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Sedimentary record of terminal Cretaceous accretions in Ecuador: The Yunguilla Group in the Cuenca area

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Abstract

A reappraisal of the "Late Cretaceous Yunguilla Formation" of the Cuenca area enables the definition of four distinct formations, correlatable with those of southwestern Ecuador. A mid- to late-Campanian marine transgression (Jadán Formation) is overlain by quartz-rich conglomerates of fan-delta to turbiditic fan environment (Quimas Formation) of latest Campanian–earliest Maastrichtian age, which are interpreted as evidence of the accretion of a first oceanic terrane (San Juan). Disconformable, arkosic turbidites and cherts (Tabacay Formation) of early Maastrichtian age are thought to represent the erosion of the newly accreted oceanic terrane. A major unconformity of late Maastrichtian age, caused by the accretion of a second oceanic terrane (Guaranda), is followed by the deposition of quartz-rich micaceous shelf sandstones (Saquisilí Formation) of Paleocene age. A third accretion event (late Paleocene) is recorded in coastal Ecuador. Each accretion event correlates with the uplift and erosion of the Eastern Cordillera and with a sedimentary hiatus in the eastern areas. In Ecuador, accretion of oceanic terranes contributed to the build up of the Andes through tectonic underplating of low-density material, and the eastern areas did not behave as flexural foreland basins during late Cretaceous–Paleogene times.

Keywords: Ecuador; Latest Cretaceous; Paleocene; Accretions; Uplift; Clastic sedimentation

1. Introduction

The Andes of Ecuador differ from the Central Andes by the presence of mafic magmatic terranes (Goossens and Rose, 1973; Gansser, 1973), interpreted as oceanic fragments accreted during Late Cretaceous and Eocene times (Feininger and Bristow, 1980; Lebrat et al., 1987; Daly, 1989; Reynaud et al., 1999; Kerr et al., 2002). More recently, some authors (Arculus et al., 1999; Guillier et al., 2001; Jaillard et al., 2002; Toro and Jaillard, 2005) have proposed that the accreted oceanic material has been tectonically underplated and constitutes the crustal root of the Andes of Ecuador.

To constrain the date, processes, and consequences of accretions on Andean tectonics, we studied the dominantly clastic sediments coeval with the accretions (Late Cretaceous–Eocene), located on the western edge of the continental margin, which corresponds to the present-day Cordillera of Ecuador.

2. Geological setting

The coast and Western Cordillera of Ecuador consist of terranes of oceanic origin, whereas the continental Andean

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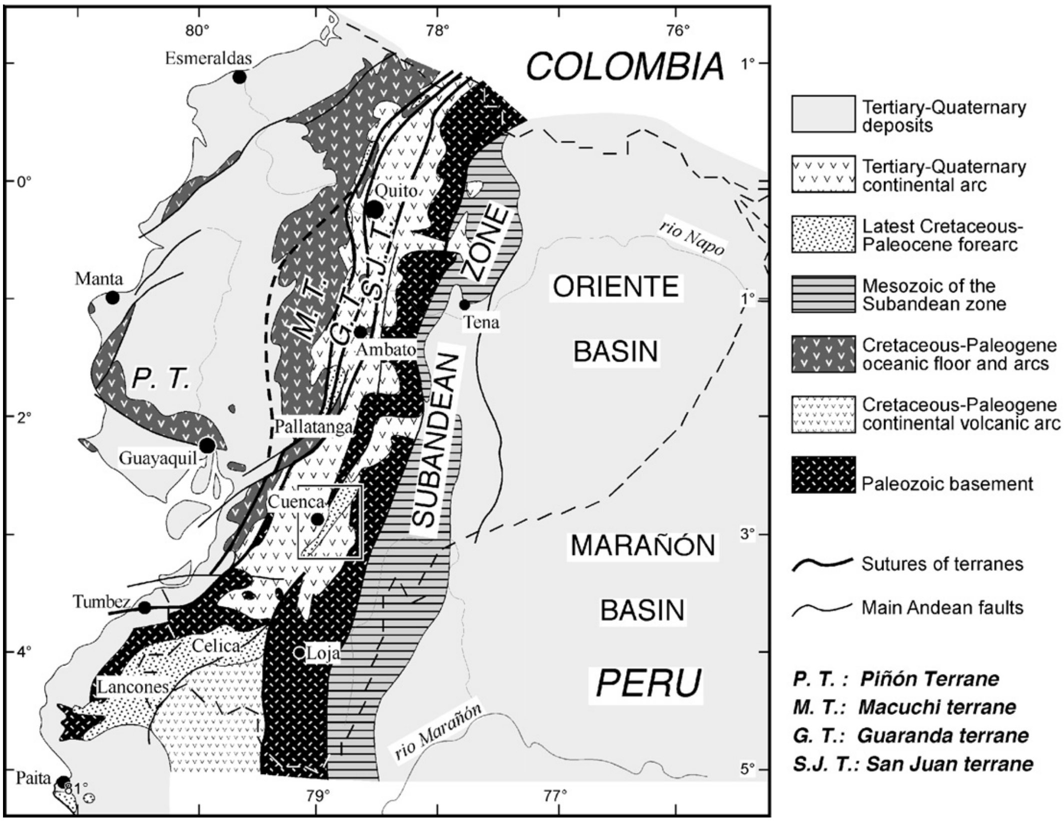

Fig. 1. Structural sketch of Ecuador and location of Fig. 2. Bold lines represent sutures bounding oceanic terranes.

margin comprises the deformed Eastern Cordillera (Litherland et al., 1994), the sub-Andean zone, and the Oriente Basin (Jaillard, 1997; Fig. 1). In northern and central Ecuador (1°N–2°S), the Western and Eastern Cordilleras are separated by the Inter-Andean Valley, infilled by products of Neogene–Quaternary volcanic arcs (Lavenu et al., 1996; Hungerbühler et al., 2002). Farther south (2°S–5°S), the tectonic boundary between the allochtonous, oceanic units and the autochtonous continental margin is located west of the Western Cordillera (Fig. 1), and the well-defined Inter-Andean Valley vanishes.

The Cuenca area (≈3°S) is situated on the western edge of the Eastern Cordillera (Litherland et al., 1994) and bounded to the west by uplifted Tertiary arc volcanic piles, the basement of which is most probably continental, as evidenced by crystalline outcrops west of Cuenca (Dunkley and Gaibor, 1998; Pratt et al., 1998). This relative depression received thick, marine to subaerial deposits during the mid-Miocene; subsequent compressional deformations were controlled by major NE-trending faults (Bristow, 1980; Noblet et al., 1988; Hungerbühler et al., 2002). As for the Celica area of southwestern Ecuador (Kennerley, 1973; Jaillard et al., 1996, 1999), the basement of the Tertiary deposits of the Cuenca area is mainly represented by Jurassic–Paleozoic metamorphic rocks and Cretaceous–Paleogene sedimentary deposits (Bristow, 1980; Litherland et al., 1994; Hungerbühler et al., 2002). The latter sediments are the focus of this study (Fig. 2).

3. Previous work

The name "Yunguilla Formation" was introduced by Thalmann (1946) for a succession of black shales and sandstones, dated with foraminifers as Maastrichtian, exposed northwest of Quito. Since then, comparable Maastrichtian sediments have been identified and dated with microfossils in the Western Cordillera of Ecuador, between Quito and Cuenca (Tschopp, 1948; Sigal, 1969; Kehrer and Kehrer, 1969; Faucher et al. 1971; Bristow, 1973; Jaillard et al., 2004), in southwestern Ecuador (Loja area; Sigal, 1969), and locally in the sub-Andean zone (Limón area; Faucher et al., 1971). Many rocks subsequently referred to the Yunguilla Formation have been dated as Paleocene or Eocene, and new Paleogene units have been defined (Faucher et al., 1971; Henderson, 1981; Egüez and Bourgois, 1986; Santos and Ramírez, 1986; Hughes et al., 1999; Jaillard et al., 2004).

In the Cuenca-Azogues area (Fig. 2), Bristow (1980) considered that the "Yunguilla Formation" rests on Cretaceous volcanic rocks, which subsequently were dated by fission track analysis as Oligocene (Steinmann, 1997). The Late Cretaceous–Paleogene succession seems to constitute the basement of the Miocene intermontane basin and rests on metamorphic rocks of the continental basement of Ecuador (Noblet et al., 1988; Steinmann, 1997; Dunkley and Gaibor, 1998; Pratt et al., 1998; Hungerbühler et al., 2002; Vaca, 2005). The Yunguilla Formation crops out east of Cumbe, Cuenca, and Azo-

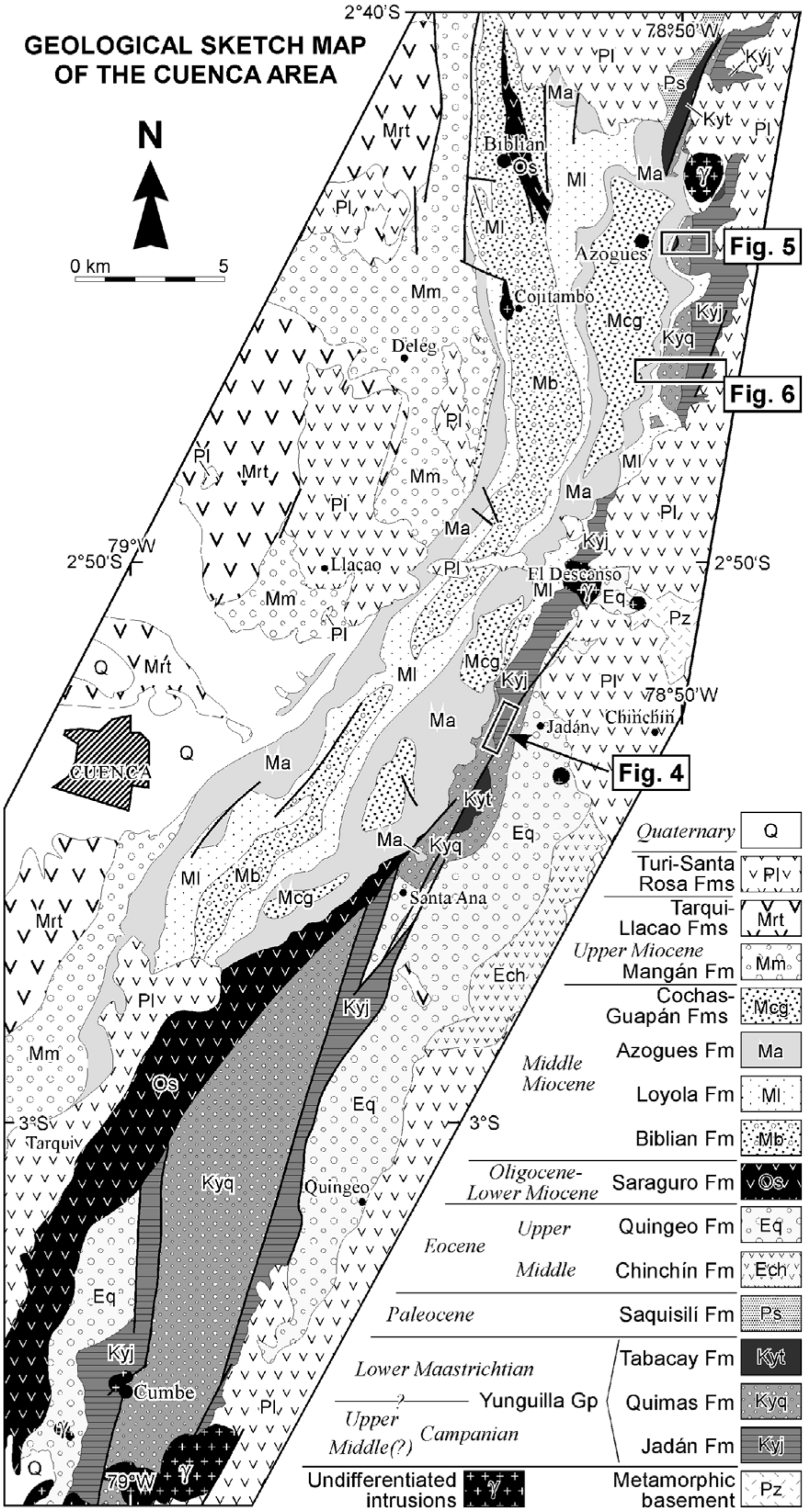

Fig. 2. Geological map of the Cuenca area, compiled from Bristow (1980), Noblet et al. (1988), Steinmann (1997), Dunkley and Gaibor (1998), Pratt et al. (1998), Hungerbühler et al. (2002) and personal observations. Note locations of Figs. 4–6.

gues along a NNE-trending belt (Fig. 2). Farther north, in the Pallatanga area, the "formation" is tectonically associated with accreted oceanic terranes, with which it is assumed to have been in stratigraphic contact (McCourt et al., 1998; Hughes et al., 1999; Jaillard et al., 2004). To the southwest, the uppermost Cretaceous succession rests unconformably on Paleozoic–middle Cretaceous rocks of the forearc zones of southern Ecuador and northwestern Peru (Olsson, 1944; Jaillard et al., 1998, 1999).

In the Cuenca-Azogues area, Faucher et al. (1971) and Bristow (1973) identify three distinct lithologic units.

1. Cherts and greywackes, commonly silicified, yield scarce, poorly preserved fossils referred to the Maastrichtian. They consider this unit the lower part of the "Yunguilla Formation" (but see discussion of the Tabacay Formation).
2. Poorly consolidated shales with limestone lenses and arkosic sandstones beds, dated with microfossils as Maastrichtian. These rocks are interpreted as the upper part of the "Yunguilla Formation" (Faucher et al., 1971). Ammonites collected from these units are assigned to the lower Maastrichtian (Bristow, in Bristow and Hoffstetter, 1977).
3. According to Bristow (in Bristow and Hoffstetter, 1977), marine shales and limestone lenses of the Cumbe area, referred to the "Yunguilla Formation," grade upward into continental, volcanogenic redbeds. From the "Yunguilla Formation," Bristow (in Bristow and Hoffstetter, 1977) reports one *Inoceramus* sp. and an unidentified ammonite, and Pratt et al. (1997) collected the ammonites *Hoploscaphites* sp. and *Baculites* sp. of Maastrichtian age. From the overlying fine-grained redbeds, Bristow (in Bristow and Hoffstetter, 1977) collected Paleocene molluscs and Pratt et al. (1997) the bivalve *Pterotrigonia* sp., known from the Maastrichtian of Peru.

In the Cuenca area, the Yunguilla Formation is overlain by middle Eocene volcanics (Chinchín Formation, approximately 43 Ma) and unconformable continental volcanogenic redbeds of mid- to late-Eocene age (Quingeo Formation, 42–34 Ma) (Steinmann, 1997; Hungerbühler et al., 2002). Pratt et al. (1997) correlate the continental volcanogenic redbeds of the Cumbe area with the Quingeo Formation (Fig. 2), defined and dated farther northeast by Steinmann (1997).

4. Stratigraphy and depositional interpretation of the Late Cretaceous–Paleocene rocks of the Cuenca area

Based on geological surveys and study of stratigraphic sections, combined with exhaustive fossil collecting, we subdivide the rock succession formerly ascribed to the Yunguilla Formation into four formations ranging in age from the mid- or late-Campanian to the Paleocene (Fig. 3). We therefore introduce the Yunguilla Group, which comprises the middle (?) to upper Campanian Jadán Formation, the conglomeratic Quimas Formation, and the lower Maastrichtian Tabacay Formation. The Yunguilla Group is overlain by the Paleocene Saquisilí Formation, formerly included in the "Yunguilla Formation."

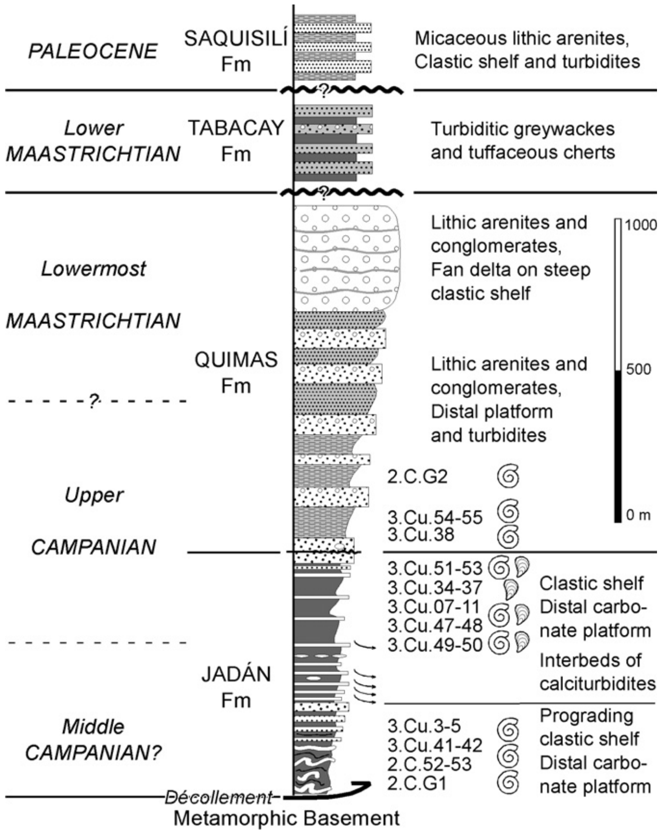

Fig. 3. Synthetic lithological succession of the upper Cretaceous–Paleocene series of the Cuenca area.

4.1. Jadán Formation (middle(?) to upper Campanian)

Although it corresponds to the lithologic unit 2 described previously, the Jadán Formation is the lowest unit of the Yunguilla Group. It consists mainly of shales and marls, with thin limestone and arkosic sandstone beds. The base of the formation is not exposed. Because metamorphic rocks crop out just east of the Yunguilla Group, the latter probably overlies the continental margin unconformably (Steinmann, 1997), as is observed farther north (Vaca, 2005). The lowermost part of the Jadán Formation is strongly deformed and probably acted as a décollement level.

The Jadán Formation is best exposed along the El Descanso–Jadán road (Loma Tunasloma), which is proposed as the type section, and east of Azogues (Santa Bárbara). It is also exposed southeast of Santa Ana, northeast of El Descanso, and around Cumbe (Fig. 2). The 500–800 m thick formation can be subdivided into three lithologic units ("members").

First, the lower part of the formation is made up of loose, silty shales and marls with thin beds of dark, micritic limestones and arkosic to lithic, fine- to medium-grained sandstones. The limestones are locally nodular and sandy. The sandstones are locally rich in micas, and cementation is generally calcareous. Local bioclastic limestones are interpreted as distal turbidites. The succession is composed of 100–200 m thick, coarsening-, thickening- and shallowing-upward sequences. The abundance of the bivalve *Pinna* sp.

indicates a moderate paleodepth (⩽100 m), whereas common wood fragments suggest proximity to land. Ammonites collected along the El Descanso–Jadán road are indentified as *Diplomoceras* sp. (upper Campanian–Maastrichtian) (sample [02.C.52] Table 1) and *Glyptoxoceras* sp. (Santonian–Maastrichtian) or *Neoglyptoxoceras* sp. (lower–middle Campanian) ([02.C.53, 02.C.G1, 03.Cu.05] Table 1).

Second, the middle part of the formation includes, in addition to the former lithologies, massive interbeds of black siliceous silts, thin-bedded calciturbidites, thin limestones interbedded with thin sandy laminae, and thick sandstone beds with coarsening-upward trends and progressive unconformities reflecting synsedimentary tectonic activity. The lower part of this unit yields the Campanian ammonite *Nostoceras* (*Nostoceras*?) sp. (upper Campanian) ([03.Cu.03] Table 1).

Third, the upper part of the formation (Fig. 4) consists of shales, marls, and limestones rich in ammonites, gastropods, oysters, inoceramids, and other bivalves. This unit is composed of prograding, thickening-upward sequences of an external, distal shelf environment; therefore, it is interpreted to represent a transgressive pulse. Near the top, the limestones become progressively more sandy and eventually grade into conglomerates. We collected the ammonites *Libycoceras* sp. [03.Cu.07] (upper Campanian to lower or middle Maastrichtian), *Nostoceras* (*Nostoceras*?) sp. [03.Cu.07] (upper Campanian), *Glyptoxoceras* sp. (Santonian–Maastrichtian) or *Neoglyptoxoceras* sp. [03.Cu.08, 09, 10] (lower–middle Campanian), and *Menuites* sp. [03.Cu.11] (Santonian–Maastrichtian) in Loma Tunasloma (location in Table 1). In addition, a loose inoceramid (found by D. Iza) is identified as *Cataceramus* cf. *pseudoregularis* (Sornay, 1962), which is known from the uppermost Campanian of Tercis, France (lower part of the *Nostoceras hyatti* Zone, Walaszczyk et al., 2002). East of

Table 1
Origin and location of the fossil samples cited in the text

Sample	Location: Map	Location: (UTM)	Stratigraphic unit
02.C.52	Jadán road, western	73580–968350	Jadán Fm Lower
02.C.53	slope of the ridge	73560–968330	unit
02.C.G1	dividing río Jadán	73570–968340	
03.Cu.05	and quebrada Huangarcucho	73530–968310	
03.Cu.03		73520–968290	Middle Jadan Fm
02.Cu.07	Loma Tunasloma,	73470–968250	Jadán Fm Upper
02.Cu.08	ridge between río	73460–968240	unit
02.Cu.09	Jadán and quebrada	73460–968240	
03.Cu.10	Huangarcucho	73450–968230	
03.Cu.11		73450–968230	
D. Iza		73460–968250	
02.C.G2	Southeast of Antonio	74040–969310	Quimas Fm
02.C.52	Borero	73580–968350	
02.C.53	Santa Barbara, east	73560–968330	
02.C.54-55	of Azogues	73570–968340	

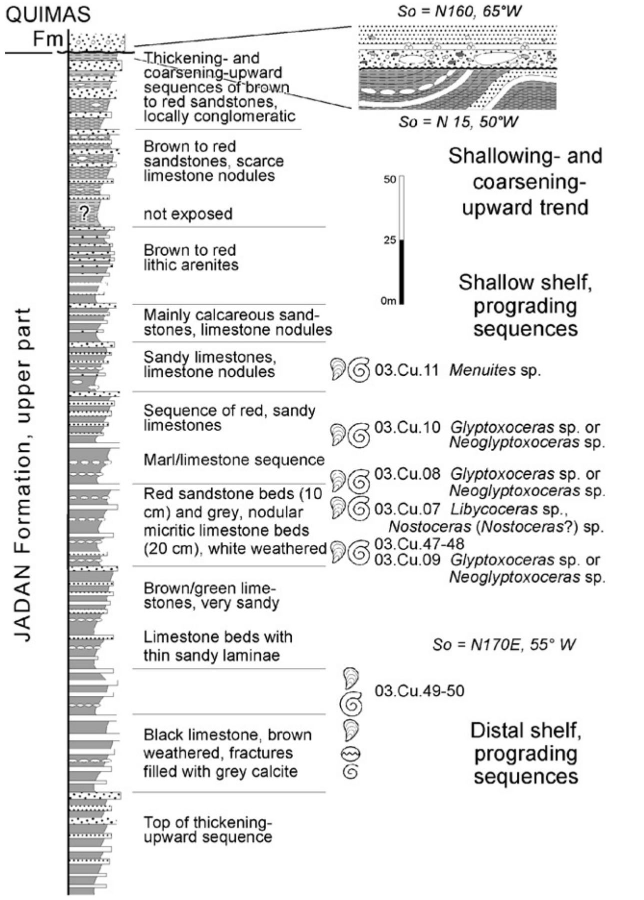

Fig. 4. Lithological succession of the upper Jadán Formation and contact with the Quimas Formation in Loma Tunasloma. Location in Fig. 2.

Azogues (Santa Bárbara), the upper part of the formation yields *Glyptoxoceras* sp. (Santonian–Maastrichtian) or *Neoglyptoxoceras* sp. [03.Cu.35, 03.Cu.36] (lower–middle Campanian) and a pachydiscid, probably *Menuites* sp. [03.Cu.34] of Santonian–Maastrichtian age (Fig. 5). Thus, the weight of evidence suggests that the upper part of the Jadán Formation is upper Campanian.

Within their lithology 2, Faucher et al. (1971) identify, among others, the planktic foraminifers *Globotruncana* [= *Gansserina*] gr. *gansseri* Bolli, 1951, *Plummerita hantkeninoides* (Brönnimann, 1952), *Rugoglobigerina macrocephala* Brönnimann, 1952, *R.* cf. *reicheli* Brönnimann, 1952, and *R.* gr. *rugosa* (Plummer, 1926), along with the benthic foraminifers *Rzehakina epigona* var. *lata* Cushman and Jarwis, 1929, *Siphogenerinoides* cf. *bramlettei* Cushman, 1929, *S. cretacea* Cushman, 1929, and *S. reticulatus* Stone, 1946 (det. J. Sigal). South of Santa Ana, in the Quebrada Salada, we collected *Platyceramus* sp., of late Coniacian–early Maastrichtian age from the undifferentiated Jadán Formation. Near Cumbe, shales and marls with limestone nodules and arkosic sandstone interbeds ascribed to the Jadán Formation yield planktic and benthic foraminifers; the association of *Bulimina midwayensis* (Cushman and Parker, 1936) (Campanian–Paleocene), *Haplophragmoides* aff. *horridus* (Grzybowski, 1901) (Campanian–Paleogene), *Hedbergella*

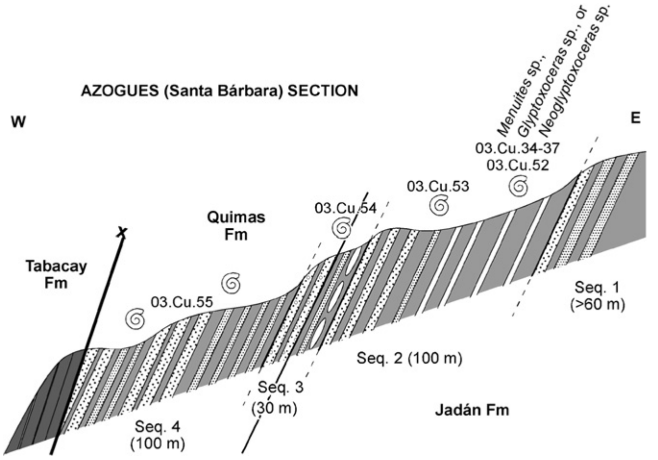

Fig. 5. Lithological succession of the upper Jadán to Tabacay formations at Santa Bárbara (east of Azogues). Location in Fig. 2.

holmdelensis Olsson, 1964 (Late Cretaceous), *Nodosaria* cf. *longiscata* d'Orbigny, 1846 (Maastrichtian–Eocene), *Praebulimina reussi* (Morrow, 1934) (Late Cretaceous), and *Turrilina carseyae* (Plummer, 1931) (Campanian–Maastrichtian) indicates a Campanian–Maastrichtian age for these outcrops.

4.2. *Quimas Formation (uppermost Campanian–lowermost Maastrichtian)*

The Quimas Formation consists of thick beds of coarse to microconglomeratic arkosic and lithic sandstones, poorly sorted conglomerates, and subordinate lithic arenites and limestone nodules containing benthic foraminifers. The base of the Quimas Formation is defined at the base of the first erosional conglomerate bed. However, the lithologic change from the upper Jadán Formation to the lower Quimas Formation is progressive and mainly expressed by the increase in conglomerates and erosional surfaces (Figs. 4 and 5). The Quimas Formation is best exposed along the Cumbe–Quingeo road, notably in the Quebrada Quimas and Loma Huairapungu. This section is proposed as the type section. Other outcrops occur north of Santa Ana and east of the El Descanso–Azogues road.

The conglomerates contain subangular to well-rounded clasts up to 10 cm in size. The clasts consist dominantly of quartz and metamorphic and sedimentary rocks, as well as scarce volcanic rocks. The sandstones are commonly turbidite beds, which contain quartz (30–50%), feldspar (20–35%), lithic fragments (30–40%), and scarce detrital micas. Steinmann (1997) reports a heavy mineral assemblage (e.g., 34% zircon, 21% tourmaline, 20% apatite, 20% garnet) typical of crystalline, plutonic, and metamorphic source zones. In the Quebrada Tabacay, north of Azogues, conglomerates with well-rounded quartz and metamorphic clasts contain gastropods and bivalves. In Loma Tunasloma, marine bivalves, plant remains, and bone fragments indicate a locally shallow-marine depositional environment. Fine-grained sediments show bioturbation, laminae, and ripples, suggesting a shelf environment.

The formation contains numerous synsedimentary unconformities, folds, and slumps, as well as debris flows, which indicate contemporaneous tectonic activity and/or a steep slope. Conglomerate beds are commonly lens-shaped and channelized, indicating the proximity of fluvial systems that fed fan deltas prograding on the shelf. The formation appears to reach a thickness of 1000 m in the Cumbe–Quingeo area and grades northward into much thinner (approximately 500 m) and finer-grained deposits, near Azogues. This trend suggests that the feeding alluvial system (alluvial fan and fan delta) was located in the Cumbe area. As a whole, the Quimas Formation is interpreted as a fan delta deposit prograding on a steep shelf.

East of Antonio Borrero (Fig. 6), Bristow (in Bristow and Hoffstetter, 1977; personal communication, 2003) reports *Sphenodiscus peruvianus* Gerth, 1928, and *Solenoceras* sp. of early Maastrichtian age (determined by M.K. Howarth, Natural History Museum, London). In the same area (Fig. 6), we find ammonite fragments, which may be either *Glyptoxoceras* sp. (Santonian-Maastrichtian) or *Neoglyptoxoceras* sp. (lower–middle Campanian) ([02.C.G2, 03.Cu.38] Table 1). East of Azogues, the base of the formation yields unidentifiable ammonites [03.Cu.54-55] that directly overlie the upper Campanian species mentioned previously (Fig. 5). On the basis of this evidences, the Quimas Formation is considered of latest Campanian to earliest Maastrichtian age.

4.3. *Tabacay Formation (lower Maastrichtian)*

The Tabacay Formation corresponds to lithologic unit 1 of Faucher et al. (1971). The base of the formation is not exposed, except to the east of Azogues (Santa Bárbara), where it is faulted (Fig. 5), and north of Azogues, where it unconformably overlies both the Quimas Formation and undated metamorphic rocks (Vaca, 2005). North of Santa Ana and in the Quebrada Tabacay, the formation seems to rest disconformably on the Quimas Formation. However, no suitable type section has been found.

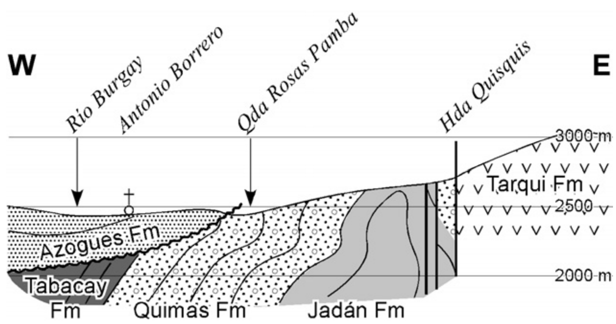

Fig. 6. Structural section of the Yunguilla Group, east of Antonio Borrero. Location in Fig. 2.

Although the stratigraphic contact is not visible, the Tabacay Formation seems to rest unconformably on the Quimas Formation, because the dip orientations and deformation styles are slightly different.

The Tabacay Formation consists of a succession of dark, laminated cherts, alternating with variably thick, fine-grained polygenetic conglomerates, volcanogenic greywackes, and arkosic lithic arenites. The clasts dominantly consist of volcanic rocks, associated with arkoses, lithic arenites, and chert fragments, as well as locally abundant white quartz. Nodules or irregularly bedded intercalations of micritic black limestones are common, whereas scarce calciturbidites with volcanic or feldspathic fragments are locally observed. The detrital beds are interpreted as turbidites on the basis of their erosional bases, presence of flat pebbles, and fining-upward bedding. The detrital components of the Tabacay Formation indicate a dominantly volcanic source area and a subordinate crystalline basement provenance. The detrital fragments were deposited in a dysaerobic pelagic environment, in which autochtonous, fine-grained, siliceous mud was laid down. Although outcrops are scarce, the thickness of the Tabacay Formation seems to reach a few hundred meters.

Faucher et al. (1971) record Maastrichtian foraminifers (buliminids, arenaceous forms, *Robulus* sp., *Globigerinella* sp.) and scarce indeterminable bivalves, inoceramids, and ammonites within their lithologic unit 1. In Quebrada Tabacay, Bristow (1973) found a diplomoceratid ammonite. Farther north, in the Pallatanga area near Huangupud, from a comparable lithology, we collected *Exiteloceras* sp. [99.G.74, 99.G.75] of Campanian age (or *Glyptoxoceras* sp., Santonian–Maastrichtian?) and a *Hypophylloceras* (*Neophylloceras*) sp. [99.G.75], of probably early Maastrichtian age (Jaillard et al., 2005).

4.4. Saquisilí Formation (Paleocene)

In the Quebrada Tabacay, though the contact is not visible, the Tabacay Formation is overlain by grey to black shales, dark siltstones, sandstone layers, and thicker beds of dark, micaceous and arkosic sandstones. North of Tabacay, the basal contact is an unconformity (Vaca, 2005). Beds or nodules of micritic dark limestones and thin-bedded sandy turbidites are locally observed. The beds of fine-grained sandstone show ripples, lamination, hummocky cross-stratification, and load structures; they contain plant remnants and *Glossifungites* or *Skolithos* burrows. These features suggest deposition in a clastic distal shelf environment, above the storm wave base. The thickness of this unit may reach 500–1000 m.

The rocks referred to here as the Saquisilí Formation formerly were included in the "Yunguilla Formation." They have yielded, among others, the benthic foraminifers *Bathysiphon gerochi* Myatlyuk, 1966 (Paleocene), *Bulimina midwayensis* (Cushman and Parker, 1936) (Campanian–Paleocene), and the palynomorph *Tricolporopollenites*? sp., indicating a Paleocene age. Due to a similar lithology with abundant detrital white micas, these beds are now referred to the Saquisilí Formation, which in the type locality has been dated as early to middle Paleocene (McCourt et al., 1998; Hughes et al., 1999). A sample from the water divide between Cuenca and Quingeo yields the benthic foraminifers *Dorothia cylindracea* (Bermúdez, 1963) (Paleocene–early Eocene) and *Haplophragmoides* cf. *eggeri* (Cushman, 1926) (Paleogene), which suggests that the Saquisilí Formation also crops out east of Cuenca.

Farther north, graded-bedded conglomerates are observed along the Azogues–Ingapirca road (Vaca, 2005). These coarser-grained deposits correlate with the Gallo Rumi Member of the Pallatanga area, which is assigned to the upper Paleocene (Jaillard et al., 2004).

Bristow and Hoffstetter (1977) assume that the "Yunguilla Formation" of the Cumbe area grades progressively upward into Paleocene variegated, fine-grained subaerial deposits. In the same area, Pratt et al. (1997) assume a progressive change from the marine "Yunguilla Formation" to Maastrichtian redbeds and then to the Eocene Quingeo Formation. However, the deformation of the Maastrichtian deposits includes tight folds, the axis of which varies from E–W to N–S, whereas the continental deposits ascribed to the Quingeo Formation only exhibit NNE-trending gentle folds. Therefore, it is probable that a major unconformity separates upper Maastrichtian–Paleocene, fine-grained subaerial deposits from the coarser-grained, Eocene Quingeo Formation.

5. Correlations with neighbouring areas

5.1. Celica-Lancones Basin (southwestern Ecuador) and Paita area (northwestern Peru)

The unconformable, transgressive Campanian–Maastrichtian sequence in the Celica-Lancones Basin appears to rest on the Albian volcanic arc in the east, deformed Cretaceous sediments in the central part, and Paleozoic basement or Albian transgressive limestones in the west (Olsson 1934; Kennerley, 1973; Morris and Alemán, 1975; Jaillard et al., 2005). The uppermost Cretaceous sequence comprises, from base to top (Fig. 7): (1) a middle to upper Campanian prograding sequence of marls, limestones, and arkosic sandstones, overlain by transgressive marls (Naranjo and Zapotillo formations); (2) coarse-grained conglomerates derived from either a volcanic source in the east (Casanga Formation) or a crystalline source in the west (Monte Grande or Tablones Formation); and (3) lower Maastrichtian dark shales interbedded with quartzose sandstones (Cazaderos Formation) (Jaillard et al., 1996, 1999). The latter are unconformably overlain by Paleocene marine shales, with sandstone and limestone interbeds (Balcones Formation) (Jaillard et al., 1999).

In the Paita area (northwestern Peru, Figs. 1 and 7), the Paleozoic basement is unconformably overlain by a middle–upper Campanian sequence of transgressive marine

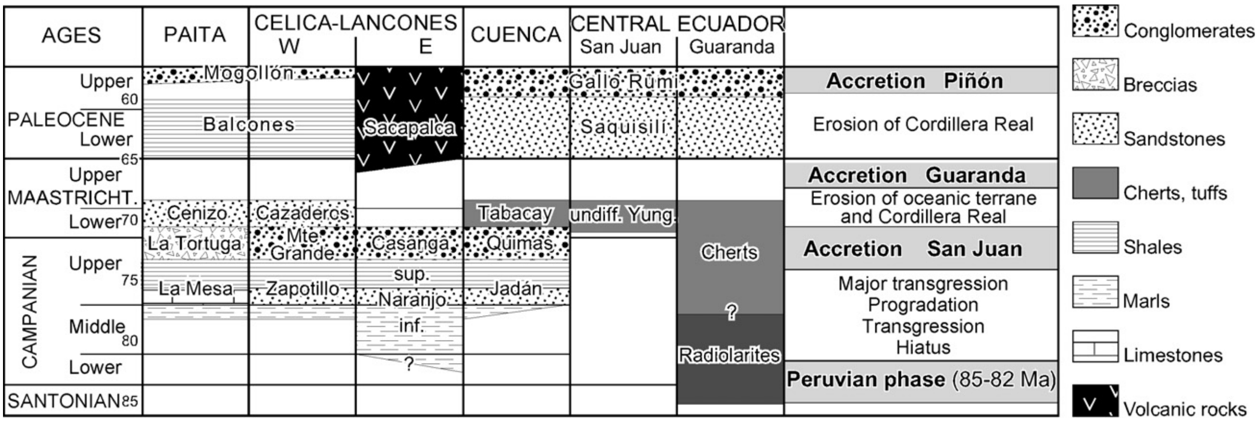

Fig. 7. Correlations between the upper Cretaceous–Paleocene series of the Cuenca area and other parts of Ecuador and northernmost Peru, and interpretation of tectonic events.

marls and sandy limestones, which ends with shallowing-upward, rudist-bearing carbonate shelf deposits (La Mesa Formation) (Olsson, 1944; Palacios, 1994; Jaillard et al., 1998). The latter formation is overlain by upper Campanian transgressive sandy marls, which rapidly grade upward into quartz-rich conglomerates. To the west, the Paleozoic basement is directly overlain by a 3500 m thick upper Campanian–lower Maastrichtian succession of fan delta breccias (La Tortuga Formation) (Jaillard et al., 1998; Taipe et al., 2004), which indicates that a deep sedimentary basin was created between the late Campanian and the early Maastrichtian. These breccias are disconformably overlain by lower Maastrichtian transgressive shoreline sandstones, which grade into shallow clastic shelf breccias and sandstones (Cenizo Formation). Paleocene marine marls unconformably overlie the Maastrichtian sandstones (Taipe et al., 2004; Jaillard et al., 2005).

The upper Campanian marls, limestones, and arkoses of the Jadán Formation in the Cuenca area are lithologically comparable and stratigraphically correlatable with the transgressive Naranjo, Zapotillo, and La Mesa formations of southwestern Ecuador and northwestern Peru. The conglomerates of the Quimas Formation are stratigraphically correlatable with those of the Casanga and Monte Grande (or Tablones) formations of the Celica-Lancones area and the La Tortuga breccias of the Paita area. Although their source areas and depositional environments differ, the lower Maastrichtian cherts and volcanogenic turbidites of the Tabacay Formation may be correlated with the quartz-rich Cazaderos Formation of southwestern Ecuador and the transgressive Cenizo Formation of northwestern Peru (Jaillard et al., 2005).

It follows that the sedimentary successions of the Paita, Celica-Lancones, and Cuenca areas represent a three-fold evolution: (1) a mid to late Campanian transgressive prograding sequence, followed by a renewed transgression; (2) a significant tectonic event, with deposition of thick, shallow-marine to continental, coarse-grained conglomerates or breccias in the latest Campanian–earliest Maastrichtian; and (3) a new transgression and clastic-shelf or deeper turbiditic deposition in the early Maastrichtian. The latter sequence closes with a regional hiatus in the late Maastrichtian–earliest Paleocene, which reflects a significant tectonic event.

5.2. Western Cordillera of central and northern Ecuador

In central Ecuador (0–2°S), the Yunguilla Group is tectonically associated with basalts, dolerites, and greywackes, interpreted as an accreted oceanic terrane (part of the Pallatanga terrane of McCourt et al., 1998; Kerr et al., 2002; Spikings et al., 2005; San Juan terrane of Mamberti et al., 2004; Jaillard et al., 2004). To the west, the late Campanian–Maastrichtian interval is represented by radiolarian-rich black cherts that overlie red or green radiolarites (Fig. 7). In northern Ecuador, the radiolarian-bearing red mudstones are dated as Santonian–early Campanian (Boland et al., 2000; Kerr et al., 2002) and constitute the sedimentary cover of basalts, ankaramites, and picrites that represent an accreted oceanic terrane (part of the Pallatanga terrane of McCourt et al., 1998; Kerr et al., 2002; Guaranda terrane of Mamberti et al., 2003; Jaillard et al., 2004). Thus, the Yunguilla Group was deposited only on the eastern San Juan oceanic terrane.

The Yunguilla sediments of central Ecuador are highly deformed, and it is difficult to ascribe them to any of the formations defined in the Cuenca area. However, their quartz content is low ($\leqslant$20%, Toro and Jaillard, 2005), available paleontological data suggest an early Maastrichtian age (Jaillard et al., 2005), and there are no quartz-rich conglomerates similar to the Quimas Formation. For these reasons, the Yunguilla sediments of the Quito–Pallatanga area are tentatively referred to the Tabacay Formation (lower Maastrichtian). If this assignment is correct, the Tabacay Formation postdates the accretion of the eastern San Juan oceanic terrane (Hughes and Pilatasig, 2002; Kerr et al., 2002) and predates the accretion of the western Guaranda oceanic terrane (Jaillard et al., 2004). Therefore, the deposition of the coarse-grained conglomerates of latest Campanian–earliest Maastrichtian age (≈75–70 Ma) are interpreted as a sedimentary response to the accretion of the San Juan oceanic terrane.

The Paleocene Saquisilí Formation in the Cuenca area exhibits similar lithologies and is coeval with that in central and northern Ecuador. In the latter area, it unconformably overlies both the Maastrichtian Tabacay Formation (San Juan Terrane) and the Campanian–Maastrichtian black cherts (Guaranda Terrane), concealing the accretion of the latter to the former (Jaillard et al., 2004). Therefore, the accretion of the Guaranda terrane occurred in the late Maastrichtian–earliest Paleocene (≈68–65 Ma; Fig. 7).

5.3. Oriente Basin of Ecuador

The Cretaceous, fine-grained, shallow-marine sediments in the Oriente Basin (Napo Group) record the arrival of significant detrital input in the Santonian, which predates a major hiatus of late Santonian–early Campanian times (Jaillard, 1997; Jaillard et al., 2005). These deposits are disconformably overlain by a 5–20 m thick, middle to upper Campanian, transgressive sequence of sandstones and thin marine shales (M-1 sandstones, Raynaud et al., 1993; Rivadeneira et al., 1995). However, in the western part of the Oriente Basin and the sub-Andean zone, Campanian sediments are absent. There, lower Maastrichtian sandstones unconformably overlie the eroded marine shales and limestones, which are dated as Turonian to Santonian, depending on the region (Faucher et al., 1971; Jaillard, 1997). Therefore, in the western part of the Oriente Basin, a late Campanian erosional hiatus coincides with the accretion of the eastern San Juan terrane (Hughes and Pilatasig, 2002; Jaillard et al., 2004).

The early Maastrichtian transgression (basal Tena Formation) is overlain by prograding, fine-grained redbeds (lower Tena Formation) (Faucher et al., 1971; Jaillard, 1997; Ruiz et al., 2004). These beds in turn are disconformably overlain by a succession of Paleocene, coarser-grained, fluvial redbeds (Mills, 1972; Jaillard, 1997). Thus, a hiatus occurred some time after the early Maastrichtian and before part of the Paleocene, coinciding with the accretion of the western Guaranda terrane (Mamberti et al., 2003; Jaillard et al., 2004).

The Paleocene upper Tena Formation is in turn eroded and unconformably overlain by coarse-grained, fluvial conglomerates of the poorly dated lower Tiyuyacu Formation (Christophoul et al., 2002). Although poorly constrained, this major unconformity may correlate with the accretion of the Piñón terrane of southern coastal Ecuador in the late Paleocene (≈58–55 Ma; Jaillard et al., 1995). These observations demonstrate that the accretion of oceanic terranes coincides with important sedimentary hiatuses in the sub-Andean zone and Oriente Basin and therefore with uplift and erosion in those areas.

6. Geodynamic interpretations and discussion

The mid- to late-Campanian Jadán Formation represents the oldest Cretaceous sediments exposed in the Cuenca area. Although the stratigraphic contact is not visible, we assume it was unconformably deposited onto the metamorphic basement of the Andean margin. A similar unconformable contact of transgressive, mid- to late-Campanian deposits resting on deformed, Albian to Paleozoic rocks of the Andean margin is known from the forearc zones of southwestern Ecuador and northwestern Peru (Jaillard et al., 1996, 1998, 1999; Taipe et al., 2004). Therefore, a strong subsidence probably affected the western edge of the Andean continental margin of southern Ecuador by the mid-Campanian. Because this subsidence event followed the compressional "Peruvian phase," we suggest that the latter was responsible for a strong tectonic erosion of the forearc continental edge, which accounts for the subsequent subsidence of the forearc zones (Jaillard and Soler, 1996).

The Cuenca succession exhibits four distinct lithological units that reflect distinct paleogeographic settings and geodynamic events (Fig. 7).

The Jadán and Quimas formations are separated by a significant, progressive coarsening of the detrital input, which implies a significant rejuvenation of the eastern reliefs in the late Campanian. Therefore, the accretion of the San Juan terrane provoked the incipient uplift and erosion of the Eastern Cordillera and ongoing coarse, quartz-rich, detrital input (Quimas conglomerates). The significant change from a crystalline source area in the Jadán and Quimas formations to a mainly volcanic source area in the Tabacay Formation reflects the onset of erosion of the newly accreted San Juan oceanic terrane. The abundance of feldspars suggests that erosion mainly affected volcanic arc rocks. However, in southwestern Ecuador (Cazaderos Formation), the volcanic clastic input is less significant.

Accretion of oceanic terranes and related uplift and erosion of the Andean continental margin traditionally is assumed to have begun in the Campanian (e.g., Lebrat et al., 1987; Daly, 1989; Reynaud et al., 1999; Kerr et al., 2002; Hughes and Pilatasig, 2002; Jaillard et al., 2004; Toro and Jaillard, 2005; Vallejo et al., 2006; Luzieux et al., 2006). Using thermochronological studies, Spikings et al. (2001, 2005) propose that (1) uplift of the Andean continental margin began earlier in southernmost Ecuador (75–65 Ma) than in the rest of the country (65–60 Ma), though Late Cretaceous (≈75 Ma) cooling of continental basement is recorded by Paleocene sediments in central Ecuador (Spikings et al., 2005); and (2) uplift of the Andean margin began earlier to the west than to the east. However, the Eastern Cordillera became a source area for deposits of the Oriente Basin by early Maastrichtian times (≈70 Ma; Baldock, 1982; Jaillard, 1997; Ruiz et al., 2004). These dates are consistent with the latest Campanian age (75–70 Ma) for the accretion of the San Juan terrane, inferred from the sedimentary record in the Cuenca area.

The Tabacay and Saquisilí formations differ in their distinct clastic sources, different deformation styles, and separation by a probable unconformity, interpreted as the result of accretion of the Guaranda terrane during the late Maastrichtian (to earliest Paleocene?; 68–65 Ma). The change from a mainly volcanic source in the Maastrichtian to a crystalline source in the Paleocene may reflect the renewed uplift and erosion of the Eastern Cordillera, related to the Guaranda terrane accretion. This interpretation is in agreement with recent studies (Spikings et al., 2001, 2005; Jaillard et al., 2005; Vallejo et al., 2006).

Most accretionary events of oceanic terranes resulted in the uplift and erosion of the Eastern Cordillera. Moreover, accretions of oceanic terranes in western Ecuador (late Campanian, late Maastrichtian, late Paleocene) correlate with significant sedimentary hiatuses in the sub-Andean zone and locally in the Oriente Basin (upper Napo/lower Tena, lower/upper Tena, and upper Tena/Lower Tiyuyacu unconformities). These observations demonstrate that accretions of oceanic terranes provoked the uplift of the Andean continental margin, which was higher toward the west (Fig. 8). The Oriente Basin of Ecuador therefore cannot be considered a flexural foreland basin at that time. Conversely, deposits in the forearc zone are thick and localized due to the structural sediment traps related to the deformation of both the Andean margin and the oceanic terranes. We propose that accretion of oceanic terranes through a subduction jam added relatively buoyant oceanic material beneath the western edge of the continental margin, thus provoking its westward increasing uplift. According to this view, accretion and tectonic underplating of oceanic material beneath the continental margin would represent a major process in the creation of relief and crustal thickening of the early Andes of Ecuador (Fig. 8).

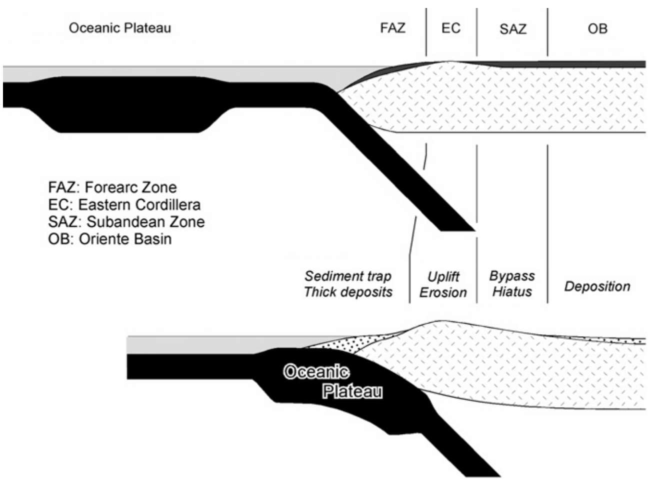

Fig. 8. Interpreted consequences of terrane accretion on syntectonic sedimentation on the Ecuadorian margin. Addition of buoyant material beneath the continental margin provokes the uplift of the western part of the margin and hiatuses in the sub-Andean zone, whereas the deformation of the continental margin and oceanic terrane creates sediment traps in the forearc zone.

7. Conclusions

The uppermost Cretaceous, unconformable clastic deposits of the Cuenca area, here referred to as the Yunguilla Group, include, from base to top, distal shelf fine-grained marls, arkoses, and limestones (Jadán Formation, middle and upper Campanian); coarse-grained, quartz-rich shelf and fan delta conglomerates (Quimas Formation, uppermost Campanian–lowermost Maastrichtian); and unconformable black cherts interbedded with volcanogenic turbidites (Tabacay Formation, lower Maastrichtian). This succession resembles that of the Paita and Celica-Lancones regions, indicating that the Campanian–Maastrichtian basin extended south as far as northern Peru. The creation of such a mid-Campanian forearc basin implies strong subsidence, interpreted as due to a significant tectonic erosion, resulting from the former compressional Peruvian phase (late Santonian–early Campanian). The Yunguilla Group is overlain, probably unconformably, by quartz-rich, micaceous distal shelf sandstones (Saquisilí Formation, Paleocene).

The conglomerates of the Quimas Formation are interpreted as reflecting the accretion of the San Juan oceanic terrane (eastern part of Pallatanga terrane), whereas the Maastrichtian–Paleocene boundary unconformity is interpreted as the result of the accretion of the Guaranda oceanic terrane (western part of Pallatanga terrane). These accretionary events correlate with a rejuvenated erosion of the Eastern Cordillera and with uplifts and erosional hiatuses in the sub-Andean zone and Oriente Basin of Ecuador, which indicates that accretion and tectonic underplating of oceanic material beneath the continental margin induced the jerky uplift of a large western part of the continental margin. Therefore, the Oriente Basin of Ecuador cannot be considered a flexural foreland basin at that time.

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