A Study of Paleomagnetism of the Nicoya Terrane, Costa Rica

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Abstract

The Chorotega Terrane constitutes the backbone of the southern Middle America volcanic arc, formed on the western edge of the Caribbean plate. The adjacent Nicoya Terrane, lying trenchward of the Chorotega Terrane, was previously determined to be located at 7° S during the Cretaceous, with conflicting data constraining accretion timing. New paleomagnetic data from Paleocene rocks reveal that the Nicoya Terrane was at its present latitude relative to the autochthonous Chorotega Terrane. These data suggest that the Nicoya Terrane accreted to the Chorotega Terrane by Paleocene time.

Introduction

The Nicoya Terrane and the adjacent Chorotega Terrane are located between the converging Caribbean and Cocos Plates along the Middle America Trench (Gardner, this volume, Fig. 1). The accretion timing of the two terranes is at present poorly understood. DiMarco et al. (1995) suggest that Paleocene coarse channel-fill and overbank deposits, including boulders of andesites and limestones, indicate the initial amalgamation of the two terranes. Previous paleomagnetic studies indicate that the Nicoya Terrane was located about 7° S latitude, compared to the 10° N latitude of the Chorotega Terrane in Late Cretaceous time (DiMarco et al., 1995). The present latitude of the Nicoya Terrane is 10° N, indicating a 17° northward latitudinal displacement (~ 1900 km). These data largely support the reconnaissance paleomagnetic work of Gose (1983). However, Gose's (1983) Tertiary paleolatitudes give equivocal results for age of accretion, possibly due to uncertain age control and/or questionable assignment of outcrops to various terranes. The purpose of this study is to provide additional paleomagnetic evidence to help constrain the accretion timing of the Nicoya Terrane.

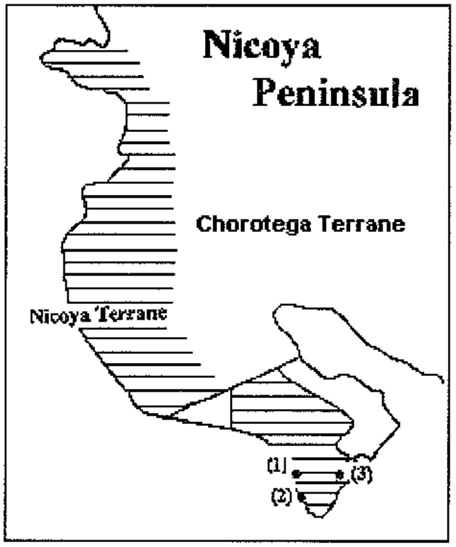

Figure 1. Diagram showing Nicoya Peninsula with Nicoya and Chorotega Terranes. Sample localities: (1) Punta Barrigona (2) Punta Cuevas (3) Playa Cabuya and adjacent Rio Lajas area. Diagram from DiMarco et al. (1995)(Figure 8).

Cabo Blanco. The orientation and vergence of folds at Cabuya Playa in the northern section supports this hypothesis. This places the shortening direction at approximately N15E, within 15 degrees of the present direction of subduction. The layer-shortening wedge faults, believed to have predated folding indicate shortening was earlier oriented close to N80E. This requires a 65 degree counterclockwise rotation of shortening between the times of formation of the faults and the folds. A counterclockwise change in the direction of shortening is supported by evidence indicating that the convergence of the Cocos Plate has rotated counterclockwise from a more easterly direction since deposition of the Cabo Blanco (Pindell and Barrett, 1990).

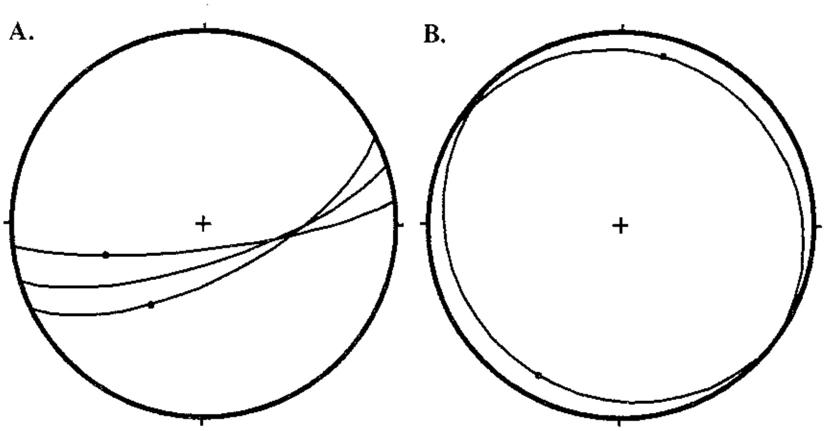

Figure 6. This set of Stereonet plots shows how the layer shortening wedge faults were rotated back to paleohorizontal. Stereonet A) shows a fault pair with rakes and local average bedding. Stereonet B) shows this fault pair after the dip was removed from bedding.

ACKNOWLEDGMENTS

I would like to recognize a few individuals whom helped make this project possible. I would like to thank Edward Beutner for his continued support and guidance throughout this year as my project sponsor. I would like to commend Tom Gardner for his organization and leadership as the director of the 1998-99 Costa Rica KECK project, his efforts made this project a joy to be a part of. I would also like to thank Alix Krull and Becky Stamski for their dedicated assistance in the field.

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Paleomagnetic Sample Localities and Technique

The Nicoya Terrane was sampled at three localities: Playa Cabuya and the adjacent Rio Lajas area (75 cores from 12 beds, Cabo Blanco Formation), Punta Barrigona (37 cores from 9 beds, Santa Teresa Formation), and Punta Cuevas (22 cores from 8 beds, Punta Cuevas Formation) (Figure 1). These three localities were chosen due to their location on the allochthonous ocean-ward side of the Nicoya Peninsula and representing a variety of Tertiary ages. Well indurated, fine grain sedimentary rocks, most likely to contain single-domain magnetite, were drilled to obtain best results. Playa Cabuya rocks were of particular importance because small scale folds could be sampled in order to apply the fold test for paleomagnetic stability.

Standard 2.5 cm x 2 cm samples were prepared and measured using a Schonstedt SSM-1A spinner magnetometer. Samples were magnetically cleaned in a stepwise manner, using a Molspin tumbling alternating field (AF) demagnetizer, to isolate secondary magnetic overprints. Vector plots of declination and inclination were used to identify secondary and characteristic components. The characteristic vectors were identified based on little or no shift in direction with decreasing intensity, indicating a stable demagnetization endpoint.

Data Analysis

Samples collected from the Eocene Punta Cuevas locality failed to yield stable demagnetization endpoints and therefore were not considered further. Well-defined characteristic directions were obtained from about 52% of the cores measured from Playa Cabuya (Paleocene) and about 47% from the cores at Punta Barrigona (Miocene). Punta Barrigona yielded 8 acceptable samples from 6 beds out of 17 measured specimens (Table 1). At all three localities, samples providing no usable data displayed overlapping coercivity spectra for both primary and secondary vectors, failing to yield stable endpoints and therefore were not included in the calculations.

Stereographic plots of both geographic and stratigraphic directions, from the Punta Barrigona locality, gave modest clustering. The geographic mean direction is 347°, 21° (declination, inclination) (k=165, alpha-95=5°, n=6) and the mean stratigraphic direction is 316°, 33° (k=74, alpha-95=8°, n=6). A fold test was not possible, at this locality, due to the homoclinal attitude of the strata.

Paleomagnetic Data from Playa Cabuya

Sample	Bed	Demag	NRM	NRM	Geo	Strat	D-P Strat
8	1	250	2.1E-5	15%	310, 40	317, -16	-
9	1	300	2.8E-5	25%	283, 51	309, 4	-
11	1	200	3.5E-5	32%	288, 53	313, 3	-
Bed 1 mean					*295, 49*	*313, 8*	
16	2	350	4.5E-5	24%	260, 62	319, 22	-
17	3	200	4.3E-5	29%	266, 57	320, 22	-
42	5	300	3.3E-5	22%	280, 66	305, 23	292, 22
49	4C	250	1.9E-5	35%	310, 58	315, 5	302, 6
35	4B	250	2.3E-5	49%	324, -11	317, 3	290, 3
36	4B	300	2.0E-5	32%	318, -21	306, 8	279, 7
37	4B	200	1.8E-5	138%	315, -5	321, 13	295, 12
Bed 4 Mean					*319, -12*	*315, 8*	*288, 7*
54	4D	400	1.6E-5	30%	286, 19	268, 2	297, 2
55	4D	200	2.9E-5	34%	301, 19	271, 16	299, 16
Bed 4D					*294, 19*	*270, 9*	*298, 9*
64	8	400	2.5E-5	14%	253, -74	202, -3	169, -3
68	9	600	7.3E-6	16%	205, -69	194, -2	167, -2
72	10	600	8.4E-6	7%	191, -77	206, -34	*191, -34*
73	10	700	1.6E-5	14%	235, -74	219, -31	*204, -31*
74	10	550	2.2E-5	9%	205, -69	209, -25	*194, -25*
Bed 10					*211, -74*	*211, -30*	*196, -30*

Table 1

The Playa Cabuya locality yielded 17 acceptable samples from 10 beds out of 33 measured cores (Table 1). Replicate samples from the same bed displayed similar characteristic directions generally within ~ 10° from each other, demonstrating reproducible results. Identifiable characteristic directions were plotted on an equal-angle stereonet in both the geographic (in situ) and stratigraphic (tilt corrected) frame of reference. Stereographic plots show a dispersed pattern trending from the NW shallow quadrant to nearly vertical vectors with both positive and negative polarity. The mean geographic direction is 282°, 18° (k=1.7, alpha-95=55°, n=10) (Figure 2A); the kappa of 1.7 is random according to the test of Watson (1956). Stratigraphic vectors show an improvement in clustering in the NW quadrant, with moderate to shallow vectors. There is also a secondary clustering in the SSW with negative inclinations (beds 8, 9, and 10) (Figure 2B). Even interpreted as reversals and inverted through the origin, the resulting NNE cluster is separated from the main NW cluster. Stratigraphic direction yielded a mean direction of 329°, 16° (k=4.7, alpha-95=25°, n=10). Beds 4C and 4D, different limbs of the same bed, show a slightly greater divergence on the stereoplot.

Figure 2

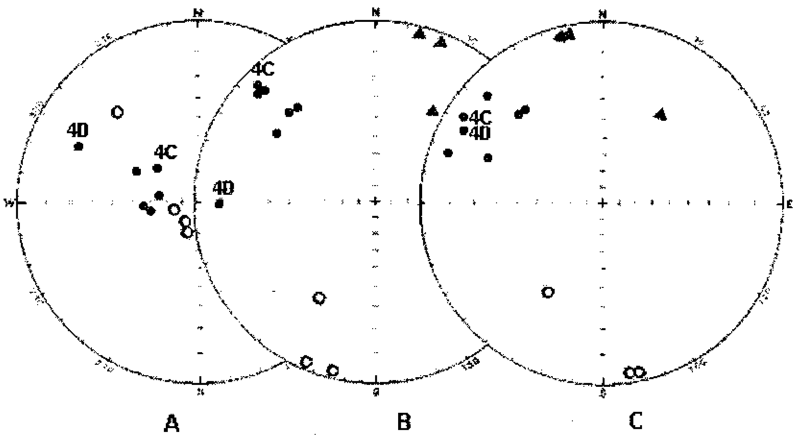

Figure 2. Equal angle projections of remanence directions for Playa Cabuya locality. A) Geographic directions (in situ), B) Stratigraphic directions (tilt corrected about present day strike-line), C) Two-stage corrections (deplunged and unfolded) remanence directions for 10 beds. Solid and open symbols represent positive and negative inclinations, respectively. Triangles represent directions inverted through 180° (reversals).

The occurrence of distinct clusters of the stratigraphic directions suggests multiple tectonic deformations. The standard tilt correction of rotating about the present-day strike line is too simplistic. A plunging fold, at Playa Cabuya, permits a two-stage structural correction to be attempted. The fold axis attitude was obtained by plotting beta diagrams, for the limbs of a plunging anticline, on an equal-area stereonet and determining the average intersection (fold axis). This fold axis was used to deplunge the poles to bedding and to deplunge geographic vectors. The deplunged geographic vectors were then restored to ancient horizontal, using the deplunged bedding attitudes to give deplunged stratigraphic vectors (D-P Strat, Table 1).

After two-stage corrections were completed, deplunged stratigraphic vectors showed improved clustering in the WNW quadrant with shallow vectors (Figure 2C). In the deplunged stratigraphic frame of reference, there is a much improved clustering of beds 4C and 4D. The two limbs are 4° apart, as opposed to 44° apart in the standard stratigraphic reference frame. This may be taken as a positive fold test, indicating a pre-folding magnetization and good evidence for a stable magnetic remanence (see Butler, 1992 for a discussion of the fold test). Because beds 8, 9, and 10 yielded negative inclinations and differed by about 110° in declination from the main cluster, the vectors were interpreted as reversals and inverted through the origin. Although the data grouping improves, the declination is off by a considerable amount. This may result from deformational rotation not accounted for in the two-stage correction. Perhaps a detailed structural analysis of the outcrop area would yield better results. The deplunged stratigraphic mean direction was calculated to be 320°, 15°(k=8.1, alpha-95=18°, n=10). The kappa of 8.1 for the deplunged vectors shows a considerable reduction of dispersion over the standard stratigraphic frame. The stratigraphic inclination from Playa Cabuya was used to calculate a paleolatitude from the equation:

$$\text{Tan } I = 2 \text{ Tan } \lambda$$

where I equals the inclination and λ equals the paleolatitude. Playa Cabuya (Paleocene) samples yielded a 7.6 ° (± 8°) N paleolatitude and Miocene cores at Punta Barrigona yield 18 ° (± 4°) N paleolatitude (Figure 3). The Playa Cabuya paleolatitude indicates that the Nicoya Terrane was at its present latitude relative to the Chorotega Terrane by the Paleocene and probably in place. With no stability tests and only 6 beds measured, the Miocene samples may not be a reliable tectonic indicator. The somewhat high paleolatitude of the Miocene samples may be due to incomplete averaging of secular variation over time; however, the paleolatitude is in rough agreement with the Paleocene value.

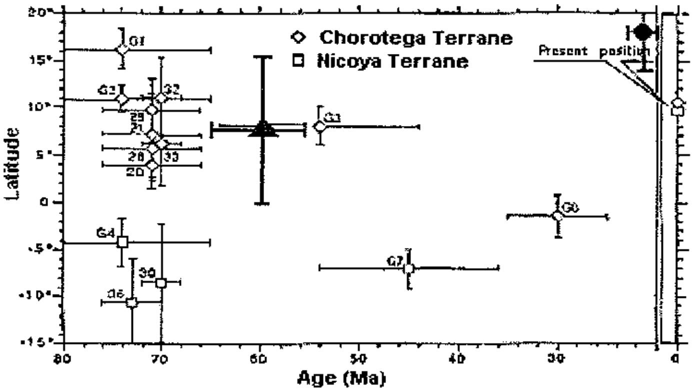

Figure 3. Compilation of paleolatitudes for Chorotega and Nicoya Terranes. Solid triangle is paleolatitude for Cabuya data. Solid hexagon is paleolatitude for Punta Barrigona data. There are no stability tests for the Punta Barrigona data and secular variation may not have been averaged out; thus, Miocene paleolatitude is not well constrained. Diagram from DiMarco et al. (1995) (Figure 22).

Conclusions

The purpose of this project is to provide data on the accretion age/timing of the Nicoya Terrane. The samples from Punta Barrigona (Miocene) yielded equivocal data possibly due to the lack of stability tests and sufficient averaging of secular variation. Data from Playa Cabuya, after a two-stage tectonic correction, pass both fold and reversal tests, insuring the presence of a primary remanence. The paleolatitude calculated for Paleocene cores give a value of 7.6° (± 8°). This value is essentially the same as today's latitude indicating that the Nicoya Terrane was in place relative to the Chorotega Terrane during the Paleocene.

Acknowledgments

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Tectonic and geochemical investigation of basalts and associated deep sea sediments in the southern Península de Nicoya, Costa Rica

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INTRODUCTION

Basalts of the Península de Nicoya represent the ocean crust platform upon which the Central American magmatic arc is being constructed due to subduction at the Middle America Trench. (Gardner, this volume: Fig. 1) The southern peninsula basement outcrops are dominated by massive and pillow basalts with lesser amounts of associated deep sea sediments, conglomeratic broken formations, and monolithic basalt breccias. There is much debate concerning these basement rocks, in relation to both the isolated peninsula in question and to the greater Caribbean region. One area of contention comes out of the discrepancy between the models of Di Marco and others (1995) and Sinton (1996). Sinton (1996) uses geochemistry and geochronology to argue that the entire Península de Nicoya is underlain by thick, basaltic ocean crust of the Caribbean-Columbian Cretaceous Igneous Province (CCCIP) (Kerr *et al.*, 1997). The theory of a large igneous province (LIP) as a model for the anomalously thick (8km to >20km) oceanic crust of the Caribbean is widely supported in Costa Rican geology (see Donnelly, 1994 for a review). The LIP model implies that a more geochemically enriched source, possibly influenced by a hot spot plume head, thickens large areas of ocean floor (CCCIP = 6×10^5 km^2) in a matter of a few million years (CCCIP = 88-90 Ma) (Kerr *et al.*, 1997). In opposition to Sinton (1996), Di Marco and others (1995) used paleomagnetism and post-basalt stratigraphy to distinguish two terranes in the Nicoya region: the autochthonous Chorotega Terrane (CT), representing the Caribbean plate on the east half of the peninsula, and the allochthonous Nicoya Terrane (NT), which was accreted to create the western peninsula (Fig. 1). A third, slightly older model developed by Kuijpers (1980) suggests that the entire peninsula was involved in accretionary burial and nappe structure formation during its accretion onto the Caribbean plate.

OBJECTIVES, SAMPLING, AND METHODS

The goal of this investigation is to utilize geochemistry, geochronology, and micropaleontology to constrain the formation and evolution of the southern section of the peninsula, a multi-faceted project which is outlined below:

1. One of the main discrepancies in the debate is the fact that Sinton (1996) sampled only the northern section of the Península de Nicoya, well within Di Marco and other's (1995) NT. This study attempts to characterize the southern CT geochemically and compare these data to both Sinton's (1996) NT data set and to four NT samples collected during this investigation. Fourteen massive and pillowed basalt samples (10 CT, 4 NT) were gathered along coastal and road outcrops (Fig. 1). X-ray fluorescence (XRF) was conducted at the University of Massachusetts to obtain major and trace element geochemistry for all fourteen samples. In addition, six samples underwent instrumental neutron activation analysis (INAA) at Oregon State University for supplemental trace element data.
2. X-ray diffraction (XRD) was employed for eight samples, including two monolithic basalt breccias, in order to examine cryptocrystalline mineral phases for signals of alteration and/or subduction-related metamorphism.
3. One of the strongest arguments in support of the CCCIP is the contemporaneous igneous activity found across the Caribbean at 88-90 Ma (Sinton 1996). In order to investigate the possible link of the CT to the CCCIP, three of the freshest samples from the CT will be dated via whole rock ^{40}Ar - ^{39}Ar at the Massachusetts Institute of Technology. In addition, three inter-pillow radiolaria chert samples were collected for microfossil dating to help constrain the timing of volcanism.

PETROGRAPHY AND MINERAL CHEMISTRY

Southern Península de Nicoya basalts are aphyric with the following mineral assemblage and modal percentages: plagioclase (dominantly An$_{50-70}$), 40-55%; augite, 30%; Ti-magnetite and illmentite, 10-15%; altered mesostasis, cryptocrystalline alteration minerals, and calcite veining; 5-15%. Augite crystals display varying degrees of Fe rimming. One sample from the NT has highly altered plagioclase in which An$_{70-73}$ has been converted to An$_{23-}$