Rotated oceanic blocks in western Ecuador

P. Roperch, F. Mégard, C. Laj, T. Mourier, T. Clube, C. Noblet

► To cite this version:

P. Roperch, F. Mégard, C. Laj, T. Mourier, T. Clube, et al.. Rotated oceanic blocks in western Ecuador. *Geophysical Research Letters*, 1987, 14 (5), pp.558-561. 10.1029/GL014i005p00558 . hal-03549051

HAL Id: hal-03549051

<https://hal.science/hal-03549051>

Submitted on 31 Jan 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ROTATED OCEANIC BLOCKS IN WESTERN ECUADOR

Roperch, P.¹, Mégard, F.², Laj, C.³, Mourier, T.⁴,
Clube, T.M.³ and Noblet, C.⁵

¹ ORSTOM, Laboratoire de Géophysique, Institut de géologie, 35042, Rennes, France

² Centre Géologique et Géophysique, U.S.T.L., Montpellier, France

³ Centre des Faibles Radioactivités, Laboratoire mixte CNRS/CEA, 91190, Gif-sur-Yvette, France

⁴ Université de Paris Sud, 91405, Orsay, France

⁵ Institut Français d'Etude Andines, Quito, Ecuador

Abstract. A paleomagnetic study of over 250 cores from 21 sites sampled over a distance exceeding 250 Km in the early Cretaceous Pinon formation in the Costa of Western Ecuador indicates that the sampled lithologies (essentially MORB-type basalts and dolerites) carry a stable remanent magnetization, whose direction significantly deviates from that of coeval formations of stable South America. Although both normal and reverse directions have been recorded, the two polarities cannot easily be distinguished because of the low latitude of the ocean floor at the time of formation. The most likely interpretation is that the entire area has undergone 70° clockwise rotation since its genesis. These results thus yield new evidence for an allochthonous origin of this suspect terrane.

Introduction

Ecuador lies immediately adjacent to a NNE-SSW trending submarine trench along which the oceanic Nazca plate is being consumed beneath the western margin of South America. The margin consists of the low elevation Costa, a 100-150 km wide zone between the coast-line and the toe of the Andes. The latter consists of the parallel submeridian Western and Eastern Cordilleras, separated by the graben-like inter-Andean valley. An intracontinental volcanic arc of Cenozoic age, which includes active volcanoes, forms the highest parts of both Cordilleras. East of the Andes, the Oriente foreland basin rests upon the eastern extension of the Guiana shield.

A prominent positive (Bouguer) gravity anomaly over the Costa indicates that it cannot be underlain by continental crust (Feininger and Seguin, 1983), and is more likely to represent a fragment of oceanic lithosphere. To the west this dense basement extends as far as the trench whereas to the east both the gravity evidence and the geology indicate that its boundary is an ophiolitic suture (Juteau et al., 1977; Duque and Santos, 1985; Lebrat et al., 1987), which lies close to the Dolores-Guayaquil megashear (DGM) zone (Feininger and Seguin, 1983; Eguez, 1986).

Although most authors agree on the major geological features of Ecuador, widely different

hypotheses have been suggested for the origin of its western part. Some authors consider that the Costa and the Western Cordillera (Fig.1) have always been attached to the South American continental lithosphere (Kennerley, 1980; Baldock, 1985; Eguez, 1986). Conversely, others believe that the Macuchi arc and the adjacent Costa were formed at a considerable distance from South America (SOAM) and have been subsequently accreted to it (Feininger and Bristow, 1980; Lebrat et al., 1987).

The purpose of this study was to obtain reliable paleomagnetic results from a large number of well distributed sites in western Ecuador and to compare the stable paleomagnetic directions of this area to those of coeval formations of stable SOAM. Indeed paleomagnetism appears to be a very appropriate method to test whether the Costa and the Western Cordillera represent an allochthonous terrane or always were an integral part of SOAM.

Geological setting and paleomagnetic sampling

The Costa is underlain by a coherent basement of mid-Cretaceous age consisting of pillow-basalts, dolerite sills and dikes, and scarce gabbros and peridotites. These rocks are called the Piñon Formation, and are believed to be part of a basement igneous complex of oceanic origin extending over Western Ecuador and Colombia, as well as part of central America (Goossens et al., 1977). These rocks are oceanic tholeiites and their geochemical features are similar to those of the MORB from the Galapagos rise and also of the tholeiites from western Colombia (Lebrat et al., 1987). They are overlain by the dominantly volcaniclastic turbiditic Cayo series of upper Cretaceous age. Basaltic flows of latest Cretaceous age are interspersed in the series in the Manta area (Goossens and Rose, 1973). They display distinct transitional MORB geochemical patterns and were called informally the San Lorenzo Formation. Similar basalts are associated to the Cayo Formation farther north near Pedernales (Faucher et al., 1971; Henderson, 1979). However, the volcanic clasts in the turbidites range from basic andesites to rhyolites and were probably derived from the Macuchi island arc that forms most of the Western Cordillera (Feininger and Bristow, 1980; Mégard and Lebrat, 1986).

* The Western Cordillera comprises the Macuchi volcanic arc and associated sedimentary rocks of

Paper number 7L7138.

0094-8276/87/007L-7138\$03.00

Fig. 1: Map showing the sampling areas over coastal Ecuador. Sites AN20 to AN31 were sampled in the Manta region. Sites AN33,34,35,36,40,41 near Guayaquil, sites EQ05 and EQ07 near Pedernales; only one site (EQ16) provides a reliable paleomagnetic result in the Macuchi island arc that forms most of the Western Cordillera. The mean declination is indicated for each area.

late Cretaceous to Eocene age, that are unconformably overlain by volcanic formations of Oligocene to recent age (Henderson, 1979; Eguez, 1986). The Macuchi volcanic rocks range from tholeiites to dacites and display REE and other incompatible elements features typical of oceanic island arcs (Lebrat et al., 1987). East of the suture, a continental margin arc called Celica developed during the late Cretaceous. In Southern Ecuador this arc ceased to be active in Campanian time, when a younger volcanic front rose farther to the east. Most probably a general rearrangement of the volcanism began at that time in southern Ecuador and progressed northward during Paleocene and Eocene times. This reorganization came to an end during the Oligocene, when the classic Andean Cenozoic continental arc was completed.

We carried out paleomagnetic sampling within three geographically separate areas of the Costa over 200 km apart, mostly of the volcanics of the Piñon and San Lorenzo formation. In most localities, these formations have only been subjected to minor warping and block faulting. In the Western Cordillera, the Macuchi volcanics have been sampled at five localities scattered over a stretch of about 200 km. At most sites, about ten cores were drilled in situ and each core was independently orientated with both magnetic and sun compasses. The latter was necessary at a number of sites where local magnetic anomalies (due to very high intensity of the natural remanent magnetization) deflected the compass needle. A variety of units were sampled including pillow lavas, massive flows, sills and dikes. At sites where a reliable paleohorizontal correction could not be applied on the basis of bedding in inter-lava sediments, less reliable criteria were used like the attitude of pillow-lava paleoslopes or columnar jointing in massive flows and sills. Gently inclined successions ($<45^\circ$) were, mainly,

sampled to avoid generating substantial declination errors when correcting any isolated remanent magnetization vector back to its pre-tilt orientation (McDonald, 1980).

Paleomagnetic results

The natural remanent magnetization was measured on 1 inch standard cylindrical samples with either a Schonstedt or a Digico fluxgate spinner magnetometer. The stability of the NRM was investigated by standard alternating (AF) field and thermal demagnetization techniques (stepwise up to 100mT or 580°C) with directional changes being studied on two component Zijderveld plots. Samples showing ambiguous demagnetization behaviour were rejected from the population and directions from specimens of a same core were averaged to provide independent directions when compiling a site with Fisher statistics.

The magnetic properties are dependent on the lithological units which have been sampled. High magnetization intensities of between 10 and 100 A/m correspond to pillow-lavas from the San Lorenzo formation near Manta. On the other hand, Curie points and unblocking temperatures are distributed above 200°C depending on the oxidation state of the titanomagnetite carriers and the amount of titanomaghemite. These magnetic properties are characteristic of submarine basalts dredged on the oceanic sea-floor and are similar to those obtained for some ophiolite massifs (Fox and Opdyke, 1973; Banerjee, 1980). Samples from the dolerite units have a lower magnetization and thermomagnetic curves indicate the presence of pure magnetite.

The majority of samples responded well to both A.F. and thermal demagnetization (Fig.2). However, large within site dispersion and/or unstable behaviour upon demagnetization led us to reject 3 sites of the 23 sites studied in the coastal area. In the Western Cordillera, most of the data concerning the Macuchi island arc are equivocal, since magnetic overprint and unstable behaviour alter the isolation of the primary remanence. The only exception concerns a site located near Macuchi mine in volcanics of Eocene age according to Eguez's map (Eguez, 1986). Moreover, this result

Fig. 2: Typical thermal and alternating field demagnetization plots from samples with different polarities. Full circles: projection on the horizontal plane; Open circles: E-W vertical plane.

TABLE 1. Paleomagnetic Results.

Site	N	Dec	Inc	S,D	Dec	Inc	α_{95}	K
		(In situ)			(after BC)			
AN20	14	67	-24	198,37NW	71	5	10.9	14
AN21	12	76	-25	199,37NW	80	5	9.9	22
AN22	9	62	-11	220,36NW	64	3	5.6	86
AN23	12	44	12	227,30NW	39	10	3.7	120
AN24	11	265	10	208,18NW	265	-5	11.1	18
AN25	9	269	9	220,27NW	269	-11	17.3	11
AN26	8	262	12	220,23NW	263	-3	6.1	82
AN27	10	60	-17	-	60	-17	2.3	382
AN28	10	58	-31	251,52NW	90	-27	9.9	25
AN29	6	52	-27	250,52NW	83	-29	3.3	297
AN30	11	76	-17	240,27NW	82	-8	9.6	24
AN31	12	75	-23	160,31SW	74	7	12.7	10
AN33	8	52	-18	150,30NE	49	-48	8.8	25
AN34	10	68	2	150,30NE	69	-27	15.9	10
AN35	7	54	14	-	54	14	11.0	20
AN36	16	66	-26	100,25SW	59	-10	1.8	399
AN40	8	239	31	90,10S	234	25	7.4	58
AN41	9	226	31	90,10S	222	24	3.9	174
EQ05	10	90	-41	180,20W	90	-21	2.4	410
EQ07	10	43	-44	195,55W	65	7	2.2	485
EQ16	13	261	6	37,49E	254	26	14.1	10

Mean 21 sites:

In situ N=21 Dec=66.3 Inc= -18.0 α_{95} =8.5 K=15.1
 After BC N=21 Dec=69.7 Inc= -10.1 α_{95} =9.3 K=12.6

N: number of independent samples used in Fisher statistics; Dec, Inc: mean declination and mean inclination In situ and after bedding correction (BC); S,D: strike and dip of the paleohorizontal; α_{95} : semi angle of confidence; K: Fisher parameter.

is in agreement with those from the coast. Detailed results are listed in table 1.

Diametrically opposite normal and reversed polarity mean directions are recorded in both sampling areas and they clearly group away from the present axial dipole field (Fig.3). However, the low inclinations recorded on these formations do not allow us to determine without ambiguity the polarity of the paleomagnetic field at the time

Fig. 3: Equal area projection of the mean paleomagnetic directions after bedding correction (BC). Open circles: projection on the upper hemisphere; Full circles: on the lower hemisphere.

Fig. 4: Schematic restored plate map and cross-sections showing the proposed plate regime for southern Colombia, Ecuador and northern Peru in Senonian and latest Eocene to earliest Oligocene times. The present sketches are oversimplified.

of acquisition of the remanence. The most likely interpretation is that the directions in the north-easterly quadrant are of normal polarity and that the Pinon basement has been rotated clockwise through an angle of c.a. 70°. The between-site dispersion which is significant in declination might result from the record of a differential rotation between sites, the age of which is not well constrained.

Discussion

Taking into account the absence of major faults in the coastal area of Ecuador, a large scale block rotation explains the paleomagnetic data better than local rotations in a strike-slip tectonic setting as proposed in similar settings by Nur et al. (1986). On the other hand, the oceanic affinity of the Pinon basement suggests an allochthonous origin. The mean paleomagnetic inclination obtained by averaging data from the 21 selected sites would indicate a paleolatitude which might be 5° to the south of its present one. (Because of the age uncertainties and the small divergence between Cenozoic virtual geomagnetic poles of South America with the geographical axis (Irving and Irving, 1982), we can assume a fixed position of the stable continent). The very low latitudinal displacement does not allow an important gap between the Coastal block and the continent. Figure 4 presents a model which involves 2 subductions and a marginal oceanic area. The progressive consumption of this marginal basin in the western SOAM trench led to the collision of the Macuchi arc from south to north. Although evidence for island arc rotations before collision is now widespread (Keating and Helsley, 1985), the large rotation inferred by the paleomagnetic data is in agreement with the possibility that the Coastal block might pivot clockwise during the collision. Feininger and Bristow (1980) proposed another tectonic solu-

tion, which is, however, also compatible with a clockwise rotation of the allochthonous block.

In the present interpretation, we assume an homogeneous block composed of the coastal oceanic crust (Pinon) and the Macuchi arc. However, further paleomagnetic and chronological work are needed both to improve our knowledge of the timing of accretion and to test the homogeneity of the allochthonous terrane.

Acknowledgements. We wish to thank Stalin Benitez, Edison, Navarrete for their help in the field. We thank Y. St. Georges for the technical support provided by the IFEA during the fieldwork. The financial support was given by the ORSTOM, the CNRS, the CEA and by the INSU-ASP Blocs, Collisions, Géodynamique.

References

- Baldock, J.W., The northern Andes: A review of the Ecuadorian pacific margin, in The Ocean Basins and Margins, 7a, The Pacific, edited by A.E.M. Nairn et al., pp181-217 Plenum Press, New-York, 1985.
- Banerjee, S.K., Magnetism of the oceanic crust: Evidence from ophiolite complexes, J. Geophys. Res., **85**, 3557-3566, 1980.
- Duque, P. and M. Santos, Rocas ofiolíticas en los Andes del Ecuador, Rev. Colegio. Ing. Geol., Min. Petrol., **1**, 37-40. (Quito, 1985).
- Eguez, A., Evolution cénozoïque de la Cordillère Occidentale septentrionale d'Equateur (0°15'-1°10'S). Les minéralisations associées. Unpub 3d. cycle thesis, U.P. and M. Curie, Paris (1986).
- Faucher, B., Vernet, R., Bizon J.J., Grekoff, N., Lys, M., and J. Sigal, Sedimentary formation in Ecuador. A stratigraphic and sedimentological Survey. BEICIP, Paris, 1971.
- Feininger, T., and G. Bristow, Cretaceous and Paleogene geologic history of coastal Ecuador, Geol. Rdsch, **69**, 684-874, 1980.
- Feininger, T. and M.K. Seguin, Simple Bouguer gravity anomaly field and the inferred crustal structure of continental Ecuador, Geology, **11**, 40-44, 1983.
- Fox, P.J. and N.D. Opdyke, Geology of the oceanic crust: Magnetic properties of oceanic rocks. J. Geophys. Res., **78**, 5139-5154, 1973.
- Goossens, P.J. and W.I. Rose, Chemical composition and age determination of tholeiitic rocks in the Basic Igneous Complex, Ecuador, Bull. Geol. Soc. Am., **84**, 1043-1052, 1973.
- Goossens, J.P., W.I. Rose and D. Flores, Geochemistry of tholeiites of northwestern South America, Bull. Geol. Soc. Am., **28**, 1711-1720, 1977.
- Henderson, W.G., Cretaceous to Eocene volcanic arc activity in the Andes of northern Ecuador, J. Geol. Soc. London, **136**, 367-378, 1979.
- Irving, E. and G.A. Irving, Apparent Polar Wander Paths Carboniferous through Cenozoic and the assembly of Gondwana. Geophysical Surveys, **5**, 141-188, 1982.
- Juteau, T., F. Mégard, L. Raharison and H. Whitechurch, Les assemblages ophiolitiques de l'occident équatorien, Bull. Soc. Geol. Fr., **19**, 1127-1132, 1977.
- Keating, B., and C.E. Helsley, Implications of island arc rotations to the studies of marginal terranes., Journal of Geodynamics, **2**, 159-183, 1985.
- Kennerley, B., Outline of the Geology of Ecuador, Overseas Geol. and Miner. Resour., **55**, London, 1980.
- Lebrat, M., F. Mégard, C. Dupuy and J. Dostal., Geochemistry of the Cretaceous volcanic rocks of Ecuador: geodynamic implications, Bull. Geol. Soc. Am. (in press, 1987).
- Mc Donald W.D., Net tectonic rotation, apparent tectonic rotation, and the structural tilt correction in paleomagnetic studies, J. Geophys. Res., **85**, 3659-3670, 1980.
- Mégard, F. and M. Lebrat, Los terranos exóticos del Occidente ecuatoriano y sus relaciones con Sumamérica, in "Actas del colloquio Ecuador 86", Quito, 1986.
- Nur A., H. Ron and O. Scotti, Fault mechanics and the kinetics of block rotations, Geology, **14**, 746-749, 1986.
- T.M. Clube and C. Laj, Centre des Faibles Radioactivités, Laboratoire mixte CNRS/CEA, 91190, Gif-sur-Yvette, France.
- F. Mégard, Centre Géologique et Géophysique, U.S.T.L., 34060, Montpellier, France.
- T. Mourier, Université de Paris Sud, 91405, Orsay, France
- C. Noblet, Institut Français d'Etude Andines, Quito, Ecuador
- P. Roperch, ORSTOM, Laboratoire de Géophysique, Institut de géologie, 35042, Rennes, France

(Received February 23, 1987;
accepted March 4, 1987.)