A Middle Mesozoic Oceanic Terrane in the Central Cordillera of Western Colombia

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RESUMEN

Un terreno sospechoso existe a lo largo del flanco occidental de la Cordillera Central en los Andes Colombianos. Está constituido por piso oceánico, material de una dorsal (?), del Jurásico o de comienzos del Cretácico, que fue acrecentado al margen continental hace 125-130 m.a. a lo largo de la falla de Romeral.

ABSTRACT

A suspect terrane exists along the western flank of the Central Cordillera in the Colombian Andes. It consists of ocean floor, (?)ridge material, of Jurassic or lowermost Cretaceous age that was accreted onto the continental edge some 125-130 m y ago along the Romeral Fault.

INTRODUCTION

Thick sequences of Upper Mesozoic oceanic basalts are found throughout western Colombia. These rocks can be divided into two major units which occur in the Pacific Coastal Range (the Serranía de Baudó), and the Western Cordillera respectively (fig. 1). The former corresponds to part of the Basic Igneous Complex of GOOSSENS *et al.* (1977) and the latter sequence, the Diabase Group of NELSON (1957), extends eastwards to include similar rocks which are exposed along the western edge of the Central Cordillera. Subsequent workers in western Colombia (BARRERO, 1979; PARIS & MARIN, 1979; MILLWARD *et al.* 1984) have accepted Nelson's correlation and the assumption implicit in it, namely that the basalts of the Western and Central Cordilleras are the contemporaneous products of a single volcanotectonic cycle. INGEOMINAS (1983), however, separated the Western and Central Cordilleran basalt sequences structurally, although still considering them to be essentially coeval, placing them in the Dagua and río Cauca - Romeral terranes respectively.

Following the completion of a 4-years geological mapping project in central western Colombia, McCOURT & ASPDEN (1983) and McCOURT *et al.* (1984) suggested that the basaltic rocks of the Western and Central Cordilleras were of different ages and that they represented two distinct periods of accretion. The Western Cordillera oceanic sequence, which includes not only basalts but also tuffs and volcanoclastic rocks together with interbedded sedimentary and metasedimentary rocks, is dominantly Upper Cretaceous Turonian - Maestrichtian, in age

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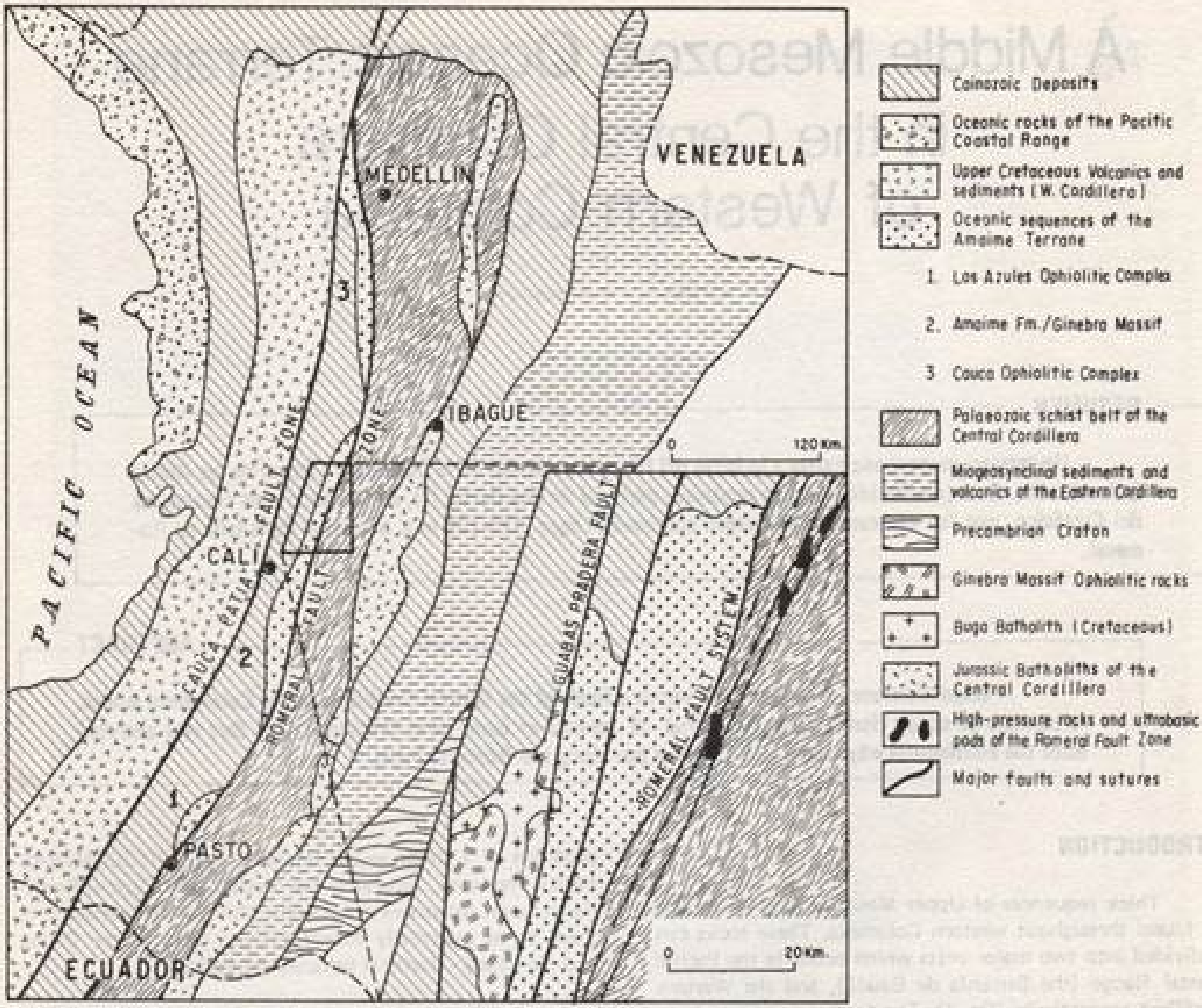

FIG. 1: Simplified geologic map illustrating the principal orogenic belts/terranes of western Colombia. The inset map shows the geologic details of the western flank of the Central Cordillera in SW Colombia. Modified, from ARANGO *et al.* (1976); ASPDEN (1984); McCOURT (1984).

(ALVAREZ, 1983; ASPDEN 1984). Based on regional considerations McCOURT *et al.* (1984) argued that the Western Cordillera, together with its southern extension in Ecuador, in unlikely to contain rocks which are older than 120 m y (cf. HOWELL *et al.* 1983) and that it represents an allochthonous terrane which was accreted between 60 - 65 m y ago, from the SW, onto the continental edge along the line of the Cauca Patía Fault (fig. 1). In contrast the basalts of the Central Cordillera, the Amaime Formation, have been shown to be older (McCOURT, 1984). This paper discusses the geology of these rocks, that of the Ginebra Ophiolitic Massif, and an associated suite of high pressure metamorphic. These rocks, together with similar sequences from elsewhere in Colombia, form a narrow, dicontinuous belt that can be traced for approximately 600 km (fig. 1). The available evidence indicates that this belt of oceanic rocks, here named the Amaime terrane, represents the remnants of a Jurassic-lowermost Cretaceous orogenic accretionary cycle that ended approximately 125-130 m y ago.

AMAIME FORMATION

The Amaime Formation consists of a suite of basic volcanic rocks composed largely of massive tholeiites with extensive horizons of pillow lavas and local komatiitic basalts (ESPINOSA,1982, pers. com.). The formation crops out along the western edge of the Central Cordillera where it occurs as a narrow, elongate, NW-SE orientated belt up to 20 km wide and 200 km in length. The eastern limit of the formation corresponds to a major regional fault zone, the Romeral Fault, and this also defines the western limit of the Paleozoic metamorphic rocks that make up the bulk of the Central Cordillera. In general, the western limit of the Amaime Formation is hidden beneath the younger Tertiary and Quaternary deposits of the Cauca Valley (graben), but locally it is defined by the Guabas - Pradera Fault (fig. 1).

The Amaime basalts are typically aphyric, and hyaline to holocrystalline. Small phenocrysts of pyroxene are common in the microcrystalline varieties and, with plagioclase, form subophitic textures. The clinopyroxenes are generally fresh augite and show only minor marginal uralitization, however labradorite is commonly extensively saussuritized. Phenocrysts generally form less than 5% (modal) of the rock and in some porphyritic samples olivine, completely pseudomorphed by serpentine minerals, is present.

The Amaime Formation basalts have a restricted compositional range (Table 1). They are characterized by low K_2O and other LIL elements (K_2O <0.22%, Rb 2-3 ppm, Ba 20-54 ppm, Th < 1 ppm) and they have SiO_2 values of between 49 - 52.5 % Fe^*/Mg (Fe^*, total Fe expressed as Fe^{2+}) varies between 1 - 1.5. The positive correlation of Fe^*/Mg with Fe^*, the presence of normative hypersthene, and the position of the Amaime basalts on a standard AFM plot confirms their tholeiitic character.

Chrondrite-normalized REE plots range from LREE depleted to LREE enriched, with LaN/YbN ratios of 0.85 - 1.35, absolute abundances 9-27 times chrondrites, and Eu anomalies are absent (McCOURT, 1984). Detailed comparison of the minor and trace element chemistry of these rocks with average tholeiite basalts from various tectonic environments (figs. 2, 3) suggest a strong affinity to transitional mid-ocean basalts (T-MORB) (SUN *et al*, 1979; TARNEY *et al.* 1979; WOOD *et al.* 1979).

TABLE 1. SELECTED ANALYSES AMAIME FORMATION

SiO_2	50.50	50.20	49.20	49.20	50.50
TiO_2	1.04	0.93	1.39	1.70	1.08
Al_2O_3	14.20	13.60	13.80	12.70	14.40
Fe_2O_3	10.15	10.14	12.05	11.70	10.24
MnO	0.17	0.18	0.20	0.18	0.17
MgO	8.91	8.95	7.35	7.79	8.50
CaO	11.82	13.61	10.28	10.57	13.98
Na_2O	1.91	1.55	3.38	2.84	1.65
K_2O	0.21	0.05	0.16	0.11	0.18
P_2O_5	0.09	0.08	0.11	0.14	0.09
TOTAL	98.97	99.32	97.86	96.95	99.96
Trace elements (ppm)					
Ni	144	139	94	96	140
Cr	444	443	210	206	140
V	283	277	345	326	289
Rb	3	2	2	2	2
Sr	141	80	104	141	102
Y	18	15	25	21	18
Zr	53	48	71	94	55
Hf	1.32	1.23	1.95	2.55	1.48
Nb	6	5	5	11	5
Ta	0.30	0.26	0.28	0.73	0.30
Ba	35	18	29	50	53
La	3.44	2.79	3.22	8.94	3.71
Ce	9.41	7.61	9.57	21.02	9.38
Nd	6.44	5.73	8.67	14.09	7.33
Sm	2.08	1.85	2.85	3.67	2.20
Eu	0.75	0.70	1.04	1.26	0.81
Gd	2.62	2.33	3.63	4.08	2.75
Tb	0.46	0.43	0.68	0.68	0.52
Tm	0.32	0.29	0.49	0.35	0.34
Yb	1.68	1.68	2.55	2.05	1.85
Lu	0.26	0.28	0.41	0.31	0.31
Th	0.41	0.36	0.33	0.93	0.40

GINEBRA OPHIOLITIC MASSIF

The Ginebra Ophiolitic Massif consist of a sequence of peridotites, layered and cumulate, gabbros, diabase dykes, metabasalts and plagiogranites (ESPINOSA, it litt). Ultrabasic and basic rocks are exposed mainly in the south and from the base upwards they consist of dunite cumulates, wehrlite cumulates, and norite gabbros. Primary magmatic layering is well displayed, especially in the cumulate rocks,

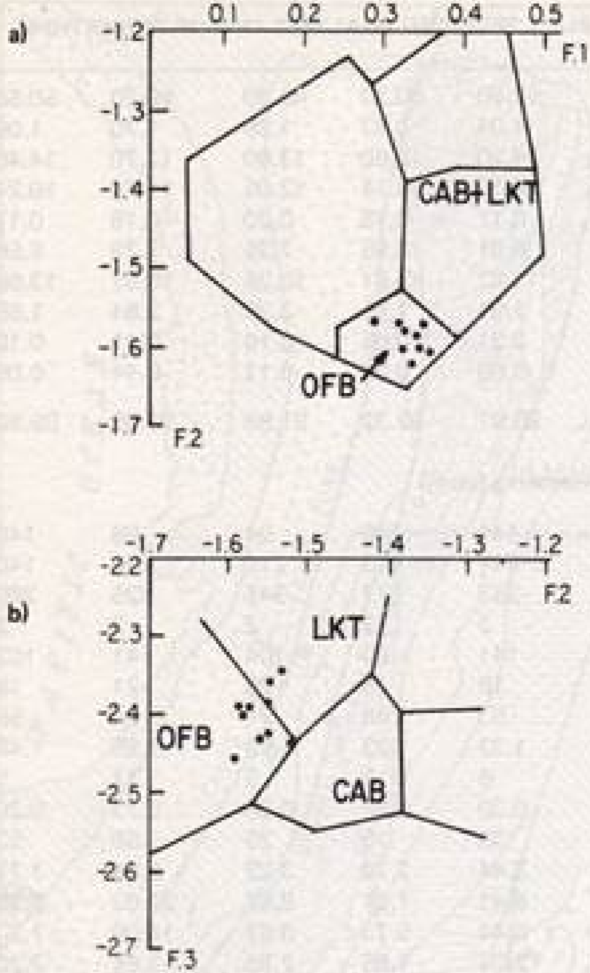

FIG. 2a/2b: Discriminant function diagrams (PEARCE, 1976) for the Amaime Formation basalts. OFB equals ocean floor basalts; CAB equals calc-alkaline basalts; LKT equals low-K tholeiites.

$F1 = 0.0088SiO_2 - 0.0774TiO_2 + 0.0102\ Al_2O_3 + 0.0066FeO - 0.0017MgO - 0.143CaO - 0.0155Na_2O - 0.0007K_2O$

$F2 = -0.013SiO_2 - 0.0185TiO_2 - 0.0129Al_2O_3 - 0.0134FeO - 0.03MgO - 0.0204CaO - 0.0481Na_2O + 0.0715K_2O$

$F3 = 0.0221SiO - 0.0532TiO - 0.0361Al_2O_3 - 0.0016FeO - 0.031MgO - 0.0237CaO - 0.0614Na_2O - 0.0289K_2O$.

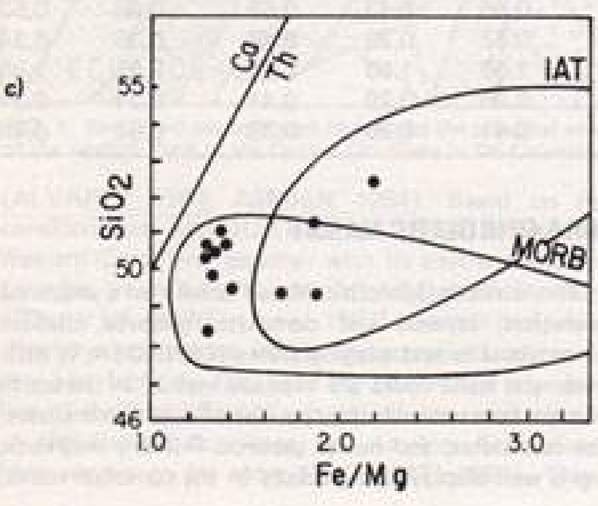

FIG. 2c: SiO_2 vs Fe^*/Mg for the Amaime Formation basalts. Ca-Th line represents the boundary between calc-alkaline and tholeiitic fields; MORB is the field of mid-ocean ridge basalts; IAT is the field of island arc tholeiites. Fe^* equals total iron expressed as FeO (Fe^{2+}).

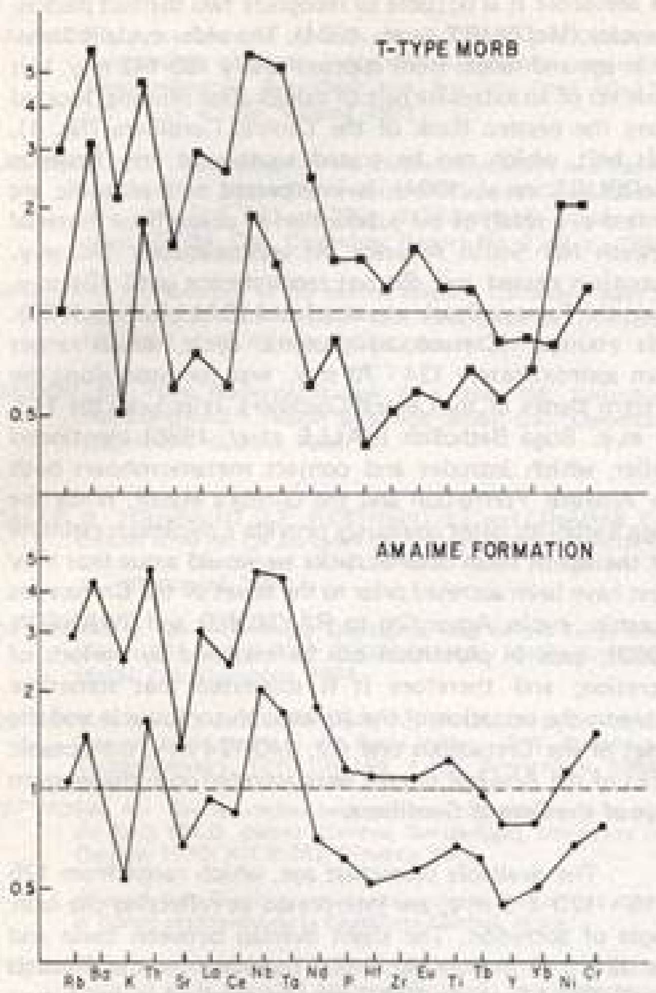

FIG. 3: Multi-element minor and trace element diagrams for T-type MORB basalts compared to the Amaime Formation basalts, normalized to N-type MORB (SAUNDERS and TARNEY, 1984).

and is emphasized by preferential weathering of the olivine rich units. The contact between the ultrabasic rocks and the norite gabbros is gradational where exposed. Dykes of diabase and veins of plagiogranitic material are common in the gabbroic unit. Metabasalts (the amphibolites of ESPINOSA, 1984) are by far the most common rock type and these enclose the ultrabasic/basic units in apparent structural conformity. The metabasalts are interpreted as representing a lower level within the Amaime Formation and the high temperature and cumulate metamorphism (ESPINOSA, 1983, pers. comm.) to be the result of contact metamorphism due to the intrusion of the Buga Batholith along the Guabas-Pradera Fault (fig.1). Similar amphibolites are also locally developed in the Amaime Formation along its contact with this intrusion (DE ARMAS, 1984).

REGIONAL CORRELATION AND AGE

The Ginebra Massif and the Amaime Formation together with correlative rocks of similar composition that occur elsewhere in the Central Cordillera make up the Amaime terrane (fig. 1). In particular they include the Cauca Ophiolitic Complex to the North and the Los Azules Ophiolitic complex to the south (RESTREPO and TOUSSAINT, 1975; ESPINOSA, 1980, 1984).

The basic to ultrabasic composition of the Amaime terrane and the generally high level of tectonism suffered by these rocks makes them difficult to date by direct means. Both the Amaime and Ginebra sequences are however intruded and contact metamorphosed by the calc-alkaline Buga Batholit from which TOUSSAINT *et al.* (1978) have reported a K/Ar (biot.) age of 113 ± 10 m.y. More recent studies, using Rb/Sr (hbl/biot.), indicate a minimum intrusive age of 99±4 m y with younger mineral age reflecting later tectonic movements (BROOK, 1984).

A K/Ar date of 126 ± 12 m.y. from a gabbro of the Cauca Ophiolitic Complex (TOUSSAINT and RESTREPO, 1975) together with the fact that these rocks are structurally overlain by sediments which contain Barremian fossils also indicates a minimum lower Cretaceous age for the complex is considered here to represent a partially reset age, reflecting later tectonism.

HIGH PRESSURE METAMORPHIC ROCKS

High pressure rocks consisting of lawsonite-glaucophane schists, eclogites, and eclogitic amphibolites are present in the Central Cordillera, close to the main trace of the Romeral Fault. They occur within a narrow, well defined, NNE trending, elongate belt some 5-10 km east of the main Romeral Fault. The belt has a minimum strike length of 50 km and the high pressure rocks occur as isolated, discontinuous, faultbounded blocks within Paleozoic graphitic schists.

Lawsonite - glaucophane - pumpellyite - albite - sericite - quartz schists are found in the area around Barragan (McCOURT and FEININGER, 1984). The presence of this mineral assemblage indicates that metamorphism took place at high pressure and low temperature in the lawsonite-albite facies under estimated P-T conditions of 325 ± 50° and 6.5 ± 2.5 Kbars (WINKLER, 1979).

The eclogites occur in intimate association with highly tectonized and serpentinized ultrabasic rocks. Omphacite, its composition confirmed by microprobe analysis, occurs as ragged grains that are partly destroyed by retrograde metamorphism and surrounded by kelphytic rims of epidote, amphibole, chlorite, and (?)plagioclase. The garnets are weakly zoned almandines with more than 25% grossular. Relative to the cores the rims are enriched in pyrope and depleted in spessartine. The amphiboles are subcalcic, alumino-edenitic hornblendes with 3.2 - 3.4 % Na_2O (FEININGER, 1983, pers. comm.). Using the geothermometers of PERCHUK (1969) and RAHEIM and GREEN (1974) the P-T conditions of formation for the eclogites are estimated at 530° ± 40°C and 8 ± 3 Kbars.

Similar associations of high pressure rocks are known from elsewhere in the Central Cordillera. They have been described from the Jambaló and Tacueyó areas to the south, in the Department of Cauca, where they are also spatially associated with the Romeral Fault (ORREGO *et al*, 1980; FEININGER, 1980, 1982; MURCIA & GONZALEZ, 1982). Radiometric K/Ar determination of the Barragan and Jambaló rocks give ages of 120 ± 5 m.y. and 125± 15 m.y respectively (BROOK, 1984; ORREGO *et al*, 1980).

DISCUSSION

The Amaime Formation and Ginebra Massif are interpreted to be a fragment of an ophiolite. The limited geochemical evidence suggests that the Amaime basalts have a T-MORB type chemistry, and these, together with the metabasalts of the Ginebra Massif, are considered to represented layer 2 of the ocean crust. The gabbros and ultramafic rocks of the Ginebra Massif could equate to layer 3 and the fault contact between the Ginebra and Amaime sequences is probably the result of syn or post emplacement tectonism. In the field the easter limit of these rocks corresponds to the principal fault of the Romeral Fault system but the presence of a discontinous belt of high pressure rocks (blueschists) within the fault zone (cf. FEININGER, 1982) leads to the conclusion that the accretion of the oceanic Amaime and Ginebra sequences probably took place along this line.

According to the episodic accretion and plutonism model of RAYMOND and SWANSON (1980), in orogenic settings, plutonism alternates with accretion. We believe that a similar model can also be used to explain the Mesozoic evolution of the Central Cordillera. In Colombia during the Mesozoic it is possible to recognize two distinct plutonic cycles (McCOURT *et al.*, 1984). The older cycle is Jurassic in age and ranges from approximately 185-142 m y. It is made up of an extensive belt of calcalkaline plutons, located along the eastern flank of the Central Cordillera (fig. 1). This belt, which can be traced southward into Ecuador (McCOURT *et al*, 1984), is interpreted as a plutonic arc formed as a result of the subduction of ocean floor material beneath NW South America. At approximately 140 m.y. plutonism ceased and did not recommence until 124 m.y. when the Tamesis Stock was emplaced (CALLE *et al*, 1980). This younger (Cretaceous) plutonic cycle, which ranges from approximately 124 - 70 m.y., was focussed along the western flanks of the Central Cordillera. It includes the 113-99 m.y. Buga Batholith (CALLE *et al*, 1980) mentioned earlier, which intrudes and contact metamorphoses both the Amaime Formation and the Ginebra Massif. While the Buga Batholith dates obviously provide a minimum estimate for the age of these oceanic rocks we would argue that they must have been accreted prior to the onset of the Cretaceous plutonic cycle. According to RAYMOND and SWANSON (1980), gaps in plutonism can be matched by periods of accretion; and therefore it is suggested that sometime between the cessation of the Jurassic plutonic cycle and the onset of the Cretaceous one (*i.e.* 140-124 m y, the oceanic rocks of the Amaime terrane were accreted onto the western edge of the Central Cordillera.

The available blueschist age, which range from 125 ± 15 - 120 ± 5 m y, are interpreted as reflecting the later stages of accretion. The slight overlap between these and the 124 ± 6 m y (K/Ar, hbl.) reported for the Tamesis Stock (CALLE *et al.*, 1980) may be resolved in the future by more detailed geochronology. At the moment, however, we believe that sufficient evidence exists to conclude that the Amaime terrane cannot have been formed before approximately 130-125 m y and it seems likely that it may represent a portion of the Jurassic ocean floor, the subduction of which gave rise to a plutonic, cal-alkaline arc throughout much of NW South America.

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