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Mesozoic terrane translations and crustal block rotations in the Eastern Cordillera and Magdalena Valley, Colombia, inferred from paleomagnetism

G. Bayona [1], A. E. Rapalini [2], V. Costanzo-Álvarez [3], C. Montes [4], G. Veloza [1], R. C. Ayala-Calvo[1], M. Gómez-Casallas [5], & C. Silva [1]

[1] Corporación Geológica Ares, Calle 57 No. 23-09 of. 202, Bogotá, Colombia (gbayona@cgares.org)
[2] Dpto. de Ciencias Geológicas, Universidad de Buenos Aires. Argentina
[3] Dpto. de Ciencias de la Tierra, Universidad Simón Bolívar, Caracas, Venezuela
[4] Carbones de Cerrejón, Colombia
[5] Ingeominas Bogotá, Colombia

Pre-Cretaceous history of accretion of terranes west of the Guyana craton (northern Southamerican plate) is still poorly understood. Detailed geochronological and geochemical analysis in granulite-cored basement uplifts of Grenvillian age in the northern Andes reveal an affinity with terranes of Mexico and the Central Andes (Restrepo-Pace et al., 1995 ; Cordani et al, in revision). According to recent proposals, fragmetation of these terranes from Laurentia took place during the opening of the Iapetus ocean (early Paleozoic), but collisions between Laurentian-affinity blocks and Gondwana are still not clear (Ordovician in Restrepo-Pace et al., 1995, or Devonian in Forero, 1990). When and how these terranes collided and arrived to its present geographic position still needs further research. We present the results of a pioneer paleomagnetic and magnetic mineralogy study carried out in Mesozoic rocks cropping out in several terranes of the Eastern Cordillera and Magdalena Valley of Colombia (Fig. 1). The major goal was to characterize componets of magnetization and to determine which components may be used for structural and tectonis analysis of the northern Andes. In addition, we integrate the results of previos paleomagnetic works in the northern Andes and cratonic South America in order to evaluate paleolatitudional translation of terranes and vertical-axis rotations of fault-bounded blocks during the Mesozoic and Cenozoic deformation.

A total of 556 paleomagnetic samples collected in 58 sites were distributed in three major areas, which from north to south are: Bucaramanga (west of the Bucaramanga Fault, 16 sites), Floresta massif (15 sites), and northern Upper Magdalena Basin (27 sites, Fig. 1). Sites were located at different structural domains allowing the performance of the tilt test. Sampled stratigraphic units are Jurassic in age. Sites in unconformable upper (Cretaceous) or lower (Jurassic) units were collected in order to carry out the unconformity test. Contact and conglomerate tests were also carried out in order to establish the relative age of magnetization. The VGP (virtual geomagnetic pole) determined from characteristic component was later compared with the VGP for stable South American craton in order to infer tectonic implications. Thermal and AF demagnetization analysis were carried out in the Paleomagnetic laboratories of Ingeominas (Bogotá, Colombia), and in the Universidad de Buenos Aires (Argentina). Termomagnetic curves and Lowrie experiments in a total of 22 samples were carried out at the Universidad Simón Bolivar (Venezuela).

Both low-tempertature/coercivities magnetic components carrying directions parallel to the present magnetic field and characteristic magnetic componets were isolated from Jurassic and Cretaceous rocks exposed in the three selected areas (Table 1). In Bucaramanga, tilt-corrected characteristic components from the Jordán Fm. (Lower-Middle Jurassic) and Girón-Los Santos Fms (Upper Jurassic-Berriasian) show negative and positive inclinations, respectively, suggesting at least two events of magnetization which are carried mainly by hematite. The comparison of declinations of the Jordán Fm between fault-bounded blocks (each block with a distinct structural domain and Jurassic stratigraphy) indicate 95.9° ± 16.2° counterclockwise rotation of one block respect to the other. Characteristic paleomagnetic directions from syn-rift deposits of the Girón Fm in the two structural domains coincide each other, but stratigraphic thickness change from a few hundred meters in the rotated block to > 4.5 km in the non-rotated block. Therefore, paleomagnetic data from the Jordán and Girón Fms. indicate vertical-axis rotation of fault-bounded blocks associated to syn-rift deposition.

In the Floresta massif, the direction of the tilt-corrected characteristic magnetic component isolated in the Girón-Tibasosa Fms (Upper Jurassic-Valanginian) is similar to the direction isolated in rocks of the same age in Bucaramanga. Variations of declinations bewteen sites at the eastern and western flank of the Floresta massif indicate 39.9 ± 18.2° clockwise vertical-axis rotations during inversion of basement-cored faults bounding the massif. Hematite in clastic rocks and sulphurs (pyrrhotite)-magnetite in calcareous beds are the carriers of these magnetic components.

In the northen Upper Magdalena Basin, characteristic components of magnetization isolated in volcaniclastic rocks of the Saldaña Fm (Upper Triassic-Lower Jurassic) and in volcanic-sedimentary rocks of the Yaví Fm (Aptian) have two directions. Characteristic directions in the Saldaña Fm. have positive inclinations with southern declinations, being antiparallel to the directions isolated in the Jordán Fm. The comparison of declinations of the Saldaña Fm from two structural blocks documents 43.3 ± 29° counterclockwise vertical-axis rotation of one block respect to the other. These blocks also show a change in stratigraphic thickness of the Yaví Fm from 0m in the non-rotated block to >220 m in the rotated block. The latter unit has a paleomagnetic direction with northern declination and shallow positive inclinations, and hematite-magnetite are the magnetic carriers.

Comprehensive analysis of paleomagnetic data from Jurassic to middle Cretaceous rocks exposed in the Sierra Nevada de Santa Marta (MacDonald and Opdyke, 1984), Perijá Range (Gose et al., 2004), Mérida Andes (Castillo et al., 1990) and cratonic areas (Randall, 1998) show a greater magnitude of northward translation of terranes west of the Bucaramanga Fault with respect to the craton and the above mentioned terranes (Table 2, Fig. 2). In terranes west of the Bucaramanga fault, the range of paleolatitudes in the Early Jurassic time varies from -14.4 to -3.6°, whilst the range of paleolatitudes in the Late Jurassic-Early Cretaceous varies from +7.5 to +11.3°. Northward translation of the craton in the same interval of time was only 5± 4°. Paleolatitudes in the other mountain belts are positive since Late Jurassic, as well as in terranes west of the Bucaramanga fault and in cratonic areas (Fig. 2). Therefore, our paleomagnetic data supports northward translation of terranes west of the Bucaramanga fault during the Early and Middle Jurassic, and the east-west translation of Southamerica and accreted terranes since Late Jurassic, as proposed previosly by MacDonald and Opdyke (1984) and Castillo et al (1991).

Northward translations and vertical-axis rotations in extensional/contractional events proposed in this study need to be tested with additional paleomagnetic data in areas east and west of the Bucaramanga fault. The paleomagnetic data presented here indicate that the complex structural setting of the sampled areas and the complex evolution of the Eastern Cordillera of Colombia and adjacent basins needs a systematic paleomagnetic investigation, since we demonstrate that this technique allows to quantify translations of terranes and rotation of fault-bounded blocks.

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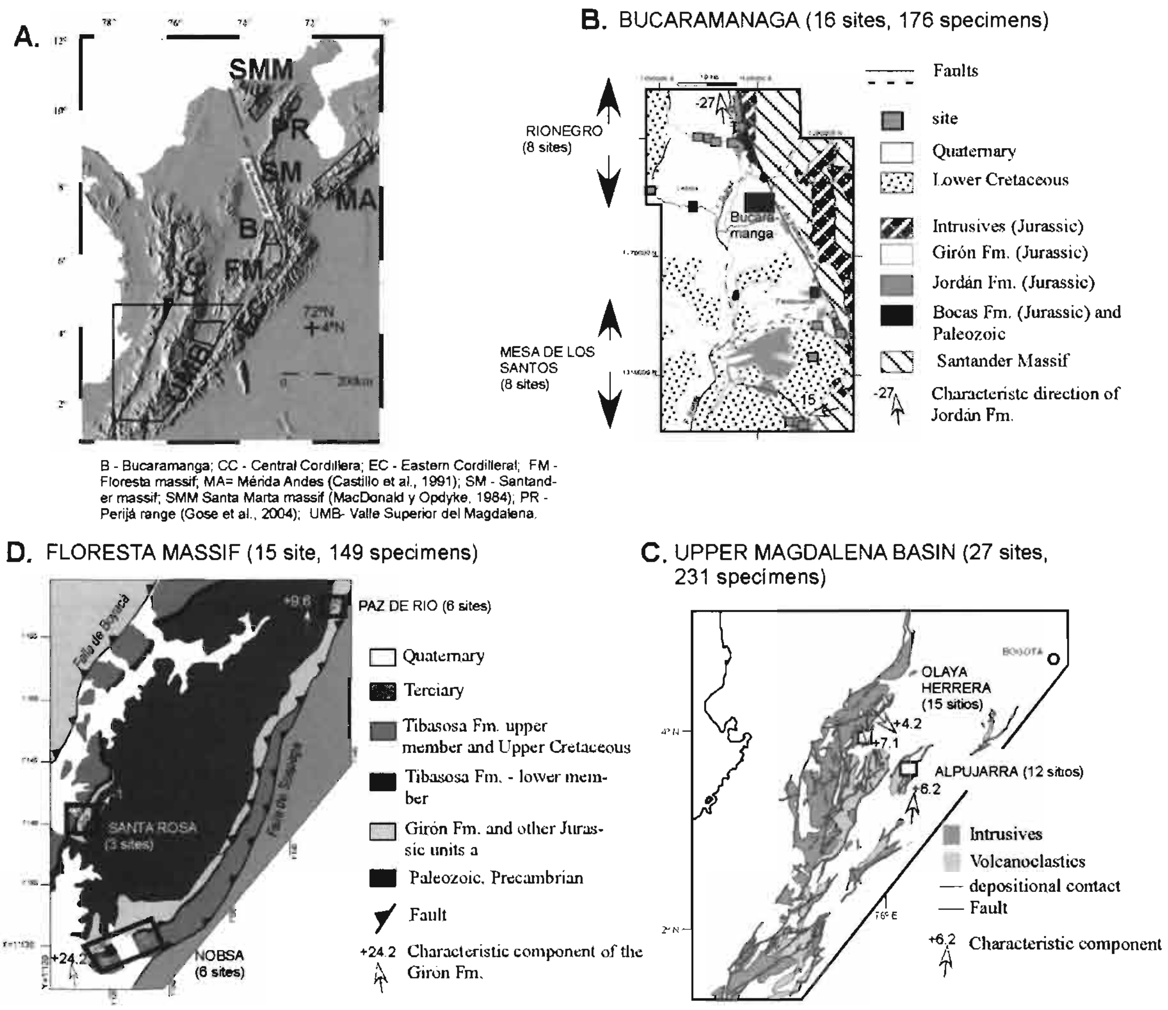
Table 1. Characteristic components and Fisher statistics

					In situ				tilt-corrected			
Area	**Sector**	**Unit**	**Age**	**N/s**	**Dec.**	**Inc.**	**k**	**a95**	**Dec.**	**Inc.**	**k**	**a95**
Bucaramanga	Rionegro	Jordán	Lower-Middle Jurassic	2/13	15.1	-5.2	10.7	13.3	353.6	-27.1	15	11.1
Bucaramanga	Mesa Los Santos	Jordán	Lower-Middle Jurassic	2/16	256	-6.1	10.7	9.5	257.7	-15.7	14.6	10
Bucaramanga	promedio	Girón	Upper Jurassic-Lower Cretaceous	5	9	13.3	29.3	14.4	1.7	21.8	29.1	14.4
Bucaramanga	promedio	Los Santos	Berriasian-Valanginian	2/21	30.4	14.9	11.7	37.7	20.6	8.4	59.6	16.1
Floresta	promedio	Girón-Tibasosa	Upper Jurassic-Valanginian	5	353.1	-14.8	12.82	22.2	352.6	14.8	32.98	13.5
UMB	Olaya Herrera-1	Saldaña	Upper Triassic-Lower Jurassic	8	175.2	15.2	16.02	14.3	179.9	7.1	17.19	13.7
UMB	Olaya Herrera-2	Saldaña	Upper Triassic-Lower Jurassic	3	316.8	6.2	24.5	25.5	316.6	-4.2	24.59	25.4
UMB	Alpujarra	Yaví	Aptian	8	5.5	-5.4	34.62	10.4	5.2	6.2	40.15	9.6

N/s= number of sites/specimens. Fisher statitics at specimen level if N=2. UMB=upper Magdalena basins



B - Bucaramanga; CC - Central Cordillera; EC - Eastern Cordilleral; FM - Floresta massif; MA= Mérida Andes (Castillo et al., 1991); SM - Santander massif; SMM Santa Marta massif (MacDonald y Opdyke, 1984); PR - Perijá range (Gose et al., 2004); UMB- Valle Superior del Magdalena.

Figure 1. A. Localization of areas with paleomagnetic studies in the northern Andes (see references) and other major ranges. B, C, and D. Location of paleomagnetic data reported in this study.

Table 2. Paleolatitude calculation for different terranes. Craton paleolatitud considered paleopolos for South America in Randall (1998).

						Paleolatitud		
Terrane/sector	Unit	Age (Ma)	N (1)	Inc (2)	a95	media	Error to south	Error to north
TERRANES W TO THE BUCARAMANGA FAULT								
VSM	Saldaña	170-210	8	-7.1	13.7	-3.6	-10.8	3.3
B/manga	Jordan	160-200	2	-27.1	11.1	-14.4	-21.5	-8.2
B/manga	Giron	140-160	5	21.8	14.4	11.3	3.7	20.1
Floresta	Giron y Tibasosa	132-160	5	14.8	13.5	7.5	0.7	15.1
VSM	Yaví	112-121	8	6.2	9.6	3.1	1.7	8.1
MERIDA ANDES (Castillo et al., 1991)								
Mérida	La Quinta	144-180	1	17.4	5.8	8.9	5.9	12.1
Mérida	La Quinta	144-180	1	0.1	5.6	0.1	-2.8	2.9
Mérida	La Quinta	144-180	1	5.9	6	3	-0.1	6
Mérida	Rio Negro	121-144	1	20.5	6.5	10.6	7.1	14.3
SANTA MARTA MASSIF (MacDonald y Opdyke, 1984)								
SNSM	Los Clavos	175-180	4	41.3	21.1	23.7	10.4	43.7
SNSM	Guatapuri	185-200						
SNSM	Guatapuri	141-181	3	47.2	26.7	28.4	10.6	60
PERIJA RANGE (Gose et al., 1984)								
Perijá	La Quinta	140-180	1	26.8	7.3	14.2	10	18.7
Perijá	Cogollo Gr.	120-140	1	27.1	8	14.4	9.8	19.4
Perijá	Cogollo Gr.	120-140	1	55.1	5.1	35.6	30.8	41.1
Perijá	Cogollo Gr.	120-140	1	45.1	10.1	26.6	19.3	35.7
CRATON (REFERENCE SITE AT 4°N 288°E)								
Guyana		221-206		-12.1	10	-6.1	-11.5	-1.3
		160-206		1.8	11.6	0.9	-4.9	6.8
		121-160		12.3	5.2	6.2	9	3.6
		112-121		16.4	3.5	8.4	10.3	6.5

(1) number of sites used for calculation of mean inclination

(2) Inc= inclination with north declinations

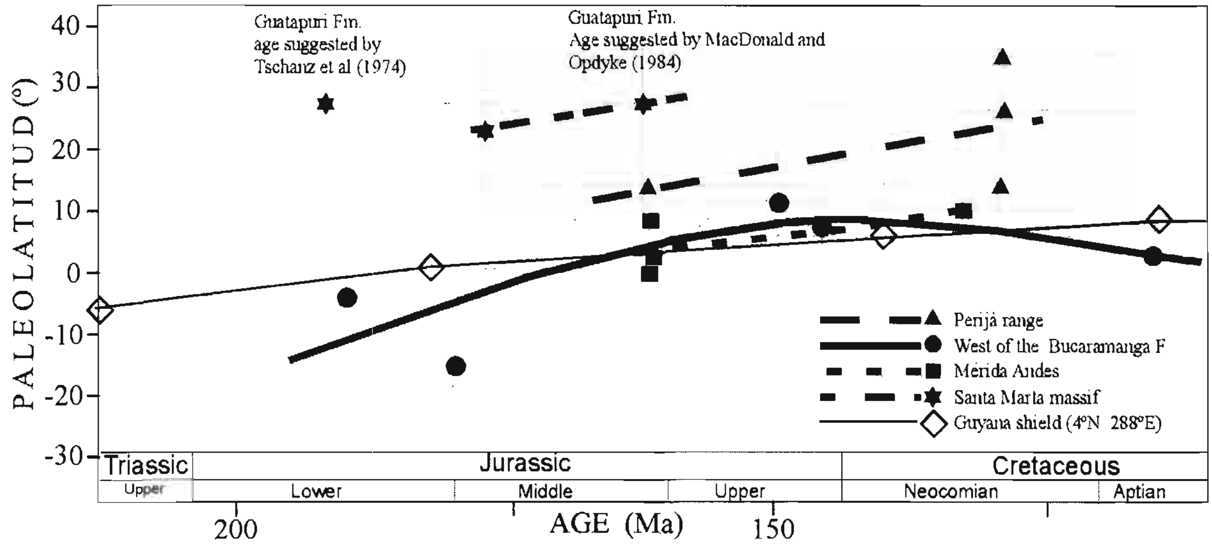


Figure 2. Paleolatitudinal change of terranes west of the Bucaramanga Fault (areas B, FM and UMB) with respect to the South American craton (reference point is 4°N 288°E, see Fig. 1) and other structural blocks East of the Bucaramanga fault (MA, PR, SMM). Note the greater magnitude of translation of terranes west of the Bucaramanga Fault with respect to other blocks during Early and Middle Jurassic time.