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By TOMAS FEININGER and MILES L. SILBERMAN

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K-Ar GEOCHRONOLOGY OF BASEMENT ROCKS ON THE NORTHERN FLANK OF THE HUANCABAMBA DEFLECTION, ECUADOR*

by

Tomas Feininger[1]

and

Miles L. Silberman[2]

*Contribution no. 7, Departamento de Geología, Escuela Politécnica Nacional, Quito, Ecuador.

[1]Departamento de Geología, Escuela Politécnica Nacional, Quito, Ecuador; present address: Département de Géologie, Université Laval, Québec, Québec, Canada G1K 7P4.

[2]U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025.

ABSTRACT

The Huancabamba Deflection, a major Andean orocline located at the Ecuador-Peru border, constitutes an important geologic boundary on the Pacific coast of South America. Crust to the north of the deflection is oceanic and the basement is composed of basic igneous rocks of Cretaceous age, whereas crust to the south is continental and felsic rocks of Precambrian to Cretaceous age make up the basement.

The northern flank of the Huancabamba Deflection in El Oro Province, Ecuador, is underlain by Precambrian polymetamorphic basic rocks of the Piedras Group; shale, siltstone, sandstone, and their metamorphosed equivalents in the Tahuín Group (in part of Devonian age); concordant syntectonic granitic rocks; quartz diorite and alaskite of the Marcabelí pluton; a protrusion of serpentinized harzburgite that contains a large inclusion of blueschist-facies metamorphic rocks, the Raspas Formation; and metamorphic rocks north of the La Palma fault.

Biotite from gneiss of the Tahuín Group yields a Late Triassic K-Ar age (210 $\pm$ 8 m.y.). This is interpreted as an uplift age and is consistent with a regional metamorphism of Paleozoic age. A nearby sample from the Piedras Group that yielded a hornblende K-Ar age of 196 $\pm$ 8 m.y. was affected by the same metamorphic event. Biotite from quartz diorite of the mesozonal Marcabelí pluton yields a Late Triassic age (214 $\pm$ 6 m.y.) which is interpreted as an uplift age which may be only slightly younger than the age of magmatic crystallization. Emplacement of the pluton may postdate regional metamorphism of the Tahuín Group. Phengite from pelitic schist of the Raspas Formation yields an Early Cretaceous K-Ar age (132 $\pm$ 5 m.y.). This age is believed to date the isostatic rise of the encasing serpentinized harzburgite as movement along a subjacent subduction zone ceased, and it is synchronous with the age of the youngest lavas of a coeval volcanic arc in eastern Ecuador. A Late Cretaceous K-Ar age (74.4 $\pm$ 1.1 m.y.) from hornblende in amphibolite north of the La Palma fault shows that rocks there are distinct from the superficially similar rocks of the Tahuín Group to the south. Biotite from schist in the Eastern Andean Cordillera

yields an Early Eocene age (56.6 $\pm$ 1.6 m.y.). Metamorphic rocks in the northern part of the Eastern Andean Cordillera are Cretaceous in age and were metamorphosed in part in early Tertiary time. They are unrelated to and were metamorphosed later than any of the diverse rocks exposed on the northern flank of the Huancabamba Deflection.

INTRODUCTION

Metamorphic basement rocks with a wide range of ages crop out sporadically in the Andean orogen of southern Ecuador and adjacent Peru (fig. 1). This part of the Andean orogen is of particular geologic interest because it constitutes the Huancabamba Deflection, the most prominent of the great oroclines that flex the Andes to and fro from southern Chile to Venezuela (Gansser, 1973, p. 104-106).

Figure 1, near here.

In this report we present a brief review of the Huancabamba Deflection, a summary of the geology of basement rocks exposed on its northern flank, and the significance of K-Ar dates of six samples of crystalline rocks from Ecuador. We shall show that four distinct metamorphic belts are exposed on the Huancabamba Deflection in Ecuador, and that none of these belts is correlative with the areally extensive metamorphic rocks that underlie the Eastern Andean Cordillera to the northeast. Field studies in Ecuador were undertaken by Feininger. Silberman carried out the K-Ar age determinations that here are reported for the first time.

THE HUANCABAMBA DEFLECTION

The axis of the Huancabamba Deflection strikes east across the Andes, roughly coincident with the Ecuador-Peru border (fig. 1). The apex of the deflection, near Talara, Peru, includes the westernmost protuberance of the South American continent. The deflection separates Andean rocks to the north that strike N 20° E, from those to the south, which in northern Peru strike N 30° W.

The northern flank of the Huancabamba Deflection constitutes an important geologic boundary in South America. To the north, in Ecuador and Colombia, coastal South America is underlain exclusively by oceanic crust; basement rocks exposed west of the Andes consist of basalt and diabase of Cretaceous age (Servicio Nacional de Geología y Minería, 1969; Instituto Nacional de Investigaciones Geológico-Mineras,

1976). The union of oceanic and continental crust in Ecuador lies at the western base of the Andes, north of the vicinity of Guayaquil (Feininger, 1977). In southernmost Ecuador and Peru, on the other hand, the crust between the Andes and the Pacific is continental, and the basement is dominated by felsic metamorphic and granitic intrusive rocks that range in age from Precambrian to Cretaceous (Bellido, 1969; Gansser, 1973, p. 106-107). The origin of this geologic boundary recently has been interpreted by Feininger and Bristow (1980) based on the interaction of the South American plate and oceanic plates to the west during Cretaceous and Paleogene time.

In the Peruvian Andes, basement rocks of Precambrian and Paleozoic age in the Huancabamba Deflection constitute a triparte division broken by two major unconformities (Mégard and others, 1971). From oldest to youngest, the rocks are a Precambrian crystalline terrain, a lower Paleozoic (pre-Carboniferous) pelitic and sandy flysch sequence from 2 to more than 15 km thick, and an upper Paleozoic (Carboniferous and Permian) molasse sequence of continental and marine clastic sedimentary rocks with minor limestone and volcanic rocks that ranges from a few hundred meters to 5 km in thickness. The rocks are further distinguished by their contrasting metamorphic and deformational histories (Mégard and others, 1971). The Precambrian rocks are everywhere polymetamorphic. Overlying lower Paleozoic rocks range from nonmetamorphic to high grade, and are characterized by extensive faulting, complex folds produced by multiple deformation, and a pervasive slaty cleavage. Upper Paleozoic rocks are not metamorphosed, are relatively less faulted, and are characterized by simple, open folds generally without slaty cleavage.

BASEMENT ROCKS ON THE NORTHERN FLANK, HUANCABAMBA DEFLECTION

Basement rocks on the northern flank of the Huancabamba Deflection are particularly well exposed in western El Oro Province, Ecuador. Here they underlie the east to northeast-striking Cordillera de Tahuín, a foothills range of the Andes that lies between the town of Arenillas and the Río Puyango. The geology of the Arenillas-Puyango area has been mapped in detail (Feininger, 1978), and is summarized below.

Seven broad rock units form the basement of the Arenillas-Puyango area (fig. 2). These include the rocks of four distinct metamorphic belts: the Piedras Group, Tahuín Group, Raspas Formation, and metamorphic rocks north of the La Palma fault, as well as three intrusive units: syntectonic granitic rocks, the Marcabelí pluton, and harzburgite. In the south, basement rocks are overlain with an angular unconformity by sedimentary and volcanic rocks of Early Cretaceous age (Bristow and Hoffstetter, 1977, p. 83-84). Alluvium of a narrow coastal plain overlaps basement rocks in the north.

Figure 2, near here.

The Piedras Group consists of polymetamorphic amphibolite and greenschist, with thin concordant layers of quartzite and quartz-muscovite schist. Hornblende from a sample of amphibolite taken at Portovelo, 52 km east southeast of Arenillas, yielded a 743 $\pm$ 14 m.y. K-Ar age (Kennerley, 1980). The Piedras Group is interpreted by Feininger (1980) as a remnant of Proterozoic ocean floor.

The Tahuín Group stratigraphically overlies the Piedras Group and is composed of a monotonous sequence of intercalated shale, siltstone, sandstone, and their metamorphosed equivalents. In the extreme south the Tahuín Group has not been metamorphosed, but northward the rocks become increasingly recrystallized, and near their contact with the Piedras Group they have been metamorphosed to coarse-grained gneiss and migmatite of the upper amphibolite facies. The age of the Tahuín Group is uncertain. No fossils have been found in Ecuador, but low-grade quartzite on strike with the Tahuín Group in Peru, 125 km to the southwest, has yielded a Devonian brachiopod fauna (Martínez, 1970). A lower Paleozoic age is consistent with the metamorphism, faulting, complex folding, and slaty cleavage that characterize the Tahuín Group.

Elongated, concordant bodies of medium- to coarse-grained, foliated to massive, syntectonic granitic rocks are found in the higher-grade parts of the Tahuín Group. The granitic rocks have a metamorphic texture, and are characterized by euhedral, poikilitic megacrysts of white orthoclase from 4 to 10 cm long. The syntectonic granitic rocks are believed to have been emplaced as magma, possibly generated by the partial melting of the highest-grade parts of the Tahuín Group, just before or during the peak of regional metamorphism.

The northwest quadrant of the Marcabelí pluton is exposed in the Cordillera de Tahuín (fig. 2). The pluton is composite, and is made up of discrete phases of medium-grained, xenomorphic to hypidiomorphic equigranular, gray quartz diorite, and coarse-grained, xenomorphic equigranular, pink alaskite. Intrusive relations establish that the quartz diorite is the relatively older phase. Sedimentary rocks of the Tahuín Group are baked in a narrow thermal aureole west of the pluton.

Extensively serpentinized harzburgite constitutes a large protrusion south and southeast of Arenillas. An unfragmented inclusion 3 km wide and more than 11 km long, known as the Raspas Formation, is encased in the harzburgite. The Raspas consists of high-pressure, blueschist facies metamorphic rocks, chiefly feldspar-free pelitic schist, but also layers of eclogite and eclogite amphibolite. The high-pressure rocks are believed to have been raised from a depth of more than 40 km during emplacement of the protrusion by isostatic rise (Feininger, 1980).

Metamorphic rocks north of the La Palma fault superficially resemble rocks in the Tahuín Group (Feininger, 1978), although the two terrains differ substantially in many petrographic details. Furthermore, the rocks in the north include extensive areas of amphibolite with distinctive brown hornblende, a rock type not found in the Tahuín Group.

K-Ar AGES

Six samples of crystalline rocks were collected for K-Ar age determinations. Five of these samples were collected in the Arenillas-Puyango area (fig. 2), and one

was collected in the Eastern Andean Cordillera, 400 km to the northeast (fig. 3). The dating was undertaken with two main objectives: 1) To clarify the unknown or uncertain metamorphic ages of basement rocks on the northern flank of the Huancabamba Deflection, and 2) To investigate the relations between metamorphic rocks on the northern flank of the Huancabamba Deflection with the more extensive belt of metamorphic rocks of the Eastern Andean Cordillera in northern Ecuador (fig. 3).

Figure 3, near here.

K-Ar ages are summarized in Table 1. Sample descriptions, analytical procedures, and other technical information are given in the appendices at the end of the report.

Table 1. K-Ar ages of crystalline rocks from Ecuador

Sample number	Rock type and formation	Mineral dated	Age (m.y.)
TF-227	Amphibolite, Piedras Group	Hornblende	196 ± 8
TF-1559	Pelitic gneiss, Tahuín Group	Biotite	210 ± 8
JS-278A	Quartz diorite, Marcabelí pluton	Biotite	214 ± 6
TF-1856	Pelitic schist, Raspas Formation	Phengite	132 ± 5
TF-675	Amphibolite, metamorphic rocks north of the La Palma fault	Hornblende	74.4 ± 1.1
3.3.92	Schist, Eastern Andean Cordillera	Biotite	53.6 ± 1.6

Piedras Group

Hornblende from amphibolite in the Piedras Group (sample TF-227) yielded an age of 196 ± 8 m.y. The amphibolite is polymetamorphic, fractured, and partly altered. The sample is believed to have been reheated during the regional metamorphism of the overlying rocks of the Tahuín Group located only 1.2 km to the south (see below). The precise geologic setting of the amphibolite from the Piedras Group at Portovelo,

dated at 743 ± 14 m.y. (Kennerley, 1980), is unknown, but the significantly older age suggests that the site may be more distant from rocks of the Tahuín Group than is TF-227.

Tahuín Group and Marcabelí pluton

Biotite gneiss in the Tahuín Group (sample TF-1559) yielded a 210 ± 8 m.y. age. The mineral assemblage of this sample, which includes orthoclase and sillimanite (without muscovite), and the intense regional migmatization of the gneiss interpreted as due to partial melting, indicate that metamorphism occurred at a temperature in excess of 650°C and at a depth greater than 11 km (Winkler, 1976, fig. 15-3). Retention of argon in the biotite after prograde metamorphic recrystallization could have begun only after extensive uplift and erosion. The exceptional freshness of the gneiss and the absence of nearby intrusive rocks argue against resetting by a later retrograde or thermal event. The 210 m.y. age is thus interpreted as a minimum age of the metamorphism, and more likely as the age of uplift for this part of the metamorphic terrain. Although the precise age of metamorphism remains unknown, these data are consistent with it being Paleozoic.

Biotite from quartz diorite of the Marcabelí pluton (sample JS-278A) yielded a 214 ± 6 m.y. age. Within analytical uncertainty, this age is the same as that of the gneiss from the Tahuín Group. The dominantly xenomorphic texture of the Marcabelí pluton is consistent with crystallization at mesozonal depth. Nevertheless, the grade of regional metamorphism of the Tahuín Group in the area of Marcabelí is much less than the grade of the gneiss in the north. The depth of emplacement of the pluton must have been significantly less than the depth of the regional metamorphism at TF-1559. Although the biotite age of the quartz diorite must be a minimum age, it may be only slightly younger than the age of magmatic crystallization. Emplacement of the pluton may postdate the regional metamorphism of the Tahuín Group.

Raspas Formation

Phengite from pelitic schist of the Raspas Formation (sample TF-1856) yielded an Early Cretaceous K-Ar age (132 ± 5 m.y.). Whereas the temperature of metamorphism of some blueschist-facies rocks is below that at which argon loss from phengite begins (Suppe and Armstrong, 1972), such is not the case for the Raspas Formation, which is postulated to have been metamorphosed at 580 ± 20°C (Feininger, 1980). These temperatures are more than adequate to cause argon loss from even coarsely crystallized muscovite (Damon, 1968). Accordingly, the K-Ar age is interpreted to date the isostatic rise of the serpentinized harzburgite that carried with it the encased high-pressure rocks from a deep subduction zone to progressively shallower and cooler levels. The subduction zone is believed to have dipped eastward, beneath the South American continent, from a trench located in the proto-Pacific Ocean to the west. Rise of the Raspas-harzburgite couplet took place upon abandonment of the subduction zone, when downward traction had ceased, and the physical barrier of the shear plane between the descending and the overriding plates was eliminated. This view is reinforced by a synchronous whole-rock K-Ar age (132 m.y.) obtained by the Texaco Petroleum Company on the youngest lavas of the coeval volcanic arc taken from the subsurface in eastern Ecuador (Feininger, 1980).

Metamorphic rocks north of the La Palma fault

Hornblende from a sample (TF-675) of amphibolite at Arenillas yielded an age of 74.4 ± 1.1 m.y. This unexpected young age was confirmed by a second determination (Appendix B). Sample TF-675 is unusually fresh and shows no petrographic evidence of postmetamorphic reheating or alteration. The distinct radiometric age of the metamorphic rocks north of the La Palma fault supports the petrographic evidence that these rocks are not correlative with the Tahuín Group to the south. The regional significance of this relatively youthful terrain remains uncertain.

Eastern Andean Cordillera

Biotite from a schist (sample 3.3.92) of the Eastern Andean Cordillera in northern Ecuador (fig. 3), was dated to test regional correlations of metamorphic rocks in the country. Aside from the small area of metamorphic rocks on the northern flank of the Huancabamba Deflection in El Oro Province, other regionally metamorphosed rocks in Ecuador are confined to the Eastern Andean Cordillera, where they form a 650-km-long belt that ranges in width from less than 20 to 70 km between the Colombian and Peruvian borders (fig. 3). In the absence of detailed studies, it has generally been assumed that the regionally metamorphosed rocks of Ecuador constitute a single, albeit somewhat disrupted belt (Sauer, 1965, p. 24-48; Servicio Nacional de Geología y Minería, 1969). Kennerley (1973) first proposed a division of these rocks, with a supposedly Cretaceous age for the metamorphic rocks in western El Oro Province (his "Tahuín Series"), and a Paleozoic age for the metamorphic rocks in the Eastern Andean Cordillera (his "Zamora Series"). Simultaneously, Bristow (1973) demonstrated in the field the Late Cretaceous age of schists in the Eastern Andean Cordillera northeast of Cuenca. Subsequently, using regional reconstructions based on plate tectonics, Feininger (1975) and Feininger and Bristow (1980) proposed that the schists in at least the northern two thirds of the Eastern Andean Cordillera are Cretaceous in age and were metamorphosed in Maastrichtian (latest Cretaceous) and early Tertiary time. This view is sustained by the Early Eocene biotite age (53.6 $\pm$ 1.6 m.y.) of the schist from Baeza, 70 km east-southeast of Quito, and points out that the metamorphic rocks of the Eastern Andean Cordillera in the north bear no genetic relation to metamorphic rocks on the northern flank of the Huancabamba Deflection.

SUMMARY

Basement rocks on the northern flank of the Huancabamba Deflection range in age from Precambrian to Cretaceous and include no less than four distinct metamorphic belts: the Piedras Group, Tahuín Group, Raspas Formation, and the metamorphic rocks north of the La Palma fault. Polymetamorphic mafic rocks of the Piedras Group, which

elsewhere have a late Precambrian hornblende K-Ar age (Kennerley, 1980), in the Arenillas-Puyango area have been reset by the Paleozoic regional metamorphism of the adjacent Tahuín Group. The Late Triassic biotite K-Ar age on gneiss from the Tahuín Group is interpreted as an uplift age, and is consistent with a Paleozoic age of regional metamorphism. The Late Triassic biotite age from quartz diorite of the Marcabelí pluton is a minimum age, but may be only insignificantly younger than the emplacement age of the pluton. The Early Cretaceous phengite K-Ar age on high-pressure pelitic schist interbedded with eclogite in the Raspas Formation dates the isostatic rise of the encasing serpentinized harzburgite, and is related to the cessation of activity in a coeval volcanic arc to the east. A Late Cretaceous hornblende K-Ar age on amphibolite from metamorphic rocks north of the La Palma fault at Arenillas demonstrates that these rocks constitute a distinct and heretofore unrecognized younger metamorphic terrain. Schist in the Eastern Andean Cordillera to the northeast was metamorphosed in latest Cretaceous or early Tertiary time and is unrelated genetically to basement rocks on the northern flank of the Huancabamba Deflection.

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APPENDIX A

ANALYTICAL EQUIPMENT AND PROCEDURES

Mineral concentrates were prepared from crushed and sized samples of rock with an electromagnetic separator and heavy liquids by Tomas Feininger and student assistants at the Escuela Politécnica Nacional, Quito. Potassium analyses were performed by Gil Ambats and Paul Klock at the U.S. Geological Survey, Menlo Park, on splits of the prepared separates using lithium metaborate fusion and flame photometry (Ingamells, 1970). Argon was extracted from mineral concentrates by RF induction heating in vacuum using standard isotope dilution techniques (Dalrymple and Lanphere, 1969). Mass analyses of the extracted argon was done with a Neir-type 60-degree-sector 15.2-cm-radius mass spectrometer operated in the static mode. Analysts were A. L. Berry and M. L. Silberman.

Analytical uncertainty is a combination of errors in potassium and argon analyses, and is calculated at one standard deviation. The constants used in age calculations were:

$$\lambda_{\varepsilon} - \lambda_{\varepsilon}' = 0.581 \times 10^{-10}\,\mathrm{yr}^{-1}$$

$$\lambda_{\beta} = 4.963 \times 10^{-10}\,\mathrm{yr}^{-1}$$

$$K^{40}/K_{total} = 1.167 \times 10^{-4} \text{ atom per cent.}$$

Appendix B

Sample number	Description	Location	K-Ar age	Estimated mode	Analytical data
TF-227[1]	Fine- to medium-grained, nematoblastic, dark green to black, gneissic amphibolite with wavy foliation planes.	Dry streambed 1.5 km S 81° W of Piedras, El Oro Province, Ecuador; 03° 38' 09" S; 79° 55' 41" W.	196 ± 8 m.y. (hornblende)	Blue-green hornblende (58 percent), epidote (22 percent), saussurite (15 percent), sphene (4 percent), and quartz (1 percent).	K_2O = 0.238%, $*Ar^{40}$ = 7.065 X 10^{-11} mole/g; $*Ar^{40}/\Sigma Ar^{40}$ = 66%
TF-1559[1]	Medium- to coarse-grained, gray, biotite gneiss.	Quebrada Lobos, 700 m upstream from El Carmen, El Oro Province, Ecuador; 03° 39' 53" S; 79° 55' 42" W.	210 ± 8 m.y. (biotite)	Exceptionally fresh gneiss is composed of (in order of decreasing abundance): quartz, andesine, biotite, garnet, orthoclase, sillimanite, and graphite, with trace amounts of apatite, tourmaline, and zircon.	K_2O = 8.51%; $*Ar^{40}$ = 2.729 X 10^{-9} mole/g; $*Ar^{40}/\Sigma Ar^{40}$ = 94%

[1]Collected by: Tomas Feininger, Escuela Politécnica Nacional, Quito, Ecuador. Dated by: M. L. Silberman, U.S. Geological Survey, Menlo Park, California.

Sample number	Description	Location	K-Ar Age	Estimated mode	Analytical data
JS-278A[2]	Medium-grained, massive, xenomorphic to hypidiomorphic equigranular, biotite quartz diorite.	Río Puyango, at at the mouth of Quebrada Marcabelí, El Oro Province Ecuador; 03° 49' 40" S; 79° 56' 44" W.	214 ± 6 m.y. (biotite)	Andesine (54 percent), quartz (31 percent), orthoclase (6 percent), biotite (9 percent), and traces of muscovite, chlorite, apatite, zircon, and magnetite.	K_2O = 7.78%; $*Ar^{40}$ = 2.539 X 10^{-9} mole/g; $*Ar^{40}/\Sigma Ar^{40}$ = 96 %.
TF-1856[1]	Medium- to coarse-grained, gnarly, silver-gray schist with wavy foliation planes, conspicuous garnet porphyroblasts, and pronounced segregation into quartz-rich and mica-rich laminae.	Quebrada Raspas, 1.3 km S 48° W of La Chilca, El Oro Province, Ecuador; 03° 35' 49" S; 79° 55' 01" W.	132 ± 5 m.y. (phengite)	Quartz (49 percent), phengite and paragonite (35 percent), garnet (6 percent), chloritoid (4 percent), graphite (3 percent), kyanite (2 percent), and rutile (1 percent).	K_2O = 8.48%; $*Ar^{40}$ = 1.671 X 10^{-9} mole/g; $*Ar^{40}/\Sigma Ar^{40}$ = 97%

[2]Collected by: Jorge Sevilla, Escuela Politécnica National, Quito, Ecuador. Dated by: M. L. Silberman, U.S. Geological Survey, Menlo Park, California.

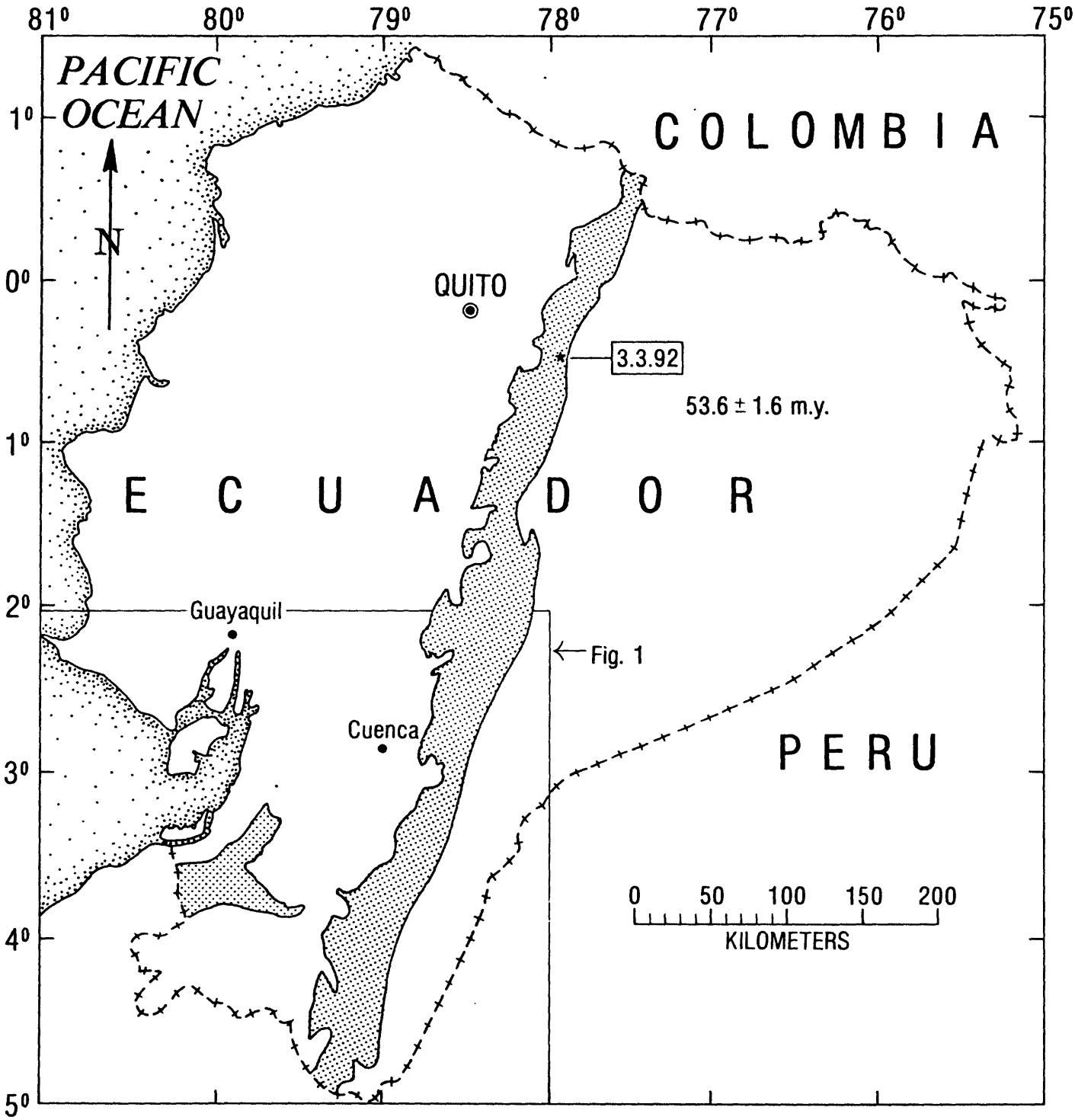
Sample number	Description	Location	K-Ar age	Estimated mode	Analytical data
TF-675[1]	Fine- to medium-grained, laminated, black amphibolite.	Cut on Pan American Highway just east of the hospital at Arenillas, El Oro Province, Ecuador: 03° 33' 10" S; 80° 03' 54" W.	74.4 ± 1.1 m.y. (hornblende)	Fresh, intermediate plagioclase (53 percent), hornblende (38 percent), clinopyroxene (7 percent), sphene (1 percent), and ore (1 percent).	K_2O = 0.444%; $*Ar^{40}$ = 4.805 X 10^{-11}, 4.905 X 10^{-11} mole/g; $*Ar^{40}/\Sigma Ar^{40}$ = 43%, 54%
3.3.92[1]	Fine- to medium-grained, mottled, black-and-green schist.	Interoceanic highway at the entrance to the Baeza Pumping Station of the Trans-Andean Oil Pipeline, Napo Province, Ecuador; 00° 26' S; 77° 56' W.	53.6 ± 1.6 m.y. (biotite)	Albite, quartz, epidote, biotite, chlorite (prograde), garnet, sphene, and pyrite.	K_2O = 8.59%; $*Ar^{40}$ = 6.721 X 10^{-10} mole/g; $*Ar^{40}/\Sigma Ar^{40}$ = 73%.

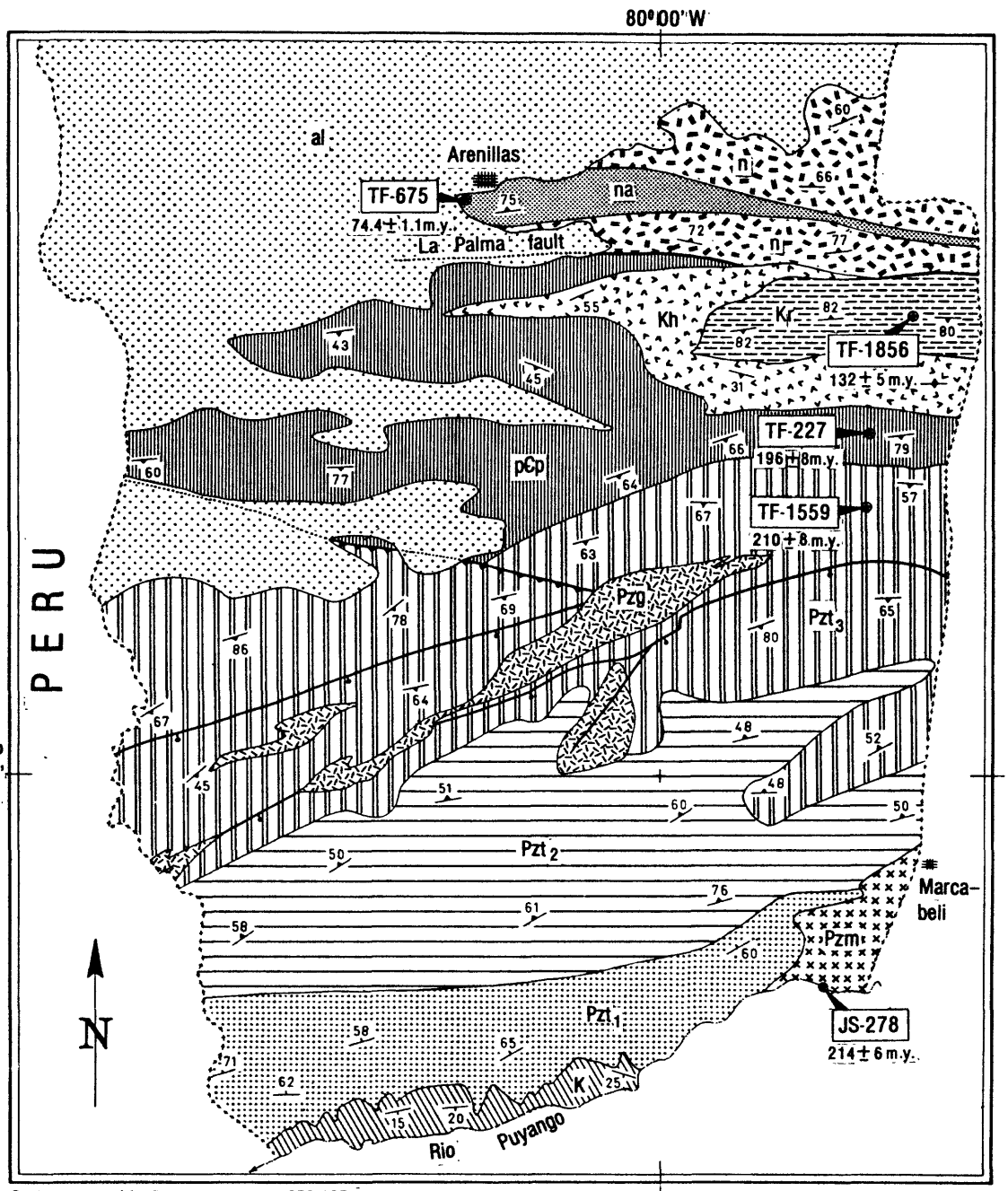
CAPTIONS OF FIGURES

Figure 1. Regional metamorphic rocks (stippled) in the Huancabamba Deflection (double broken line). Modified from Mégard and others (1971) and Servicio Nacional de Geología y Minería (1969). Note: The Government of Ecuador does not recognize the political border with Peru.

Figure 2. Generalized geologic map of the Arenillas-Puyango area, western El Oro Province, Ecuador (Feininger, 1978). Note: The Government of Ecuador does not recognize the political border with Peru.

Figure 3. Regional metamorphic rocks (stippled) in Ecuador. Modified from Servicio Nacional de Geología y Minería (1969). Note: The Government of Ecuador does not recognize all the political borders shown here.


81°
80°
79°
78°
77°
76°
75°
1°
0°
1°
2°
3°
4°
5°
PACIFIC
OCEAN
N
COLOMBIA
QUITO
3.3.92
53.6 ± 1.6 m.y.
E C U A D O R
Guayaquil
Fig. 1
Cuenca
PERU
0 50 100 150 200
KILOMETERS



Geology mapped by Tomas Feininger, 1972-1974, assisted by Eduardo Almeida, 1973-1974

EXPLANATION

al — Alluvium

K — Sedimentary and volcanic rocks

n, na — Metamorphic rocks north of the La Palma fault
n, gneiss, schist, phyllite and quartzite
na, amphibolite

Kh — Harzburgite

Kr — Raspas Formation
Pelitic schist, eclogite, and eclogite amphbolite

CRETACEOUS

Pzm — Marcabeli pluton
Quartz diorite and alaskite

Pzg — Syntectonic granitic rocks

Pzt1, Pzt2, Pzt3 — Tahuin Group
Pzt_1, shale and sandstone
Pzt_2, phyllite, schist, and quartzite; mostly greenschist facies
Pzt_3, gneiss and migmatite; amphibolite facies

PALEOZOIC

pCp — Piedras Group
Chiefly amphibolite and greenschist

PRECAMBRIAN

Contact

High-angle fault
Dotted where covered; bar and ball on downthrown block

Thrust fault
Dotted where covered; sawteeth on upper plate

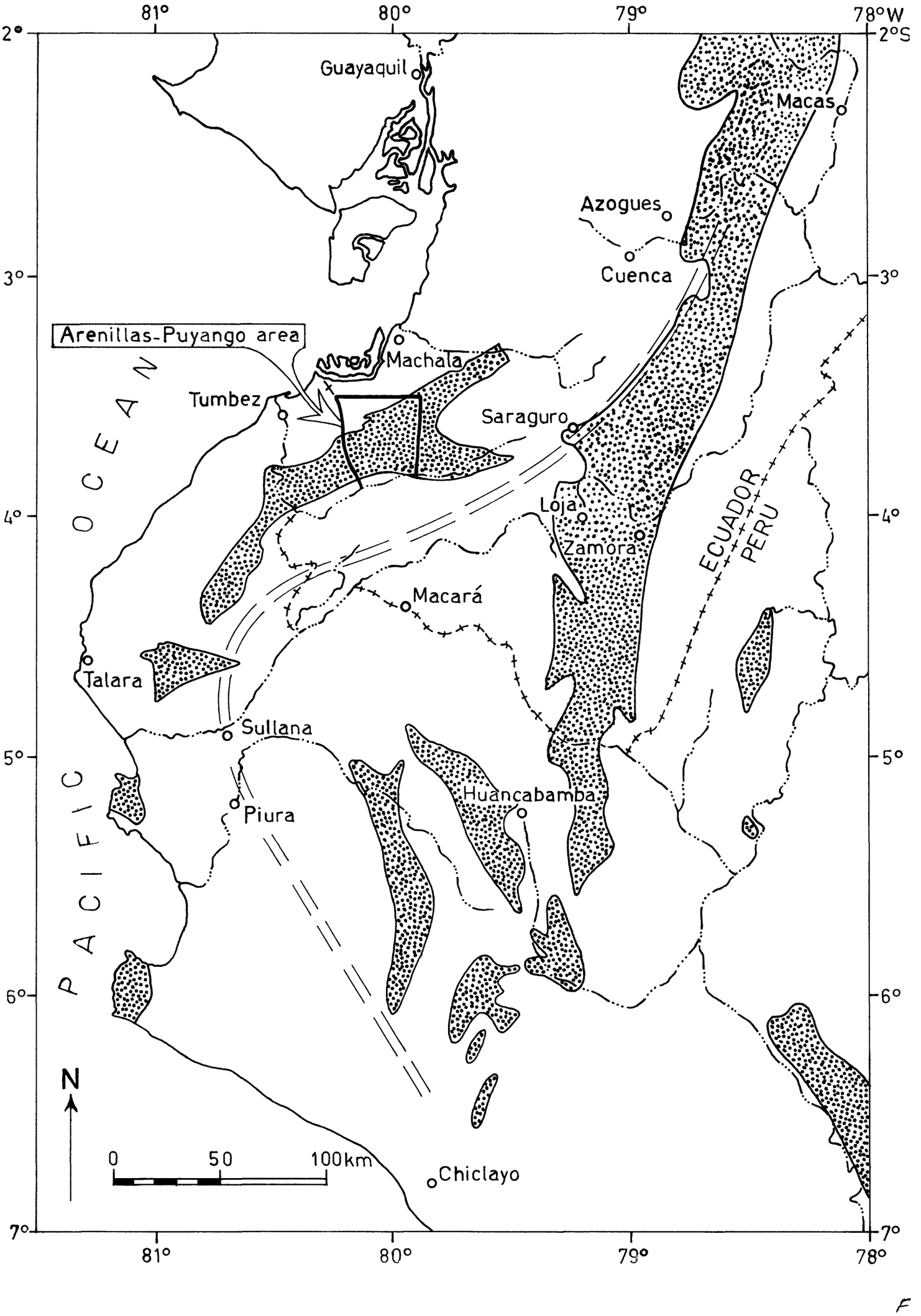
56 inclined — vertical
Strike and dip of foliation

45
Strike and dip of bedding

TF-227
Sample locality

Limit of mapped area

82-20


81°
80°
79°
78°W
2°
2°S
3°
4°
5°
6°
7°
Guayaquil
Macas
Azogues
Cuenca
Arenillas-Puyango area
Machala
Tumbez
Saraguro
Loja
Zamora
Macará
Talara
Sullana
Piura
Huancabamba
Chiclayo
PACIFIC OCEAN
ECUADOR
PERU
N
0
50
100km

F