

Sedimentary evolution of an active margin during middle and upper cretaceous times: the north Peruvian margin from late aptian up to senonian

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With 14 figures

Zusammenfassung

Die sedimentäre Entwicklung des nordperuanischen Kontinentalrandes zeigt während der Ober-Kreide folgende Etappen: die Transgression des Oberaptes erstreckt sich über den gesamten Kontinentalrand und geht mit leichten synsedimentären tektonischen Diskonformitäten einher, die gleichzeitig mit der Entstehung des westlichen Randbeckens zu sehen sind. Die Transgression erreicht ihren Höhepunkt im mittleren Alb, sie ist verbunden mit anoxischen Ablagerungen und mit den Hauptbewegungen im randlichen Becken. Im Oberalb folgt eine Regression. Sie zeigt sich im unteren Cenoman durch intertidale Ablagerungen, durch nach Westen progradierende Deltas und durch synsedimentäre Tektonik. Der Höhepunkt der Regression ist verbunden mit der tektonischen Isolation und Faltung des westlichen Randbeckens.

Die große Transgression während der Oberkreide beeinflusst vor allen Dingen die östlichen Teile des Randes. Wesentliche Eintiefungsphasen erscheinen im oberen Mittelcenoman und an der Basis des Turons. Während des Turons entwickelt sich ein weiter Karbonatschelf. Ein größerer Transgressionsvorstoß erscheint an der Grenze von Turon zu Coniac. Als Ergebnis einer generellen Heraushebung wird der gesamte Kontinentalrand diachron zwischen Santon und Campan herausgehoben und es entstehen kontinentale Rotablagerungen. Diese Sedimente dokumentieren eine neue tektonische Phase im obersten Senon. Während der Oberkreide wird die sedimentäre Weiterentwicklung des nordperuanischen Kontinentalrandes durch globale Meeresspiegelschwankungen zusammen mit tektonischen Ereignissen (Oberapt, Oberalb-unteres Cenoman, Senon und oberstes Senon) kontrolliert.

Abstract

The sedimentary evolution of the North Peruvian margin during upper Cretaceous can be summarized as follows:

The upper Aptian transgression involved the whole margin, and was accompanied by minor, local, synsedimentary tectonic features. It could be coeval with the individualization of the Western ensialic marginal basin. The transgression reached its maximum during middle Albian, and is

associated with anoxic deposits, and with the main activity of the marginal basin.

A regression followed during the upper Albian. It was materialized during lower Cenomanian by intertidal deposits, by a westward deltaic progradation, and by synsedimentary tectonic features. This regressive maximum is correlatable with the tectonic closure and folding of the western marginal basin.

Then, the great upper Cretaceous transgression affected the eastern parts of the margin. Major deepening stages occurred during late Middle Cenomanian and at the base of the Turonian. During Turonian, a widespread, calm carbonate shelf developed. A new major transgressive pulse occurred at the Turonian-Coniacian boundary. As a result of a general uplift, the whole margin emerged diachronically between Santonian and Campanian, leading to the deposition of continental Red Beds. The latter recorded a new tectonic phase of uppermost Senonian age.

During upper Cretaceous times, the sedimentary evolution of the North Peruvian margin appears to be controlled both by the eustatic sea-level changes, and by the uppermost Albian to early Cenomanian, and the upper Senonian tectonic events.

Résumé

L'évolution sédimentaire de la marge nord-péruvienne au Crétacé supérieur peut être résumée ainsi:

La transgression de l'Aptien supérieur affecte toute la marge, et s'accompagne d'une légère instabilité tectonique localisée. Celle-ci peut être contemporaine de l'individualisation du bassin marginal occidental. La transgression atteint son maximum à l'Albien moyen. Elle est contemporaine de dépôts anoxiques et de l'activité du bassin marginal.

Une régression survient au cours de l'Albien supérieur. Elle se matérialise au Cénomaniens inférieur par l'installation d'une plate-forme carbonatée, puis par la progradation du delta oriental et par des mouvements tectoniques syn-sédimentaires. Cette régression est en relation avec la fermeture du bassin marginal occidental.

La grande transgression du Crétacé supérieur affecte ensuite les zones orientales de la marge, les étapes majeures d'approfondissement se situant à la fin du Cénomaniens moyen et à la base du Turonien. Au Turonien, une vaste plate-forme carbonatée s'installe, et un nouvel approfondissement survient à la limite Turonien-Coniacien. A la suite d'une surrection générale, la marge émerge de façon dia-

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chrone entre le Santonien et le Campanien, donnant lieu au dépôt des Couches Rouges continentales qui enregistrent au Sénonien terminal un nouvel événement tectonique.

Au Crétacé supérieur, l'évolution sédimentaire de la marge nord-péruvienne semble donc contrôlée à la fois par les variations eustatiques, et par les événements tectoniques de l'Albien terminal-Cénomanien inférieur, et du Sénonien.

Краткое содержание

В развитии осадочного чехла на материковом крае Северного Перу за период верхнего мела отмечаются следующие этапы: Трансгрессия в период верхнего Апта по всему материковому краю с незначительными синседиментными тектоническими нарушениями, одновременно с которыми образуется западный краевой бассейн. Кульминационная точка трансгрессии приходится на средний Альб; она связана с отложениями в бескислородной среде и основными движениями в краевом бассейне. В верхнем Альбе наступает регрессия, проявляющаяся в нижней сеномане отложениями зоны прилива-отлива, перемещением дельты на запад и синседиментными тектоническими событиями. Кульминационная точка регрессии связана с появлением складчатости в западном краевом бассейне и обособлением его в результате тектонических процессов. Обширная трансгрессия в верхнем меле повлияла прежде всего на восточную часть края. Важные фазы проседания отмечаются в верхнем сеномане и в начале турона. Во время последнего образовался еще дополнительно карбонатный шельф. Значительное продолжение трансгрессии проявляется на рубеже туронского/коньякского веков. Вследствие общего подъема весь континентальный край между сантонским и кампанским веками оказался поднятым; при этом образовались красные материковые отложения. Эти последние отмечают новую фазу тектонической активности в верхнем сеномане. Во время верхнего мела дальнейшее развитие осадочного чехла на материковом крае северного Перу зависит от колебания уровня мирового океана в глобальном масштабе и от тектонических событий, связанных с этими колебаниями (верхний апт, верхний альб, нижний сеноман, сеноман и верхний сеноман).

Introduction

The Peruvian Andes have been studied for a long time. Fundamental stratigraphic syntheses of the Andean cretaceous series are due to KUMMEL (1948), who studied the Amazonian versant of the North Peruvian Andes; to BENAVIDES (1956) who established the cretaceous stratigraphy of Northern Peru; to WILSON (1963) who did a similar work for the Andes of Central Peru; and to MYERS (1974, 1980) who unravelled the geological history of the coastal area. For more recent works, one should refer to

the syntheses by AUDEBAUD et al. (1973, 1976), by MEGARD (1978), and by DALMAYRAC et al. (1980) for Central and Southern Peru; and by MYERS (1975), REYES (1980), COBBING et al. (1981), JANJOU (1981), and WILSON (1984) for Northern Peru.

Following these works, the Cretaceous paleogeography of Peru is generally regarded as being controlled by NNW-SSE-trending structures. These structures were born during Jurassic times (Nevadan orogeny, ARTHAUD et al. 1977); their trend is more or less parallel to the present axis of the Andes, and to the paleosubduction trench (fig. 1 and 2). During Cretaceous times, it is convenient to distinguish the following, from the Western subduction trench to the Eastern Brazilian shield (fig. 1 and 2):

(1) The hypothetical »Paracas Geanticline« (MYERS 1975), a continental high land with perhaps an overlying discontinuous volcanic arc (MEGARD 1978).

(2) The »Huarmey Trough« (MYERS 1975), which behaved as an »ensialic marginal basin« during Albian times (ATHERTON et al. 1983, 1985), and then emerged and was the site of repeated magmatic intrusions during upper Cretaceous times (PITCHER 1978, COBBING et al. 1981, MOORE 1984, MUKASA 1986).

(3) The »West Peruvian Platform« (WPPF) (JAILLARD 1986) which was separated from the Huarmey Trough by a mobile fault zone (Tapacocha axis, MYERS 1974). Upon this platform, sediments, first deltaic, later marine were deposited during Cretaceous times.



Fig. 1. Present outcrops of the main Cretaceous paleogeographic domains of Peru.

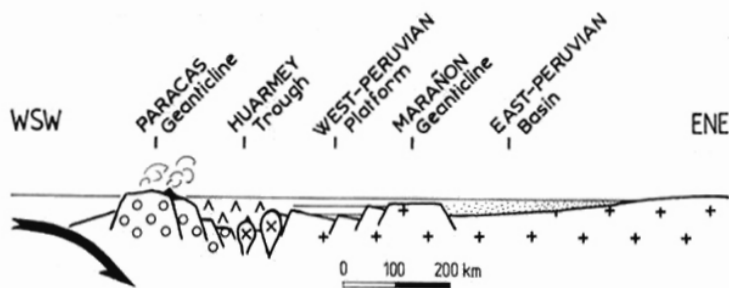


Fig. 2. Hypothetical paleogeographic section of the North Peruvian margin during Albian times.

(4) The »Marañon Geanticline« (BENAVIDES 1956) was a submerged (locally emerged) high shelf, which separated the WPPF from the East Peruvian Basin. Northward, the Marañon Geanticline progressively disappears, being replaced by the »Olmos« and »Yupicruz« arches (fig. 1).

(5) The East Peruvian Basin, which was bounded by the Guianese and the Brazilian shields, received Neocomian clastic deposits, and in turn marine/deltaic sediments during upper Cretaceous times.

As of today, no sedimentological study of the Cretaceous series of the Peruvian Andes has been undertaken. This work constitutes an attempt at synthesizing the sedimentary evolution of the Northern part of the WPPF during the upper Cretaceous. Most of the data here provided concern the Cajamarca and the Jaén areas. But comparisons will be made with Central Peru, with the East Peruvian Basin and with the Huarmey Trough, in order to propose a general model of the evolution of the whole margin.

Stratigraphic data

BENAVIDES (1956) and WILSON (1963) subdivided the Andean Cretaceous series into lithologic Groups, Formations (Fm), and Members. We shall use their terminology (fig. 3). Each formation has been dated through exhaustive macrofauna collections and determinations (BENAVIDES 1956, WILSON 1963). Nevertheless, some of these ages must be revised in the light of more recent works (fig. 3).

The Inca Fm has been ascribed to the lower Albian by BENAVIDES (1956), although he noted the affinities between the Inca fauna and the French Clansay species (BENAVIDES 1956, p. 393) of upper Aptian age. Then, assignment of the Inca Fm (and of the equivalent Pariahuanca Fm) to the upper Aptian has been proposed by REYES (1980), JANJOU (1981), and ROMANI (1982, after a suggestion of THIEULOU).

Following the conclusions of the Congress of Lyon on the lower Cretaceous stratigraphy (LYON 1963),

VON HILLEBRANDT (1970) suggested that the Chulec and Pariatambo Fms are older than assumed by BENAVIDES (1956) (see discussion in VON HILLEBRANDT 1970). However, the Pariatambo Fm being defined by its bituminous facies, the formation may be diachronic (see discussion in JAILLARD 1986).

In the Jumasha Fm of Central Peru, microstratigraphic particulars were given by VON HILLEBRANDT (1970) and by ROMANI (1982) (see discussion in JAILLARD 1986, summarized on fig. 3).

In Northern Peru, BENAVIDES (1965) assigned the Romirón Fm to the upper Cenomanian. Nevertheless, the presence of *Acanthoceras* species in this formation suggests a middle Cenomanian age (KENNEDY pers. com.), whereas *Neolobites kummeli* (= *N. vibryanus*, KENNEDY and JUIGNET 1981) and *Forbesiceras* sp. indicate an upper Cenomanian age for the upper part of the Romirón Fm (fig. 3).

The discovery of *Globotruncana* gr. *praevelvetica* associated with *Pseudodinia drorimensis* (det. of HAMAOU) in the upper part of the Cajamarca Fm of Northern Peru suggests a lower to middle Turonian age for this formation (HAMAOU pers. com.). The absence of upper Turonian deposits is therefore possible.

Finally, The presence of Maastrichtian ammonites in the Celendín Fm in the Northern part of the WPPF (RIVERA 1956) has recently been disproved (MOURIER et al. 1986). Latest unpublished data indicate that the Celendín Fm locally reaches up to the middle Campanian in the Jaén area (MOURIER pers. com.). In Central Peru, this formation does not go beyond the Santonian age (MEGARD 1978) and it then appears to be diachronic. On the other hand, WILSON (1963) regarded the Celendín Fm of Central Peru as solely Santonian in age. But the ammonites he collected from this formation are both Coniacian and Santonian in age (see discussion in JAILLARD 1986).

These stratigraphic revisions are summarized on fig. 3.

NORTHERN PERUVIAN ANDES			CENTRAL PERUVIAN ANDES		
V. Benavides	1956	this work	main reported fossils	this work	J.J. Wilson 1963
lower ? SANTONIAN	CELENDÍN	CAMPANIAN-SANTONIAN	Lenticeras baltai, Desmophyllites gaudana, Texanites sp., Tisotia sp. ... (1,2)	lower ? SANTONIAN	SANTONIAN
CONIACIAN		CONIACIAN	Buthiceras bilobatum, Barroiseras sp., Heterotissotia sp., Tisotia sp. ... (1,2)	CONIACIAN	
TURONIAN	CAJAMARCA	upper ?	Colopoceras newelli (1)	TURONIAN	
URONIAN		middle	Globotruncana gr. praeahelvetica (3)		
URONIAN			Pseudodoma dromiensis (3)		
URONIAN	COÑOR	lower	Mamites nodosoides, Thomasites sp., Colopoceras jenkinsi, Pseudospidoceras sp., Inoceramus labiatus, Vascoceras sp. (1)		
URONIAN			Neolobites vibrejanus (= kummeli) (1,5)		
CENOMANIAN	ROMIRÓN	upper	Acanthoceras chasca (1)		
CENOMANIAN			Forbesiceras sp.		
CENOMANIAN	MUJARRÚN	middle	Acanthoceratidae		
CENOMANIAN			Exogyra africana		
CENOMANIAN			Exogyra cf. Exogyra ponderosa (1)		
CENOMANIAN		lower	Mariella lewesiensis (1)		
CENOMANIAN			Nummuloculina heimi (7)		
CENOMANIAN	YUMAGUAL	upper	Ostrea scyphax		
CENOMANIAN			Engonoceras sp. (1)		
ALBANI		upper	Oxytropidoceras carbonarium, Venezoloceras sp., Lyelliceras lyelli, Dipoloceras sp., Inoceramus salomoni. (1,2)	ALBANI	
ALBANI	PARIATAMBO	middle		middle	PARIATAMBO
ALBANI			Lyelliceras lyelli, Knemiceras raimondi, Douvilleiceras monile, (1,2)		
ALBANI	CHULEC	lower	Profanisoceras blancheti, Parenconoceras sp. (1,2)	lower	CHULEC
ALBANI			Knemiceras ollonense (1)		
ALBANI	INCA	upper	Parahoplites nicholsoni, P. inti, P. quilla. (2)	upper	PARIAHUANCA
ALBANI		APTIAN		APTIAN	lower
GOYLLARISQUIZGA GROUP NEOCOMIAN					

Fig. 3. Stratigraphic synthesis of the marine Cretaceous sediments of the West-Peruvian Platform in Central and Northern Peru.

References: (1): BENAVIDES 1956; (2): WILSON 1963; (3): JAILLARD unpublished; (4): ROMANI 1982; (5): KENNEDY & JUIGNET 1981; (6): VON HILLEBRANDT 1970; (7): JANJOU 1981.

Sedimentological data

Our personal data mostly concern the late middle Albian to Campanian interval. Therefore, we shall use bibliographic data and spot observations to sum up the evolution of the older deposits.

I. The Upper Aptian to Middle Albian transgression

During Neocomian times, the WPPF were submitted to a delta-controlled siliciclastic sedimentation

(Goyllarisquiza group). From upper Aptian times up to Santonian or Campanian times, the sedimentation on the WPPF is mostly marine. This period began with a widespread transgression of upper Aptian to middle Albian age. These deposits have been divided into three formations.

A) The Inca Fm

(80 to 200 m, upper Aptian (and lowermost Albian?))

The formation consists of iron-rich, often sandy, sometimes oolitic, marl-limestones sequences (BENAVIDES 1956, COBBING et al. 1981). To the East, the sandstone ratio increases and the formation grades into the upper part of the Neocomian Goyllarisquiza group (BENAVIDES 1956, JANJOU 1981, JANJOU et al. 1981).

At the base, erosional surfaces (WILSON and REYES 1964, WILSON 1984), disconformities (COBBING et al. 1981), basal conglomerates (BALDOCK in press, BENAVIDES 1956), breccias (WILSON 1984), local volcanic manifestations (PAREDES 1982), and minor syn-sedimentary normal faults and slumpings indicate a minor tectonic instability.

In the type locality (fig. 4), only a basal ferruginous crust has been observed. In this place, the Inca Fm can be subdivided into three sequences (fig. 4; HIGA inedited work). The whole formation constitutes a transgressive megasequence, from proximal, shallow platform to deeper, open shelf environments. The top of the Inca Fm is a coarse nodular reworking surface, which could represent a sedimentation gap of early lower Albian age.

B) The Chulec Fm

(100 to 400 m, Lower Albian to early middle Albian)

This formation consists of a monotonous succession of thin marl-limestone sequences, in which no detailed studies have been made. The fauna is very abundant and diversified: echinoids, oysters, pectinids and other bivalves, gastropods, serpulids, *hedbergellae* ..., with very numerous ammonites, indicating an outer shelf environment.

Sand and marl increase eastward; tuff levels appear northward (WILSON 1984, BALDOCK in press). To the West, the formation thins out (WILSON 1984) and becomes more calcareous (BENAVIDES 1956).

C) The Pariatambo Fm

(80 to 200 m, Middle Albian)

It is characterized by black, bituminous, fetid, marly limestones, which often include laminae and cherts. The typical fauna consists of numerous am-

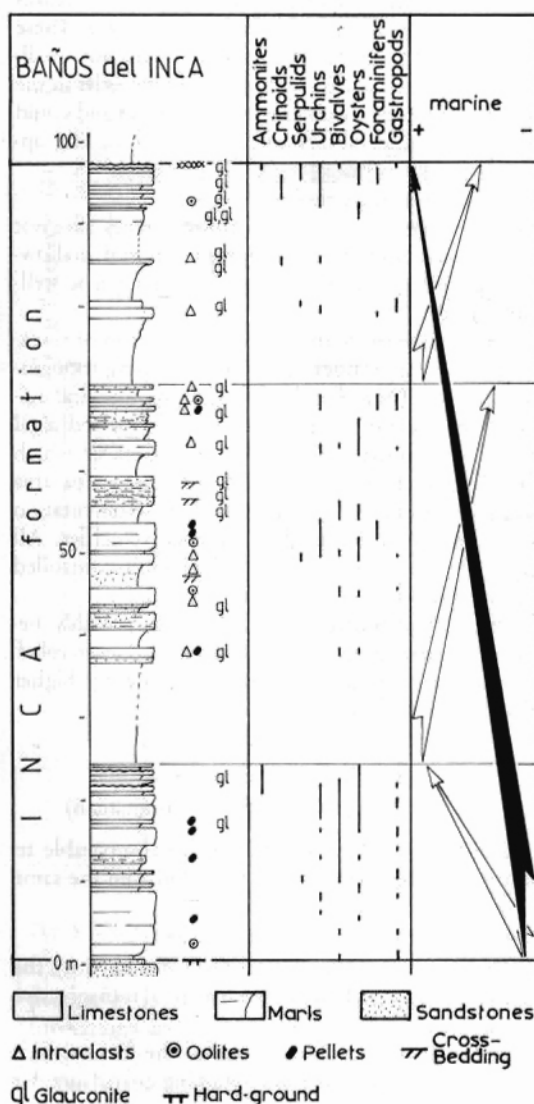


Fig. 4. Section of the Inca Fm (upper Aptian) at Baños del Inca (after E. Higa unpublished).

monites, fish teeth or scales (BENAVIDES 1956), planctonic Foraminifera (Hedbergellae), and some Inoceramids. Locally, other bivalves, oysters, and gastropods can be found. The Pariatambo Fm is interpreted as a deposit of moderately deep outer shelf environment in anoxic conditions. However, this anaerobic facies locally disappears, particularly to the North (JANJOU 1981) and to the East of the WPPF (BENAVIDES 1956, JANJOU *et al.* 1981, WILSON 1963). The bituminous Pariatambo limestones are regarded as representing in Peru the Albian Anoxic Event (OAE₁) (SCHLANGER and JENKINS 1976, JENKINS 1980).

Another noteworthy feature of this formation is the abundance of volcanic sills and of tuff levels, especially toward the Western parts of the WPPF (WILSON 1984, BALDOCK *in press*).

In summary, the Inca transgressive formation marks the beginning of the so-called Albian transgression, and seems to be coeval with a minor tectonic instability. The Chulec and Pariatambo Fms represent the lower to middle Albian transgressive maximum. The latter is contemporaneous with a well-marked anoxic event, and with local sills and dykes swarm.

II. The upper Albian to middle Cenomanian sedimentation

About the end of middle Albian, the bituminous marls and limestones grade into nodular marly limestones showing the development of carbonate shelf sedimentation which will continue, together with local deltaic influences until part of the middle Cenomanian. These sediments form the Yumagual and the Mujarrún Fms (BENAVIDES 1956). The Cenomanian sedimentation has been studied along two paleogeographic traverses.

A) The Yumagual Fm (50 to 400 m, late middle Albian to lower Cenomanian)

1- The Cajamarca traverse (fig. 5)

In the Cajamarca area, the Yumagual Fm begins with marl-limestones regressive sequences of outer shelf environment, which become more calcareous upward (shallow inner shelf environment). Lack of any oolitic or reef deposits, together with the abundance of algae, of bioturbations, and of shell beds, indicate a flat, sheltered, calm sedimentary environment. In the most regressive levels, the advent of plant-bearing sandstones denotes the progradation of an adjacent eastern delta.

The facies repartition illustrates a SWward deepening slope. Parallely, massive algae-rich limestones of

shallow environment are much thicker to the NE, thus indicating a probable diachronic progradation from the NE to the SW. The terrigenous distribution is more abundant in the NE area, where it accompanies frequent supratidal facies (fig. 5). Hence, the platform was bordered by a NE clastic system, viz., the Cenomanian delta of the East Peruvian Basin (Agua Caliente Fm, RODRIGUEZ and CHALCO 1975, SOTO 1979).

Facies succession demonstrates the shallowing-upward evolution of the formation. Three sequences can be recognized (Yu₁ to Yu₃, fig. 5).

JANJOU mentions large-scale slumping structures in the Yumagual Fm in the La Encañada area. These disturbances have not been found again, but small-size slumps associated with minor faults exist in the Yumagual Fm of the Sucre section (fig. 5) and could indicate local instability of the platform during uppermost Albian times.

2- The Jaén traverse (fig. 6)

In the Jaén area, the Yu₁ to Yu₃ sequences have not been clearly identified, though the general shallowing-upward evolution of the Yumagual Fm is well-supported.

The variability both of facies details and of thickness indicates an uneven, SWward sloping topography (fig. 6). Then, shoals with shallow, low, and agitated sedimentation (frequent oolitic or red algal facies), delimited sheltered, deeper areas in which facies comparable to those of the Cajamarca area were deposited, and where higher sedimentation rates suggest differential subsidence velocities. All these observations suggest a mobile, fault-controlled topography (fig. 7).

The clastic contribution is lacking, possibly because of entrapping farther N-E by the uneven relief. The average depth of deposition is slightly higher than in the Cajamarca area.

B) The Mujarrún Fm (60 to 300 m, early middle Cenomanian)

The facies and environments are comparable to those described for the Yumagual Fm, and the same two traverses will be described.

1- The Cajamarca traverse (fig. 5)

Three sequences can be defined (Mu₁ to Mu₃), the succession of which illustrates a general transgressive trend.

In San Juan (fig. 5), the base of the formation is marked by a thick breccia containing coarse angular clasts from the whole Cretaceous series. These breccias possess a sandy, marly matrix and can fill open cracks. This important synsedimentary tectonics ap-

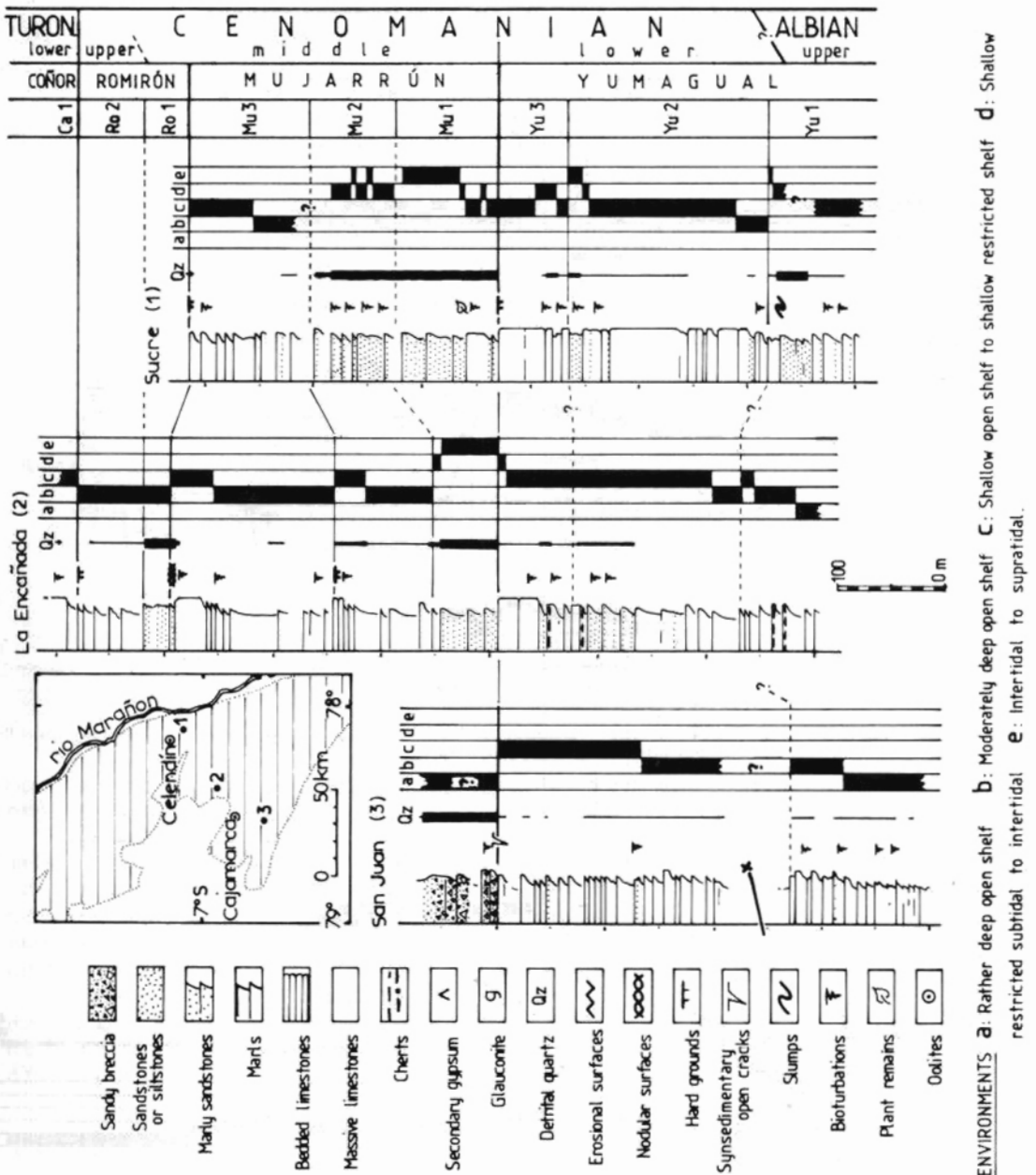


Fig. 5. The Cenomanian sedimentation along the Cajamarca traverse. Inset: Location sketch.

pears to be marked, S-W of Bambamarca, by olistolite formations and by volcanic activity (PAREDES pers. com.).

Farther N-E, the WPPF is invaded by thick levels of fine-grained sandstones (Mu₁, fig. 5) proceeding from the eastern delta, and showing abundant intertidal to continental sedimentary figures.

In the following shallowing-upward sequences (Mu₂ and Mu₃, fig. 5), the amount of sand diminishes, and the depth of deposition increases. To the N-E, terrigenous clastic contribution still remains noticeable, and the algae-rich limestones are poorly developed (fig. 5).

The Mujarrún Fm is capped by a marked discon-

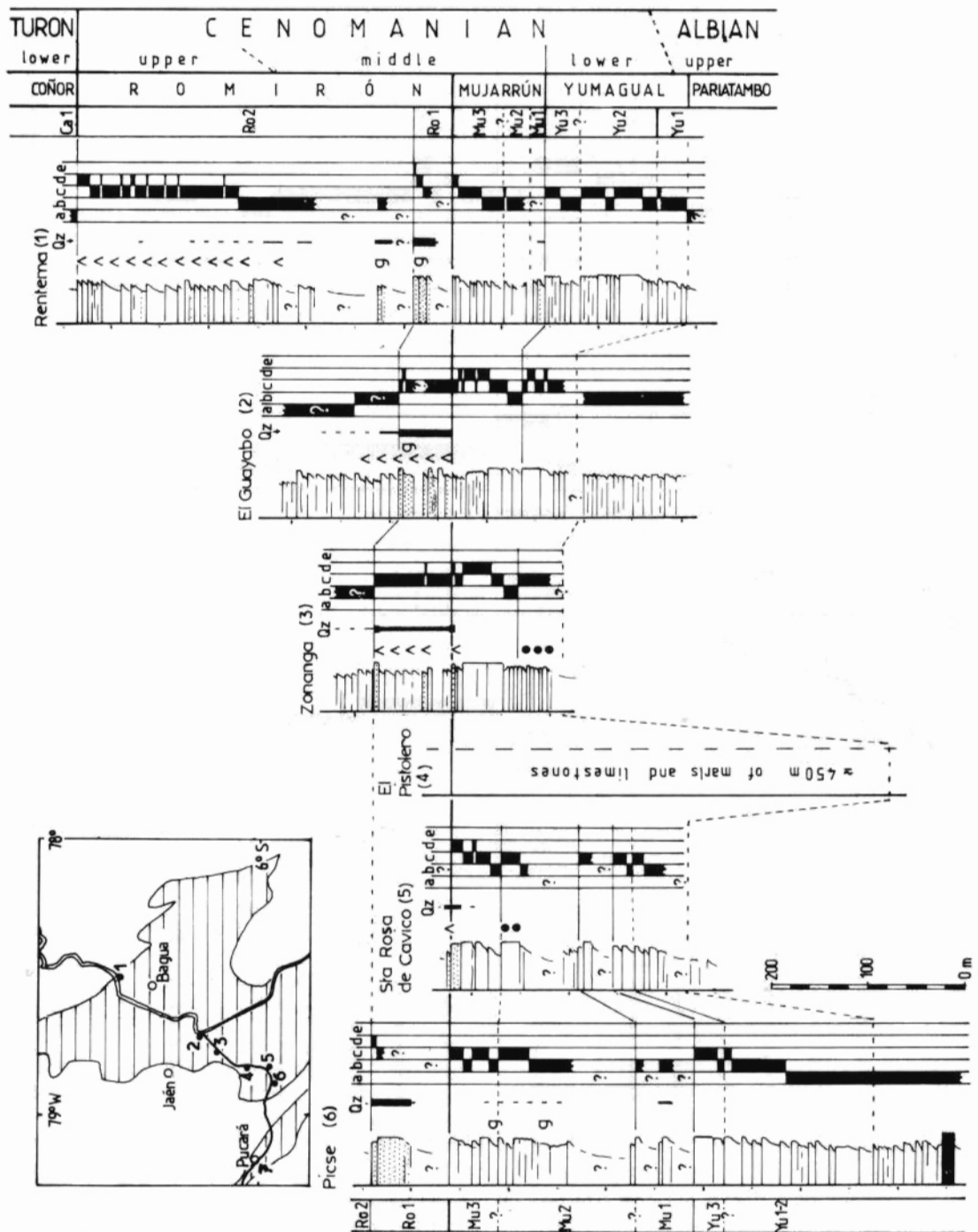


Fig. 6. The Cenomanian sedimentation along the Jaén traverse. Inset: Location sketch; Same captions as fig. 5.

tinuity, which is represented by a hard-ground or by an ammonite-bearing, coarse, nodular surface.

2- The Jaén traverse (fig. 6)

As in the preceding Yumagual Fm, the sedimentary sequences have not been clearly recognized. The Mujarrún Fm shows a shallowing-upward evolution,

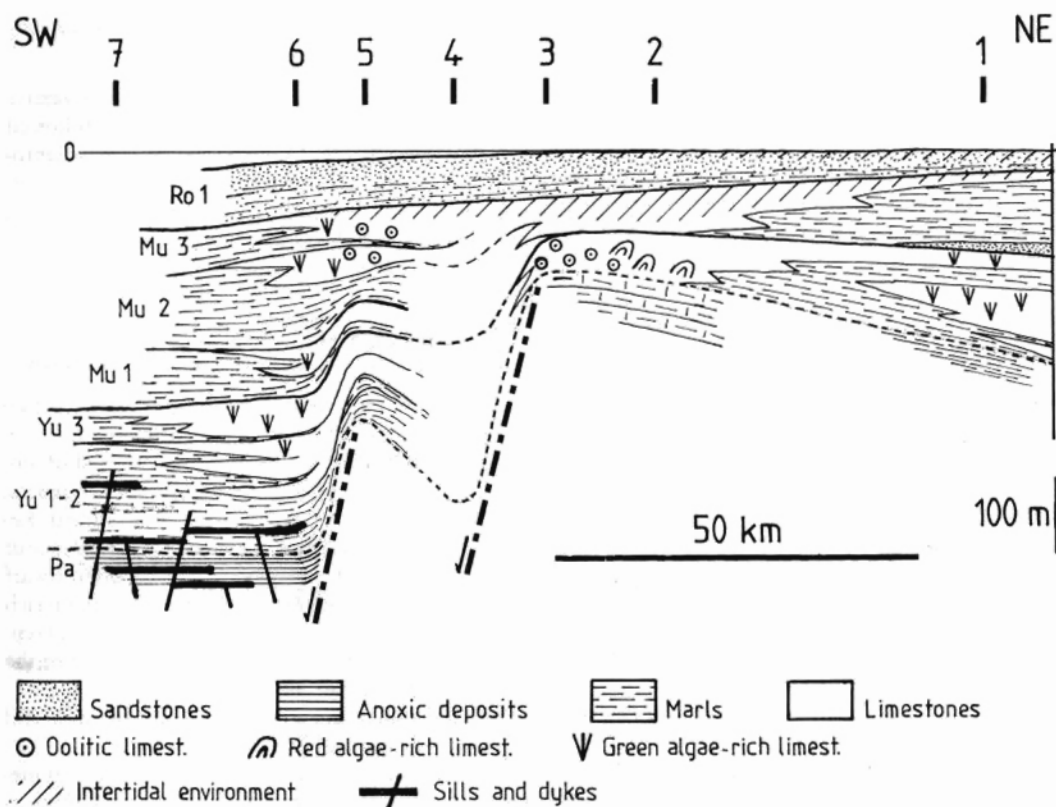


Fig. 7. Model of fault-controlled sedimentation along the Jaén traverse from upper Albian to early middle Cenomanian. For location (1 to 7) see inset fig. 6.

and its top exhibits emersion facies in the whole N-E part of the traverse. No syndimentary tectonic features have been encountered, and the scarcity of siliceous detritics suggests that the platform was sheltered from deltaic influences by a N-E swell.

Both deposition depth and sediment thickness remain variable (fig. 6); these features suggest a remaining fault-controlled paleotopography and an active differential subsidence (fig. 7).

C) Conclusions about the upper Albian-middle Cenomanian sedimentation

From upper Albian up to lower Cenomanian times, the WPPF underwent a regressive evolution, whereas since the middle Cenomanian, a transgressive trend began.

The lower to middle Cenomanian boundary is marked by a regressive maximum, by local syndimentary tectonic features, by the arrival of N-E-proceeding deltaic sandstones (Cajamarca area), and by a probably fault-controlled sedimentation (Jaén area). These observations suggest a relative sub-

stratum mobility due to a noticeable tectonic activity, especially around the lower to middle Cenomanian boundary.

III. The late middle Cenomanian to upper (?) Turonian sedimentation

To that period correspond the Romirón Fm, the Coñor Fm, and The Cajamarca Fm.

A) The Romirón Fm (60 to 400 m, late middle Cenomanian to upper Cenomanian)

Everywhere in the Northern part of the WPPF, the Romirón Fm begins with a 20- to 80-meter thick, coarsening-upward sequence (Ro₁) of glauconitic calcareous sandstones (fig. 5 and 6) (JAILLARD *et al.* 1985). However, whereas this sandy level is deposited in marine conditions in the W or S-W parts of the WPPF, its top denotes an intertidal environment along the N-E fringe of the platform. This indicates a persistent S-Wward-sloping topography and a N-E origin for these sandstones.

In the overlying marls (Ro₂), the sand amount generally decreases upward, and the fauna indicates deeper outer shelf conditions (fig. 5). However, in the N-E areas, the whole Romirón Fm shows numerous dessication cracks (JANJOU 1981, JAILLARD et al. 1985), and comprises often sandy, unusually thick deposits (fig. 5 and 6), thus expressing both the importance of the eastward flowing detrital material, and the rapid infilling of these areas.

B) The Turonian carbonate shelf (fig. 8)

The Turonian time is represented on the WPPF by two formations: The marly Coñor Fm (10 to 200 m, lower Turonian), and the Cajamarca Fm (50 to 500 m, middle Turonian).

Contrary to the lower to middle Cenomanian shelf, the Turonian sedimentation exhibits a fairly uniform sedimentary pattern. Two megasequences (Ca₁ and Ca₂) can be recognized and correlated all over the region (fig. 8) (JAILLARD 1985).

The lower Turonian Ca₁ sequence is a carbonate shelf progradation sequence. Its ammonite-rich, marly base (Coñor Fm) indicates a transgressive maximum, whereas its upper part consists of fine-grained, light coloured limestones (lower Cajamarca Fm), that represent the probably diachronic progradation of a very calm, shallow, open carbonate shelf, which maximum development occurs in the Cajamarca area, together with a minor depth of deposition (fig. 8).

The Ca₂ sequence (upper Cajamarca Fm) also expresses a carbonate shelf progradation process, but the association of both planctonic (Pithonellae, Globotruncanidae) and benthic Foraminifera (Alveolinidae) with algae indicates a shallow, but wide open environment. Moreover, the badly marked regressive trend (JAILLARD 1985) suggests a drowned-platform sedimentation (KENDALL and SCHLAGER 1981, READ 1982), thus recording a slight sea-level rise during middle Turonian times in this area. The Ca₂ sequence is capped by a hard-ground in the Northern parts, and by an iron-rich, nodular discontinuity surface in the southern parts of the area (fig. 8).

In summary, the transgressive trend which started during the middle Cenomanian, went on during the upper Cenomanian. The WPPF recorded a transgressive maximum during lower Turonian times. During the late Cenomanian, the inflow of detrital material remains strong in the N-E parts of the WPPF. Since lower Turonian times, a very calm, even, open carbonate shelf developed, whose latest deposits recorded a slight sea-level rise.

IV. The Coniacian to middle Campanian sedimentation

This period is characterized by a transgressive maximum of Coniacian-Santonian age. It is followed by a major, probably diachronic regression of Santonian to middle Campanian age, which is due to the »Peruvian« tectonic phase (STEINMANN 1929, MOURIER et al. 1986), and which leads to the deposition of upper Senonian continental Red Beds.

A) The Celendín Fm (up to 300 m, Coniacian to middle Campanian)

Because of its crumbly lithology and of subsequent erosion, it is, as a rule, poorly exposed. In Rentema (MOURIER et al. 1986), it is composed of ammonite-rich, marl – nodular limestones sequences, which denote a rather deep marine environment. Restricted conditions are expressed by the abundance of secondary gypsum and pyrite, and of often dwarf monospecific shell-beds. In Rentema, sulphur-rich black shales in the upper part of the section could represent the well-known Oceanic Anoxic Event of the Coniacian-Santonian limit (JENKINS 1980).

Detrital quartz and volcanic sand are common and appear to be more abundant to the West.

Marine sedimentation ends with a few tens of meters of marls, grading (at least locally) into continental Red Beds. The uppermost marine levels have yielded a middle Campanian ammonite fauna in the Jaén area (MOURIER pers. com.). In other areas, only lower Santonian, or even Coniacian faunas are known (BENAVIDES 1956, JANJOU 1981, COBBING et al. 1981, WILSON 1984).

B) The Senonian regression and the upper Senonian Red Beds

The apparent diachronism of the top of the Celendín Fm can be ascribed to erosion before the Red Beds were deposited (WILSON 1984). But a true large-scale diachronism of the regression is proved by the fact that the top of the Celendín Fm is of middle Campanian age in the Jaén area, whereas the lowermost Red Beds were locally dated of Santonian age in Central Peru (MEGARD 1978).

The lowest Red Beds are fluvial, flood plain, or lacustrine green or red marls which are rich in calcareous stromatolitic crusts, and which comprise thin beds of sandstones (MOURIER et al. 1986). This continental marly sedimentation is disconformably overlain by coarse-grained, sandy conglomeratic fluvial deposits, rich in dinosaurian and mammalian fragments (MOURIER et al. 1986).

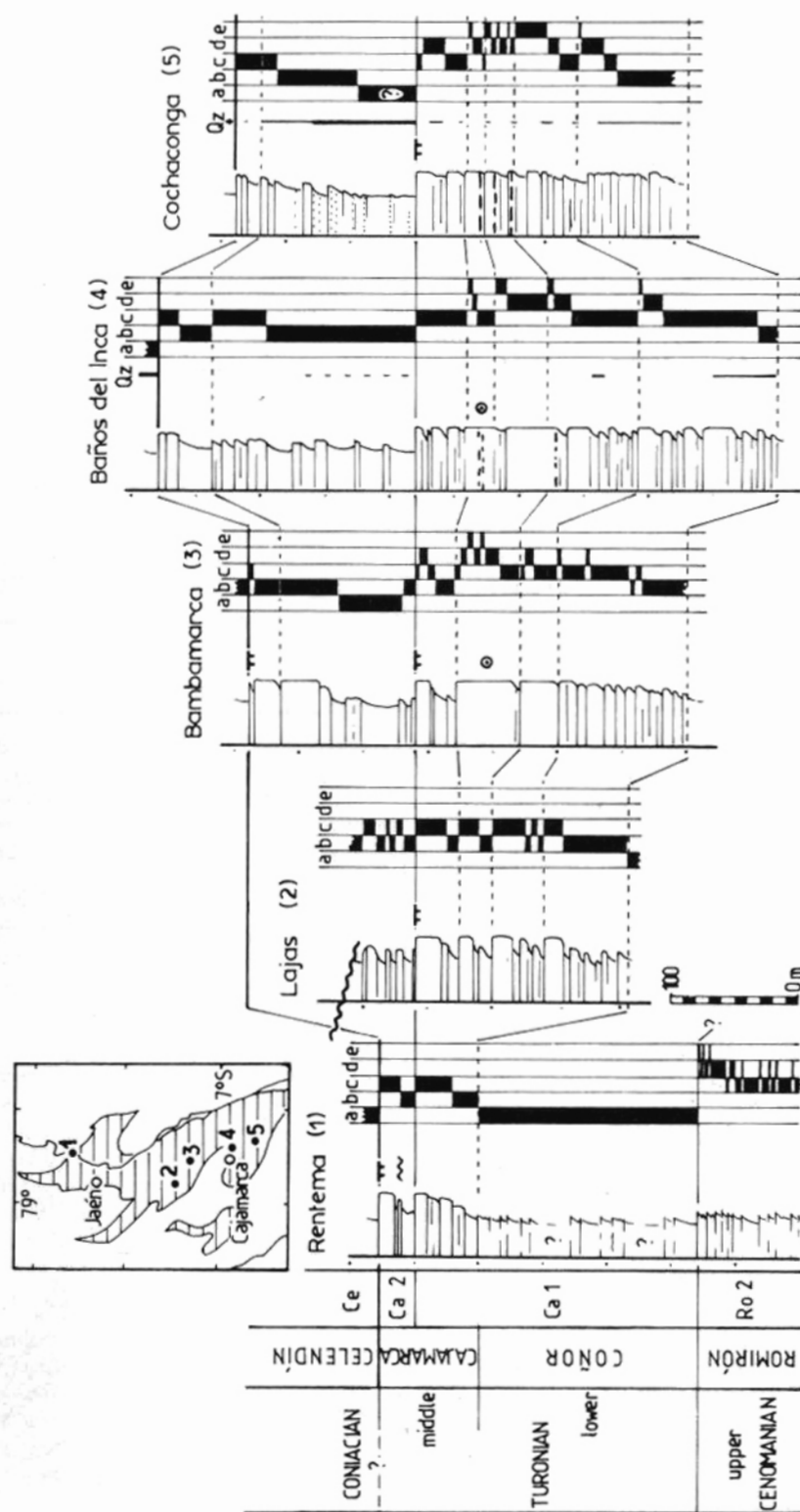
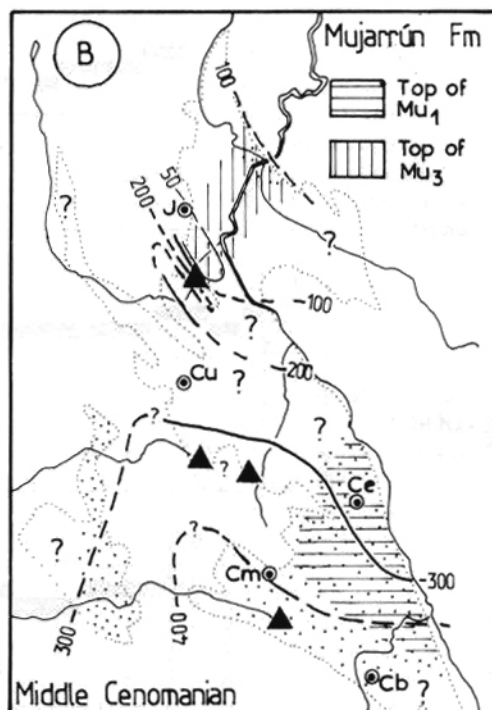
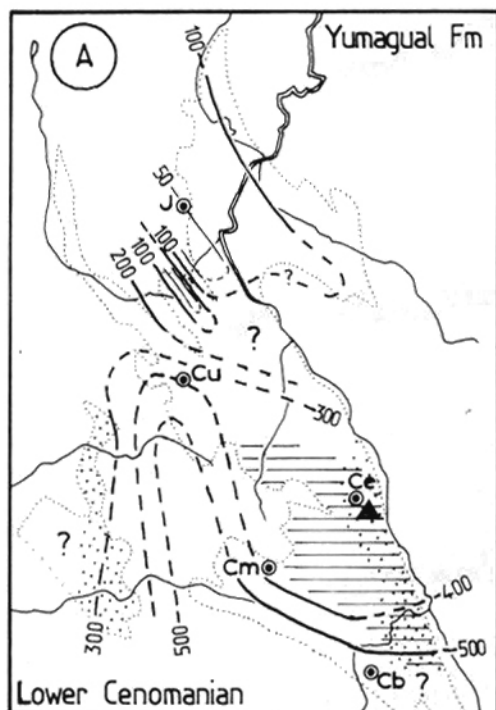
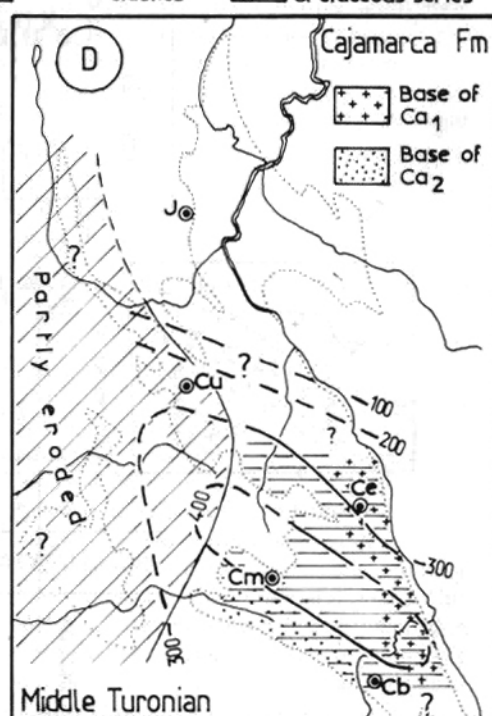
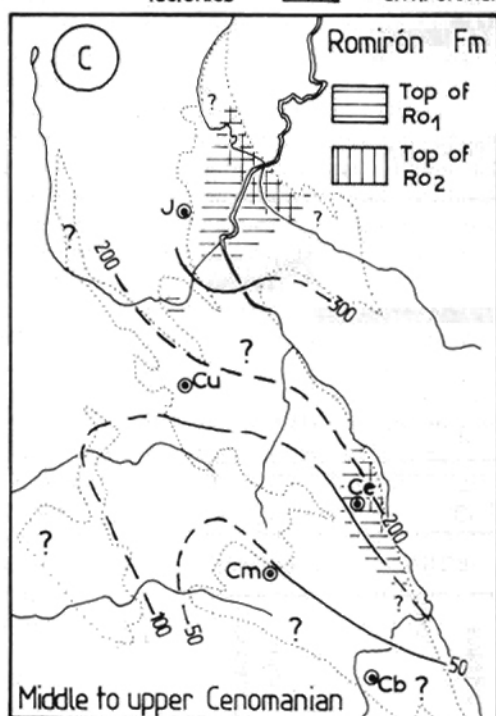


Fig. 8. The Turonian sedimentation through the Northern part of the West-Peruvian platform. Inset: Location sketch; Same captions as fig. 5.



Cb: Cajabamba Ce: Celendín Cm: Cajamarca Cu: Cutervo J: Jaén — 100 Isopachs
 ▲ Syntectonic tectonics Intertidal environment Siliceous clastics Outcrops of upper Cretaceous series



Hence, it seems that two distinct events composed the so-called Peruvian phase in the Jaén area. Firstly, a diachronic uplift of Santonian to middle Campanian age led to the deposition of fine-grained continental levels. There, followed a second tectonic event, which induced the disconformable deposition of coarser-grained conglomeratic beds of uppermost Senonian age.

Note that this second event could be related to the second Red Bed level deposition in the Eastern Andean basins (Cachiyacu Fm, SOTO 1979; or Tena Fm, BRISTOW and HOFFSTETTER 1977), of Maastrichtian age, and could be correlated with the 70 M y. event recorded in the Western Huarmey Trough (WEBB 1976, AGUIRRE and OFFLER 1985).

Paleogeography

The paleogeographic sketches presented on the fig. 9 suffer from paucity of data about the Cutervo, the Cajabamba, and the Western areas. They nevertheless reveal important features.

A) Spatial and evolutionary contrasts (fig. 9)

Whereas, during upper Albian to middle Cenomanian, the paleogeography is contrasted and some paleostructures are locally active (fig. 7, 9A and 9B), the activity of the latter clearly diminished during Turonian time (fig. 9D). This change may be ascribed to the levelling effects of the mid Cenomanian deltaic advances, but also more probably to the opposition between an unstable tectonic context during upper Albian to early middle Cenomanian times, and a tectonic quiescence during late middle Cenomanian to upper Turonian times.

The Jaén area has uneven and weak subsidence rates during lower and middle Cenomanian (fig. 9A), whereas it shows a strong sedimentation rate during late middle Cenomanian to lower Turonian times (fig. 9C). This region appears as a rather mobile zone, affected by fault motions, especially during lower to middle Cenomanian times. This could be explained by its location at the latitude of the hinge »Huanabamba deflexion« (GANSER 1973, AUBOUIN 1973).

B) Paleogeographic structures (fig. 10)

Andean, NNW-SSE-trending, longitudinal paleogeographic structures have already been described (BENAVIDES 1956, WILSON 1963, WILSON and REYES 1964, WILSON et al. 1967, COBBING et al. 1981, JANJOU 1981, JANJOU et al. 1981). They appear clearly along

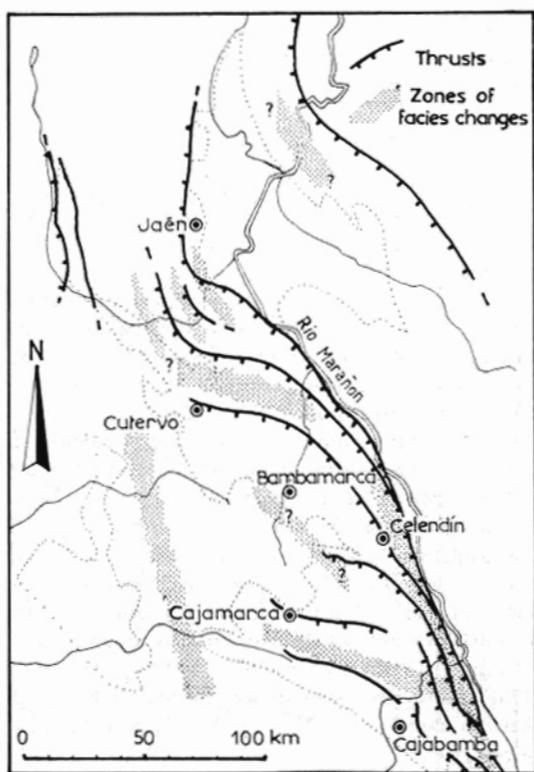


Fig. 10. Sketch map showing the relationship between paleogeographic and tertiary, tectonic structures.

the Marañon swell, where their effects certainly are magnified by the andean shortening (Marañon Thrust and Fold Belt, MEGARD 1984). It seems that these NNW-SSE-trending faulted structures controlled the paleotopography of the Cenomanian platform in the Jaén area (fig. 7, and 9A), though the interaction of two paleodirections is probable.

Other major zones of facies changes appear to possess a direction oblique to the present-day axis of the Andean Cordillera (fig. 10). One of these lines lies North of Cutervo, a second one exists a little South of Cajamarca, and both show a ESE-WNW trend. A third paleolineament with a NW-SE-trending direction is suspected by JANJOU (1981) South of Bambamarca. Some of these oblique structures acted since the Jurassic (REYES 1974, COBBING et al. 1981). They seem to be inherited from the hercynian structures that possess a NW-SE to WNW-ESE direction (DALMAYRAC et al. 1980, MARTINEZ 1980). They probably played a part in the WNW-ESE orientation

of the Andean tectonic structures North of 8° S (Though polyphased folding could also have been involved (HOLLISTER 1977).

C) Distribution and significance of the detritism

At the beginning of the transgression, the upper Aptian siliciclastics (Inca Fm) is imputable to the decreasing deltaic influences.

BENAVIDES (1956) proposed to ascribe to lower to middle Cenomanian sandstones to the existence of an emerged source-zone. This is unlikely: as a matter of fact, good sorting, fine grain size, distribution (fig. 9A and 9B), and deposition conditions clearly show this sand coming from the S-W-ward progradation of the N-E Agua Caliente delta (SOTO 1979).

The increase of detrital material toward the S-W in the upper part of the Turonian platform (Ca₂, fig. 9D), suggests the existence of a S-W-located source zone at that time. It should be noted that the abundance of sandy detritism in the Cenomanian and Turonian deposits of the Westernmost outcrops led BENAVIDES (1956), MYERS (1975), and COBBING et al. (1981) to propose the existence of a now disappeared Western continental high land («Paracas geanticline»).

Comparison with neighbouring areas

I. Comparison with the West-Peruvian Platform of Central Peru

In the Andes of Central Peru, the upper Aptian to upper Albian sedimentation is rather similar to that of Northern Peru (WILSON 1963, VON HILLEBRANDT 1970, MEGARD 1968, 1978, ROMANI 1982).

There, the upper Albian to upper Turonian interval is represented by one single, mostly calcareous formation, called the Jumasha Fm. A section has been studied near Oyón, and correlations with the North Peruvian Andes have been proposed (fig. 11) (JAILLARD 1986).

The Jumasha Fm is characterized by the presence of three marly ledges (fig. 11), each one materializing a transgressive stage. The proposed correlations are shown on the fig. 11, and call for the following remarks:

- The first marly level of the Jumasha Fm (base of Ju₂) seems to be equivalent to the probably contemporaneous base of the Yu₂ sequence.
- The regressive maximum of Cenomanian age (Ju₃), which is associated with tectonic features, is clearly correlatable with the Mu₁ sequence of Northern Peru, which possesses the same features.

- The third marly level which corresponds to the major mid-Cenomanian deepening stage in Central Peru (base of Ju₆) is contemporaneous with the Ro₂ sequence of Northern Peru, also characteristic of a major transgressive stage. This correlation has already been proposed by von HILLEBRANDT (1970).

However some differences do exist:

- No clastics are visible in Central Peru, where the Marañón swell acted as an efficient sheltering swell at this latitude. Thus, the mid-Cenomanian sedimentation took a development much greater than in the North, and some discontinuities are differently expressed (e.g. the base of the Ju₃ = Mu₁ sequences).
- In Central Peru, the mid-Cenomanian sedimentation (and subsidence) rate is much more important than in Northern Peru.

Nevertheless, the sedimentary evolution of Central Peru is comparable to that of Northern Peru, and the main sequences appear to be fairly well correlatable (fig. 11). This proves that tectonic events did not obliterate the eustatic phenomena which mainly controlled the sedimentation all over the West-Peruvian Platform.

II. Comparison with the East-Peruvian Basin and with the Ecuadorian Oriente.

A sketch of the general features of the East-Peruvian sedimentation has been proposed (fig. 12) after the stratigraphic works of KUMMEL (1948), ROSENZWEIG (1953), DUCLOZ and RIVERA (1956), ZEGARRA (1964), GUTTIEREZ (1975), and ALVAREZ (1979), and after the sedimentologic studies of SANZ (1974), RODRIGUEZ and CHALCO (1975), SOTO (1979) and MARTINEZ (1980). A similar sketch has been made for the Ecuadorian Oriente, after the works of TSCHOPP (1953), BRISTOW and HOFFSTETTER (1977), and CANFIELD et al. (1981) (fig. 12).

The important facts are as follows:

- The Albian transgression seems to begin during the early Albian. It reaches its maximum, with bituminous deposits during the middle Albian (Raya Fm and lower marls of Lower Napo Fm).
- The deltaic sandstones of the Agua Caliente Fm, and the «middle sandstones» of the Lower Napo Fm can be correlated with the late Albian to early Cenomanian regression (Yumagual Fm of the WPPF).
- The upper parts of the Agua Caliente and Lower Napo Fms may represent the late Cenomanian transgression (Mujarrún Fm of the WPPF).

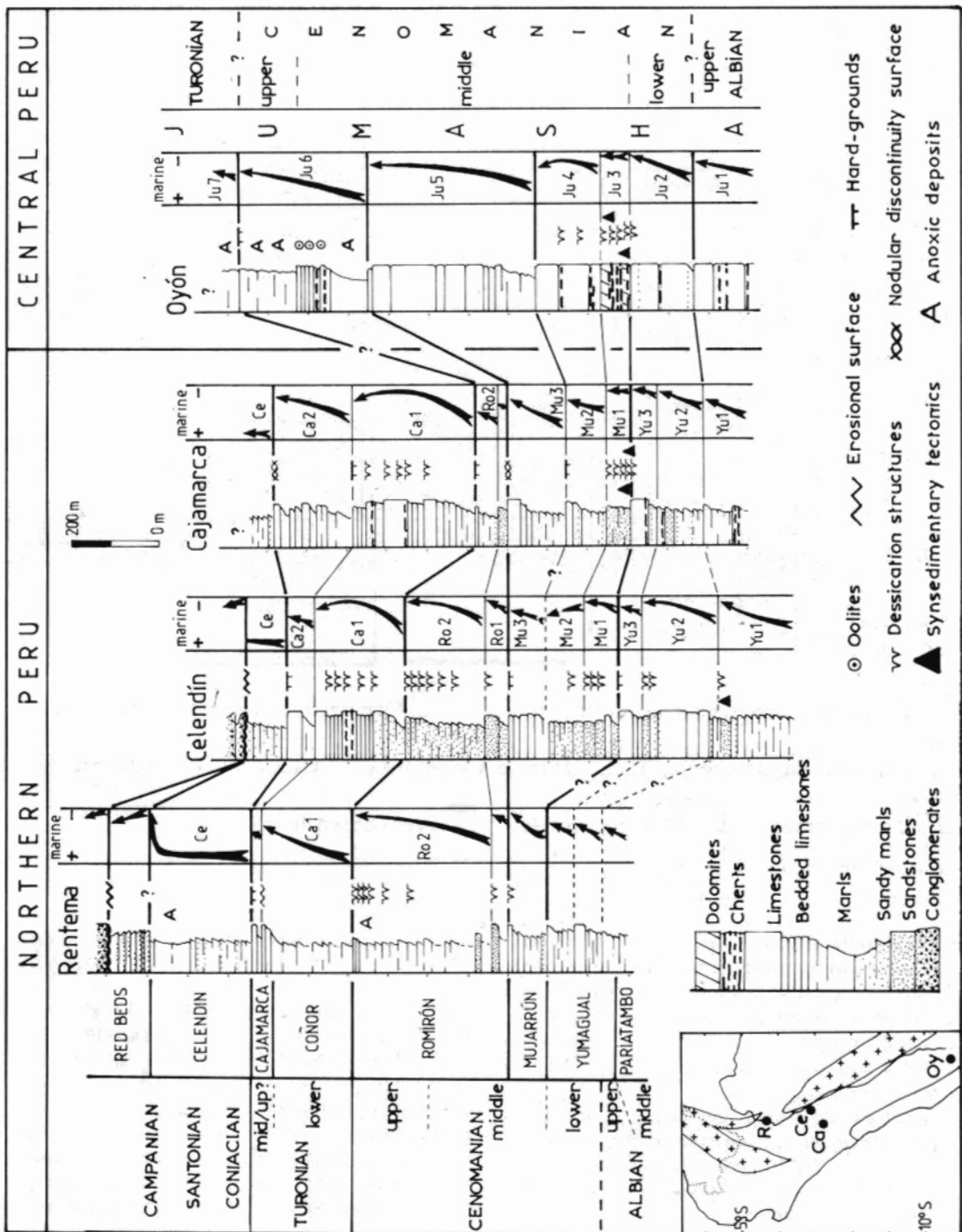


Fig. 11. Proposed correlations throughout the West-Peruvian Platform. Inset: Location sketch.

– The well-dated lower Chonta and the upper marls of the Lower Napo Fm (fig. 12) represent the early

Turonian transgressive stage (Coñor Fm of the WPPF).

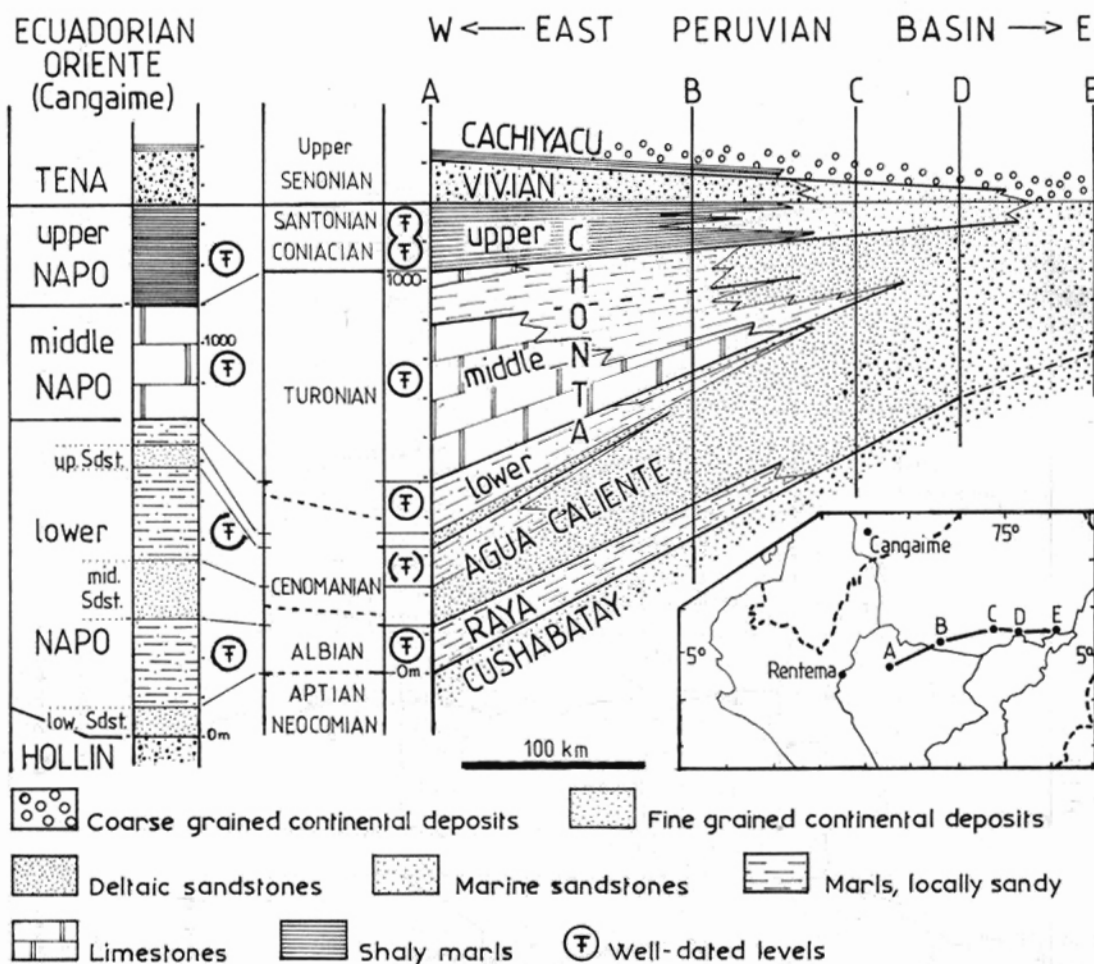


Fig. 12. Lithostratigraphy of the Eastern basins, with proposed correlations. Inset: Location sketch.

- The Middle Napo and the Middle Chonta limestones are equivalent to the mid-Turonian carbonate shelf sedimentation (Cajamarca Fm of the WPPF).
- The upper Napo and upper Chonta marls are stratigraphically equivalent to the Coniacian-Santonian transgressive maximum (Celendín Fm of the WPPF).
- The Tena and Vivian Fms of post-Coniacian to post-Santonian age are comparable to the Red Beds of the WPPF, and materialize there the so-called Peruvian tectonic phase (STEINMANN 1929, MOURIER et al. 1986).

The sedimentary evolution of the eastern basins is therefore very similar to that of the WPPF; especially, the upper Albian to middle Cenomanian regression is well represented by the deltaic sandstones of the Agua Caliente Fm.

III. Comparison with the Western Ensialic Marginal Basin (Huarney Trough)

The stratigraphy of the Huarney Trough series is known through the works of MYERS (1974, 1975, 1980), WEBB (1976), GUEVARA (1980), and COBBING et al. (1981) (fig. 13). Its tectonic and magmatic history was studied by MYERS (1974, 1975, 1980), WEBB (1976), PITCHER (1978), AGUIRRE et al. (1978, 1985), COBBING et al. (1981), COBBING (1982), ATHERTON et al. (1983, 1985), BUSSEL (1983), BUSSEL and PITCHER (1985), MOORE (1984), and MUKASA (1986).

The important facts are as follows (fig. 13):

- The upper Aptian (?) transgression is accompanied by local, thick conglomerates; it appears to be contemporaneous with the individualization of the Huarney Trough.

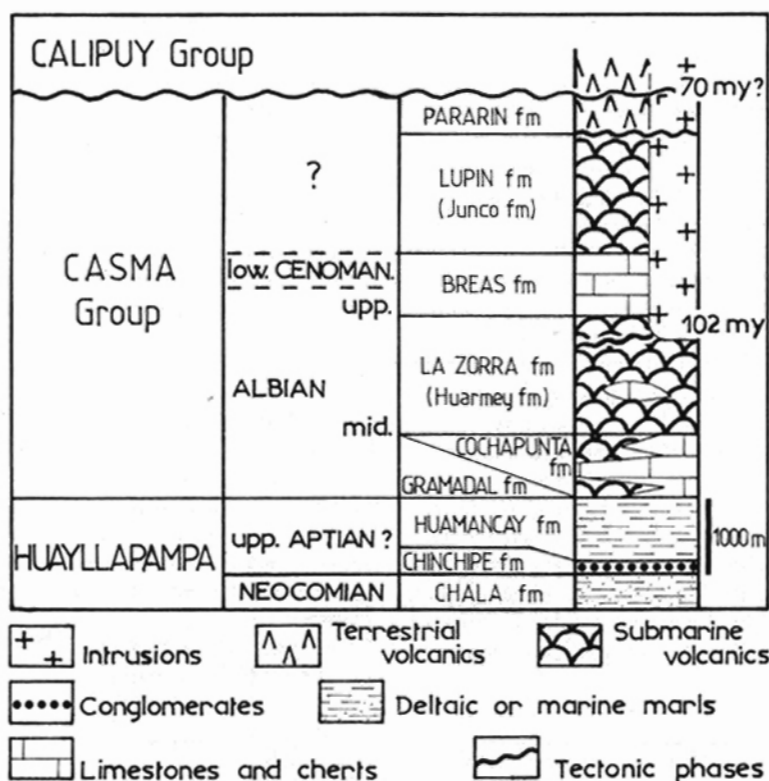


Fig. 13. Lithostratigraphy of the Huarney Trough ..

- Volcanic activity begins during lower (?) to middle Albian times.
- The deposits of well-documented middle Albian age are bituminous; They are rich in pyroclastics and in submarine andesitic flows. These formations are thus coeval with the first transgressive maximum of the West Peruvian margin. They accompany the period of distensive activity of the Huarney marginal basin (ATHERTON et al. 1983, 1985), and are associated with a strong geothermal gradient (AGUIRRE and OFFLER 1985).
- The marine sedimentation continued, at least locally, up to the upper Albian and lower Cenomanian, since the marine Breas Fm has yielded in the Lima area, a *Mortoniceratid* and a *Mantelliceras* sp. (GUEVARA 1980), and is overlain by submarine pillow-lava flows (Lupin Fm) (fig. 13).

However, the destruction of the marginal basin is generally regarded as upper Albian in age (MYERS 1975, PITCHER 1978, COBBING et al. 1981, COBBING 1982, MEGARD 1984), since gabbros which cut through granites of upper Albian age (102 my., WILSON 1975, MUKASA 1986) are intrusive into already folded Albian sediments (WILSON 1975, PITCHER

1978). Moreover, BUSSEL (1983, BUSSEL and PITCHER 1985) shows that a distension occurred during upper Aptian to late middle Albian (110 to 105 my.) which is materialized by basic lava emissions from fissures, and that a generally compressive phase followed from upper Albian up to Santonian (105 to 80 my.), which is associated with a high rate of strike-slip motion and with gabbroic to granodioritic intrusions.

This chronology is roughly consistent with the stratigraphically documented events: The upper Aptian to middle Albian transgression is coeval with the distensive activity of the marginal basin. The upper Albian to lower Cenomanian deformations of the Huarney Trough are coeval with the general regression recorded by the WPPF; and the closure of the Huarney marginal basin could explain the tectonic activity that affects the WPPF, especially at the lower to middle Cenomanian boundary.

Conclusions

In the Northern part of the Peruvian margin, marine sedimentation began with the upper Aptian transgression, which is accompanied by slight, local

instability. The transgression reaches its maximum during the middle Albian; it is associated with widespread anoxic deposits, and with sills and dykes intrusions. It is contemporaneous with the distensive activity of the Western marginal basin (fig. 14).

Since the upper Albian up to the lower Cenomanian, a general regression occurred, and was coeval with the appearance of compressive deformations in the marginal basin. The early to middle Cenomanian boundary is a period of regressive maximum, marked by widespread deltaic deposits, and by synsedimentary tectonic movements which seem to be in relation with the closure of the Huarmey Trough, which definitely emerged (fig. 14). At that time, the sedimentation is controlled by both hercynian, ESE-WNW-trending, and andean, NNW-SSE-trending paleo-structures.

Late middle Cenomanian times are characterized by a well-marked transgressive trend which is materialized by two major deepening stages. At earliest Turonian times, a third transgressive stage occurred, and was followed by the diachronic development of a calm, widespread carbonate shelf sedimentation (fig. 14).

A final deepening stage occurred at the base of the Coniacian, and this transgressive maximum is interrupted, from upper Santonian to middle Campanian, by an apparently diachronic uplift leading to the deposition of the Senonian continental Red Beds. These latter seem to record, during the uppermost Senonian, a tectonic event materialized by discordant conglomerates (fig. 14).

Then, this sedimentary evolution appears to be mainly controlled by world-wide sea-level rises, as shown by the comparisons with the eustatic curves (VAIL *et al.* 1977, HANCOCK and KAUFFMAN 1979, SCHLAGER 1981, MÖRNER 1980, MATSUMOTO 1980), or with the major sedimentary discontinuities recorded in other parts of the world (VAIL *et al.* 1980, JUIGNET 1980, FLOQUET 1983, FLEXER *et al.* 1986, ...).

But three tectonic events of increasing importance and extension disturb this evolution.

The upper Aptian minor event accompanies the upper Cretaceous transgression and seems to be coeval with the individualization of the Huarmey Trough.

The lower to middle Cenomanian event expresses a slight uplift of the margin. It is related to the com-

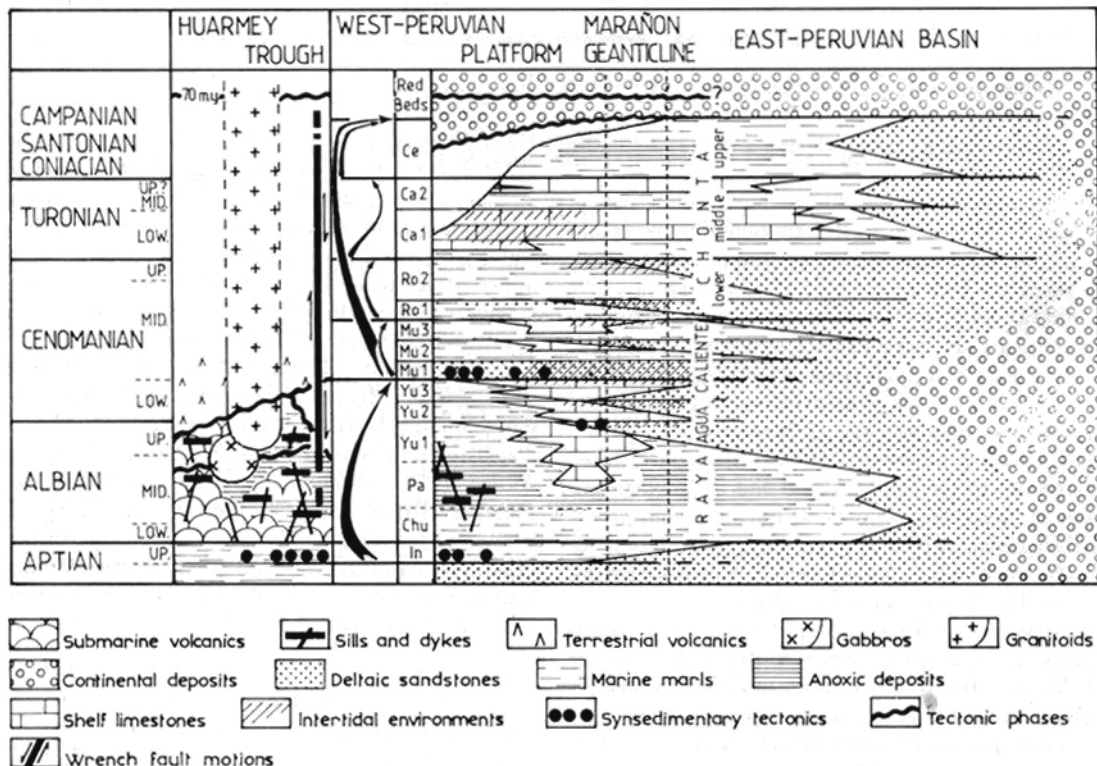


Fig. 14. Synthetic sketch showing the evolution of the North-Peruvian margin.

pressive mid-Cretaceous »Mochica phase« which brings about the closure and the emersion of the Huarmey Trough (fig. 14). This event is known along the whole Western margin of South America (CHOTIN 1976, NELSON et al. 1980, DALZIEL 1981, 1985, COIRA et al. 1982, ÅBERG et al. 1984).

Marine sedimentation ends on the North-Peruvian margin with the Peruvian phase, which appears to

comprise two distinct events of Santonian to mid-Campanian, and of uppermost Senonian ages respectively.

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