Documenting Translation and Vertical-Axis Rotations using Paleomagnetic Techniques along the Panama Isthmus: Preliminary Results

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Abstract - *Along the Isthmus of Panama 23 paleomagnetic sites were sampled in order to determine preliminary block rotations and paleolatitudinal movements. The lithology selected for this research corresponds to volcanic and sedimentary rocks with ages ranging from Upper Cretaceous to Pleistocene.*

Counterclockwise vertical axis rotations were uncovered in Paleocene and Oligocene units separated by a sinistral fault. Mean directions of two sites collected in Cenozoic rocks to the north of the fault are westerly (D 275.4, I -20.8, k 20.46, a95 10.9; D 264.6, I 5.3, k 292.35, a95 3.5), whereas the mean direction uncovered in one site collected in Oligocene rocks to the south of the fault yields a northward declination and positive inclination (D 346.3, I 14.3, k 18.43, a95 14.4). Vertical axis rotation of 81.7º ± 13.3º, of the Paleocene rocks with respect to the Oligocene rock. Cenozoic sites record the northward path of the trailing edge of the Caribbean plate, from 10.8ºS for Paleocene to 6.6ºN for Oligocene. However, more sites are needed to be collected in order to better constraint this northward translation. Components isolated in El Valle volcano and Canal areas using Middle Miocene to Pleistocene rocks, indicate normal and reverse directions similar to the current direction of the Earth magnetic field. Therefore, no major latitudinal displacement of the Panama Isthmus has occurred during the Neogene.

Northward migration of the Panama arc is consistent with the Pacific origin of the Caribbean plate and counter-clockwise vertical axis rotation of several blocks in Panama could be related with the South American Plate collision since Pliocene.

Keywords - *Caribbean Plate, Paleogene, Neogene, paleomagnetism, sinistral fault, volcanic arc.*

Resumen - *Con el objetivo de determinar rotaciones de bloques y movimientos paleolatitudinales del arco volcánico de Panamá, fueron muestreados 23 sitios de tobas, lavas y arenitas calcáreas con edades Pleistocenas a Cretácicas.*

Rotaciones de bloques en sentido antihorario fueron registradas en unidades Paleocenas y Oligocenas separadas por la falla sinestral del Río Gatún. Dos sitios de edad Cenozoica, al norte de la falla, registran direcciones hacia el occidente (D 275.4, I -20.8, k 20.46, a95 10.9; D 264.6, I 5.3, k 292.35, a95 3.5), mientras un sitio de edad Oligoceno, al sur de la falla, registra declinación hacia el norte con inclinación positiva (D 346.3, I 14.3, k 18.43, a95 14.4). Rotaciones sobre el eje vertical de 81.7º ± 13.3º son registradas en rocas de edad Cenozoica. Estos sitios a su vez indican un movimiento paleolatitudinal hacia el norte del borde sur de la Placa Caribe, desde 10.8° sur a 6.6° norte, entre el Paleoceno hasta el Oligoceno. Sin embargo, una mayor cantidad de sitios de muestreo es necesaria para aseverar más claramente esta translación latitudinal. Otros componentes aislados en rocas volcánicas del Mioceno Medio al Pleistoceno, en El Valle de Antón y el área del Canal, indican direcciones normales y reversas del campo magnético similares al campo magnético actual. Estas direcciones permiten sugerir que no ha habido significantes movimientos latitudinales del Istmo de Panamá durante el Neógeno.

El movimiento hacia el norte del arco volcánico de Panamá es consistente con la hipótesis del origen Pacífico de la Placa Caribe. Las rotaciones de bloques en sentido antihorario de varios terrenos en Panamá puede estar relacionada a la colisión con la Placa Suramericana durante el Plioceno.

Palabras Claves - *Placa Caribe, Paleógeno, Neógeno, paleomagnetismo, falla sinestral, arco volcánico.*

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1. INTRODUCTION

The formation of the Isthmus of Panama has been explained by several theories during last decades but the explanation is still unclear. One of the most acceptable theories is the accretion of allochthonous terrains that were migrating from southern latitudes since Cretaceous [1] Coates et al.,

Figure 1. Geologic terrains of Panama indicating sampled areas and quantity of paleomagnetic sites at each area.

1992; [2] Kellogg & Vega, 1995; [3] Hoernle et al., 2002. The Isthmus of Panama is represented by, at least, three terrains, 'Chocó', 'Chorotega' and the 'Galapagos Igneous Complexes' (Figure 1). Using fossil record of mammals and reptiles, [4] Kirby et al. (2008) suggest that there was a 'landbridge' between North America and the Isthmus of Panama since Paleocene.

The 'Chocó' terrain is located at eastern Panama, is the extension of the Baudó range and the Atrato basin. The 'Chocó' terrain is represented by shallow marine rocks of Miocene age (Chucunaque basin). The 'Chorotega' terrain located at western Panama, is the extension of the Costa Rica – Panama Volcanic Arc. Volcanic rocks of Upper Miocene to Pleistocene age represent the 'Chorotega' terrain. The Galapagos Igneous Complexes (GIC) is the group of rocks that have a geochemical affinity with the Galapagos hotspot. The GIC are mainly ophiolithic rocks like basalts, chert, turbidites and other marine affinity rocks. The age of this complex is around Upper Cretaceous to Paleocene.

Several structural styles have been proposed to explain the shape of the Isthmus. Interpretations of seismic profiles suggest the origin of an orocline due to the interaction of the Nazca plate with the South American plate [5] Silver et al., 1990.

2. METHODOLOGY

Five areas of Panama (Azuero, El Valle, Colon, Canal and Darien) were sampled with a total of 23 paleomagnetic sites. The age of the sampled units are in between Upper Cretaceous and Pleistocene, and mainly volcanic rocks.

Alternating field (AF) and thermal progressive demagnetization analysis were carried out at the paleomagnetism laboratory of the University of Florida in Gainesville, FL. Component analysis [6] Kirschvink (1980) interpreted from orthogonal demagnetization diagrams [7] Zijderveld (1967), gave us the mean magnetization directions, calculated using statistical methods by Fisher (1953) [8].

Mean Virtual Geomagnetic Pole (VGP) were determined from the characteristic components and then compared with the reference poles of the South American craton, in order to compare tectonic implications. For vertical-axis rotations, the confidence limits for structural domain declinations and the relative difference of declinations with an arbitrary point in the stable craton, following the criteria given by Demarest (1983) [9].

3. RESULTS

From 23 sites, 16 sites uncovered reliable directions (Table 1). In the Canal area, five sites uncovered directions with southerly declinations and

Table 1. Mean components isolated in this research. Di Marco et al. (1995) [10] direction was isolated in the same terrain of the Azuero area.

Area	Site	Bedding	Comp	N/n	R	Range AF (mT)	Range Thermal (_ C)	Before tilt correction Dec	Before tilt correction Inc	After tilt correction Dec	After tilt correction Inc	alfa95	kappa
CANAL	PAN2	170/31	a	7/5		_15	_250	Dispersed direction. NW - moderate positive inclination					
			b	7/7	6.83	15-100	250-560	183.4	-4.5	186.3	-34.5	10.3	35.02
	PAN5	220/35	b	7/6	5.87	10-60		127.9	-12.8	120.9	-9.2	11.1	37.48
	PAN6	176/29	b	6/6	5.92	30-100	300-540	151.1	9.5	150.3	-16.9	8.5	62.88
	PAN8	210/35	b	6/6	5.58	15-60	_560	125.2	27.4	140.5	19.3	20.2	11.9
	PAN9	227/27	a	8/5		_10	_200	Dispersed direction. S - moderate positive inclination					
			b	8/8	7.98	10-90	300-620	179.6	3.7	177.7	-14.4	3.3	287.61
	PAN24	138/30	b	7/5	4.99	15-100	200-590	147	-10.8	149.6	-40.3	4.4	298.56
	PAN25	161/52	b	6/6	5.88	15-100	300-660	129.6	53.1	142.7	5.1	10.6	41.06
AZUERO	PAN13	204/27	a	9/7		_10	_450	Dispersed direction. E - low positive inclination					
			b	9/9	8.71	20-70	_590	314.6	8.3	308.8	16.6	9.9	27.92
COLON	PAN14	278/22?	a	7/5		_15	_300	Dispersed direction. N - high positive inclination					
			b	7/7	6.98	20-100	400-620	263.1	26.6	264.6	5.3	3.5	292.35
	PAN15	288/56	b	16/10	9.56	10-100	250-620	273.7	33.9	275.4	-20.8	10.9	20.46
	PAN17	320/25	a	8/7		_10	_200	Dispersed direction.					
			b	8/8	7.66	10-80	200-560	352.3	35	346.7	13.1	12.5	20.73
EL VALLE	PAN18	164/36	a	12/4		5-25	_450	Dispersed direction.					
			b	12/7	6.92	_70	300-640	174.2	-12.6	178.9	-47.8	6.9	78.54
	PAN19	194/18	a	8/5	4.48	_10	_200	93.1	76.4	152.3	69.8	29.4	7.71
			b	8/8	7.87	10-100	300-640	170.3	0.2	169.3	-16.2	7.6	54.57
	PAN20	340/07	a	10/2		_10		28.3	27.5	25.1	24.8	53.9	23.61
			b	10/9	8.89	_70	_620	351.3	13.7	350.6	7.8	6	73.47
DARIEN	PAN22	69/18	a	8/4		_15		276.6	12.1	279.9	27.9	39.2	6.46
			b	8/7	6.33	15-100		323.1	11.6	327.5	15.9	21.4	8.92
	PAN23	98/32?	?	6/6	5.81	15-100	300-590	196.5	25.8	180.4	26.1	13.4	25.79
GOLFITO	DiMarco et al., 1995			5	4.8			306.4	18.1	304.8	5.4	18.9/11.4	17.4/46.1

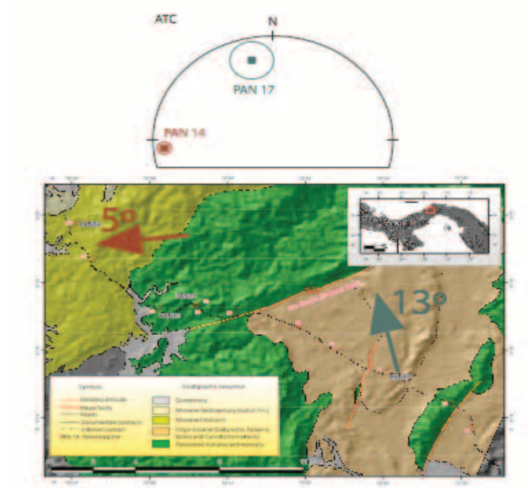

Figure 2. Counterclockwise vertical axis rotation of the tectonic block to the north of the Rio Gatun sinistral fault.

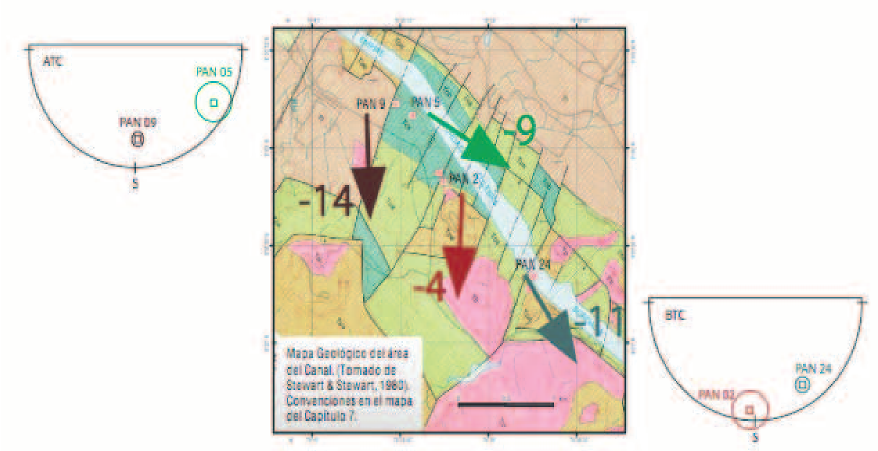

Figure 3. Counterclockwise vertical axis rotation at the Canal area.

shallow to moderate negative inclinations after tilt correction, such as PAN 2 (D 186.3, I -34.5, k 35.02, α95 10.3), PAN 5 (D 120.9, I -9.2, k 37.48, α 95 11.1), PAN 6 (D 150.3, I -16.9, k 62.88, α95 8.5), PAN 9 (D 177.7, I -14.4, k 287.61, α95 3.3), and PAN 24 (D 149.6, I -40.3, k 298.56, α95 4.4). Other two directions uncovered in the Canal area show southerly declinations, as well, but positive inclinations, PAN 8 (D 140.5, I 19.3, k 11.9, α95 20.2), and PAN 25 (D 142.7, I 5.1, k 41.06, α95 10.6).

In Azuero, only one site uncovered a reliable direction, PAN 13 (D 308.8, I 16.6, k 27.92, α95 9.9); the other three sites of this area showed scattered directions. The Colon area uncovered three reliable directions from four sites sampled. Sites PAN 14 (D 264.6, I 5.3, k 292.35, α95 3.5) and PAN 15 (D 275.4, I -20.8, k 20.46, α95 10.9) show good grouping with westerly declinations but inclinations are remarkable different. The third site is PAN 17 (D 346.7, I 13.1, k 20.73, α95 12.5) shows north declination with shallow inclination, similar to the recent magnetic field direction (Table 1).

El Valle area uncovered three directions, PAN 18 (D 174.2, I -12.6, k 78.54, α95 6.9), PAN 19 (D 170.3, I 0.2, k 54.57, α95 7.6), and PAN 20 (D 351.3, I 13.7, k 73.47, α95 6). And Darien area uncovered scattered directions not used for statistical analysis (Table1).

4. DISCUSSION

The Colon area shows a very clear counterclockwise vertical axis rotation between volcanic rocks of Cenozoic age (Figure 2). Mean directions of two sites collected in Cenozoic rocks to the north of the fault are westerly (PAN 15 D 275.4, I -20.8, k 20.46, α95 10.9; PAN 14 D 264.6, I 5.3, k 292.35, α95 3.5), whereas the mean direction uncovered in one site collected in Oligocene rocks to the south of the fault yields a northward declination and positive inclination (PAN 17 D 346.7, I 13.1, k 20.73, α95 12.5).

Several sites indicate counterclockwise vertical axis rotation due to transverse faults along the Canal area (Figure 3). Three sites uncovered normal and reversal directions were isolated in El Valle, in Upper Miocene to Pleistocene volcanoclastics, show a very good example of a polarity change of the magnetic field. Site PAN 13, in Azuero, indicates a moderate grouping with one direction isolated by Di Marco et al., (1995) [10] in the same terrain (Golfito terrain).

Table 2. Vertical axis rotations uncovered in this research. Colon area, sites PAN 14 and PAN 17; Canal area, sites PAN 9 and PAN 5, PAN 2 and PAN 24; Chorotega direction is represented by site PAN 20 in El Valle area, and Golfito direction is represented by site PAN 13 of Azuero area.

Sites	Dec (_)	alfa95	Rotation (_)	Uncertainty (±)
PAN 14	264.6	3.5150278	**81.7**	**13.3066441**
PAN 17	346.3	12.8339922		
PAN 9	177.7	3.40703838	**56.8**	**11.74946905**
PAN 5	120.9	11.2446482		
PAN 2	183.4	10.3318496	**36.4**	**11.26106642**
PAN 24	147	4.47934145		
Chorotega	351.3	6.17570422	**44.5**	**27.29629938**
Golfito	306.8	26.5885057		

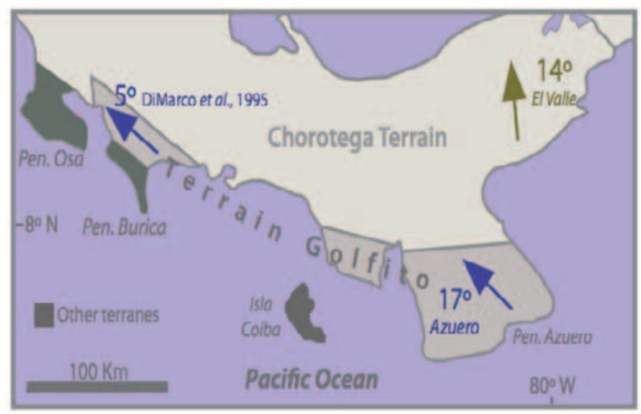

Figure 4. Counterclockwise vertical axis rotation of the 'Golfito' terrain with respect to the 'Chorotega' terrain.

Table 3. Paleolatitudes of the Panama arc for two sites in the Colon area.

Sites	Inc (¼)	alfa95	Paleolatitude	Uncertainty (±)
PAN 15	-20.8	10.9	**10.8¼ S**	10.9¼
PAN 17	13.1	12.5	**6.6¼** N	12.5¼

Directions isolated for Colon and the Canal area, suggest a counterclockwise vertical axis rotation tendency of the Panama Isthmus. Vertical axis rotation of the Colon area is 81.7º ± 13.3º (Table 2, Figure 2) and 56º±11.7º in the Canal area (Table 2, Figure 3). An average of a direction from one site in Azuero and a direction from one site of the 'Golfito' terrain [10], compared with the direction isolated for 'Chorotega' terrain (El Valle), suggest a

counterclockwise vertical axis rotation of 44.5º ± 27.3º of the 'Golfito' terrane compared with the 'Chorotega' terrain (Table 2, Figure 4).

Figure 5. New paleomagnetic areas in order to have better resolution about rotations and translations in the Panama volcanic arc.

5. CONCLUSIONS

Directions of El Valle area show the best grouping before tilt correction, indicating an actual magnetic field direction. Furthermore, the directions isolated in this area indicate a non-rotated block since Upper Miocene (age of the oldest site of this area, PAN 18).

Directions from Colon uncovered in Cenozoic volcanic rocks, at north of the Rio Gatun Fault, indicate a counterclockwise vertical axis rotation due to the Rio Gatun sinistral fault (Figure 2; Table 2). A similar rotation is shown in the Canal area, in basaltic dikes and tuffs of Middle Miocene units (Figure 3; Table 2). The magnitude of the rotation is greater in the Colon area than in the Canal area.

Two sites of Colon area allow us to calculate a VGP for Paleocene and Oligocene rocks. These two VGP indicate that the Panama Volcanic Arc was formed at southern latitudes since Paleocene Paleolatitudes of two sites in Colon area (Table 3), indicate a 10.8º S latitude for a Paleocene site and a 6.6º N latitude for an Oligocene site. It means that the northward translation of the Panama Volcanic Arc was since Paleocene (or before) until the Oligocene, and after Oligocene, there is not major latitudinal movement of the mentioned arc.

6. RECOMMENDATIONS

In order to get more confidence about the rotations and translations is necessary to get more samples in other locations of the Panama Isthmus.

Following that idea, other areas have been sampled along the eastern Caribbean coast (Kuna Yala), and upstream along Mamoni and Terable rivers (Figure 5). Collected samples are volcanic rocks of the ophiolithic complex (Early Arc), and other associated bedded sedimentary rocks, with age ranging between Upper Cretaceous to Paleocene.

This new data will allow us to determinate events of rotation and trace paleolatitudinal path of the Panama Volcanic Arc more accurately.

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