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Stratigraphy and evolution of the Cretaceous forearc Celica-Lancones basin of southwestern Ecuador

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Abstract

The "Celica–Lancones" forearc Basin of southern Ecuador and northern Peru is located between the Paleozoic Amotape–Tahuin Massif to the west and NW and the continental volcanic arc to the east and SE. The study of nine sections and exhaustive sampling of the poorly fossiliferous, mainly clastic Cretaceous deposits of this Basin allowed us to define five distinct series, which display two depositional periods.

The first period corresponds to the development of an Early (?) and Middle Albian carbonate shelf, interrupted during Late Albian times by the creation of a tectonically generated trough filled by turbidites of Late Albian–Coniacian age. Geological mapping indicates that this "Celica–Lancones Basin *s.s.*" includes distinct tectonic units, characterized by distinct early Late Cretaceous stratigraphic series and separated by major faults. These units can be grouped into two main paleogeographic domains. The southeastern one comprises mainly volcaniclastic deposits, whereas the northwestern domain exhibits quartz-rich deposits.

Between Early Coniacian and Middle Campanian times, the "Celica–Lancones Basin *s.s.*" forerarc trough was deformed and eroded as a result of the Late Cretaceous "Peruvian" tectonic phase. The second period corresponds to the latest Cretaceous, during which a new forearc basin was created (Paita–Yunguilla Basin), which is much wider and strikes obliquely with respect to the Celica–Lancones Basin. The sediments of the Paita–Yunguilla Basin exhibit a comparable succession of Campanian–Maastrichtian age throughout the area and conceal the tectonic juxtaposition of the early Late Cretaceous tectonic units. The occurrence of thick Early(?) Maastrichtian coarse-grained conglomerates and breccias express a new significant tectonic event. © 1999 Elsevier Science Ltd. All rights reserved.

Resumen

La "cuenca" de ante-arco de Celica–Lancones del Suroeste de Ecuador y Noroeste del Perú está ubicada entre el Macizo paleozoico de Amotape–Tahuin al Oeste y el arco volcánico continental al Este y SE. El estudio de una decena de secciones de campo y el muestreo de estos depósitos cretácicos mayormente clásticos y poco fosilíferos permite definir cinco series distintas, que evidencian dos períodos de depositación.

El primer período corresponde al desarrollo de una plataforma carbonatada de edad Albiana inferior (?) a medio, interrupido en el Albiano superior por la creación de una cuenca turbidítica tectonicamente activa. El mapeo geológico demuestra que la "Cuenca Celica–Lancones *s.s.*" incluye unidades tectónicas distintas con diferentes series estratigráficas de edad Cretáceo superior temprano, separadas por fallas mayores. Las unidades pueden ser agrupadas en una provincia paleogeográfica suroriental caracterizada por depósitos mayormente volcanoclásticos, y un dominio noroccidental marcado por depósitos clásticos ricos en cuarzo detrítico.

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Entre el Coniaciano inferior y el Campaniano medio, la cuenca de "Celica–Lancones *s.s.*" fue deformada y erosionado ("Fase Peruana" del Cretáceo superior). El segundo período corresponde al Cretáceo terminal, durante el cual se formó una nueva cuenca de ante-arco (Cuenca Paita–Yunguilla) caracterizada por una serie Campano-Maastrichtiana homogénea en toda el área, que sella la yuxtaposición tectónica de las unidades pre-santonianas. Más luego, la ocurrencia de potentes conglomerados y brechas de grano grueso en el Maastrichtiano (?)temprano espresa un nuevo evento tectónico importante.

1. Introduction/geological setting

In Late Cretaceous times, the northern Andean margin was marked by the beginning of compressional deformation in Peru and Bolivia (Peruvian phase, Steinmann, 1929; Mégard, 1984; Jaillard, 1994), by accretion of oceanic terranes in Ecuador and Colombia (Feininger and Bristow, 1980), by the progressive emergence of the Andean Basin of Bolivia, Peru and Ecuador (Dashwood and Abbotts, 1990; Mathalone and Montoya, 1995; Sempéré et al., 1997; Jaillard et al., 1997), and by thermal events in the Ecuadorian Cordillera (Aspden et al., 1992; Litherland et al., 1994). These events are regarded as the beginning of the Andean orogen.

Due to subsequent tectonic erosion, deformation and/or displacement, and because they are often covered by thick Tertiary sedimentary or volcanic deposits, Mesozoic sediments of the arc and forearc zones of the Andean margin are poorly preserved, and the geological evolution of these areas during Cretaceous times is still poorly understood. Since they were very close to the subduction zone, the forearc zones contain the most compelling evidence for constraining the age, nature and intensity of these tectonic events, as well as their relationship to subduction processes.

The "Celica forearc Basin" of southwestern Ecuador (Kennerley, 1973) represents one of the few examples of Cretaceous turbidite series, and one of the few Cretaceous forearc basins known on the continental Andean margin. It was developed on continental crust during early Late Cretaceous times and extends into northwestern Peru where it is named "Lancones Basin". The sediments of the "basin" rest on the Paleozoic basement of the Amotape–Tahuin Massif to the West, and on the Cretaceous continental volcanic arc to the east (Fig. 1). Hence, the sediments are mainly siliciclastic toward the west and volcaniclastic toward the east.

The poorly dated Celica volcanic arc is considered to have developed on continental crust (Lebrat et al., 1987; Reynaud et al., 1996). It probably constitutes the northward extension of the NNW-trending volcanic arc of Peru developed on continental crust, which was mainly active during Albian times (Casma Fm; Cobbing et al., 1981; Soler, 1991).

The Amotape–Tahuin Massif is mainly made of metamorphic and sedimentary rocks of Paleozoic age (Aspden et al., 1995). It is probably composite and has been regarded as a displaced terrane accreted to the Andean margin during latest Jurassic or Early Cretaceous times (Mourier et al., 1988).

The Celica–Lancones basin is usually interpreted as an extensional basin opened between the volcanic arc and the Amotape–Tahuin Massif (Kennerley, 1973; Reyes and Caldas, 1987; Mourier, 1988). Paleomagnetic data from the arc and forearc zones of northern Peru and southern Ecuador indicate that sig-

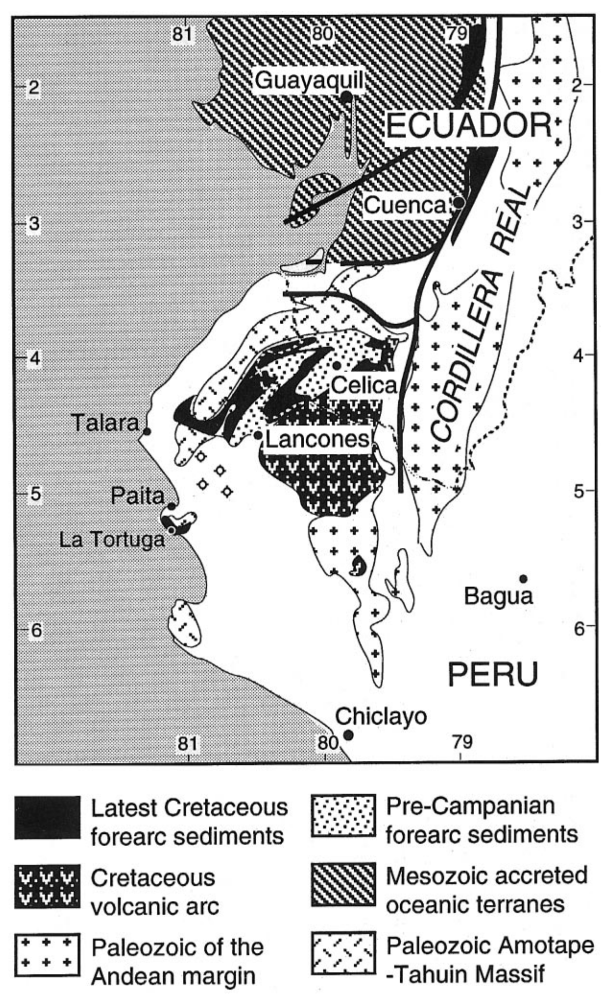

Fig. 1. Location sketch map of the "Celica–Lancones Basin".

nificant clockwise rotations occurred during Cretaceous–Paleocene (≈45° to 70°) and post-Paleocene (≈25°) times (Mourier et al., 1988; Mitouard et al., 1990; Roperch et al., unpubl. data), although no large-scale latitudinal movements have been recognized (Kissel et al., 1992). Together with other geological observations, this suggests that important dextral movements occurred during Cretaceous and Paleogene times (Bussel, 1983; Soler, 1991; Jaillard, 1994). In this work, paleocurrents and paleogeographic trends are indicated according to their present-day strike.

The studied area is a ≈50 × 150-km wide rectangle, striking roughly NE–SW, the average altitude of which decreases southwestward. Since relief chiefly controls precipitation and vegetation, outcrop conditions are very poor in the higher northeastern part of the area. They become much better southwestwards, and are generally very good in the arid Peruvian part of the Basin. In addition, fossils are very scarce and the sedimentary series are affected by numerous faults and folds, the intensity of which increases toward the NW. As a consequence, the Ecuadorian part of the area was very poorly understood.

This contribution is a first attempt to establish the stratigraphic series and to reconstruct the tectono-sedimentary evolution of this forearc "Basin". It is based mostly on field observations and must be considered as a "reconnaissance survey", which will provide a basis for further detailed studies. We present and discuss new stratigraphic results and observations obtained from the western part of the Celica Basin of southwestern Ecuador. These have led us to distinguish two depositional periods, of Aptian to Coniacian and Campanian to Maastrichtian age, respectively, separated by a major unconformity. We propose comparisons and correlations with the stratigraphic series of northwestern Peru and central Ecuador, which require recognition of two distinct forearc basins of early Late Cretaceous and latest Cretaceous age, respectively.

Moreover, these new data strongly suggest that the Celica–Lancones "Basin" constitutes several fault-bounded tectonic units, characterized by distinct early Late Cretaceous stratigraphic successions and paleogeographic origin. The present-day structure probably results from the pre-Campanian tectonic juxtaposition of these tectonic units by means of large-scale dextral wrench movements.

2. Previous work

In Ecuador, the cover of the Amotape–Tahuin massif had been defined as a single unit of Aptian–Campanian age (Puyango Gp or Cazaderos Gp, Kennerley, 1973; 1980; Bristow and Hoffstetter, 1977; Fig. 2). This unit comprises several formations principally defined by their lithology and geographical extension. These formations would be laterally equivalent, and would grade eastward into the volcaniclastic series (Kennerley, 1973; 1980; Bristow and Hoffstetter, 1977).

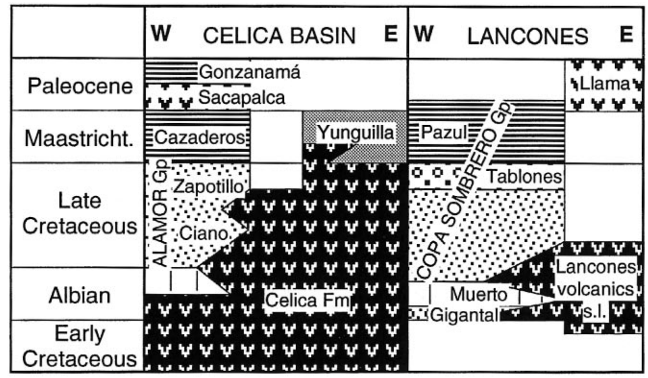

Fig. 2. Stratigraphic models of the Celica Basin (Ecuador) according to Kennerley (1973; 1980) and the Lancones Basin (Peru) according to Reyes and Caldas (1987).

In Peru (Fig. 2), stratigraphic and sedimentological studies of the Amotape Massif cover resulted in the definition of more detailed and better defined stratigraphic units, ascribed to the Albian–Maastrichtian (e.g. Iddings and Olsson, 1928; Olsson, 1934; Fischer, 1956; Morris and Alemán, 1975), or even Albian–Paleocene time-span (Reyes and Caldas, 1987). This succession is interpreted as grading eastward into, or resting on, volcanic rocks of the continental arc.

The stratigraphy of the eastern part of the Celica Basin of Ecuador has been established by Jaillard et al. (1996), who distinguished two major deposition periods (Fig. 3). The lower one comprises volcanic rocks originated in a continental magmatic arc (Celica Fm, Lebrat, 1985; Reynaud et al., 1996) believed to be Albian in age (Jaillard et al., 1996). They are associated with forearc volcaniclastic deposits (Alamor Fm), for which an Albian to early Late Cretaceous age had been assumed because of their stratigraphic position and the occurrence of Late Cretaceous microfossils. However, recent observations on newly exposed outcrops demonstrate that the post-Turonian age determined in the upper part of the Alamor Formation (Jaillard et al., 1996) had been actually obtained from the basal strata of the unconformably overlying deposits (El Naranjo Fm). Therefore, the Celica and Alamor formations are thought to be mainly of Albian age.

The upper depositional succession comprises unconformable, transgressive marine sediments of Late Santonian (?) to Early Maastrichtian age (El Naranjo Fm), and conglomerates and shales (Casanga Fm) of Maastrichtian age (Jaillard et al., 1996; Baudino, 1995 p. 288). These seem to be overlain unconformably by

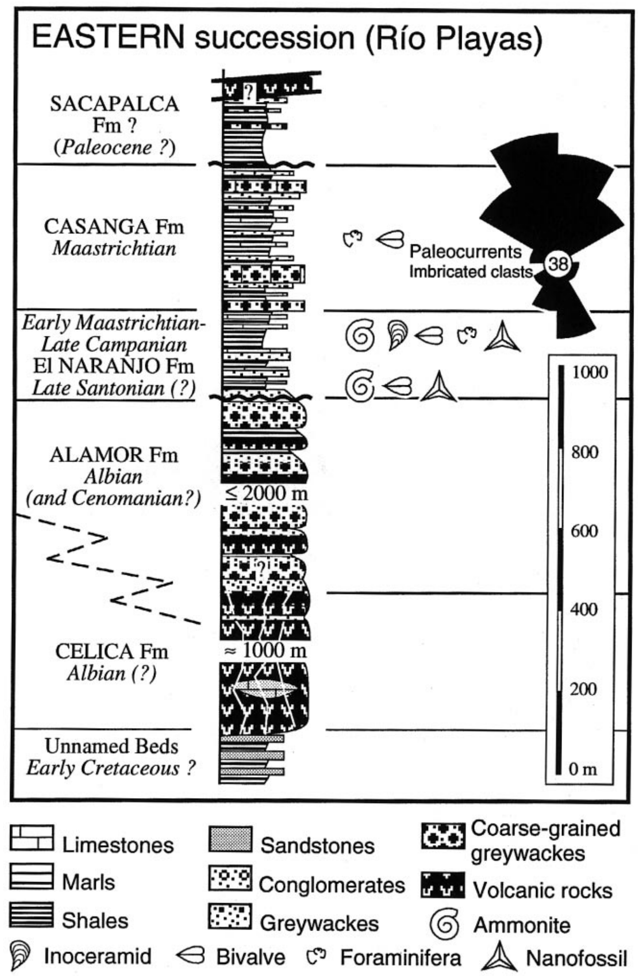

Fig. 3. Stratigraphic sketch of the eastern series of the Celica Basin (after Jaillard et al., 1996).

mainly Tertiary volcanic rocks and subordinate red beds (Sacapalca Fm; Hungerbühler, 1997) (Fig. 3).

3. Stratigraphy of the western Celica basin (Aptian?–early Late Cretaceous)

The central and western parts of the Celica Basin present distinct lithologic facies and successions according to the regions (Figs. 4 and 5). We shall describe the series from the West–Northwest to the East–Southeast.

3.1. Puyango–Cazaderos succession (cover of the Amotape Massif)

The Puyango–Cazaderos succession is the best known stratigraphic series of the western Celica Basin, because of acceptable outcrop conditions, widespread exposures and easy correlations with the North Peruvian series of the Amotape Massif and Lancones Basin (Figs. 6 and 7).

3.1.1. Basal greywackes

In the Puyango area (Fig. 4), the Amotape–Tahuin Massif basement is unconformably overlain by a ≈300 m thick series of altered, unfossiliferous medium- to coarse-grained greywackes and shales (Fig. 6). Locally, they bear silicified tree-trunks and blocks of light-coloured limestones, and include red quartzose sandstones of continental origin. Because of their stratigraphic position, these strata are of pre-Albian, possibly Late Jurassic age.

Along the road from Balsas to Chaguarpamba, north of the bridge on the Río Puyango, the Paleozoic rocks of the Amotape–Tahuin Massif are unconformably overlain by red beds made of altered greywackes, overlain by a 5 m thick coarse-grained conglomerate of alluvial fan environment. In the latter, the poorly sorted, rounded boulders, are as large as 0.5 m and consist of greywackes, intrusive rocks and lavas in a quartzose sandy and pebbly matrix. Although the contact is poorly exposed, these alluvial fan deposits seem to be overlain by a ≈1000 m thick series of coarse-grained silicified greywackes, which crops out near the bridge on the Río Puyango (Losumbé). This series includes coarse-grained conglomeratic greywackes, medium- to fine-grained greywackes, frequently silicified black laminated cherts, and scarce thin beds of lava flows. Detrital sediments are arranged in fining-upward sequences with erosional base, capped by often laminated black cherts, and are interpreted as turbidite deposits.

The lithology and petrography of these acidic greywackes differ significantly from the Cretaceous basic greywackes of the Celica area. In spite of extensive searches, we could not find diagnostic fossils. Since they rest unconformably on the Amotape–Tahuin Massif, the Basal Greywackes of Losumbé may be of Late Jurassic to Early Cretaceous age, and are probably equivalent to the Basal Greywackes of the Puyango section.

3.1.2. Conglomerates and sandstones (Bosque de Piedra Formation)

In the Puyango area, the basal greywackes are sharply overlain by massive, moderately sorted, cross-bedded conglomeratic quartzites, deposited in fluvial to shoreline environments. The top of the beds exhibits numerous plant remains. They grade rapidly upwards into shales and sandstones with thin beds of limestone and tuff, which contain numerous silicified tree-trunks (Bosque de Piedra, Fig. 6). From unspecified layers, Shoemaker (1982) determined Araucariaceae of Early Cretaceous age. Tuffs yielded reset K/Ar ages of 75 ± 9 and 64 ± 6 Ma (Shoemaker, 1982).

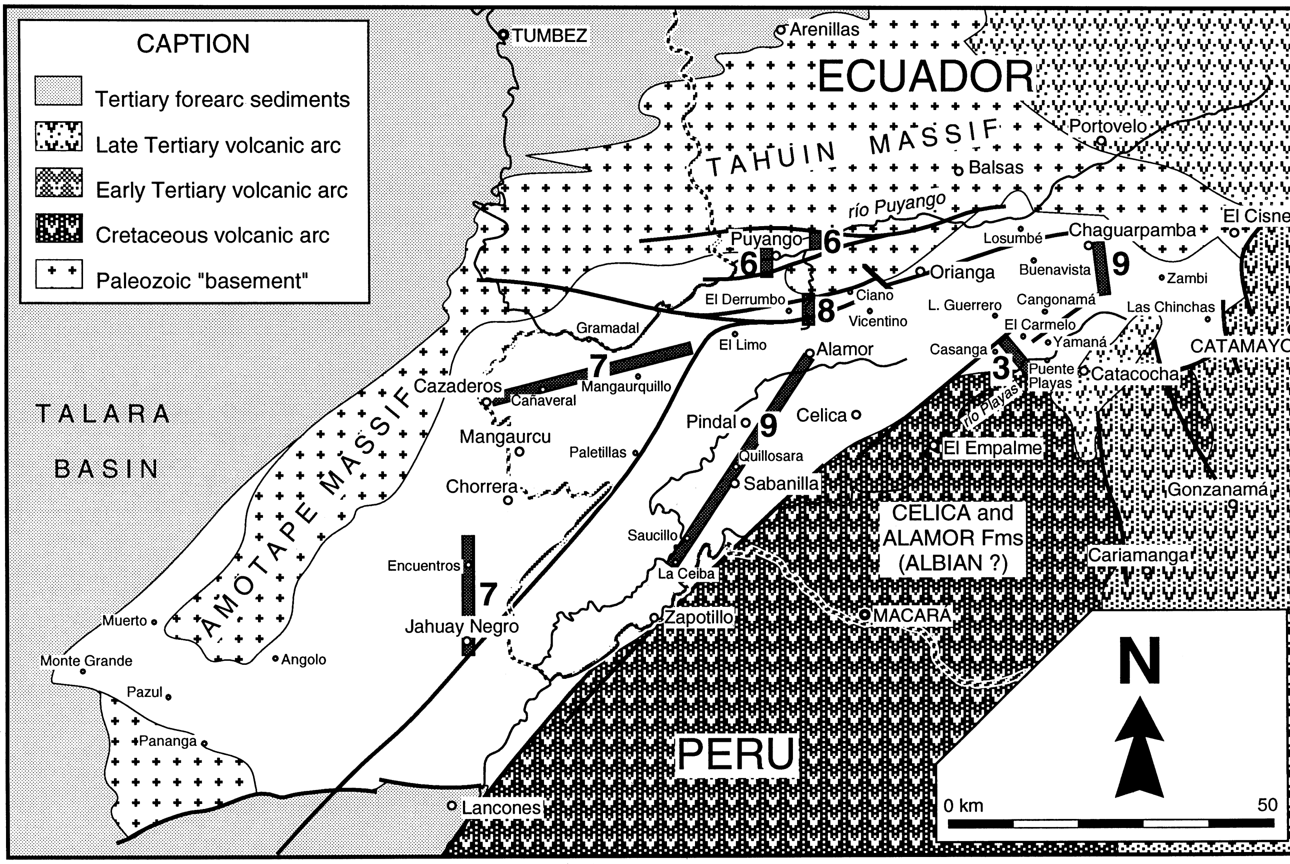

Fig. 4. Location of the main localities cited in the text. Numbers refer to the figures where the sections are described. (3) Río Playas section; (6) Puyango sections; (7) Alamor–Cazaderos (Ecuador) and Encuentros sections (Peru, Chávez and Nuñez del Prado, 1991); (8) Río Cochurco section; (9) Chaguarpamba and Sabanilla sections, according to which the Chaguarpamba–Sabanilla succession has been reconstructed.

In Peru, similar transgressive quartzose conglomerates that unconformably rest on the Paleozoic rocks of the Amotape–Tahuin Massif are ascribed to the Albian because of their stratigraphic position (Gigantal conglomerate, Reyes and Vergara, 1987).

3.1.3. Lower limestones (Puyango Formation)

In the Puyango area, the Bosque de Piedra Formation is overlain by a thick succession of grey to black laminated bituminous marls and limestones, which exhibit very thin interbeds of light-coloured calcarenites and greywackes with graded bedding and scoured bases, and interpreted as distal turbidites. Because of important pre-Campanian deformation and erosion, the thickness is difficult to estimate, but reaches at least 300 meters. Unspecified beds yielded *?Hypacanthoplites* sp., *Parahoplites* sp., *Brancoceras aegoceratoides, Desmoceras latidorsatum, Hysteroceras orbignyi, Oxytropidoceras* (*?Laraiceras*) sp. and *Oxytropidoceras* (*Venezoliceras*) *commune* of Early Albian to early Late Albian age (Bristow and Hoffstetter, 1977; Shoemaker, 1982). In Puyango, beside numerous casts of *Oxytropidoceras* sp. s.l., we collected the bivalves *Ceratostreon* sp., *Cucullaea* sp. and undetermined heterodonts. A loose ammonite probably proceeding from these beds or from the upper part of the Bosque de Piedra Formation, has been identified as *Epicheloniceras s.l.* sp. of Late Aptian age (Fig. 6).

In Peru, comparable limestones are dated as Middle to Late Albian by foraminifera, inoceramids and ammonites (Pananga and Muerto Fms, Iddings and Olsson, 1928; Chalco, 1955; Zuñiga and Cruzado, 1979; Reyes and Caldas, 1987).

3.1.4. Greywackes and shales (Copa Sombrero Formation)

In Ecuador, the Albian limestones are overlain by a thick series of black shales and well-sorted medium-bedded turbiditic sandstones with few marl and limestone intercalations. It crops out in the western part of the studied area (NW of a line Puyango–El Derrumbo–Paletillas, Fig. 4), and is considered equivalent to the Copa Sombrero Group of Peru (Fig. 7). However, the basal stratigraphic contact has not been seen in Ecuador, nor a detailed lithologic succession has been established. Good exposures of the Copa Sombrero Formation can be seen along the old road

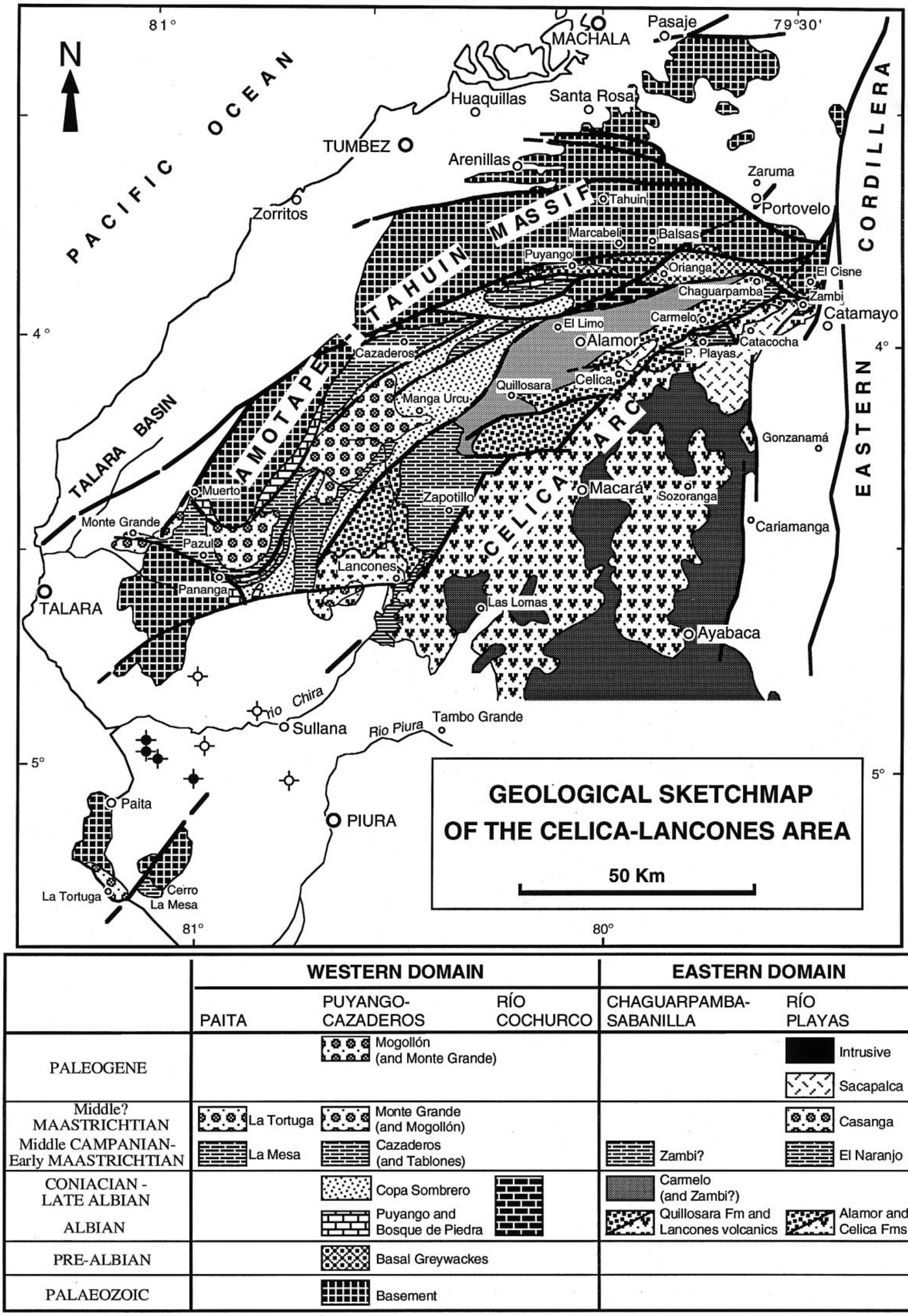

Fig. 5. Simplified geological map of the Celica–Lancones area. South of the outcrops, wells allow us to determine whether the Copa Sombrero Gp and/or Pazul Fm are present (white) or absent (black) (after Morris and Alemán, 1975).

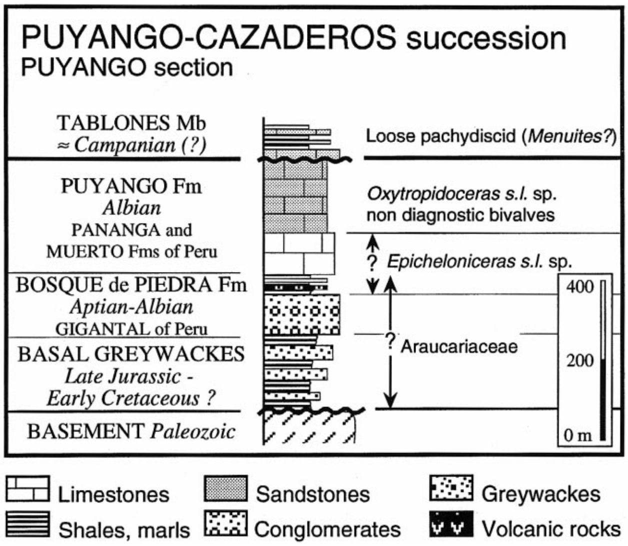

Fig. 6. Stratigraphic section of the Puyango area.

joining Puyango and Alamor, and along the Alamor–Cazaderos and Cazaderos–Paletillas roads. The turbiditic beds, although partly volcaniclastic, are of predominantly crystalline origin. The succession includes locally (North of Mangaurquillo) several meters-thick intercalations of volcaniclastic turbiditic beds. Intercalations of pyroclastic beds seem to be more abundant toward the South (Bolaspamba, Paletillas area). Slumped units are common. Sole marks from turbiditic beds indicate NE-ward paleocurrents, similar to those measured in the Copa Sombrero Group of the Lancones Basin of Peru where they are thought to record deposition in the axis of the trough (Morris and Alemán, 1975; Fig. 7). This succession contains locally numerous silicified tree trunks.

No diagnostic microfauna have been found in the few collected samples. In the lower part of the succession that crops out along the Alamor–Cazaderos road, we found unidentifiable inoceramids and some poorly preserved impressions of *Oxytropidoceras*? sp., an ammonite genus restricted to the Middle and Late Albian. In the upper part, we found a few undeterminable inoceramids and incompletely preserved ("skulptursteinkern") and undescribed crassatellids (Fig. 7).

In Peru, the lower part of the Copa Sombrero Group stratigraphically overlies the Albian limestones (Reyes and Vergara, 1987), and consists of black shales and calcareous siltstones, with sandstone and pyroclastite intercalations (Huasimal Fm, Morris and Alemán, 1975; Reyes and Caldas, 1987), interpreted as basin plain to slope deposits (Chávez and Nuñez del Prado, 1991). It yielded ammonites of late Middle Albian to Late Albian age (Fischer, 1956; Olsson, 1934). The coarse-grained and thick-bedded middle part of the series (Jahuay Negro Fm) contains scarce and poorly preserved Cenomanian ammonites

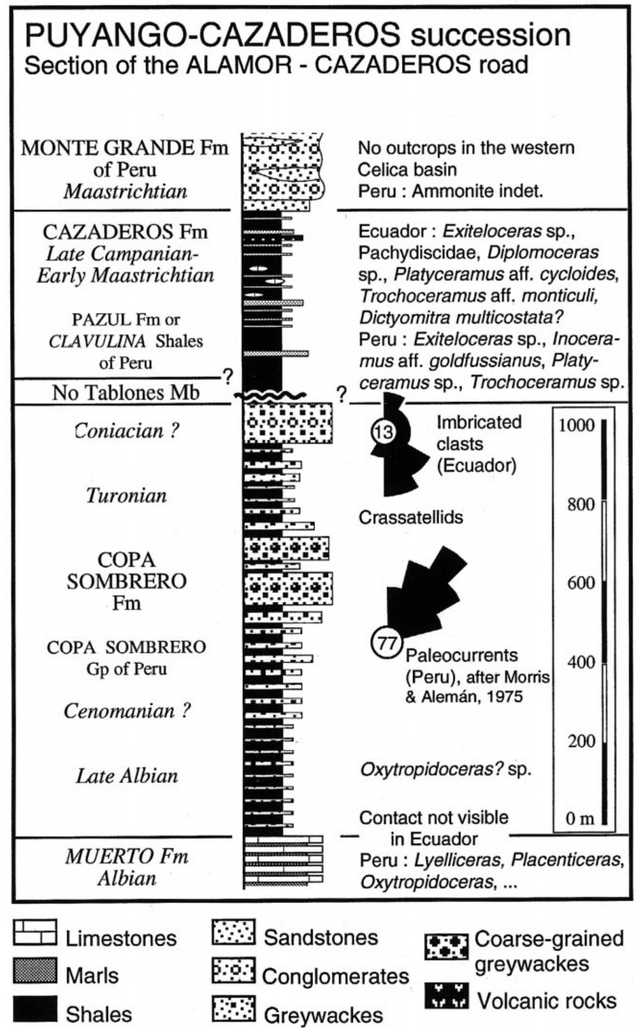

Fig. 7. Composite section of the Puyango–Cazaderos series, and stratigraphic data. Lithology is drawn after Reyes and Caldas (1987) and Chávez and Nuñez del Prado (1991).

(acanthoceratid, *Schloenbachia* sp.) and Cenomanian–Turonian inoceramids (Reyes and Caldas, 1987; Reyes and Vergara, 1987). The upper part of the series consists of shales with interbeds of arkosic sandstones (Encuentros Fm, Morris and Alemán, 1975). Reyes and Caldas (1987) reported *Inoceramus inconstans* and *I.* cf. *regularis* from the Encuentros Formation and ascribed it to the early "Senonian", although the latter species usually indicates the Campanian.

In the western part of the studied area of Ecuador, the greywackes and shales of the Copa Sombrero Formation seem to be overlain by unfossiliferous, coarse-grained arkosic and micaceous sandstones and conglomerates containing metamorphic, granitic and quartzose clasts (Fig. 7). These conglomerates crop out in the Gramadal, Cañaveral (Quebrada Don Juan) and Manga Urcu areas, and form a salient ridge 5 km East of Cazaderos (Cordillera Juan Mateo Vivas). Paleocurrents indicate a dominantly southeastward transport, although a northward direction is also expressed (Fig. 7, upper part). Therefore, the Amotape–Tahuin Massif is likely to represent the source area. The conglomerates are overlain by the unconformable Cazaderos Formation of Late Campanian–Early Maastrichtian age (see below). These conglomerates may constitute either the upper part of the Copa Sombrero Group *s.s.*, or a distinct tectonic unit, since the Manga Urcu Bolaspamba area is affected by important NE-trending faults.

In Peru, these upper quartzose conglomerates, which crop out south of Cazaderos, have been correlated either with the "middle Conglomerate" of Olsson (1934) (Chalco, 1955), or with the "Tablones Formation" ascribed to the Campanian (Reyes and Caldas, 1987; Palacios, 1994). However, the youngest faunas reported so far from the Copa Sombrero Group of Peru are the ammonite cf. *Barroisiceras haberfellneri* of Early Coniacian age (Petersen, 1949) and microfauna of "Senonian" age (Weiss, 1955). Therefore, if belonging to the Copa Sombrero Group, the unfossiliferous upper conglomerates of Peru and Ecuador are interpreted as of Coniacian (or Santonian ?) age (Fig. 7).

3.2. Río Cochurco succession

The Cochurco series consists of a thick succession of detrital massive limestones, conglomerates and shales, which have only been observed in the río Cochurco and along the new road between Puyango and Alamor (Fig. 4). To the North, the Cochurco series is separated from the siliceous black slates of the Amotape–Tahuin Massif by an ENE-trending fault of regional importance, expressed on Spot imagery by sharp reflectance contrast. In the lower part of the río Cuchurco, this fault trends N70°E and dips 65° to the south, and structural criteria indicate successive normal and reverse movements.

Because of abundant faults, the presented succession must be considered as tentative.

3.2.1. Massive conglomeratic limestones

The lower part of the Cochurco series consists of a grossly fining-upward succession of conglomeratic limestones, coarse- to fine-grained greywackes and black laminated limestones. Nature of the clasts indicates both volcanic (feldspars, amphiboles) and crystalline sources (quartz, metamorphic rocks). At the base, the occurrence of turbidite beds, breccias, clastic dykes, and olistoliths of black, probably Albian limestones, indicates a tectonically unstable environment coeval with the beginning of the sedimentation. The overlying dark laminated limestones exhibit scarce burrows, thus suggesting a deep, restricted shelf environment. Higher in the section, sedimentary features (channels, cross-bedding, burrows) indicate a shallow marine shelf environment.

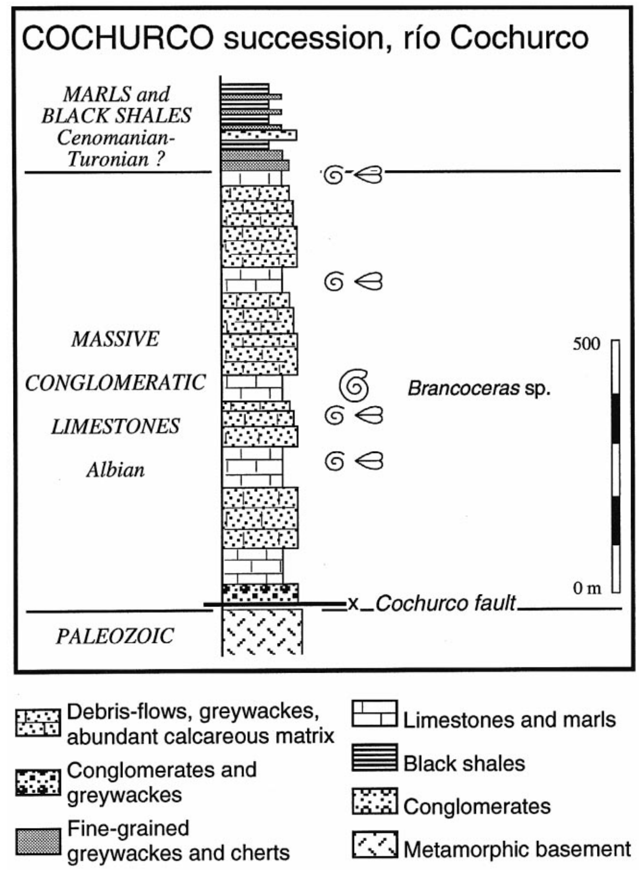

Fig. 8. Stratigraphic section of the Cochurco River.

Along the new Puyango–Alamor road, in the lower part of the succession (Fig. 8), we collected the ammonite *Brancoceras* sp. of early Middle Albian age.

3.2.2. Marls and black shales

Upwards (southward) in the río Cochurco, the succession follows with dark-coloured, skeletal limestones containing crinoids, echinoids, large bivalves, algae, tree trunks, indicating an open shallow marine environment. Farther south (higher in the section), shales, radiolarian-bearing cherts, greywackes and calcschists suggest a deeper environment (Fig. 8). The upper part of the section does not crop out. These finer-grained facies of deeper environment may correlate with the base of the Copa Sombrero Formation. The Cochurco succession is interpreted to have been deposited on the border of the Celica–Lancones Basin, close to the Amotape Massif.

No diagnostic fauna has been found in this succession, which is tentatively ascribed to the early Late Cretaceous.

3.2.3. Conglomerates, greywackes and shales

The marls and black shales appear to be overlain by black shales interbedded with thick beds of quartzose conglomerate, feldspathic siltstones and few limestone beds (not shown on Fig. 8). Undeterminable molds of inoceramids have been found in these sediments between Alamor and Orianga.

Toward the South, the Cochurco series is in contact with a ≈1000 m-thick succession of black shales and cherts, thin-bedded, medium- to fine-grained greywackes, and scarce marls and limestone interbeds, strongly deformed by ENE-trending, tight folds with southeastward dipping axial planar slaty cleavage. The latter unit resembles the Carmelo Formation of the Chaguarpamba–Sabanilla series (see below).

3.3. Chaguarpamba–Sabanilla succession

The Chaguarpamba–Sabanilla succession corresponds to large outcrops of thick beds of massive greywackes, well-bedded sandstones and greywackes, and shales with minor limestone beds, ascribed to the Albian–Coniacian(?) time-span. It crops out along a NE-trending zone including Sabanilla and Chaguarpamba (Figs. 4 and 5).

To the North, the Sabanilla–Chaguarpamba series is separated from the Cochurco and Puyango sequences by major faults marked by strongly deformed sediments and small intrusive bodies. The Chaguarpamba–Sabanilla succession is limited to the Southeast by another major NE-trending fault system.

3.3.1. Massive greywackes (Quillosara Formation)

The Quillosara Formation crops out along a NE-trending zone between Sabanilla and north of Chaguarpamba. Good outcrops can be observed north of Chaguarpamba, in the Alamor and Pindal areas, and near Sabanilla, especially in the río Quillosara (Fig. 4). It consists of massive thick-bedded, medium- to coarse-grained greywackes, which exhibit locally cross bedding and slumps. They are arranged in fining-upward sequences capped by laminated shales or cherts, and are interpreted as turbidity current deposits, locally of high density. Paleocurrent measurements (cross-bedding, imbricated clasts, slumps) indicate an average transport to the North or NW (Fig. 9), which contrasts with the transport directions of the western part of the basin (see Fig. 7). In the upper part, the massive greywackes locally include blocks of basalts. The Quillosara Formation is interpreted as the middle to distal facies of the proximal forearc turbidite deposits of the Alamor Formation of the eastern series, deposited at the foot of the active Celica arc (Jaillard et al., 1996). Therefore, it is ascribed to the Albian (and Cenomanian?).

Toward the south (north of Saucillo), the Quillosara Formation is stratigraphically and conformably overlain by black fossiliferous slates (Fig. 9) which are

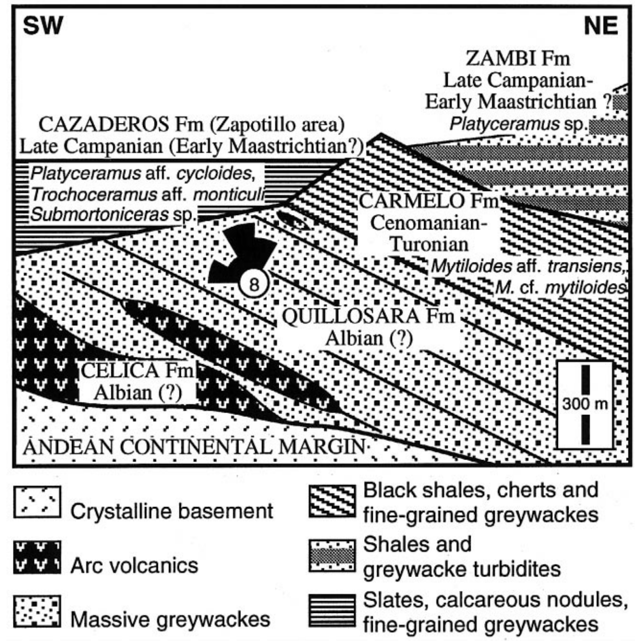

Fig. 9. Stratigraphic sketch of the Chaguarpamba–Sabanilla succession.

well-exposed in the Zapotillo area, and are ascribed to the Late Campanian–Early Maastrichtian(?) Cazaderos Formation (see below). Northeast of Celica, the Sabanilla series is overlain by undated, unconformable volcanic rocks, which seem to include two volcanic events of latest Cretaceous to early Tertiary, and recent age, respectively.

3.3.2. Thin-bedded black cherts (Carmelo Formation)

This unit crops out in the center of the "basin", following an ENE-trending zone including Chaguarpamba and Alamor (Fig. 4). Good outcrops can be found near Chaguarpamba, north of Yamaná, near Alamor, and along the Alamor–Cazaderos road between El Limo and Mangaurquillo. The Carmelo Formation consists of poorly fossiliferous black shales and cherts with few marl and limestone intercalations, interbedded with thin-bedded, fine-grained greywackes. Although often very altered, the greywacke beds exhibit scoured bases and graded-bedding, and are interpreted as distal turbiditic layers. In the Chaguarpamba and Alamor–Sabanilla areas, the Carmelo Formation stratigraphically overlies the Quillosara Formation (Fig. 9). The Carmelo Formation is frequently strongly deformed, and presents tight folds with axial plane slaty cleavage, and steep-dipping, even overturned beds.

Along the Yamaná–Congonamá road, 1 km East of El Carmelo, we collected poorly preserved plant remains, an unidentifiable teleostean fish, an indeterminate ammonite, and numerous crushed inoceramids belonging to the genus *Mytiloides*, of Late

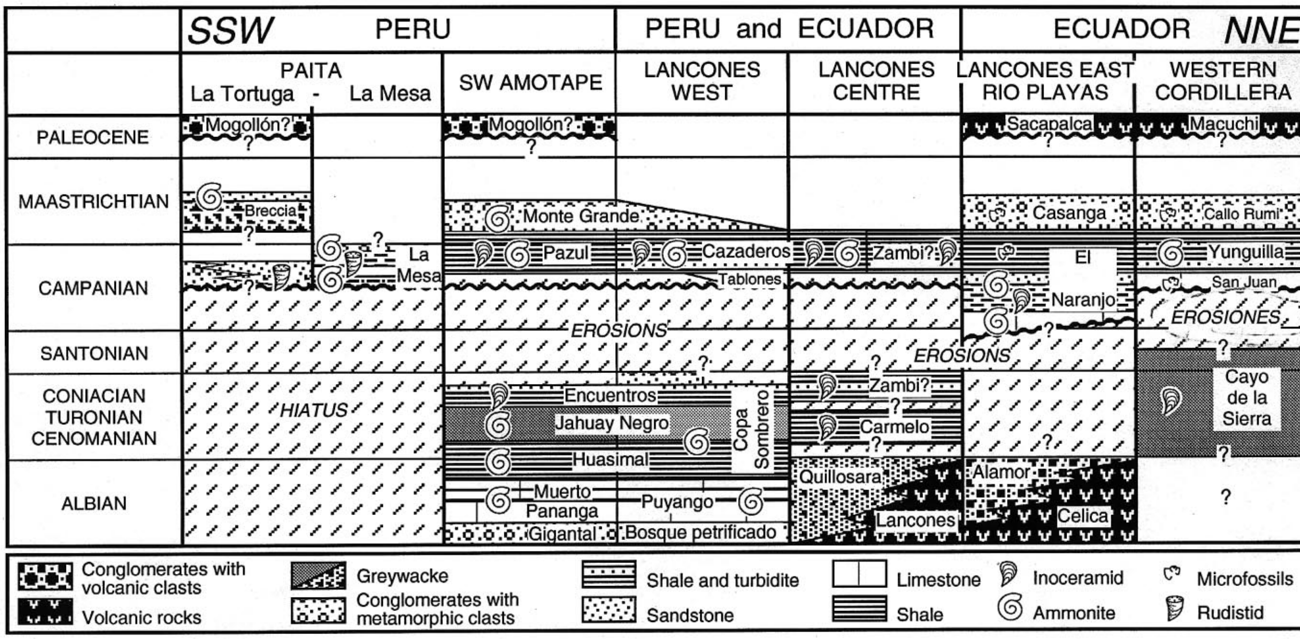

Fig. 10. Stratigraphic chart of the Cretaceous forearc deposits of Northwestern Peru and Southwestern Ecuador.

Cenomanian–Turonian age. The best-preserved specimens are determined as *Mytiloides* aff. *transiens* and *M.* cf. *mytiloides*, which are indicative of the Early Turonian in Brazil (Hessel, 1988). The Carmelo Formation is assumed to be of early Late Cretaceous age (Cenomanian–Turonian). It would be, therefore, equivalent to part of the Copa Sombrero Formation of the western succession.

In the Lauro Guerrero, Buenavista and Chaguarpamba areas, unfossiliferous black shales and turbidites seem to overlie the Carmelo Formation. Unidentifiable inoceramids have been found near Vicentino. However, in the latter area, the stratigraphic relations of this unit with the Carmelo Formation have not been established.

4. Stratigraphy of the post-early Late Cretaceous strata

Deposits unconformably overlying the Late Aptian–early Late Cretaceous series have been observed in the central and western parts of the basin, where they stratigraphically overlie both the Puyango–Cazaderos and the Chaguarpamba–Sabanilla series. These lithologic units seem to be widely correlatable throughout northwestern Peru and western Ecuador. They are usually much less deformed than the older ones, and the dips hardly exceed 20°. A comparable succession is known in the eastern part of the Celica "Basin".

4.1. Unconformable upper limestones (Tablones Member)

In Ecuador, in the northern part of the studied area (Puyango River at Puyango), thick-bedded, sandy, coarse-grained bioclastic and in part oolithic limestones with large bivalves locally rest unconformably upon the strongly deformed black laminated limestones of Albian age (Fig. 6). They represent high-energy, open shallow marine, transgressive facies. These unconformable limestones grade upwards into yellow marls interbedded with few skeletal, sandy and oolithic limestones rich in oysters and other large bivalves, interpreted as open marine, outer shelf deposits. From these outcrops, we found an ammonite fragment and scarce inoceramids, which remained undetermined. However, a loose ammonite found downwards on the bank of the Puyango river, is a smooth pachydiscid, the shell form of which suggests the genus *Menuites*. The range of this genus is Santonian through Maastrichtian, although most records appear to fall in the mid-Campanian to mid-Maastrichtian interval. The Campanian foraminiferal assemblage mentioned by Sigal (1969; Bristow and Hoffstetter, 1977) may be derived from these beds.

Northwest of Cazaderos, the upper limestones seem to be represented by bioclastic and sandy limestone beds and calcareous cross-bedded conglomerates bearing plant fragments, coarse bivalves (oysters) and selachian teeth, indicating a high-energy nearshore environment.

Correlations: These unconformable beds, which are only locally present, are considered to be equivalent to part of the Late Santonian?–Early Campanian El Naranjo Formation of the eastern part of the Celica basin, which unconformably overlies the Albian (and Cenomanian?) volcanic arc rocks (Celica and Alamor Fms; Jaillard et al., 1996; Bengtson and Jaillard, 1997) (Fig. 3).

Farther North, in the Western Cordillera of central Ecuador (Riobamba area), early Late Cretaceous greywackes (Cayo de la Sierra Fm of Faucher et al., 1971; Pilatón unit of Kehrer and Van der Kaaden, 1979) are unconformably overlain by transgressive shallow marine limestones of Campanian age (San Juan Limestones of Kehrer and Kehrer, 1969; Faucher et al., 1971; Bristow and Hoffstetter, 1977) (Fig. 10).

In northwestern Peru, Morris and Alemán (1975) interpret the unconformable Campanian Tablones Formation as a shallow-water deposit, which postdates the emergence and deformation of the Copa Sombrero Group. The Tablones Formation of Morris and Alemán (1975) (misused by Reyes and Vergara, 1987; Palacios, 1994) correlates with the Upper Limestones of Ecuador. In the Talara Basin, transgressive sandy and conglomeratic limestones of Campanian age (Redondo Fm) rest unconformably on Paleozoic rocks or on Albian limestones (Weiss, 1955; González, 1976). Farther south, in the Paita area, shales, calcareous sandstones, massive limestones and subordinate conglomerates of Campanian age (La Mesa Fm) rest unconformably on Paleozoic rocks (Olsson, 1944). In these latter beds, numerous ammonites and bivalves support a Late Campanian age (Bengtson and Jaillard, 1997; Dhondt and Jaillard, 1997) (Fig. 10).

These widespread unconformable calcareous deposits of Ecuador and northwestern Peru (La Mesa, Redondo, El Naranjo Fms, Tablones Mb and San Juan Limestones) express a regional transgression in open marine shallow shelf to nearshore environments, of Middle to Late Campanian age, which locally may have commenced earlier (río Playas).

4.2. Black shales and turbidites (Cazaderos and Zambi formations)

In Ecuador, the uppermost unit of the western Celica Basin consists mainly of black shales, which are well exposed in the western (Cazaderos) and southern (Zapotillo) parts of the studied area (Figs. 4 and 5).

In the Cazaderos area, they contain yellow-coloured nodules of black limestones and thin-bedded sandstone turbidites. Few paleocurrent measurements suggest NE-ward transport. Numerous clastic dykes orientated NW–SE, N–S and NE–SW indicate a roughly E–W extensional regime during deposition. In this area, poorly preserved ammonites were identified as *Exiteloceras* sp. (Campanian), *Diplomoceras* sp. (Late Campanian–Maastrichtian) and Pachydiscidae indet. This association suggests a Late Campanian age (Fig. 7). In the same area, we found inoceramids among which a large *Platyceramus* sp. indicates the Coniacian–Early Maastrichtian interval. Micropaleontological sampling of the shales in the Cazaderos and Zapotillo areas yielded the foraminifers *Bathysiphon alexanderi, Gavelinella* sp., *Haplophragmoides* sp., *H. eggeri* and *Rhabdammina* sp., the nannofossils *Tetralithus* sp. and *Watznaueria barnesae*, the *palynomorphs Deltoidospora* sp. and *Psilatricolpites* sp., and fish remains which together indicate a Late Cretaceous age. The radiolarian *Dictyomitra multicostata*? found northwest of the Cazaderos village suggests a Late Campanian to Maastrichtian age. The Cazaderos outcrops, which seem to correspond to the lower part of the Cazaderos Formation, can be ascribed to the Late Campanian (Fig. 7).

Farther southeast, in the Zapotillo area (Figs. 4 and 5), thick, siliceous black slates are intercalated with thin-bedded sandstone turbiditic beds. In these slates, the occurrence of light-coloured cross-bedded calcareous sandstones and of few beds of calcareous nodules suggests a depositional environment shallower than in the Cazaderos area. Clastic dykes are abundant and slumps occur locally. Among the numerous large inoceramids, we collected *Platyceramus* aff. *cycloides* (*sensu* Seitz, 1970) and *Trochoceramus* sp. aff. *Tr. monticuli*, which indicate the Late Campanian–Early Maastrichtian interval. From the same site, and in two other localities around Zapotillo, we collected *Submortoniceras* sp., which indicates an age between Late Santonian and Mid Campanian (Fig. 9). The Zapotillo outcrops of the Cazaderos Formation can be considered as Middle to Late Campanian age, although an Early Maastrichtian age cannot be ruled out for part of the formation.

In the northeastern areas of the Celica Basin, alternations of dark shales, quartz sandstones and medium- to coarse-grained quartzose greywackes, and subordinate carbonates were named Zambi Formation (Kennerley, 1973; Fig. 9). Outcrops of these deformed quartzose greywackes and slaty black shales have been observed between Catacocha and Catamayo, near Chaguarpamba, Zambi and around El Cisne (Figs. 4 and 5). The relations between the Zambi and Carmelo Formations of the Chaguarpamba–Sabanilla series are not clear because of bad outcrop conditions.

In most outcrops, the Zambi Formation only yielded unidentifiable inoceramids. However, near Chinchas (road of Santa Rosa, Fig. 4), we found a large *Platyceramus* sp. which indicates the Coniacian–Early Maastrichtian interval. Since specimens of *Platyceramus* sp. have been only found so far in the latest Cretaceous unconformable deposits, a Late Campanian–Maastrichtian age is more probable for the Zambi Formation, as suggested by Litherland et al. (1993) (Fig. 9). In this interpretation, the Zambi Formation would constitute an eastern facies of the Cazaderos Formation. However, because it is locally intensely deformed, the Zambi Formation may have been affected by the Santonian–Campanian tectonic phase (see below), and a Turonian–Santonian age cannot be ruled out.

Correlations: In the eastern part of the Celica Basin (Río Playas), the black shales dated as Maastrichtian at Limón (Sigal, 1969; Bristow and Hoffstetter, 1977) and the upper part of the El Naranjo Formation of Late Campanian to Middle Maastrichtian age (Jaillard et al., 1996; Fig. 3) correlate with the Cazaderos Formation (Fig. 10). In the Western Cordillera of central Ecuador, the Campanian–early Maastrichtian San Juan Limestones (Kehrer and Kehrer, 1969) are conformably overlain by black shales interbedded with medium-bedded sandy and partly volcaniclastic turbiditic beds (Yunguilla Fm, Thalmann, 1946; Faucher et al., 1971), bearing Early Maastrichtian ammonites (Bristow and Hoffstetter, 1977). In the Cuenca basin (Quebrada Salada), several hundred meters of shales and limestone nodules yielded a Maastrichtian micropaleontological assemblage (Bristow and Hoffstetter, 1977). These units correlate with the Cazaderos Formation of southwesternmost Ecuador (Fig. 10).

In Peru, the upper shaly unit of the Lancones Basin (Pazul Fm) is considered Coniacian (Fischer, 1956), Campanian (Morris and Alemán, 1975) or Maastrichtian to Paleocene in age (Reyes and Caldas, 1987). It is regarded as a lower fan or basin plain deposit (Chávez and Nuñez del Prado, 1991). In the southern part of the Lancones Basin (El Angolo road), we collected *Platyceramus* sp. together with *Inoceramus* aff. *goldfussianus*, and *Platyceramus* sp. associated with *Trochoceramus* sp.. Both associations indicate a Late Campanian–Early Maastrichtian age. Since these outcrops constitute the western and southwestern extensions of the Cazaderos exposures, the Pazul Formation is believed to be equivalent to the Cazaderos Formation of Ecuador.

On the southwestern end of the Amotape Massif of NW Peru (Pazul area, Figs. 4 and 5), the Copa Sombrero Formation is overlain by black shales (*Clavulina Shales* of Olsson, 1934). In the Clavulina Shales of the Monte Grande area (Figs. 4 and 5), we found *Exiteloceras* sp. of Campanian age (Fig. 7). Therefore, the Clavulina Shales are a lateral equivalent of the Pazul and Cazaderos formations (Fig. 10). Farther south, in the Paita area, no deposits are known above the transgressive La Mesa beds.

4.3. Upper conglomerates (Casanga and Monte Grande Formations)

The upper conglomerates have not been observed in the western part of the Celica area of Ecuador. On the Amotape Massif of northwestern Peru, the Clavulina Shales are overlain by coarse-grained quartzose conglomerates of the Monte Grande Formation of Maastrichtian age (Iddings and Olsson, 1928; Olsson, 1934). East of Talara, near Monte Grande (Fig. 4), at the base of the formation, we found an unidentifiable ammonite which indicates a still Cretaceous, most probably Maastrichtian age for the base of the formation.

In the Talara Basin, the Maastrichtian and Paleocene stages are represented by black marine shales (González, 1976). Farther south, near Paita, a 3500 m-thick pile of coarse-grained breccias of Maastrichtian age mainly contains clasts of metamorphic rocks (La Tortuga Fm, Olsson, 1934; 1944). Near the top of the formation, in layers already quoted by Olsson (1944), we collected inoceramids and other bivalves of Early to Middle Maastrichtian age, and the ammonites *Eubaculites* cf. *carinatus* and *Phylloceras* (*Neophylloceras*) *surya*, which indicate a Maastrichtian (possibly Middle Maastrichtian) age (Fig. 10).

The Monte Grande Formation of Peru correlates with the conglomeratic Casanga Formation of Maastrichtian age, known from the eastern part of the Celica "Basin" of Ecuador (Jaillard et al., 1996) (Fig. 3). In the western Cordillera of central Ecuador, the Maastrichtian Yunguilla "flysch" grades upward into conglomerates with quartzose, metamorphic and volcanic clasts, locally interbedded with limestones of Maastrichtian age (Callo Rumi Mb, Kehrer and Kehrer, 1969), which we correlate with the Casanga Formation of southern Ecuador and the La Tortuga and Monte Grande Formations of northwestern Peru. In the Cuenca Basin (near the Cumbe village), red shales and greywackes containing abundant bivalves are assigned to the Maastrichtian–Danian interval (Bristow and Hoffstetter, 1977).

The widespread, thick conglomerates and breccias that cap the Late Campanian–Early Maastrichtian shales are thought to be roughly correlatable and to express a significant regional tectonic event of Early(?) Maastrichtian age.

5. Discussions and interpretations

5.1. Paleogeography and tectonic evolution of the Celica–Lancones basin

This study indicates that rapid transverse (NW–SE)

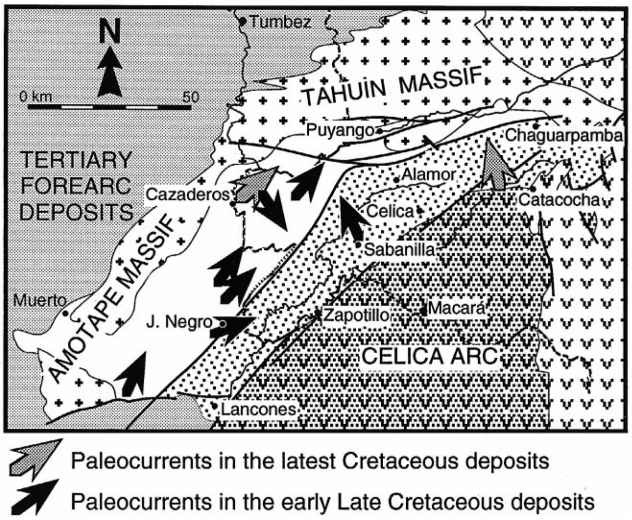

Fig. 11. Paleocurrents in the Celica–Lancones and Paita–Yunguilla Basins. Shaded area: Volcaniclastic domain. White area: quartz-rich domain. Paleocurrents in Peru are from Morris and Alemán (1975).

petrographic and lithologic changes occurred in the Albian–early Late Cretaceous deposits of the Celica–Lancones basin, which reflect differences in nature and proximity of the sources areas, i.e. the metamorphic Amotape–Tahuin Massif to the NW and the Celica calcalkaline volcanic arc to the SE (Figs. 4 and 5). Despite the complex structure, the above-described pre-Campanian sequences can be divided, into a northwestern quartz-rich province and a southeastern volcaniclastic domain, which reflect the paleogeographic asymmetry of the "Celica Basin".

The quartz-rich northwestern province includes the Puyango–Cazaderos and Cochurco series, which are assumed to represent the autochtonous and parautochtonous sedimentary cover of the Amotape Massif, respectively (Fig. 5). The Puyango–Cazaderos succession unconformably overlies the metamorphic Amotape–Tahuin Massif by means of the Basal Greywackes. A significant part of the detrital material of the Puyango–Cazaderos series results from the erosion of the Amotape–Tahuin Massif. Paleocurrents toward the south, SE or East support this assumption. Nevertheless, the abundance of volcanic clasts and the NE-directed paleocurrents in the Copa Sombrero Formation suggest that the latter unit was deposited in the axis of the trough (Fig. 11). Little is known about the late evolution of the early Late Cretaceous Celica–Lancones Basin. The western quartzose conglomerate layers, which may overly the Copa Sombrero Formation, suggest that a tectonic event could have also affected the Amotape–Tahuin massif. The Cochurco succession is interpreted as shallow-marine deposits developed along the margin of the Basin. The high proportion of volcanic clasts in the sediments of the Cochurco series implies either the existence of a volcanic source on the Amotape–Tahuin Massif, possibly the Basal Greywackes, or the proximity of the Celica volcanic arc.

It should be noted, however, that the Puyango–Cazaderos and Cochurco series are presently separated by a tectonic contact (Fig. 5) and neither intermediate facies nor lateral facies changes have been observed in the field between both series.

The volcaniclastic southeastern domain includes the Chaguarpamba–Sabanilla succession (Quillosara and Carmelo Fms, probably Zambi Fm) and the Río Playas succession (Celica, Alamor, Naranjo and Casanga Fms, Figs. 4 and 5, Jaillard et al., 1996). The massive greywackes of the Quillosara Formation are petrographically very similar to those of the Alamor Formation, which clearly derive from the activity, and erosion of the Celica volcanic arc (Jaillard et al., 1996). Since the Quillosara Formation is finer-grained than the Alamor Formation and bears evidence of north- to NW transport, it probably represents a lateral equivalent of the latter (Fig. 11). The fine-grained Carmelo Formation (Turonian *p.p.*) is a basinal deposit, which may represent a distal part of the Celica–Lancones forearc basin and/or a period of tectonic quiescence.

The eastern río Playas series comprises the autochtonous sedimentary cover of the Celica volcanic arc, which is believed to rest on the metamorphic basement of the Andean margin. A comparable setting is assumed for the Chaguarpamba–Sabanilla series. However, no intermediate facies have been observed, and both series are separated by the major NE-trending río Playas fault (Fig. 5), which is well marked in the present-day topography. It involves slices of metamorphic Paleozoic micaschists (near Yamaná), and belongs to the well-developed NE-trending faults of southern Ecuador, which controlled Eocene (Hungerbühler, 1997) and Miocene sedimentation (Baudino, 1995) and Late Miocene deformation (Lions, 1995).

Because of their lithologic and petrographic contrast, it is suspected that a major tectonic contact separates the northwestern province from the southeastern domain. In Peru, near Jahuay Negro, the contact between the Copa Sombrero Group and the "Lancones volcanics" (Reyes and Caldas, 1987), equivalent to the Quillosara Formation, is a deformed NE–SW trending fault zone. Farther northeast, this contact is inferred to lay northwest of Alamor (Fig. 5), where fine-grained greywackes and cherts (Carmelo Fm?) are strongly folded. East of Losumbé, a major fault zone marked by the occurrence of strongly deformed sediments and mylonites separates the Sabanilla–Chaguarpamba series from the Cochurco and Puyango series. However, in spite of careful field investigations, neither suture-like structure nor intensely faulted zone

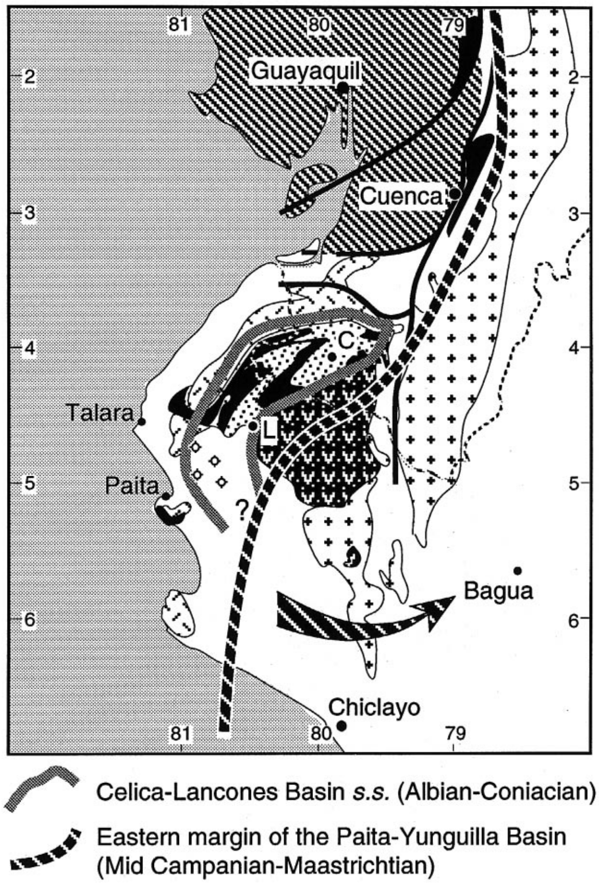

Fig. 12. Geographical extension of the Celica–Lancones Basin s.s. (Albian–Coniacian) and Paita–Yunguilla Basin (Middle Campanian–Maastrichtian). The probable extension of the latter to the Bagua area is indicated. Same caption as Fig. 1.

separating both domains could be detected along the Puyango–Alamor and Alamor–Cazaderos roads.

Indeed, the successions of the Celica–Lancones "Basin" seem to belong to independent tectonic units separated from each other by important tectonic contacts. Since the unconformable latest Cretaceous deposits exhibit roughly comparable sequences in both the eastern and western areas, tectonic juxtaposition of the independent northwestern and southeastern units had been achieved probably prior to Late Campanian times (Figs. 5 and 10). However, subsequent wrench movements deformed the Late Cretaceous faults.

5.2. Sedimentary and tectonic evolution of the forearc zone of northern Peru–southern Ecuador during the Cretaceous

The stratigraphic series described above display a two-cycle depositional history (Fig. 10). The Puyango–Cazaderos, río Cuchurco and Chaguarpamba–Sabanilla series represent a first depositional cycle of Late Aptian to Coniacian (or Santonian) age, which we consider to represent the filling of the forearc "Celica–Lancones Basin *sensu stricto*" (Figs. 12 and 13). The Basal Greywackes of the Losumbé and Puyango areas may represent the beginning of this cycle or may be part of an older cycle.

The unconformably overlying deposits of Middle(?) Campanian–Middle(?) Maastrichtian age exhibit more homogeneous depositional facies, which we consider to have constituted the filling of a new forearc basin, referred to here as the "Paita–Yunguilla Basin" (Figs.

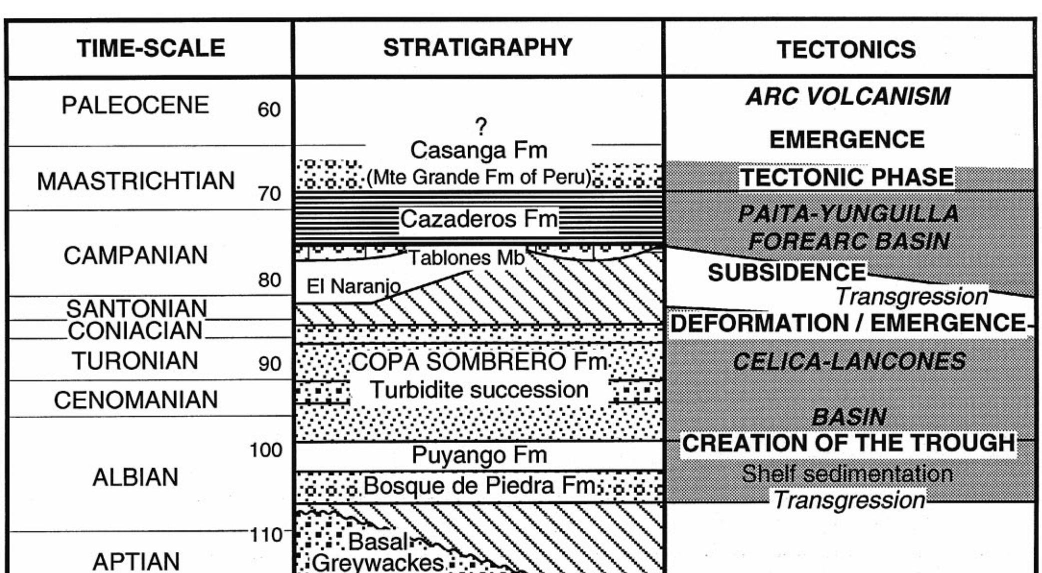

Fig. 13. Tectonic evolution of the western Celica–Lancones "Basin" s.l. during Cretaceous times.

12 and 13). Both depositional cycles are separated by a major unconformity, which postdates the deformation and erosion of the Celica–Lancones Basin s.s. during the Late Coniacian–Early Campanian interval.

5.2.1. The Celica–Lancones Basin s.s. (Late Aptian–Coniacian (?))

During the Late Aptian to Middle Albian, the Amotape–Tahuin Massif was a relatively stable and moderately subsiding area of the Andean forearc zone which resulted in deposition of nearshore sandstones (Bosque de Piedra Fm) and shelf carbonates (Puyango Fm).

The creation of the Celica–Lancones turbiditic trough occurred during the late Middle Albian to early Late Albian (base of the Copa Sombrero Fm, Fig. 13). This sharp increase in subsidence was associated with a strong synsedimentary tectonic instability expressed by slumps, olistoliths, clastic dykes and turbiditic flows, as already noted in northwestern Peru (Morris and Alemán, 1975; Reyes and Caldas, 1987; Chávez and Nuñez del Prado, 1991). This event can be correlated with the Mochica tectonic phase of Peru (Mégard, 1984), marked by the alternation of contractional and extensional deformations, probably due to a dextral shear regime (Cobbing et al., 1981; Bussel, 1983; Soler, 1991; Jaillard, 1994).

Tectonic instability continued during Cenomanian and Turonian times, as shown by the thick accumulations of turbidite beds, and the abundance of slumps and olistoliths (Morris and Alemán, 1975; Reyes and Caldas, 1987; Chávez and Nuñez del Prado, 1991).

To the west, the occurrence of quartz-rich conglomerates in the upper part of the succession suggests that the Amotape–Tahuin Massif was subject to active erosion during early "Senonian" times.

5.2.2. The Late Cretaceous tectonic event (Late Coniacian–Early Campanian)

Following deposition of the Copa Sombrero Formation, the Celica–Lancones Basin underwent strong compressional tectonism and erosion (Figs. 10 and 13). The available stratigraphic data indicate that these events occurred between the Early Coniacian and the Middle Campanian. They are coeval with contractional deformation phases dated elsewhere as Early Coniacian to Campanian (Peruvian phase, Steinmann, 1924; Jaillard, 1994). In Ecuador, this major tectonic event is expressed by an "arc jump" in the oceanic coastal terranes (Jaillard et al., 1995), by the pre-Maastrichtian unconformity of the quartz-rich Yunguilla Formation upon early Late Cretaceous (Coniacian in part) oceanic sediments in the Western Cordillera (Faucher and Savoyat, 1973; Kehrer and Van der Kaaden, 1979; Eguëz, 1986; Cosma et al., 1998), by a significant thermal event on the Eastern Cordillera (85–80 Ma; Aspden et al., 1992; Litherland et al., 1994), and by regional sedimentary hiatuses of Late Santonian to Late Campanian age in the Oriente Basin (Rivadeneira, 1996; Jaillard et al., 1997).

Several lines of evidence including displacements observed in the field (Bussel, 1983), creation of subsiding pull-apart basins (Soler, 1991), paleostress analysis (Jaillard, 1994) and clockwise rotations (Mourier et al., 1988; Roperch, unpubl. data) of the arc and forearc zones of northern Peru indicate that they were affected by significant dextral wrenching movements during Late Cretaceous and Paleocene times. Evidence of pre-Late Campanian, probably synsedimentary dextral wrench faulting was noted in the Cochurco series. Therefore, we suspect that the juxtaposition of the units in the Celica–Lancones Basin (Fig. 5) was due to the interplay of important dextral wrench-faults coeval with Late Albian–Coniacian sedimentation, and the compressional tectonic event of Late Coniacian–Early Campanian age. These major faults were subsequently reactivated during Tertiary contractional deformation, thus obscuring the recognition of the "suture" zone.

The complex structure of the "Celica–Lancones" Basin suggests that the intensity of deformation and importance of dextral displacement in the forearc zones of the Andean margin during the Late Cretaceous have been probably underestimated as yet.

5.2.3. The Paita–Yunguilla Basin (Middle(?) Campanian–Middle(?) Maastrichtian)

Deformation and erosion of the Celica–Lancones Basin *s.s.* is postdated by the unconformable limestones and shales of probable Campanian age (Tablones Mb of the Cazaderos Fm, Figs. 10 and 13). The latter correlate with the Middle to Late Campanian transgressive beds recognized in the western Cordillera of Ecuador (San Juan Limestones), in northwestern Peru (Redondo and La Mesa Fms), on the eastern side of the Celica Basin of Ecuador (base of El Naranjo Fm) where it could be older (Late Santonian–Early Campanian), and maybe in the Bagua syncline of northern Peru (top of Celendín Fm, Mourier et al., 1988; Naeser et al., 1991) (Fig. 12).

This regional transgression records the development of a wide forearc basin of Middle(?) Campanian to Maastrichtian age, which extended at least from the Paita area (5° 20′ S) to north of Quito (0° 30′ N). In central and northern Ecuador, sediments of this basin presently crop out along the suture between oceanic allochtonous units and the continental margin (Fig. 12). The NNE trending Paita–Yunguilla Basin covers a much wider area than the Celica–Lancones Basin *s.s.* and is strongly oblique with respect to the latter, the axis of which is deformed (Fig. 12). This indicates that the Coniacian–Campanian Peruvian tectonic phase resulted in strong deformation and in a complete reorganization of the depocenters and structural trends in these forearc zones.

In contrast to the early Late Cretaceous succession, the latest Cretaceous succession is weakly deformed, and is lithologically rather homogeneous across the whole basin (Fig. 10). It comprises Middle Campanian to Early Maastrichtian black shales (Pazul Fm, upper part of the El Naranjo Fm) locally intercalated with turbidites of mixed crystalline–volcanic origin (Cazaderos and Yunguilla Fms, and maybe the Zambi Fm), and thick sequences of coarse-grained breccias or conglomerates of Middle (?) Maastrichtian age (La Tortuga, Monte Grande, Casanga Fms, and Callo Rumi Mb). The presence of Paleocene beds has not yet been proven.

The occurrence of thick, coarse-grained conglomerates of Early(?) Maastrichtian age suggests that a significant tectonic event occurred at that time, and was probably followed by the emergence of the basin (Figs. 10 and 13). This event could be related to the ≈ 70 Ma reset K/Ar ages evidenced in the metamorphic Cordilleras of Ecuador (Aspden et al., 1992) and Colombia (McCourt et al., 1984; Toussaint and Restrepo, 1994), to the high dextral strike-slip rates measured in the forearc zone of northern Peru (70–60 Ma; Bussel, 1983), and to the $\approx 65 \pm 3$ Ma deformational event recently dated in the Eastern Cordillera of Colombia (Cheilletz et al., 1997).

6. Summary and conclusions

The Albian–Coniacian Celica–Lancones forearc Basin is made of several paleogeographic units, presently separated from each other by tectonic contacts. According to their sedimentary content, the units can be divided into a northwestern quartz-rich domain and a southeastern volcaniclastic domain. Shelf deposition during the Early and Middle Albian was interrupted in the Late Albian by the creation of an elongated trough (Mochica phase). The sedimentary fill of the latter was dominated by turbidites deposited in an unstable tectonic context, interpreted as being related to significant synsedimentary dextral wrench movements. The tectonic juxtaposition, deformation and erosion of the paleogeographic units occurred during the Late Coniacian–Early Campanian interval (Peruvian phase).

This event is post-dated by the creation of the Paita–Yunguilla Forearc Basin, which trends obliquely with respect to the former, and extends into central Ecuador. The related deposits are presently weakly deformed and exhibit rather homogeneous successions across the studied area. They comprise Late Santonian(?) to Middle Campanian transgressive limestones, Middle to Late Campanian black shales and turbidites, and Maastrichtian coarse-grained conglomerates. The latter express a tectonic event of Late(?) Maastrichtian age.

This study suggests that the deformation and displacement in the forearc zones during the Cretaceous has been underestimated in previous studies.

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References

Aspden, J.A., Harrison, S.H., Rundle, C.C., 1992. New geochronological control for the tectono-magmatic evolution of the metamorphic basement, Cordillera Real and El Oro Province of Ecuador. Journal of South American Earth Sciences 6, 77–96.

Aspden, J.A., Bonilla, W., Duque, P., 1995. The El Oro metamorphic complex, Ecuador: geology and economic mineral deposits. Overseas Geology and Mineral Resources 67, pp. 63, 1 map, British Geological Survey publ., Nottingham.

Baudino, R., 1995. Evolution des Andes d'Équateur au Néogène: les enseignements de l'étude des bassins montagneux. Thesis University of Pau, pp. 437, unpublished.

Bengtson, P., Jaillard, E., 1997. Stratigraphic revision of the Upper Cretaceous of the Peruvian–Ecuadorian border region: preliminary data and tectonic consequences. Gaea heidelbergensis 4, 71–72 Heidelberg.

Bristow, C.R., Hoffstetter, R., 1977. Ecuador. Lexique Stratigraphique International V, 5a2, CNRS ed. Paris, pp. 410.

Bussel, M.A., 1983. Timing of tectonic and magmatic events in the Central Andes of Peru. Journal of the Geological Society, London 140, 279–286.

Chalco, R.A., 1955. Estudio geológico preliminar de la región Sullana–Lancones. In: Boletín Técnico Empresa Petrolera, vol. 3. Ministerio de Fomento Público, Lima.

Chávez, A., Nuñez del Prado H, 1991. Evolución vertical de facies de la serie turbidítica cretácea (Grupo Copa Sombrero) en el perfil-tipo Huasimal–Encuentros (Cuenca Lancones en el Noroeste del Perú). Boletín de la Sociedad geológica del Perú 82, 5–21 Lima.

Cheilletz, A., Giuliani, G., Branquet, Y., Laumonier, B., Sánchez, A.J., Féraud, G., Arhan, T., 1997. Datation K-Ar et $^{40}Ar/^{39}Ar$ à 65 ± 3 Ma des gisements d'émeraude du district de Chivor-Macanal: argument en faveur d'une déformation précoce dans la Cordillère orientale de Colombie. Comptes Rendus à l'Académie des Sciences de Paris 324 (IIa), 369–377.

Cobbing, E.J., Pitcher, W.S., Wilson, J.J., Baldock, J.W., Taylor, W.P., McCourt, W., Snelling, N.J., 1981. The geology of the Western Cordillera of Northern Peru. Institute of Geological Sciences, London, Overseas Memoir 5, 143.

Cosma, L., Lapierre, H., Jaillard, E., Laubacher, G., Bosch, D., Desmet, A., Mamberti, M., Gabriele, P., 1998. Pétrographie et géochimie de la Cordillère Occidentale du Nord de l'Équateur (0°30′S): Implications tectoniques. Bulletin de la Société géologique de France 169, 739–751 Paris.

Dashwood, M.F., Abbots, I.L., 1990. Aspects of the petroleum geology of the Oriente Basin, Ecuador. In: Brooks, J. (Ed.), Classic Petroleum Provinces, vol. 50. Geological Society Special Publication, pp. 89–117.

Dhondt, A., Jaillard, É, 1997. Cretaceous bivalves from Ecuador and Northern Peru. Gaea heidelbergensis 4, 117–118 Heidelberg.

Egüez, A., 1986. Evolution Cénozoïque de la Cordillère Occidentale Septentrionale d'Equateur (0° 15′ S–1° 10′ S): les minéralisations associées. Thesis University Paris VI, pp. 116, unpublished.

Faucher, B., Vernet, R., Bizon, G., Bizon, J.J., Grekoff, N., Lys, M., Sigal, J., 1971. Sedimentary Formations in Ecuador. A stratigraphic and micropaleontological survey. Bureau d'Études Industrielles et Coopération de l'Institut Français du Pétrole (BEICIP) vol. 3, pp. 220.

Feininger, T., Bristow, C.R., 1980. Cretaceous and Paleogene history of coastal Ecuador. Geologische Rundschau 69, 849–874.

Fischer, A.G., 1956. Desarollo geológico del Noroeste peruano durante el Mesozóico. Boletín de la Sociedad geológica del Perú 30, 177–190.

González, G., 1976. Bioestratigrafía del Eoceno en la región de Talara. Thesis Universidad San Agustin Arequipa, pp. 225, 68 Fig., 9 pl. h.t.

Hessel, M.H.R., 1988. Lower Turonian inoceramids from Sergipe, Brasil: systematics, stratigraphy and palaeoecology. Fossils and Strata 22, 49 Oslo.

Hungerbühler, D., 1997. Neogene basins in the Andes of southern Ecuador: evolution, deformation and regional tectonic implications. PhD thesis, ETH Zürich, 12371, pp. 182, 1 map.

Iddings, A., Olsson, A.A., 1928. Geology of Northwest Peru. American Association of Petroleum Geologists Bulletin 12, 1–39.

Jaillard, E., 1994. Kimmeridgian to Paleocene tectonic and geodynamic evolution of the Peruvian (and Ecuadorian) margin. In: Salfity, J.A. (Ed.), Cretaceous tectonics in the Andes, Earth Evolution Sci, . Fried. Vieweg & Sohn, Braunschweig/Wiesbaden, pp. 101–167.

Jaillard, E., Ordoñez, M., Benítez, S., Berrones, G., Jiménez, N., Montenegro, G., Zambrano, I., 1995. Basin development in an accretionary, oceanic-floored forearc setting: southern coastal Ecuador during late Cretaceous to late Eocene times. American Association Petroleum Geologists Memoir 62, 615–631.

Jaillard, E., Ordoñez, M., Berrones, G., Bengtson, P., Bonhomme, M., Jiménez, N., Zambrano, I., 1996. Sedimentary and tectonic evolution of the arc zone of Southwestern Ecuador during Late Cretaceous and Early Tertiary times. Journal of South American Earth Sciences 9, 131–140.

Jaillard, É, Caron, M., Dhondt, A., Ordoñez, M., Andrade, R., Bengtson, P., Bulot, L., Cappetta, H., Dávila, C., Díaz, R., Huacho, J., Huamán, C., Jiménez, D., Jiménez, N., Lascano, M., Montenegro, J., Néraudeau, D., Rivadeneira, M., Toro, J., Villagómez, R., Zambrano, I., 1997. Síntesis estratigráfica y sedimentológica del Cretáceo y Paleógeno de la cuenca oriental del Ecuador. Orstom-Petroproducción publ, Quito pp. 164.

Kehrer, W., Kehrer, P., 1969. Die oberkretazische San Juan Formation der Westkordillere Ecuadors. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 133, 1–22.

Kehrer, W., Van der Kaaden, G., 1979. Notes on the Geology of Ecuador with special reference to the Western Cordillera. Geologisches Jahrbuch B35, 5–57.

Kennerley, J.B., 1973. Geology of the Loja Province, Southern Ecuador. London Institute of Geological Sciences Report 23, pp. 34.

Kennerley, J.B., 1980. Outline of the geology of Ecuador. Overseas Geol. Min. Resources 55, 1–16.

Kissel, C., Laj, C., Surmont, J., Macedo-Sánchez, O., Mitouard, P., 1992. South American active margin: Andean deflections and crustal thickening. Bulletin de la Société géologique de France 163, 371–380.

Lebrat, M. 1985 Caractérisation géochimique du volcanisme antéorogénique de l'Occident équatorien: implications géodynamiques. Thesis Univ. Montpellier, Documents et Travaux CGGM 6, 118 p.

Lebrat, M., Mégard, F., Dupuy, C., Dostal, J., 1987. Geochemistry and tectonic setting of pre-collision Cretaceous and Paleogene volcanic rocks of Ecuador. Geological Society of America Bulletin 99, 569–578.

Lions, R., 1995. Évolution géodynamique d'un bassin d'avant-arc néogène en contexte décrochant: l'ouverture du Golfe de Guayaquil (Equateur). DEA thesis, Univ. Grenoble I, pp. 83.

Litherland, M., Zamora, A., Egüez, A., Aspden, J., Baez, N., Beate, B., Benítez, S., Jaillard, E., Van Thournout, F., 1993. Mapa geológico de la República del Ecuador, escala 1:1,000,000. British Geological Survey, Keyworth.

Litherland, M., Aspden, J.A., Jemielita, R.A., 1994. The metamorphic belts of Ecuador. Overseas Memoir 11, 2 maps, British Geological Survey, Keyworth, pp. 247.

McCourt, W.J., Aspden, J.A., Brook, M., 1984. New geological and geochronological data from the Colombian Andes: Continental growth by multiple accretion. Journal of the Geological Society, London 141, 831–845.

Mathalone, J.M.P., Montoya, M., 1995. Petroleum geology of the Sub-andean Basins of Peru. American Association of Petroleum Geologists Memoir 62, 423–444.

Mégard, F., 1984. The Andean orogenic period and its major structures in Central and Northern Peru. Journal of the Geological Society, London 141, 893–900.

Mitouard, P., Kissel, C., Laj, C., 1990. Post-Oligocene rotations in southern Ecuador and northern Peru and the formation of the Huancabamba deflection in the Andean Cordillera. Earth Planet. Sci. Lett. 98, 329–339.

Morris, R.C., Alemán, A.R., 1975. Sedimentation and tectonics of middle Cretaceous Copa Sombrero formation in Northwest Peru. Boletín de la Sociedad geológica del Perú 48, 49–64.

Mourier, T. 1988 La transition entre Andes marginales et Andes cordilléraines à ophiolites. Evolution sédimentaire, magmatique et structurale du relais de Huancabamba (3°–8° S, Nord Pérou–Sud Equateur). Dr Thesis, Université Paris XI, pp. 275, unpublished.

Mourier, T., Bengtson, P., Bonhomme, M., Buge, E., Cappetta, H., Crochet, J.-Y., Feist, M., Hirsch, K., Jaillard, E., Laubacher, G., Lefranc, J.-P., Moullade, M., Noblet, C., Pons, D., Rey, J., Sigé, B., Tambareau, Y., Taquet, P., 1988a. The Upper Cretaceous-Lower Tertiary marine to continental transition in the Bagua basin, Northern Peru. Newsletters on Stratigraphy 19, 143–177.

Mourier, T., Laj, C., Mégard, F., Roperch, P., Mitouard, P., Farfan-Medrano, A., 1988b. An accreted continental terrane in Northwestern Peru. Earth Planetary Science Letters 88, 182–192.

Naeser, C.W., Crochet, J.-Y., Jaillard, E., Laubacher, G., Mourier, T., Sigé, B., 1991. Tertiary Fission-Track ages from the Bagua syncline (Northern Peru). Stratigraphic and tectonic implications. Journal of South American Earth Sciences 4, 61–71.

Olsson, A.A., 1934. Contributions to the Paleontology of Northern Peru. The Cretaceous of the Amotape region. Bulletin of American Paleontology 20, 104.

Olsson, A.A., 1944. Contributions to the Paleontology of Northern Peru. Part VII: The Cretaceous of the Paita region. Bulletin of American Paleontology 28, 113.

Palacios, O., 1994. Geología de los cuadrángulos de Paita, Talara, Sullana, Libitos, Quebrada Seca, Zorritos, Tumbes y Zarumilla. Boletin del Intituto Geológico, Minero y Metalúrgico 54 (A), 190 p Lima.

Petersen, G., 1949. Condiciones geográficas y geológicas de la Cuenca del río Zarumilla. Sociedad geológica del Perú, Volumen Jubilar 7, 1–40.

Reyes, L., Caldas, J., 1987. Geología de los cuadrángulos de Las Playas, La Tina, Las Lomas, Ayabaca, San Antonio, Chulucanas, Morropón, Huancabamba, Olmos y Pomahuaca. Boletín del Instituto Geológico, Minero y Metalúrgico 39 (A), 83.

Reyes, L., Vergara, J., 1987. Evaluación geológica y potencial petrolífero de la Cuenca Lancones. Petroperú unpublished report, pp. 57.

Reynaud, C., Lapierre, H., Jaillard, Ŕ, Benítez, S., Berrones, G., Mascle, G., 1996. Mineralogical and geochemical characterization of middle Cretaceous to Paleocene oceanic and continental volcanic rocks from southwestern Ecuador. In: 3rd International Symposium on Andean Geodynamics-ISAG, Saint-Malo, ORSTOM ed., pp. 633–636 sér. Colloques et Séminaires.

Rivadeneira, M., 1996. Cretaceous–Paleogene stratigraphic sequences and the early Andean orogenic events in the Ecuadorian Oriente basin. In: 3rd International Symposium on Andean Geodynamics-ISAG, Saint-Malo, ORSTOM ed., pp. 469–472 sér. Colloques et Séminaires.

Seitz, O., 1970. Über einige Inoceramen aus der Oberen Kreide. 2. Die Muntigler Inoceramen fauna und ihre Verbreitung im Ober-Campan und Maastricht. Beihefte zum Geologischen Jahrbuch 86, 105–171.

Sempéré, T., Butler, R.F., Richards, D.R., Marshall, L.G., Sharp, W., Swisher III, C.C., 1997. Stratigraphy and chronology of Upper Cretaceous–Lower Paleogene strata in Bolivia and northwest Argentina. Geological Society America Bulletin 109, 709–726.

Shoemaker, R.E., 1982. Fossil leaves from the Lower Cretaceous Ciano Formation, Southwestern Ecuador. Palaeontographica Abt. A 180, 120–132.

Sigal, J., 1969. Quelques acquisitions récentes concernant la chronostratigraphie des formations sédimentaires de l'Équateur. Revista Española de Micropaleontología 1, 205–236.

Soler, P., 1991. Contribution à l'étude du magmatisme associé aux zones de subduction. Pétrographie, géochimie et géochimie isotopique des roches intrusives sur un transect des Andes du Pérou Central. Implications géodynamiques et métallogéniques. Dr Thesis Univ. Paris VI, pp. 950.

Steinmann, G., 1929. In: Winter, K. (Ed.), Geologie von Peru, Heidelberg, p. 448.

Thalmann, H.E., 1946. Micropaleontology of Upper Cretaceous and Paleocene in Western Ecuador. American Association of Petroleum Geologists Bulletin 30, 337–347.

Toussaint, J.-F., Restrepo, J.J., 1994. The Colombian Andes during Cretaceous times. In: Salfity, J.A. (Ed.), Cretaceous tectonics in the Andes, Earth Evolution Sciences, . Fried. Vieweg & Sohn, Braunschweig/Wiesbaden, pp. 61–100.

Weiss, L., 1955. Planktonic index foraminifera of northwestern Perú. Micropaleontology 1, 301–319.

Zuñiga, F., Cruzado, C., 1979. Bioestratigrafía del Noroeste Peruano. Boletín de la Sociedad geológica del Perú 60, 219–232.