (Kimmeridgian ?), but it is still unknown farther North. k 01 is defined as the basal contact of the Chicama turbidites of earliest Late Tithonian age. It could be responsible for the sedimentary gap (Late Tithonian-Berriasian) in the southern WPS (Batty and Jaillard, 1989). The base of the Tinajones Fm of the northern WPS, of (Early ?) Berriasian age represents k 02, which is unknown farther south.

<u>III.2. The K 1-2 Sequence</u> (Earliest Valanginian - Late Aptian).

The Neocomian clastics (Goyllarisquizga Gp, Huancané Fm, Lower Cotacucho Gp, Cushabatay Fm) often disconformably overlie Berriasian, Jurassic or Paleozoic rocks (Mégard, 1978), thus defining the k 1 disconformity.

In the WPS, k 1 overlies beds of Latest Berriasian age (Wiedmann, 1981). On the other hand, it is postdated by an Early to Middle Valanginian fauna, found less than 100 m above (Herradura Fm of the Lima area, Fernández, 1958; Rivera et al., 1975; Wiedmann, 1981). Thus, in the Lima area, k 1 can be considered as Earliest Valanginian in age. This east-proceeding detritics may have deposited somewhat earlier in the eastern areas, but the geographic extension of the phenomenon suggests that the diachronism, if present, is minor.

Two transgressive stages are later recorded, in Early to Middle Valanginian times (Herradura Fm) and in Late Valanginian to Earliest Hauterivian times (Lower Pamplona Fm, Rivera et al., 1975; Santa Fm, Benavides, 1956). Till Aptian times, the clastic sedimentation went on in the WPS, and recorded various eustatic sequences of unknown age (Moulin and Séguret, 1989; Batty and Jaillard, 1989), while a carbonate shelf developed in the coastal area (Pamplona and Atocongo Fms, Rivera et al., 1975; Ostermann et al., 1982).

In the eastern domain, the whole pre-Albian Cretaceous period is represented by a thick detrital series. In the Oriente, k 1 is a large-scale disconformity recognized in field and subsurface studies (Kummel, 1948; Tschopp, 1953; Rodriguez and Chalco, 1975; Laurent, 1985).

In Bolivia, k 1 is only known in the southwestern part of the Potosî basin, where fluvial to upper delta sandstones ("P 12" sequence of Sempere et al., 1988) sharply overlie alluvial plain red beds (Kosmina Fm). Elsewhere, red alluvial sedimentation went on without clear discontinuities. Synsedimentary tensional tectonics progressively produced a deep change in the basin structure, and led to the individualization of a lacustrine graben in the northeastern part of the Potosî basin (Tawarreja-Thokori graben), where deposition went on continuously till discontinuity k 3B.

III.3. The K 2-3 Sequence (Late Aptian - Early Cenomanian).

The base of the third megasequence is marked by a major transgressive discontinuity (k 2), which is postdated by Late Aptian fauna, and led to the rapid waning of the detrital supply.

In northern and central Western Peru, K 1-2 is overlain by shallow marine terrigenous sediments (Huamancay Fm, Myers, 1980; Chilca and Chancay Fm, Rivera et al., 1975; Inca and Pariahuanca Fm, Benavides, 1956; Wilson, 1963; Moulin, thesis in progress). In the southern WPS, azoic continental to lagoonal red beds abruptly overlie the Early Cretaceous sandstones (Mara Fm, Pecho, 1981; Huambo Fm of Batty and Jaillard, 1989). A few tectonic features suggest a weak tectonic instability (Jaillard, 1987).

In the eastern domain, k 2 has not been identified.

In the whole WPS, k 21 marks the beginning of an open marine sedimentation of well-documented Early to Middle Albian age (K 21-22 sequence: Chulec and Pariatambo Fms, base of the Ferrobamba and Arcurquina Fms). It also underlies the transgression of the Pananga and Muerto Fms of the Lancones basin (Fisher, 1956; Zuñiga and Cruzado, 1979; Reyes and Caldas, 1987). As it is pre- and postdated by Early Albian fauna, k 21 is of Early Albian age.

In the coastal area, k 21 roughly coincides with the beginning of a major effusive episode, which is interpreted as the opening of an intracontinental marginal basin (Atherton et al., 1983) (Casma Gp, Myers, 1974; Guevara, 1980; Ostermann et al., 1982; Copara Fm, Caldas, 1979). Coeval volcanics are also known in the southern WPS (Matalaque Fm, Marocco and Del Pino, 1966; Batty and Jaillard, 1989), and in the Lancones basin (Reyes and Caldas, 1987). The volcanics locally directly overlie the K 1-2 sequence, thus indicating either local diachronism or erosional processes (Batty and Jaillard, 1989).

In the northern and western parts of the eastern domain, the K 21-22 transgression is attested by Albian ammonites (Raya Fm, Kummel, 1948; Lower Napo Fm, Tschopp, 1953; Lower

Moho Gp, Lisson, 1924; Cabrera and Petersen, 1936; Lower Chonta Fm, Zegarra, 1964; Davila and Ponce de León, 1971), while continental detrital sedimentation went on in its eastern and southern parts (part of Cotacucho Gp, Laubacher and Marocco, 1989; Kosmina and/or Tarapaya Fms, Sempere et al., 1988).

In many places of the WPS, the K 21-22 sequence ends up with intertidal to continental facies (top of the Pariatambo and Muerto Fms, Mégard, 1968; Séranne, 1987; Jaillard, 1989; Moulin, thesis in progress), which are sharply overlain (k 22) by marine marls and limestones (K 22-3A). The top of K 21-22 is of well-established mid-Albian age (Benavides, 1956; Jaillard, 1987), but can locally reach Late Albian times, since some Mortoniceras species have been reported (Mégard, 1968; Janjou, 1981). On the other hand, K 22-3A is of Late Albian and Early Cenomanian age (Yamagual Fm, Benavides, 1956; base of the Jumasha Fm, Wilson, 1963; Jaillard, 1986; first Ayavacas limestone member, Cabrera and Petersen, 1936), and k 22 thus can be ascribed to earliest Late Albian times.

In the whole WPS, and as far as the western Peruvian Altiplano, K 22-3A is a shallowing-upward sequence, which is locally capped by regressive, deltaic sandstones and bears clear evidences of strong coeval tectonics (Audebaud, 1971; Jaillard, 1987, 1989). In the coastal area, volcanic effusions went on in the marginal trough, but compressive deformation began during Late Albian times (Cobbing et al., 1981; Bussel, 1983; Mégard, 1984, 1987).

The tectonic activity recorded in the upper part of K 22-3A is interpreted as the result of the closure of the coastal marginal basin, which was achieved at the Early-Middle Cenomanian boundary (Jaillard, 1987). Then, the coastal area possibly remained emerged and an active magmatic arc developed (Coastal Batholith, Cobbing et al., 1981; Beckinsale et al., 1985; Soler and Bonhomme, 1989).

In the Oriente this time span seems to be represented by two lower part of the regressive deltaic Agua Caliente Fm (Soto, 1979; Jaillard, 1987). In the eastern Peruvian Altiplano, clastic sedimentation went on (part of the Cotacucho Gp).

In Bolivia, the base of the Tarapaya Fm (pelitic red beds) may rest upon different Paleozoic and Mesozoic units, and locally even pass transitionally to the underlying Kosmina Fm (e.g. in the Tawarreja-Thokori graben). It is clearly diachronous, and cannot be correlated with the discontinuities characterized above, though it is posterior to the K 1-2 sequence.

III.4. The K 3A-3C hinge-period (Middle and Late Cenomanian).

In the whole Peru, this time span separates the Albian transgression from the Turonian one, while a major transgression is recorded in the southeastern domain.

In the WPS, k 3A separates the regressive top of K 22-23, from the transgressive base of the shallowing-upward carbonate shelf K 3A-3B sequence, of mid-Cenomanian age (Mujarrún Fm, Benavides, 1956; Jaillard, 1987; parts of the Jumasha, Arcurquina and Ferrobamba Fms). It seems that this new transgression deposited a second Ayavacas limestone member on the western Peruvian Altiplano.

In the Lancones basin, k3A seems to correspond to the end of the volcanic outflows (Reyes and Caldas, 1987), and with the beginning of thick turbiditic deposition (Copa Sombrero Fm, Morris and Aleman, 1975). Nevertheless, in its western part (part of the Talara basin), the carbonate sedimentation went on till (Late ?) Cenomanian times (Muerto Fm, Zuñiga and Cruzado, 1979).

In the Oriente, the deltaic sedimentation continued (upper parts of the lower Napo and Agua Caliente Fms). In Bolivia, the non-marine red beds of the Tarapaya Fm underlie the K 3B-3C sequence with a discontinuity so slight that no chronological gap can be inferred from this surface. Therefore, the top of the Tarapaya Fm is considered as Mid-Cenomanian in age, and no correlations can be established with k 3A.

In the WPS, k 3B records a first major transgression, expressed by the overlying open marine marls of late Middle Cenomanian, and Late Cenomanian age (Romirón Fm, Benavides, 1956; Jaillard, 1987; parts of the Jumasha and Ferrobamba Fms, Hillebrandt, 1970; Jaillard, 1986).

In the Oriente, the Huaya Mb (top of the Agua Caliente Fm) of supposed Cenomanian age (Kummel, 1948) may represent the k 3B transgression.

In southern Peru and Bolivia, <u>Neolobites</u> specimens characterize altogether the K 3B-3C sequence of the Arcurquina Fm of the Arequipa region (Benavides, 1962), the Yuncaypata Fm of the Cuzco area (Kalafatovitch, 1957), the probably third member of the Ayavacas limestones of the Peruvian Altiplano (Lisson, 1924; Cabrera and Petersen, 1936), and the Miraflores Fm of Bolivia (Branisa et al., 1966; Branisa, 1968). Therefore, the Late Cenomanian carbonate shelf sequence seems to represent the maximum southeastward extension of the pre-Senonian transgression. Thus, the "Huatasane dolostone" of the eastern Peruvian Altiplano (Newell, 1949) is probably correlative with this episode (Audebaud et al., 1976; Laubacher and Marocco, 1989).

<u>III.5. The K 3-4 Sequence</u> (Earliest Turonian - Late Campanian).

In the WPS, k 3C (=k 30) is a major transgressive discontinuity which gives way to the deposition of the subsequent well-dated Early Turonian open marine marls (Conor Fm, Benavides, 1956). In most of the Oriente, the base of the Chonta Fm is of Early Turonian age (Kummel, 1948; Rosenzweig, 1953; Ducloz and Rivera, 1956), thus recording the k 3C transgression. Afterwards, in the whole area, a Late Turonian carbonate shelf developed (Cajamarca, middle Napo, and middle Chonta Fms, Tschöpp, 1953; Benavides, 1956; Soto, 1979; Jaillard, 1987), and probably reached the westernmost Peruvian Altiplano where a fourth, thin-bedded

Ayavacas limestone member is locally known. Farther east, undated marine clastics (top of Cotacucho Gp) abruptly overlie (k 30) the presumably Cenomanian "Huatasane dolostone".

In central and northern Peru, k 31 separates the Late Turonian shelf limestones from overlying marine marls of Early Coniacian age (Celendín, upper Napo and upper Chonta Fms). In the southern WPS, k 31 precedes the deposition of azoic evaporitic red shales (Chilcane Fm) which pass upward (perhaps disconformably, Vicente et al., 1979) to fluvial red beds (Lower Querque Fm, Vicente, 1981).

In the Peruvian Altiplano, lacustrine red marls (Lower Vilquechico Fm, middle Moho Gp, Newell, 1949), and evaporitic red shales (upper Yuncaypata, Kalafatovitch, 1957) may be correlative with K 31-32. In the Potosî basin of Bolivia, k 31 is not identified. K 30-32 is characterized there by widespread rifting processes, associated with numerous basaltic flows, and with thick red bed deposits. These fill reactivated or newly-formed troughs and end locally with gypsum and halite deposited in structurally-controlled endoreic lakes (Aroifilla and lower Torotoro Fms, Sempere et al., 1988).

The k 32 surface has been defined in Bolivia (Sempere et al., 1988) and in southern Peru, but its identification elsewhere in Peru is not yet possible. In the northern WPS and in the Oriente, marly marine sedimentation went on, and k 32 might be represented by the apparent gap expressed by the lack of Late Coniacian fauna (Mourier et al., 1988). K31-40 is generally considered as ending after Early Santonian times (Benavides, 1956; Mégard, 1978), but in Rentema, it reaches Mid-Campanian times (Mourier et al., 1988). There, marine deposits quickly grade upward into flood plain red beds of possible Campanian age (El Triunfo Fm, Mourier et al., 1986, 1988). However, unsufficient stratigraphic data do no allow to state whether k 40 is correlative with the base or the top of the El Triunfo Fm.

In the southern WPS, the k 32 transgression is recorded by shallow marine limestones of Early Santonian age (parts of the Querque and Omoye Fms, Hosttas, 1967; Vicente, 1981). The upper part of K 32-40 is represented by coarsening-upward fluvial deposits.

In the eastern Peruvian Altiplano, k 32 may be represented by the transgressive sandy base of a marine to lacustrine regressive series, probably correlative with K 32-40. In this area, and in the Cuzco zone, charophyte oogons indicate a Senonian age (Peck and Recker, 1947; Kalafatovitch, 1957).

In the Potosí basin, red shales sharply overlie the red beds or evaporites of the top of K 30-32, and pass upward to the marine "basal limestones" of the Chaunaca Fm, which yielded a palynological assemblage of Santonian to Earliest Campanian age (Pérez, 1987). This organic-rich, locally euxinic transgressive limestones and marls are correlated with the k 32 transgressive deposits of southern Peru. The rest of K 32-40 mostly consists of red beds of coastal plain to continental origin, which frequently present a thickening- and coarsening-upward trend (Coroma Fm). The same organization is observed in the Cuzco-Sicuani basin Noblet et al., 1987; K'ayra Fm of López and Córdova, 1988), which displays all the characteristics of a very subsident foreland basin.

During most of the K 3-4 interval, the Lancones basin received turbiditic deposits, locally and sporadically associated with submarine volcanics (Morris and Aleman, 1975).

III.6. The K 4-5 Sequence (Late Campanian - Latest Paleocene).

The k 4 discontinuity is often marked by the onset of relatively coarse detrital sedimentation, followed in some areas by an important marine transgression (eastern domain, Talara basin). The stratigraphy of K 4-5 has been established in Bolivia (Sempere et al., 1987) and generalized to other areas when possible.

In the eastern domain, the base of K 40-41 is often characterized by light-coloured sandstones or coarser sediments of fluvial to coastal origin (base of the Tena, Areniscas de Azucar and El Molino Fms, upper part of the Vilquechico Fm and of the Moho Gp). In the Oriente, these sandstones yielded a Campanian palynological assemblage (Vivian Fm, Seminario and Guizado, 1976). In basinward localities of Bolivia, facies superposition is clearly retrogradational and thus indicates a rapid transgression. In the Talara basin of northwesternmost Peru, the Tablones conglomerates unconformably overlie Paleozoic and Mesozoic rocks (k 40), and pass upward to Campanian marine shales (Olsson, 1944; Zuñiga and Cruzado, 1979; Séranne, 1987). These chronological data and the ones from the underlying K 32-40 sequence support an intra-Campanian, probably Late Campanian age for k 4 (= 77 Ma).

The marine realm reached its Late Cretaceous maximum extension in the whole eastern domain after the k 41 discontinuity, which marks a further and apparently instantaneous transgression (Sempere et al., 1987; Sempere, 1989). The K 41-42 transgression in the eastern domain (Cachiyacu Fm, Areniscas de Azucar 2 and 3, parts of El Molino and upper Vilquechico Fms) may have also reached part of the WPS, since Mabire (1961) reports marine Cretaceous foraminifera from Central Peru.

Regressive sedimentary successions are first observed after the k 42 discontinuity, which seems mostly of climatic origin. K 42-43 shows the areal development of red continental sedimentation in the eastern domain.

Though a weak easterly transgressive pulse and a climatic change (drying) are recorded with the k 43 surface, K 43-44 presents a paleogeographic map view similar to the previous one.

The mainly climatic k 44 discontinuity also marks a regression in some areas of the eastern domain. Below k 44 dinosaur footprints, sclerorhynchid selachians, ammonites

No. These fossils are actually situated in the K42 and K43 sequences) -

and palynological or charophyte assemblages secure a Cretaceous age for the K 40-44 interval (El Molino and Arenisca de Azúcar Fms; Koch and Blissenbach, 1960; Dávila and Ponce de León, 1971; Seminario and Guizado, 1976; de Muizon et al., 1983; Sempere et al., 1987; Sempere, 1989). The red beds K 44-45 sequence yielded in northwestern Argentina an Early Cenozoic mammal fauna only 18 m above k 44 (Mealla Fm; Pascual et al., 1978), suggesting that the Cretaceous-Tertiary boundary is close to this discontinuity (Sempere et al., 1987). Total regression was completed during the K 44-45 interval.

the K-T boundary would be located within the K43 sequence

The K 45-50 sequence (Impora Fm) only shows alluvial to lacustrine facies in a few outcrops preserved in southern Bolivia below the k 5 unconformity, and in the Oriente where sedimentation seems to be more continuous. Palynological data from northwestern Argentina (Volkheimer et al., 1984) suggest a Late Paleocene age for this sequence (Sempere et al., 1988).

In most of the western domain, continental sedimentation progressively established during the K 3-4 interval and remained unaffected by the Latest Cretaceous marine transgression. For instance, coarsening-upward foreland sedimentation continued in the Cuzco-Sicuani basin during Latest Cretaceous times (Soncco Fm, López and Córdova, 1988), but seems to have waned during Paleocene times (Noblet et al., 1987). In the southern WPS, similar undated foreland deposits (Uchurca Fm, Vicente et al., 1979) disconformably overlie the K 3-4 sequence.

III.7. The k 5 unconformity (Latest Paleocene, = 56 Ma).

The younger boundary of the "Cretaceous" supersequence (K 0-5) is a widespread unconformity characterized on the whole margin by the sudden onset of coarse continental sedimentation (e.g. Cirbián et al., 1986).

In Bolivia, the Cayara Fm of Latest Paleocene to Early Eocene age (Sigé et al., 1984) can rest on the K 42-43 to K 45-50 sequences, with local angular unconformity, or on the Ordovician basement (Marocco et al., 1987). In the eastern Peruvian Altiplano, the Muñani Fm of Early Tertiary (Eocene ?) age (Audebaud et al., 1976; Feist et al., 1989) similary overlie the Latest Cretaceous Vilquechico Fm. In the Oriente, the same unconformity could be represented by the base of the Contamana Gp (Sempere, 1989) or by the base of the Capas Rojas 3 Fm (Koch and Blissenbach, 1960). Farther north, it could be correlative with the Tiyuyacu Fm (Tschopp, 1953) of Paleocene or Early Eocene age (Bristow and Hoffstetter, 1977).

In the northern WPS, volcanic intercalations in the conglomerates of the unconformable Chota Fm provide K-Ar ages close to the Early-Middle Eocene boundary (49-50 Ma, Noble et al., 1989). In the Talara basin, the "basal Salinas" conglomerates disconformably overlie the Paleocene hemipelagic Balcones Fm and are transitionally overlain by the Eocene fluvio-deltaic Salinas Gp (Zuñiga and Cruzado, 1979; Séranne, 1987).

In summary, k 5 marks the end of a period of partly marine, fine detrital sedimentation in the eastern domain, and seals a noteworthy tectonic event of Late Paleocene age (Marocco et al., 1987). From then on, the geodynamic evolution of the central Andes back-arc develops in an almost exclusively continental setting, characterized by the deposition of thick foreland sedimentary wedges (Sempere et al., 1989).

CONCLUDING REMARKS

Many of the pre-Senonian discontinuities recognized in the Peru-Bolivia margin coincide with major sedimentary discontinuities defined by seismic stratigraphy analysis (Haq et al., 1987) (see k 0, k01, k 10, k21, k22 and k 31 for example). Eustatic changes thus played a leading part in the pre-Senonian evolution of the central Andean margin. This clearly appears in the WPS during the K 1-2 megasequence (Moulin and Séguret, 1989), and less evidently during the Aptian-Senonian period (K 2-4 period)(Jaillard, 1987, 1989).

Nevertheless, tectonic events played a significant role at various times, either reinforcing the eustatic effects, or disturbing them (fig. 2). Discontinuity k 0 has been ascribed to the Araucan phase of Latest Jurassic age (Sempere et al., 1988); k 01 has been related to the collision of allochthonous terranes (Jaillard and Jacay, 1989); and k 1 to the incipient rifting of the South Atlantic Ocean. These events seem to be linked with drastic geodynamic changes (Aspden et al., 1987; Jaillard et al., in press).

During Late Aptian times, weak and/or localized tectonic instability accompanied both the opening of the Huarmey marginal basin, and the beginning of an important volcanic activity. The end of this volcanic episode and the closure of the Huarmey trough are marked by important tectonic events in most of the western domain during Late Albian to early Mid-Cenomanian times (Cobbing et al., 1981; Jaillard, 1987 and unpublished data). K 3-4 is characterized by the diachronous beginning of tectonics in the Peru-Bolivia realm. It is recorded by Turonian times in Bolivia (rifting processes, Sempere et al., 1988); by Coniacian times in the southern WPS (emersion); by Santonian times in most of the WPS (tectonic uplift, Mégard, 1978), and by middle Campanian times in the northeastern WPS (rapid emersion, Mourier et al., 1988).

As a result of both eustatic and tectonic phenomena, the locus of marine sedimentation progressively shifted eastwards through time. During the K 0-2 interval, marine sedimentation occurred mostly in the coastal area; during K 2-3, marine sedimentation took place in the whole western domain, and locally reached the eastern realm; whereas during most of K 3-4, the coastal area emerged, and marine deposits occupied both the WPS and great parts of the eastern domain. By the end of K 3-4, the WPS progressively emerged, and marine sedimentation was restricted to the eastern domain during K 4-5.

As a consequence, the classical notion of a single "Peruvian phase" has to be reconsidered. The Senonian emersion of the WPS rather appears to be a progressive process which began by Earliest Senonian times in the southern areas, and was grossly achieved with the widespread intra - Campanian discontinuity (see also Macellari, 1988).

Moreover, further studies might concentrate on the Late Paleocene tectonic phase, the effects of which seem to have been often mistaken either for the so-called "Peruvian phase", or for the subsequent "Incaic phase".

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APPENDIX 1: Stratigraphic data from the K 0-1 sequence.

LATE CALLOVIAN - EARLY OXFORDIAN

k 0

Fauna reported from the LABRA Fm (lower part of K 00-01) (Diagnosis often difficult).

Ammonites: Peltoceras (Peltomorphites) sp. (19) Spiticeras cf. negrelli (15)

Other species from correlative formations:

Ammonites: Hoplites (Favrella) lorensis (A17) Peltoceras euaspidoceras sp. (B18)

Fauna from the GRAMADAL and JAGUAY Fms (upper part of K 00-01), and other occurrences:

Ammonites:	
Aulacosphinctoides sp. (20)	Aspidoceras sp. (12)
Perisphinctes sp. (12)	Hoplites cf. peregrinus (12)
Perisphinctes aff. transitorius (12)	Perisphinctes cf. colibrinus (12)
Simoceras cf. catrianum (12)	? Proniceras sp. (12)
Virgatosphinctes aff. pseudolictor (7)	Virgatosphinctes mexicanus (7)
	Virgatosphinctes sp. (7,14,20,J9)

Corals: Astrocoenia (5,7,17) Gastropods: Nerinea (5,7)

Other species from correlated formations:

Ammonites: Substeueroceras sp. (C21,J8) Brachiopods: Terebratula subtetraedra (D22)

OXFORDIAN (?) - EARLY TITHONIAN

k 01 ?

Index fauna from the PUNTA MORENO and ZAPOTAL Fms (K 01-02), and other occurrences:

Ammonites:	
Berriasellidae (21,H16)	Aulacosphinctes cf. subvetustus (21)
Himalayites egregius (21)	Durangites sp. (21)
Micracanthoceras sp. (21,J9)	Himalayites sp. (21,J6)
? Neocosmoceras sp. (21)	Moravisphinctes sp. (21)
Parodontoceras sp. (21,J6,J15)	Paraulacosphinctes cf. eudichotomus (21)
Substeueroceras sp. (21,J8,J15)	Protacanthodiscus sp. (21)

Other species from the correlated TIABAYA outcrops, and other occurrences:

Ammonites:	
Berriasella (Hegaratella) cf. jacobi (15)	Berriasella fraudans (15)
Berriasella cf. chillonensis (10)	Berriasella (Malbosiceras) doris (15)
Cuyaniceras sp. ex gr transgrediens (15)	Berriasella sp. (10,J9)
Hemispiticeras steinmanni (15)	Dickersonia ramonensis (15)
Micracanthoceras cf. vetustum (15)	Leptoceras sp. ex gr hubachi (15)
Parahoplitidae (10)	Neochetoceras tiabayense (15)
	Parodontoceras antilleanum (15)

LATE TITHONIAN (?) - BERRIASIAN

K 02 ?

Index fauna from the PUENTE PIEDRA Fm (K 02-10 ?), and other occurrences:

Ammonites:	
Berriasella limensis (3)	Aulacosphinctes aff. proximus (3)
Berriasella laxicostata (3,J15)	Berriasella chillonensis (3)
Berriasella callisto (3,13,J1,J2,J9,J13)	Berriasella broggi (3)
Berriasella peruviana (3)	Berriasella callistoides (3,J1,J2,I 4)
Berriasella caudelaensis (3)	Berriasella curvicostata (3)
Leptoceras lissoni (3,13)	Berriasella aff. tenuicostata (3)
Octagoniceras occidentalis (3)	Leptoceras steinmanni (3)
Protacanthodiscus pacificum (3)	Protacanthodiscus quadripartitus (3,13)
Protancyloceras sp. (13)	Protacanthodiscus puenteingaensis (3)
Substeueroceras steueri (3,J9)	Spiticeras limaensis (3,13)
Substeueroceras permulticostatum (3)	Substeueroceras koeneni (3, ruled out: 13,J15)
Thurmanniceras pertransis (3,13)	Substeueroceras angasmarcaensis (3,J6,J8,J9)
	Thurmanniceras douvillei (3)

Other species from correlative formations:

Ammonites:	
Berriasellidae (H16)	Berriasella sp. (I 4)
Leopoldia cf. peruvianum (I 4)	Substeueroceras sp. (I 4)

LATEST TITHONIAN (?) - LATEST BERRIASIAN

k 1

EARLY to MIDDLE VALANGINIAN

Other species from the undifferentiated CHICAMA BEDS (K 0-1):

Ammonites:	
Aulacosphinctes aff. saldensis (2)	Aspidoceras cf. acanthicum (1,13)
Aulacosphinctes ssp. (15)	Aulacosphinctes mangaensis (15)
Berriasella chaperi (1,13)	Berriasella vetustus (1)
Berriasella cf. aspera (6)	Berriasella oppeli (2)
Berriasella aff. mendozana (2)	Berriasella cf. krantzi (15)
Berriasella (Malbosiceras ?) inaequicostata (15)	Berriasella aff. privasensis (9)
	Berriasella sp. (9,15)
Blanfordiceras stappenbecki (15)	Cuyaniceras cf. transgrediens (15)
Cuyaniceras acanthicum (15)	Cuyaniceras sp. (15)
Cuyaniceras praeneocomienne (15)	Cuyaniceras sp. ex gr raripartitum (15)
Hemispiticeras steinmanni (15)	Himalayites egregius (15)
Limaites nsp. (15, =Streblites griesbachi of 2)	Himalayites sp. (6)
Micracanthoceras tapiai (15)	Micracanthoceras cf. submendozanum (15)
Micracanthoceras sp. ex gr vetustum (15)	Neocomites praeneocomiensis (2,9)
Olcostephanus sp. ex aff. (Spiticeras) conservans (1,6)	Olcostephanus sp. (1,8)
Parodontoceras cf. beneckei (15)	Parodontoceras sp. ex gr callistoides (15)
Perisphinctes interspinosus (9)	Riasanites ? sp. (9)
Simoceras cf. volanense (1,13)	Substeueroceras disputabile (15)
Thurmanniceras angasmarcaensis (1,15)	Thurmanniceras sp. (9,15)
Virgatosphinctes sp. (9)	

EARLY TITHONIAN - BERRIASIAN

Formations: A: Chuchucamane; B: Querullpa; C: Simbal; D: Sipin; E: Tiabaya outcrops; F: Punta Moreno; G: Zapotal; H: Tinajones; I: unnammed beds near Castrovirreyna; J: Chicama beds undifferentiated.

References: 1: Welter 1913; 2: Stappenbeck 1929; 3: Rivera 1951, 1979, Rivera et al. 1975; 4: Bellido 1956; 5: Benavides 1962; 6: Cruzado 1959; 7: Rüegg 1961; 8: Cossio 1964; 9: Cossio and Jaen 1967; 10: Garcia 1968, Vargas 1970; 11: Garcia 1978; 12: Caldas 1978; 13: Wiedmann 1981; 14: Chavez 1982; 15: Geyer 1983; 16: Wilson 1984; 17: Salinas 1985; 18: Garcia 7. 1987; 19: Loza 1987; 20: Batty in progress; 21: Jacay in progress; 22: Emp. Petrol. Fisc. Internal report.

APPENDIX 2: Stratigraphic data from the K 1-2 sequence:

LATE BERRIASIAN

k 1 ————————————————————————————————

Index fauña from the HERRADURA Fm (upper part of K 10-11):

Ammonites:
Argentiniceras pardoi (7, contested by 8)
Hoplites aff. austrates (3)
Raimondiceras raimondii (7,8)

Argentiniceras aff. malarguense (3)
Favrella lorensis (7, contested by 8)
Lissonia riveroi (3,7,8)
Raimondiceras pflückeri (7)

EARLY TO MIDDLE VALANGINIAN

k 11 ————————————————————————————————

Index fauna from the MARCAVILCA Fm (base of K 11-12):

Ammonites:
Raimondiceras raimondii (3,7)

Lissonia riveroi (7)
Raimondiceras pflückeri (7)

Index fauna from the PAMPLONA Fm (upper part of K 11-12 and part of K 12-13):

Ammonites:
Olcostephanus aff. astierianus (C7,C8)
Olcostephanus cf. delicatecostatus (C9)

Capeloites larosai (C7,C8,C9)
Olcostephanus cf. boussaingaulti (C9)

LATE VALANGINIAN - EARLIEST HAUTERIVIAN

Fauna from the SANTA and lower CARHUAZ Fms, correlated with the PAMPLONA Fm:

Ammonites: Olcostephanids (D1)

Valanginites broggi (D1)

Pelecypods:
Cyrena huarazensis (D1,D4,D5)
Buchotrigonia flexicostata (D1)
Buchotrigonia inca (D1)

Paraglauconia studeri (D1,D4,D5)
Paraglauconia strombiformis (D1,D2,D4)
Paraglauconia sp. (D6)
Buchotrigonia gerthi (D1)

LATE VALANGINIAN

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k 13 to k 20 no detailed stratigraphic studies

k 2 ————————————————————————————————

LATE APTIAN

"Wealdian" flora from the undifferentiated GOYLLARISQUIZGA group (K 1-2): Alethopteris, Antholitus, Brachyphyllum, Cladophlebis, Cycadolepis, Equisetites, Filicites, Klukia, Otozamites, Podozamites, Ruffordia, Sphenopteris, Taeniopteris, Thuites, Weichselia, Zamites, Zamiostrobus, ... see Berry (1922), Steimann (1929), Rivera et al. (1975), Doubinger & Marocco (1976), Caldas (1978),...
Cycadocarpidium is reported by Alleman (1985).

Formations: A: Herradura; B: Marcavilca; C: Pamplona; D: Santa and lower Carhuaz; E: unnammed beds near Castrovirreyna.

References: 1: Benavides 1956; 2: Bellido 1956; 3: Fernandez 1958; 4: Cruzado 1959; 5: Wilson 1963; 6: Hillebrandt 1970; 7: Rivera et al. 1975, Rivera 1979; 8: Wiedmann 1980, 1981; 9: Thieuloy unpublished.

APPENDIX 3: Stratigraphic data from the K 2-3 sequence:

NEOCOMIAN

k 20 ————————————————

Index fauna from the INCA Fm (K 20-21), and other occurrences:

Ammonites:

Desmoceras chimuense (7)
Knemiceras ollonense (7,26)
Parahoplites nicholsoni (7,21,24,A18)
Parahoplites guilla (7,26)
Parahoplites inti (7)
Parahoplites sp. (11,15,27,B9,C17)

Other species from correlated formations: Parahoplites sutoni (A18)

LATE APTIAN - EARLIEST ALBIAN

k 21 ————————————————

Index fauna from the CHULEC Fm (lower part of K 21-22), and other occurrences:

Ammonites:

Brancoceras aegoceratoides (7,9,15,27, E3,E10)
Desmoceras cf. schlagintweiti (15)
Douvilleiceras monile (7,9,27)
Douvilleiceras sp. (15,18,21,A18)
Knemiceras sp (11,21,24,D1,E10,H11,H14,H24)
Knemiceras ovale (7)
Knemiceras attenuatum (7,9,24,E3,I 4)
Knemiceras syriacum (7,9)
Knemiceras gabbi (7,9,15)
Knemiceras triangulare (7,9)
Knemiceras crassinodosum (21,E3)
Knemiceras ? ziczag (7,9)
Knemiceras raimondii (7,9,21,24,25,26,27,28,E3)
Lyelliceras lyelli (7,9,15,27,E10)
Lyelliceras sp. (11,13,21,24,E3,F10,F22, G6,H11,I 4)
Parahoplites sp. (15)
Parengonoceras haasi (7,15)
Parengonoceras pernodosum (7,9,14,21,25)
Parengonoceras guadalupaeforme (7,15)
Parengonoceras tetranodosum (7,9,27,H24)
Parengonoceras ? champaraense (7,H24)
Parengonoceras sp. (11,15,24,H11,H14,H24)
Prolyelliceras peruvianum (7,14,F22)
Protanisoceras blancheti (7,9,27)
Protanisoceras cf. blancheti (15)
Protanisoceras sp. (28)

EARLY ALBIAN - EARLY MIDDLE ALBIAN

Index fauna from the PARIATAMBO Fm (upper part of K 21-22), and other occurrences:

Ammonites:

Acanthocerataceans (21)
Brancoceras lyelli (27)
Brancoceratid (21)
Desmoceras latidorsatum (7,9,27)
Dipoloceras sp. (7,9,13,21)
Lyelliceras pseudolyelli (7,9,E3)
Lyelliceras ulrichi (7,9,14,25,E3,E16)
Mojsisoviczia sp. (21)
Mortoniceras aff. inflatum (14)
Mortoniceratid (24,F22)
Oxytropidoceras carbonarium (7,9,14, 15, 21,24,27,E3,E10,F17,H26)
Oxytropidoceras peruvianum (7,14,F16)
Oxytropidoceras douglasi (7,9,E3,E10,E16)
Oxytropidoceras sp. (11,13,21,E3,E10,G6, G20,H13,I 4)
Venezoliceras venezolanum (7,9,27)
Venezoliceras harrisoni (7,9,14)
Venezoliceras sp. (13,14,21,F17,I 4)

Pelecypods: Inoceramus concentricus (7,9,14,E3,J28)

MIDDLE ALBIAN - EARLIEST LATE ALBIAN

Other species from formations correlative with K 21-22:

Ammonites:

Brancoceras sp. (F17)
Hamitid (F17)
Hysteroceras orbigny (F17)
Knemiceras semicostatum (E3)
Knemiceras crassicostatum (E3)
Knemiceras moorei (E3)
Laymeriella sp. (F17)
Lyelliceras mathewsi (E3)
Lyelliceras ulrichi (7,9)
Neophlyticeras sp. (I 4)
Oxytropidoceras parinensis (G2)
Oxytropidoceras karsteni (G2)
Oxytropidoceras bosei (E3)
Oxytropidoceras hubbardi (E3)
Oxytropidoceras multifidum (I 4)
Pervinquiera sp. (G6)
Placenticeras sp. (G2)
Venezoliceras cf. karsteni (I 4)

k 22 ————————————————

Index fauna from the YUMAGUAL Fm (K 22-23), and other occurrences:

Ammonites: Engonoceras sp. (7)
Lyelliceras ulrichi (7,9)
Oxytropidoceras douglasi (7,9)
Paraturrilites lewesensis (7)
Paraturrilites sp. (11,21,27)
Sharpeiceras occidentale (7)

Pelecypods: Ostrea scyphax (7,21,24,27,L8,L23) Exogyra mermeti (7,K19,L8,M5)

Foraminifera: Nommoloculina heimi (24)

MIDDLE (?) and LATE ALBIAN - EARLY CENOMANIAN

Other species from formations correlated with K 22-23:

Ammonites: Mantelliceras sp. (F22)
Mortoniceras inflatum (F21)
Mortoniceras peruvianum (D1)
Mortoniceras cf. marrecacia (F22,J28)
Schloenbachia sp. (G2)

k 3A ————————————————

MIDDLE CENOMANIAN

Formations: A: Chilca and Chancay; B: Pariahuanca; C: Huamancay; D: Lower Moho group; E: Raya, Esperanza or basal Chonta fms; F: Casma gp; G: Pananga and Muerto; H: Crisnejas; I: Lower Napo; J: La Bocana and Lancones; K: Ferrobamba; L: Arcurquina; M: Agua Caliente.

References: 1: Lisson 1924 (also Cabrera and Petersen 1936); 2: Olsson 1934; 3: Kummel 1948; 4: Tschopp 1953; 5: Rosenzweig 1953; 6: Fisher 1956; 7: Benavides 1956; 8: Benavides 1962; 9: Wilson 1963; 10: Zegarra 1964; 11: Wilson and Reyes 1964; 12: Cossio and Jaen 1967; 13: Wilson et al. 1967; 14: Mégard 1968; 15: Hillebrandt 1970; 16: Davila and Ponce de Leon 1971, 17: Myers 1974, 1980; 18: Rivera et al. 1975; 19: Marocco 1978; 20: Zuniga and Cruzado 1979, Cruzado 1985; 21: Reyes 1980; 22: Guevara 1980; 23: Olchauski 1980; 24: Janjou 1981, Janjou et al. 1981; 25: Romani 1982; 26: Wilson 1984; 27: Cordova 1986; 28: Reyes and Caldas 1987.

APPENDIX 4: Stratigraphic data from the K 3A-3C period:

k 3A — EARLY CENOMANIAN

Index fauna from the MUJARRUN Fm (K 3A-3B), and other occurrences:

Ammonites: Acanthoceras sp. (11,14) — Acanthoceratid (4)

Pelecypods: Exogyra cf. ponderosa (4,11,12,14) — Exogyra africana (4,11)
Exogyra olisiponensis (4,11,12,A6) — Neitheia tenouklensis (4,14)

Echinids: Orthopsis titicacana (4,A6,B3)

MIDDLE CENOMANIAN

Other species from correlative formations:

Ammonites: Schloenbachia aff. varians (F2) — Schloenbachia sp. (G7)

k 3B

Index fauna from the ROMIRON Fm (K 3B-3C), and other occurrences:

Ammonites:
Acanthoceras pollocense (4,14)
Acanthoceras sangalense (4)
Acanthoceras sp. (11)
Acanthoceras chasca (4,14)
Forbesiceras sp. (4)
Lissoniceras mermeti (4,14)
Neolobites kummeli (4,D8)

Pelecypods: Exogyra olisiponensis (4,11,14,A6) — Neitheia alatus (4,14)

Echinids: Orthopsis titicacana (4,11,A6,B3)

Vertebrates: Elasmosaurid (13,14)

LATE MIDDLE CENOMANIAN - LATE CENOMANIAN

Other species from correlative formations:

Ammonites: Neolobites bassleri (B1) — Neolobites sp. (A6,C5)

Foraminifera: Haplophragmoides concavus (E9)
Textularia cf. chapmani (E9)
Heterohelix cf. washitensis (E9)
Hedbergella delrioensis (E9,H10)
Hedbergella planispira (E9,H10)
Globigerinelloides bentonensis (E9,H10)

Other species from formations partly correlative with the K 3A-3B sequences:

Foraminifera:
Globigerina gauteriensis (H10)
Globigerina washitensis (H10)
Globigerinelloides aff. algerianus (H10)
Globigerinelloides aff. eaglefordensis (H10)
Clavihedbergella simplex (H10)
Gümbellina sp. (H10)
Hedbergella aff. amabilis (H10)
Heterohelix moremani (H10)
Ticinella aff. aprica (H10)

k 3C — EARLY TURONIAN

Formations: A: Arcurquina; B: Ayavacas limestones; C: Yuncaypata limestones; D: upper part of Miraflores Fm; E: part of Jumasha; F: Copa Sombrero; G: Agua Caliente or Chonta; H: Muerto (of the Talara basin).

References: 1: Lisson 1924 (also Cabrera and Petersen 1936); 2: Olsson 1934; 3: Newell 1949; 4: Benavides 1956; 5: Kalafatovich 1957; 6: Benavides 1962; 7: Zegarra 1964; 8: Branisa et al. 1966; 9: Hillebrandt 1970; 10: Zuniga and Cruzado 1979, Cruzado 1985; 11: Reyes 1980; 12: Janjou 1981, Janjou et al. 1981; 13: Jaillard et al. 1985; 14: Cordova 1986.

APPENDIX 5: Stratigraphic data from the K 3-4 sequence:

LATE CENOMANIAN

k 3C = k 30 ———

Index fauna from the CONOR Fm (lower part of K 30-31):

<u>Ammonites</u>:
Broggiceras humboldti (8)
Broggiceras olssoni (8,21)
Coilopoceras jenksi (8,21)
Hoplitoides inca (8,18,21)
Mammites nodosoides (8,21)
Mammites sp. (19)
Pseudoaspidoceras reesidei (8)
Pseudoaspidoceras sp. (18)
Thomasites fisheri (8,19)
Vascoceras aff. silvanense (8)
Vascoceras sp. (19)

<u>Pelecypods</u>: Inoceramus labiatus (8,21,B5,C2)

<u>Foraminifera</u>: Heterohelix reussi (19) Hedbergella simplex (19)

EARLY TURONIAN

Index fauna from the CAJAMARCA Fm (upper part of K 30-31):

<u>Ammonites</u>: Coilopoceras newelli (8,18,19,21)

<u>Foraminifera</u>:
Pseudedomia drorimensis (22)
Globotruncana praehelvetica (22)
Stephani sp. (19)

MIDDLE TO LATE TURONIAN

Other species from formations correlated with K 30-31:

<u>Ammonites</u>:
Coilopoceras lassali (C?)
Coilopoceras sp. (B5,C6,C7,C11,D20)
Mammites aff. barkeri (B5)
Mammites sp. (C 11)
Neoptychites sp. juv. (B5)
Vascoceras ameirense (C2)

<u>Foraminifera</u>: Archaias (perouvianella) peruviana (D15, resituated by 20)

k 31 ———

Fauna from the lower CELENDIN Fm (correlative with K 31-32), and other occurrences:

<u>Ammonites</u>:
Barroisiceras (Barroisiceras) kayi (8)
Barroisiceras (Solgerites) brancoi (8,21)
Barroisiceras (Forresteria) alluaudi (8,F7)
Barroisiceras sp. (10,18,F 11)
Buchiceras bilobatum (8,10,18,19,20,21,F11)
Barroisiceras (Barroisiceras) haberfellneri (8,F7,F11)
Heterotissotia peroni (8,10,18,19)
Heterotissotia bucheri (8,18)
Heterotissotia peruviana (19)
Metatissotia cf. fourneli (20)
Tissotia hedbergi (8,10,21,F7)

EARLY CONIACIAN

k 32 ? ———

Index fauna from the OUEROUE Fm (F 32-33):

<u>Ammonites</u>: Tissotia steinmanni (12)

EARLY SANTONIAN

Fauna from the middle CELENDIN Fm (correlative with the lower part of K 32-33), and other occurrences:

<u>Ammonites</u>:
Anapachydiscus aff. gardneri (21)
Bostrychoceras sp. (8)
Desmophyllites gaudana (8,10,21)
Desmophyllites sp. (18,23)
Lenticeras baltai (3,8,10,18,21,23,F2)
Lenticeras lissoni (8,10,21,F2)
Pachydiscus (Parapachydiscus) aff. gardneri (3)
Texanites bourgeoisi (8,21)
Texanites aff. bourgeoisi (3)
Texanites sp. (8,10,18,23,F11)
Tissotia steinmanni (8,10,F2,F6,F7,F11)
Tissotia fourneli (8,10,21,F2)
Tissotia halli (8,21)
Tissotia singewaldi (3,F2,F6)
Tissotia sp. (18,F6,F7,F11)

Fauna from the upper CELENDIN Fm (upper part of K 32-33):

<u>Ammonites</u>:
Menabites s. l. (23)
Lybicoceras sp. (23)
Pachydiscus sp. (23)
Manambolites sp. (23)
Submortoniceras sp. (23)

MIDDLE CAMPANIAN

Flora from formations correlated with the upper part of K 32-33:

<u>Charophytes</u>:
Porochara ovalis (G1,G4,H4,I 9,I 16)
Platychara perlata (G1,I 9)
Porochara sp. (G1,I 16)

Other species from formations correlated with K 31-32 and K 32-33:

<u>Ammonites</u>:
Barroisiceras welteri (F7)
Desmophyllites cf. ellsworthi (F2,F7)
Eulophoceras berryi (F2,F7)
Heterotissotia lissoni (F2,F7)
Heterotissotia sp. (F11)
Lenticeras gerhardti (F2)
Lenticeras andii (F7)
Lenticeras sp. (F11)
Paralenticeras sieversi (F2)
Peroniceras sp. (E5,F7,F11)
Sphenodiscus sp. (14, to be reconsidered)
Tissotia reesideana (F2,F6,F7)
Tissotia waltheri (F2)
Tissotia compressa (F2,F7)
Tissotia stephensoni (F2)
Tissotia obesa (F2)

<u>Vertebrates</u>: Ichtyosaurian (F?13)

Other species from formations correlative with K 3-4:

<u>Foraminifera</u>:
Globotruncana lapparenti (J17)
Heterohelix sp. (J17)
Siphogenerinoides cf. cretacea (J17)

k 40 ———

CAMPANIAN

<u>Formations</u>: A: Arcurquina; B: Middle Napo; C: Middle Chonta; D: Upper Jumasha; E: Upper Napo; F: Upper Chonta; G: Middle Vilquechico; H: Upper Moho gp; I: Upper Yuncaypata; J: Copa Sombrero.

<u>References</u>: 1: Peck and Recker 1947; 2: Kummel 1948; 3: Rivera 1949; 4: Newell 1949; 5: Tschopp 1953; 6: Rosenzweig 1953; 7: Ducloz and Rivera 1956; 8: Benavides 1956; 9: Kalafatovich 1957; 10: Wilson 1963; 11: Zegarra 1964; 12: Hosttas 1967; 13: Hoempler 1974; 14: Rodriguez and Chalco 1975; 15: Dizon et al. 1975; 16: Marocco 1978; 17: Zuniga and Cruzado 1979, Cruzado 1985; 18: Reyes 1980; 19: Janjou 1981, Janjou et al. 1981; 20: Romani 1982; 22: Jaillard 1987; 23: Mourier et al. 1988.