Journal of South American Earth Sciences, Vol. 1, No. 3, pp. 225–238, 1988
Printed in Great Britain

0895-9811/88 $3.00 + 0.00
Pergamon Press plc

Oligocene and Miocene continental sedimentation, tectonics, and S-type magmatism in the southeastern Andes of Peru (Crucero Basin): Geodynamic implications

G. LAUBACHER,[1] M. SEBRIER,[2] M. FORNARI,[3] and G. CARLIER[3]

[1]ORSTOM, 213 rue La Fayette, 75010 Paris, and Centre Géologique et Géophysique, USTL, Place E, Bataillon, 34060 Montpellier; [2]Laboratoire de Géologie Dynamique Interne, Université de Paris-Sud, 91405 Orsay Cedex; [3]ORSTOM, 213 rue La Fayette, 75010 Paris

(*Received for publication December 1987*)

Abstract—The Crucero Basin, located north of Lake Titicaca (70°W, 14°20'S), was probably connected with the Altiplano endoreic basin since Oligocene time. During the Oligocene and Miocene, this basin was filled by nearly 1000 meters of fanglomerate and lacustrine sediments — *e.g.*, the Cayconi Formation, which unconformably overlies upper Paleozoic and Cretaceous rocks and is unconformably overlain by fanglomerates and palustrine sediments of Pliocene age. Basic and silicic volcanic rocks are interbedded and associated with the Cayconi Formation. Major element analyses indicate intracrustal melting for the silicic volcanic rocks, whereas the basic volcanics seem to be mantle derived. K-Ar dating of these volcanic rocks yielded ages ranging from 25.9 Ma to 15.5 Ma. Thus, in the Cordillera Oriental, magmatism is at least as old as late Oligocene.

Resumen—La cuenca de Crucero, situada al norte del lago Titicaca (70°W, 14°20'S), estaba en conexión con la depresión endorreica del Altiplano probablemente desde el Oligoceno. Dicha cuenca fue rellenada durante el Oligoceno y el Mioceno por cerca de 1000 metros de material conglomerádico aluvial y sedimentos lacustres de la Formación Cayconi. Esta formación descansa en discordancia angular sobre rocas del Paleozoico superior y del Cretacico y está, a su vez recubierta discordantemente por conglomerados aluviales y sedimentos palustres del Plioceno. Rocas volcánicas básicas y ácidas se encuentran intercaladas en la Formación Cayconi. Los análisis de elementos mayores indican que las rocas volcánicas ácidas derivan de una corteza fundida, mientras que las básicas parecen proceder del manto. De estas rocas se han obtenido edades radiométricas K-Ar comprendidas entre 25.9 Ma y 15.5 Ma lo que indica que la Cordillera Oriental fue el sitio de una fuerte actividad magmática desde por lo menos el Oligoceno superior.

INTRODUCTION

DURING the last fifteen years it has been shown that the approximately 300 km wide Cenozoic magmatic arc of the Central Andes was composed of two major belts: a calc-alkaline western belt located in the Cordillera Occidental, and a shoshonitic eastern belt located in the Altiplano and part of the Cordillera Oriental (Lefevre, 1973; Thorpe and Francis, 1979). Besides this broad magmatic arc, Pliocene peraluminous volcanism has been documented in the Cordillera Oriental of southern Peru (Barnes *et al.*, 1970). The peraluminous character and crustal origin of this volcanism has been emphasized in recent studies (Herrera *et al.*, 1984; Kontak and Pichavant, 1984; Kontak *et al.*, 1984; Noble *et al.*, 1984). Clark *et al.* (1983) and Kontak *et al.* (1984) have described and dated peraluminous stocks as between 23 and 26 Ma, which suggests that peraluminous magmatism began in late Oligocene time. Although this magmatism has been studied either for economic reasons or to constrain modeling of crustal magma genesis, little attention has been given to its geologic setting.

We have studied the relationship of these peraluminous rocks with continental deposits of the Crucero Basin and with the basalts described by Laubacher (1978). Our field work and new K-Ar dates show that the Crucero Basin is mainly Oligocene and Miocene in age. Sedimentological, structural, and petrological analyses allow us to specify basin dynamics and to address the tectonic setting of the peraluminous silicic magmatism, the relationship between basaltic and silicic volcanic suites, and the possible origin of these magmas.

THE CRUCERO BASIN

The Crucero Basin (60 km long, 25 km wide; Figs. 1 and 2) is located 50 km to the north of Lake Titicaca and belongs to a string of small intermontane depressions (Macusani, Crucero, Ancocala-Ananea, and Cojata-Ulla Ulla) that are situated between 14°S and 15°15'S on the western edge of the Cordillera Oriental. The Crucero Basin has a mean elevation of 4300 meters; it is bounded to the northeast by the 4800-5400 meter summits of the Cordillera Oriental, and to the southwest by the 4600-5100 meter Carabaya Precordillera. The latter range separates the Crucero Basin from the Altiplano and is cut by the Río Carabaya, which drains from the basin toward Lake Titicaca.

The Oligocene-Pleistocene fill of the Crucero Basin unconformably overlies Paleozoic and Mesozoic rocks that have been successively deformed by the Eohercynian (latest Devonian to earliest Car-

SAES 1/3-A

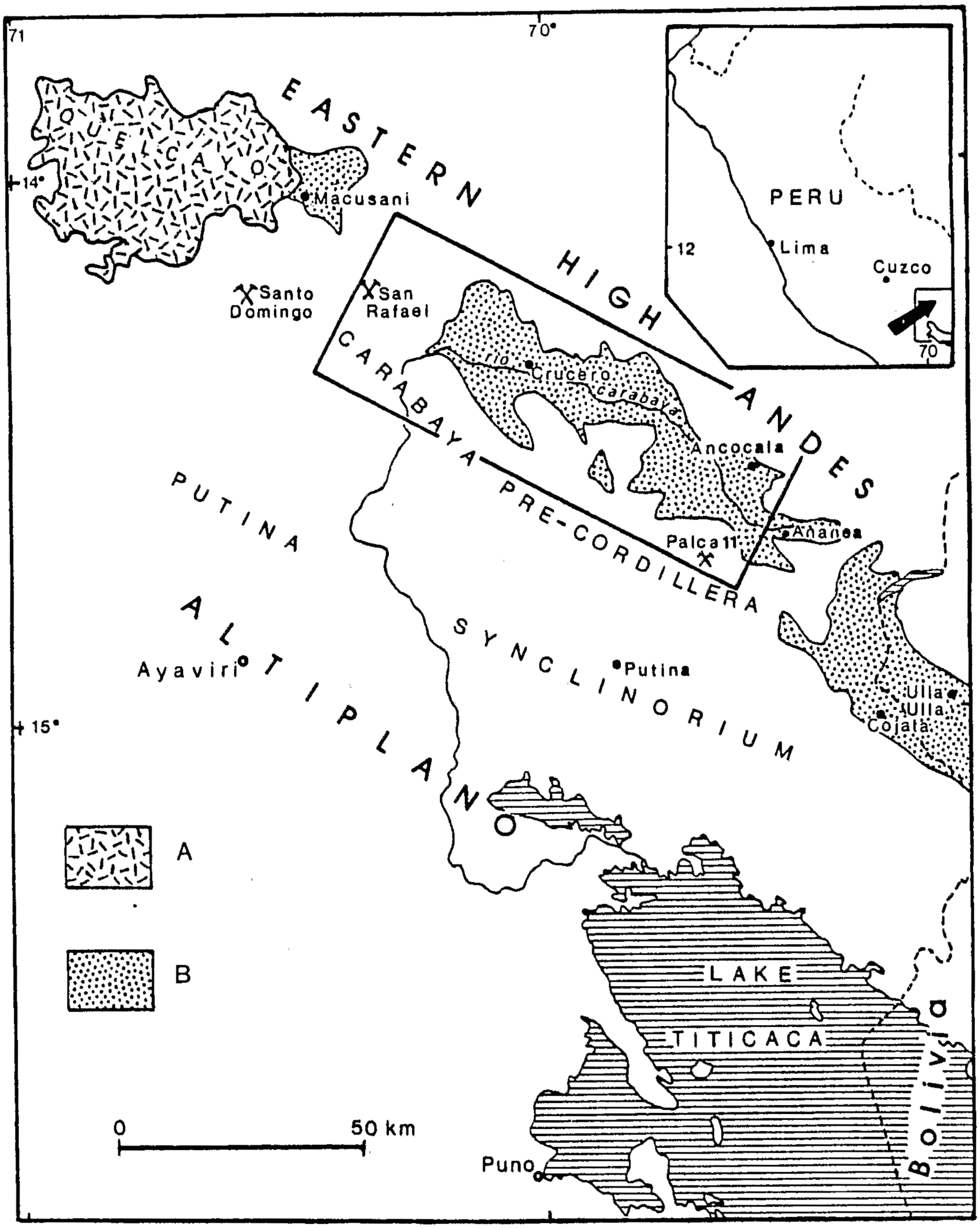

Fig. 1. Oligocene to Quaternary continental sedimentation and volcanism in the Cordillera Oriental of southern Peru: A) Macusani, Crucero-Ancocala, and Cojata-Ulla Ulla intermontane basins with mid-Tertiary to Quaternary deposits; B) Quelcayo Neogene ignimbritic plateau. The box indicates location of Fig. 2.

boniferous), Tardihercynian (mid-Permian), and Incaic (late Eocene to early Oligocene) tectonic phases (Audebaud and Laubacher, 1969; Audebaud *et al.*, 1976; Laubacher, 1978). The Mesozoic rocks are composed of Cretaceous continental sandstones and shales that are equivalent to Newell's (1949) Cotacucho and Vilquechico Groups exposed in the northeastern limb of the Putina synclinorium (see Fig. 1). Eocene sandstones are known only south and west of the Crucero Basin in the Carabaya Precordillera and in the Putina synclinorium; they conformably overlie Cretaceous rocks and indicate that folding prior to formation of the Crucero Basin was probably coeval with the late Eocene to early Oligocene (Incaic) tectonic phase reported on the Peruvian Altiplano (Chanove *et al.*, 1969).

The Crucero Basin was initiated during Incaic deformation and was filled with sediments that lap unconformably across the folded Paleozoic and Mesozoic rocks. Two main series of rocks (Fig. 3) comprise the basin fill: the Oligocene-Miocene Cayconi Formation, and Pliocene-Pleistocene deposits. A number of planar surfaces occur within the basin; their step-like nature indicates seven major episodes of surface formation. The oldest episode corresponds to a 4500-4600 meter pediment that lies on the Cayconi Formation and that seems to correlate with the topographic surface which cuts the Cordillera Oriental series at the edges of the Crucero Basin. The six younger pediments are related to Pliocene and Pleistocene erosion. The oldest of these six lies on the Pliocene(?) Mercedes Formation (see below) at a

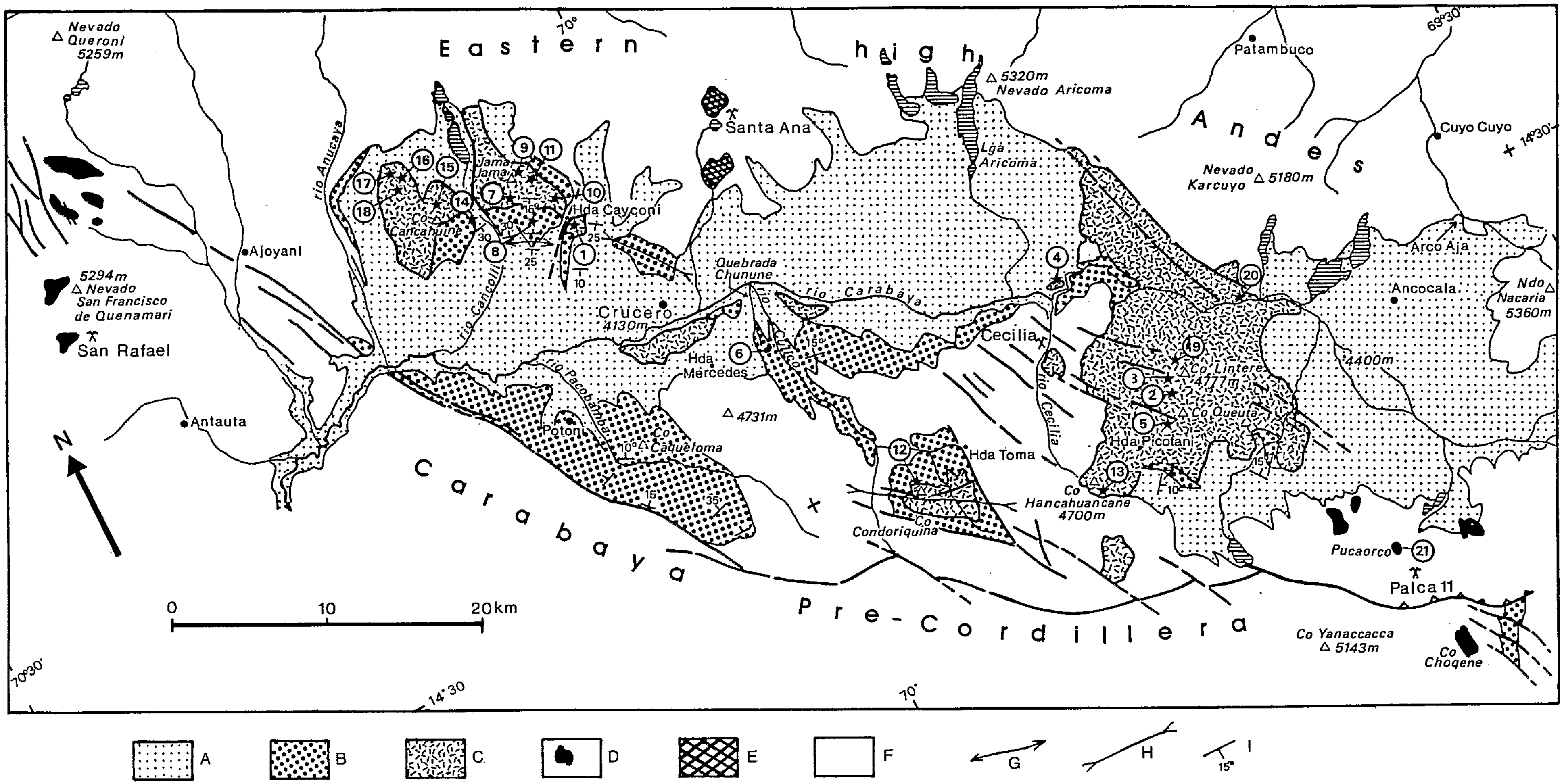

Fig. 2. Geological sketch map of the Crucero area: A) Pliocene and Quaternary sediments; B) Oligocene and Miocene sediments; C) Oligocene and Miocene acidic and basic volcanic rocks; D) Oligocene and Miocene acidic plutonic rocks; E) micro-dioritic plutons of probable Andean age; F) pre-Oligocene rocks; G) anticline; H) syncline; I) dip of strata. Circled numbers indicate rock samples located with stars.

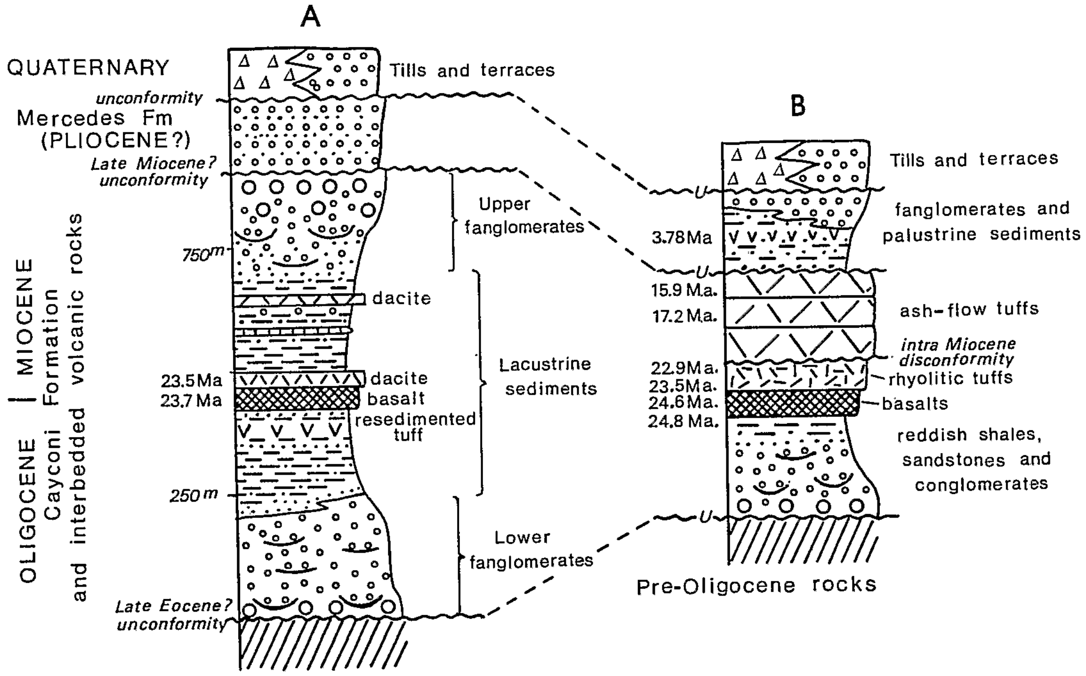

Fig. 3. Oligocene to Quaternary stratigraphic records of the Crucero Basin: A) synthesized record with typical facies of the Cayconi Formation from the Crucero area; B) synthesized but rather incomplete record from the Hacienda Picotani area with only clastic facies of the Cayconi Formation.

mean elevation of 4250 meters, whereas the others correspond to surfaces of Pleistocene fluvial and outwash deposits.

Table 1 gives the location of the rock samples from the Crucero area.

The Oligocene-Miocene Cayconi Formation

The type section of the Cayconi Formation is located 10 km to the northwest of Crucero, near Hacienda Cayconi (see Fig. 2), as defined by Laubacher

Table 1. Location of the rock samples from the Crucero area.

Specimen No.	Field Numeration	Location			Rock Type
		Latitude	Longitude	Site Name	
1	MF 171080-1	14°17'S	70°03'W	Hda Cayconi	Basalt
2	MS 82008	14°32'S	69°46'W	Co Lintere	Basalt
3	MS 82009	14°32'S	69°46'W	Co Lintere	Basalt
4	MS 82017	14°27'S	69°48'W	Rio Carabaya	Basalt
5	MS 82007	14°33'S	69°47'W	Co Queuta	Basalt-andesite
6	MS 82004	14°24'S	69°59'W	Islane	Altered andesite
7	MS 82001	14°16'S	70°04'W	Hda Pachachaca	Dacite
8	MS 82002	14°17'S	70°04'W	Qda Alkamarine	Dacite
9	MS 82003	14°15'S	70°04'W	Co Jama Jama	Dacite
10	MF 271080-2	14°17'S	70°03'W	Hda Cayconi	Dacite
11	MF 281080-1	14°15'S	70°04'W	Co Jama Jama	Dacite
12	MS 82005	14°31'S	69°56'W	Co Condoriquiña	Rhyolitic tuff
13	MS 82006	14°34'S	69°50'W	Co Huancahuancane	Rhyolitic tuff
14	MS 82011	14°16'S	70°06'W	Co Cancahuine	Rhyolite
15	MS 82012	14°15'S	70°07'W	Co Cancahuine	Rhyolite
16	MS 82013	14°13'S	70°08'W	Co Pirhuacaca	Rhyolite
17	MS 82014	14°13'S	70°08'W	Co Pirhuacaca	Rhyolite
18	MS 82015	14°13'S	70°08'W	Co Pirhuacaca	Rhyolite
19	MS 82010	14°32'S	69°46'W	Co Lintere	Rhyolitic altered tuff
20	PO32	14°31'S	69°42'W	Rumicasca	Ignimbrite
21	Palca 11	14°42'S	69°41'W	Co Pucaorcco	Rhyolite

(1978). This author attributed a Pliocene age to the unit, but the present work demonstrates an Oligocene to Miocene age for these sediments (see K-Ar dates in Table 2 and below). The Cayoni Formation is approximately 800-1000 meters thick (see Fig. 3A) and is a partial time equivalent of the Puno Group and Tacaza volcanics of the Altiplano (Newell, 1949; Audebaud *et al.*, 1976). The most complete sequence of the Cayconi Formation is exposed north and northwest of the village of Crucero, in the small Cayconi, Salamancane, and Pachachaca Valleys (see IGM topographic map of Peru, 1:100,000 scale). The base of the formation is seen approximately 2 km north of Hacienda Cayconi on the western flank of the Cayconi Valley. The pre-depositional surface displays irregular morphology and the lowest strata of the formation are characterized by channel structures. These strata overlie, with low-angle unconformity, Early Cretaceous, well stratified, reddish sandstones and microconglomerates.

The Cayconi Formation is deformed in WNW/ESE-trending open and upright folds of kilometer wavelength. The dip of the limbs is always less than 35°. Reverse and normal faulting is observed. In a NE-SW profile across the Cayconi Formation, more than 800 meters of sediments and interbedded volcanic rocks are exposed and three members can be differentiated (see Fig. 3A).

The lowest member consists of a basal portion, including 10-15 meters of coarse polygenic conglomerate of predominantly upper Paleozoic derived rocks and, in minor proportions, sandstone cobbles derived from Lower Cretaceous rocks. The matrix is reddish and consists of gravel and muddy sandstone. This is overlain by 150-200 meters of poorly stratified conglomeratic red beds with lenses of gravel and sand. The base of these beds defines channel structures. Diamictic beds are present that are interpreted as mudflows.

The middle member consists of 150-200 meters of fine-grained lacustrine sedimentary rocks. These are well stratified, thinly bedded, whitish-grey sandstone, grey shales, millimeter thick coals beds with plant remains, siliceous lenticular carbonate beds, and thin beds of reworked fine-grained whitish tuff. Interbedded in this middle member is a 50-80 meter thick sequence of dark, spheroidal-jointed basaltic flows (Fig. 3A). A K-Ar age determination of 23.7± 1.3 Ma and 22.3±0.7 Ma (Table 2, Specimen 1) indicates a late Oligocene to early Miocene age for these rocks. White rhyodacitic ash-flow tuffs 50-70 meters thick (Fig. 3A) and covering several kilometers directly overlie the basalt flows. A late Oligocene to early Miocene age (23.5±0.3 Ma; Table 2, Specimen 9) was also obtained on a sample of these rocks. Above the ash-flow tuffs are 100-150 meters of lacustrine strata similar to those underlying the basalt flows. These sedimentary rocks include microconglomeratic beds that become thicker and coarser upward. The top of the middle member consists of 10-15 meters of altered rhyodacitic tuff.

The upper member of the Cayconi Formation includes more than 70 meters of well stratified microconglomerate, sandstone, and shale that crop out near Alkamarine. The formation, which is exposed in a syncline, is truncated by an erosion surface so

Table 2. K–Ar age determination on Tertiary volcanic rocks from the Crucero area.

Specimen No.[1]	Petrographic Definition	Analyzed Fraction[2]	K_2O (wt %)	$^{40}Ar_{rad}/^{40}Ar_{tot}$ (%)	$^{40}Ar_{rad}$ (10^{-10} mole/g)	Age (Ma ± 1σ)
1	Basalt	R I	1.32	20.9	4.533	23.7 ± 1.3
		R II	1.32	24.5	4.257	22.3 ± 0.7
3	Basalt	R	1.97	39.1	7.024	24.6 ± 1.3
5	Basalt-andesite	R	2.56	54.2	9.183	24.8 ± 0.7
9	Dacite	F_K	11.49	98.1	9.913	23.5 ± 0.3
13	Rhyolitic tuff	V	4.47	61.1	1.481	22.9 ± 0.6
		B	8.88	82.4	3.012	23.5 ± 0.4
15	Rhyolite	F_K	10.90	96.8	3.498	22.2 ± 0.2
18	Rhyolite	F_K	10.19	97.2	3.306	22.4 ± 0.3
20	Rhyolitic tuff	F_K	6.15	95.1	1.417	15.9 ± 0.4
	(Ignimbrite)	B	7.24	83.0	1.799	17.2 ± 0.5
21	Rhyolite	F_K	7.57	81.5	1.383	12.7 ± 0.6
		B	8.80	78.5	1.535	12.1 ± 0.3

[1]Specimens 1, 3, 5, 9, 13; 15, 18, and 20 were processed in the Laboratoire de Géochronologie, Institut Dolomieu, Université de Grenoble, France; for a technical discussion, see Bonhomme *et al.* (1988). Specimen 21 was processed in the Laboratoire de Géologie et Géochimie, Université de Nice, France.

[2]Key: R, whole rock; V, glass; B, biotite; F_K, K-feldspar.

that its total thickness is not known. The upper parts of the Cayconi Formation are present at Cerro Caqueloma and Cerro Cancahuine, located SSW and WNW, respectively, of the village of Crucero (see Fig. 2). These strata lie unconformably on top of upper Paleozoic rocks and consist of coarse, well rounded quartzite pebbles derived from lower and middle Paleozoic rocks. This lithology indicates that the last stage of basin evolution was infilling by coarse alluvial fans. The top of the conglomerate beds is a high surface, located at an elevation of about 4550 meters, that dips slightly toward the Carabaya Valley; this old surface is probably late Miocene in age.

The presence of lacustrine strata in the intermediate part of the Cayconi Formation indicates that a lake occupied the Crucero Basin during late Oligocene to early Miocene times. These strata are restricted to the Crucero area; east and south of Crucero, Oligocene and Miocene paleovalleys of the Carabaya, Pacobamba, and Cullco Rivers are filled by thick red beds consisting of coarse, locally derived material with no lacustrine intercalation. In the Hacienda Picotani area (see Figs. 2 and 3B), these red beds are overlain by basic volcanic flows dated at 24.6±1.3 Ma and 24.8±0.7 Ma (Table 2, Specimens 3 and 5) and by silicic ash flows dated at 22.9±0.6 Ma (glass) and 23.5±0.4 Ma (biotite) (Table 2, Specimen 13). This volcanism is thus coeval with the late Oligocene to earliest Miocene volcanics of the Cayconi Formation, and the underlying red beds are partly coeval with the lower and middle members of the Cayconi Formation (see Fig. 3). Approximately 10 km west of the Hacienda Cayconi, Specimens 15 and 18 (see Fig. 2), which were collected from silicic volcanic lava flows at Cerro Cancahuine and Cerro Pirahuacaca, yielded ages of, respectively, 22.2±0.2 Ma (feldspar) and 22.4±0.3 Ma (feldspar). Specimen 20, dated at 15.9±0.4 Ma (feldspar) and 17.2±0.5 Ma (biotite), is a rhyolitic tuff collected approximately 8 km north of Cerro Lintere from a large ash-flow sheet that directly overlies the late Oligocene to earliest Miocene volcanic rocks of the Hacienda Picotani area; a probable unconformity separates both groups of volcanic rocks. Specimen 21 (12.1±0.3 Ma on biotite, and 12.7±0.6 Ma on feldspar) comes from a small rhyolitic stock that intrudes upper Paleozoic rocks at Pucaorco, 2 km north of the Palca-11 mine on the southeastern edge of the Crucero Basin; its relationship with Crucero Basin sedimentation is unknown.

No fossils have been found in the Cayconi Formation, but radiometric dating of volcanic rocks interbedded in this unit indicates it is Oligocene and Miocene in age (see Tables 1 and 2). The ages obtained on silicic rocks (Specimens 9, 13, 15, and 18) and on basic rocks (Specimens 1, 3, and 5) are in good agreement with the age suspected on geologic criteria. Both volcanic suites show that an intense magmatic pulse occurred between 25.9 and 21.6 Ma (see Table 2). The basic rocks (25.9 to 21.6 Ma) yield slightly older ages than the silicic rocks (23.8 to 22 Ma), which is in agreement with the stratigraphic position of the basalts that are always at the bottom of the rhyolitic and dacitic sequence. Radiometric data on Specimens 20 and 21 indicate that silicic magmatism also took place during middle and late Miocene times in the Crucero Basin and on its margins.

Pliocene-Pleistocene Deposits

The Plio-Pleistocene deposits of the Crucero Basin are composed of the Pliocene(?) Mercedes Formation and Quaternary fans and terraces. The top surface of these deposits is cut by pediments.

The Mercedes Formation (see Fig. 2), defined 4 km southeast of the village of Crucero in the vicinity of Hacienda Mercedes, is about 150 meters thick and is composed mainly of polygenic conglomerate and fluvial sand that form 0.5-2.0 meter thick beds. Several local debris and mud flows are present. Most of the sediments are derived from the pre-Oligocene substratum, but some pebbles are reworked from the Cayconi Formation. The Mercedes Formation, which unconformably overlies the Cayconi Formation, has facies ranging from fluvio-torrential fans to fluvial terraces. This unit fills an ancient valley system carved during a major incision period of latest Miocene age that occurred after the late Miocene tectonic phase in southern Peru and Bolivia (Audebaud *et al.*, 1976; Martinez, 1980; Sébrier *et al.*, 1980, 1982; Lavenu and Marocco, 1984). The continental beds of the Mercedes Formation are locally slightly tilted and faulted. There are no paleontologic and radiometric ages for this formation. We consider it to be Pliocene, however, because similar continental beds of the Arco-Aja Formation (Fornari *et al.*, 1982), in the vicinity of Ananea (see Fig. 1), contain an interbedded ash-flow tuff that has been dated by K-Ar at about 3.8 Ma (Laubacher *et al.*, 1984a).

The Quaternary fans and terraces comprise at least five levels, consisting of fluvial, outwash, and till deposits that fill old valleys carved in the Mercedes Formation. Widespread till deposits are exposed, mainly on the northeastern slope of the Crucero Basin, but only the youngest glacial events exhibit well preserved moraines.

DYNAMICS OF THE CRUCERO BASIN

Oligocene to Recent deformation has been moderate in the Crucero Basin; the most significant structures are caused by compressional deformation that occurred between late Miocene and early Pleistocene times. Basin evolution can be subdivided into two major episodes based on the stratigraphic record — one is Oligocene and Miocene, the other is Pliocene and Pleistocene. The first episode is characterized by active basin formation and the second by the evolution of an inherited depression. The Oligocene and Miocene episode reveals no direct evidence of deformation, and basin dynamics have been deduced from sedimentologic analysis of the Cayconi Formation.

For the Pliocene and Pleistocene episode, structural analysis has been used to determine the evolution of the Crucero depression.

The Oligocene and Miocene Crucero Basin

The sedimentologic evolution of the Cayconi Formation is characterized by two thick rock sequences. A mostly Oligocene sequence extends from the bottom of the formation to the upper Oligocene and lower Miocene volcanic intercalations. In the upper part of this sequence, the strata decrease in thickness and the depositional environment changes from fluvio-torrential to palustro-lacustrine. A Miocene sequence includes volcanic intercalations at the top of the unit. This interval is characterized by increasing stratal thickness and clast size.

The Crucero Basin developed in Oligocene time after the Incaic pulse that affected the Cordillera Oriental during late Eocene to early Oligocene times (Laubacher, 1978). This pulse gave rise to NW/SE-striking open folds in Cretaceous strata unconformably overlying upper Paleozoic strata deformed during Middle Permian time (Tardihercynian phase) into NNW/SSE-striking folds and reverse faults (Fig. 4A). To the west and northwest of Crucero, folds of both Tardihercynian and Incaic phases are bent to the NE-SW orientation in a 20-30 km wide belt. We interpret this bending as the superficial effect of a deep crustal fault system with a nearly NW-SE trend and dextral strike-slip movement (Fig. 4A). This complex fold and fault system and an uplift of the Carabaya Precordillera seem to have induced the formation of the Crucero Basin. The principal effect of the Incaic pulse was the destruction of the lower Paleogene drainage system, which resulted in intensified erosion that produced a new topography later partially buried by the Cayconi Formation. The beginning of aggradation indicates that tectonic conditions changed in the basin. There is no direct evidence of a connection of the new drainage with the Altiplano or with the Sub-Andes; however the Oligocene and Miocene evolution of the Cordillera Oriental suggests a connection with the Altiplano Basin.

The sedimentary characteristics of the lower member of the Cayconi Formation suggest: *(i)* that the basin subsided approximately 500 meters during Oligocene time; *(ii)* that basinal conditions became more lacustrine upward (*i.e.*, the basin extended to its margins or the supply of clastics decreased); *(iii)* that the basin margins were generally characterized by fan embayments and were not rectilinear; and *(iv)* that although no synsedimentary faulting has been identified, the occurrence of olistolitic facies in the lower member could be indicative of tectonic activity — necessary to cause sedimentary instability and to induce subsidence. The available data indicate that the basin was subjected to extensional tectonics, which appears to be compatible with a low convergence rate between the Nazca and South American plates calculated for Oligocene time between 35 and 26 Ma (Mammerick *et al.*, 1975, 1980; Pilger, 1983).

The sedimentologic evolution of the Crucero Basin during Miocene time differed from that of Oligocene time. During the late Oligocene, the onset of volcanic activity was coeval with the widest development of

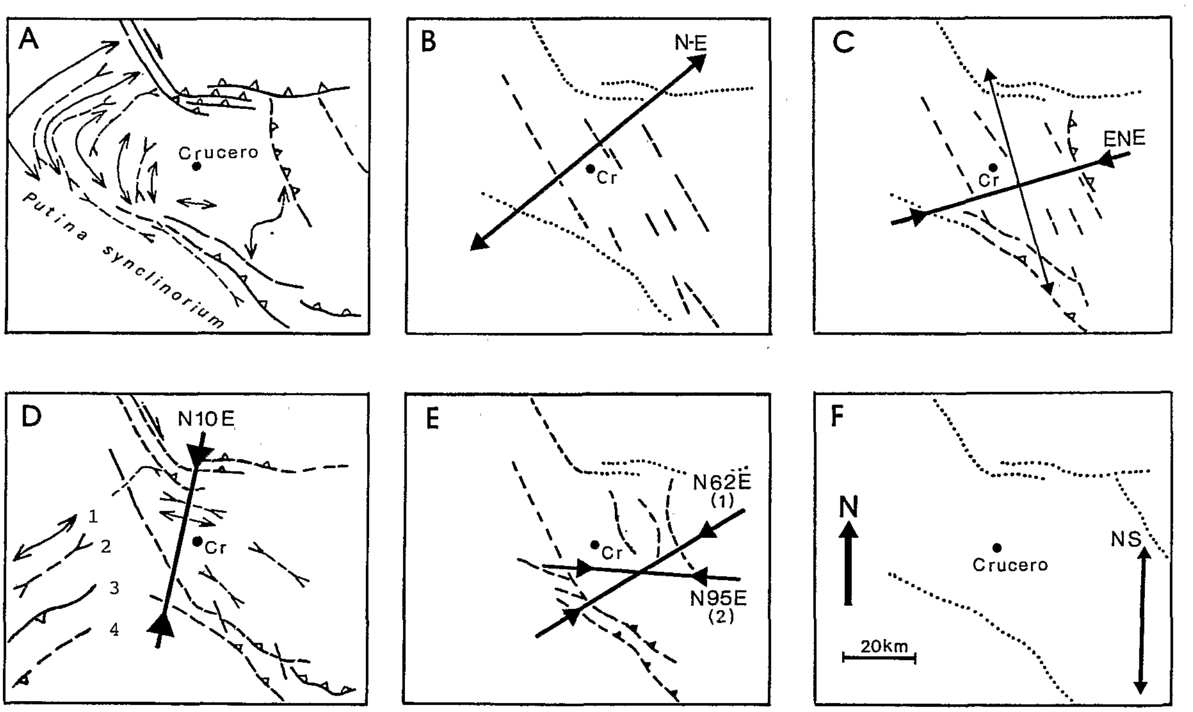

Fig. 4. Dynamics of Oligocene to Recent evolution of the Crucero Basin: A) late Eocene to early Oligocene Incaic compressional tectonics; B) Oligocene; C) late Oligocene to Miocene; D) late Miocene compressional tectonics; E) late Pliocene to early Pleistocene compressional tectonics; F) Pleistocene to present-day extensional tectonics. Stages A and F are from Laubacher (1978) and Sébrier *et al.* (1985), respectively. Stages B and C are hypothetical. Stages D and E are based on field data and structural analyses of the Crucero Basin faults presented in Fig. 5. Legend to D: 1, anticline; 2, syncline; 3, active fault and overthrust; 4, probably active fault and overthrust.

the basin. The Miocene evolution was marked by progradation of conglomeratic fans that became coarse grained upward. We think that this drastic change in basin sedimentology reflects a change from regional subsidence and basin extension in the Oligocene to uplift and reduction in basin size in the Miocene. Thus, the tensional tectonics that prevailed during Oligocene times were replaced during Miocene times by either compressional or strike-slip tectonics. As there is no evidence of compression coeval with sedimentation, it is unlikely that this basin developed in a compressional regime. No unconformity has been seen in the type section of the Cayconi Formation. However, in the Hacienda Picotani area, the probable unconformity between the late Oligocene and early Miocene volcanic rocks and the middle Miocene ash flows suggests that the southeastern edge of the basin was uplifted during the middle Miocene (Quechua 1 tectonic pulse(?); Mégard *et al.*, 1984).

The late Oligocene change in Crucero basinal dynamics and volcanic activity seems coeval with compressional tectonics recognized in other parts of the Central Andes (Noble *et al.*, 1974, 1985; Martinez, 1980; Lavenu and Marocco, 1984; Macharé *et al.*, 1986; Sébrier *et al.*, 1985). These changes are coincident with the onset of a broad magmatic arc in the Central Andes (Noble *et al.*, 1979; Clark *et al.*, 1983) and with late Oligocene plate reorganization (Mammerick *et al.*, 1975, 1980; Pilger, 1983) that produced an acceleration of Andean convergence which changes from a NE-SW to a nearly E-W direction.

In summary, we propose that, during Oligocene and Miocene times, the Crucero Basin underwent two successive and different dynamics: *(i)* extension during Oligocene time when plate convergence was NE-SW and slow, and *(ii)* strike-slip deformation coeval with volcanism during the Miocene when plate convergence was E-W and faster.

The Pliocene and Pleistocene Crucero Depression

The Cayconi Formation is gently folded and faulted in a broad WNW/ESE-trending synclinorium. The age of this deformation is not well constrained, but it is older than the Mercedes Formation. The youngest radiometric ages obtained on the Cayconi Formation are middle Miocene, and we assume a Pliocene age for the Mercedes Formation (see above). Thus, the major folding pulse of the Crucero Basin probably occurred during late Miocene time. This phase of compressional deformation is reported in many other Andean areas (Audebaud *et al.*, 1973, 1976; Schwab and Lippolt, 1974; Van Houten, 1976; Laubacher, 1978; Martinez, 1980; Mégard, 1978; Sébrier *et al.*, 1980, 1982; Drake *et al.*, 1982; Lahsen, 1982; Jordan, 1984; Lavenu and Marocco, 1984). In addition, a younger compressional event of minor magnitude occurred during the late Pliocene to early Pleistocene, which resulted in the local tilting and reverse faulting of the Mercedes Formation. This tectonic activity is coeval with compressional movements reported in the Bolivian and Peruvian Andes (Lavenu, 1978; Lavenu *et al.*, 1980; Martinez, 1980; Sébrier *et al.*, 1980, 1982; Blanc, 1984; Bonnot, 1984; Cabrera, 1984; Huaman, 1985; Macharé *et al.*, 1986).

Analysis of faults and fault striations in the Cayconi and Mercedes Formations (Fig. 5) provides evidence of three different episodes of tectonism. Their successive kinematics are in agreement with, respectively: *(i)* a nearly N/S-trending shortening, *(ii)* a roughly WSW/ENE-trending shortening, and *(iii)* an E/W-trending shortening. Computation of the stress tensor (Carey, 1979) confirms these results (Fig. 5). As the N/S-trending episode exhibits the oldest striations and is seen only in the Cayconi Formation, it must have been responsible, therefore, for the upper Miocene folding. Faults related to the second and third episodes are seen in both the Cayconi and Mercedes Formations, and their striations are posterior to the first episode. Thus, the WSW/ENE-trending and E/W-trending episodes should be related to compressional movements of late Pliocene to early Pleistocene age; however, these second and third episodes could represent small variations in a single compressional pulse as their kinematics are not very different.

The present-day stress seems to be characterized by N/S extensional tectonics, as normal E/W faults offset Pleistocene tills in the vicinity of Ananea (Sébrier *et al.*, 1985) (Figs. 1 and 4F), but this tensional deformation is of small magnitude and does not appear to control the recent evolution of the Crucero depression. Therefore, the present morphostructural outlines of the depression are mainly inherited from the late Miocene tectonic structuration. During Pliocene to Recent times, the morphologic evolution of the basin was mostly controlled by climatic factors.

VOLCANISM IN THE CRUCERO BASIN

Volcanic rocks are intercalated in the middle member of the Cayconi Formation. These rocks are of latest Oligocene to early Miocene age, with K-Ar dates ranging from 24.6 ± 1.3 Ma to 22.3 ± 0.7 Ma (see Table 2; see also Bonhomme *et al.*, 1988). Another volcanic pulse, coeval with the upper member of the Cayconi Formation, occurred in middle-late Miocene time (Specimen 20: 17.2 ± 0.5 and 15.9 ± 0.4 Ma). According to their petrological and geochemical characteristics (Tables 3 and 4), these volcanic rocks comprise two distinct suites — crustal silicic lavas and tuffs, and mantle-derived mafic lavas. Several silicic stocks of Oligocene and Miocene age, coeval with the volcanism of the Crucero Basin, crop out on the northwestern (San Rafael mine area) and southeastern (Palca-11 mine area) edges of the Crucero Basin (see Fig. 2).

Silicic volcanism constitutes the major part of volcanism in the Crucero Basin and crops out across an area of about 15 km^2. This volcanism comprises lava

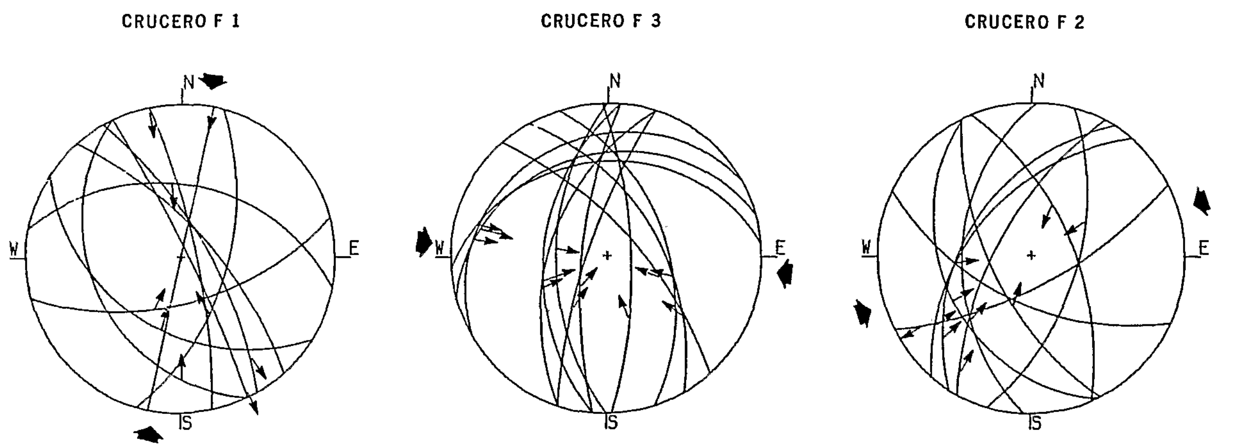

Fig. 5. Reverse strike-slip fault data from the Crucero Basin. Arrows attached to fault traces correspond to the measured slip vector (Wulff stereonet, lower hemisphere). Large black arrows give azimuth of the maximum principal stress computed by Carey's (1979) method. F1 striations have been measured in the Oligocene and Miocene Cayconi Formation and are due to late Miocene compressional deformations. F2 and F3 striations have been measured either in the Oligocene and Miocene Cayconi Formation or in the Pliocene Mercedes Formation; they are likely due to late Pliocene-early Pleistocene compressional deformations. F2 and F3 deformations could represent variations in the same tectonic phase.

flows and tuffs of rhyolitic to dacitic composition. Welded tuffs (ignimbrites) form an important part of the total volume, and beds of reworked silicic tuffs are interbedded in lacustrine sediments of the Cayconi Formation. The lavas are porphyritic and contain phenocrysts of corrosion rimed quartz, zoned plagioclase, biotite (Table 4), and aluminous silicates such as sillimanite, cordierite-osumilite, and muscovite. Major element analyses and petrographic data are summarized in Tables 3 and 4. A rather strong alteration is observed in several thin sections and is confirmed by the high H_2O content of the rocks. Chemical analyses show the high K and peraluminous nature of these rocks (*i.e.*, Al/Na+K+2Ca>1 and the presence of normative corundum). These characteristics indicate an S-type parental magma and an intracrustal origin for the late Oligocene and early Miocene Crucero Basin silicic volcanism. Clark *et al.* (1983) reported peraluminous late Oligocene plutonic rocks in the High Andes of Peru, and Herrera *et al.* (1984) and Noble *et al.*, (1984) described crust-derived late Miocene and Pliocene volcanic rocks from near the village of Macusani northwest of Crucero (see Fig. 1). Recently, a 35.6±0.6 Ma age obtained on an ignimbritic ash-flow sample (Bonhomme *et al.*, 1985) collected at 70°40'W and 13°50'S, 25 km NW of Macusani, shows that magmatism — possibly crust derived — was active in the Eastern Andes at least since the early Oligocene.

The mafic volcanic suite consists of basalts and basalt-andesites that crop out in several parts of the Crucero Basin, but represent a minor proportion in relation to the silicic volcanics. The basalts are porphyritic with phenocrysts of zoned plagioclase and olivine, microcrysts of plagioclase, olivine, clinopyroxene, and opaque minerals; alteration minerals are calcite, epidote, chalcedony, and serpentinized olivine. Mafic lavas always appear at or near the bottom of the volcanic sequence in the Cayconi Formation and are among the oldest rocks in the Crucero Basin (K-Ar ages range from about 25.9 to 21.6 Ma; Specimens 1, 3 and 5). Although few analyses of major elements are available, those that exist show that these rocks have been somewhat altered. The data are insufficient to determine whether this volcanism is alkaline or subalkaline. We assume that, for these mafic rocks, the parental magma is mantle derived.

North of the Crucero Basin, plutonism is represented by two undated microdioritic stocks that crop out near the Santa Ana mine (see Fig. 2). These stocks are probably Late Cretaceous to Miocene in age. They intrude rocks of the Late Permian Mitu Group, but the relationship with basic magmatism of the Cayconi Formation is not known.

MODELS OF CRUCERO BASIN MAGMATISM

Two models can be considered to explain the origin of the basic magmatism in the Crucero Basin. The first model (Fig. 6A) assumes that the basic volcanism is alkaline and is related to a rift-type tectonic setting. The few data we have on the dynamics of the Crucero Basin do not support such an interpretation because, from late Oligocene to early Miocene, deformation appears to be of small magnitude and the basin tectonic configuration (absence of rectilinear margins, low sedimentation rate) is not entirely consistent with a rift setting. The second model (Fig. 6B) assumes that the basic volcanism is subalkaline (*i.e.*, calc-alkaline or shoshonitic), thus implying a relationship with Oligocene and Miocene Andean subduction.

We think that the regional setting favors the second model because a broad magmatic arc, coeval

Table 3. Major element composition (%) of the Oligo-Miocene volcanic rocks from the Crucero area, analyzed in the Laboratoire de Spectrochimie ORSTOM (Paris)

	Specimen[1]											
Oxides	1	2	5	7	8	9	10	11	12	13	15	21
SiO_2	49.50	49.90	55.40	61.80	62.80	64.20	62.60	61.03	67.90	64.90	71.80	69.80
Al_2O_3	16.98	16.60	17.80	14.20	13.90	14.10	15.34	14.80	17.20	15.80	14.90	16.90
Fe_2O_3	0.56	2.97	2.55	2.41	2.14	2.22	2.01	3.53	1.03	1.93	0.57	0.58
FeO	8.70	4.54	3.19	2.17	2.06	2.02	0.45	0.59	0.81	1.77	0.42	0.47
MnO	0.20	0.08	0.11	0.10	0.09	0.14	0.05	0.20	0.04	0.04	0.02	0.05
MgO	6.32	4.06	3.54	3.01	5.47	2.29	1.71	3.20	0.34	1.76	0.10	0.17
CaO	7.82	7.19	6.95	2.51	2.52	2.17	2.38	2.28	0.94	2.24	0.87	0.75
Na_2O	2.44	2.61	2.97	2.25	2.10	2.47	1.98	2.26	3.34	2.72	2.91	2.97
K_2O	1.29	1.74	2.25	5.50	4.65	4.69	6.12	4.21	4.65	4.25	4.97	4.59
TiO_2	1.03	1.01	1.27	0.65	0.51	0.49	0.39	0.31	0.26	0.70	0.20	0.15
P_2O_5	0.14	0.14	0.24	0.53	0.46	0.24	0.51	0.34	0.42	0.25	0.29	0.34
H_2O^+	0.22	10.03	0.05	1.84	1.28	1.60	1.85	2.71	2.16	2.78	1.26	1.85
H_2O^-	2.83	0.34	2.14	1.44	0.37	1.51	2.92	3.23	0.70	0.47	1.12	0.70
TOTAL	98.04	100.21	99.46	98.41	98.35	98.14	98.31	98.69	99.79	99.61	99.03	99.22
Al/K+Na+2Ca				1	1.06	1.08	1.07	1.2	1.4	1.2	1.3	1.5

[1]Key to specimens: 1, basalt; 2, basalt; 5, basalt-andesite; 7, dacite; 8, dacite; 9, dacite; 10, dacite; 11, dacite; 12, rhyolitic tuff; 13, rhyolitic tuff; 15, rhyolite; 21, rhyolite.

Table 4. Modal analyses of volcanic rocks from the Crucero area (counted out on 1000 points).

		Phenocrysts[1]								Micro-Phenocrysts[1]										
Specimen No.	Rock Type	Qtz	San	Pla	Bio	Mus	Cor &/or Osu	Oli	Ground Mass	Qtz	San	Pla	Bio	Mus	Cor	Sil	Oli	Cli	Apa	Zir
2	Basalt (altered)	–	–	2.07	–	–	–		97.93	–	–	+	–	–	–	–	+	+	–	–
3	Basalt	–	–	4.07	–	–	–	8.57	87.36	–	–	+	–	–	–	–	+	+	–	–
4	Basalt	–	–	3.62	–	–	–	7.32	89.06	–	–	+	–	–	–	–	+	+	–	–
5	Basalt-andesite	–	–	8.16	–	–	–	6.31	85.53	–	–	+	–	–	–	–	+	+	–	–
6	Andesite	0.09	0.36	–	2.99	–	–	–	96.56	–	–	+	+	–	–	–	–	–	+	–
7	Dacite	8.02	0.89	3.48	8.42	–	–	–	79.29	+	+	+	+	–	–	+	–	–	+	+
8	Dacite	5.55	4.01	4.85	2.74	–	–	6.12	76.67	+	+	+	+	–	–	+	–	–	+	+
9	Dacite	9.21	1.55	11.12	6.36	–	3.92	–	67.84	+	+	+	+	–	+	+	–	–	+	+
12	Rhyolite (tuff)	23.13	6.79	5.93	+	–	–	–	74.15	+	+	+	+	+	–	+	–	–	+	+
13	Rhyolite (tuff)	24.14	8.97	6.21	+	–	–	–	60.68	+	+	+	+	–	–	–	–	–	+	+
14	Rhyolite	7.26	12.10	6.80	–	–	2.98	–	70.86	+	+	+	+	–	+	+	–	–	+	+
15	Rhyolite	7.65	17.08	3.57	0.25	–	3.98	–	67.57	+	+	+	+	–	+	+	–	–	+	+
16	Rhyolite	4.68	14.79	5.25	1.10	–	2.29	–	72.89	+	+	+	+	+	+	+	–	–	+	+
17	Rhyolite	6.78	18.22	1.30	+	–	5.11	–	68.69	+	+	+	+	–	+	+	–	–	+	+
18	Rhyolite	5.06	16.63	6.40	1.10	–	1.65	–	70.16	+	+	+	+	–	+	+	–	–	+	+
19	Tourmalinized rhyolitic tuff (27% tourmaline?)	28.80	–	+	–	3.84	–	–	67.36	+	+	+	+	–	–	+	–	–	+	+

[1]Key: Qtz, quartz; San, sanidine; Pla, plagioclase; Bio, biotite; Mus, muscovite; Cor, cordierite; Osu, osumilite; Oli, olivine; Sil, sillimanite; Cli, clinopyroxene; Apa, apatite; Zir, zircon.

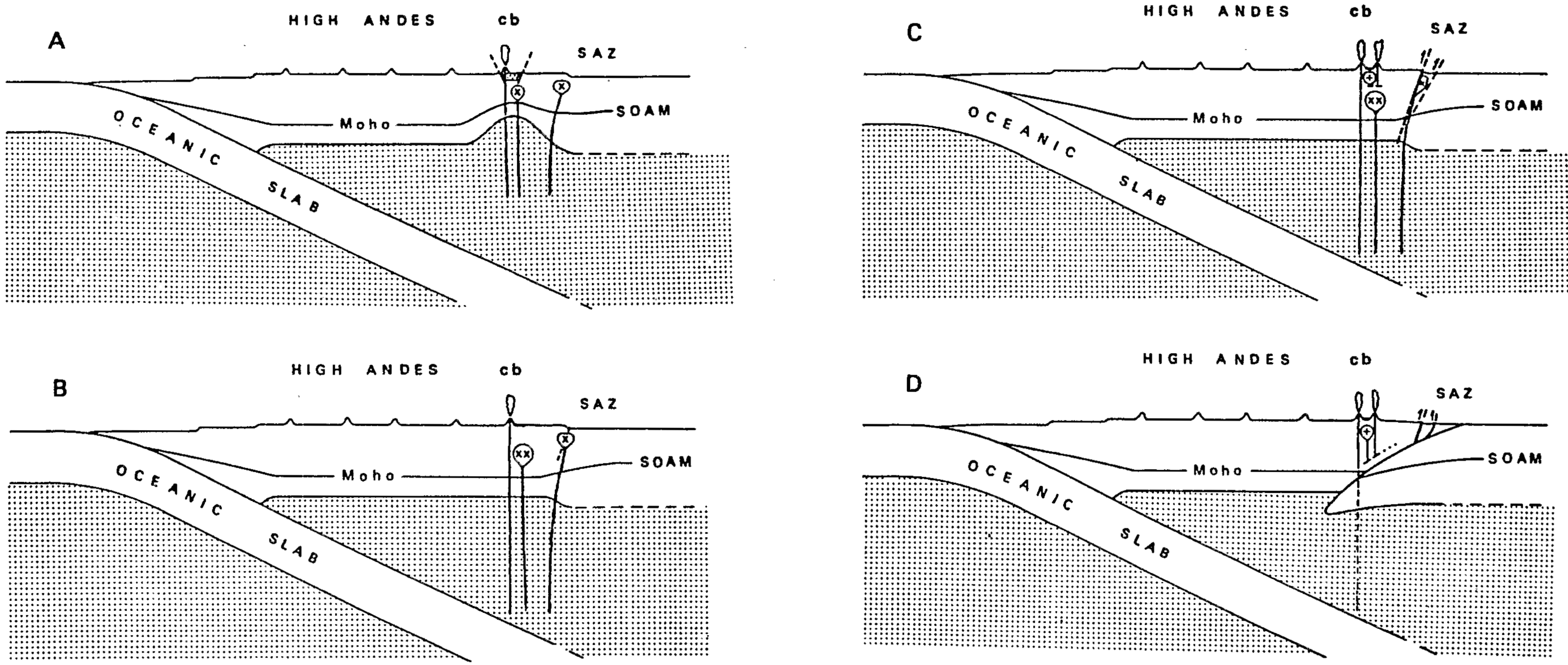

Fig. 6. Models for Oligocene and Miocene magmatism. A and B concern basic magmatism: A) alkaline magmatism related to rifting; B) subalkaline magmatism related to the subduction process. C and D concern acidic magmatism: C) crustal melting produced by uprising of a subalkaline basic magma; D) crustal melting due to shear-heating produced by upthrusting of the Cordillera Oriental on the Amazonian foreland. Key: cb, Crucero Basin; SAZ, Sub-Andean Zone; SOAM, South American Craton.

with an acceleration in the rate and a reorientation of plate convergence (Mammerick *et al.*, 1975, 1980; Pilger, 1983), was initiated at roughly 25 Ma in the Cordillera Occidental and the Altiplano (Clark *et al.*, 1983).

The silicic peraluminous magmatic rocks that crop out in the Cordillera Oriental around and within the Crucero Basin are considered to be from crust-derived magmas (Clark *et al.*, 1983; Herrera *et al.*, 1984; Kontak and Pichavant, 1984; Kontak *et al.*, 1984; Noble *et al.*, 1984). Noble *et al.* (1984) and Herrera (1984) stated that the silicic magmatism originated in the upper part of the crust from assimilation of variable amounts of pelitic material. However, this magmatism can correspond either to intracrustal melting triggered by a subalkaline basic magma or to melting originated directly in the crust without any participation of mantle material. These two possibilities are summarized in Fig. 6, Models C and D.

Model C considers the crustal magmatism a secondary consequence of the uprising of subalkaline basic magmas related to Andean subduction. In this case, the subalkaline magmatism should induce an elevated geothermal gradient and the proposed Miocene strike-slip tectonics should favor decompressed and restricted areas in the crust, inducing crustal melting.

Model D considers that the crustal magmatism is a consequence of intracrustal melting due to overloading and shear-heating produced by upthrusting of the Cordillera Oriental on the Amazonian foreland (Pardo, 1982; Jordan *et al.*, 1983; Jordan, 1984). This upthrust model has recently been tested for Bolivia by Lyon-Caen *et al.* (1985) using available gravimetric data. They calculated that between 100 and 400 km of continental crust of the Brazilian Shield could have thrust beneath the Eastern Andes. They indicated, however, that the data used in their model were insufficient to constrain the magnitude of the upthrusting. Generally, Sub-Andean upthrusting is considered to have occurred since the late Miocene (Jordan *et al.*, 1983; Laubacher *et al.*, 1984b). Possibly, upthrusting could have begun earlier — during the late Eocene or early Oligocene — with the Incaic II tectonic pulse. The crustal magmatism of the Crucero area may belong to an antithetic magmatic arc located in the Cordillera Oriental of southern Peru and northern Bolivia. Nevertheless the Quincemil diorite of southern Peru (dated at 26 Ma; Audebaud *et al.*, 1979), located on the boundary fault system that divides the Cordillera Oriental from the Sub-Andean zone, suggests that a Model D type situation could not exist prior to early Miocene time.

More definitive conclusions will require additional data, including isotopic geochemistry of Oligocene and Miocene rocks and further analysis of the tectonic and structural features of the Sub-Andean zone.

Acknowledgements—Fieldwork was done in 1980 and 1982 as part of the scientific cooperation agreement between INGEMMET (Peru) and ORSTOM (France). We are indebted to ORSTOM (Lima) and ATP Godynamique II (INAG, Paris) for field assistance and support. ORSTOM (Paris) and Institut Dolomieu, UA 69 (CNRS), Grenoble, supported the cost of radiometric dating and major element analyses. We thank Dr. McKee for revision of the manuscript and his valuable suggestions.

REFERENCES

Audebaud, E., and Laubacher, G. 1969. Présence de Tertiaire plissé (Groupe Puno) dans la Cordillère orientale du sud du Pérou. *Comptes Rendus de l'Académie des Sciences (Paris)* **269**, 2301-2304.

Audebaud, E., Bernard, D., Vatin-Perignon, N., and Vivier, B. 1979. *Quelques âges K/Ar sur les roches ignées cénozoiques du Sud-Est péruvien: Conséquences géodynamiques.* Résumé de Réunion Annuelle des Sciences de la Terre, Lyon, 18 p.

Audebaud, E., Capdevila, R., Dalmayrac, B., Debelmas, J., Laubacher, G., Lefèvre, C., Marocco, R., Martinez, C., Mattauer, M., Mégard, F., Paredes, J., and Tomasi, P. 1973. Les traits géologiques essentiels des Andes Centrales (Pérou-Bolivie). *Revue de Géographie Physique et Géologie Dynamique (Paris)* **15** (1-2), 73-114.

Audebaud, E., Laubacher, G., and Marocco, R. 1976. Coupe géologique des Andes du sud du Pérou de l'Océan Pacifique au Bouclier brésilien. *Geologische Rundschau* **65** (1), 223-264.

Barnes, V. E., Edwards, G., McLaughlin, W. A., Friedmann, L., and Joensu, O. 1970. Macusanite occurrence: Age and composition, Macusani, Peru. *Bulletin of the Geological Society of America* **18** (5), 1539-1545.

Blanc, J. L. 1984. *Néotectonique et Sismotectonique des Andes du Pérou Central dans la Région de Huancayo.* Unpublished thesis, University of Paris-Sud, Orsay, 162 p.

Bonhomme, M. G., Audebaud, E., and Vivier, G. 1985. K-Ar ages of Hercynian and Neogene rocks along an east-west cross section in southern Peru. In: *Evolución Magmática de los Andes* (Edited by Hervé, F., and Munizaga, F.). *Comunicaciones (Santiago)* **35**, 27-30.

Bonhomme, M. G., Fornari, M., Laubacher, G., Sébrier, M., and Vivier, G. 1988. New Cenozoic K-Ar ages on volcanic rocks from the eastern High Andes. southern Peru. *Journal of South American Earth Sciences* **1** (2), 169-177.

Bonnot, D. 1984. *Néotectonique et Tectonique Active de la Cordillère Blanche et du Callejon de Huaylas (Andes Nord-Péruviennes).* Unpublished thesis, University of Paris-Sud, Orsay, 94 p.

Cabrera, J. 1984. *Etudes sur la Néotectonique de la Région de Cuzco: Zone Andine et Zone Subandine, Sud Pérou.* Report DEA, University of Paris-Sud, Orsay, 55 p.

Carey, E. 1979. Recherche des directions principales de contraintes associées au rejeu d'une population de failles. *Revue de Géographie Physique et Géologie Dynamique (Paris)* **21** (1), 57-66.

Chanove, G., Mattauer, M., and Mégard, F. 1969. Précisions sur la tectonique tangentielle des terrains secondaires du massif de Pirin (NW du lac Titicaca, Pérou). *Comptes Rendus de l'Académie des Sciences (Paris)* **268**, 1698-1701.

Clark, A.H., Palma, V. V., Archibald, D. A., Farrar, E., Arenas, M. J., and Robertson, R. C. 1983. Occurrence and age of tin mineralization in the Cordillera Oriental, southern Peru. *Economic Geology* **78**, 514-520.

Drake, R., Vergara, M., Munizaga, F., and Vicente, J. C. 1982. Chronology of Mesozoic-Cenozoic magmatism in central Chile, lat. 31°-36°S. *Earth Science Reviews* **18**, 353-363.

Fornari, M., Hérail, G., and Laubacher, G. 1982. El oro en la Cordillera sur-oriental del Perú: El placer fluvioglacial de San Antonio de Poto (Dpto. de Puno) y sus relaciones con la mineralización primaria de la Rinconada. *Actas, V Congreso Latinoamericano de Geología, Buenos Aires* 4, 369-386.

Herrera, J. V., Pichavant, M., and Esteyries, C. 1984. Le volcanisme ignimbritique peralumineux plio-quaternaire de la région de Macusani, Pérou. *Comptes Rendus de l'Académie des Sciences (Paris)* 298, 77-82.

Huaman, D. 1985. *Evolution Tectonique Cénozoique et Néotectonique du Piémont Pacifique dans la Région d'Arequipa (Andes du Sud du Pérou).* Unpublished thesis, University of Paris-Sud, Orsay, 220 p.

Jordan, T. E. 1984. Cuencas, volcanismo y acortamientos cenozoicos, Argentina, Bolivia y Chile, 20-28° latitud sur. *Actas, IX Congreso Geolgico Argentino, San Carlos de Bariloche* 2, 7-24.

Jordan, T. E., Isacks, B. L., Allmendinger, R. W., Brewer, J. A., Ramos, V. A., and Ando, C. J. 1983. Andean tectonics related to geometry of subducted Nazca plate. *Bulletin of the Geological Society of America* 94 (3), 341-361.

Kontak, D. J., and Pichavant, M. 1984. Petrology of the peraluminous volcanics from Macusani, SE Peru. *EOS, Transactions of the American Geophysical Union* 65, 299.

Kontak, D. J., Clark, A. H., and Farrar, E. 1984. The magmatic evolution of the Cordillera Oriental, southeastern Peru. In: *Andean Magmatism: Chemical and Isotopic Constraints. Proceedings of a Special American Geophysical Union Symposium*, pp. 203-250. Shiva Geological Service, London.

Lahsen, A. 1982. Upper Cenozoic volcanism and tectonism in the Andes of northern Chile. *Earth Science Reviews* 18, 285-302.

Laubacher, G. 1978. Géologie de la Cordillère Orientale et de l'Altiplano au Nord et au Nord-Ouest du Lac Titicaca (Pérou). ORSTOM, *Travaux et Documents* 95, 217.

Laubacher, G., Bonhomme, M., Fornari, M., Hérail, G., and Vivier, G. 1984a. *Le Bassin d'Ananea-Ancocala, Témoin de l'Evolution Plio-Quaternaire des Andes Sud-Orientales du Pérou.* Résumé de Réunion Annuelle des Sciences de la Terre, Bordeaux, 336 p.

Laubacher, G., Hérail, G., Fornari, M., and Sébrier, M. 1984b. Le piémont amazonien des Andes sud-orientales du Pérou. In: *Montagnes et Piémonts*, pp. 71-8. Special volume, Revue de Géographie des Pyrenées et du Sud-Ouest, Paris.

Lavenu, A. 1978. Néotectonique des sédiments plio-quaternaires du nord de l'Altiplano bolivien (région de La Paz, Ayo-Ayo, Umala). *Cahiers ORSTOM, Série Géologique* 10 (1), 115-126.

Lavenu, A., and Marocco, R. 1984. Sédimentation continentale et tectonique d'une chaîne liée à une zone de subduction: L'exemple des Andes Centrales (Pérou-Bolivie) pendant le Tertiaire. *Bulletin des Centres de Recherche, d'Exploration et de Production d'Elf-Aquitaine* 8 (1), 57-70.

Lavenu, A., Sébrier, M., and Servant, M. 1980. Néotectonique des Andes Centrales: Pérou, Bolivie. *Bulletin of the International Quaternarist Association* 3, 56-58.

Lefèvre, G. 1973. Les caractères magmatiques du volcanisme plioquaternaire des Andes dans le sud du Pérou. *Contributions to Mineralogy and Petrology* 41, 259-272.

Lyon-Caen, H., Molnar, P., and Suarez, G. 1985. Gravity anomalies and flexure of the Brazilian Shield beneath the Bolivian Andes. *Earth and Planetary Science Letters* 75, 81-92.

Macharé, J., Sébrier, M., Huaman, D., and Mercier, J. L. 1986. Tectónica cenozoica de la margen continental peruana. *Boletín de la Sociedad Geológica del Perú* 76, 45-77.

Mammerick, J., Anderson, R., Menard, H., and Smith, S. 1975. Morphology and tectonic evolution of the east-central Pacific. *Bulletin of the Geological Society of America* 86, 111-118.

Mammerick, J., Herron, E., and Dorman, L. 1980. Evidence for two fossil spreading ridges in the southeast Pacific. *Journal of Geophysical Research* 87, 6751-6759.

Martinez, C. 1980. *Structure et Evolution de la Chaîne Hercynienne et de la Chaîne Andine dans le Nord de la Cordillère des Andes de Bolivie.* ORSTOM, *Travaux et Documents* 119, 352 p.

Mégard, F. 1978. *Etude Géologique des Andes du Pérou Central.* ORSTOM, *Mémoire* 86, 310 p.

Mégard, F., Noble, D. C., McKee, E. H., and Bellon, H. 1984. Multiple pulses of Neogene compressive deformation in the Ayacucho intermontane basin, Andes of central Peru. *Bulletin of the Geological Society of America* 95, 1108-1117.

Newell, N. D. 1949. *Geology of the Lake Titicaca Region, Peru and Bolivia.* Geological Society of America, *Memoir* 36, 111 p.

Noble, D. C., Farrar, E., and Cobbing, E. J. 1979. The Nazca Group of south-central Peru: Age, source, and regional volcanotectonic significance. *Earth and Planetary Science Letters* 45, 80-86.

Noble, D. C., McKee, E. H., Farrar, E., and Petersen, U. 1974. Episodic Cenozoic volcanism and tectonism in the Andes of Peru. *Earth and Planetary Science Letters* 21, 213-221.

Noble, N. D., Sébrier, M., Mégard, F., and McKee, E. H. 1985. Demonstration of two pulses of Paleogene deformation in the Andes of Peru. *Earth and Planetary Science Letters* 73, 345-349.

Noble, N. D., Vogel, T. A., Peterson, P. S., Landis, G. P., Grant, N. K., Jezek, P. A., and McKee, E. H. 1984. Rare-element enriched S-type ash-flow tuffs containing phenocrysts of muscovite, andalousite and sillimanite, southeastern Peru. *Geology* 12, 35-39.

Pardo, A. A. 1982. *Características Estructurales de la Faja Subandina del Norte del Perú: Comunicación al Simposio "Exploración Petrolera en las Cuencas Subandinas de Venezuela, Colombia, Ecuador y Perú."* Asociación Colombiana de Geólogos y Geofísicos del Petróleo, Bogotá.

Pilger, R. H. 1983. Kinematics of the South American subduction zone. *Geodynamics* 9, 113-125.

Schwab, K., and Lippolt, H. 1976. K/Ar mineral ages and late Cenozoic history of the Salar de Cauchari area, Argentina Puna. In: *Proceedings of the IAVCEI Symposium on Andean and Antarctic Volcanology Problems* (Edited by González, O.), pp. 698-714. Napoli, Giannini and Figli, Santiago.

Sébrier, M., Huaman, D., Blanc, J. L., Macharé, J., and Cabrera, J. 1982. *Observaciones Acerca de la Neotectnica del Perú (Meeting on Seismicity and Seismic Risk of the Andean Region.* Unpublished report of the Instituto Geofsíco del Perú, Lima, 109 p..

Sébrier, M., Laubacher, G., Marocco, R., Lavenu, A., and Servant, M. 1980. Evolution tectonique cénozoique des Andes centrales (sud Pérou-Bolivie). *Abstracts of the 26th International Congress on Geology (Paris)* 1 (5), 387.

Sébrier, M., Mercier, J. L., Mégard, F., Laubacher, G., and Carey-Gailhardis, E. 1985. Quaternary normal and reverse faulting and the state of the stress in the Central Andes of south Peru. *Tectonics* 4 (7), 739-780.

Thorpe, R. S., and Francis, P.W. 1979. Variation in Andean andesite compositions and their petrogenetic significance. *Tectonophysics* 57, 53-70.

Van Houten, F. B. 1976. Late Cenozoic volcaniclastic deposits: Andean foredeep, Colombia. *Bulletin of the Geological Society of America* 87, 481-495.