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Stratigraphical and Sedimentological Constraints on Western Colombia: Implications on the Evolution of the Caribbean Plate

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ABSTRACT

New data on five regions of western Colombia combined with available information allow us to suggest that at least five structural complexes constitute the northwestern border of South America: Quebradagrande-Alao, Arquía-Guamote, Amaime-Chaucha, Cordillera Occidental, and Panamá-Chocó. The geologic characteristics and age of these complexes support the hypothesis of the Pacific origin of the Caribbean; we propose that the origin of these complexes are related to progressive accretion of oceanic blocks against northwestern South America in the following phases: Early Cretaceous diagonal accretion of the proto-Caribbean oceanic crust with an associated volcanic arc, Late Cretaceous diagonal collision of the Caribbean plate (oceanic plateau) against northwestern South America, followed by a frontal collision during the early Tertiary.

INTRODUCTION

Western Colombia includes ophiolitic rocks that outcrop in the western flank of the Central Cordillera, Cauca Valley, Western Cordillera, and Serranía del Baudó; they represent 20% (240,000 km^2) of the Colombian surface (Figure 1). The tectonic complexity of this region, coupled with the dense tropical vegetation, makes it unfavorable for geologic research; furthermore, most available cartographic works use local lithostratigraphic terms, which increase the complexity (Alvarez and González, 1978; Parra et al., 1983; Barrero, 1979). Geochronological, geochemical, and stratigraphic research in this area (Aspden and McCourt, 1986a, b; Restrepo and Toussaint, 1988, 1989; Gómez et al., 1995; Maya and González, 1995; Nivia, 1996; Nivia et al., 1996; Toussaint, 1996; Pardo et al., 1999; Kerr et al., 1997a, b) recognizes different structural complexes, each possessing lithologic and/or chronostratigraphic diagnostic characteristics. The first purpose of this paper is to reveal new detailed stratigraphic and sedimentologic data from five sectors of western Colombia that will allow discussion of constraints on accretionary event timing and to review the general characteristics of each one of these complexes. Then, comparing our data with regional

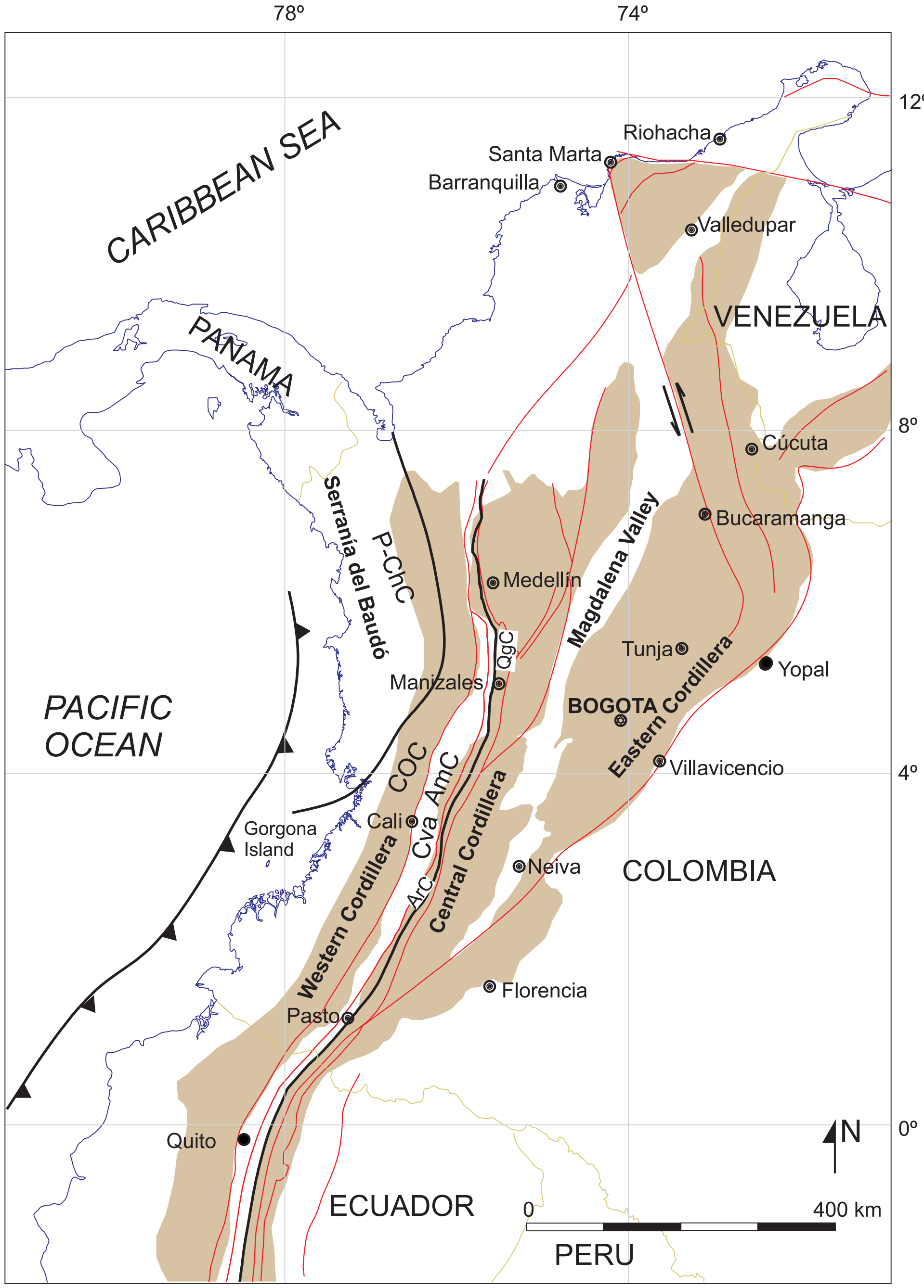


Figure 1. Physiography and tectonic complexes of western Colombia. P-ChC = Panamá-Chocó complex; COC = Cordillera Occidental complex; AmC = Amaime-Chaucha complex; ArC = Arquía-Guamote complex; QgC = Quebradagrande-Alao complex; Cva = Cauca Valley. In brown, Andean mountain ranges; red and black lines represent major faults.

information on the evolution of the Caribbean, we propose a reevaluation of the current geological evolutionary models for the northwestern corner of South America.

SUMARY OF CHARACTERISTICS OF WESTERN COLOMBIA COMPLEXES

Quebradagrande-Alao Complex

The Quebradagrande-Alao complex (modified from Aspden and Litherland, 1992; Maya and González, 1995; and Nivia et al., 1996) is in fault-bounded contact with the Paleozoic metamorphic rocks (e.g., Cajamarca complex) of the Central Cordillera to the east (San Jeronimo fault in Colombia and Baños Front in Ecuador; Maya and González, 1995; Aspden and Litherland, 1992). It outcrops as a discontinuous fringe along the western flank of the Central Cordillera, north of the town of Santa Fé de Antioquia, 10 km west of Medellín, between the metamorphic and igneous rocks of the Cajamarca and Arquía-Guamote complexes (Maya and González, 1995). From north to south, the following units are recognized: the Quebradagrande (Botero, 1963), Abejorral (Etayo-Serna et al., 1986) and Valle Alto (González, 1980) Formations, the Valle Alto, San Fèlix, and El Establo stratigraphic-tectonic intervals (Rodríguez and Rojas, 1985), Eastern and Western intervals of Manizales (Gómez et al., 1995), Aranzazu-Manizales metasedimentary complex (Mosquera, 1978), Quebradagrande Formation (*sensu* McCourt et al., 1984b). In southern Colombia, this complex has not been differentiated from the volcanic and sedimentary units of the Cordillera Occidental complex; however, similar volcanic-sedimentary rocks are reported as far south as the area of Puyana in Ecuador (Basal Greywackes, Bosque de Piedra, Puyango, Alamor and Celica Formations; see Jaillard et al., 1999), and in the Melange ofiolítico de Peltec, turbidites of Maguazo, and greenstones of the "División de Alao" (Aspden and Litherland, 1992).

The Bosque de Piedra Formation (called also Ciano Formation) on the eastern side of Amotape-Tahuin Massif (Figure 2) yields an Early Cretaceous plant assemblage (Shoemaker, 1982) similar to that recorded in the Campanas creek (for location, see "Campanas basalt" in Figure 3).

The Quebradagrande-Alao complex is composed of an ophiolitic suite of ultramafic rocks, gabbros, basalts, mudrocks, cherts, feldspathic sandstones, conglomerates, breccias, and pyroclastic rocks usually affected by dynamic metamorphism. Based on fossil remains, a Berriasian-Albian (140–100 Ma) age is proposed (González, 1980; Botero and González, 1983; Etayo-Serna, 1985a; Gómez et al., 1995). The depositional environments deduced from the sedimentary rocks vary from fluvial, coastal, coarse-grained deltas, platform (Rodríguez and Rojas, 1985), and slope and submarine fans associated with volcanism (Gómez et al., 1995). The composition of the clastic fragments suggests a passive continental margin to the east (see Rodríguez and Rojas, 1985; Gómez et al., 1995) and strong volcanic influence to the west (Western Interval of Gómez et al., 1995). Nivia et al. (1996) demonstrated that the basalts were formed in a geochemical environment associated with a volcanic arc on oceanic floor independent of the Caribbean-Colombian Cretaceous Igneous Province (CCCIP of Kerr et al., 1997a).

The Quebradagrande-Alao complex is crossed by a braided system of north-south faults with separating blocks in which a stratigraphic and a tectonic trend may be recognized. The dip of this tectonic "pile" is vertical or inclined to the east, but most of the sedimentary structures suggest inverted stratigraphic polarity. Internal changes in the degree of deformation are common, and in some areas, fault-bounded Paleozoic (?) metamorphic blocks similar to Cajamarca complex rocks occur, hindering the distinction from adjacent metamorphic complexes. Intruding Cretaceous-Paleocene granite bodies (e.g., the Stock of Manizales) and upper Miocene–Pliocene hypabyssal rocks also occur. These lithologies are covered partially by Pliocene to Holocene volcanic-sedimentary deposits (Thouret et al., 1985; Kroonenberg et al., 1990).

Geophysical studies carried out between 4° and 5.5° N latitude (Case et al., 1971; Meissner et al., 1976) show that these rocks overlie the metamorphic basement of the Central Cordillera. We propose that this complex represents an accretionary pile composed of the remains of a volcanic arc and some portions of the Proto-Caribbean Plate (Pindell et al., 1988; Pindell and Barrett, 1990), which were accreted and obducted at the western border of Colombia during the Late Cretaceous.

Arquia-Guamote Complex

The Arquia-Guamote complex (modified from González and Núñez, 1991; Aspden and Litherland, 1992), limited to the east by the Silvia-Pijao fault system (the Silvia-Pijao Fault, sensu Maya and González, 1995, in Colombia; and the Peltec Fault in Ecuador, Aspden and Litherland, 1992), corresponds to a narrow fringe with a north-south trend extending to Ecuador (blue schists and eclogites of Raspas, in the Provincia del Oro, Toussaint, 1996; and the quartzites and phyllites of the Guamote Division, Aspden and Litherland, 1992). From north to south it includes (Figure 2): the Sabaletas schists (Grosse, 1926), the Arquía Group (Toussaint and Restrepo, 1974), the Lisboa-Palestina schists (Mosquera, 1978), the Bugalagrande Group, the Bolo Azul and Rosario complexes (McCourt et al., 1984b), the Barragán schists (McCourt and Feininger, 1984), the Jambaló schists (Orrego et al., 1980a), the Secuencia metamórfica de Buesaco (Murcia and Cepeda, 1991a, b), the Guamote Division, and the Raspas eclogites in Ecuador. It comprises middle- to high-pressure metamorphic rocks (e.g., lawsonite-glaucophane-actinolite schists and eclogites), with sedimentary or oceanic igneous protoliths, gabbros, and ultramafic rocks, and, occasionally, quartzites. Usually, these rocks are highly tectonized. Fringes of Late Cretaceous sedimentary and volcanic rocks also are included tectonically (volcanic-sedimentary rocks of Pijao and Palestina, see section "Western Border of the Central Cordillera") and often have been mapped as part of the Quebradagrande-Alao complex (see Mosquera, 1978; González and Núñez, 1991; Estrada and Viana, 1993). The Arquía-Guamote complex has greater tectonic complexity than the Quebradagrande-Alao complex. It is crossed by a dense system of faults that juxtapose rocks with different degrees of metamorphism and from different geologic environments (e.g., ultramafic rocks with graphitic schists). Cretaceous granitoids (e.g., Pueblito diorite, Cambumbia stock, Santa Rosa–Córdoba complex; Figure 2) and Miocene-Pliocene hypabyssal rocks are present. Oligocene to early Miocene (?) fluvial sediments (Amagá Formation), late Miocene (Combia Formation) and Quaternary volcaniclastic deposits locally overlay this complex.

An age range of 127 to 94 Ma has been proposed for the main metamorphic phase, based on K/Ar

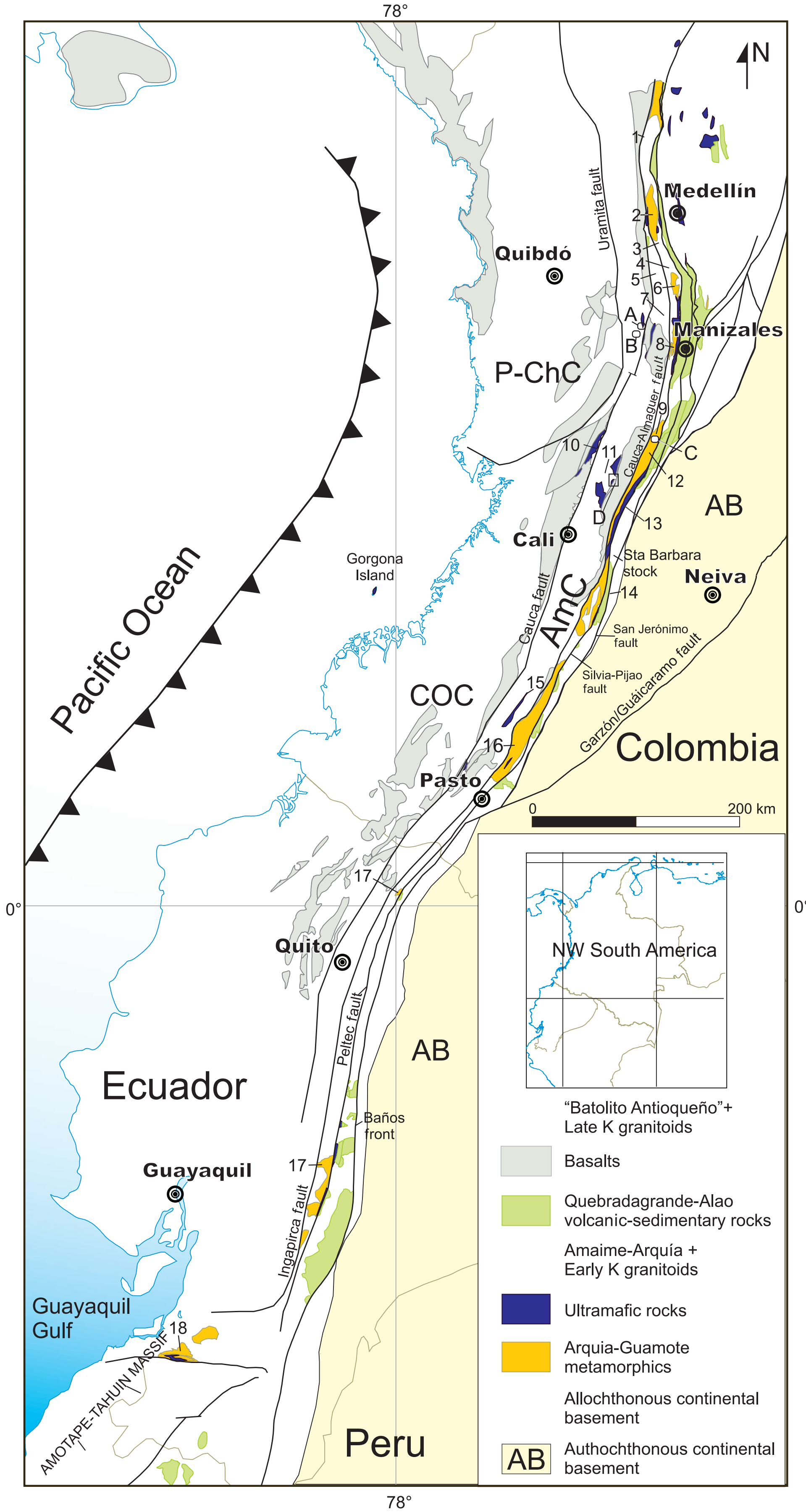


Figure 2. Map of the localities studied in this work. A = Belén de Umbría; B = Apía-Pueblo Rico; C = Pijao; D = Tuluá sector; 1 = Sabanalarga batholith; 2 = Sabaletas schists; 3 = Pueblito diorite; 4 = Cambumbia stock; 5 = Támesis stock; 6 = Arquía Group; 7 = Irra stock; 8 = Lisboa-Palestina schists; 9 = Bugalagrande Group; 10 = Bolivar ultramafic complex; 11 = Buga batholith; 12 = Río Rosario complex; 13 = Bolo Azul complex; 14 = Jambaló blue schists; 15 = Los Azules ultramafic complex; 16 = Metamorphic sequence of Buesaco; 17 = Guamote División; 18 Raspas eclogites; P-ChC = Panamá-Chocó complex; COC = Cordillera Occidental complex; AmC = Amaime-Chaucha complex; AB = Autochthonous basement. Compiled from several sources.

radiometric data (Table 1); nevertheless, until now, the age of the protoliths has not been known (see section titled "Discussion"). We suggest that this complex represents a multistage zone of deformation composed of Paleozoic (?), Mesozoic, and Cenozoic tectonic blocks affected by Late Jurassic–Cretaceous subduction, magmatism, and/or shear processes. Similar rocks are recognized in the northwestern border of the Sierra Nevada of Santa Marta (e.g., Concha schists, Taganga phillyte, El Rodadero schists, Etayo-Serna et al., 1986), on the Leeward Antilles to the north of Venezuela (e.g., Margarita Island; Stöckhert et al., 1995; Pindell, 1993), in the area of Villa del Cura (Venezuela), and on the borders of the Caribbean Plate.

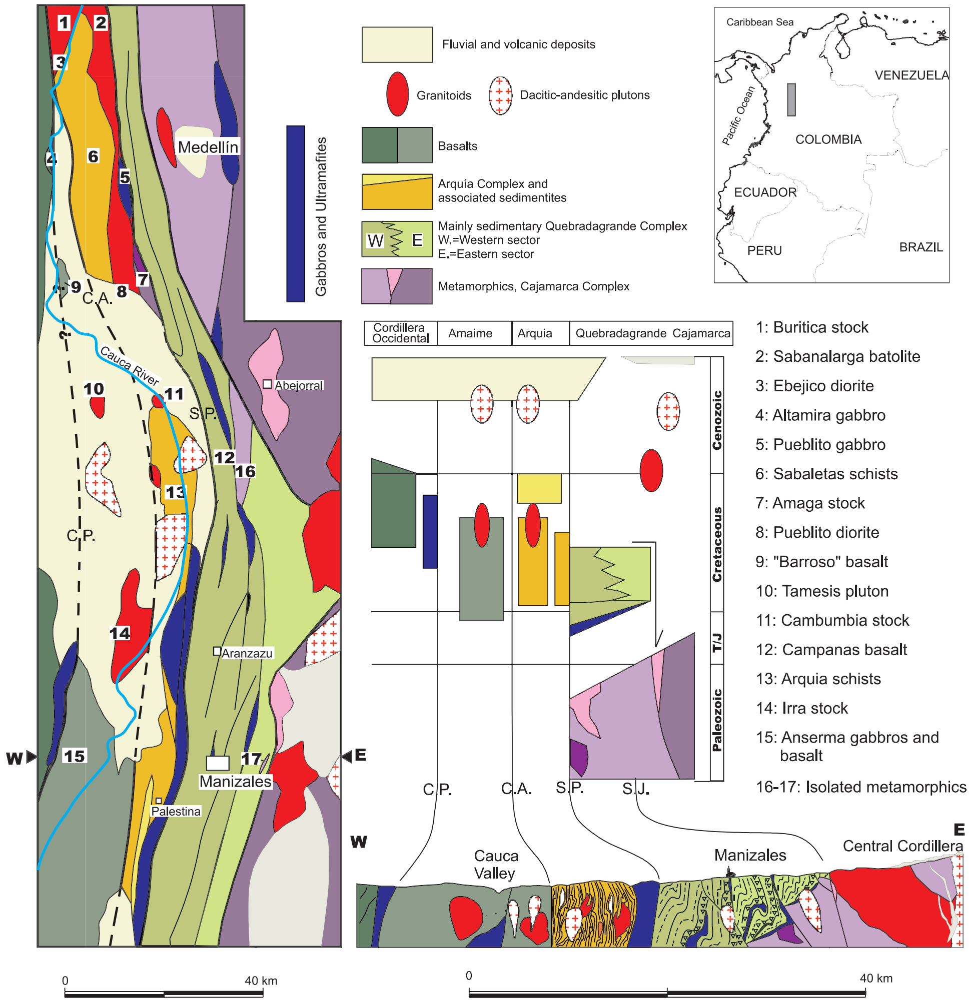


Figure 3. Geological map of the Manizales-Medellín region; chronostratigraphic and lithostratigraphic relations. C.P. = Cauca-Patía fault system; C.A. = Cauca-Almaguer fault system; S.P. = Silvia-Pijao fault system; S.J. = San Jerónimo fault system. Compiled from several sources.

Aimaime-Chaucha Complex

The Aimaime-Chaucha complex (modified from McCourt and Aspden, 1984 and Lebrat et al., 1987), limited to the east by the Cauca-Almaguer Fault (Maya and González, 1995) (called Romeral Fault in Kerr et al., 1997a; named Ingapirca Fault by Litherland and Aspden, 1992), corresponds to an elongated fringe extending to the Guayaquil Gulf in Ecuador (Chaucha Terrane of Litherland and Aspden, 1992; see also Lebrat et al., 1987; Kerr et al., 1997a). It includes the Amaime Formation in the Valle del Cauca department (McCourt and Aspden, 1984; Aspden and McCourt, 1986b). To the north and south, it is not well differentiated from the basic volcanic rocks of the Cordillera Occidental complex (Barroso Formation, Volcánica Formation, and Diabasic Group).

The Amaime-Chaucha complex is composed of a core consisting of an ophiolitic suite (e.g., Ginebra, Venus, and Los Azules ophiolitic complexes and Anserma gabbro) intruded by igneous granitoids (e.g., Buga batholith, Pueblito diorite, Támesis stock, and Sabanalarga batholith). Pillow and massive basalts of oceanic plateau type (Nivia, 1989) are tectonically associated; picritic lavas and thin sedimentary levels are less frequent. Late Cretaceous tuffs and sedimentary rocks are included tectonically (e.g., Nogales Formation). This complex is covered partially by Cenozoic sedimentary rocks (e.g., Amagá and Cartago Formations, among others) and volcaniclastic deposits (Combia and La Paila Formations). Radiometric data obtained from plutonic rocks (e.g., Buga batholith, Támesis pluton, Irra stock) suggest a Jurassic (?)–Early Cretaceous age for the older oceanic basement (Armas, 1984; see Table 1). Additionally, new $^{40}Ar/^{39}Ar$ radiometric data obtained from some basalts of the Amaime-Chaucha complex gave a Cenomanian-Turonian age (A. C. Kerr, personal communication, 2002), but radiometric data of basalts intruded by the Buga batholith are not available. We propose that the Amaime-Chaucha complex has rocks that were formed in two main tectonic events: An Albian-Maastrichtian diagonal accretion of a volcanic arc, followed by a Late Cretaceous–Tertiary progressive accretion of a portion of the Caribbean Plateau.

Cordillera Occidental Complex

The lithologic similarity of the Cordillera Occidental complex to some of the Amaime-Chaucha rocks linked to Tertiary and Quaternary sedimentary covers makes it difficult to delimit toward the east; this has resulted in misinterpretations in mapping the area. In the present work, we place this limit in the Cauca Fault System (Figure 2). From north to

Table 1. Western Colombia radiometric data. Except for Santa Barbara stock, Tertiary data are not included.

COMP.	*LOCALITY*	*TIME INTERVAL*	*FOSSILS*	*REFERENCES*
QG-A	Encimadas (Antioquia)	*Early Cretaceous*	*Oxytropidoceras* sp.	González (1980)
	Campanas creek (Antioquia)		*Coniopteris martinezzi, Piazopteris branneri, ? Klukia* sp., *cf. Sphenobaiera*, cf. *Sagenopteris* sp. *3., Nilssoniopteris major, Zamites cf. quiniae, Zamites* sp., *Cupressinocladus lepidophylla, Cyparissidium* sp., *Elatocladus* sp., *Holcostephanus* sp., *Neohopliceras* sp.	Lemoigne (1984); Vakhrameev (1991)
			Trigonia (Yaadia) hondaana, Idonearca brevis, Cardita dietrichi, Protocardia aff. *Peregrinorsum, Cyprina (Venilicardia)* sp.*?*	Botero and González (1983)
	Arma (Caldas)		*Pseudoglauconia* aff. *Strombiformia, Cucullaea brevis, Cardita* sp., *Trigonia abrupta, Trigonia hondaana, Trigonia tocaimaana*	
	Guargurubú creek (Caldas)		*Trigonia (Yaadia) hondaana, Trigonia (Notoscabrotrigonia) tocaimaana, Idonearca brevis, Protocardia* sp. *?, Glauconia (Paraglauconia)* aff. *Luján, Turritella* aff. *Vibrayeana, Acteon vibrayeana, Cerithium* sp. *?*	
	Abejorral, San Félix-Valle Alto (Caldas)	*Berriasian- Albian*	*Oxytropidoceras carbonarium, Oxytropidoceras* cf. *peruvianum, Venezoliceras karsteni, Inoceramus* sp. *Dipolaceras ?* sp.	Burgl and Radelli (1962)
			Gleichenites san martini, Gleichenites porsildii, Cladophlebis denticulata, Cladophlebis exiliformis, Cladophlebis (Klukia?) koraiensis, Sphenopteris sp., *Pachypteris* sp., *Sagenopteris* sp. *1., Anomozamites minor*, cf. *Nilssoniopteris major, Otozamies* cf. *Peruvianus, Otozamites simonatoi, Otozamites* sp., *Zamites lucerensis, Ctenozamites* sp. *1, Ctenozamites* sp. *2, Ptilophyllum* cf. *Cutchense, Ptilophyllum* cf. *distans, Desmiophyllum* sp.	Lemoigne (1984); Vakhrameev (1991)

Table 1. Western Colombia radiometric data. Except for Santa Barbara stock, Tertiary data are not included (cont.).

COMP.	*LOCALITY*	*TIME INTERVAL*	*FOSSILS*	*REFERENCES*
			Olcostephanus nicklesi, Neomiodon sp.	Etayo-Serna (1985a)
	Manizales (Caldas)	*Middle Albian*	*Oxytropidoceras* sp.	Gómez et al. (1995)
Ar-G	Pijao (Quindío)	*Campanian*	*Nostoceras* sp.	Pardo et al. (1999)
Am-Ch	Tulua-Monteloro (Valle del Cauca)	Campanian-Maastrichtian	*Trochoceramus* sp., *Nostoceras* sp.	Pardo et al. (1993)
CO	Dabeiba (Antioquia)	*Cenonian*	*Globotruncana* sp.	Thery (1980)
	Peque (Antioquia)	*Campanian-Maastrichtian*	*Nostoceras* cf *hyatti, Nostoceras* cf *pauper, Trochoceramus*	Etayo-Serna (1989)
	Buriticá (Antioquia)	*Late Aptian- Middle Albian*	*Ptycocheras* sp., *Metahamites* sp., *Globigerinella scheri*	Etayo-Serna et al. (1980)
		Santonian-Maastrichtian	*Rugoglobigerina* sp.	
	Puente Umbría (Risaralda)	*Campanian-Maastrichtian*	*Pachidyscus* sp.	Moreno et al. (1993)
	Apía (Risaralda)	*Campanian-Maastrichtian*	*Trochoceramus* sp., *Pachidyscus* sp.	Pardo et al. (1999)
			Frondicularia mucronata	J.I. Martinez (written comunication, 2000).
	West of Toro (Valle del Cauca)	*Santonian-Maastrichtian*	*Rugoglobigerina* sp.	Etayo-Serna et al. (1982)
		Albian-Maastrichtian	*Durania* sp.	
			Archaelitothamium sp.	
	Buga–Buenaventura road (Valle del cauca)	*Post-Coniacian*	*Psiphogenerinoides* sp., cf. *S. Clavata, Plectofrondicularia rugosa proyecta*	Aluja et al. (1975)
		Turonian	*Artostrobiidae* sp.	Etayo-Serna et al. (1982)
		Campanian-Maastrichtian	*Trochoceramus* sp.	Etayo-Serna (1985b)
	San Marcos creek (Valle del Cauca)	*Early Coniacian*	*Inoceramus cf. I. peruanus*	Barrero (1979)
	San Antonio, Jamundi (Valle del Cauca)	*Late Cretaceous*	*Haplophragmoides excata, Haplofragmoides* cf. *Glabra, Ammodiscus Glabratus*	Keizer (1954)
	Macuchi Formation (Ecuador)	*Early Coniacian*	*Inoceramus peruanus, Globotruncanela* sp.	Henderson (1979)

south, the Cordillera Occidental complex includes the Barroso and Penderisco Formations (Alvarez and González, 1978), the Cisneros and Espinal Formations, and the Diabasic Group (see Barrero, 1979), the Volcánica Formation (Aspden et al., 1985), and many informal units that make correlations difficult (e.g., Bourgois, Calle et al., 1982). It is composed of a tectonic association of diabases and pillow and massive basalts, locally intruded by plagiogranites (Aspden and McCourt, 1986a), gabbros, ultramafic rocks, basic pyroclastics, pelagites, hemipelagites, and terrigenous rocks of variable grain size that, in some cases, are highly deformed, presenting penetrative foliation.

Paleontologic and radiometric data allow the probable inclusion of these rocks in the Albian(?)-Maastrichtian, and more precisely, between the Cenomanian-Maastrichtian interval (Barrero, 1979; Etayo-Serna et al., 1980, 1982; Aspden and McCourt, 1986a; Etayo-Serna, 1989; Ossa and Pardo, 1989; Nivia, 1996; see Tables 1 and 2). In its central and northern parts, the Cordillera Occidental complex is intruded by many Miocene granitic and hypabyssal plutons, and toward the south, it is overlain by Tertiary clastic rocks (the Grupo del Cauca of Nelson, 1957; Van der Hammen, 1957).

The Cordillera Occidental complex corresponds to a portion of the Caribbean Plate that began to be accreted to the western border of Colombia during the Late Cretaceous.

Panamá-Chocó Complex

The Panamá-Chocó complex is limited to the east by the Uramita fault (Duque-Caro, 1990) and includes the Bloque Chocó of Duque-Caro (1990). It comprises the eastern part of the Panamá Canal area up to Buenaventura Bay in Colombia (Figure 2). Regarded as associated structurally with the Chorotega block of Costa Rica (Dengo, 1983; Pindell, 1993), it is composed of blocks of tonalitic intrusives, oceanic igneous rocks, and pelagic, hemipelagic, and terrigenous sedimentary rocks without stratigraphic coherence inserted within mafic volcanic rocks. The eastern limit of this complex, the Arco de Dabeiba (Baudo Suture of some authors), consists of a mixture of rocks yielding Cretaceous-Paleocene, Eocene-Oligocene broken strata and inclusions of exotic blocks dispersed among a sheared middle Miocene pelitic matrix (Duque-Caro, 1990). It corresponds to an area of deformation related to accretionary processes. Ultramafic rocks also have been recognized in the contact area with the Cordillera Occidental complex (e.g., Complejo Ultramáfico Zonado del Alto Condoto; Muñoz et al., 1990). Geochemical and radiometric data (Kerr et al., 1997a) indicate that the Panamá-Chocó complex represents a 70–76 Ma segment of the Caribbean Plate (not a volcanic arc, as is suggested by many authors) that was progressively deformed against the northwestern border of Colombia during the late Tertiary and was then uplifted in the middle Miocene (Duque-Caro, 1990).

DESCRIPTION OF THE STUDIED SECTORS

The geologic model proposed in this work is supported by new stratigraphic and paleontologic information collected from five regions (Figure 2). These new data on western Colombia, together with the relevant data available in the literature, are discussed below.

Western Border of the Central Cordillera (Medellín-Manizales Sector)

In this area, four of the five complexes mentioned above are observed: the Quebradagrande-Alao, the Arquía-Guamote, the Amaime-Chaucha, and the Cordillera Occidental (Figure 3).

The Quebradagrande-Alao complex, which is in tectonic contact (San Jerónimo Fault) with the Paleozoic metamorphic rocks of the continental basement (Cajamarca complex) to the east, can be divided into two regions with different petrography and facies characteristics. The eastern sector is composed of black mudrocks, cherts, cross-bedded quarzitic conglomerates, and quartz sandstones deposited in fluvial, coarse-grained deltas and platform environments (Rodríguez and Rojas, 1985; Gómez et al., 1995). This contrasts with the western sector, which is composed of black mudrocks, cherts, and siliceous mudstones, feldspathic sandstones, and volcanic-rich lithic conglomerates interlayered with basic tuffs, andesites, and basalts. Sandy clastic dikes and synsedimentary faults are common in the western sector, indicating tectonic instability during sedimentation. These facies were formed in turbiditic fans near submarine cliffs and hemipelagic environments associated with volcanism (Gómez et al., 1995). North of Manizales, mixed quarzitic and volcanic-rich conglomerates are observed, suggesting continuity of the eastern and western facies. The occurrence of diabases, ultramafic rocks, and gabbros complete the ophiolitic suite. Wide areas of mylonites are frequent; they have been mapped by some authors as regionally metamorphosed rocks (see Mosquera, 1978). However, tectonic blocks derived from an old metamorphic basement have been reported (e.g., schists associated with the Permian-Triassic Amagá stock, Aguadas muscovite schists, and tourmaline schists to the east of Manizales (cf. Figure 3).

The rocks of the eastern sector yield Early Cretaceous invertebrates (Etayo-Serna, 1985b; Gómez et al., 1995; see Table 2) and Early Cretaceous plant fossils (Vakhrameev, 1991); the same plant assemblage were dated originally as Late Jurassic by González et al. (1977) and Lemoigne (1984). To the northwest of Aguadas (Campanas and Guargurubú creeks, Figure 3), basalts are interbedded with shales yielding Valanginian-Albian mollusk and plant remains (Botero and González, 1983). One basalt associated with the fosilliferous layers gave a 67 ± 5 Ma K/Ar age (Restrepo et al., 1991), which suggests a superposed later Cretaceous event (Table 1).

West of the Silvia-Pijao fault system, the Arquía-Guamote complex, which is partially covered by Cenozoic fluvial and/or volcanic deposits, is observed in outcrops. It is intruded by the Sabanalarga batholith with a 98.2 ± 3.5 to 97 ± 10 Ma K/Ar age (Maya, 1992; Table 1), the Cambumbia Stock with a 112 ± 5 and 113 ± 3 Ma age (Maya, 1992), and the 135 Ma old Pueblito gabbro west of Medellín (Toussaint and Restrepo, 1976). The metamorphic rocks of this area are 127 ± 5 Ma K/Ar (Esquistos de Sabaletas) and 110 ± 10 Ma old (Grupo Arquía, *sensu* Toussaint, 1996). Studies carried out in this complex show several wrench-and-thrust tectonic phases (Hincapié and Moreno, 2001).

The protoliths of the metamorphic rocks were mafic igneous and sedimentary oceanic rocks (Toussaint, 1996; Hincapié and Moreno, 2001). Fringes of ultramafic rocks and metagabbros complete the typical ophiolitic association. Another notable characteristic is the occurrence of tectonic blocks of sedimentary rocks in the Arquía-Guamote complex. Near the town of Palestina (Figure 3), basic lava and sedimentary sequences were observed, yielding *Zoophycos* and *Chondrites* ichnogenera. These ichnofossils commonly are recorded in Upper Cretaceous rocks of the Cordillera Occidental complex (Etayo-Serna, 1986) but have not been reported from the Quebradagrande-Alao complex.

Near the town of Pijao, Quindío ("Puente La Tabla sector), appears a small fringe composed of quartz sandstones, tuffs and peloidal and bioclastic limestones in tectonic contact with serpentines, schists, and garnetiferous amphibolites of the Arquía-Guamote complex, dated at 110 ± 10 Ma K/Ar (Toussaint and Restrepo, 1978b). The limestones contain algal laminites, serpulids, oysters, and Campanian ammonoids (*Nostoceras* sp.; F. Etayo-Serna, personal communication, 1998; see also Pardo et al., 1999).

To the west of the Cauca Almaguer fault the Amaime-Chaucha and Cordillera Occidental complexes are recognizable, limited by a fault with north-south trend that makes up part of the Cauca system of faults. The Amaime-Chaucha complex is composed mainly of basalts and diabases, locally covered by Cenozoic volcanic and sedimentary deposits (Amagá and Combia Formations). Intrusive bodies such as the Támesis (124 ± 6 Ma K/Ar) and Irra stocks (97 ± 10 Ma; see Table 1) are in this complex, but their contact is hidden below Cenozoic deposits. To the southeast of the town of Tuluá, however, the intrusive contact between the Buga batholith (114–94 Ma) and the basalts of the Amaime Formation is clearly observed (Figure 4). To the southwest of Medellín, a body of basalts included in the Barroso Formation has a K/Ar 105 ± 10 Ma age (Toussaint and Restrepo, 1978a), and its tectonic position justifies its inclusion within the Amaime-Chaucha complex. In the El Cicuco oil field, to the north of the Central Cordillera, a 103 Ma old granite in the Cicuco-1 well (Maya, 1992) probably corresponds to the continuation of the Lower Cretaceous plutons associated with the Amaime-Chaucha complex beneath the Lower Magdalena Valley Cenozoic deposits.

From the paleontologic data available, we conclude that the Quebradagrande-Alao complex was deposited during the Early Cretaceous, and the younger radiometric data obtained in some basalts probably indicate isotopic resetting because they are interbedded with fossiliferous Lower Cretaceous beds (Tables 1 and 2). The Arquía-Guamote complex has a 127–97 Ma age range for its metamorphic phase and Lower Cretaceous magmatism. Tectonic blocks of Upper Cretaceous volcanic and sedimentary rocks also are present. The Amaime-Chaucha complex basement predates a 124–97 Ma period of magmatism that probably continues toward the north beneath the Lower Magdalena Valley Cenozoic deposits.

Stratigraphy of the Tuluá Sector (Amaime-Chaucha Complex)

Figure 4 shows a detailed sector inside the Amaime-Chaucha complex. The oldest unit (Amaime Formation of McCourt and Aspden, 1984) corresponds to basalts, diabases, and thin levels of interbedded siliceous mudrocks. It is intruded by the Buga batholith,

Table 2. Western Colombia paleontologic data. Tertiary data are not included. QG-A = Quebradagrande-Alao complex; Ar-G = Arquía-Guamote complex; Am-Ch = Amaime-Chaucha complex; Co = Cordillera Occidental complex.

COMPLEX	ROCK	AGE (Ma)	METHOD	LOCALIZATION AND REMARKS	REFERENCES
QUEBRADA-GRANDE-ALAO	Basalt	*77 ± 5*	*K/Ar rock*	*Antioquia*	Restrepo et al. (1991)
	Basalt	*75 ± 8*	*K/Ar rock*	*West of Medellín (Antioquia)*	
	Basalt	*67 ± 5*	*K/Ar*	*Campanas creek (Caldas). Thermal event because this rock is associated with Early Cretaceous fossiliferous beds*	
ARQUÍA-GUAMOTE	Tonalite	*91.1 ± 6.4*	*K/Ar*	*Near Buritica town (Antioquia). Buriticá Stock*	Göbel and Stibane (1979)
	Tonalite	*98.2 ± 3.5*	*K/Ar*	*Liborina (Antioquia). Sabanalarga Batholith*	Maya (1992)
	Quartzdiorite	*97 ± 10*	*K/Ar*	*Liborina (Antioquia). Sabanalarga Batholith*	González et al. (1978)
	Diorite	*82 ± 22*	*K/Ar*	*Ebéjico (Antioquia). Ebéjico Diorite*	Restrepo et al. (1991)
	Gabbro	*131 ± 9 (133)*	*K/Ar*	*Pueblito (Antioquia). Pueblito Gabbro*	Toussaint and Restrepo (1976)
	Gabbro	*92.5 ± 4.2 (95)*	*K/Ar*	*Corregimiento Cangrejo (Altamira, Antioquia). Altamira Gabbro*	
				Sabaletas Schists	
	Diorite	102 ± 28	K/Ar	Amagá-Bolombolo road (Antioquia). Pueblito Diorite	
	Schist	127 ± 5 (127)	K/Ar	Albania-Bolombolo road (Antioquia). Sabaletas Schists	Toussaint et al. (1978a)
	Not described	112 ± 5	K/Ar	La Pintada-Supía road (Caldas). Cambumbia Stock	Restrepo et al. (1991)
	Diorite	113 ± 3	K/Ar	Santo Creek (Caldas)	Maya (1992)
	Amphibolite	110 ± 5 (113)	K/Ar	Arquía river (Antioquia). Arquía Group	Restrepo and Toussaint (1976)
	Granatiferous amphibolite	110 ± 10 (110)	K/Ar	Pijao-Armenia road	Toussaint and Restrepo (1978b)
	Diorite	72 ± 2	K/Ar	Córdoba-Pijao road (Quindío). Río Rosario Igneous metamorphic Complex. Diorites that intrude the Anphibolites	Brook (1984)
	Diorite	77 ± 4	K/Ar		
	Diorite	83 ± 2	K/Ar	La Siberia-Córdoba road (Quindío). Santa Rosa-Córdoba Complex	
	Amphibolite	107 ± 10	K/Ar	Pijao-Génova road (Quindío). Rosario Complex	

Table 2. Western Colombia paleontologic data. Tertiary data are not included. QG-A = Quebradagrande-Alao complex; Ar-G = Arquía-Guamote complex; Am-Ch = Amaime-Chaucha complex; Co = Cordillera Occidental complex (cont.).

COMPLEX	*ROCK*	*AGE (Ma)*	*METHOD*	*LOCALIZATION AND REMARKS*	*REFERENCES*
	Amphibolite	109 ± 9	K/Ar	Génova-Puente Barragán road (Quindío). Rosario Complex	
	High-pressure metamorphic rock	110 ± 3	K/Ar	Pijao-Génova road (Quindío). Rosario Complex	
	Amphibolite	114 ± 4	K/Ar	Pijao-Puente Barragán road (Quindío). Rosario Complex	
	Lawsonite schist	120 ± 5	K/Ar	Barragán-Santa Lucia road (Valle del Cauca)	
	Amphibolite	114 ± 8	K/Ar	Río Verde-Pijao road (Quindío)	
	Amphibolite	115 ± 3	K/Ar	Lejos River. Puente Barragán-Génova road (Quindío)	
	Amphibolite	94 ± 12	K/Ar	Rosario Complex (Valle del Cauca)	
	Not described	116 ± 3	K/Ar	Florida-La Rivera road (Valle del Cauca). Bolo Azul Complex	
	Ultramaphic rock	117 ± 6	K/Ar	Barragán-Cumbarco road. (Valle del Cauca)	
	Amphibolite	123 ± 12	Rb/Sr	Bugalagrande Group (Valle del Cauca)	
	Ultramaphic rock	125 ± 10	K/Ar	Barragán-Cumbarco road. (Valle del Cauca)	
	Glaucofana schist	104 ± 14	K/Ar	Calambas creek (Cauca). Jambaló Glaucophanic schists	De Souza et al. (1984)
	Amphibolite	70 ± 10 (71.8)	K/Ar	SE of Jambaló (Cauca). San Antonio Anphibolites	Maya (1992)
	Amphibolite	72 ± 3 (73.9)			
	Sericitic schist	125 ± 13 (125)	K/Ar	La Cera creek (Cauca). Jambaló Glaucophanic schists	Orrego et al. (1980b)
	Glaucophana schist	217 ± 10	K/Ar	Quebrada Calambás (Cauca). Jambaló Glaucophanic schists	De Souza et al. (1984)
	Phengite	132 ± 5	K/Ar	Raspas Metamorphic Complex (Ecuador)	Feininger and Silberman (1982)
AMAIME-CHAUCHA	Granite	113 ± 4 (115.8)	K/Ar	El Cicuco oil field. North of Mompos (Bolivar)	Pinson et al. (1962)
	Basalt	105 ± 10	K/Ar	Albania-Bolombolo road (Antioquia). Barroso Formation (sensu Toussaint y Restrepo, 1978a). Nivia et al (1996) put it in the Quebradagrande Complex	Toussaint and Restrepo (1978a)

Table 2. Western Colombia paleontologic data. Tertiary data are not included. QG-A = Quebradagrande-Alao complex; Ar-G = Arquía-Guamote complex; Am-Ch = Amaime-Chaucha complex; Co = Cordillera Occidental complex (cont.).

COMPLEX	*ROCK*	*AGE (Ma)*	*METHOD*	*LOCALIZATION AND REMARKS*	*REFERENCES*
	Quartzdiorite	124 ± 6	K/Ar	Támesis-Jericó road (Antioquia). Támesis Stock	Calle et al. (1980)
	Plutonic rock	97 ± 10	K/Ar	Irra-Arauca road (Risaralda). Irra Stock	Maya (1992)
	Basalt	64 ± 2	K/Ar	Palmira-Aují road (Valle del Cauca). Amaime Formation	Brook (1984)
	Basalt	67 ± 2	K/Ar	Palmira-Potrerillo road (Nima river). Amaime Formation	
	Quartzdiorite	69 ± 2	K/Ar	Buga Batholith	
	Diorite	75 ± 2	K/Ar		
	Quartzdiorite	78 ± 2	K/Ar		
	Quartzdiorite	80 ± 4	K/Ar		
	Quartzdiorite	81 ± 5	K/Ar		
	Quartzdiorite	89 ± 2	K/Ar		
	Quartzdiorite	94 ± 2	K/Ar	Tulúa-Monteloro road. Buga Batholith	
	Granodiorite	96 ± 4.1	K/Ar	Guadalajara River. Buga Batholith	Maya (1992)
	Quartzdiorite	99 ± 4	Rb/Sr	Buga-Santa Lucia road (Valle del Cauca). Buga Batholith	Brook (1984)
	Tonalite	113 ± 10 (113)	K/Ar	La Habana-Nápoles road (Valle del Cauca). Buga Batholith	Toussaint et al. (1978b)
	Quartzdiorite	114 ± 3	K/Ar	Buga Batholith	Brook (1984)
	Amphibolite	96 ± 3	K/Ar	Ginebra (Valle del Cauca)	Espinosa (1985)
	Basalt	61 ± 6 (61)	K/Ar	Guayabillas (Cauca). Los Azules Ophiolitic Complex	Espinosa (1980)
	Basalt	61.4 ± 4.9 (61)	K/Ar		
	Basalt	63.6 ± 7 (64)	K/Ar		
	Basalt	64.9 ± 5 (65)	K/Ar		
	Basalt	65.4 ± 5 (65)	K/Ar		
	Gabbro	78.8 ± 6 (79)	K/Ar		
	Gabbro	86.1 ± 6.2 (86)	K/Ar		
	Gabbro	97.8 ± 7.9 (98)	K/Ar		
	Basalt	105 ± 24.4 (105)	K/Ar		
	Basalt	105.4 ± 16 (105)	K/Ar		
	Basalt	325.7 ± 82 (326)	K/Ar		
	Basalt	81 ± 11	K/Ar rock	El Tambo-El Peñol (Cauca). Diabásico Group	De Souza et al. (1984)

Table 2. Western Colombia paleontologic data. Tertiary data are not included. QG-A = Quebradagrande-Alao complex; Ar-G = Arquía-Guamote complex; Am-Ch = Amaime-Chaucha complex; Co = Cordillera Occidental complex (cont.).

COMPLEX	*ROCK*	*AGE (Ma)*	*METHOD*	*LOCALIZATION AND REMARKS*	*REFERENCES*
	Basalt	68.4 ± 10.5 (68)	K/Ar	El Tambo-San Pedro road (Nariño)	Espinosa (1980)
	Basalt	70.6 ± 9.2 (71)	K/Ar		
	Basalt	77.2 ± 19.8 (77)	K/Ar		
	Basalt	78.1 ± 24.5 (78)	K/Ar		
	Basalt	97.0 ± 20.3 (97)	K/Ar		
	Basalt	115.1 ± 26.4 (115)	K/Ar		
AMAIME-CHAUCHA WESTERN LIMIT	Gabbro	92.5 ± 4.2 (95)	K/Ar	Cangrejo-Altamira road (Antioquia). Altamira Gabbro	Toussaint and Restrepo (1976)
	Not described	78 ± 14	K/Ar	Bolivar (Valle del Cauca)	Brook (1984)
	Not described	102 ± 18	K/Ar		
	Not described	70 ± 14	K/Ar		
	Hornblende hornfels	68.8 ± 13.8	K/Ar		Barrero (1979)
	Hornblendic pegmatite	106 ± 18 (108)	K/Ar	Bolivar-Primavera road. Bolivar Complex	
	Amphibolite	88 ± 13	K/Ar rock	Metamorphosed basalt. Bolívar Complex	Barrero (1979)
	Basalt	136 ± 20	K/Ar rock	Bolívar (Valle del Cauca). Anomalous age of metamorphosed rock	
CORDILLERA OCCIDENTAL	Mudrock	95 ± 5	K/Ar	Penderisco Formation. Dabeiba-Uramita road	Restrepo et al. (1979)
	Gabbro	71 ± 2.7	K/Ar	Anserma-La Virginia road (Risaralda) Anserma Gabbro	Maya (1992)
	Phylite	81.8 ± 3.5 (84)	K/Ar	Buga-Buenaventura road (Valle del Cauca). Cisneros Formation	Barrero (1979)
	Leucotonalite	83 ± 2	K/Ar	Vijes-Restrepo road (Valle del Cauca). Tambor Stock	Brook (1984)
	Gabbro	84 ± 2	K/Ar		
	Gabbro	94 ± 16	Rb/Sr		
	Basalt	96 ± 4	K/Ar	Cañasgordas Group	Restrepo and Toussaint (1976)
	Picrite	93 ± 4	$^{40}Ar/^{39}Ar$	Bolo Blanco river, east of Cali city	A.C. Kerr (personal communication, 2002)
	Picrite	89 ± 3	$^{40}Ar/^{39}Ar$	El Encenillo, south of Popayán town	A.C. Kerr (personal communication, 2002)
	Basalt	91.72 ± 2.7	$^{40}Ar/^{39}Ar$	Western Cordillera	Sinton (1996)

Table 2. Western Colombia paleontologic data. Tertiary data are not included. QG-A = Quebradagrande-Alao complex; Ar-G = Arquía-Guamote complex; Am-Ch = Amaime-Chaucha complex; Co = Cordillera Occidental complex (cont.).

COMPLEX	*ROCK*	*AGE (Ma)*	*METHOD*	*LOCALIZATION AND REMARKS*	*REFERENCES*
	Basalt	86 ± 5	40Ar/39Ar	Gorgona island	Sinton et al. (1993); Espinosa et al. (1982)
	Basalt	87 ± 3	K/Ar		
	Gabbro	88 ± 2	K/Ar		
	Gabbro	88 ± 2	K/Ar		
	Tonalites	94 ± 16;	Rb/Sr isochrone K/Ar in hbl.	Tambor Stock (Valle del Cauca)	McCourt et al. (1984a)
		84 ± 2;			
		83 ± 2			
PANAMA-CHOCO	Basalt	70 ± 3.5	K/Ar	Serrania de Baudó (Chocó)	Bourgois, Azéma et al. (1982)
	Basalt	72. 9 ± 0.8	$^{40}Ar/^{39}Ar$	South-west of Cupica (Chocó). Serranía de Baudó	Kerr et al. (1997a, b)
	Basalt	71. 8 ± 1.4	$^{40}Ar/^{39}Ar$		
	Basalt	76. 2 ± 1.1	$^{40}Ar/^{39}Ar$	North of Bahía Solano (Chocó). Serranía de Baudó	

which consists of quartz-diorite-hornblendic tonalite dated between 114 ± 3 and 75 ± 4 Ma K/Ar (Toussaint et al., 1978b; Brook, 1984; see Table 1). One kilometer to the north, outside the map area, the ultramafic rocks of Venus, of unknown age, are observed. They are composed of peridotites, serpentinites, and gabbros. The occurrence of numerous diabase dikes cutting the Buga batholith is remarkable. In the central part of the map, two sedimentary units tectonically included in the basalts are recognized: the Nogales Formation (Van der Hammen, 1957) and a clastic unit of red mudstones and conglomerates discovered by Pardo et al. (1999) and named here the Monteloro Formation from the name of the nearby town (Figure 4). At the base of the Nogales Formation, invertebrate fossils were discovered that are Campanian-Maastrichtian in age (F. Etayo-Serna, personal communication, 1998), not Jurassic as proposed earlier by Armas (1984). Dispersed pollen grains suggest a Paleocene age for the upper part of the Nogales Formation (Van der Hammen, 1957). It must be emphasized that these two units are not intruded by the Buga batholith.

On the basis of stratigraphic relationships, at least two periods of sedimentation and volcanism are proposed: the first occurred before the intrusion of the Buga batholith (114–94 Ma), and the second took place during the Late Cretaceous, as evidenced by strata of fine tuffs in the Nogales Formation. Geochemical studies carried out in the younger basalts of the Amaime Formation allow this to be considered an oceanic plateau environment (Nivia, 1989, 1994; Kerr et al., 1997a).

In the area illustrated on the map, the Nogales Formation is divided into three segments (Figure 4). From base to top these are:

1) Calcareous sandstones, debris-flow conglomerates, and mudrocks. The conglomerates are massive, matrix-supported, and composed of metamorphics, basic vulcanites, and sedimentary rocks. Some bioclasts are ostreids, trigonids, fish remains, and Campanian ammonites (*Nostoceras* sp., F. Etayo-Serna, personal communication, 1998). The sandstones are feldspathic or mixed terrigenous-micritic; the terrigenous fraction is composed of plagioclase, monocrystalline quartz, and metamorphic clasts (quartzites, quartz-micaceous schists), volcanic and sedimentary (cherts, sandstones, and quartz siltstones) rock fragments; the bioturbation is conspicuous. These rocks yield several fossiliferous levels, including

abundant badly preserved plant remains, some carbonized trunks, planktonic foraminifera, heteromorphous ammonites, and bivalve mollusks (ostreidae, trigonides, and inoceramides); several bioclasts are bioeroded— an observation that indicates prolonged exposure in coastal areas. Crustacean coprolites, *Palaxius caucaensis* (Blau et al., 1995) are included as a silicified detrital component of the conglomerates, but they do not appear to be contemporaneous with the deposition of the Nogales Formation, as already suggested.

The lithological characteristics of this segment, especially the conspicuous vegetal remains and the occurrence of trunks and shallow-water mollusks, lead us to consider that the deposition took place under nearshore conditions with strong currents and debris flows as the main physical processes, probably in a coarse-grained delta environment.

2) Siliceous mudrocks, turbiditic sandstones with slump structure. This second segment consists mainly of black and green shales and siliceous mudstones interfingered with turbiditic sandstones and crystalline-vitreous tuffs. Slump structures and bioturbation (*Chondrites,* among other unidentified ones) also are frequent. Serpentinite fragments and basic volcanic rocks are recognized in the sandstones (Pardo et al., 1999). The shales yielded *Trochoceramus* sp. of Campanian-Maastrichtian age (F. Etayo-Serna, personal communication, 1998). This segment is interpreted as a slope deposit developed along the shore.
3) Turbiditic sandstones and shales. In the third segment, which is composed of sandstones and muddy sandstones interbedded with shales, clastic dikes are frequent. Bioturbation and badly preserved plant remains commonly are observed in the fine-grained levels. The sandstones correspond to turbidites with metamorphic (quartzites), plutonic, and sedimentary (siltstones) rock fragments; some bioclasts (ammonites and small plant remains) are present. In some sectors, thickening-upward metric sand-shale sequences are noticed. This third segment is interpreted as corresponding to turbiditic fan deposits (Pardo et al., 1999).

The Monteloro Formation overlies the former units in paraconformity. It is composed of detritic rocks, with a measured thickness of 1500 m, but its upper contact with the Amaime Formation is missing (Figure 4). In the Piedrahitas Creek, this unit is well-exposed and consists of massive or cross-bedded, poorly sorted conglomerates and sandstones with volcanic (basalts and diabases) and milky quartz components, interbedded with red and green shales. The fine layers yielded bone fragments.

The Nogales Formation and the Pijao sedimentary rocks are very important for understanding western Colombian paleogeography because they correspond to the easternmost Campanian-Maastrichtian units in the Caribbean-Colombian Cretaceous Igneous Province (CCCIP, Kerr et al., 1997a). They represent the remains of depositional basins that were located on the western border of Colombia during this period. In general, the above-described sequence corresponds to deepening conditions and records the last marine sediments deposited in the area before or simultaneously with the first Colombian Andean orogenic phase. The Monteloro Formation shows the first Paleogene subaerial sedimentation. The occurrence of granitoids and metamorphic and basic volcanic rock fragments in this unit indicates the first record of erosion of older oceanic materials in this area, and plutonic and metamorphic basements— an observation that allows us to suggest that accretion and deformation of the eastern CCCIP took place before or concurrently with the deposition of the Nogales Formation and after the emplacement of the Buga batholith.

Cordillera Occidental Complex

The Cordillera Occidental complex has a basement composed of oceanic plateau basalts and ultramafic rocks (Nivia, 1989; Kerr et al., 1997b) associated with pyroclastic rocks, basic epiclastites, pelagites, detrital deposits, and siliceous and calcareous hemipelagites. In a broad sense, the sedimentary environments proposed are submarine fans, abyssal plains, and coarse deposits associated with volcanic mounts (Barrero, 1979; Etayo-Serna et al., 1982; Alvarez, 1983; Etayo-Serna, 1986). The Cordillera Occidental complex is composed of fault-bounded blocks affected by imbrications of crustal fragments that form discontinuous belts; thus, continuous stratigraphic sequences are not likely to be found. This, combined with scarce fossiliferous localities and dense tropical vegetation, makes precise correlation difficult. Nevertheless, the available biostratigraphic data, together with the radiometric ages, allow restriction of the age of this complex to the Turonian-Maastrichtian interval (see Tables 1 and 2). The tectonic position of the Cordillera Occidental complex appears to have been achieved during the Cenozoic. Two new localities yielded macrofossil

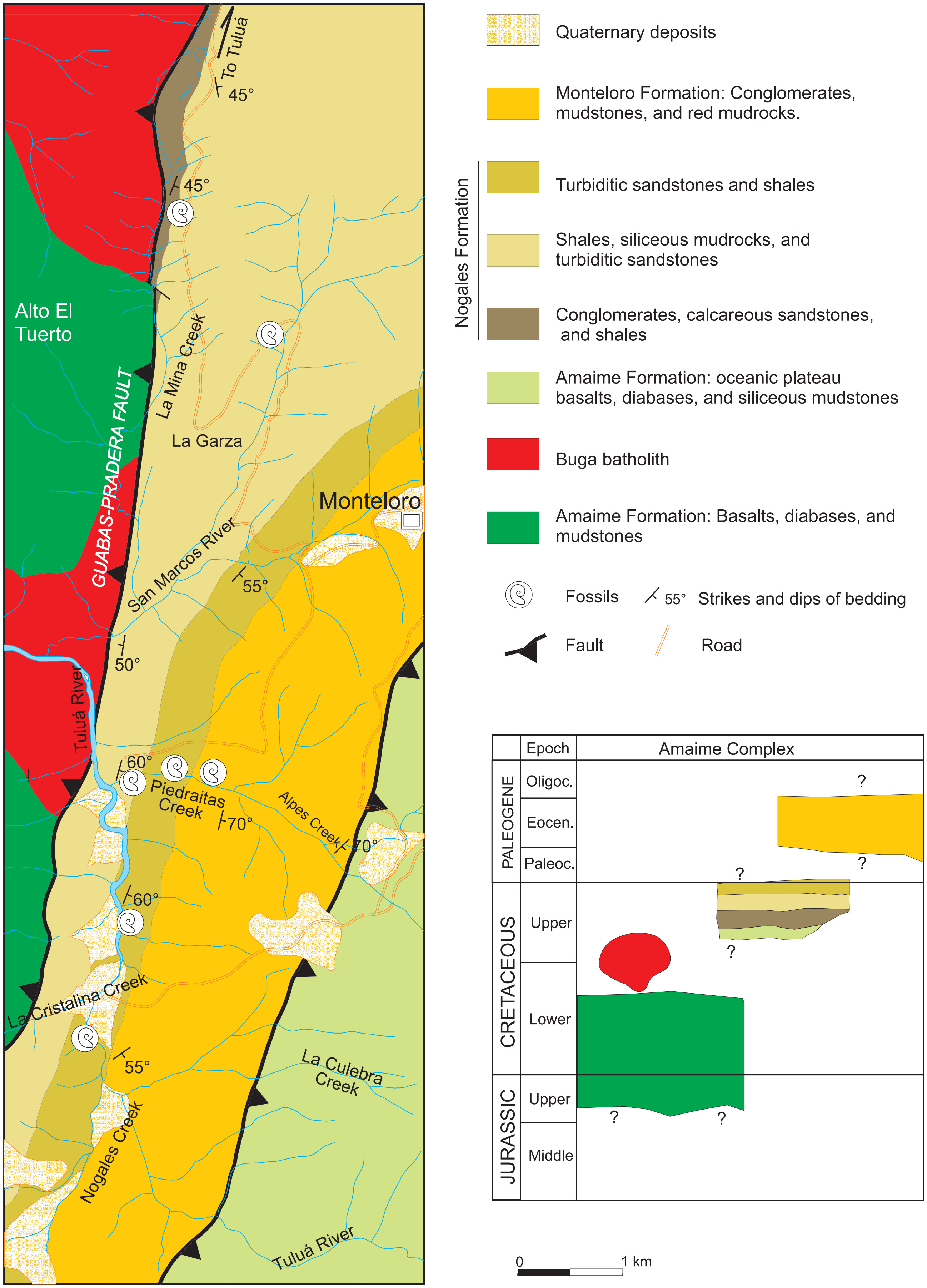
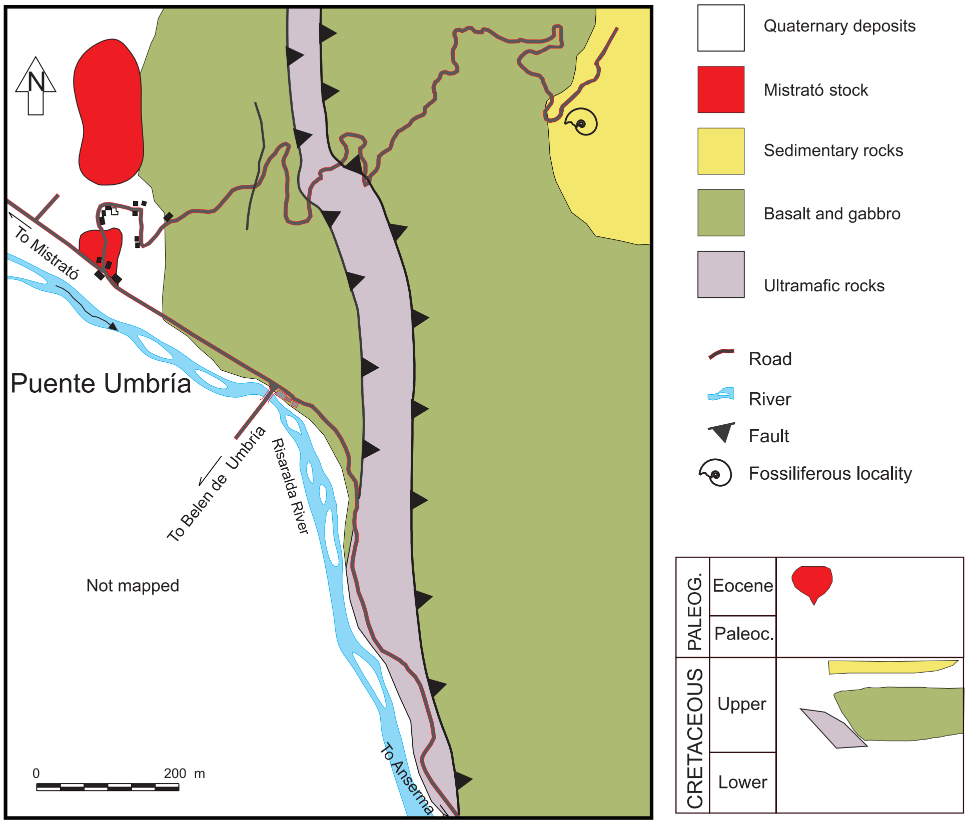

To Tuluá
45°
45°
Alto El
Tuerto
La Mina Creek
GUABAS-PRADERA FAULT
La Garza
Monteloro
San Marcos River
55°
50°
Tuluá River
60°
Piedraitas
Creek
70°
Alpes Creek
70°
60°
La Cristalina Creek
55°
La Culebra
Creek
Nogales Creek
Tuluá River
Quaternary deposits
Monteloro Formation: Conglomerates, mudstones, and red mudrocks.
Nogales Formation
Turbiditic sandstones and shales
Shales, siliceous mudrocks, and turbiditic sandstones
Conglomerates, calcareous sandstones, and shales
Amaime Formation: oceanic plateau basalts, diabases, and siliceous mudstones
Buga batholith
Amaime Formation: Basalts, diabases, and mudstones
Fossils
55° Strikes and dips of bedding
Fault
Road
Epoch
Amaime Complex
PALEOGENE
Oligoc.
Eocen.
Paleoc.
CRETACEOUS
Upper
Lower
JURASSIC
Upper
Middle
?
0
1 km

Figure 5. **Geological map of Puente Umbría sector (Cordillera Occidental complex) and chronostratigraphic chart. For locality, see Figure 2.**



remains, and a brief description of their geologic implication follows.

Belén de Umbria Region

The fossiliferous beds of Belén de Umbría represent the sole record of Late Cretaceous subaerial exposure of the oceanic basement of the CCCIP. This outcrop is remarkable because it differs from all the Cretaceous beds in the region, which are indicative of open-marine environments. These fossiliferous beds are located on the eastern flank of the Western Cordillera. They rest on an eroded igneous basic basement, implying emersion before, or simultaneous to, sediment deposition. To the west (see Figure 5), a narrow unit of deformed serpentinites (Ultramafitas de Puente Umbria–la Isla, Estrada and Viana, 1993) is exposed in a fault zone between 76 Ma K/Ar gabbros and basalts (Maya, 1992; Estrada, 1995). The gabbros have been intruded by the tonalitic Mistrató stock that yielded a 46 ± 7 Ma K/Ar age (Maya, 1992).

In the Belén de Umbría region, the sedimentary facies consist of sandy shales, laminated coarsening and fining-upward sandstones, muddy sandstones, and bioclastic matrix-supported conglomerates; the detrital components are volcanic rocks and chert. The coarse facies yields randomly distributed fragments of carbonized tree trunks, colonial corals, ammonites, fissurellid limpets, and gastropods. The fine-grained facies contains well-preserved leaf remains and articulated pelecypod casts (Moreno et al., 1993). Occurrence of the ammonite genus *Pachydiscus* (F. Etayo-Serna, personal communication, 1998) points to the Campanian-Maastrichtian interval.

The fossil remains are part of a thanatocoenosis comprising organisms originating in four coastal communities.

1) A well-established and diversified terrestrial community was present in coastal areas and provided the land-plant remains, leaves, tree trunks, fruits and seeds. Fine-grained sediments yield fossil leaves of the angiosperm form genus *Dicotylophyllum* sp., while conglomerates and sandstones enclose trunk remains.
2) Patella-fisurella and litorine gastropods adapted to a rocky substratum are derived from an intertidal community that, presumably, consists of partially emerged basic rocks subjected to coastal erosion. These organisms were dragged and mixed with the remains of other communities (during storms?).
3) Scleractinian corals and terebra-like gastropods were transported from a subtidal community; the corals were indicative of the occurrence of a hard substrate, and the gastropods of a soft, calcareous

Figure 4. **Geological map of Tuluá sector and chronostratigraphic relationship of the Upper Cretaceous–Paleogene sedimentary units of the Amaime-Chaucha complex. Modified from Pardo et al. (1993). For locality, see Figure 2.**

sandy bottom, as confirmed by the presence of bivalve diggers from the cardides group. These remains are often bioeroded, indicating long residence on a shallow bottom with low sedimentation rate. This last community dwelled beneath the level of tidal action and is suggestive of coastal tropical areas with clear water and absence of rapid sedimentation.

4) Finally, the open-sea environment is represented by the cosmopolitan cephalopods (*Pachydiscus* sp.) found in the finer-grained facies.

The variation in lithofacies prevents determination of the bathymetric position of the final deposit, but the biotic association suggests that deposition occurred under relatively shallow-marine conditions. The interpreted processes suggest mass flows, traction currents, and vertical settling. The absence of particles, indicative of a continental source (e.g., quartz, metamorphic rocks), is a petrographic characteristic that suggests an isolated oceanic basement (see, for example, Einsele, 1992, p. 413). Volcanic tuffs in the Barroso Formation (*sensu* Alvarez and González, 1978; included in the Cordillera Occidental complex of this work) in northwestern Antioquia have yielded possible coral remains (Hall et al., 1972, p. 57). Thus, the assemblage of plant remains and coral and mollusk debris indicate that some areas in the CCCIP had emerged during the Late Cretaceous, probably along an emerged rocky coast of an island covered with tropical vegetation.

Apia and Pueblo Rico Region

In this sector, the Cordillera Occidental complex exposure permits detailed observations. The lithology consists of a tectonic association of basalt lavas, volcanic-sedimentary, and sedimentary successions (Figure 6). The volcanic-sedimentary unit is made up of massive or pillowed basalts, crystallovitreous tuffs, lapillistones, breccias, and agglomerates interbedded with cherts, siliceous shales, sandstones, and conglomerates. Faulting and other deformation does not permit the establishment of a continuous stratigraphic succession in this area; nevertheless, in some outcrops, the textures and even the original structures still are visible. The conglomerates are matrix- and clast-supported and associated with feldspathic sandstones and siliceous shales in $T_{a\text{-}d}$ $T_{b\text{-}d}$ Bouma sequences. Slumped beds and synsedimentary faults suggest deposition on slopes. Matrix-supported conglomerates originated as submarine mass flows. The conglomerate components are intraformational clasts, felsic and volcanic basic rocks, and serpentinite clasts. Serpentinite debris has been mentioned in some places in the CCCIP Upper Cretaceous deposits (Duque-Caro, 1978; Etayo-Serna, 1989), and they suggest tectonic exposure of the lower crust of the oceanic plateau (see also Nivia, 1996; Kerr et al., 1998) or the action of serpentinite diapirs in an accretionary prism (e.g., Fryer et al., 1985).

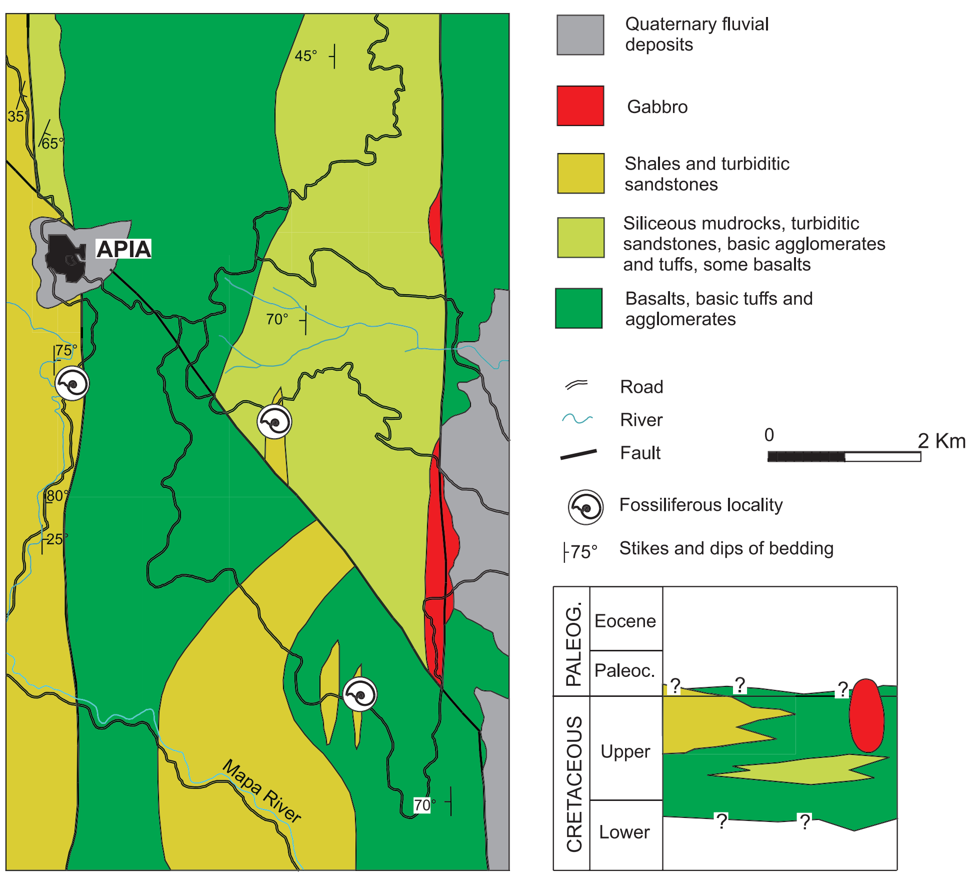


Figure 6. Geological map of Apía sector (Cordillera Occidental complex) and chronostratigraphic chart. Modified from Ossa and Pardo (1989). For locality, see Figure 2.

The sedimentary succession consists of laminated gray shales with some interbedded fine-grained turbiditic sandstones. The tectonic complexity makes it impossible to determine their original thickness. However, they can be followed for several kilometers along the western Cordillera as far as the department of Antioquia (Urrao Member of Alvarez and González, 1978). The whole sequence is interpreted to be deposited in a turbidite fan and abyssal plain. Fossil mollusks (*Pachydiscus* sp. and *Trochoceramus* sp.; F. Etayo-Serna, personal communication, 1998) and the foraminifer *Frondicularia mucronata* (J. I. Martínez, personal communication, 1999) of Campanian-Maastrichtian age were collected in these units.

Along the road between Apia–Pueblo Rico and San Antonio del Chamí, to the west, and outside the map area, outcropping strata of matrix-supported lithic conglomerates as much as 10 m thick and interbedded with laminated sandstones and shales and bioeroded molluscan remains (gastropods and oysters) suggest nearby emergent areas. The lithic clast types are siltstones, cherts (radiolarites), sandstones, tonalitic rocks (granophyres), quartzites, and phyllites. This association is similar to the current basement of the Central Cordillera (Amaime-Chaucha and Cajamarca complexes). Similar petrographic associations are described in Upper Cretaceous units of the department of Valle del Cauca by Etayo-Serna et al. (1982) and by Barrero (1979; Espinal Formation).

Increased conglomerate content toward the west is a characteristic pattern of this sector of the Western Cordillera (see Calle and González, 1980; Duque-Caro, 1990) that could be interpreted as a westward migration of the depositional axis at the end of the Cretaceous-Paleocene(?). We suggest that the conglomerates of Pueblo Rico and San Antonio del Chamí might be the remains of molasse wedges shed from the Central Cordillera uplift. Nevertheless, comparison and correlation with another sedimentary series require much better biostratigraphic control than presently available.

GEOLOGIC EVOLUTION

Based on the previously presented information and available geologic data, we present a geologic model for the evolution of western Colombia during the Late Jurassic–Miocene:

During the Jurassic, stretching of the continental lithosphere in the western region of Colombia produced red beds and volcanic sequences (Saldaña and La Quinta Formations and Girón Group) probably deposited in grabens that originated during an early phase of brittle extension. Continued rifting caused the generation of an Early Cretaceous Proto-Caribbean marine basement, separating blocks of the South American continental crust (Figure 7); e.g., Tahuín Terrane of Ecuador (El Oro Province), central Cuba,

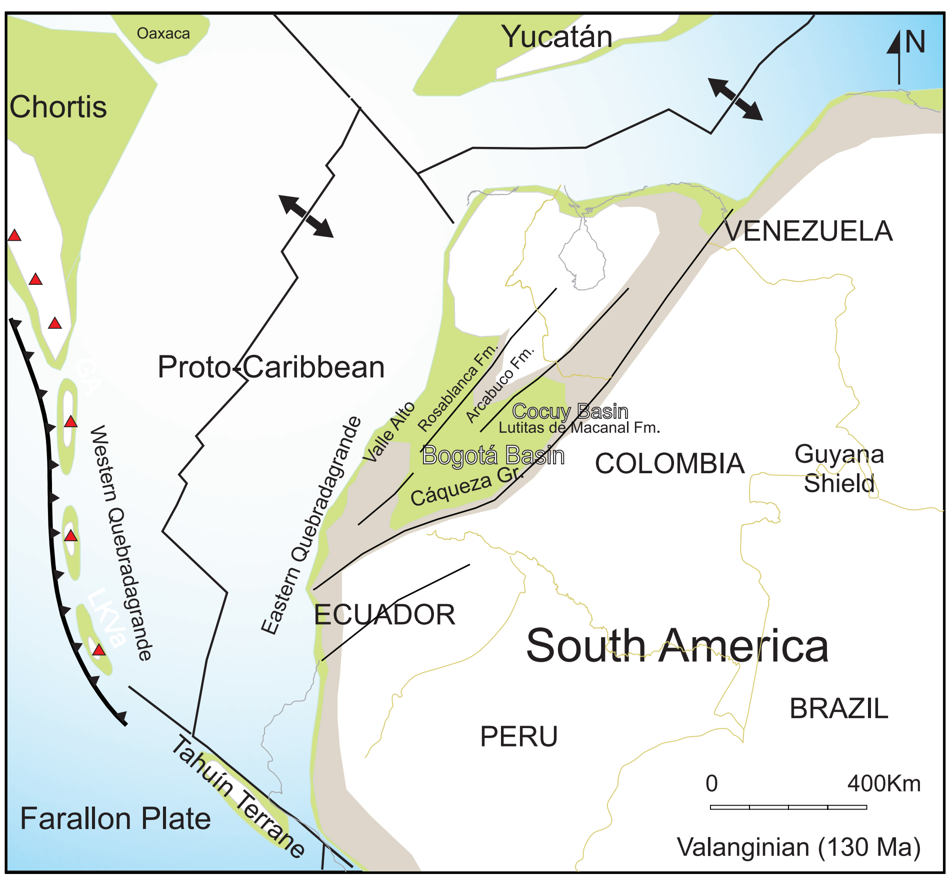


Figure 7. Valanginian (about 130 Ma) paleogeographic reconstruction of northwestern South America. LKVa = Lower Cretaceous volcanic arc; GA = Greater Antilles. Modified from the tectonic reconstructions of the Caribbean region of Pindell (www.fiu.edu/orgs/caribgeol/Caribreconstr.html). Movements are relative to the South American Plate.

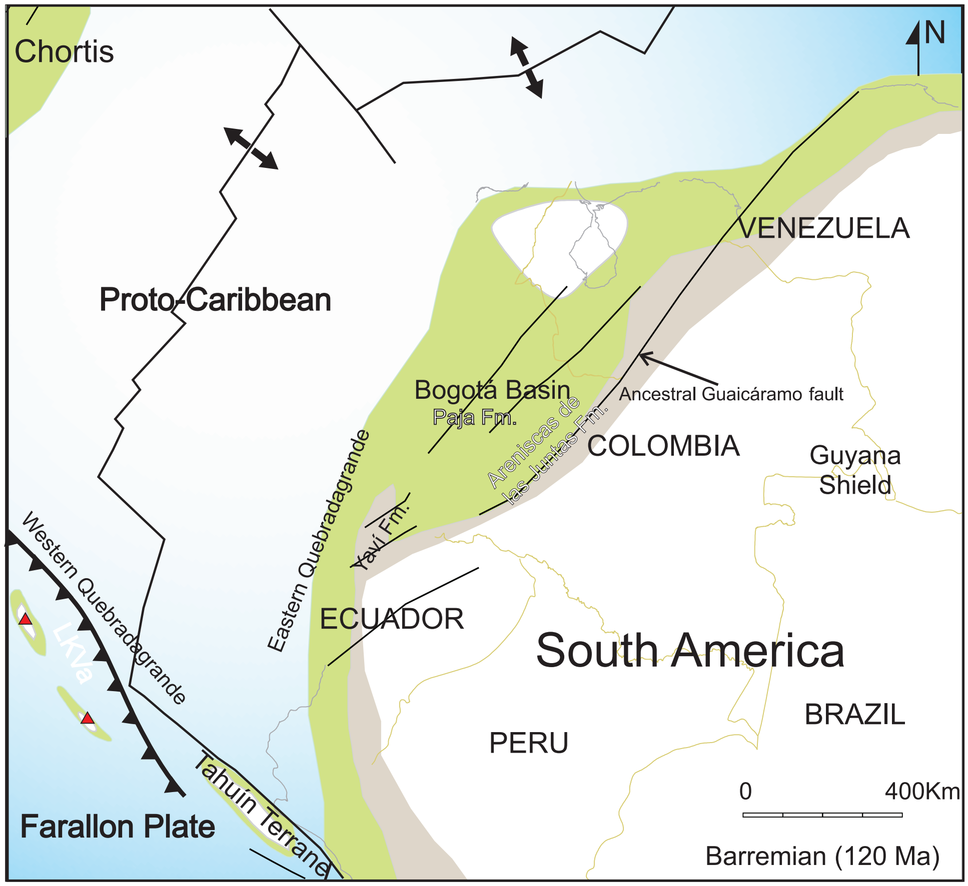


Figure 8. Barremian (about 120 Ma) paleogeographic reconstruction of northwestern South America. Abbreviations are as in Figure 7.

the Chortis Block, and Zapoteco Terrane (Oaxaca) of Mexico (see Sedlock et al., 1993). Eastward subduction of oceanic lithosphere (Farallon Plate) generated a magmatic arc on the western side of these blocks and southwestern Mexico and an island arc to the south (Greater Antilles and Lower Cretaceous volcanic arcs; Figure 7). Early Cretaceous arc plutons now are widespread throughout the Greater Antilles (Smith et al., 1998).

During the Berriasian-Albian, much of the continental eastern part of Colombia was affected by extension (Fabré, 1983a, b). The Bogotá Basin, limited to the east by the ancestral Guaicaramo fault, originated during this stage of tensional stress (Figures 7 and 8). A strong episode of subsidence and accumulation of thick shallow- (Cumbre and Rosablanca Formations) and moderately deep–marine sequences occur (Cáqueza Group and Murca Formation). Alkaline basic intrusive rocks were intruded throughout the continental crust during the final stage of extension (Fabré and Delaloye, 1983). Concomitant with oceanic spreading in the Proto-Caribbean, subsidence resulted in the deposition of deep-marine strata in association with basic volcanic rocks (Quebradagrande-Alao complex basement). Adjacent to the volcanic arc, volcanic-derived clastic sediments accumulated in the western side of the Proto-Caribbean marine basin (western sector of the Quebradagrande-Alao complex). To the east, mature quartz-bearing strata were deposited in marine and passive-continental margin environments distant from the magmatic arc (eastern sector of the Quebradagrande-Alao complex; e.g., Valle Alto Formation; Figures 7 and 8). Pelagic and hemipelagic deposits predominated in the central portion of this basin.

A polarity reversal in the volcanic arc occurred during the Barremian (± 120 Ma; Figure 8). A new subduction zone was initiated on the opposite side of the arc, causing subduction of the Proto-Caribbean ocean floor (a portion of the Atlantic ocean floor of Smith et al., 1998). Volcanic centers associated with this new subduction zone probably are preserved now as stocks and batholiths in the ophiolitic core of the Amaime-Chaucha and in the Arquía-Guamote complexes in Colombia (Buga batholith, Pueblito diorite, Cambumbia stock, and others). Jurassic(?)–Early Cretaceous Proto-Caribbean rocks were pervasively deformed, and some fragments may have been metamorphosed under blueschist or eclogite-facies conditions (now tectonically included in the Arquía-Guamote complex). This hypothesis is sustained by the coincidence of the radiometric ages of the Amaime-Chaucha complex intrusive rocks and the Arquía-Guamote complex metamorphites (Table 1).

Extension in the Bogotá Basin terminated in the Aptian when the volcanic arc started to close the Proto-Caribbean ocean basin. At the same time, a eustatic transgression in the Bogotá Basin took place (Etayo-Serna et al., 1976) with its maximum highstand in the Coniacian-Santonian interval (Fabré, 1983a). The approach of the volcanic arc and the Caribbean Plate (ancient Farallon Plate) to the northwestern corner

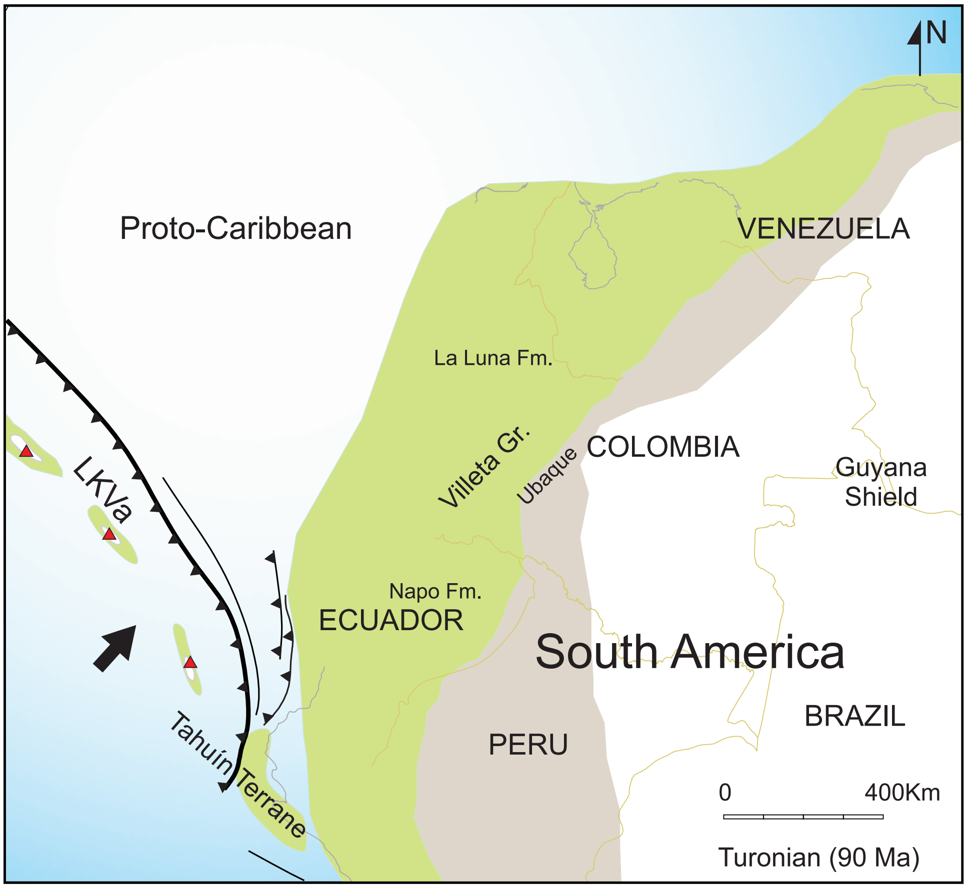


Figure 9. Turonian (about 90 Ma) paleogeographic reconstruction of northwestern South America. Abbreviations are as in Figure 7.

of South America was a diachronous response to right-oblique convergence (Pindell, 1993). This started in Ecuador during the Albian and continued through northwestern Colombia to the Campanian (Figures 9–11). The closing of the oceanic basin to the east of the volcanic arc caused overthrusting of sedimentary, basic volcanic, and ultrabasic rocks onto the metamorphic basement of the Central Cordillera and generated part of the tectonic mixture of rocks that constitutes the Quebradagrande-Alao complex (Appendix 1); this tectonic event may explain the absence of an Upper Cretaceous record in this complex (Figure 18). The accretion progressively destroyed the subduction zone and caused the arc volcanism to cease in this area (Figures 10–12). An outstanding feature of the present eastern Caribbean physiography is the Aves Ridge, which seems to be a continuation of the Amaime-Chaucha volcanic arc that did not collide with South America (Figures 11 and 12); its linear western border was part of the dextral system faults of the Caribbean Plate.

During the Campanian-Maastrichtian (75–65 Ma), some sectors of the Caribbean Plate emerged as vegetated islands associated with coral bioherms (see Belen de Umbría sedimentary rocks, Moreno et al., 1993). Moreover, hemipelagic and turbidite sedimentation was the dominant process (Apía sedimentary rocks and Urrao and Espinal units). In contrast, eastern Colombia was covered at the same time by quartzarenites, limestones, phosphorites, cherts, and shales deposited in a shallow-marine environment (Cimarrona and Umir Formation and Guadalupe Group; Figures 11 and 12). The absence of volcanic deposits precludes a nearby volcanic arc, as suggested in some alternative models (e.g., Barrero, 1979; Meschede and Frisch, 1998). The sedimentation was derived mainly from the Guyana shield, although the Cajamarca complex and its quartz-rich Lower Cretaceous sedimentary cover (e.g., San Luis Formation, and San Pablo, San Félix, and Valle Alto stratigraphic-tectonic intervals) were uplifted during overthrusting of the oceanic rocks and became a new source of clastic sediments. The metamorphic basement was eroded, but the bulk of sedimentation was caused by the erosion of the mature, coarse clastic cover that was then redeposited on the western border of the Bogotá Basin (La Tabla, Monserrate, and Cimarrona Formations).

During the late Campanian–Paleocene (70–60 Ma) interval, the north-northeastward translation of the Caribbean Plate produced dextral slip among the rocks of the Cajamarca, Quebradagrande-Alao, and Amaime-Chaucha complexes (Figures 11–13). The Arquía-Guamote complex reflects the tectonic mixture resulting from one of the most important transcurrent movements complex. This megashear extends to the metamorphic rocks on the western border of the Sierra Nevada de Santa Marta (see Santa Marta Terrane, Etayo-Serna et al., 1986). The younger radiometric ages obtained in the Santa Marta metamorphic rocks can be explained by the diachronism

Figure 10. Santonian (84 Ma) paleogeographic reconstruction of northwestern South America. Qg = Quebradagrande-Alao basement.

between the lateral displacement of the Caribbean Plate and its current position.

The presence of Late Cretaceous–Paleocene granitoids in the current Central Cordillera (e.g., Antioqueño and Sonson batholiths and Manizales stock, Ordoñez et al., 2001) could suggest that part of the unthickened Caribbean oceanic crust was subducted during this period. However, evidence for volcanic products does not exist in the contemporary deposits of the Magdalena Valley (La Tabla, Umir, Seca, Guaduas, and Lisama Formations). The composition of detrital sediments of the Nogales Formation (volcanic, metamorphic, and plutonic fragments) suggests that the metamorphic rocks of the Central Cordillera and part of the oceanic floor (Quebradagrande-Alao and Amaime-Chaucha complexes) were exposed to erosion starting in the Campanian (Figure 11). The presence of fine volcanic ash interbedded with the sediments indicates a recognizable phase of volcanism (Pardo et al., 1999; Grösser, 1989).

During the late Paleocene-Eocene (50 Ma), the Caribbean Plate began to move toward the east after the Greater Antilles volcanic arc (Cuba and Puerto Rico) started to collide with the Bahamas Platform in the north (Pindell and Barrett, 1990; Joyce, 1991; Pindell, 1993). During this period, part of the Caribbean oceanic plateau collided with the northwestern border of South America, increasing uplift of the Colombian Andes (Figures 13 and 14). It is remarkable that from the Paleocene until the present, the dextral lateral displacement of the Caribbean Plate in northern Colombia and Venezuela is similar to that which took place during the Turonian-Campanian on the northwestern border of Colombia (thrusting of oceanic basement and accretion of high-pressure metamorphic rocks; Figures 9–11). During the Paleocene-Eocene, the thrusting of the oceanic Caribbean floor started to uplift the Western Cordillera of Colombia. The uplifted blocks became new sources of sediments that generated sands and gravels with gabbro, basalt, sandstone, mudrocks, and chert fragments that accumulated in fluvial and coastal environments (Confites and Monteloro Formations of this work, Peña Morada and Chimborazo Formations; Figures 13 and 14; see also Van der Hammen, 1957, p. 123).

The outcroppings of the Colombian Central Cordillera and the Santander Massif(?) metamorphic basements during the Paleocene-Eocene are evidenced by the first appearance of metamorphic clasts

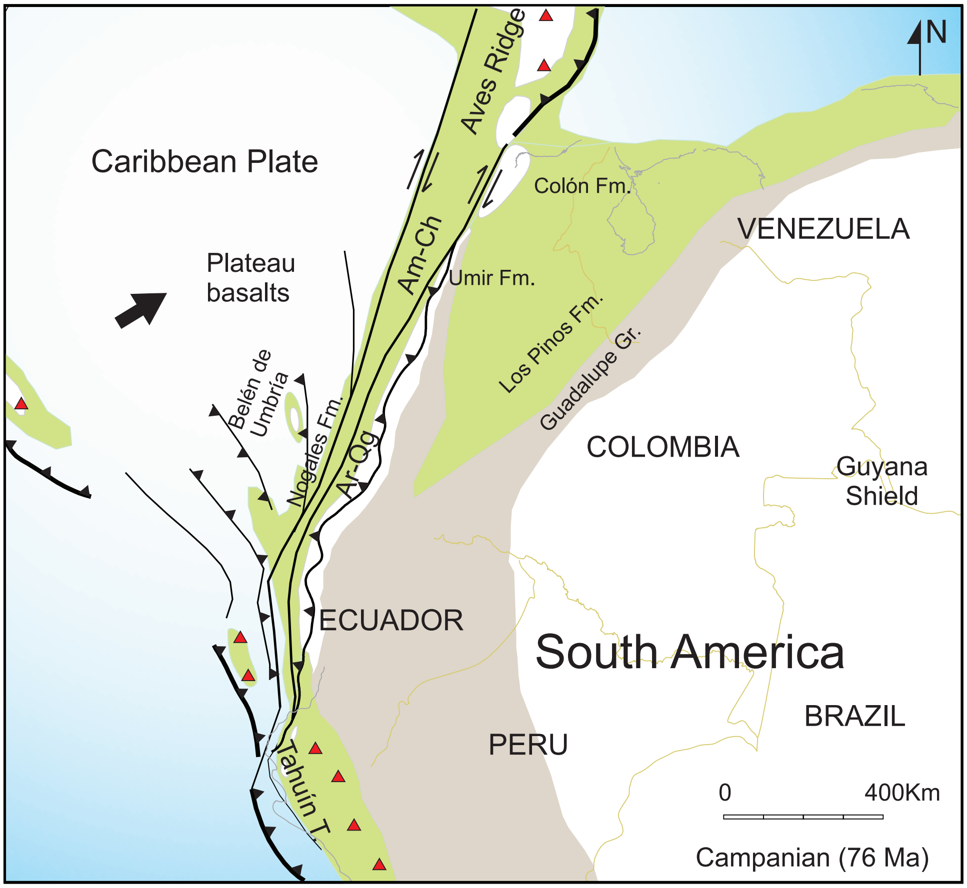


Figure 11. Campanian (about 76 Ma) paleogeographic reconstruction of northwestern South America. Am-Ch = Amaime-Chaucha basement; Ar-Qg = Arquía-Guamote and Quebradagrande-Alao basements.

in the Middle Magdalena Valley and the Cocuy Basin sandstones (Lisama and Arcilla de Socha Formations; Hanton and Espejo, 1997; Fabré, 1983b; Gómez, 2001). Minor folding of the Cretaceous units produced erosion in a great part of the anticlines, but the sedimentation continued in the synclines (Julivert, 1961). It is probable that some faults of the present Llanos border exercised tectonic control on the sedimentation (Cooper et al., 1995), but Jaramillo and Dilcher (2000, 2001) suggest continuous sedimentation. During the Paleocene-Eocene, volcanism and plutonism took place in northern Colombia (e.g., Santa Marta batholith, Mandé batholith) in contrast with their absence from the central part of Colombia, probably because of the obstruction to subduction caused by arrival of the thick Caribbean plateau (Figures 13 and 14).

During the Eocene-Oligocene interval, thrust fronts to the west of the Magdalena Valley (Butler and Schamel, 1988) produced thick accumulation of sediments in eastern Colombia (e.g., the Gualanday Group; Figures 14 and 15) as a consequence of the strong compressive tectonic activity associated with a change in direction and increasing convergence between the Caribbean and South American Plates (Pindell, 1993). Simultaneously, coastal and terrestrial clastic deposits started to accumulate to the west of the Central Cordillera (e.g., Amagá, Cartago, and Guachinte Formations; Figure 15). The local presence of reefal carbonates (upper Eocene–lower Oligocene Vijes Formation, Camargo and Pardo, 2001) suggests communication with the open sea and the absence of significant relief in the Western Cordillera. Volcanic deposits occur in northern Colombia and Ecuador, but they are absent in western central Colombia. This suggests that the oceanic plateau obstructed subduction, even in this area.

In the middle Miocene, subduction of the Nazca Plate began to the west of the Chocó complex (Figure 16). It is now documented in the intermediate volcanics of the Combia and La Paila Formations in the Cauca Valley (proximal volcanic deposits) and the Cira Formation and the Honda and Real Groups in the Magdalena Valley (distal volcanic deposits; see Van Houten, 1976). This volcanic activity started in the Western Cordillera and migrated progressively toward the east until reaching its current position in the axis of the Central Cordillera (Toussaint and

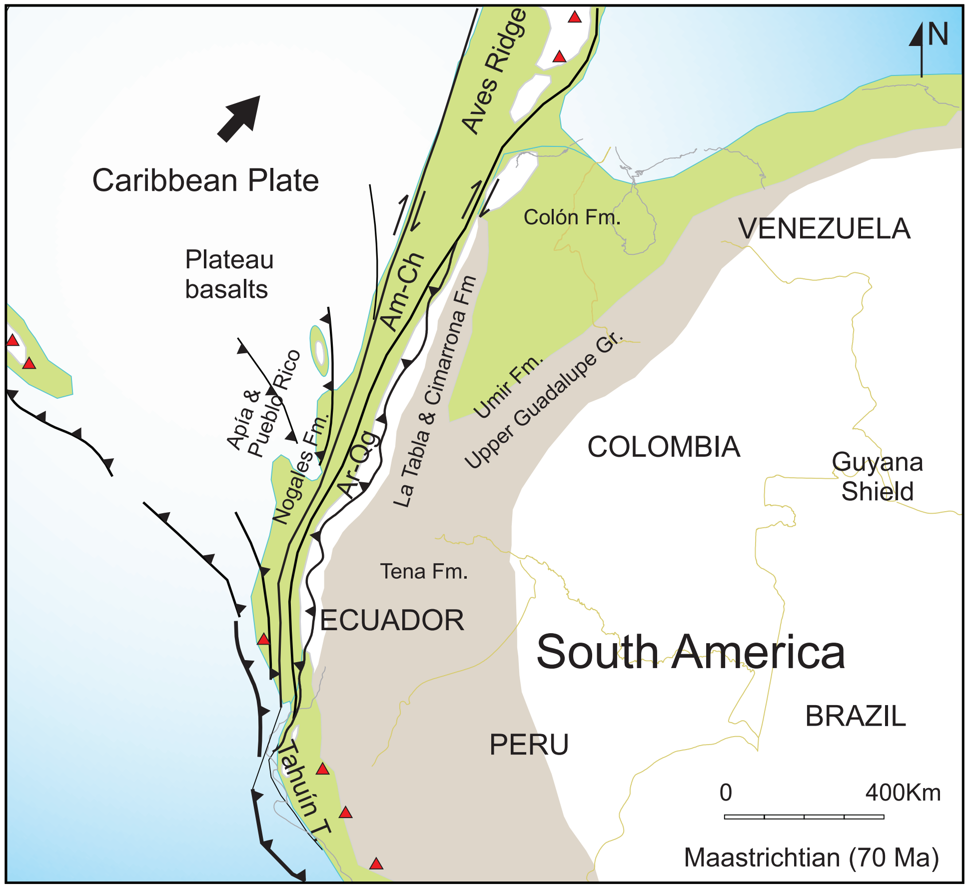


Figure 12. Maastrichtian (about 70 Ma) paleogeographic reconstruction of northwestern South America. Abbreviations are as in Figure 11.

Restrepo, 1993). During this period, the Guaicaramo-Boconó Fault started to move as a dextral slip-and-thrust system (Figure 16). At the end of the Miocene, the uplift of the Eastern Cordillera isolated the Magdalena Basin from the Amazonas and Llanos Basins (Van Houten and Travis, 1968; Hoorn et al., 1995).

During the Pliocene, the collision of the Panamá-Chocó complex basement with the northwestern border of South America produced the uplift of the isthmus of Panamá and the Colombian Serranía del Baudo (Duque-Caro, 1990; Toussaint, 1996). This is in agreement with the faunal data (''great American interchange'' of Marshall et al., 1979) and floral (Hooghiemstra, 1984) migration dates from South America and North America. This tectonic event also generated the biggest uplift in the Oriental, Central, and Occidental Cordilleras of Colombia, which presently remain below the elevation of 3000 m (Van der Hammen, 1957; Kroonenberg et al., 1990).

In conclusion, the geological evolution of western Colombian Cretaceous-Tertiary rocks can be divided into the following phases:

1) Late Jurassic–Albian extensional phase that originated the Proto-Caribbean oceanic crust between the Central and North American terranes and South America; a subduction zone generated a volcanic arc to the west of the Proto-Caribbean. During this period, the continental border of Colombia was a passive margin.
2) Albian-Paleocene oblique dextral slip phase of the Caribbean Plate in relation to the South American Plate. This also originated thrusting of oceanic materials over the metamorphic basement of the current Central Cordillera (Quebradagrande-Alao complex). This event can be considered the first northern Andean orogenic uplift.
3) Paleocene-Miocene frontal accretional phase of the Caribbean Plate in northwestern South American that caused the first uplift of some sectors of the Eastern and Western Cordilleras of Colombia. At this time, the northwestern border of Colombia became an active margin.
4) Miocene accretion phase of the Panamá-Chocó complex basement against the Western Cordillera, which originated the present Andean mountain ranges. The subduction of the Nazca Plate in the west produced intermediate volcanism that progressively migrated to the east and to its current position.

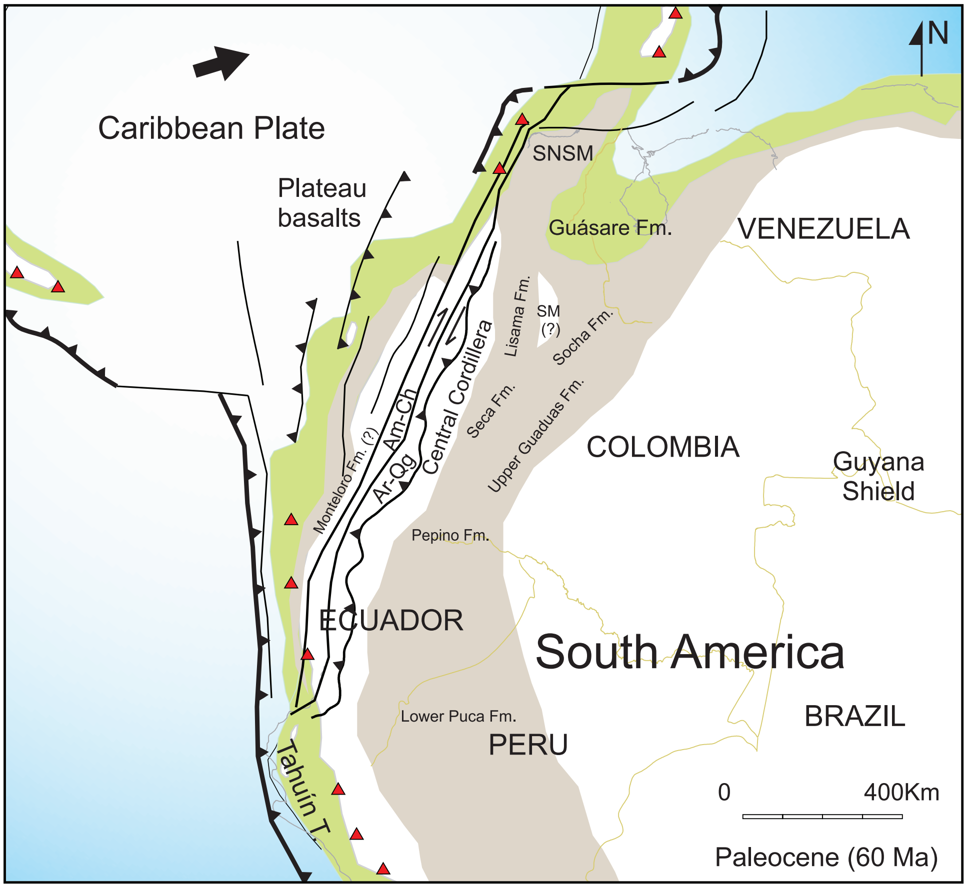


Figure 13. Paleocene (about 60 Ma) paleogeographic reconstruction of northwestern South America. Ar-Qg = Arquia-Guamote and Quebradagrande-Alao basements; Am-Ch = Amaime-Chaucha basements; SNSM = Sierra Nevada de Santa Marta; SM = Santander Massif.

DISCUSSION

Biostratigraphic and radiometric information constrains the subdivision of different portions of western Colombia's oceanic rocks. The hypothesis of progressive accretion of discrete portions of Caribbean-type basalts in western Colombia fits well with a Pacific origin of the Caribbean Plate (Pindell et al., 1988; Kerr et al., 1997a). Models of the evolution of western Colombia (e.g., Barrero, 1979; McCourt et al., 1984a; Aspden and McCourt, 1986b; Cooper et al., 1995; Meschede and Frisch, 1998; White et al., 1999) consider Cretaceous western Colombia as an active margin with a magmatic arc related to the present Central Cordillera. McCourt et al. (1984a , p. 837), in their Cretaceous reconstruction of Western Colombia, interpreted the Amaime Group and the Quebradagrande Formation as an autochthonous volcanic arc; this interpretation is not supported by new geological data. The Amaime rocks are related to the history of the CCCIP, and Quebradagrande Formation volcanism originated in an oceanic basement (this work). Additionally, the absence of plutonics and tephra in the Cretaceous deposits to the east of the Central Cordillera discard an autochthonous volcanism; thus, the hypothesis of allochthony of the volcanic rocks of the western flank of the Central Cordillera is coherent with geological evidence.

Geochemical analyses show that the basaltic rocks of the Cordillera Occidental, the Panamá-Chocó, and part of the Amaime-Chauca complexes originated in an oceanic plateau, in contrast with the volcanic-arc influence of the Quebradagrande-Alao complex (Nivia et al., 1996; Kerr et al., 1997a). Nivia (1993) grouped the assemblage of Amaime-Chaucha and Cordillera Occidental complexes into the Provincia Litosférica Oceánica Cretácica Occidental (PLOCO) and believes that it was unnecessary to separate these complexes because they have similar plateau-type basaltic geochemistry. However , we distinguish two complexes within PLOCO, taking into consideration the presence of basalts and ultramafic rocks intruded by Early Cretaceous plutonic rocks restricted to the western border of the Central Cordillera–Cauca Valley (Amaime-Chaucha complex), which could represent an older oceanic basement and portions of a dismembered volcanic arc(?). A. Nivia (personal communication, 2001) suggests that some of these plutonic rocks, such as the Buga and Sabanalarga batholiths, were formed by magmatic differentiation in lower levels

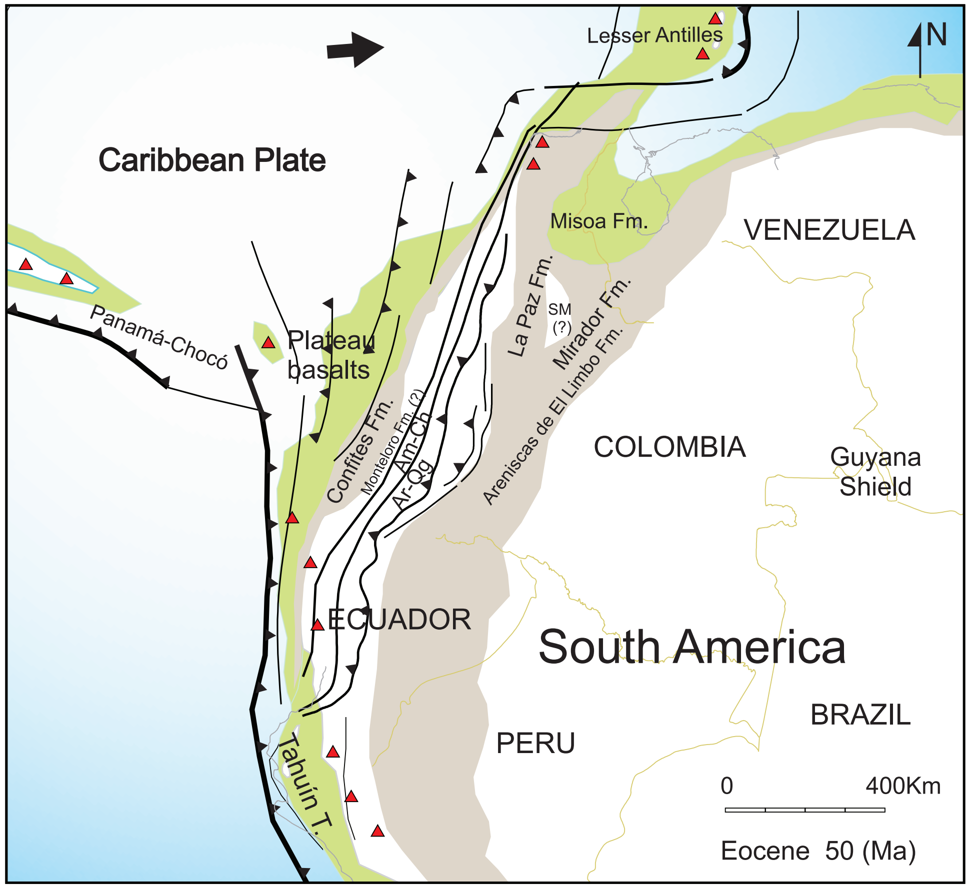


Figure 14. Middle Eocene (about 50 Ma) paleogeographic reconstruction of northwestern South America. Abbreviations are as in Figure 13.

of the thick oceanic Caribbean Plateau. Without new geochemical data, this problem still is pending, but we think that the presence of Early Cretaceous granitoids intruding in both Amaime-Chaucha basalts (e.g., Buga batholith, Irra stock, and Támesis pluton) and Arquia-Alao metamorphic rocks (e.g., Pueblito diorite and Cordoba igneous complex) could suggest an arc-related magmatism. These rocks could be correlated with the Leeward Antilles batholiths (e.g., Aruba batholith), about which geochemical interpretation still is controversial (White et al., 1999). Geochemical studies in the granitoids and their associated basalts are necessary to demonstrate their geological setting. It is noteworthy that among the basalts studied by Kerr et al. (1997a), only one (Sample AMA-12) is intruded by the Buga batholith, but its geochemical pattern is remarkably different from the dominant "plateau-type" samples. On the other hand, the presence of proximal volcanic-arc deposits in the Quebradagrande-Alao complex undoubtedly indicates occurrence of an arc during the Early Cretaceous to the southwest of the Proto-Caribbean (considered here as the southern prolongation of the Greater Antilles Volcanic Arc of Pindell, 1993). Nevertheless, if the absence of volcanic-arc-type rocks in the Amaime complex is demonstrated, it means that the arc that produced the volcanic deposits in the Quebradagrande-Alao complex was displaced farther to the north, as we suggest in this paper.

Based on the radiometric ages of the Greatest Antilles calc-alkaline granites, some authors (e.g., Pindell, 1993) suggest a Late Jurassic–Barremian east-deepening subduction zone on the western side of the Lower Cretaceous volcanic arc (LKVa; Figure 7 and 8) that reversed polarity at 120 Ma as a consequence of the arrival of a thick oceanic crust (see http://www.ig.utexas.edu/CaribPlate/reports/IGCP_433_report_2002_part1.pdf; IGCP project 433 reports for discussion). The geological data of western Colombia support an Early Cretaceous (120 Ma) west-deepening subduction plate on the eastern side of the Quebradagrande complex; this hypothesis is supported by several pieces of evidence: a Cretaceous granitoid belt in the Amaime-Chaucha and Arquia-Guamote complexes; occurrence of Lower Cretaceous eclogites and blue schist (Table 1) to the east of the Amaime Chaucha complex; and bipolarity in the petrographic composition of the Quebradagrande complex (considered here as remains of the Proto-Caribbean plate), suggesting a passive continental margin to the east and volcanic-arc influence to the

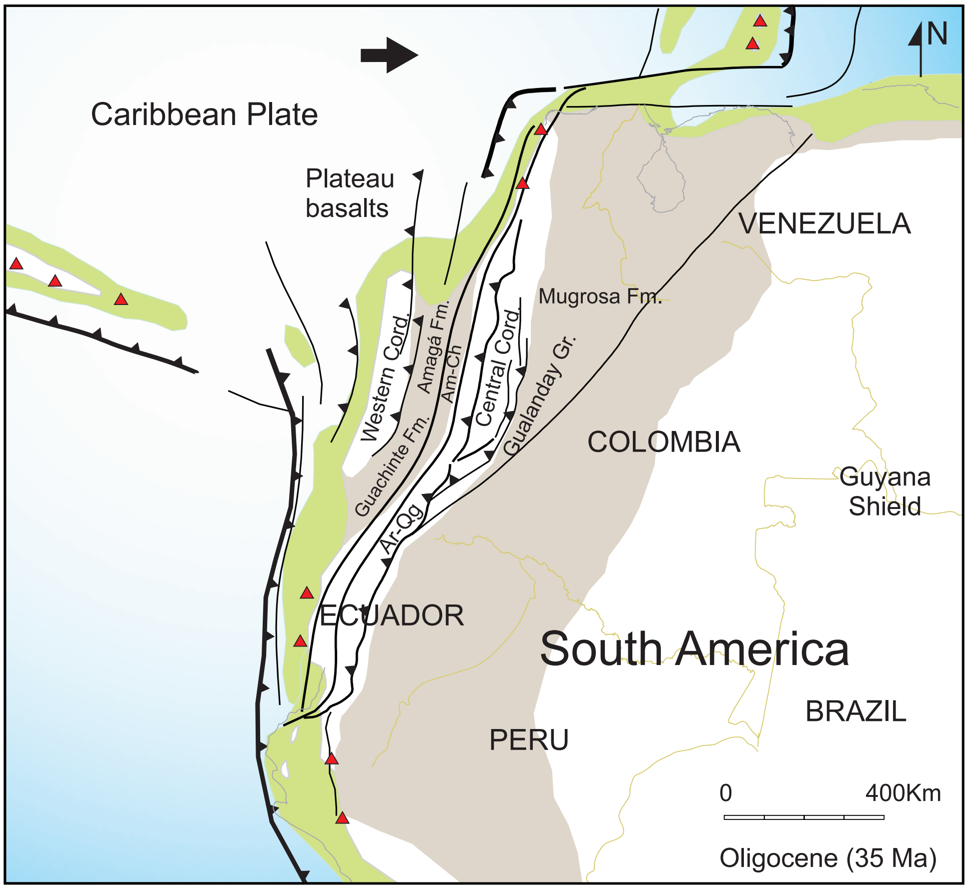


Figure 15. Early Oligocene (about 35 Ma) paleogeographic reconstruction of northwestern South America. Abbreviations are as in Figure 11.

west (see above). Additionally, in a recent tomographic section across the northern Andes, an ancient west-dipping plate is suggested (FaP of Taboada et al., 2000, p. 791), which can be interpreted as remains of the Early Cretaceous subducting Proto-Caribbean Plate.

The available biostratigraphic data and new information presented here allow us now to distinguish an Upper Jurassic(?)–Early Cretaceous Quebradagrande-Alao complex from the Late Cretaceous Cordillera Occidental and Panamá-Chocó complexes (Figure 18). In contrast, the Arquía-Guamote complex is considered to be part of a Paleozoic paired metamorphic belt (McCourt et al., 1984a; Nivia et al., 1996). This age is based only on the relationship between the Amagá and Santa Barbara Triassic plutons that apparently intruded the Arquía-Guamote metamorphic rocks. However, almost all the radiometric dates obtained from the high-pressure metamorphic rocks of the Arquía-Guamote complex give a narrow range of Early Cretaceous dates (Table 1; Figures 17 and 18), which seems to point to the age of the principal metamorphic event. We propose here that the Amagá pluton could be a window or a detached wedge of the Cajamarca complex (Figure 3), which is a sensible hypothesis if we consider this complex to be a mega-shear zone. On the other hand, a reexamination of the mapped Santa Barbara batholith (McCourt et al., 1984a) is necessary because most of the radiometric ages appear to be Early Cenozoic (Table 1; Figure 17). In addition, it is difficult to accept that the fault that separates the Cajamarca from Arquía-Guamote complexes in this area (named Romeral Fault by McCourt et al., 1984a, or Falla de San Jerónimo of McCourt et al., 1985) cut without offset the Triassic Santa Barbara batholith but affects the Cretaceous Quebradagrande and Tertiary igneous rocks (McCourt et al., 1985).

The model presented is intended as a synthesis of all the available information about the evolution of western Colombia. Nevertheless, the scarcity of biostratigraphic and radiometric data, combined with the structural complexity and lithologic resemblance between diachronous units, require additional multidisciplinary research that will permit more detailed reconstruction for particular periods of time.

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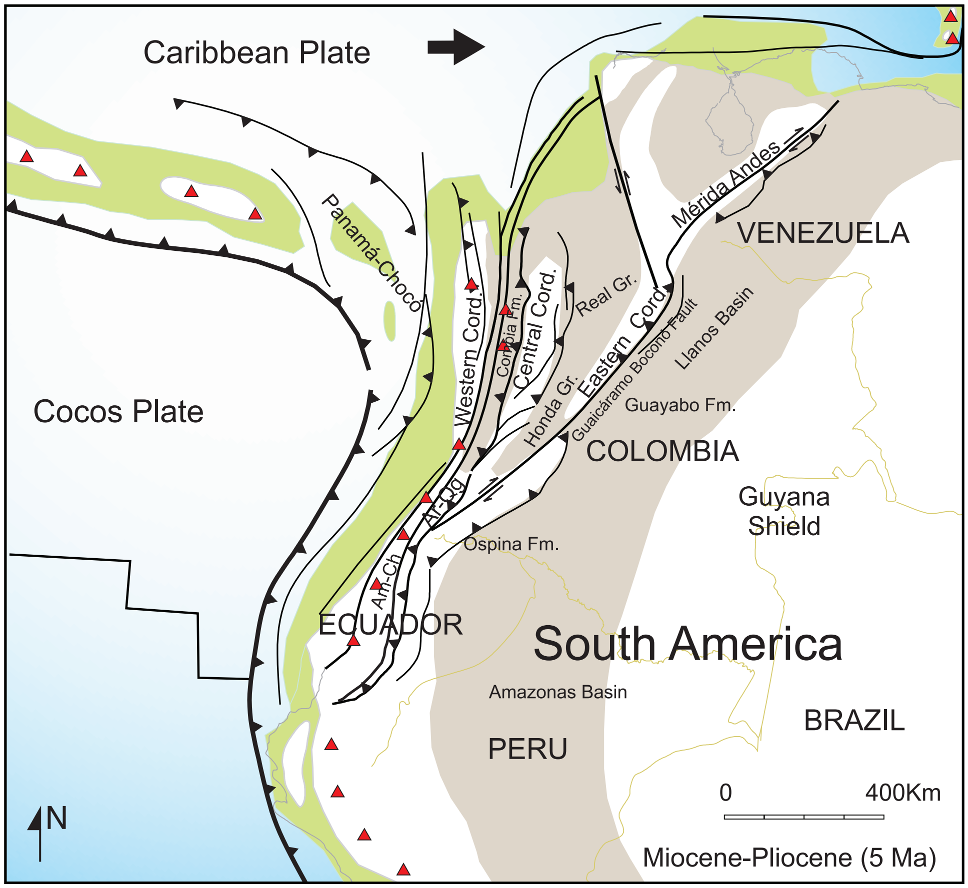

Figure 16. Late Miocene (about 5 Ma) paleogeographic reconstruction of northwestern South America. Abbreviations are as in Figure 11.

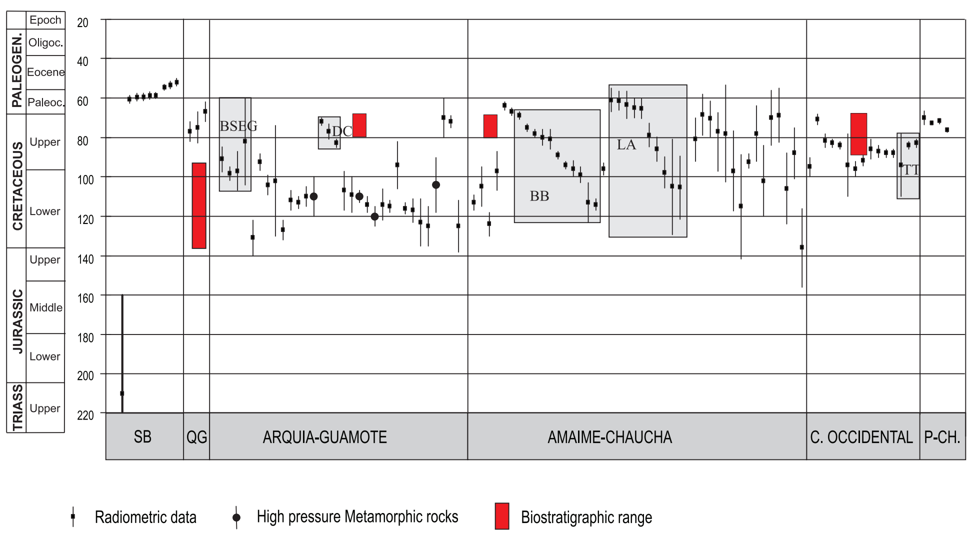

Figure 17. Radiometric and paleontologic ages of western Colombia complexes. Abbreviations: BSEG = Buriticá, Sabanalarga, and Ebéjico granitoids; DC = Córdoba diorite; BB = Buga batholith; LA = Los Azules ophiolitic complex; TT = Tambor tonalite; SB = Santa Bárbara stock data; QG = Quebradagrande-Alao complex; P-CH = Panamá-Chocó complex.

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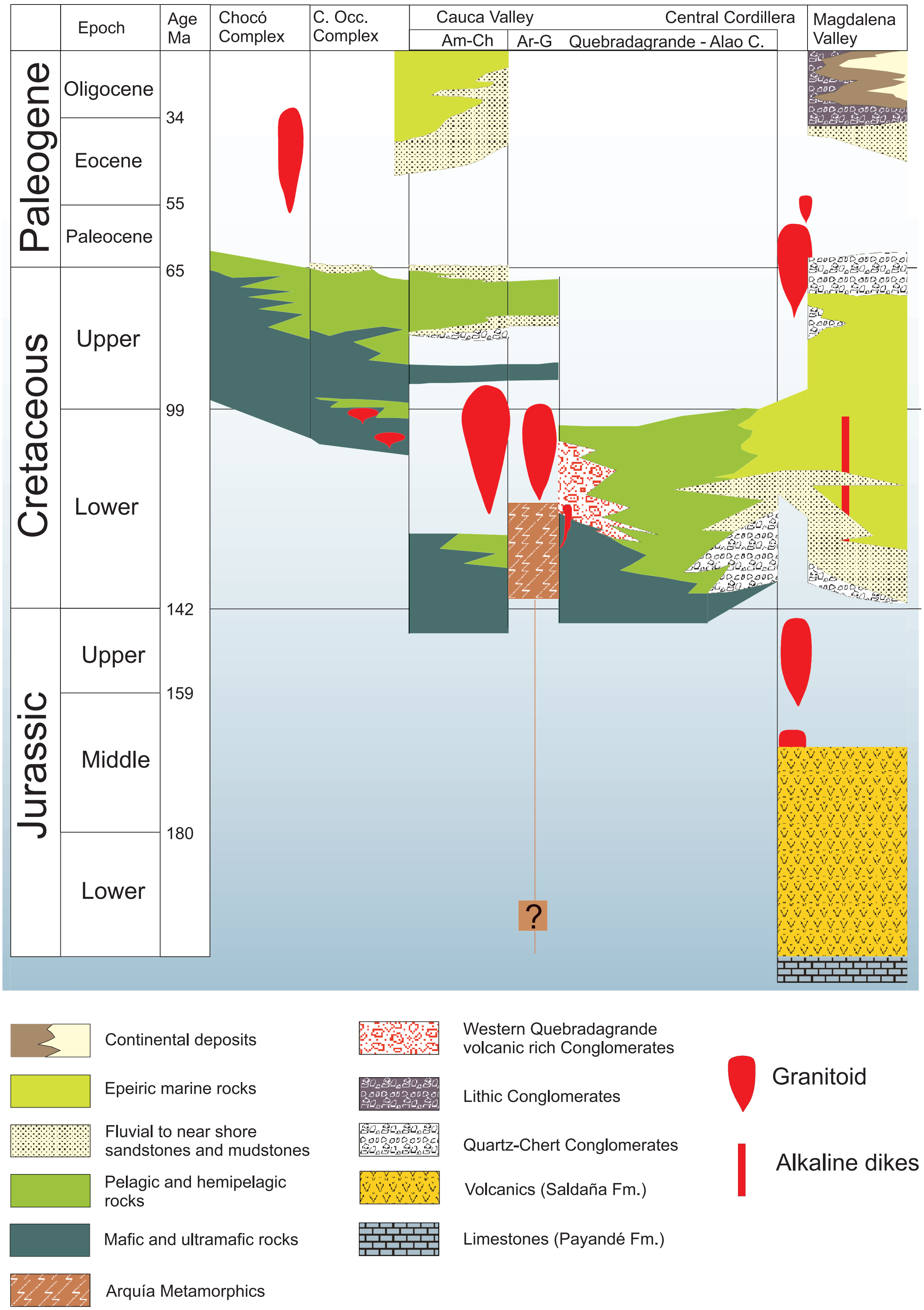
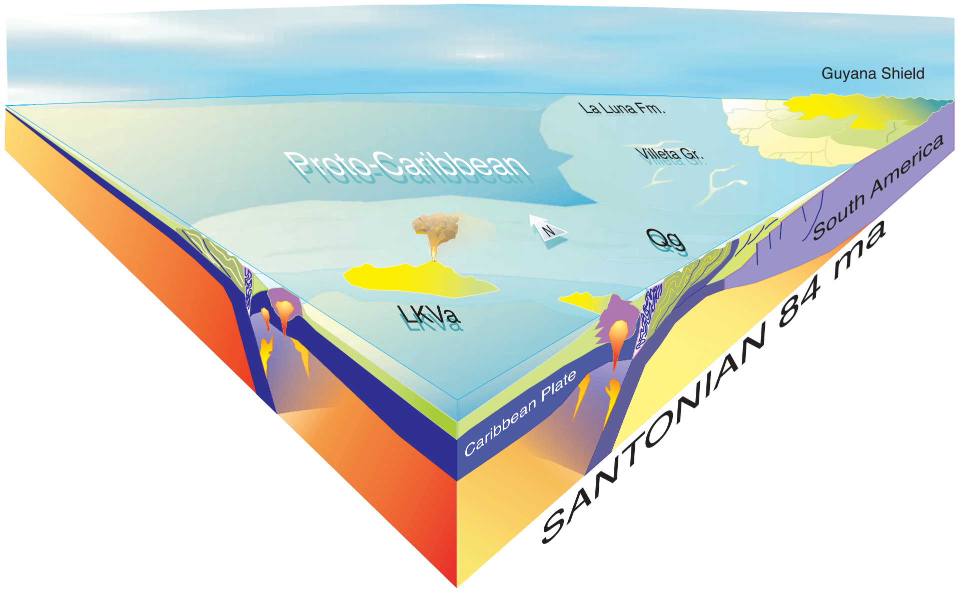


Figure 18. Chronostratigraphic chart of western Colombian complexes and eastern Colombia.



APPENDIX 1

Santonian (84 Ma) three-dimensional paleogeographic reconstruction of northwestern South America. Abbreviations are as in Figure 10.

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