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Stratigraphy of the late Cretaceous–Paleogene deposits of the cordillera occidental of central ecuador: geodynamic implications

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Abstract

Two accreted oceanic terranes are classically recognized in the Cordillera Occidental of central Ecuador: the Macuchi island arc to the west and the Pallatanga oceanic terrane to the east. Detailed stratigraphic studies of the sedimentary cover of the Pallatanga terrane show that it actually comprises two terranes. During the late Campanian-early Maastrichtian, the eastern terrane received partially continent-derived turbidites, which demonstrates that it was accreted to the Andean margin before mid-Campanian times (i.e. 85–80 Ma ago). Meanwhile, the western terrane received fine-grained, pelagic, siliceous black cherts, which indicates that it belonged to the oceanic realm during mid-Campanian–Maastrichtian times. Both series are unconformably overlain by a thick, coarsening upward, siliciclastic series of Paleocene age; thus, the western terrane accreted to the eastern one during the late Maastrichtian (≈69–65 Ma). The thick Paleocene clastic series records the uplift of the Eastern Cordillera, which was triggered by the latter accretion and enhanced by the Late Paleocene accretion (≈58 Ma) of the Piñón oceanic terrane of southern coastal Ecuador.

Keywords: Accretion of oceanic terranes; Clastic sequences; Cordillera Occidental of Ecuador; Late Cretaceous–Paleogene

1. Introduction

The Cordillera Occidental of central Ecuador consists of accreted oceanic rocks (Fig. 1) associated with a variety of sediments (Faucher and Savoyat, 1973; Kehrer and Van der kaaden, 1979; Feininger and Bristow, 1980; Mamberti, 2001; Kerr et al., 2002). However, the nature, age, and accretion date of these oceanic terranes are poorly known and still debated. According to various authors, accretions took place in the Campanian (Lebrat et al., 1987; Aspden et al., 1992; Hughes and Pilatasig, 2002), the Late Paleocene (Daly, 1989; Jaillard et al., 1995; Reynaud et al., 1999), and/or the Eocene (Feininger and Bristow, 1980; Egüez, 1986; Bourgois et al., 1990; Spikings et al., 2001; Kerr et al., 2002).

Most authors agree that the Cordillera Occidental of central Ecuador comprises a western island arc terrane (Macuchi terrane; Kehrer and Van der kaaden, 1979; Baldock, 1982; Egüez, 1986; Hughes and Pilatasig, 2002) and an eastern oceanic terrane of oceanic floor to plateau nature (Lebrat et al., 1987; Pallatanga terrane of McCourt et al., 1998; Hughes and Pilatasig, 2002; Kerr et al., 2002). Mégard (1989) suggests that the eastern oceanic terrane actually comprises two distinct terranes (Fig. 2). On the basis of geochemical studies, Lapierre et al. (2000) and Mamberti (2001) also subdivide the Pallatanga terrane into an eastern Early Cretaceous terrane (San Juan–Multitud oceanic plateau) and a western Late Cretaceous terrane, which is part of the Caribbean plate.

In this work, we report the results of a lithostratigraphic and biostratigraphic study of the Late Cretaceous–Eocene clastic sediments of the Cordillera Occidental of Ecuador between 0°40′S–2°S, which enable us to constrain the date of the various accretions and support the existence of two accreted oceanic units in the Pallatanga terrane.

2. Previous work

The poorly dated sedimentary rocks of the Cordillera Occidental long have been grouped into the Yunguilla Formation, which was assigned to the Campanian–Maastrichtian (Thalmann, 1946). The earliest records of

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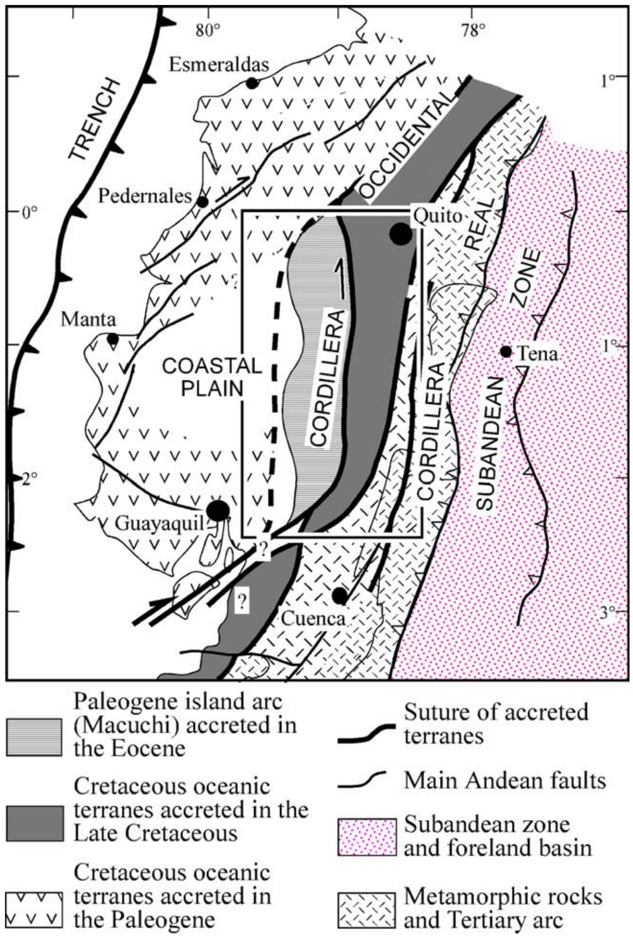

Fig. 1. Structural sketch of western Ecuador showing location depicted in Fig. 3.

pre-Maastrichtian and Tertiary beds were reported by Sigal (1969) and Faucher et al. (1971) (Fig. 2). More recently, Eocene limestones (Unacota limestones) and Middle Eocene turbidites (Apagua Formation), capped by coarse-grained conglomerates (Rumi Cruz Formation), have been identified locally (Bristow and Hoffstetter, 1977; Henderson, 1981; Baldock, 1982; Santos and Ramírez, 1986; Egüez and Bourgois, 1986a,b; Bourgois et al., 1990; Fig. 2). From extensive mapping of the Cordillera Occidental of Ecuador, McCourt et al. (1998) date Paleocene beds ascribed to the Apagua Formation, and Hughes et al. (1998) define the Early–Middle Paleocene Saquisilí Formation at the eastern edge of the Cordillera Occidental. According to the latter authors, the Paleocene–Eocene interval, represented by the Angamarca Group, includes the Apagua Formation, which includes local and/or lens-shaped stratigraphic units—namely, the Paleocene–Early Eocene Gallo Rumi Formation, the Early Eocene Pilaló Formation, the Middle Eocene Unacota Formation, and the Late Eocene Rumi Cruz Formation (McCourt et al., 1998; Hughes et al., 1998; Fig. 2).

New detailed mapping of selected areas of the Cordillera Occidental between 0°40′S–2°S (Fig. 3) associated with lithostratigraphic studies and biostratigraphic sampling enabled us to refine the stratigraphic framework of the Late Cretaceous–Eocene deposits of this area.

3. Stratigraphy of the late Cretaceous–Paleogene deposits of the cordillera occidental (0°40′S–2°)

Good outcrops of Late Cretaceous–Paleogene deposits can be found in two areas of central Ecuador (Fig. 3):

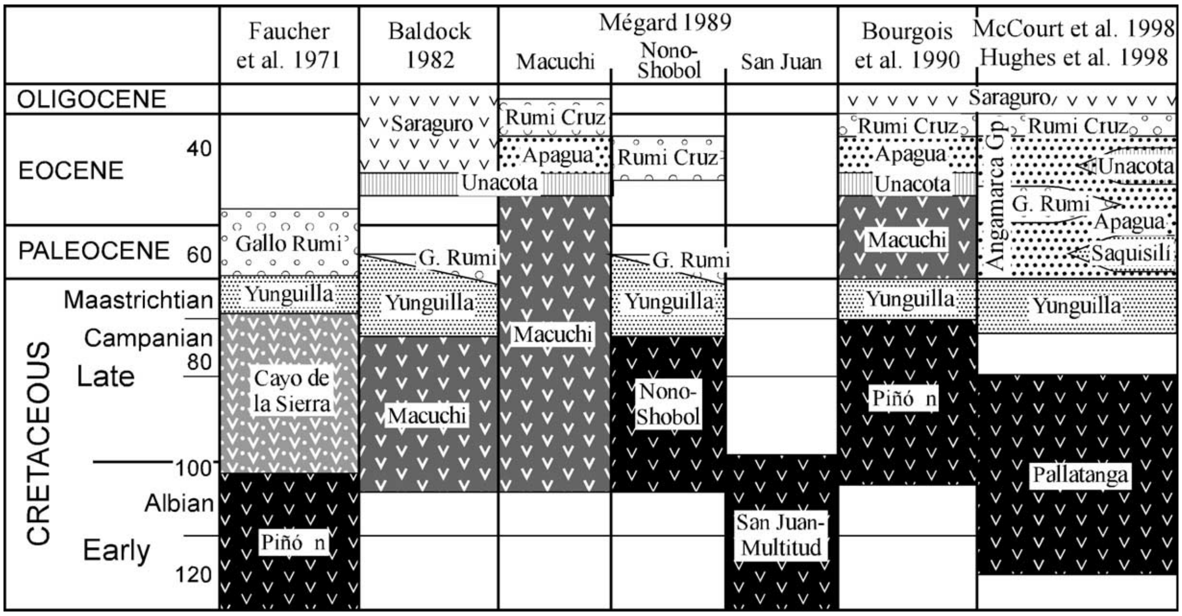

Fig. 2. Previous stratigraphic framework of the magmatic and sedimentary rocks of the Cordillera Occidental of Ecuador (0°–2°30′S). See Fig. 9 for key.

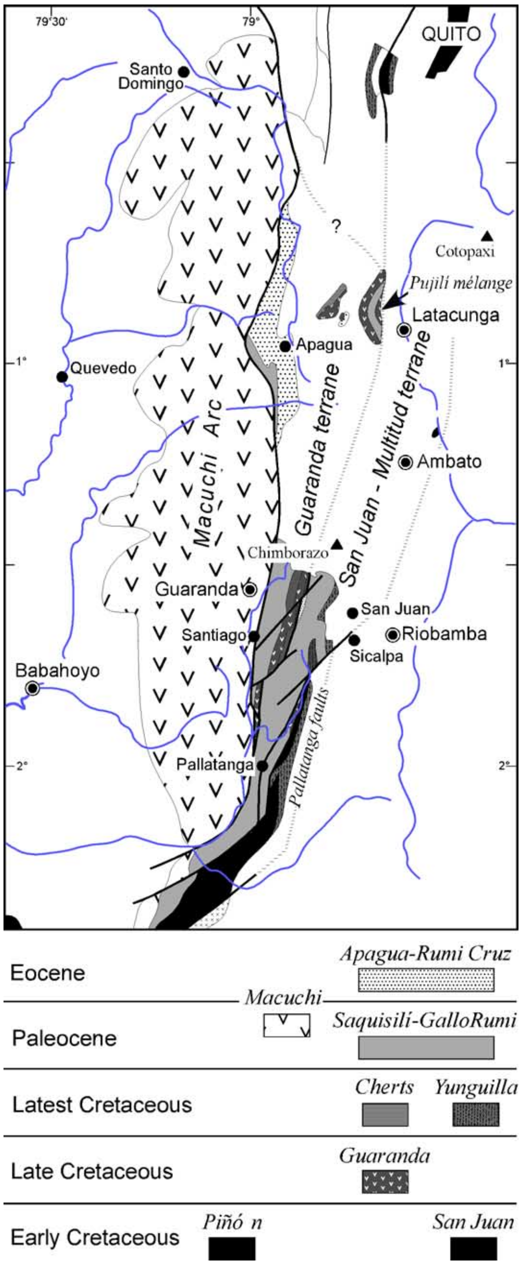

Fig. 3. Structural sketch of the Western Cordillera of Ecuador (0°–2°30′S).

west of Latacunga (0°40′S–1°15′S) and west of Riobamba, between the Chimborazo volcano and Pallatanga (1°30′S–2°S).

3.1. Latacunga traverse (0°40′S–1°15′S)

Late Cretaceous–Paleogene outcrops are bound to the east by a major, north-trending fault system, which contains tectonic slices of sedimentary, metamorphic, and basic or acidic intrusive rocks (Pujilí Mélange of Hughes and Pilatasig, 2002). To the west, they are bound by a major, north-trending fault, which separates the area from the Paleogene Macuchi island arc terrane (McCourt et al., 1998).

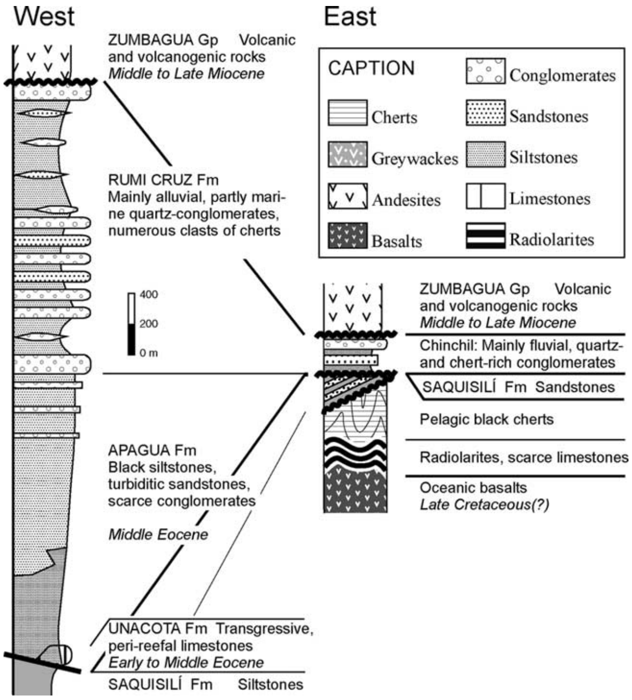

Fig. 4. Simplified stratigraphy of the Pallatanga terrane along the Latacunga traverse.

Two areas may be distinguished (Fig. 4): east and west of 78°50′W.

East of 78°50′W, the oceanic magmatic basement consists of deformed Mg-rich basalts, which are assumed to be part of the Caribbean oceanic plateau (Lapierre et al., 2000; Mamberti, 2001; Kerr et al., 2002; Mamberti et al., 2003) and have been dated radiometrically elsewhere as Turonian–Coniacian (92–85 Ma, Sinton et al., 1998).

The basement is locally overlain stratigraphically by red radiolarites, which can be locally observed in the Pujilí mélange (where they are interbedded with basalts) and on Loma Ashpachaza [74490–990470]. The 100–200 m thick interbedded radiolarites and basalts are overlain by pelagic, micritic black limestones. Although the contact has not been observed, the radiolarites are believed to be overlain by a deformed series of pelagic, siliceous black cherts, which is clearly exposed north of the Latacunga–Apagua road. These pelagic cherts are lithologically comparable to the cherts of the Guayaquil Formation (Jaillard et al., 1995), though they are not exactly coeval. The cherts are frequently deformed by tight to isoclinal folds associated with cleavage and subsequently folded by north-trending folds. Their thickness may reach 300–500 m.

These fine-grained, siliceous deposits are devoid of detrital quartz and interpreted to represent pelagic oozes deposited in an oceanic basin floored by the Turonian–Coniacian oceanic plateau. Although not dated along the Latacunga traverse, the cherts can be correlated with those located west of Riobamba, which have been dated as Middle Campanian–Maastrichtian.

Locally (Loma Ashpachaza, Guayrapungu), the black cherts and radiolarites are in fault contact with thin-bedded, fine- to medium-grained lithic sandstones that alternate with black slates. North of Guayrapungu [74305–990350], the latter yield radiolarians of probable Paleocene or Early Eocene age (Egüez, 1986, p. 43). Therefore, we interpret this unit as belonging to the Paleocene Saquisilí Formation.

In the Quebrada Chinchil [74755–990210], both the oceanic basement and the chert succession are unconformably overlain by approximately 100 m of coarsening-upward sandstones and conglomerates, which rework both metamorphic rocks and the oceanic black cherts (Fig. 4). Although not dated, the Chinchil conglomerates can be correlated with the Rumi Cruz Formation of probable Late Eocene age.

West of 78°50′W (Apagua area), the magmatic basement is not exposed. The Tertiary sequence has been studied by Egüez (1986), Egüez and Bourgois (1986), Santos and Ramírez (1986), Bourgois et al. (1990), McCourt et al. (1998), and Hughes et al. (1998).

Black siltstones and fine-grained sandstones cropping out in the western part of the area [72750–988530] have been dated as Early–Middle Paleocene and ascribed to the Angamarca Group by McCourt et al. (1998). The deposits of this area yield a palynomorph assemblage (*Echinatisporites* sp., *Foveotriletes* sp., *Polyadosporites* sp., *Polyadosporites mariae*, *Retitricolpites* cf. *antoni*, *Tricolporites* sp.), which suggests a Paleocene–Eocene age. We ascribe this series to the Saquisilí Formation. Due to its complicated structure, its thickness cannot be estimated. At least locally, these Paleocene deposits are separated from the Middle Eocene sequence by NW-trending faults visible in aerial photographs. One fault, found along the road Apagua–El Corazón [72840–988570], where it is marked by numerous NW-trending dykes, truncates the southern end of the basal limestones of the Eocene sequence.

The Middle Eocene sequence begins with lens-shaped transgressive limestones of a shallow-water, peri-reef environment (Unacota Formation), dated as Middle Eocene (Bristow and Hoffstetter, 1977; Henderson, 1981; Egüez, 1986; Bourgois et al., 1990). These limestones are overlain by a 1000 m thick, coarsening-upward succession of siltstones and sandstones organized in turbiditic sequences (Apagua Formation), dated as Middle Eocene (Santos and Ramírez, 1986; Egüez, 1986; Bourgois et al., 1990; Fig. 4). These clastic rocks include sublitharenites, litharenites, and subordinate lithic greywackes (Toro and Jaillard, 2002).

The Apagua Formation progressively grades into an approximately 1500 m thick, coarsening-upward series of undated siltstones, sandstones, and conglomerates of a mainly continental, partially shallow marine environment (Rumi Cruz Formation). These have been assigned to the late Middle Eocene–Late Eocene (Faucher et al., 1971; McCourt et al., 1998). The Chinchil conglomerates probably correlate with the Rumi Cruz Formation (Fig. 4).

As noted by Santos et al (1986), the Eocene series of the Cordillera Occidental is very similar to the Middle Eocene sequence of the forearc basins of western Ecuador (Faucher and Savoyat, 1973; Evans and Whittaker, 1982; Jaillard et al., 1995) and was deposited in a similar paleogeographic and geodynamic setting.

Throughout the Cordillera Occidental of central Ecuador, the Late Cretaceous–Eocene sediments are unconformably overlain by Middle–Late Miocene volcanic and volcaniclastic rocks dated as 17–8 Ma (Zumbagua Group; McCourt et al., 1998; Hughes et al., 1998).

3.2. Riobamba traverse (1°30′S–2°S)

Along the Riobamba traverse, two successions (eastern and western) have been recognized, separated by a major, N- to NNE-trending fault zone (Fig. 5) that is characterized by varied tectonic slices (e.g. amphibolites, mafic rocks, radiolarites, cherts, volcaniclastic red beds). We correlate this fault with the system that, farther north, includes the Pujilí mélange of Hughes and Pilatasig (2002).

3.2.1. Eastern succession

The Yunguilla Formation (≈500 m) consists of deformed tuffaceous cherts, fine-grained feldspathic greywackes, and lithic arkose turbidites (Toro and Jaillard, 2002). Calciturbidites are locally present, which rework shallow water calcerous organisms (San Juan Formation of Kehrer and Kehrer, 1969). Along the Pallatanga fault zone, the Yunguilla Formation is associated tectonically with basalts, dolerites, and scarce greywackes. Near Hacienda El Rosario, cherts associated with the basalts yield scarce, nondiagnostic palynomorphs (*Polyadospollenites* sp., *Polypodiaceoispollenites* sp.). Although its base has not been observed, the Yunguilla Formation is assumed to rest unconformably on these oceanic volcanic and volcaniclastic rocks (Fig. 6). The Yunguilla Formation is deformed by tight folds with dispersed, NW- to NE-trending axis directions, which suggests that a first generation of tight folds was deformed by subsequent regional, N-trending folding that also affected the Tertiary beds.

Near Huangupud [73950–98064] (Fig. 5), the Yunguilla Formation yields two specimens of *Exiteloceras* sp. of Campanian age (or possibly *Glyptoxoceras* sp. of Santonian–Maastrichtian age) and one *Phylloceras (Neophylloceras)* sp. The latter is comparable to *Phylloceras (Neophylloceras) surya*, determined from the Early Maastrichtian Cenizo Formation of northern Peru (Jaillard et al., 2004). These ammonites indicate a Late Campanian–Early Maastrichtian age (Fig. 7). From the same area, we collected the radiolarian *Amphypindax* cf. *tylotus* of Middle Campanian–Maastrichtian age, which is associated with benthic foraminiferas (*Haplophragmoides* sp., *Hormosina ovulum*, *Kalamopsis grzybowskii*, and *Saccammina* sp., among others). West of San Juan [74200–981980] (Fig. 3), shales interbedded in calciturbidites yield the planktonic

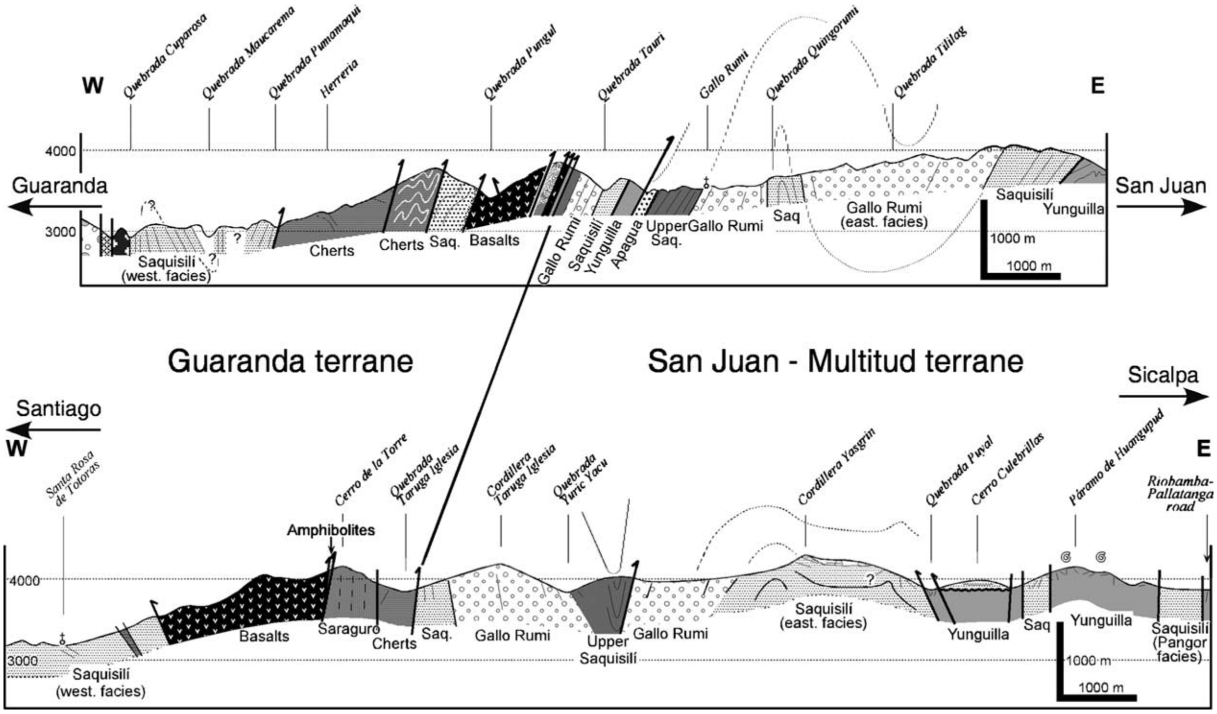

Fig. 5. Geological cross-sections of the Western Cordillera at approximately 1°30′S. (Above) San Juan-Guaranda section; (below) Sicalpa–Santiago section.

foraminifera *Pseudogümbelina excolata* of Late Campanian–Maastrichtian age, as well as less diagnostic benthic foraminiferas and palynomorphs. We therefore constrain the age of the Yunguilla Formation to within the Late Campanian–Early Maastrichtian interval (Fig. 7).

The 2000–3000 m thick Saquisilí Formation unconformably overlies the deformed Yunguilla Formation (Fig. 6). The lower part consists of black shales, silts, and fine-grained lithic sandstones rich in detrital white micas and interpreted as clastic shelf deposits. It crops out only locally, north of Pallatanga and along the Sicalpa–Santiago road, where it includes olistoliths from the Yunguilla Formation. The middle part consists of medium- to thick-bedded, coarse-grained turbidites, which comprise lithic greywackes, sublitharenites, and litharenites rich in detrital white mica (Toro and Jaillard, 2002). West of San Juan, this facies directly overlies the Yunguilla Formation (Fig. 5), whereas to the south and west, it becomes much finer grained. This trend suggests that the basin was fed by an alluvial system located in the San Juan area. The upper part of the Saquisilí Formation is composed of coarse-grained sandstones and conglomerates corresponding to the Gallo Rumi Formation of McCourt et al. (1998) (Figs. 2, 6). Similar to the sandstones of the Saquisilí Formation, the Gallo Rumi conglomerates wedge out to the west and south and thereby support an interpretation of a feeding fan located near San Juan. Because the Gallo Rumi conglomerates represent only a local facies, they cannot be considered a formal formation; we therefore refer to them as the Gallo Rumi Member of the Saquisilí Formation.

The Saquisilí Formation yields numerous benthic foraminiferas. The association of *Bathysiphon* cf. *discretus*, *Bathysiphon* cf. *eocenicus*, *Bathysiphon* aff. *rufescen*, *Bolivinopsis trinitatensis*, and *Haplophragmoides stomatus* indicates a post-Maastrichtian age, whereas the occurrence of *Rzehakina* sp. and *Nodellum* cf. *velascoense* in the upper part of the Formation suggest that the Gallo Rumi conglomerates are pre-Middle Eocene (Fig. 7). Many long-ranging palynomorphs indicate a Paleogene age. The undifferentiated Saquisilí-Gallo Rumi series is thus ascribed to the Paleocene, with a possible extension into the Early Eocene. The lower, finer grained part of this sequence thus

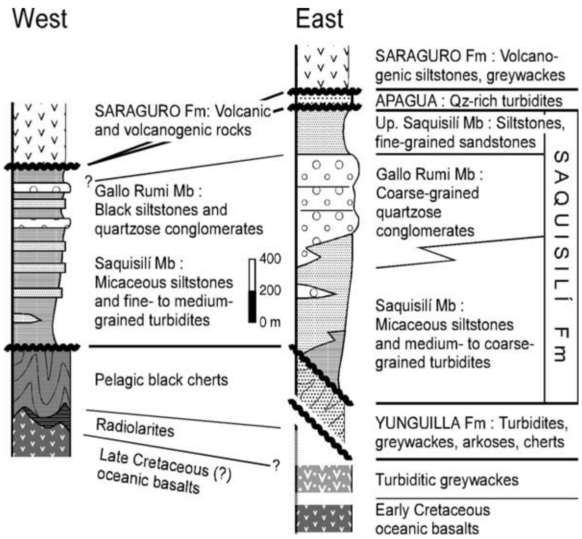

Fig. 6. Simplified stratigraphy of the two units of the Pallatanga terrane along the Riobamba traverse.

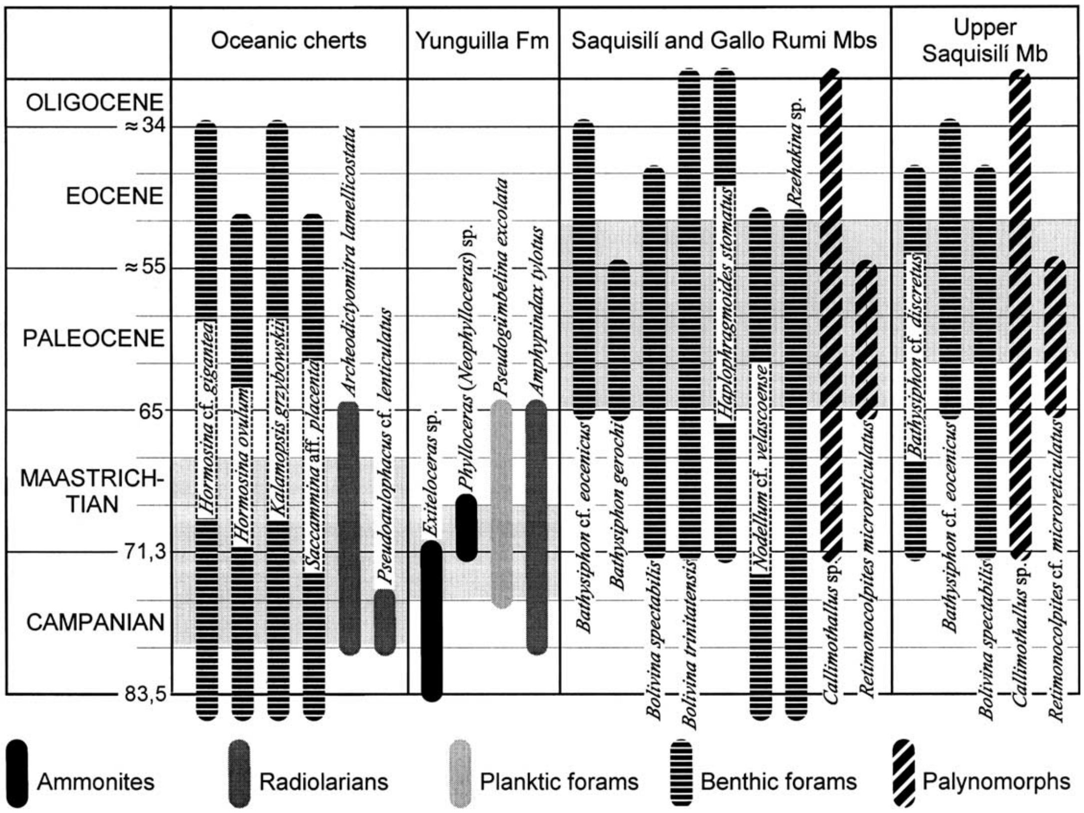

Fig. 7. Diagnostic fossils from Late Cretaceous–Eocene formations of the Riobamba traverse.

is correlated with the Saquisilí Formation of Early–Middle Paleocene age, defined by Hughes et al. (1998), west of the town of Saquisilí.

The Gallo Rumi conglomerates grade upward into an approximately 300 m thick series of fine-grained siltstones and sandstones, preliminarily referred to as the Upper Saquisilí member (Fig. 6). These beds are marked by palynomorphs (*Callimothallus* sp., *Microthallites* sp.) and foraminiferas of Paleogene age. Along with nondiagnostic species (*Haplophragmoides* sp., *Trochammina* sp.), the cooccurrence of the benthic foraminiferas *Bolivinopsis spectabilis* (Maastrichtian–Middle Eocene), *Bathysiphon* aff. *eocenicus*, and *Bathysiphon* cf. *discretus* suggests an Early–Middle Eocene age, in that *B. eocenicus* characterizes the Middle Eocene deposits of coastal Ecuador (Ancón Group, Jaillard et al., 1995). Because of its stratigraphic position below the Middle Eocene Apagua Formation, the Upper Saquisilí member is tentatively ascribed to the Early Eocene (Fig. 7).

The Upper Saquisilí member is unconformably overlain by feldspathic quartz-sandstones intercalated with black siltstones and dominated by sublitharenites and litharenites (Fig. 6). Along the San Juan–Guaranda road, west of the Gallo Rumi settlement [73635–98220] (Fig. 5), the latter series begins with continental sandstones with ferruginous paleosoils and root casts, which grade into shallow marine shelf sandstones and then into turbidites. This series indicates a transgression after a period of emergence. The beds yield a fauna of benthic foraminiferas (*Bathysiphon eocenicus*, *Bolivinopsis spectabilis*, *Haplophragmoides* sp., *Trochammina* sp.) comparable to that of the Upper Saquisilí member, which suggests an Eocene age. Together with the basal unconformity, this enables us to separate the series from the Saquisilí Formation and correlate it with the Apagua Formation, which is dated as Middle Eocene west of the town of Latacunga (Egüez and Bourgois, 1986; Santos and Ramírez, 1986; Bourgois et al., 1990; Fig. 4). In addition, the Apagua sandstones are better sorted, less arkosic, and richer in quartz than are the Saquisilí sandstones (Toro and Jaillard, 2002).

The Paleocene–Eocene marine deposits were deformed by mainly N- to NNE-trending, cylindrical folds and then unconformably overlain by subaerial volcanic and volcaniclastic suites of mainly Oligocene age (Saraguro group; McCourt et al., 1998).

In the Pallatanga valley, a series of clast-bearing black siltstones, sandstones, and conglomerates rich in quartz and metamorphic and volcanic clasts is caught within the Pallatanga fault zone. The series yields palynomorphs (*Callimothallus* sp., *Fusiformisporites* sp., *Microthallites* sp.) and benthic foraminiferas (*Anomalina* sp., *Bathysiphon gerochi*, *Bulimina* sp., *Cibicides* sp.?, *Clavulinoides* cf *asper*, *Dorothia* sp., *Haplophragmoides* cf *eggeri*), among which *Bathysiphon gerochi* indicates a Paleocene age.

This series probably represents a lateral facies of the Saquisilí-Gallo Rumi succession dismembered by the Pallatanga fault zone.

3.2.2. Western succession

The basement of the western succession consists of basalts, tuffs, ankaramites, and picrites that are ascribed to the Caribbean oceanic plateau (Mamberti, 2001; Kerr et al., 2002; Mamberti et al., 2003) of Turonian–Coniacian age (Sinton et al., 1998).

The oceanic magmatic basement is stratigraphically overlain by fine-grained, siliceous, pelagic deposits. Red radiolarites appear in Quebrada Trencilla [73475–982360], whereas in the Quebrada Diablo Sacha [73180–981970], we observe the stratigraphic contact between the basalts and a series of monotonous, well-bedded, pelagic black cherts, similar to those of the Latacunga area (Fig. 6). These cherts are characterized by a rich radiolarian fauna of Campanian–Maastrichtian age (*Gongylothorax* sp., *Rhopalosyringium* sp., *Prunocarpus* sp., *Spongodiscus* sp.?, *Stichocapsa* sp., etc). The presence of *Archeodictyomitra lamellicostata* and *Pseudoaulophacus* cf. *lenticulatus* supports a Middle–Late Campanian age (Fig. 7). They are associated with less significant benthic foraminiferas (*Bulimina* sp., *Haplophragmoides* sp., *Hormosina* cf. *gigantea*, *Hormosina ovulum*, *Kalamopsis grzybowskii*, *Saccammina* sp., *Vulvulina* sp.?) and palynomorphs (*Echitricolpites* sp., *Foveodiporites* sp.?, *Microthallites* sp., *Polyadosporites* sp.). Because of their similar lithology and stratigraphic position, we correlate these black cherts and consider them coeval with those of the Latacunga area. The pelagic cherts are intensely deformed and commonly show isoclinal folds, subsequently deformed by N- to NNE-trending folds. The apparent thickness of the chert series may reach several hundred meters.

The Saquisilí Formation unconformably overlies the deformed pelagic black cherts (Fig. 6). It consists of black siltstones and fine- to medium-grained lithic sandstones of turbiditic origin. Scarce conglomerate beds can be correlated with the Gallo Rumi conglomerates of the eastern series. As a whole, the Saquisilí Formation of the western succession is thinner (1000–1500 m) and finer grained than that of the eastern succession, which suggests that the source areas were located to the east. The Saquisilí Formation yields mainly benthic foraminiferas (*Bathysiphon* sp., *Bathysiphon* aff. *rufescens*, *Haplophragmoides* sp., *Saccammina* sp.) and a few palynomorphs (*Monocolpites* sp., *Monoletes* sp., *Retimonocolpites* cf. *microreticulatus*, *Polyadosporites* sp.). The association of *Bathysiphon* aff. *rufescens* and *Retimonocolpites* cf. *microreticulatus* indicates a Paleogene, and more likely a Paleocene, age (Fig. 7). This Paleocene series is deformed by NNE-trending folds and faults.

The Apagua Formation, however, has not been identified in the western series of the Riobamba traverse.

This succession ends with unconformable subaerial volcaniclastic beds, which are mainly volcanic to the west and northwest and volcaniclastic to the east and southeast. These beds are assigned to the Late Eocene-Oligocene Saraguro group (38–23 Ma, Dunkley and Gaibor, 1998; McCourt et al., 1998; Fig. 6).

4. Discussion and geodynamic implications

This work suggests a revision to the present-day stratigraphic nomenclature. Further works should determine whether the radiolarites and pelagic cherts of the Guaranda unit can be considered formal formations. According to McCourt et al. (1998), the Angamarca Group encompasses all clastic sediments of Paleocene–Eocene age (Fig. 8).

According to our new data, the Angamarca Group includes, from base to top, (1) the Saquisilí Formation of Early Paleocene–Early Eocene (?) age, (2) the unconformable late Early Eocene–Middle Eocene Unacota limestones, (3) the Middle Eocene Apagua Formation, and (4) the Rumi Cruz Formation, ascribed to the late Middle Eocene–Late Eocene. The Saquisilí Formation includes, from base to top, (1) the lower, fine- to medium-grained Saquisilí Member of Early–Middle Paleocene age; (2) the coarse-grained Gallo Rumi Member ascribed to the Late Paleocene; and (3) the fine-grained Upper Saquisilí Member assigned to the Early Eocene (Fig. 8). Further works may recategorize the Upper Saquisilí member as an independent formation.

The quartz-bearing turbidites of the Late Campanian–Early Maastrichtian Yunguilla Formation are assumed to rest unconformably on the oceanic magmatic and volcaniclastic rocks, which crop out on the eastern side of the Pallatanga valley along the Multitud section, south of Pallatanga (Lebrat et al., 1985; Mamberti, 2001) and locally south of San Juan (Fig. 3). The arrival of continent-derived detrital quartz on this oceanic unit demonstrates that it was accreted to the Andean margin before Early Maastrichtian

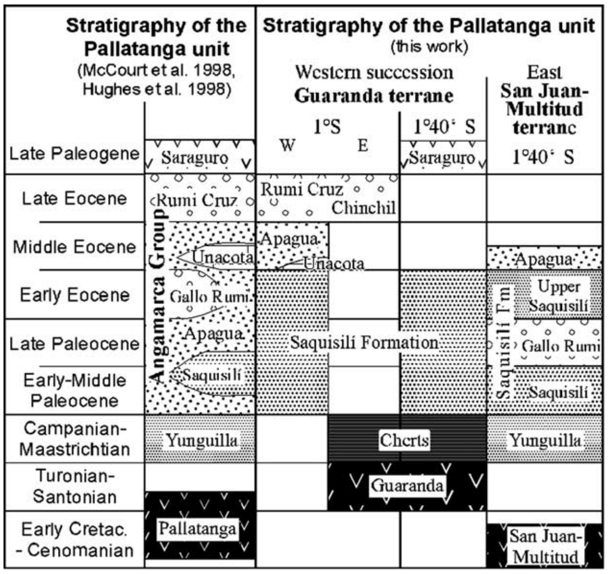

Fig. 8. Synthetic stratigraphic sketch of the Pallatanga unit. See Fig. 9 for key.

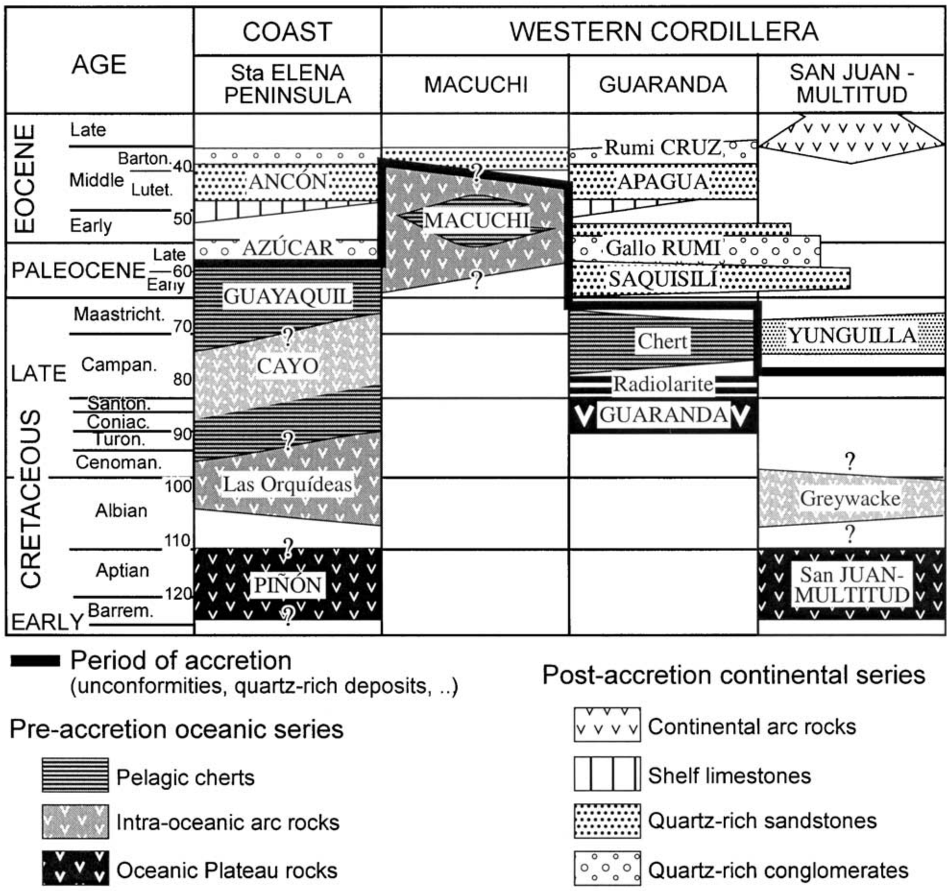

Fig. 9. Chronostratigraphic sketch of the oceanic units of western Ecuador (0°–2°30′S). The thick line corresponds to major unconformities and the appearance of detrital quartz in the oceanic units and is therefore interpreted as the accretion date of the latter to the Andean margin.

times and probably before part of the Late Campanian. Because the underlying oceanic rocks are not dated, the age of accretion cannot be specified directly. However, the widespread hiatuses of Late Santonian–Late Campanian deposits in the eastern Andean basins (Mathalone and Montoya, 1995; Jaillard, 1997) suggest that the accretion took place during the Late Santonian–Late Campanian (i.e. 85–77 Ma) (Lebrat et al., 1987; Aspden et al., 1992; Reynaud et al., 1999; Kerr et al., 2002; Fig. 9).

The Middle Campanian–Maastrichtian pelagic cherts of the Latacunga traverse and the western series of the Riobamba traverse are at least partly coeval with the Yunguilla Formation (Fig. 9). However, the former unit is a typical oceanic sedimentary deposit, rich in radiolarians and devoid of detrital quartz, whereas the latter is made of quartz-bearing turbidites and, locally, of calciturbidites reworking shallow-water carbonate shelf deposits. Moreover, whereas the oceanic cherts are always associated with the radiolarites and basalts of the western unit, the Yunguilla Formation may rest on either the recently accreted terrane (Riobamba traverse) or the continental margin (Cuenca area, Dunkley and Gaibor, 1998; Pratt et al., 1998). The Yunguilla Formation therefore represents a forearc deposit of the accretionary Andean margin. Finally, it is unlikely that the pelagic chert series represents a basinal equivalent of the turbidite succession of the Yunguilla Formation, because no transitional facies have been observed. Therefore, we propose that the pelagic cherts and the Yunguilla Formation were deposited in distinct, and probably distant, areas. Furthermore, both series are unconformably overlain by similar, quartz-rich deposits of Paleocene age, which implies that the western unit was accreted to the eastern one after the deposition of both the pelagic cherts and the Yunguilla Formation and before the unconformable Paleocene deposits, that is during the Middle-Late Maastrichtian (≈69–65 Ma; Fig. 9). This conclusion is strongly supported by (1) the deformation recorded by the pelagic cherts and Yunguilla Formation with respect to the overlying Paleocene–Eocene deposits, (2) the occurrence of a strong thermal event in the Cordillera Real of Ecuador between 75 and 60 Ma (Aspden et al., 1992; Litherland et al., 1994) and a rapid uplift around 70 and 65 Ma (Spikings et al., 2001), and (3) the extensive sedimentary hiatus of Late Maastrichtian age recorded in the margin of northern Peru and Ecuador (Jaillard et al., 2004).

In this interpretation, the Pallatanga unit of McCourt et al. (1998) includes two distinct oceanic terranes. We propose that the eastern Pallatanga unit should be referred to as the San Juan–Multitud terrane, the basement of which has been dated southwest of Quito at 123 ± 12 Ma (Lapierre et al., 2000). In turn, the western Pallatanga unit should be referred to as the Guaranda terrane, of probable early Late Cretaceous age (Mamberti et al., 2003; Fig. 9).

The Paleocene series of the Cordillera Occidental is a thick, coarsening-upward clastic sequence derived from an eastern continental source area (Toro and Jaillard, 2002). Therefore, it reflects the continuous and accelerating uplift of the source area, as corroborated by the widespread uplift of the Cordillera Real between 70 and 50 Ma (Spikings et al., 2001; Ruiz et al., 2002). Deposition of the Gallo Rumi conglomerates may be a consequence of the Late Paleocene accretion of the Piñón oceanic terrane of southern coastal Ecuador (Fig. 9), in that they roughly correlate with the coarse-grained Late Paleocene Azúcar group, which seals this accretion event (Jaillard et al., 1995; Fig. 9). Note that farther north, the Paleocene La Cubera unit exhibits a comparable coarsening-upward trend (Boland et al., 2000), which has been interpreted as the result of the incipient accretion of an oceanic terrane in the Late Paleocene (Kerr et al., 2002).

5. Conclusions

The Paleocene–Eocene Angamarca Group can be subdivided into four formations (from base to top): the Saquisilí (Early Paleocene–Early Eocene), the Unacota and Apagua (Middle Eocene), and the Rumi Cruz (late Middle Eocene–Late Eocene). The Saquisilí Formation in turn includes three members (from base to top): the Saquisilí, Gallo Rumi, and Upper Saquisilí.

The Pallatanga oceanic unit of the Cordillera Occidental of central Ecuador (0°30′S–2°S) includes two distinct stratigraphic successions that record distinct Late Cretaceous tectonic histories. During the Middle Campanian–Maastrichtian, the western Guaranda terrane received a fine-grained, pelagic, siliceous sedimentation devoid of detrital quartz, which overlaid radiolarites and basalts. Thus, this terrane belongs to the oceanic realm. Meanwhile, deposition of quartz-bearing turbidites (Yunguilla Formation) on both the eastern San Juan–Multitud terrane and the Andean margin (Cuenca) indicates that the latter was already accreted to the continental Andean margin. The quartz-rich Paleocene sedimentation (Saquisilí Formation) is comparable in both units, though the western succession is finer grained, which indicates an eastern source area.

These data also indicate that the eastern San Juan–Multitud terrane accreted before the deposition of the Late Campanian–Early Maastrichtian Yunguilla Formation, whereas the accretion of the western Guaranda terrane occurred after the deposition of both the Yunguilla Formation and the pelagic black cherts and before the deposition of the Early–Middle Paleocene sandstones, this means during the Late Maastrichtian (≈69–65 Ma) (Fig. 9). That the eastern and western units of the Pallatanga terrane experienced distinct tectonic histories during the latest Cretaceous supports the idea that these units belonged to distinct oceanic plateaus, as is suggested by their distinct petrographic, geochemical, and isotopic signatures (Lapierre et al., 2000; Mamberti, 2001; Mamberti et al., 2003).

The thick Paleocene clastic deposits of the Cordillera Occidental record the exhumation and rock uplift in the Cordillera Real, which may have been driven by the successive accretion of the Guaranda oceanic terrane in the Late Maastrichtian (≈68 Ma) and the Piñón terrane of southern coastal Ecuador in the Late Paleocene (≈58 Ma) (Fig. 9).

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