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Sedimentary and tectonic evolution of the arc zone of Southwestern Ecuador during Late Cretaceous and Early Tertiary times

[1]ETIENNE JAILLARD, [2]MARTHA ORDOÑEZ, [2]GERARDO BERRONES, [3]PETER BENGTSON, [4]MICHEL BONHOMME, [2]NELSON JIMENEZ and [2]ITALO ZAMBRANO

[1]ORSTOM, 213 rue La Fayette, F-75014 Paris Cedex 10, France
[2]Petroproducción, casilla 10829, Guayaquil, Ecuador
[3]Geologisch-Paläontologisches Institut, Im Neuenheimer Feld 234, D-69120 Heidelberg, Germany
[4]Institut Dolomieu, 15 rue Maurice-Gignoux, F-38031 Grenoble Cedex, France

Abstract — The eastern part of the "Celica basin" of southwesternmost Ecuador exhibits Late Cretaceous to Tertiary sediments which belong to the magmatic arc paleogeographic zone. Important N-S to NE-trending faults separate a western, mainly Late Cretaceous series (Río Playas) from an eastern succession (Catamayo-Gonzanamá) of (?) Late Cretaceous to early Tertiary age. The analysis of these sediments indicates a complex geologic history, which recorded the main stages of the early tectonic evolution of the Andes.

In the Río Playas area, a submarine andesitic volcanic pile (Celica Fm) represents the products of a volcanic arc of probably Albian age. It is apparently overlain by a thick, early Late Cretaceous series of volcanic flows and coarse-grained volcaniclastic high-density turbiditic beds (Alamor Fm), the deposition of which might result from the Mochica phase (late Albian-early Cenomanian). Deformation, uplift and erosion (early Peruvian phase) are followed by the sedimentation of unconformable marls and greywackes of marine open shelf to deltaic environment. These comprise Santonian and/or Campanian fine- to medium-grained deposits (Naranjo Fm), abruptly overlain (late Peruvian phase ?) by fan-delta coarse-grained marine deposits of latest Cretaceous age (Casanga Fm). They are locally capped by undated, partly volcaniclastic red beds, indicating an important regression/uplift of latest Cretaceous-early Tertiary age.

In the Catamayo-Gonzanamá area, thick subaerial andesitic volcanic rocks (Sacapalca Fm) are intruded by Paleocene to early Eocene plutons and are overlain by undated fluvial red beds. They express uplift movements of latest Cretaceous-early Tertiary age. To the South, these are capped by slumped lacustrine black shales and greywackes of possible Maastrichtian-Paleocene age (Gonzanamá Fm). Farther north, the Sacapalca volcanics and red beds are overlain by variegated shales, sandstones and conglomerates, dated as latest Oligocene-early Miocene (Catamayo Fm). They are eroded by an angular unconformity and capped by early Miocene volcanics and sediments, which express an early Miocene deformation phase. The apparent sedimentary hiatus including most of Eocene-Oligocene times is interpreted as a result of the late Paleocene and late Eocene Incaic tectonic phases. Copyright © 1996 Elsevier Science Ltd & Earth Sciences & Resources Institute

Resumen — La parte oriental de la "Cuenca Celica" del Suroeste ecuatoriano presenta sedimentos del Cretáceo superior al Terciario, que pertenecen a la zona paleogeográfica del arco magmático andino. Importantes fallas de dirección N-S separan una serie occidental, mayormente del Cretáceo superior (Río Playas), de una serie oriental (Catamayo-Gonzanamá) de edad Cretaceo superior (?) y Terciario inferior. El análisis de estos depósitos evidencia una historia geológica compleja, que registró las etapas principales de la evolución tectónica precoz de los Andes.

En la zona de Río Playas, volcánicos andesíticos submarinos (Fm Celica) representan los productos de un arco magmático de probable edad albiana. Parecen ser sobreyacidos por una serie potente de coladas volcánicas y turbiditas volcano-clásticas de alta densidad (Fm Alamor). Su deposición podría ser relacionada con la fase tectónica Mochica del Albiano superior-Cenomaniano inferior. Estas rocas fueron levantadas y erosionadas (fase Peruana temprana) antes del depósito discordante de margas de plataforma marina y grauacas deltaicas. Estas comprenden depósitos de grano fino de edad Santoniano y/o Campaniano (Fm Naranjo), abruptamente sobreyacidos (fase Peruana tardía ?) por conglomerados marinos de cono aluvial costero (fan delta) del Cretáceo terminal (Fm Casanga). La serie se termina localmente con capas rojas no datadas, en parte volcanoclásticas, que indican una regresión y/o un levantamiento de edad Cretáceo terminal o Terciario inferior.

En la zona de Catamayo-Gonzanamá, una espesa serie de rocas volcánicas andesíticas subaéreas (Fm Sacapalca) está intruida por plutones del Paleoceno a Eoceno inferior, y sobreyacida por capas rojas fluviátiles no datadas, que expresan un levantamiento importante en el Cretáceo superior-Terciario inferior. Hacia el Sur, están sobreyacidas por lutitas negras y grauacas lacustres de posible edad maastrichtiana-paleocena, con deformaciones sinsedimenatrias (Fm Gonzanamá). Hacia el Norte, los volcánicos y capas rojas Sacapalca están sobreyacidos por lutitas, areniscas y conglomerados abigarrados, datados del Oligoceno terminal a Mioceno inferior (Fm Catamayo). Estos están erosionados por volcánicos y sedimentos del Mioceno inferior, lo que indica una deformación de edad Mioceno inferior. El hiato aparente de gran parte del Eoceno-Oligoceno está interpretado como una consecuencia de las fases tectónicas incáicas del Paleoceno superior y Eoceno superior.

INTRODUCTION

The western edge of the Peruvian continental active margin is characterized by the development of important arc-related volcanic and volcaniclastic series, mainly of Albian age (Casma Group, Myers, 1974; Atherton *et al.*, 1985), which gave place progressively to a voluminous "Coastal Batholith" of late Albian to late Cretaceous age (Beckinsale *et al.*, 1985; Soler and Bonhomme, 1990). In most of the continental margin of Ecuador, arc-related magmatic activity is hardly lacking during Cretaceous

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times (Hall and Calle, 1982; Aspden *et al.*; 1987, 1992). However, in southwesternmost Ecuador and northwesternmost Peru, thick volcanic accumulations are considered as early Cretaceous (Celica Formation, Kennerley, 1973; Lancones volcanics, Morris and Alemán, 1975; Reyes and Caldas, 1987).

Although the petrology and geochemistry of the volcanic arc are rather well known, the sedimentary and tectonic evolution of this paleogeographic zone is still poorly understood, because of scarce fossils, complex tectonism and subsequent erosions. This paper mainly deals with the Late Cretaceous and early Tertiary series of the western edge of the continental margin of southern Ecuador, that overly the volcanic arc accumulations and are well preserved in the Río Playas and Catamayo area of southern Ecuador (Fig. 1). These rocks belong to the eastern flank of what is considered as a basin or a synclinorium, referred to as the Celica basin in southernmost Ecuador, and the Lancones synclinorium in northernmost Peru. This basin is located between the Andean continental margin and the Amotape-Tahuin Palaeozoic massif, which is thought to have been accreted to the margin at about the Jurassic-Cretaceous boundary (Mourier *et al.*, 1988). New stratigraphic and sedimentologic data, as well as a partial geological survey in the eastern part of the "Celica Basin" of southwesternmost Ecuador have led to a better understanding of the geologic history of the arc zone of this part of the Andean margin. Structural and paleomagnetic studies are currently being carried out, in order to determine the tectonic relationship between the arc series, the Andean basement (Cordillera Real) and the Amotape-Tahuin massif.

GEOLOGICAL SETTING

The volcanic and volcanoclastic series of the Celica zone were interpreted as the products of a volcanic arc (Lebrat, 1985; Lebrat *et al.*, 1987) or as the infilling of a back-arc basin (Aguirre, 1992) located on the suture of the Amotape-Tahuin displaced terrane. In these interpretations, the western sedimentary and volcanosedimentary series of Cretaceous age unconformably overly the Paleozoic rocks of the Amotape-Tahuin massif, and laterally grade eastward into volcanic and volcaniclastic basin deposits. These are in turn separated from the eastern Andean margin by important faults (Kennerley, 1973; Morris and Alemán, 1975; Bristow and Hoffstetter, 1977; Reyes and Caldas, 1987; Mourier, 1988).

Therefore, we shall distinguish (1) a western succession which outcrops in the Río Playas area and would correspond to the eastern flank of the "Celica basin"; and

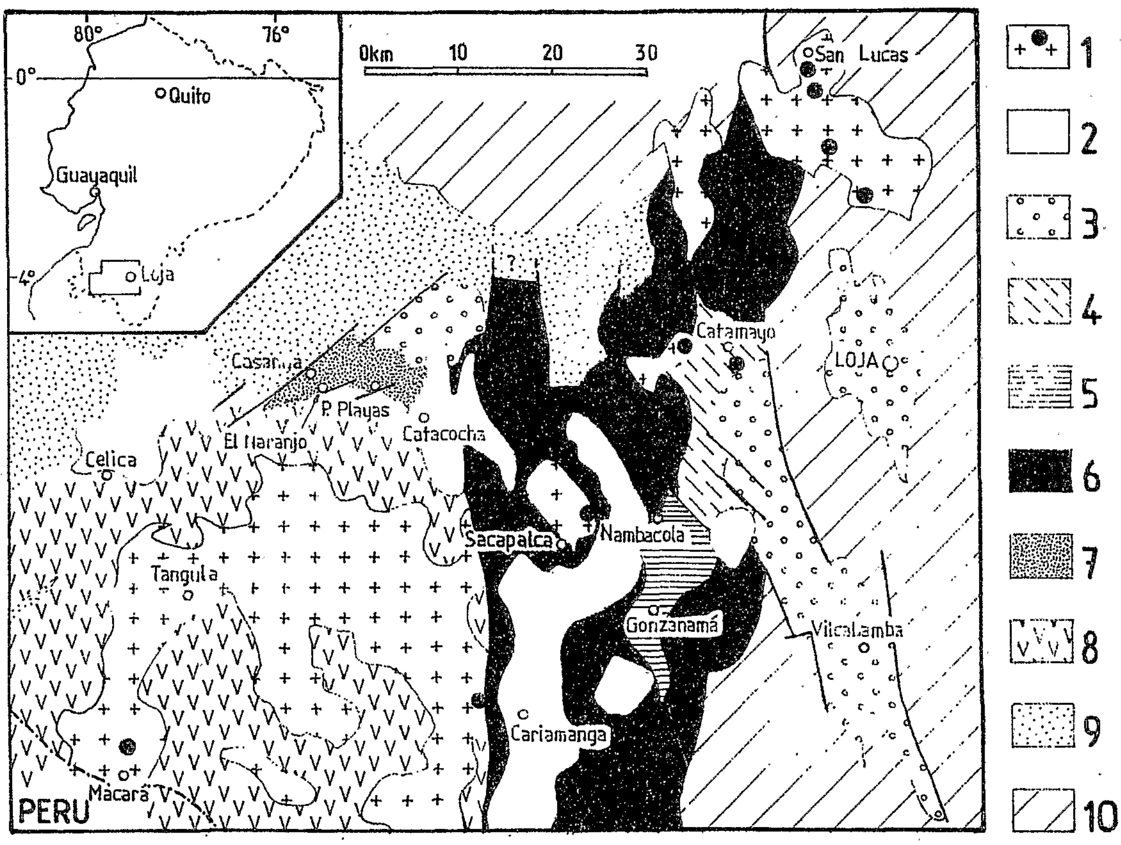

Fig. 1. Geological sketch of the arc zone of Southern Ecuador. 1: Intrusions, black dots: radiometric sites cited in the text; 2: Late Tertiary volcanics; 3: Miocene volcanics and sediments; 4: Catamayo Formation (latest Oligocene-early Miocene); 5: Gonzanamá Formation (Maastrichtian-Paleocene ?); 6: Sacapalca Formation (late Cretaceous ?, early Paleocene ?); 7: Naranjo and Casanga Formations (Santonian to Maastrichtian); 8: Celica and Alamor Formations ((?)Albian to (?)Santonian); 9: Undifferentiated Cretaceous series of the "Celica basin"; 10: Undifferentiated Palaeozoic rocks.

(2) an eastern series exposed in the Catamayo-Gonzanamá area, considered as part of the Andean margin (Fig. 1). The first one begins with the Celica volcanics and is mainly of marine environment and of Late Cretaceous age, whereas the latter rests on the poorly dated Sacapalca volcanics, and is mainly terrestrial and of latest Cretaceous (?)-Tertiary age. The two areas are separated by important N-S to NE-trending faults concealed by subhorizontal volcanic cover, that make difficult any correlations between the series.

STRATIGRAPHY

I. THE RIO PLAYAS SECTION (CELICA SERIES)

The best sections of the arc series and its sedimentary cover are located in the fault-bounded Río Playas depression located west of Catacocha, indicated as Tertiary (Kennerley, 1973) or as Maastrichtian (Baldock, 1982), according to the geological maps.

Celica Volcanics

The lowermost unit is a thick series of faulted and locally very altered volcanic rocks ascribed to the Celica Formation (Kennerley, 1973), which has not been studied in detail by us. It consists of massive lava flows, welded tuffs, pillow breccias, rough conglomerates and agglomerates of mainly andesitic mineralogy, with a few thin intercalations of black laminated limestones. The best section is found along the Río Playas river, south of El Naranjo. There, undated medium-bedded and medium-grained sandstones and greywackes seem to be intercalated in the lower part of the Celica Formation (Fig. 2).

The Celica Formation is crosscut by the Tangula batholith which yielded varied K-Ar ages (Fig. 1). Hornblendes and plagioclases from two different sites yielded Aptian ages: 114 ± 30, 113 ± 3, 110 ± 3 Ma, whereas biotites gave younger ages: 95 ± 1 Ma (early Cenomanian) and 49 ± 2 Ma (early to middle Eocene) (Kennerley, 1973, 1980). As yet, an Aptian age for the Tangula pluton had been preferred, and the age of the Celica Formation was considered as late Jurassic to early Cretaceous (Kennerley, 1980; Bristow and Hoffstetter, 1977; Baldock, 1982). However, because the Tangula batholith locally intruded and metamorphosed the overlying early Late Cretaceous sedimentary rocks (Pik, 1993), the Celica Formation may be considered of pre-Late Cretaceous age.

Therefore, the Celica Formation is thought to correlate with the mainly Albian volcanic series of the continental arc of western Peru (Casma Group, Myers, 1974; Cobbing *et al.*, 1981; Atherton *et al.*, 1985; Soler, 1991; Copara and Matalaque Formations, Soler, 1991).

Alamor Formation

Kennerley (1973) included in the Alamor Group all the volcaniclastic rocks of Cretaceous age in the Celica area.

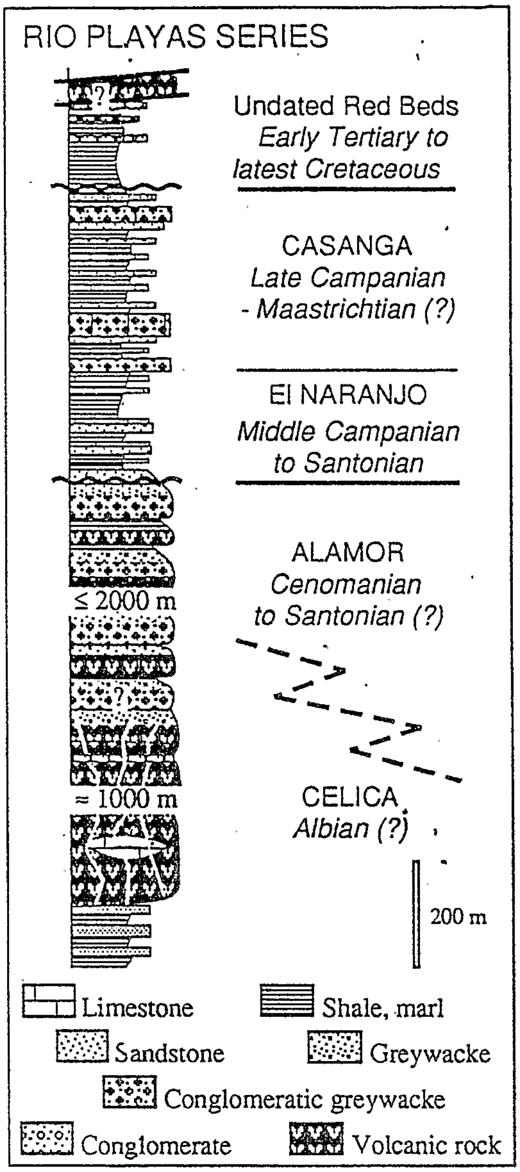

Fig. 2. General stratigraphy of the Celica series, outcropping in the Río Playas area.

We propose to restrict this name to the 1000 to 2000 m-thick series of volcanic flows and thick-bedded coarse-grained volcaniclastic rocks which seems to overly the Celica volcanics (Fig. 2). In many localities, however, the distinction between the two formations is quite difficult, and the Alamor Formation may represent the upper part or a lateral equivalent of the Celica Formation.

Locally, the upper part of the formation yielded calcareous nannofossils among which *Eiffelithus eximius*, *E. turriseifelli*, *Micula decussata* and *Quadrum gartneri* associated with a poor foraminiferal assemblage, indicate a Turonian to early Senonian age. However, this age would need confirmation. Since it apparently overlies the Celica Formation of assumed Albian age, and is overlain by the Santonian and/or Campanian Naranjo Formation, the age of the Alamor Formation is within the Albian-Santonian interval (Fig. 2). These rocks are locally intruded and metamorphosed by the Tangula batholith, at least part of which must therefore be younger than early Cretaceous.

Naranjo Formation

The Naranjo Formation (≈ 150–200 m) can overly unconformably either the Celica volcanics or the Alamor volcaniclastic rocks. It begins with transgressive pebbly and fossiliferous calcareous marls, followed by coarsening-upward sequences of marls, fossiliferous limestones and few greywacke beds (Fig. 2).

Near the village of Puente Playas, the basal marls yielded ammonites among which the association of *Plesiotexanites (Eutexanites) sextuberculatus*, *Phylloceras* sp. and *Menuites*? sp. suggests a Santonian age. Further west (Palos Verdes), the lower part of the Naranjo Formation yielded some foraminifers and radiolarians, among which *Amphypindax* aff. *pseudoconulus*, *Pseudoaulophacus lenticulatus* and *P. pargueraensis* indicate a Campanian age. At the same site, the upper part of the formation contains a rich microfauna assemblage, among which the planktic foraminifers *Globigerinelloides* aff. *prairiehillensis*, *Rugoglobigerina rugosa*, and the calcareous nannofossils *Eiffelithus eximius*, *Lithraphidites carniolensis*, *Microrhabdulus decoratus*, *Micula decussata* and *M. staurophora* indicate the middle Campanian to early Maastrichtian interval. The latter data is consistent with the presence of the ammonite *Pachydiscus* sp. found in an other area, in the upper part of the formation. Although the base of the formation could be diachronous, the age of the Naranjo Formation is within the Santonian-early Maastrichtian interval, and is more probably of Santonian and/or Campanian age (Fig. 2).

Casanga Formation

The Casanga Formation (≈ 200–400 m) consists of shales, thin-bedded turbiditic greywackes and nodular limestones, which differ from the underlying strata in the presence of coarse-grained conglomeratic lenses and beds (Fig. 2). The first conglomeratic beds rest conformably on the Naranjo Formation, and the top is commonly faulted or eroded beneath the overlying unconformable Tertiary conglomerates (Baudino, thesis in prep.).

The Casanga Formation locally yielded a poor foraminiferal assemblage including *Anomalina* cf. *spissiformis*, *Bulimina* cf. *petroleana*, *Cibicides subcarinatus*, *Pseudoglandulina marguliniformis* and *Hedbergella holmdelensis* of Late Cretaceous age. Since it overlies beds of middle Campanian or younger age, the Casanga Formation must belong to the late Campanian — Maastrichtian interval (Fig. 2).

Unconformable Continental Deposits

Red Beds and volcanics. Locally, the Casanga Formation is unconformably overlain by purple-coloured, continental shales, siltstones and volcaniclastic beds, which crop out 2 km NNW of Catacocha, and 2 km east of El Naranjo. No diagnostic fauna have been found, but their stratigraphic relationship indicate a post-Campanian age (Fig. 2). Near Puente Playas, they are associated with fault-bounded, mainly red-coloured andesitic rocks. These poorly outcropping beds might be tentatively correlated with part of the Sacapalca Formation, that crops out farther east (Kennerley, 1973). However, more data is necessary before conclusions can be reached.

Río Playas Formation. The Río Playas Formation was defined by Kennerley (1973) to designate all the non volcanic rocks of the Río Playas area. We propose to restrict this name to the yellow-coloured, coarse-grained conglomerates, sandstones and shales that unconformably overly the undated Red Beds, the Casanga or the Alamor Formations. These deposits are currently being studied by Baudino (thesis in prep.).

II. THE CATAMAYO-GONZANAMA SECTION (SACAPALCA SERIES)

East of the Catacocha faults, the tectonic complexity and the scarcity of paleontologic and radiometric data makes a statement of a chronostratigraphic succession difficult.

Sacapalca Formation

The Sacapalca Formation is made up of thick, subaerial, mainly andesitic tuffs and agglomerates, with intercalations of fluvial red beds in the upper part (Fig. 3), that crops out east of the faults of Catacocha (Fig. 1). The subhorizontal volcanic flows and tuffs underlying the Catacocha village, attributed to the Sacapalca Formation

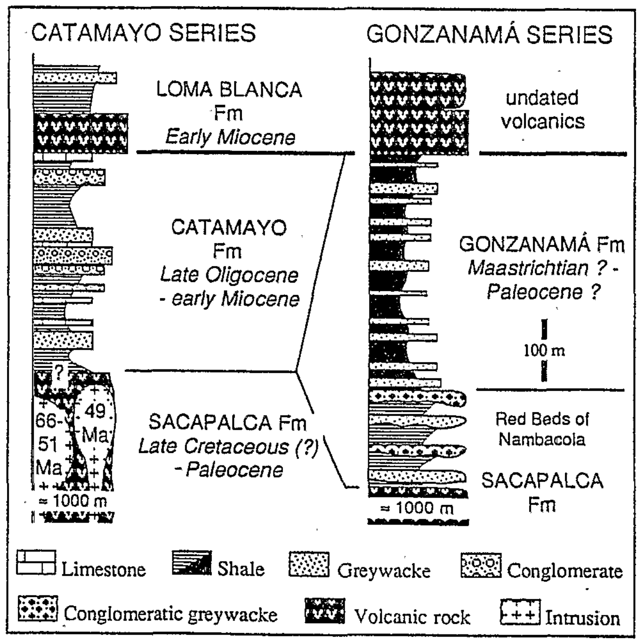

Fig. 3. General stratigraphy of the Catamayo and Gonzanamá areas.

by Kennerley (1973), are clearly younger. 4 km West of the Catamayo village (Fig. 1), the Sacapalca Formation is crosscut by a pluton (El Tingo) which gave concordant early Eocene K-Ar ages (47 ± 2 Ma on hornblende, 50 ± 3 Ma on biotite, Kennerley, 1980). A sample that we collected from the Palo Blanco pluton which intrudes the Sacapalca Formation near Peña Negra, 6 km West of Nambacola (Fig. 1) yielded 21,2 ± 0,6 Ma (whole rock) and 26,6 ± 1,6 Ma (plagioclases) K-Ar ages, indicating a latest Oligocene to early Miocene age.

The Sacapalca Formation was ascribed to the early Tertiary (Bristow and Hoffstetter, 1977; Kennerley, 1980). In this interpretation, it might be coeval with the volcanic deposits of the Llama Formation of northern Peru, radiometrically dated as early to middle Eocene (55 to 44 Ma, Noble *et al.*, 1990). However, the age of the Sacapalca Formation seems to be older. According to the geological map sheet of Loja (Kennerley and Almeida, 1975), the San Lucas pluton intrudes the Sacapalca Formation 20 to 25 km NNE of Catamayo (Fig. 1). Aspden *et al.* (1992) dated the San Lucas pluton as late Paleocene to early Eocene by concordant K-Ar ages on biotites (59 to 51 Ma), and as early Paleocene on hornblende (66 and 61 Ma). If the map is correct, the Sacapalca Formation is of Paleocene or older age (Fig. 3).

The Sacapalca volcanics are commonly capped by undated fluvial Red Beds (NW of Nambacola, North of Catamayo, SW of Catacocha), which might correlate with the undated unconformable red beds and volcanics of the Río Playas area, of post-Campanian age.

Gonzanamá Formation

Near Gonzanamá, the volcanic rocks of the Sacapalca Formation are overlain by hundreds of meters of black shales and intercalated greywackes exhibiting abundant slumpings and a few olistolites, referred to as the Gonzanamá Formation (Kennerley, 1973). The latter formerly included the variegated sediments of the Catamayo area (Kennerley, 1973; Bristow and Hoffstetter, 1977), which crops out farther north and are probably younger.

Based on the presence of a Cytherid ostracod in the Gonzanamá area (Sigal, 1968), the Gonzanamá Formation was initially ascribed to the Maastrichtian (Kennerley, 1973), and then to the early Tertiary (Bristow and Hoffstetter, 1977; Kennerley, 1980). Extensive sampling yielded a poor palynomorphic assemblage, among which *Foveipites longus* and *Tricornites* cf. *elongatus* suggest a Maastrichtian to Paleocene age (Fig. 3). This preliminary result suggests a mainly Late Cretaceous age for the underlying Sacapalca Formation and the associated Red Beds. The age of the Gonzanamá Formation, however, needs confirmation.

Catamayo Formation

Around Catamayo (or La Toma), the Sacapalca volcanics and undated Red Beds are overlain by a 400 m-thick series of variegated shales, sandstones and conglomerates, with a conspicuous intercalation of white resedimented tuff. We propose to call it the Catamayo Formation, since the Gonzanamá outcrops present a very different lithology and are probably older (Fig. 3). The stratigraphic relationships between the Catamayo and Gonzanamá Formations are unknown; important faults separate both outcrops. The Catamayo Formation is unconformably overlain by volcanic and sedimentary rocks of Miocene age (Marocco *et al.*, in press).

Near the base of the formation, we found a foraminifera (*Bolivina* sp.) and the palynomorph *Zonocostites* cf. *ramonae* of late Eocene or younger age. In the middle and upper parts of the formation, the palynomorphs *Buttinia andreevi*, *Sinoponipollis* cf. *mullensis*, *Spinizonocolpites* sp., the foraminifers *Gavelinella* sp., *Lagena* cf. *laevigata* and the calcareous nannofossil *Micula* sp. altogether suggest a Late Cretaceous, probably Maastrichtian age. However, large clasts of acidic tuff collected near Catamayo (Fig. 1) from a thick conglomeratic breccia in the middle part of the sequence yielded K-Ar ages of 21,0 ± 0,5 Ma on whole rock, and 25,1 ± 0,8 Ma on plagioclases. This early Miocene age, is similar to that of the Palo Blanco intrusion and is consistent with the indication of *Zonocostites* cf. *ramonae*. As a consequence, the Late Cretaceous microfossils are interpreted as redeposited. Because it is overlain by Miocene deposits, the Catamayo Formation must be considered as latest Oligocene to early Miocene in age (Fig. 3).

Neogene Deposits

The Catamayo Formation is unconformably overlain by the undated volcanic rocks of the Loma Blanca Formation (Fig. 3), and then by the continental sediments of the Vilcabamba-Malacatos Basin, ascribed to the late early to early late Miocene (Marocco *et al.*, in press).

SEDIMENTARY AND TECTONIC EVOLUTION OF THE ARC ZONE

(?) Albian — (?) Santonian

Lebrat (1985; Lebrat *et al.*, 1987) and Wallrabe-Adams (1990) determined a continental arc origin for the Celica calc-alkaline volcanics, whereas Aguirre (1992) interpreted these rocks as the products of an intracontinental back-arc basin. However, many of the samples studied by these authors were collected either from outcrops located north of the Celica area, or from a few dykes crosscutting the Celica and Alamor Formations. Pik (1993) shared Lebrat's interpretations and considered the Celica Formation as the products of a continental volcanic arc. This interpretation is supported by the fact that the Celica Formation constitutes the northern prolongation of the Albian volcanic arc of western Peru, and is probably partly coeval with these formations. The presence of pillow-lavas indicates a marine environment.

The Alamor Formation consists of thick accumulations of volcanic flows and coarse-grained greywackes interpreted as high-density turbiditic beds. From the Río Playas area to the west, the Alamor Formation presents finer-grained deposits, whereas its thickness increases. This disposition, as well as the exclusively volcaniclastic nature of the detritism suggest that the volcanics of the Celica Formation was the source of the detrital material of the marine Alamor Formation. These observations are consistent with the scarce palaeocurrent data, which indicate a north- to westward transport. As a whole, the Alamor Formation expresses the decrease of the effusive activity, and the increasing erosion of the volcanic arc. Its lower part might be the volcaniclastic apron deposited on the proximal fore-arc part of the active volcanic arc, whereas its upper part can represent the product of the erosion of the already inactive volcanic arc. The end of the activity of the Celica arc and the erosion of this latter during the deposition of the Alamor Formation might be related to the late Albian-early Cenomanian Mochica phase of Peru (Mégard, 1984; Jaillard, 1994). However, more studies are necessary in order to specify the nature and age of the contact between the two formations.

Santonian-Maastrichtian

The Naranjo Formation consists of three coarsening- and thickening-upward sequences of marine shelf to deltaic environment. The first ones contain shallow-marine benthonic fauna (gastropods, oysters, bivalves, . . .), secondary gypsum veinlets, and ends with the progradation of shallow-marine to deltaic greywackes. The third one is characterized by the abundance of inoceramids and planktic foraminiferas, and by the decrease of terrigenous supply, indicating a deeper environment and an important marine transgression (Fig. 4).

The marked basal unconformity of the Naranjo Formation is related to the deformation and partial erosion of the underlying rocks. Since the Naranjo Formation presents transgressive, shallow-marine basal beds, the whole area was probably uplifted and emergent before Santonian-Campanian times. This important deformational event (deformation, uplift, erosion) is correlatable with the early Peruvian tectonic phase of late Turonian to early Coniacian age (Jaillard, 1994; Sempere, 1994).

The Casanga Formation is characterized by the sudden arrival of coarse-grained conglomerates on the marine shelf (Fig. 4). The fine-grained intervals contain fine-grained turbiditic beds, and present abundant plant fragments and benthonic marine fauna, indicating an open marine shelf environment and the proximity of the continent. The conglomerates contain mainly volcanic and greywacke elements, and commonly exhibit cross stratification, imbricated rounded clasts and normal or reverse grading. Palaeocurrents measurements indicate an average NNW-ward transport direction (Fig. 4). Some beds have a sharp base, present a fining-upward trend and are interpreted as channel fills, whereas others present a thickening-upward trend and are interpreted as the result of the progradation of coastal fans. The Casanga Formation is interpreted as deposited in a shallow-marine environment submitted to the sporadic progradation of coastal alluvial fans (fan-deltas).

The reactivation of the erosion of volcanic and volcaniclastic rocks (probably the Celica and Alamor Formations) and the arrival of coarse-grained conglomerates express a paleogeographic change and a topographic rejuvenation of the Andean continental margin. This tectonic event could be correlated with the major Peruvian tectonic phase, of late (?) Campanian age (Jaillard, 1994; Sempere, 1994). In Ecuador, this tectonic phase is responsible for a major unconformity in the Oriente (Faucher and Savoyat, 1973), for a metamorphic event in the Cordillera Real (Aspden *et al.*, 1992), and for a probable change in the subduction régime in Southern coastal Ecuador (Jaillard *et al.*, in press).

Late Cretaceous and/or early Tertiary

The thick Sacapalca subaerial volcanics indicate the resumption of a volcanic arc activity. With respect to the (?) Albian Celica Formation, the location of the arc magmatism shifted to the east, suggesting the deformation and shortening of the margin. This is supported by the presence of intercalated and overlying fluvial red beds, which indicate that the area had been uplifted. However, the age of this deformation is poorly constrained. If the Sacapalca Formation is of early Eocene age, the tectonic phase would correlate with the early Incaic tectonic phase, of late Paleocene-earliest Eocene age (Noble *et al.*, 1990; Jaillard *et al.*, in press). If the Sacapalca Formation is older (? late Cretaceous, ? Paleocene), this tectonic phase might be the major Peruvian phase of Campanian age (Jaillard, 1994; Sempere 1994).

The black shales and turbiditic greywackes of the overlying Gonzanamá Formation suggest that the Sacapalca Formation was already submitted to erosion. The lack of marine fauna and the confined environment indicate that the Gonzanamá Formation was deposited in an isolated continental lacustrine basin. Moreover, the presence of abundant slumpings and olistolites of magmatic rocks expresses a syntectonic deposition, the age of which remains to be specified.

The available data evidence a major sedimentary hiatus during most of the Eocene-Oligocene interval. Although reliable chronologic constraints are lacking, this major gap can be related to the Incaic tectonic phases, of late Paleocene-earliest Eocene, and late Eocene age (Noble *et al.*, 1990; Jaillard, 1993; Sempere, 1994). In western Ecuador, these events are responsible for the accretion of the Coastal oceanic displaced terranes (Bourgois *et al.*, 1990; Jaillard *et al.*, in press).

Late Oligocene-early Miocene

The Catamayo Formation of latest Oligocene to early Miocene age can be divided into several sedimentary sequences (Fig. 5). The first one begins with mainly

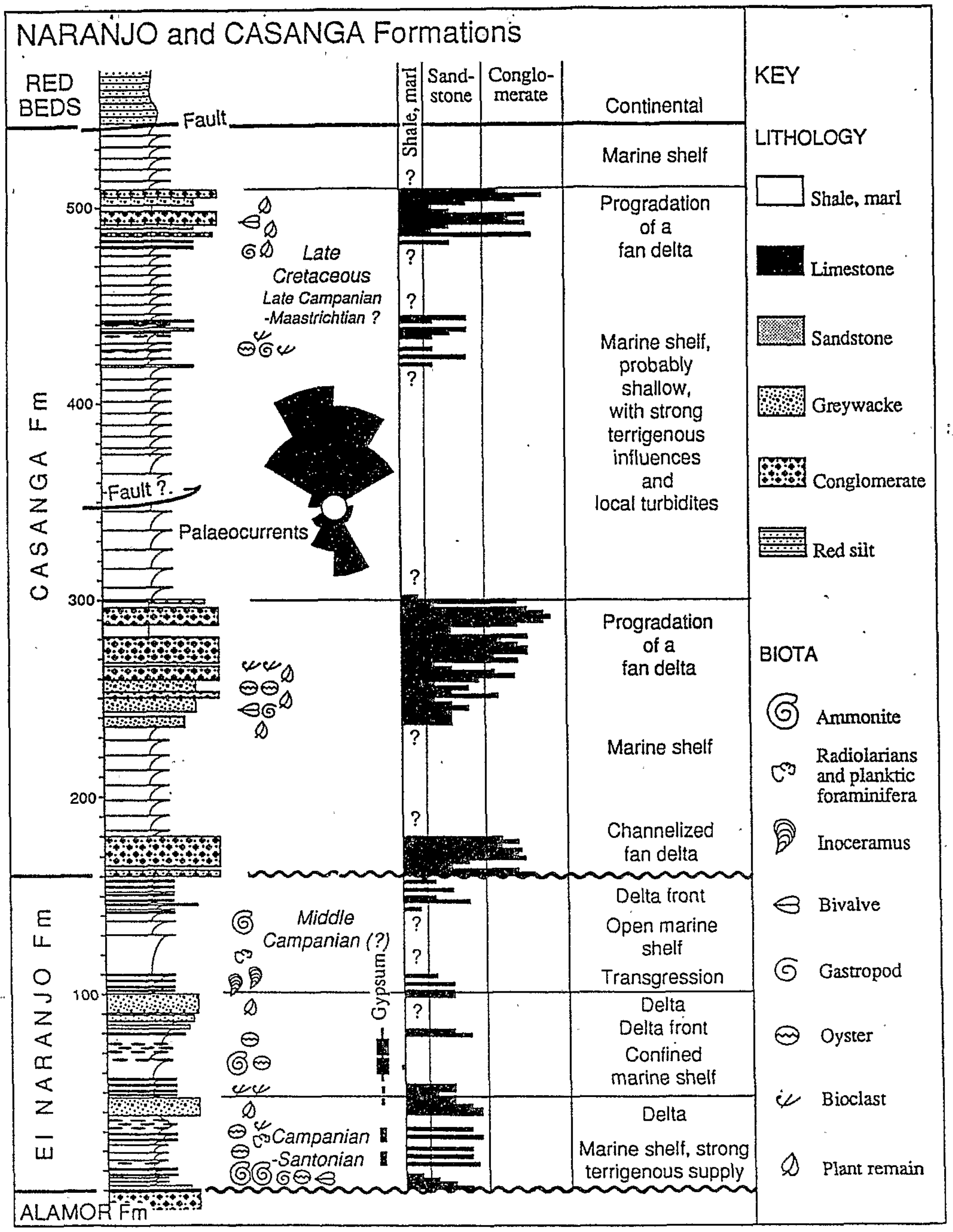

Fig. 4. Section of the Naranjo and Casanga Formations (Santonian-Maastrichtian) of the Río Playas area.

black,green or yellow, fine-grained deposits, rich in carbonates and gypsum, which indicate a coastal to marine, hypersaline environment (sabkha). These beds grade into green or red shales and sandstones, coarse-grained sandstone and conglomerates of fluvial environment, with few carbonates and gypsum bands. The first sequence ends with a conspicuous layer of hard, white breccias, conglomerates and sandstones reworking acidic tuff and metamorphic crystalline rocks in a fluvial and then lacustrine environment. The second sequence begins with variegated shales of coastal plain environment, and ends up with black to green coarse-grained sandy conglomerates, yellow limestones and gypsum, of probably coastal alluvial plain environment (Fig. 4).

Locally, the occurrence of foraminifers in carbonate- and gypsum-rich, fine-grained layers supports the existence of marine incursions (Fig. 4). This would indicate that this zone was still close to the sea level by latest Oligocene-early Miocene times, as suggested also by Bristow and Parodiz (1982) for the Cuenca basin, and that the major uplift phase began later. However, the presence of a Cretaceous microfauna in some samples suggests that the foraminifers may be reworked.

In the upper part of the formation, the conglomerates mainly contain clasts of metamorphic rocks, and thus contrast with the underlying, mainly volcaniclastic formations. This indicates that an important paleogeographic change occurred, which provoked the erosion of the Palaeozoic basement of the Andean margin (Cordillera Real). These, and the angular unconformity observed between

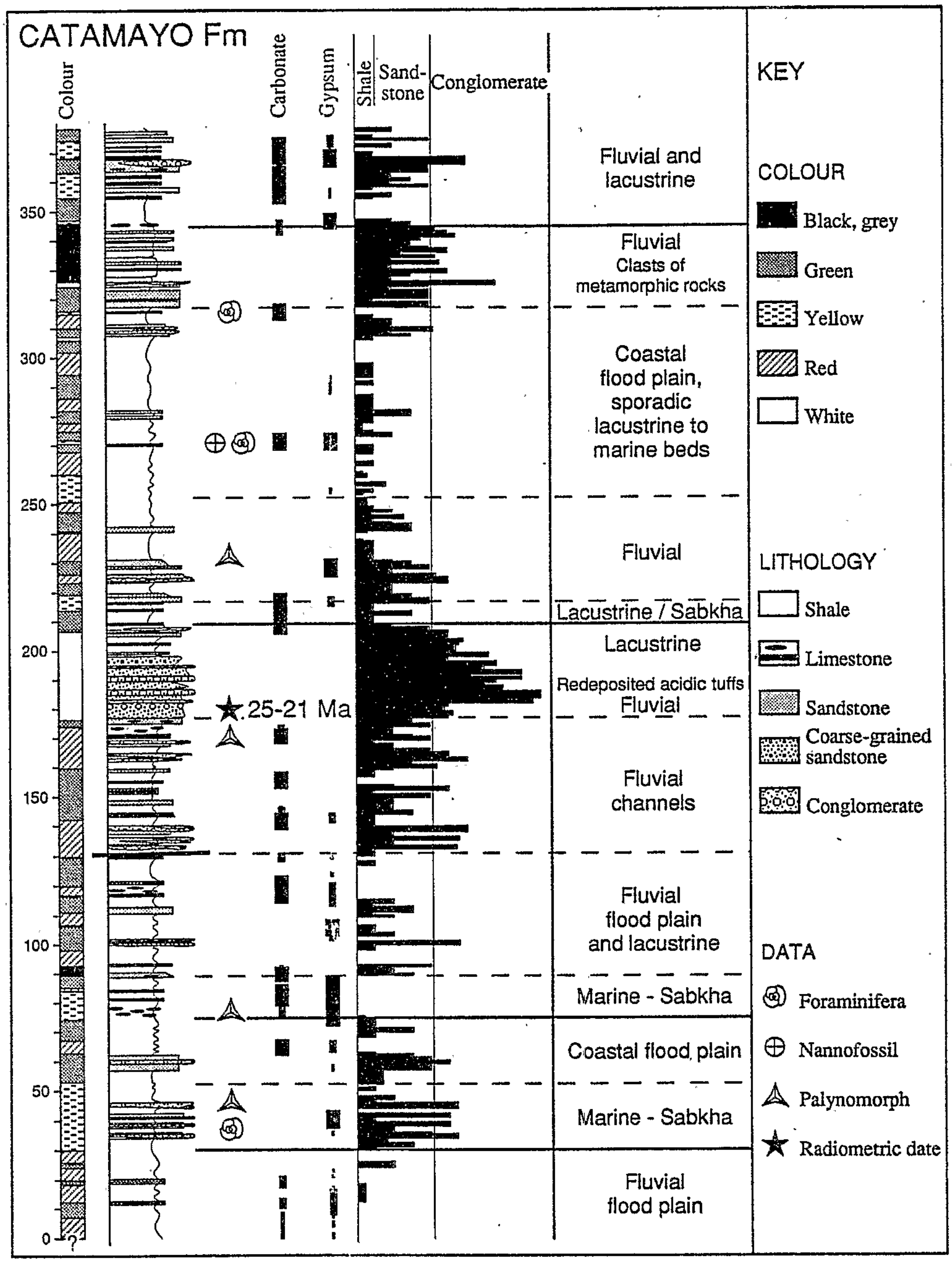

Fig. 5. Detailed section of the Catamayo Formation (latest Oligocene-early Miocene), studied near Catamayo.

the Catamayo and Loma Blanca Formations are interpreted as a result of a deformational event of early Miocene age, related to the opening of the Miocene interandean basins of Ecuador (Winkler *et al.*, 1993, Baudino *et al.*, 1994, Marocco *et al.*, in press).

The ages of the tuff intercalated in the Catamayo Formation, and of the Palo Blanco pluton confirm the occurrence of an significant magmatic pulse of late Oligocene to early Miocene age (≈ 29–19 Ma, Kennerley, 1980; Hall and Calle, 1982; Lavenu *et al.*, 1992; Aspden *et al.*, 1992, Winkler *et al.*, 1993).

CONCLUSIONS

The Río Playas and Catamayo-Gonzanamá areas present volcanic and sedimentary successions deposited in an arc setting. Such series are quite scarce throughout the whole central Andes. In spite of still poor stratigraphic data, they recorded the major early Andean tectonic and geodynamic events (Soler and Bonhomme, 1990; Jaillard, 1993; Sempere, 1994).

The thick andesitic Celica Formation probably represents the products of the Albian subduction-related volcanic arc, which is well known along the Peruvian margin. Its erosion during the deposition of the Alamor Formation would result from the late Albian-early Cenomanian Mochica compressive phase of Peru (Mégard, 1984).

The unconformity below the Naranjo Formation seems to result from the early Peruvian phase, well-expressed in southwestern Peru and Bolivia (Sempere, 1994). The

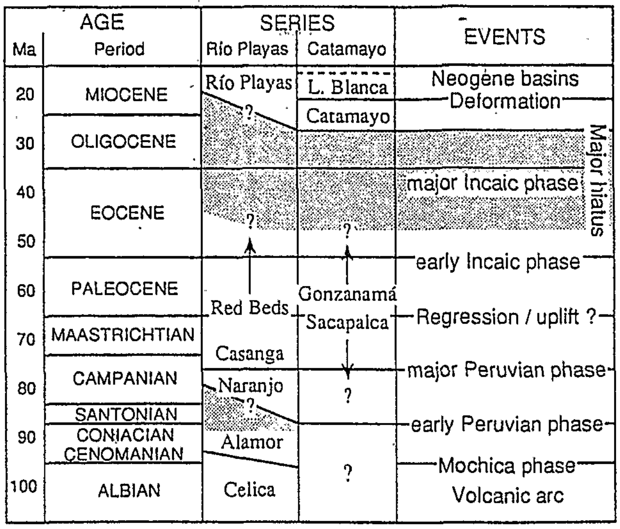

Fig. 6. Interpretation of the tectonic evolution of the arc zone of Southern Ecuador between Albian and early Miocene times.

appearance of coarse-grained conglomerates in the Casanga Formation would be coeval with the late Campanian major Peruvian compressive phase (Jaillard, 1993; Sempere, 1994).

The latest Cretaceous or Paleocene regression and uplift, the intense volcanic activity of the Sacapalca Formation, and the syntectonic deposition of the Gonzanamá Formation still need chronostratigraphic confirmations, prior to attempt correlation with Andean events known elsewhere. However, the subsequent major hiatus of Eocene and/or Oligocene age could be related to the important Incaic compressional phases.

Finally, the arc zone of southwestern Ecuador was probably located close to the sea-level during latest Oligocene-early Miocene times, and recorded deformations and a significant magmatic activity during early Miocene times.

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