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Tertiary fission-track ages from the Bagua syncline (northern Peru): Stratigraphic and tectonic implications

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Abstract—The results of five zircon fission-track ages of volcanic tuffs intercalated within the continental deposits of the Bagua syncline (northern Peru) are reported. These 2500-meter-thick deposits overlie mid-Campanian to lower Maastrichtian fine-grained red beds (Fundo El Triunfo Formation). The disconformable fluvial conglomerates of the Rentema Formation are associated with a 54 Ma tuff (upper Paleocene-lower Eocene?) and would reflect the Inca-1 tectonic phase. The Sambimera Formation (Eocene to mid-Miocene) is a coarsening-upward sequence (from lacustrine to fluvial) that contains three volcanic tuffs of 31, 29, and 12 Ma, respectively. A probable stratigraphic gap, upper Eocene-lower Oligocene, would be related to the late Eocene Inca-2 phase. Neither deformation nor sedimentary discontinuity has been recognized so far. However, the lacustrine to fluvial transition could relate to the late Oligocene Aymara tectonic phase. The unconformable fanglomerates and fluvial deposits of the San Antonio Formation contain in their upper part a 9 Ma tuff (mid- to upper Miocene), and their base records a major tectonic event (Quechua-2 phase?). The unconformable fanglomerates of the Tamborapa Formation date the folding of the Bagua syncline, which could be ascribed to the latest Miocene Quechua-3 tectonics. These formations are correlative with comparable deposits in the sub-Andean basins, suggesting that these eastern areas underwent strong tectonic subsidence of the foreland basin type since mid-Miocene times.

Resumen—Se presentan aqui los resultados de cinco dataciones por trazas de fisión sobre tobas volcánicas intercaladas en los depósitos continentales del sinclinal de Bagua (norte del Peru) que permiten revisar la estratigrafía y precisar la evolución tectosedimentaria del area. Dichos depósitos de 2500 m de potencia sobreyacen estratos continentales finos (Formación Fundo El Triunfo) datados del Campaniano medio-Maastrichtiano inferior. Los conglomerados fluviatiles ligeramente discordantes de la Formación Rentema están asociados con una toba volcanica datada de 54 Ma (Paleoceno superior-Eoceno inferior?) y podrían representar un testigo de la fase Incáica-1. La Formación Sambimera (Eoceno-Mioceno medio) es una secuencia grano–creciente (lacustre hasta fluviatil) que contiene tres niveles de tobas datados de 31, 29, y 12 Ma respectivamente. Una probable laguna estratigráfica del Eoceno superior-Oligoceno inferior podría estar relacionada con la fase Incáica-2 del Eoceno tardío. Deformaciones sinsedimentarias o discontinuidades no han sido reconocidas. La transición lacustre-fluviatil parece corresponder a la fase Aymara del Oligoceno superior. Los conglomerados discordantes (cono aluvial, fluvios) de la Formación San Antonio (Mioceno medio a superior) contienen en su parte superior una toba de 9 Ma de edad, y su base registra una importante fase tectónica (Quechua-2?). La discordancia en la base de los conglomerados de la Formación Tamborapa (cono aluvial) sella el plegamiento del sinclinal de Bagua y puede representar la fase Quechua-3 (Mioceno superior). Estas formaciones son correlacionables con formaciones del Oriente Ecuatoriano y Peruano y demuestran que estas regiones fueron sometidas a una fuerte subsidencia tectónica de tipo cuenca de antepais desde el Mioceno superior.

INTRODUCTION

IN NORTHERN PERU (Fig. 1), the NW-trending Bagua syncline (5°30'S, 78°30'W) is made up of more than 3000 meters of marine to continental Cretaceous and Tertiary strata that record the Late Cretaceous emergence of the Andes. These strata also record the tectonic events that occurred regionally. In particular, it can be expected that the sedimentation in the Bagua area, which lies close to the front of the so-called Marañon Fold and Thrust Belt (MFTB; Mégard, 1984), would have recorded the first stages of the development of the MFTB. Moreover, the Bagua area is currently the only zone in Peru where the Late Cretaceous emergence has been dated with any accuracy. Thus, this region appears to be a key area, the study of which will help in understanding and establishing the timing of early Andean orogenic events in the northeastern Andes of Peru.

Recent paleontologic data (based mainly on ammonites; Bengtson, in Mourier *et al.*, 1988) indicate a mid-Campanian age for the uppermost beds of the

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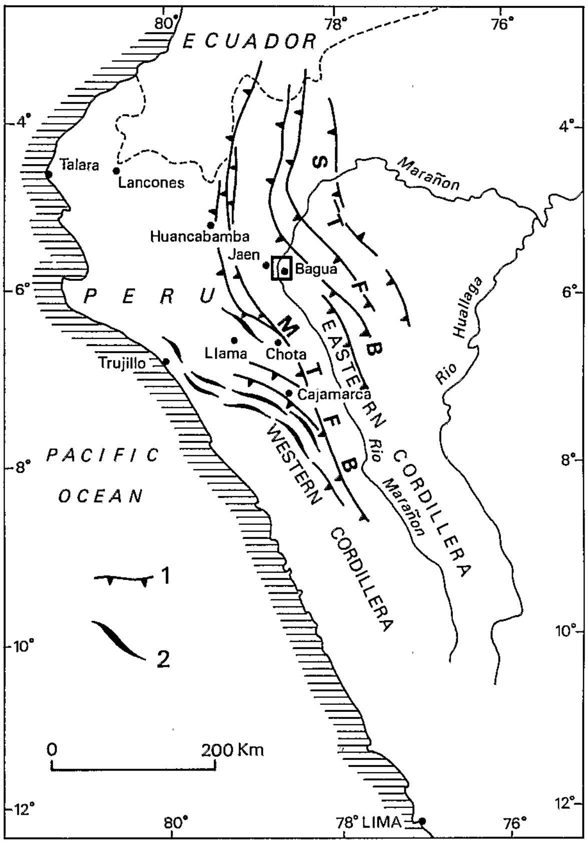

Fig. 1. Location of the Bagua area and major Andean structures of the Northeastern Andes of Peru (after Mourier *et al.*, 1988b): 1, overthrusts; 2, major folds; MTFB, Marañon Thrust and Fold Belt; STFB, Subandean Thrust and Fold Belt.

marine Celendín Formation. In the transitionally overlying fine-grained red beds of the Fundo El Triunfo Member (Bagua Formation), a fossil assemblage of vertebrates and charophytes provided a mid-Campanian to Maastrichtian age (Mourier *et al.*, 1988). An early Paleocene to late mid-Eocene charophyte association was found in the overlying continental strata of the Sambimera Member, Bagua Formation. A volcanic tuff about 50 meters above the latter charophyte-bearing level provided K/Ar ages ranging from 68.1±4.6 Ma up to 53.6±3.1 Ma (Bonhomme, in Mourier *et al.*,1988). The accuracy of this age is questioned here.

In this paper we report on fission-track (F-T) ages of five samples of volcanic tuffs intercalated at different levels in the Tertiary continental sequence of the Bagua syncline. The F-T ages of these tuffs range from 54.2±6.4 Ma near the base of the sequence up to 8.6±1.1 Ma near the top (Table 1). A F-T age 31.0±3.1 Ma was obtained on a sample from the tuff dated as 66.0±1.6 Ma with the K/Ar method (Bonhomme, in Mourier *et al.*, 1988). Volcanic tuff samples recovered from the upper part of the Bagua section have been dated for the first time. Our objectives here are to present these new geochronologic data, to consider possible reasons for the discrepancy between previous K/Ar and new F-T data, and to discuss the stratigraphic and tectonic implications of these new ages. The timetable used in this paper is that of Haq *et al.* (1987).

GEOLOGIC SETTING

Previous reports on the Cretaceous of the Northern Andes of Peru have been provided by Olsson (1944), Rivera (1949), Benavides-Cáceres (1956), Wilson (1963), Cobbing *et al.* (1981), Janjou *et al.* (1981), Cordova (1985), and Mourier *et al.* (1986). Additional biostratigraphic and chronologic control on the marine Upper Cretaceous formations, as well as on the transitional overlying red beds, have been provided by Jaillard (1987) and Mourier *et al.* (1988). The overlying thick continental formations (of Late Cretaceous and Tertiary age) that crop out regionally along the Marañon River remain poorly dated. In the Bagua region, these formations have been divided into the "Bagua Formation" (Mourier *et al.*, 1988), the "San Antonio Formation," and the "Tamborapa Formation" (Mourier, 1988).

As previously defined, the Bagua Formation overlies the Senonian marine Celendín Formation, the top of which has been dated as mid-Campanian by a rich fossil record, including ammonites (Bengtson, in Mourier *et al.*, 1988). From base to top, the Bagua Formation is divided into three members. The *Fundo El Triunfo Member* is made up of transitional, marine to continental, marly and sandy, occasionally microconglomeratic red beds with selachian, dinosaur, mammal, wood, and charophyte remains to which a mid-Campanian to early Maastrichtian age has been given (Mourier *et al.*, 1988). The *Rentema Member* comprises 10-90 meters of reddish conglomerates and sands of fluvial origin, overlying with a low-angle unconformity the Fundo El Triunfo Member. A volcanic tuff (V1) is associated with this unit. No fossils have been found so far in the Rentema beds. The *Sambimera Member* forms the upper part of the Bagua Formation and is made up of more than 800 meters of lacustrine grading upward into fluvial deposits containing thin intercalated and at least partly reworked volcanic tuffs. The lower lacustrine unit (about 150 m) yielded a charophyte association ranging from Dano-Montian (early Paleocene) to Bartonian (late mid-Eocene; Feist, in Mourier *et al.*, 1988). Some 50 meters above this unit is an intercalation of volcanic tuffs (V2 and its lateral equivalent V3). The V2 tuff provided the K/Ar age of 66.0±1.6 Ma (Bonhomme, in Mourier *et al.*, 1988). The upper part of the Sambimera Member is a 700-meter-thick, coarsening-upward sequence deposited in a fluvial environment. The volcanic tuff V4 is present near the top of this member.

The San Antonio Formation disconformably overlies the Bagua Formation. Its base is made up of two 30- to 50-meter-thick packages of coarse conglomerates that represent an alluvial fan environment. The overlying strata are made up of nearly 750 meters of more or less coarse alluvial and fluvial conglomerates, sands, and shales. A few volcanic tuffs are intercalated in the San Antonio Formation, one of which (V5) has been sampled and dated with the F-T method.

Table 1. Fission–track analysis on zircons from Tertiary volcanic tuffs intercalated within the Rentema, Sambimera, and San Antonio Formations, Bagua syncline, northern Peru.

Sample	DF	Mineral	Number of Grains	$\rho_s \times 10^6$ t/cm^2	Fossil Tracks Counted	$\rho_i \times 10^6$ t/cm^2	Induced Tracks Counted	Neutron Dose $\times 10^{15}$ n/cm^2	Tracks Counted	Age (Ma)	± 2σ
V–1	5657	zircon	6	3.87	806	4.97	518	1.17	3223	54.2	6.4
V–2	5655	zircon	6	4.26	927	8.44	918	1.03	2882	31.0	3.1
V–3	5656	zircon	6	2.89	495	6.19	530	1.03	2882	28.7	3.7
V–4	5653	zircon	5	1.65	360	8.26	899	1.04	2882	12.4	1.6
V–5	5654	zircon	6	1.46	324	10.6	1176	1.04	2882	8.6	1.1
FC–3	4891–14	zircon	6	6.54	1515	15.2	1762	1.05	2882	27.0	2.1

Key: $\lambda_f = 7.03 \times 10^{-17}$ yr^{-1}; DF, laboratory number; t, tracks; n, neutrons.

The above formations have been folded to form the large NW/SE-trending Bagua syncline (Fig. 2). Subsequent sedimentary beds of probable late Miocene to Quaternary age unconformably overlie the folded formations and consist of the slightly deformed Tamborapa Formation and undeformed Quaternary alluvial conglomerates filling paleovalleys carved in the Bagua syncline.

SAMPLING

It is important to point out that the stratigraphic positions of volcanic tuffs V1, V2, and V3 as shown on Figs. 3 and 4 are inferred from field observations and lateral correlations, and make allowance to their present F-T dating. Sample locations are given in Fig. 2.

The V1 tuff (T Bag-1; 5°44'30"S, 78°27'15"W) was collected from a 10-meter-thick white to brown volcanic tuff, 3 km west of Bagua Grande on the southwestern limb of the Bagua syncline. This tuff overlies red beds of the Fundo El Triunfo Member, which at this locality contain vertebrate and charophyte remains. There is no evidence of typical Rentema beds cropping out in the area. The V1 tuff is overlain by lacustrine strata of the Sambimera Member.

The V2 tuff (Be 84-11; 5°42'30"S, 78°33'30"W) was collected from a 15- to 20-meter-thick white volcanic tuff that forms the Cerro Fila Larga — a conspicuous bank in the landscape on the southwestern limb of the Bagua syncline some 13 km west of Bagua Grande along the main road. This V2 tuff is intercalated within the lacustrine strata of the Sambimera Member and lies about 100 meters above the V1 tuff. A sample of the V2 tuff (Be 84-11) already provided K/Ar ages of 53.6±3.1 Ma and 57.3±3.9 Ma on two fractions of plagioclase. A second sample from the same V2 tuff and locality (Si 84-4) provided K/Ar ages ranging from 68.1±4.6 Ma up to 56.0±3.0 Ma on three fractions of plagioclase (see Radiometric Data, Bonhomme, in Mourier *et al.*, 1988, p. 153).

The V3 tuff (Si 84-5; 5°31'10"S, 78°32'40"W) was collected from a 10-meter-thick white volcanic tuff on the northeastern limb of the Bagua syncline at approximately 1 km upstream from the Rentema Canyon at the El Chullo site. This tuff is intercalated in vertically dipping strata of the Sambimera Member, near the transition from lacustrine to fluvial depositional environment.

The V4 tuff (Be 84-6; 5°35'33"S, 78°38'30"W) was collected from a 1-meter-thick reworked white volcanic tuff intercalated in the uppermost conglomeratic strata of the Sambimera Member nearly 1 km northwest of the Sambimera locality.

The V5 tuff (Be 84-7; 5°37'08"S, 78°34'30"W) was collected from a 5-meter-thick white volcanic tuff intercalated in the uppermost conglomeratic strata of the San Antonio Formation at several hundred meters above the V4 tuff, approximately 3 km north of the Sambimera locality.

FISSION-TRACK METHODS AND RESULTS

The zircons were mounted in teflon and etched in an eutectic melt of KOH-NaOH (Gleadow *et al.*, 1976) at 215°C for 30-50 hours. The teflon mounts were covered with a muscovite detector and irradiated along with neutron dose monitors (U-doped glasses SRM 962 also covered with muscovite detectors) in the U.S. Geological Survey reactor at Denver, Colorado. The neutron dose was determined using the track density in the muscovite detectors and the Cu calibration for SRM 962 (Carpenter and Reimer, 1974).

The samples from this study underwent two separate irradiations. With the exception of V1, all of the samples were irradiated with a mount of zircons from the Fish Canyon Tuff (FC-3; Naeser *et al.*, 1981). The Fish Canyon Tuff is used as an age standard for fission-track dating. Biotite and sanidine from this tuff yield concordant ^{40}Ar-^{39}Ar ages averaging 27.79 Ma (relative to 519.4 Ma for MMhb-1; Cebula *et al.*, 1986). The zircon fission-track ages for the five samples and the Fish Canyon Tuff are shown in Table 1. Two of the samples (V4 and V5) failed the Chi-square test, indicating that there was excessive scatter in the ages of the individual grains dated from these samples. Four of the samples (V1, V2, V3, and FC-3) passed the Chi-square test at the 5% level, indicating that the ages derived from these data sets represent grains from a single age population.

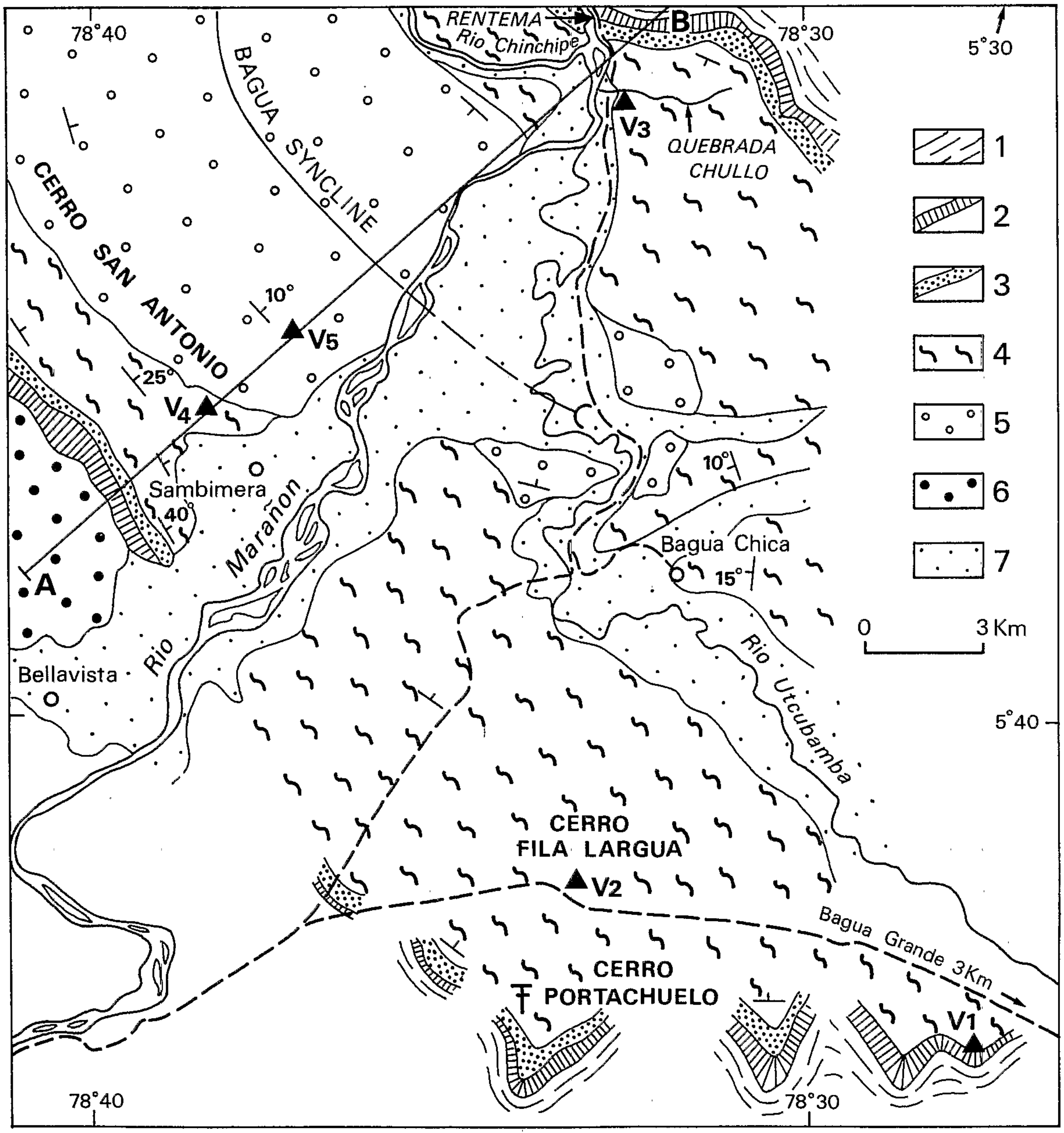

Fig. 2. Geologic map of the Bagua area. 1, Celendín Formation; 2, Fundo El Triunfo Formation; 3, Rentema Formation; 4, Sambimera Formation; 5, San Antonio Formation; 6, Tamborapa Formation; 7, Quaternary alluvial deposits; black triangles, location of the F–T dated tuffs; A-B, location of the geologic section shown in Fig. 3.

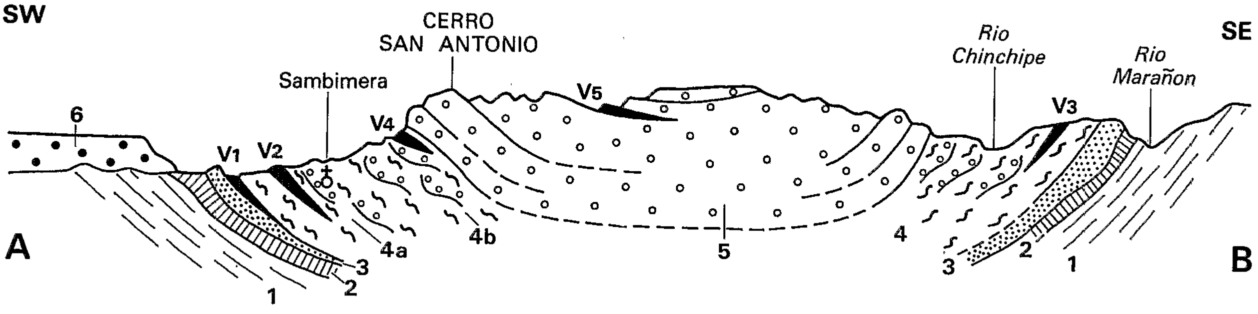

Fig. 3. Geologic SW-NE section through the Bagua syncline (see location in Fig. 2): 1, Celendín Formation; 2, Fundo El Triunfo Formation; 3, Rentema Formation; 4a and 4b, lower and upper Sambimera Formation; 5, San Antonio Formation; 6: Tamborapa Formation. The F-T dated volcanic tuffs are shown as black intercalations; tuffs V4 and V5 are cut by the section, whereas tuffs V1, V2, and V3 crop out SW of the section and their position is inferred by lateral correlation.

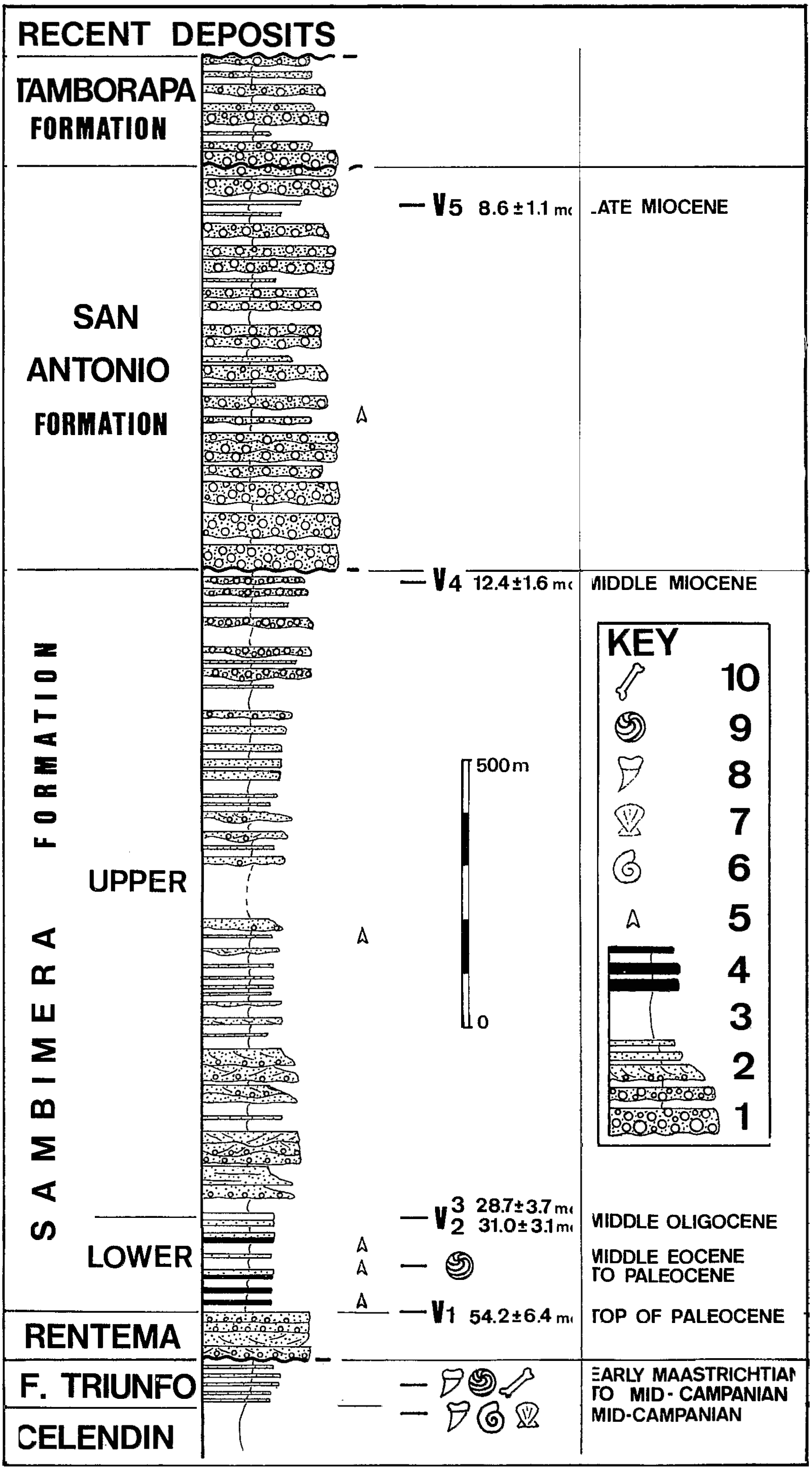

Fig. 4. Composite section and calibration of the continental red beds sequence of the Bagua area: 1, conglomerates; 2, sands; 3, shales; 4, limestones; 5, gypsum; 6, ammonites; 7, other molluscs; 8, selachians; 9, charophytes; 10, tetrapods.

DISCREPANCIES BETWEEN K/Ar AND F-T AGES

Prior to determination of the F-T ages reported here, the lower part of the Sambimera Member was the only continental Tertiary deposit in the Bagua syncline to be dated by paleontologic and isotopic data (Mourier *et al.*, 1988). The Cerro Portachuelo charophyte association is assigned to the early Paleocene to late mid-Eocene. This age assignment is in broad agreement with the K/Ar ages of the overlying V2 tuff (which ranges from 53.6±3.1 up to 68.1±4.6 Ma). It is, however, also consistent with the new F-T ages obtained from the same tuff (31.0±3.1 Ma) and from the underlying V1 tuff (54.2±6.4 Ma). The new F-T dates indicate much younger ages than those obtained by the K/Ar method.

The most obvious conflict involves the K/Ar and F-T dating of the Cerro Fila Larga (V2) tuff (samples Be 84-11 and Si 84-4 of Mourier *et al.*, 1988). K/Ar ages of these samples ranging from 53.6±3.1 to 68.1 ±4.6 Ma were reported (Mourier *et al.*, 1988), whereas the F-T age is 31.0±3.1 Ma. This significant discordance of ages on the same tuff and sample must be due to differences in the methodology. The K/Ar data were obtained on several splits of plagioclase, each dated split contained thousands of crystals. The possibility of detrital contamination must always be considered when an age is determined on a multi-grained concentrate. The K/Ar results of two splits of sample Si 84-4 were considered the most valid because of their apparent freshness, homogeneity, and purity; their mean value of 66.0±1.6 Ma was regarded as the most reliable (Mourier *et al.*, 1988).

It must be pointed out that the zircon concentrates from all samples contained euhedral zircon crystals, as well as a high percentage of subhedral and rounded zircon crystals; this latter group represents detrital crystals from older source terrains that were incorporated in the tuff during deposition. Some of these subhedral and rounded zircons from sample Be 84-6 (V4 tuff) were deliberately included in the analysis of this tuff, and their F-T ages are significantly older than those of the euhedral (primary) crystals of the same separate. The fission-track data of the individual crystals from sample V4 are given in Table 2. The three older grains (V4, grains 1-3) were not included in the age calculation and data shown in Table 1. For all the remaining samples, *only euhedral grains were counted.* Samples V1, V2, and V3 all yielded individual grains ages representative of a single age population.

As stated earlier, sample V5 also failed the Chi-square test, which suggests that there is excess scatter in the data set (this scatter could be caused by grain selection during the analysis or by detrital contamination). In this sample, only euhedral grains were counted. As shown in Table 2, the ages of the individual grains from this sample formed two groups. The youngest group (grains 1-2) has an age of 6.4±1.3 Ma and the older group (grains 3-6) yielded an age of 11.1±1.9 Ma. There are two possible interpretations concerning the age of the tuff. The first is that the age is 8.6±1.1 Ma, which represents a single age population and the grains chosen for counting happened to fall into two groups; this occasionally happens (Naeser, unpublished data). The other interpretation is that the age is 6.4±1.3 Ma and the slightly older group represents detrital contamination from a nearby igneous source. Based on the currently available data, the preferred interpretation is that the age of tuff V5 is 8.6±1.1 Ma. Either interpretation, however, indicates that the tuff and its enclosing sediments were deposited during the late Miocene.

Table 2. Individual grain data and ages for samples that failed the Chi-square test.

Tuffs		Grain	Fossil Tracks Counted	Induced Tracks Counted	Age (Ma)	± 2σ
V4	Detrital	1	28	15	57.8	37
		2	134	166	25.0	5.8
		3	214	95	69.7	17
	Primary	4	76	197	12.0	3.2
		5	88	202	13.5	3.5
		6	46	149	9.6	3.2
		7	71	164	13.5	3.8
		8	79	187	13.1	3.5
	grains	1–3	376	276	42.2	6.9
	grains	4–8	360	899	12.4	1.6
	all grains	1–8	736	1175	19.5	2.0
V5		1	47	266	5.5	1.7
		2	84	370	7.1	1.7
		3	45	147	9.5	3.2
		4	31	91	10.6	4.4
		5	85	241	11.0	2.8
		6	32	61	16.3	7.1
	grains	1–2	131	636	6.4	1.3
	grains	3–6	193	540	11.1	1.9
	all grains	1–6	324	1176	8.6	1.1

V4, Sambimera Formation; V5, San Antonio Formation;
dose = 1.04×10^{15} n/cm^2; tracks counted = 2882; $\lambda_f = 7.03 \times 10^{-17}$ yr^{-1}

In the fission-track method, individual crystals are dated, whereas with the K/Ar method, hundreds or thousands of crystals are analyzed as a part of the age determination. It is suggested that within the plagioclase splits analyzed by the K/Ar method, an undetermined quantity of detrital plagioclase was also present. This could account for the wide range of ages reported by Mourier *et al.* (1988) and older ages obtained by the K/Ar method on the felspar fractions. It should also be noted that the fission-track ages stack up in stratigraphic order. Thus, we are led to conclude that F-T data yield the more geologically meaningful ages of the tuffs in the Bagua syncline.

STRATIGRAPHIC AND TECTONIC IMPLICATIONS

The F-T ages of five volcanic tuffs intercalated in the Tertiary continental deposits of the Bagua syncline imply considerably younger ages for the strata overlying the V1 tuff. Moreover, together with the paleontologic data, they reveal important stratigraphic gaps that lead us to a revision of the stratigraphic terminology stated by Mourier *et al.* (1988). The Bagua Formation is now defined as the Bagua Group, and the previous members (Fundo El Triunfo, Rentema, and Sambimera) now become formations on the basis of their lithologic contrasts and/or the stratigraphic discontinuities that separate them (Figs. 4 and 5).

Fundo El Triunfo Formation

The age of the Fundo El Triunfo Formation remains unchanged and is constrained to a mid-Campanian to early Maastrichtian time span on the basis of its own fossil record and its transitional and close biostratigraphic relation with the mid-Campanian upper part of the underlying Celendín Formation (Mourier *et al.*, 1988). It illustrates the emergence period of the western Peruvian margin, except for the Talara-Lancones Basin (Olsson,1944; Séranne, 1987), which has a different history.

Rentema Formation

The conglomeratic red beds of the Rentema Formation overlie the Fundo El Triunfo Formation with a low-angle unconformity and appear to be overlain by the V1 tuff, which is dated as *ca.* 54 Ma by the F-T method (*i.e.*, the Paleocene-Eocene boundary, according to Haq *et al.*, 1987). Thus, the deposition of the Rentema Formation occurred within a mid-Maastrichtian to earliest Eocene interval.

In the Ecuadorian Oriente, conglomerates of the Tiyuyacu, Cuzutca, and lower Pastaza Formations ascribed to the lower Eocene disconformably overlie the Upper Cretaceous Tena Formation (Tschopp, 1953; Faucher and Savoyat, 1973; Bristow and Hoffstetter, 1977). For the Peruvian Oriente, Koch and Blissenbach (1962) described a conspicuous layer of locally conglomeratic sandstones at the base of the Capas Rojas 3 Formation of Eocene age ("Basissand"). In the Talara Basin of northwestern Peru, Paleocene hemipelagic shales are disconformably overlain by the basal conglomeratic strata of the Eocene Salinas

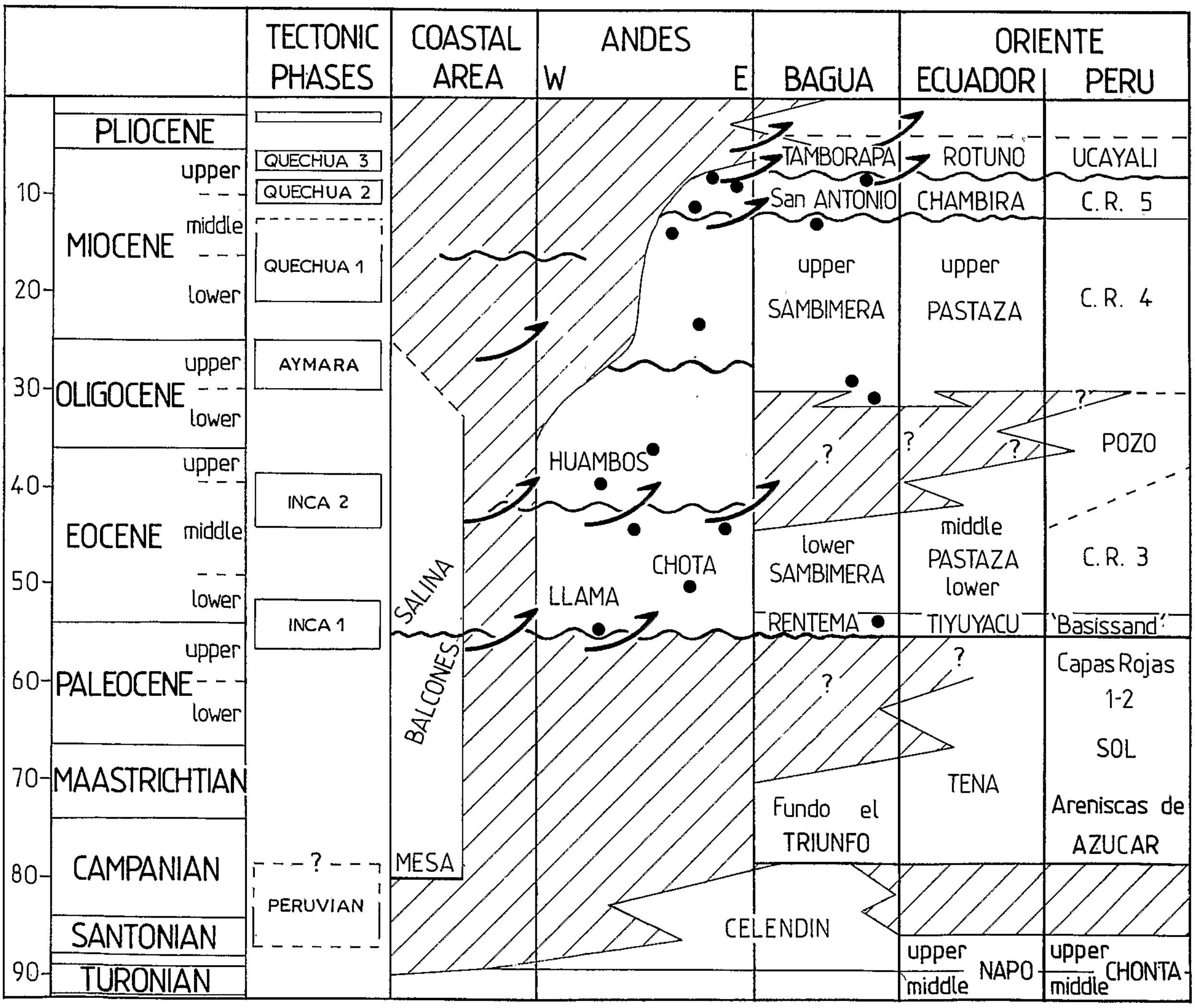

Fig. 5. Chronology of the sedimentary and tectonic episods in the Bagua basin from Late Cretaceous to Recent time, and tentative correlations with adjacent areas of Ecuador and Peru (partly after Mourier, 1988; Noble *et al.*, 1989). Black spots represent radiochronologic data.

Group (Zuñiga and Cruzado, 1979; Séranne, 1987). Noble *et al.* (1990) described an unconformity at the base of the lower to mid-Eocene Chota and Llama Formations, approximately 100 km south of Bagua, and ascribed it to the Incaic-1 phase that occurred near the Paleocene-Eocene boundary. Thus, the unconformity seen below the Rentema Formation seems to be widely correlative and may be related to the Incaic-1 phase and to the K5 discontinuity of Jaillard and Sempéré (1989). The Rentema conglomeratic sandstones may represent a distal response to late Paleocene tectonic activity (Incaic-1 phase) of the Cajamarca Fold and Thrust Belt south of the Bagua area (Mourier, 1988; Noble *et al.*,1990). If true, the Rentema Formation would be of latest Paleocene to earliest Eocene age, and an important stratigraphic gap probably exists between the Campanian-Maastrichtian Fundo El Triunfo Formation and the Rentema Formation (Fig. 5).

Sambimera Formation

Sedimentary conditions completely changed with the palustrine lower strata of the Sambimera Formation that overlie the Rentema Formation (and the V1 tuff), but neither unconformity nor disconformity is clearly seen at the contact. However, a time gap and/or regional truncation cannot be ruled out, especially as the Rentema Formation is thicker on the northeastern limb of the syncline than on the southwestern one. At Cerro Portachuelo, approximately 11 km west of Bagua Grande, a charophyte association is known from a thin carbonate layer of the Sambimera Formation some tens of meters above its base. This flora ranges within a Dano-Montian to Bartonian interval (Feist, in Mourier *et al.*, 1988). According to the *ca.* 54 Ma F-T age of the underlying V1 tuff, the lacustrine lower unit of the Sambimera Formation must be considered as early to mid-Eocene in age.

The fluvial deposits of the upper part of the Sambimera Formation constitute an upward-coarsening detrital sequence that is devoid of lacustrine beds. Two tuffs (V2 and V3), one on each side of the syncline, intercalated at the base of the upper part of the Sambimera Formation are dated by F-T at 31.0±3.1 Ma and 28.7±3.7 Ma, respectively. Because the two ages are the same within analytical uncertainty, we consider that both tuffs represent a single volcanic event, whereas previously they were considered separate volcanic events in the interpolated stratigraphic sequence (Mourier *et al.*, 1988). The age is close to the early-late Oligocene boundary according to Haq *et al.* (1987). The V4 tuff sample, recovered from the upper detrital strata of the Sambimera Formation, is dated by F-T at 12.4±1.6 Ma (*i.e.*, middle Miocene, according to Haq *et al.*, 1988). The fluvial upper part of the Sambimera Formation is therefore mid-Oligocene to middle Miocene in age. Accordingly, the whole Sambimera Formation must be regarded as ranging from the lower Eocene to the middle Miocene. A stratigraphic gap of upper Eocene-lower Oligocene is suggested by the isotopic data (Fig. 5), although no discontinuities have been seen in the field.

An Eocene-Miocene sequence, such as we propose, is known in the Ecuadorian Oriente (Tschopp, 1953; Faucher and Savoyat, 1973; Bristow and Hoffstetter, 1977). There, gypsum-bearing shales and marls with brackish fauna (middle Pastaza and Chalcana Formations) are overlain by coal-bearing sandstones with freshwater fauna (upper Pastaza and Arajuno Formations). These deposits are ascribed to a poorly constrained late Eocene to Miocene time span.

The lacustrine lower unit of the Sambimera Formation may be correlated either with the gypsum and coal-bearing sandstones, shales, and marls of the Capas Rojas 3 Formation of (late?) Eocene age (Koch and Blissenbach, 1962), or with the marine to brackish Pozo Formation (Contamana II Formation of Koch and Blissenbach, 1962) of the Peruvian Oriente, which has been attributed to a late Eocene-Oligocene time span (Williams, 1949; Koch and Blissenbach, 1962; Gutierrez-Chavez, 1975; Vargas, 1988). The Pozo Formation is overlain by marly and sandy deposits considered to be Miocene (CR4 Formation of Koch and Blissenbach, 1962; Gutierrez-Chavez, 1975; Seminario and Guizado, 1976) that correlate with the upper unit of the Sambimera Formation.

The existence of a high-angle unconformity related to the late Eocene Incaic-2 phase (*ca.* 43 Ma), considered to be the main Andean tectonic phase (*e.g.*, Mégard, 1984; Sébrier *et al.*, 1988), has been definitely established (Noble *et al.*, 1990) approximately 100 km south of Bagua in the Llama-Bambamarca and Chota region. In the northern Peruvian sub-Andes, Pardo (1982) reported a sharp disconformity in seismic sections below the Pozo Formation, which he attributed to a late Eocene event. Surprisingly, in the Bagua area, the Sambimera Formation does not record a clear tectonic or sedimentary discontinuity that could correspond to the late Eocene Incaic-2 phase. However, the suggested upper Eocene-lower Oligocene stratigraphic gap could represent an effect of this phase. Further evidence of Eocene tectonism can be seen south of Peru in Bolivia. Benjamin *et al.* (1987) dated the beginning of a major period of uplift at 45 Ma in the Eastern Cordillera of Bolivia, just north of La Paz, using fission-track ages of apatite and zircon concentrates from the plutonic and metasedimentary rocks. This period of uplift and cooling began in the middle Eocene and continues to the present.

In southern Peru, a 25-30 Ma tectonic phase has been reported ("Aymara phase" of Sébrier *et al.*, 1988; see also Ellison *et al.*, 1989). This late Oligocene tectonic event, also recorded in the Ecuadorian and Peruvian Oriente (Fig. 5), seems to correlate with the transition from lacustrine lower to fluvial upper facies of the Sambimera Formation (*ca.* 28-30 Ma).

San Antonio Formation

The approximately 850-meter-thick fanglomerates of the San Antonio Formation disconformably overlie the Sambimera Formation. At the top of the San Antonio Formation, the V5 tuff is now dated at 8.6±1.1 Ma by F-T. A broad late Miocene age is suggested for the San Antonio Formation. These coarse, disconformable deposits are probably correlative with the 1500-meter-thick alluvial fan deposits of the Chambira and Ushpa Formations of the Ecuadorian Oriente, which are ascribed to the upper Miocene or Pliocene (Tschopp, 1953; Campbell, 1974; Bristow and Hoffstetter, 1977) and express a major late Miocene tectonic event (Faucher and Savoyat, 1973). In the Peruvian Oriente, the up to 1000-meter-thick Capas Rojas 5 Formation (conglomerates, sands, and shales) of late Miocene age (Koch and Blissenbach, 1962) may be another distal equivalent of the San Antonio Formation. Deposition of the San Antonio Formation in the Bagua region seems to have been related to a major pulse of the Marañon Thrust and Fold Belt. This major tectonic event is predated by the 12.4 Ma V4 tuff and broadly correlates with the Quechua-2 phase (8-11 Ma; Sébrier *et al.*, 1988; Noble *et al.*, 1989). However, Mégard (1984) mentioned that the Quechua-1 phase, usually bracketed between 15 and 20 Ma (Sébrier *et al.*, 1988), possibly reaches 12.5 Ma locally.

Tamborapa Formation

The Tamborapa Formation unconformably overlies the San Antonio Formation and postdates the folding phase reponsible for the Bagua syncline. Although the Tamborapa Formation remains undated, its basal unconformity is preceded by the 8.6-Ma V5 tuff; therefore, this tectonic event could represent either the Quechua-2 phase (*ca.* 10 Ma) or, more probably, the Quechua-3 phase (6-7 Ma; Mégard, 1987; Sébrier *et al.*, 1988; Ellison *et al.*, 1989) of late Miocene age. Tectonic activity seems to have followed this event, at least in the MTFB where conglomerates regarded as equivalent to the Tamborapa Formation are affected by plurihectometric overthrusting (Mourier, 1988). Because most of the cobbles proceed from Cretaceous formations, the active MTFB seems to have been the source of detrital Neogene sedimentation in the Bagua area. In the Peruvian and Ecuadorian Oriente, east-thinning wedges of undeformed fanglomerates are considered as Plio-Pleistocene in age (Mesa, Rotuno, and Ucayali Formations; Kummel, 1948; Tschopp, 1953; Baldock, 1982). They possibly correlate with the Tamborapa Formation of the Bagua area, as they are similarly dissected by recent erosions (Faucher and Savoyat, 1973) and are in the same stratigraphic situation.

Quaternary alluvial deposits fill deep valleys carved into older formations, including the Tamborapa Formation, by rivers running toward the Amazonian lowlands. The incision of these valleys relates to the recent high uplift rates of the Eastern Andes of northern Peru.

CONCLUSIONS

1. The K/Ar ages previously reported for a reworked volcanic tuff of the Bagua syncline appear to be geologically unreliable in view of new F-T data, as contamination by older detrital plagioclase material is probable.
2. The F-T ages presented here provide numerical age assignments for the Bagua red beds that fit well with the previous fossil record for the lower part of the section. They allow a rather good bracketing and recognition of probable large stratigraphic gaps within the sedimentary sequence. The F-T ages thus lead us to revise the stratigraphy of the Bagua area and to change former age assignments for the middle and upper parts of the section. Finally, they allow large-scale stratigraphic correlations with Tertiary formations of the sub-Andean basins of Ecuador and Peru that are roughly consistent with the available paleontologic data. Such correlations indicate a coherent tectono-sedimentary evolution of the eastern part of the Andes of northern Peru.
3. The tectonic Incaic-1 phase of late Paleocene age (*ca.* 56 Ma; Noble *et al.*, 1990) seems to be recorded by the basal disconformity of the Rentema Formation.
4. In contrast, the effects of the widespread Incaic-2 major phase of middle Eocene age (40-45 Ma; Mégard, 1984, 1987; Benjamin *et al.*, 1987; Sébrier *et al.*, 1988; Noble *et al.*,1990) are unclear in the Bagua area. The probable gap of upper Eocene to lower Oligocene sediments in the Bagua region could be related to this phase of tectonism, which has been recognized from Ecuador to Bolivia.
5. The transition from lacustrine to fluvial deposits in the Sambimera Formation could be related to the Oligocene Aymara tectonic phase (25-30 Ma; Sébrier *et al.*, 1988).
6. The sharp basal discontinuity of the San Antonio Formation of middle Miocene age, which is widely correlative through the eastern Andean basins, may represent the Quechua-2 phase (*ca.* 10 Ma), because the age of the tectonic phase in the Bagua area (*ca.* 12 Ma) appears somewhat younger than those determined in most of the Peruvian areas for the Quechua-1 phase (Mégard, 1984, 1987; Sébrier *et al.*, 1988).
7. The strong basal unconformity of the Tamborapa Formation of late Miocene age (*ca.* 8 Ma) could be synchronous either with the well bracketed Quechua-2 phase, or, more probably, with the Quechua-3 phase (6-7 Ma; Mégard, 1987; Sébrier *et al.*, 1988; Ellison *et al.*, 1989).
8. The coarse deposits, high sedimentation rates, and sharp unconformities recorded in the Bagua

area since late Oligocene time contrast with the low deposition rates and weakness of tectonic effects on sedimentation during late Cretaceous to Eocene time. These reflect, on the one hand, eastward migration of the deformation through time, and, on the other hand, strong tectonic subsidence (of foreland basin type) in the Eastern Andes areas since Miocene time.

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