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$^{40}Ar/^{39}Ar$ ages from blueschists of the Jambaló region, Central Cordillera of Colombia: implications on the styles of accretion in the Northern Andes

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ABSTRACT

This paper presents the first argon dating of blueschists from the Jambaló area (Cauca Department) in the Central Cordillera of the Colombian Andes. Step-heating $^{40}Ar/^{39}Ar$ spectra were obtained for mica from several lenses of blueschists including greenschist facies rocks. The blueschists are mainly constituted of preserved lenticular cores in strongly mylonitic rocks, which resulted from retrometamorphic processes that affected the high pressure rocks during their exhumation. The majority of $^{40}Ar/^{39}Ar$ data points to metamorphic ages close to 63±3Ma, but some ages are older than 71Ma. These Maastritchtian–Danian ages correspond to the timing of exhumation of the blueschists near metamorphic peak conditions, because the dated paragonite and phengite crystallized during development of the mylonitic foliation. The continuous exhumation of this blueschist belt between 71–63Ma reflects the flow on an accretionary system/subduction channel environment that was interrupted by the collision of an intra-oceanic arc with the continental margin. Regional geological correlations suggest that this arc–continent collision also took place in Ecuador. This collisional event, although synchronous with other arc–continent collisions in the Northern Andes, was apparently not related to the formation of the great Caribbean arc, but to an arc built in the southeastern margin of the Caribbean plate.

KEYWORDS **Blueschists. Colombian Andes. Jambaló area. $^{40}Ar/^{39}Ar$ geochronology.**

INTRODUCTION

Because blueschist facies rocks are associated with convergent limits of tectonic plates (Bowes, 1989), metamorphic and deformational events registered in the blueschists may reveal the type of subduction and the characteristics of the collisional and exhumation regimes (Ernst, 1988; Smith et al., 1999). Usually these high-pressure and low-temperature rocks record the P–T variations with time, which can reflect the complex exhumation processes associated with either subduction or collisional events or with later transpressive regimes (Cloos, 1982). Consequently, the identification and characterization of blueschists in the geological record can provide insights on the nature and timing of the convergence zones that characterize the terranes in which they occur (Draper and Lewis, 1991; Avé-Lallemant, 1996).

The Meso-Cenozoic orogeny in the Northern Andes, especially in Ecuador, Colombia and Caribbean, is characterized by a series of island arc and plateau collisions against the South American continental margin, accompanied by subduction and tectonic imbrication of slices of oceanic crust, either in the continental margin or intra-oceanic domains (Kerr et al., 1997, 2002; Luzieux et al., 2006). These processes resulted in obduction of ophiolitic complexes, Barrovian metamorphic belts, high-pressure metamorphic rock units, and in the amalgamation and strong interaction of several tectonic terranes (Ramos, 1999; Ramos and Aleman, 2000; Kerr et al., 1997, 2002; Giunta et al., 2002). Some suture zones, such as those recognized in Colombia (González, 1977; Chicangana, 2005), are marked by the occurrence of tectonic slices of blueschist-facies metamorphic rocks, which have been considered as late Cretaceous in age (Orrego et al., 1980a; De Souza et al., 1984). The origin of these blueschists has been related to oceanic subduction, accretion or collision of an oceanic plate coming from northwest and reaching the South American plate (Feininger, 1980; Aspden and McCourt, 1986; Mégard, 1987; Bourgois et al., 1987; Aspden et al., 1995). In order to test such possibilities, the detailed petrotectonic evolution and the ages of the different Mesozoic Barrovian and high-pressure metamorphic belts in western Colombia should be established by means of detailed geochronologic dating. In this contribution new Ar–Ar data are presented for white mica of the blueschists of the Jambaló region, in the western flank of the Central Cordillera of the Colombian Andes.

GEOLOGICAL SETTING

In Colombia, the Andean Cordillera is divided into three mountain ranges, the Eastern, Central and Western Cordilleras (Fig. 1), which underwent different tectonic and geologic histories. The Eastern Cordillera is composed mainly of a Paleozoic to Tertiary thick sedimentary sequence (Restrepo and Toussaint, 1982; Forero-Suárez, 1991). The Western Cordillera is made up of oceanic volcanic sequences accreted since Cretaceous times, whereas the Central Cordillera comprises a polymetamorphic complex associated with syn-tectonic granitoids, with K-Ar ages varying between Paleozoic to Cretaceous (Restrepo and Toussaint, 1982, 1988; Restrepo, 1986). Well defined blueschist occurrences have been recognized in the

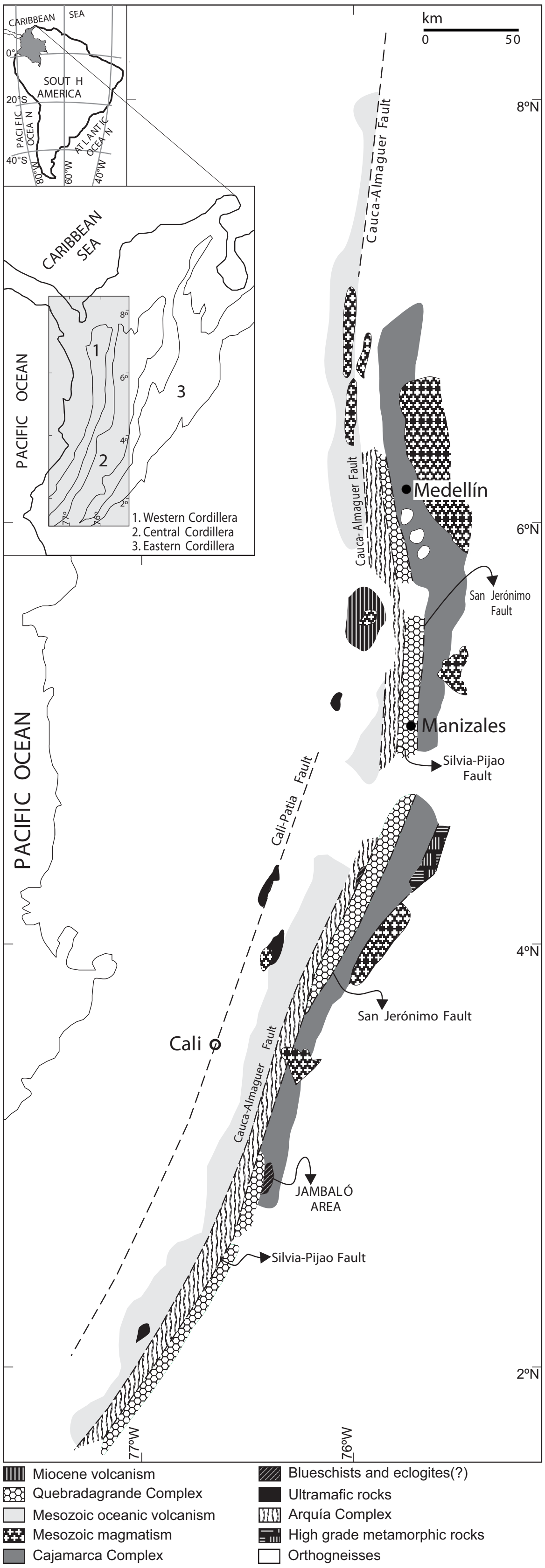

FIGURE 1 | **Lithodemic units of the Central Cordillera of Colombia, after Maya and González, (1995).**

western flank of the Central Cordillera in Jambaló and Barragán. Another occurrence of blueschist rocks has been described in the Pijao area (Núñez and Murillo, 1978), but the geology, petrography and ages have not been clearly defined yet.

The Jambaló blueschists are limited to the east by the polymetamorphic rocks of the Cajamarca Complex (Maya and González, 1995), whereas to the west the contact is tectonic with arc-related volcanic rocks, which are regionally grouped in the Quebradagrande Complex. This complex includes units of different ages, probably formed in oceanic settings (Maya and González, 1995; Nivia et al., 2006). The regional geological setting of the Jambaló blueschists is illustrated in Figure 1, and the geologic map of the study area is summarized in Figure 2.

Previous studies have considered the age of the Jambaló blueschist as Early Cretaceous (Orrego et al., 1980a; De Souza et al., 1984). This interpretation will be discussed considering new ^{40}Ar–^{39}Ar isotopic data obtained for paragonite and phengite from the blueschists.

^{40}Ar/^{39}Ar METHODOLOGY

Micas from six samples of blueschist facies rocks were concentrated and analyzed by the ^{40}Ar/^{39}Ar method. Rarer phengite from only one sample was analyzed.

Mineral concentrates were prepared by manual separation of grains present in the 0.5–1mm fraction. Two or three grains from each sample were analyzed, although for some samples only one grain was analyzed.

^{40}Ar/^{39}Ar analyses were performed at the Argon Geochronology Laboratory of the University of Michigan using a continuous laser for step-heating and a VG 1200S noble gas mass spectrometer equipped with a Daly detector operated in analog mode using the methods outlined in Streepey et al. (2000) and Keane et al. (2006). Samples were packed within pure Al foil packs and irradiated for 10.83hr at location 5C at the McMaster Nuclear reactor. Quoted ages are calculated relative to an age of 520.4Ma for hornblende standard MMHb–1. After irradiation two or three crystals were chosen from each sample for extraction and purification of argon by the step-heating method.

HIGH PRESSURE METAMORPHIC ROCKS FROM THE JAMBALÓ AREA

Orrego et al. (1980b) divided the metamorphic rocks of the Jambaló area in three units: 1) San Antonio Amphibolite, composed of metagabbro, metadiabase, metabasalt and subordinated metasedimentary rocks, all of them metamorphosed to the amphibolite facies; 2) La Mina Greenschist, which includes rocks similar to those of the San Antonio Unit, but metamorphosed to the greenschist facies, and 3) Glaucophanic Schist, formed by glaucophanic, chloritic, amphibolitic and micaceous schists associated with foliated quartzites, marbles and metaperidotites (serpentinites). This 25km-long blueschists unit was considered to be a continuous body, elongated north–northeast and parallel to the regional Andean trend (Orrego et al., 1980b; Feininger, 1982). Our field observations, however, do not support the existence of a continuous belt, but of a series of discontinuous lenses

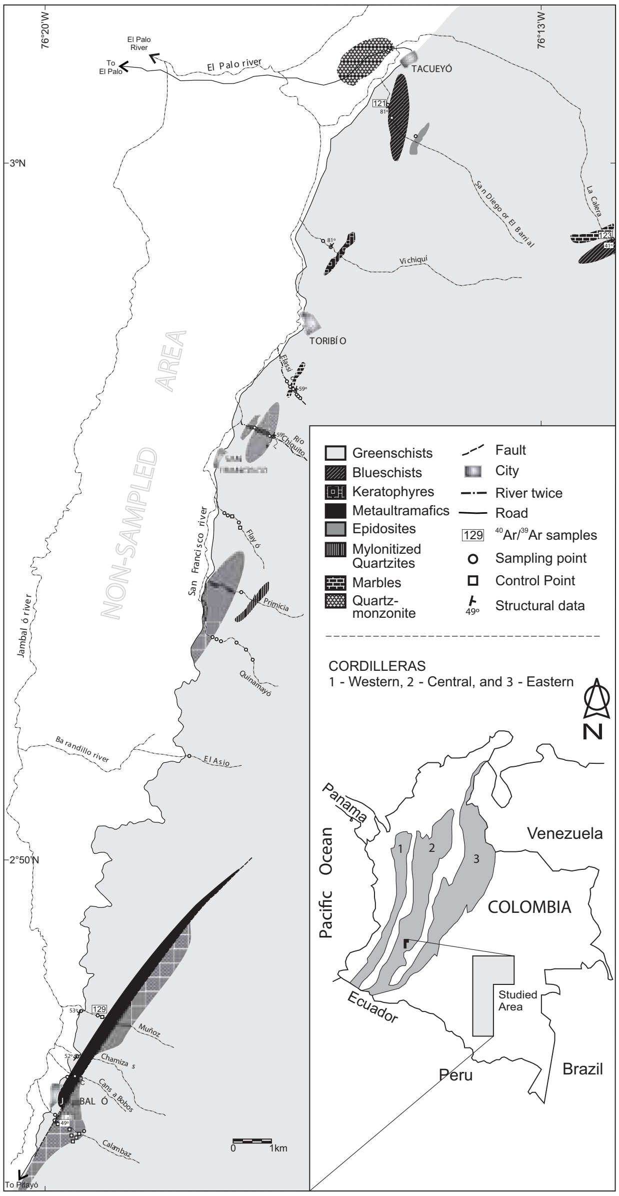

FIGURE 2 | **Simplified geologic map of the Jambaló area.**

of blueschist rocks in a greenschist matrix resultant from retrograde metamorphism to the greenschist facies, which is mainly associated with contemporaneous mylonitic foliation.

All structural data were obtained from the greenschist facies rocks. North of the Jambaló area, the strike of the foliation varies between N8ºW and N67ºE, dipping SW and NW respectively. In the middle of the studied area, near the Toribío city, the attitudes vary between N38ºE and N12ºE strongly dipping NW and SE respectively. Close to Jambaló, the foliation is approximately N28ºE, dipping NW. Although field relationships are not clearly seen, the three units could constitute tectonic blocks in a tectonic mélange (Orrego et al., 1980b), whose major tectonic implications will be discussed later.

Blueschist facies rocks from the Jambaló area are fine-grained, grey-bluish in color, strongly foliated, and occasionally folded. The main foliation is defined by white mica and glaucophane. Some samples show discontinuous greenish white bands, due to a mixture of epidote and white mica. Glaucophane crystals are slightly oriented according to foliation, but are usually randomly distributed or arranged radially in relation to the main foliation.

PETROGRAPHY

Jambaló blueschists and blueschist-facies rocks are associated with greenschists and greenschist-facies rocks, impure marbles, serpentinized peridotites, and quartzites. The relationships between the rock bodies are not well exposed, but we interpret that the greenschists are the product of retrograde metamorphism of blueschists.

The blueschist-facies rocks from the Jambaló area can be classified as mica-glaucophane schists or glaucophane-mica schists, depending on the glaucophane/white mica ratio, but due to the intense shearing all of them are mylonitic rocks. Some samples could be classified as epidote–glaucophane schists (e.g. sample 123A). More details on the petrography of these rocks are found in Bustamante (2008).

The blueschists are made up of glaucophane (30–50%), white mica (10–36%), quartz (5–12%), epidote–clinozoisite (1 to 30%), chlorite (1 to 12%) and calcite (1 to 5%). Accessory and trace minerals are albite, pyrite, ilmenite, magnetite, titanite, zircon, garnet, rutile, apatite and stilpnomelane. The mineral composition of the representative samples are summarized in Table 1 and the blastesis versus metamorphic facies are illustrated in Figure 3.

TABLE 1 | **Mineral composition of dated samples**

Sample	121B	123A	124F	124G	124J	125M	129C
Glaucophane	○	○	○	○	○	○	○
White mica	○	●	○	○	○	○	○
Quartz	○	○	○	○	○		○
Epidote–Clinozoisite	●	○		●	●	●	
Chlorite	○	●	●	●	●	○	●
Calcite	●		●	●	○		●
Albite	●	–	–	●	●	●	●
Pyrite			–	–	●		
Ilmenite	●	–	●	●		–	●
Magnetite	●	●				●	●
Titanite	●	●	●	●	●	●	
Rutile		●					●
Zircon		–			–		
Garnet					–		
Apatite	–	–	–	–	–		
Stilpnomelane	●						

○ Mineral contents varying between 10 to 50%, ● accessory minerals varying between 1 to 9% and – mineral in traces contents <1%

Glaucophane grains vary from 0.25 to 6.6mm in length and are subidioblastic and xenoblastic. Optical zoning is common and more intense in the core of the crystals. The core of glaucophane grains is also rich in inclusions of epidote–clinozoisite, opaque minerals, zircon, and locally rutile. The rims are relatively clean and commonly replaced by barroisite and/or actinolite+chlorite. Glaucophane may define a weak S_n foliation and a marked penetrative S_{n+1} mylonitic foliation, but is usually arranged radially (Fig. 4) indicating that crystallization was pre-, syn- and locally post-mylonitization. Pressure shadows of symmetrical and asymmetrical shapes possibly resulted from shearing. Polygonal arcs are also observed.

White mica grains vary from 0.05 to 0.3mm in size and are subidioblastic and continuous with foliation S_{n+1}. In most cases white mica accompanies quartzose beds. In samples with epidote–clinozoisite, mica grains are isolated. Optically this white mica is similar to phengite and/or muscovite, but X–ray diffraction analysis of several mica grains from the concentrates reveals a mixture of paragonite and phengite. Usually chlorite and epidote

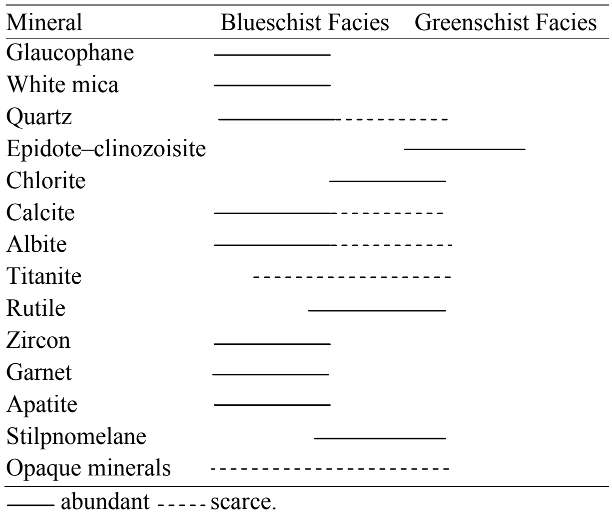

FIGURE 3 | **Mineral blastesis and metamorphic facies of representative rocks from Jambaló area.**

formed during retrograde metamorphism define the mylonitic foliation. In some samples with white mica and glaucophane defining a strong mylonitic foliation (Fig. 4), no evidence of retrograde metamorphism was detected, suggesting that shearing started in near-peak blueschist facies metamorphic conditions and continued during retrograde (i.e, exhumation-related) greenschist facies.

Quartz grains vary from 0.05 to 0.65mm in size and are generally disseminated and locally aggregated in thin lenses. Quartz also occurs as inclusions in glaucophane pressure shadows, and also in calcite, chlorite and white mica. In general, quartz constitutes xenoblastic grains with undulatory extinction. Locally polygonal texture and triple junctions are developed.

Epidote–clinozoisite grains vary from 0.05 to 0.2mm in width. They are xenoblastic to subidioblastic and occur more rarely as disseminated idioblastic crystals. These minerals are either oriented according to S_{n+1}, or have a matrix of strongly hydrothermally altered rocks.

Chlorite is disseminated and generally forms xenoblastic and subidioblastic crystals. It concentrates at rims, cleavage planes and fractures of other minerals, mainly glaucophane. Chlorite may also completely replace glaucophane, resulting in pseudomorphs ranging from 0.1 to 0.9mm in size, which are preferentially oriented along the mylonitic foliation (S_{n+1}). Chlorite with a rosette habit is also present, indicating crystallization under static or hydrothermal regimes. Calcite occurs as xenoblastic grains varying between 0.2 and 0.6mm in width, as inclusions in glaucophane or filling fractures. Some crystals show deformation lamellae. Albite ($An_{2–5}$) grains (up to 0.3mm in length) are subidioblastic and xenoblastic, usually associated with quartz, and systematically oriented along the mylonitic foliation.

FIGURE 4 | **Plane-polarized light microphotography of a blueschist from the Jambaló area. The mylonitic foliation is defined by glaucophane (Gln) and white mica (Wm), with some glaucophane crystals arranged radially.**

Opaque minerals are found disseminated in all rocks, and they are represented by magnetite, ilmenite and pyrite. Titanite crystals are generally subidioblastic and rarely idioblastic, varying from 0.025 to 0.075mm in size. They occur as aggregates or ribbons that follow the main foliation. Titanite inclusions in glaucophane are associated with cleavage planes and fractures.

Garnet is rare and occurs in a few samples. The crystals vary from 0.2 to 2.6mm in size, are subidioblastic and, occasionally, exhibit very well defined rims. When in contact with glaucophane, garnet grains exhibit thin rims replaced by chlorite.

Apatite, rutile, and zircon occur as small crystals up to 0.05mm in length, disseminated in the rock or as inclusions in glaucophane. Stilpnomelane was found in one sample, reaching 3% in modal proportion. Generally it is elongated according to foliation S_{n+1} and is partially replaced by chlorite.

Texturally, the rocks show lepidonematoblastic or nematolepidoblastic arrangements, depending on the amphibole/mica proportions. Porphyroblastic texture defined by glaucophane is usually observed and some of these crystals are poikiloblasts with inclusions of opaque minerals, micas, carbonate, quartz and rutile. Locally, garnet crystals develop pressure shadows indicating pre to syn-kinematic crystallization. Two metamorphic foliations associated with the generation of the high-pressure rocks were identified. The oldest is observed as a fine schistosity (S_n) observed in some glaucophane-rich rocks and a folded S_i in glaucophane crystals oriented along the mylonitic foliation. This S_i is defined mainly by fine-grained quartz and mica inclusions. The second foliation (S_{n+1}) is mylonitic and is associated with recrystallization and re-orientatation of glaucophane crystals. Usually, the development of this foliation resulted in crystallization of greenschist-facies mineral assemblages and partial to total replacement of glaucophane. In some samples, randomly oriented glaucophane suggests that it formed under near-static tectonic condition close to high-pressure metamorphic-peak conditions.

$^{40}Ar/^{39}Ar$ GEOCHRONOLOGY

Paragonite and phengite coexist in samples 123A (epidote-glaucophane schist) and 124J (mica-glaucophane schist). In other samples, white mica is represented only by paragonite.

The $^{40}Ar/^{39}Ar$ analyses resulted in consistent ages of 59–63Ma. The quality of some analyses is not good due to the low potassium contents of the paragonite and, possibly, the effect of paragonite–phengite intergrowths, as described by Boundy et al. (1997).

Mineral argon isotopic ages either indicate the time of growth, recrystallization or cooling through the blocking temperature for a given cooling rate (McDougall and Harrison, 1999). Experiments of McDougall and Harrison (1999) and Harrison et al. (2009) suggest closure temperature for the Ar–Ar system in muscovite between 325 and 375°C and 425°C, respectively. Geothermobarometric calculations of Jambaló blueschists show that the high-pressure metamorphism occurred at ca. 450°C (Bustamante, 2008), just above the estimates of muscovite closure temperatures of Harrison et al. (2009), indicating that our ages could reflect the timing of (near) peak high-pressure/low-temperature metamorphism. However, the strong deformation in a ductile shear zone and the development of mylonitic foliation defined by glaucophane and greenschist-facies mineral assemblages strongly argues for argon isotope ages corresponding to a post-peak blueschist event (i.e., beginning of exhumation) or shortly afterwards.

The Ar-Ar blocking temperature in paragonite is uncertain (Faure, 1986; Dickin, 1995). However, the concordant $^{40}Ar/^{39}Ar$ ages for Jambaló paragonite and phengite suggest that either the blocking temperature is similar, or that $^{40}Ar/^{39}Ar$ ages have been reset during recrystallization during the mylonitic event. It seems, however, that a spread in $^{40}Ar/^{39}Ar$ ages reflects differences in grain size and/or mineralogy that modulate the precise blocking temperature. Rocks that yield variable ages may relate to continuously moving crustal segments in the accretionary system/subduction channel (Ring et al., 1999).

Our data indicate:

1) The plateau age of 66.9 ±0.2Ma yielded by sample 129C (Fig. 5A), composed of glaucophane + albite + paragonite + calcite + chlorite + quartz, likely represents the age of (near-) peak blueschist-facies metamorphism.

2) Paragonite of sample 124F, consisting of glaucophane + albite + paragonite + calcite + chlorite + titanite + quartz, yielded three spectra (Figs. 5B, 5C, and 5D). The plateau ages obtained for this sample agree within error (62.9±1.0, 61.8±0.9, and 62.4±0.2Ma).

3) Paragonite of sample 124G (glaucophane + paragonite + calcite + chlorite + quartz) yielded two spectra with ages of 62.3±1.1 and 63.0±0.3Ma (Fig. 6). The first steps of one spectrum (Fig. 6A) indicate argon excess and a plateau for intermediate fractions of ^{39}Ar-released. The final steps in both spectra correspond to Ca/K ratios of ca. 4 (Fig. 6B). A third additional spectrum is characterized by Ca/K<1 (Fig. 7), resulting in an apparent age of 54.5±1.6Ma. The wide variation of Ca/K, and the saddle shape of the latter spectrum suggests that this later age is unreliable.

4) Phengite of sample 124J (phengite + glaucophane + albite + calcite + chlorite ± paragonite ± quartz) yielded a

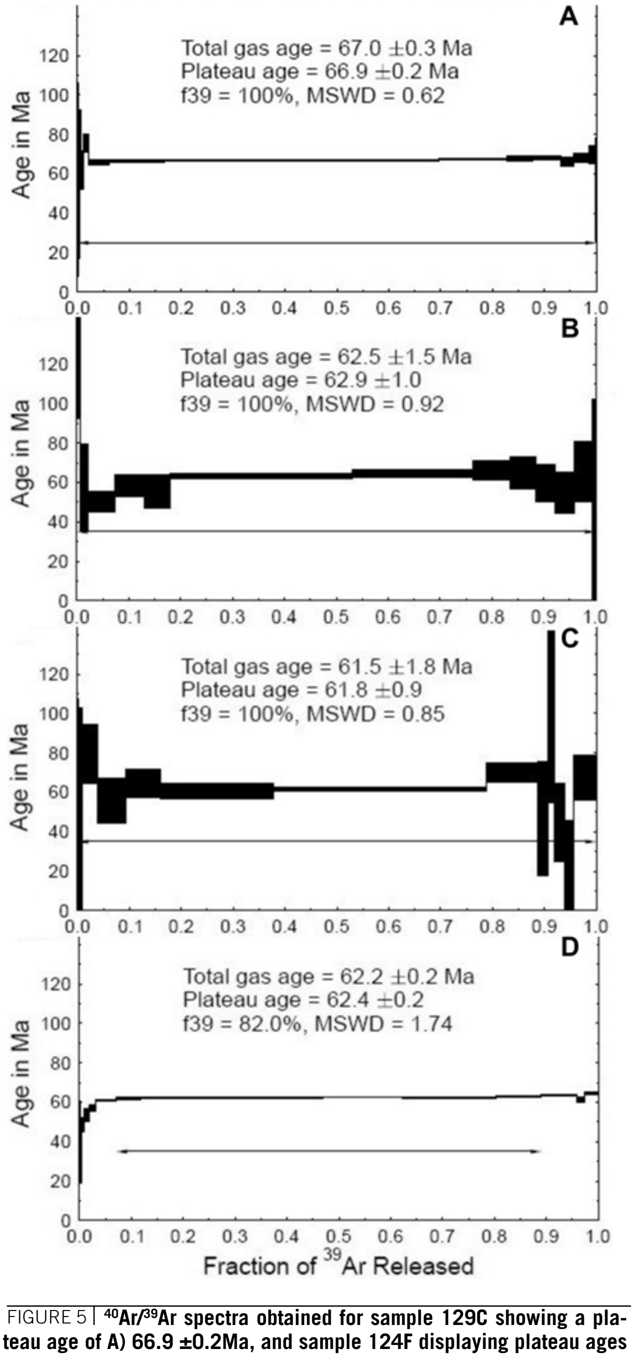

FIGURE 5 | **$^{40}Ar/^{39}Ar$ spectra obtained for sample 129C showing a plateau age of A) 66.9 ±0.2Ma, and sample 124F displaying plateau ages of B) 62.9 ±1.0,Ma C) 61.8 ±0.9Ma, and D) 62.4 ±0.2Ma.**

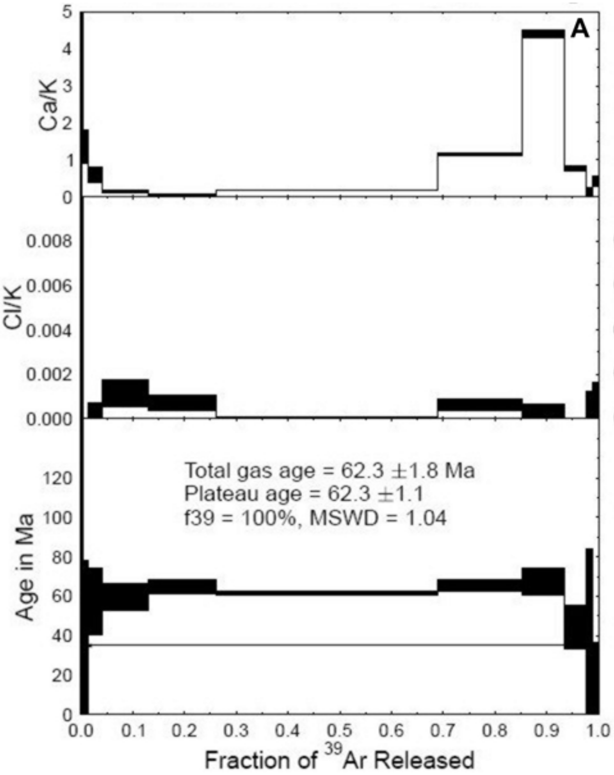

FIGURE 6 | **^{40}Ar/^{39}Ar spectra obtained for sample 124G showing plateau ages of A) 62.3 ±1.1Ma, and B) 63.0 ±0.3Ma.**

spectrum with last steps characterized by Ca/K ratios close to 3 and a plateau age of 67.5±1.1Ma (Fig. 8A).

5) The spectrum of paragonite of sample 121B (glaucophane + paragonite + calcite + chlorite + quartz) yielded a plateau age of 67.8±1.1Ma (Fig. 8B).

6) Paragonite of sample 123A (glaucophane + epidote/clinozoisite + paragonite + phengite + quartz) yielded a spectrum with a Ca/K ratio near 1.5 and a plateau age of 66.0±0.7Ma (Fig. 8C) and 66.3±2.5Ma (Fig. 8D).

7) Paragonite of sample 125M (blueschist-greenschist transitional rock composed of glaucophane + albite + paragonite + calcite + chlorite) yielded a plateau age of 63.5±1.3Ma (Fig. 8E).

DISCUSSION OF THE GEOCHRONOLOGICAL RESULTS

Previous geochronological data for the Jambaló rocks were based on the K–Ar method. Orrego et al. (1980a) reported a minimum whole-rock K–Ar age for the metamorphism of 125±15Ma. Dating glaucophane by the same method De Souza et al. (1984) obtained ages of 104±14Ma and 217±10Ma, the former result being

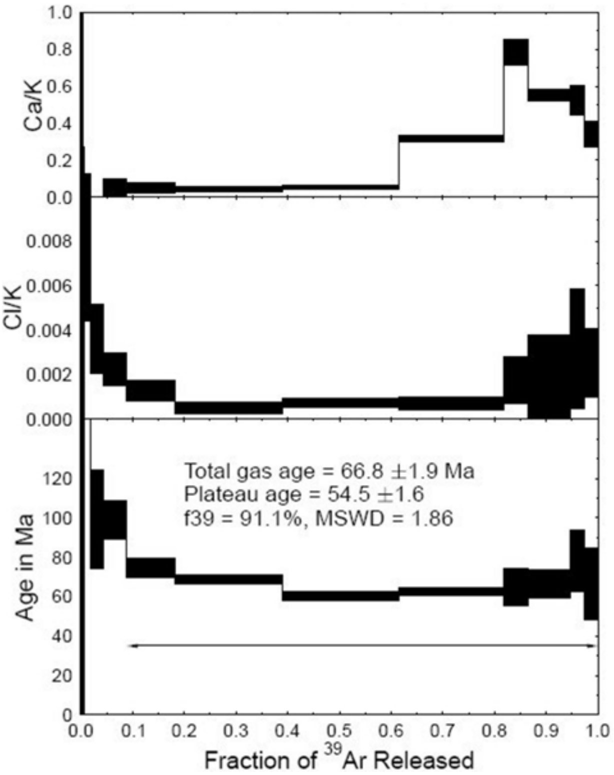

FIGURE 7 | **^{40}Ar/^{39}Ar spectrum obtained for sample 124G showing a plateau age of 54.5 ±1.6Ma.**

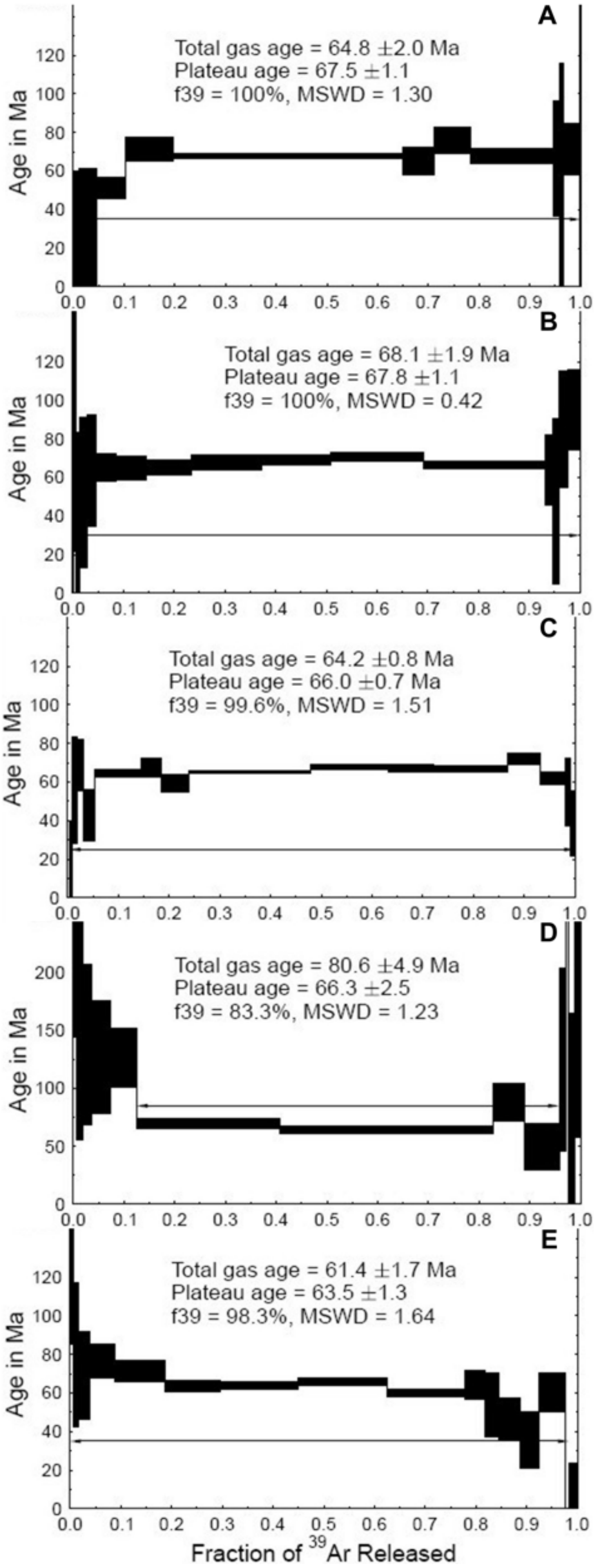

FIGURE 8 | **^{40}Ar/^{39}Ar spectrum obtained for sample 124J displaying a plateau age of A) 67.5 ±1.1Ma; for sample 121B showing a plateau age of B) 67.8 ±1.1Ma; for sample 123A with plateau ages of C) 66.0 ±0.7Ma and D) 66.3 ±2.5Ma; and for sample 125M presenting a plateau age of E) 63.5 ±1.3Ma.**

interpreted as the minimum age of the blueschist-facies metamorphism and the latter as due to argon excess. However, the K–Ar method has several limitations concerning the dating of metamorphic rocks as far as argon loss or excess cannot be determined and the thermal history of minerals (i.e., white micas) cannot be discriminated (Dallmayer and Takasu, 1992; Clauer and Chauduri, 1999). Another well-known disadvantage of traditional K–Ar dating is the application of different analytical techniques for K and Ar, resulting in large propagated errors. In the case of bulk rock analyses, contributions from several K-bearing phases with different K and Ar isotope composition can render the resultant bulk age geologically meaningless (Faure, 1986; Dickin, 1995). On the other hand, the use of glaucophane K–Ar geochronology is questionable because it seldom has measurable potassium by electron microprobe and the detected potassium most likely is due to very fine inclusions of K-bearing minerals such as muscovite-phengite, stilpnomelane or barroisite. Also, ^{40}Ar in glaucophane may have not been produced after in-situ decay of ^{40}K in glaucophane, but simply after trapping of Ar diffusing through the rock (Dickin, 1995).

The ^{40}Ar/^{39}Ar data set presented here indicates that metamorphism of the Jambaló blueschists occurred between 67 and 61Ma (Maastritchtian–Danian). The variability in the spectra are related to variable Ca/K ratios, which most likely represent the effects of inclusions. An example of Ca-rich inclusions is illustrated by sample 123A (Fig. 8D). The high and variable Ca/K ratios most likely represent contributions from contamination by Ca-rich minerals such as epidote, calcite and/or barroisite. The high Ca/K ratio in the highest temperature steps is probably related to refractory inclusions and has nothing to do with the mica itself. From a geochronological viewpoint, there are no evidences for ages older than 68Ma.

Considering all lines of evidence, including experimental evidence for closure temperature of ca. 425°C for muscovite-phengite (Harrison et al., 2009) and recrystallization and formation of retrograde assemblages during mylonitic blueschist-greenschist facies overprints, it is suggested that our 70–60Ma ages obtained for the Jambaló white micas record the mylonitic event responsible for the exhumation of the blueschist facies rocks.

TECTONIC IMPLICATIONS

The Jambaló blueschist-facies rocks, associated with serpentinized peridotite, metabasite and metasedimentary rocks, were affected by an intense retrograde greenschist-facies metamorphism in shear zones. This lithological association can be interpreted as a tectonic mélange bearing mixed metamafic–metaultramafic rocks of intra-oceanic affinity and metasedimentary rocks (Bustamante, 2008) metamorphosed at different grades, being compatible with an accretionary system or subduction channel environment (see Agard et al., 2009).

It is not possible to distinguish whether the somewhat younger ages may be related to early retrogressive cooling, or to a collisional event in an arc in the western margins of the Caribbean plate. Early retrogressive cooling of paragonite would reset the paragonite ages. Or else, it could happen during a collisional event that took place during exhumation of this blueschist belt between 71–63Ma. In either case the ages would be the same and we interpret that this accretionary system/subduction channel which may be transformed into a collisional zone was actively exhumed from ca. 67Ma to 60Ma as suggested by different Ar–Ar ages that could reflect the flow of the accretionary system/subduction channel.

Late Cretaceous to Paleogene tectonics of the Northern Andes is related to the accretion of several oceanic terranes (Spadea and Espinosa, 1996; Toussaint, 1996; Kerr et al., 1997). Vestiges of these terranes extend from the western flank of the Central Cordillera and the Western Cordillera, and include several arc- and plateau-related terranes. The Jambaló blueschists are limited to the east by a major metasedimentary unit of continental affinity that probably represents a mixture of the continental margin and its older Pre-Jurassic basement (Maya and González, 1995; Vinasco et al., 2006) and to the west by major basaltic terranes of oceanic affinity.

Several models for the Colombian margin have considered that the Maastrichtian tectonic event is a consequence of the accretion of the plateau-like margins of the Caribbean plate (Kerr et al., 1997, Kerr and Tarney, 2005; Pindell and Kennan, 2009), as shown in Figure 9. Petrological constraints in southern Colombia oceanic terranes have shown that as well as this major plateau remnant, there are evidences for the existence of a Campanian intra-oceanic arc remnant in southernmost Colombia (Spadea and Espinosa, 1996). It is therefore suggested that the Jambaló blueschists are remnants of the subduction zone related to the approach of this Campanian

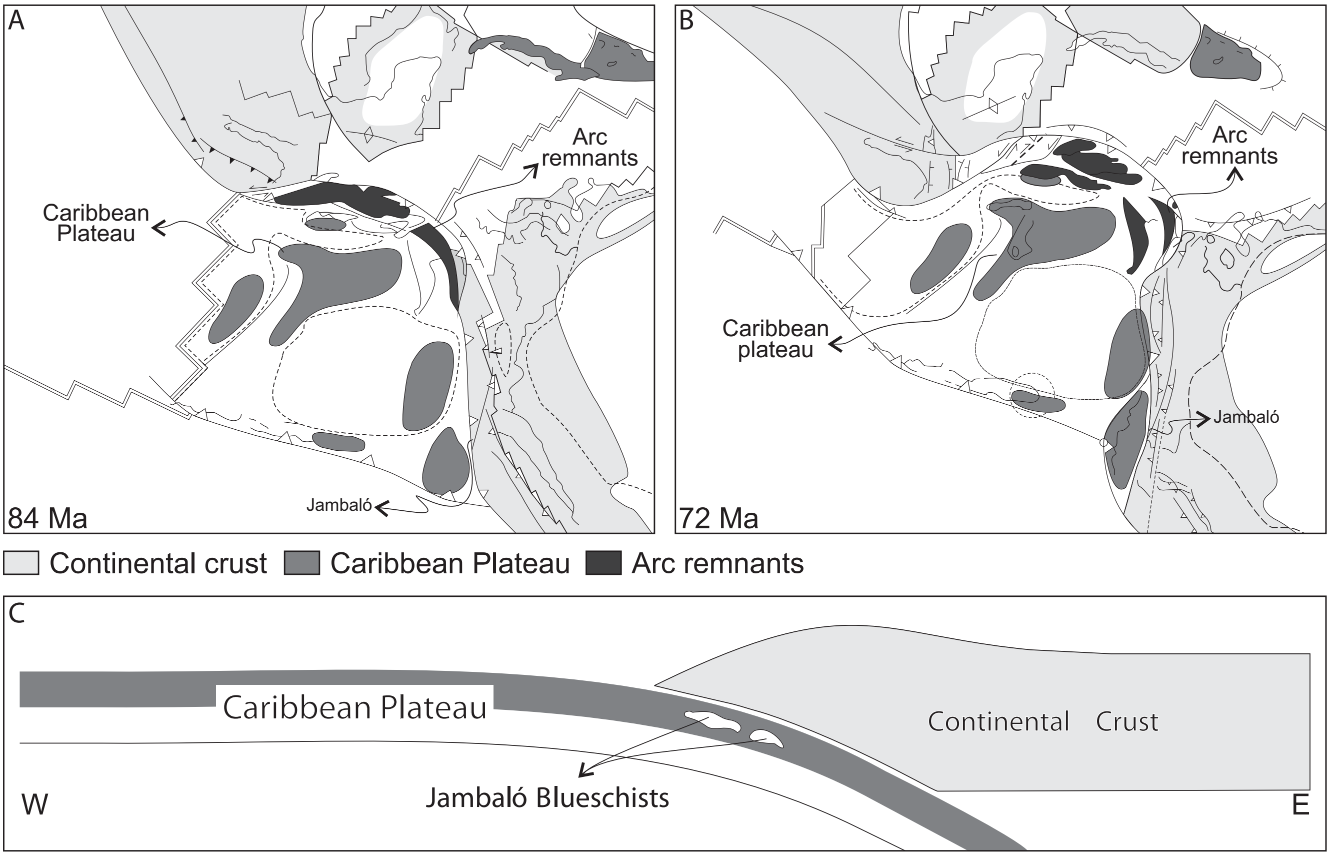

FIGURE 9 | **Model for the Caribbean-South American interactions in the Cretaceous (Pindell, 1993; Pindell et al., 2005). A) Approach of the allochthonous Caribbean arc to the Continental margin. B) Multiple arc-continent collision: in northern South America collision of the Great Caribbean arc, whereas similar contemporaneous accretion is seen along most of the Northern Andean margin. C) Cross section of the development of southwest Colombia showing the possible configuration of the Caribbean and its relationship with the Jambaló Blueschists and the Continental Crust.**

intra-oceanic arc to the continental margin (Fig. 9). Recent tectonic constraints from the Ecuadorian Andes have also shown the existence of similar Campanian arc rocks built on a Caribbean plateau-like substrate (Vallejo et al., 2006, 2009). We therefore envision a model for the southwestern Colombian Andes, with the southeastern margin of the Caribbean plate approaching South America (Pindell and Keenan, 2009). Contemporaneous accretionary events are recorded farther north in the Colombian Caribbean realm, which are related to the arc-continent collision of the Caribbean arc with the margin of northern South America (Cardona et al., 2010). This contrasts with what is seen farther south, including the Jambaló region and Ecuador, where the collision took place with the southeastern margin of the Caribbean plate, and shows the existence of multiple arc-continent collision along the eastern margin of the Caribbean plate.

REGIONAL CORRELATIONS

Barrovian and high-pressure metamorphic belts located between the Central and Western Cordillera of the Colombian Andes and groups within the Arquía Complex (Fig. 1) have been related either to Albian–Aptian metamorphism or to remnants of Pre-Triassic basement (Maya and González, 1995; Toussaint, 1996; Nivia et al., 2006).

At present there are two major ideas on the origin and evolution of the Arquía Complex. The first comprises the remobilization of a possibly Pre-Triassic basement (Maya and González, 1995; Toussaint, 1996; Nivia et al., 2006; Vinasco et al., 2006) and the second considers it as a sequence generated and evolved in Albian–Aptian times (Restrepo and Toussaint, 1976; Toussaint and Restrepo, 1978; Restrepo et al., 2009). Our geochronological data indicates that the Arquía Complex contains a heterogeneous assemblage of blocks including Pre-Triassic fragments, Albian–Aptian metamorphic blocks, and Maastrichtian–Danian rocks such as the Jambaló blueschists described here. In this sense, each one of the different blocks could be used as to decipher the history and evolution of the western South America margin.

The geochronological results presented here show that, as well as older fragments, there are also remnants of a Late Maastrichtian to Paleogene metamorphic belt. Different metamorphic complexes were assembled during the complex series of Meso-Cenozoic accretionary events and the over-imposed dispersion tectonics experienced by the margin (Toussaint, 1996). In this context it is possible to consider that "The Romeral Zone ophiolites" and their related volcanic sequences from the Central Cordillera are oceanic terranes accreted onto the continental margin before ca. 120Ma (Aspden and McCourt, 1986), whereas the Western Cordillera volcanic arc sequences (Spadea and Espinosa, 1996) are an allochtonous terrane accreted onto the continental edge ca. 65–60Ma ago (McCourt et al., 1984).

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