LINEAMENT ANALYSIS IN NORTHERN COLOMBIA, SOUTH AMERICA

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ABSTRACT

Relationships that allow inferring buried structures from surface lineaments can be a powerful tool in research and exploration of natural resources such as water, hydrocarbons, and economic ores. A linear characteristic of a superficial parameter genetically related to a structural, stratigraphic, sedimentary, geochemical or to a combination of these factors is a “lineament”. The way lineaments reflect structures depends on the exposure degree of the affected rock. In areas not covered by recent deposits, lineaments directly reflect structures since lineaments are the intersection between planes of discontinuity with the surface. The relationship between lineaments and structures in regions covered by recent deposits may be more complex. Without neotectonics, covered structures can control both the pre-depositional topography and the location of fluids affecting deposits. Both the original materials and its subsequent affectation have the potential to print linear signals to the surface.

Derived products from satellite imagery and DEMs were used to identify 46000 km of lineaments in 52000 km2 of exposed and covered areas. This project presents a high density of directional data collected at different scales and from different sources, providing methodological contributions in data processing, particularly in external attribute acquisition. Possible fracture patterns were characterized and geological controls on lineament orientation was described using directional analyses grouped by information on province, age and rock type affected by lineaments.

INTRODUCTION

Geological lineaments represent the intersection between discontinuity planes (e.g. faults, fractures, joints, etc.) and an observation surface. They might be enhanced by presence, linear changes or absence of drainage and vegetation. It also might be obscured when instead of a continuous line, it is expressed as an alignment of separate features. O’Leary’s et al [1]–widely accepted- lineament definition is the basis for the present work: *“a mappable, simple or composite linear feature of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon.*”

A comparison between lineaments and mapped structures show that lineaments “are largely a reflection of tectonic fractures emphasized on the surface by topography, drainage, and vegetation”[2]. If no man-made linear feature is collected and bedding-related lineaments are avoided, treating lineaments as structures is a possibility. Since most important faults are probably mapped in our work area, it is likely that non-fault-matching-lineaments represent fractures.

Lineament research has been focused in diverse manners used diverse source datasets and with multiple applications. Using multispectral data ([3],[4]), topography from relief maps and DEMs([5],[6],[3]), Radar ([7]). Popular applications include mineral mapping ([7]), groundwater ([8]), neotectonics ([2]), regional geology ([9],[10],[5],[6],[3]) and volcanism ([4]).

Because lineament interpretation is highly subjective, multiple attempts to produce a more robust, repeatable and interpreter-independent method have been proposed. Examples include Hough-transform ([11],[12]), edge-detection ([13]), object-oriented analysis ([14]), and fuzzy B-spline algorithm ([15]).

While most accepted lineament definitions don't involve scale, we did not find work examples with short lineaments. There are however multiple examples of regional-only lineaments in Colombia ([5],[6]) and elsewhere ([10],[7]).

The goal of this paper is to describe the methods employed in collecting and processing lineaments from multispectral and topographic datasets, using low-length threshold, high-density collection. This approach might produce less dependence on interpreter subjectivity. By adding geological attributes to the lineaments, the present work also pretends to characterize the possible controls that rock age, type and province might exert on geometric aspects of lineaments in this region of northern Colombia.

Location

The project is located in the northern part of Colombia (Fig 1) by the Caribbean Sea, in an area withtwo regions with contrasting precipitation regimes:lush mountain ranges in the southand a desert lowland region with three hilly areas in the north (Fig 2). Sierra Nevada de Santa Marta (SNSM), a triangular massif having the highest point on earth by the sea side (5800m) and Serranía de Perijá (PER) a lower mountain range reaching 3500m in the Colombia-Venezuela border; Cesar-Ranchería (CR) basin is a lowland lying between these elevated regions. Guajira peninsula contains two main lowland regions, Alta and Baja Guajira. The former contains three hilly areas the Serranías of Macuira (MAC), Jarara (JAR) and Cocinas (COC) with elevations below 600m.

Figure 1. Work area (yellow box)

Geology

Figure 2 displays geological provinces of the work area, which is located along the southern Caribbean Plate boundary, a margin owing its character to the oblique convergence and right lateral shearing between the Caribbean plate and northwestern South America ([16]). Baja and Alta Guajira are depressed provinces filled with Neogene and Recent deposits, while the three ranges in Alta Guajira expose mostly metamorphic and sedimentary Precambrian to Mesozoic rocks. Right-lateral Oca Fault separates northern from southern provinces. Cesar-Ranchería Basin fills with Recent sediments the space and masks the suture between Sierra Nevada de Santa

Marta, a triangular 5800m massif of mostly Precambrian to Mesozoic metamorphic and intrusive rocks, and Serranía de Perijá, a mountain range mainly composed of sedimentary Paleozoic to Mesozoic rocks.

Table 1 contains the main features of the provinces included in Figure 2.

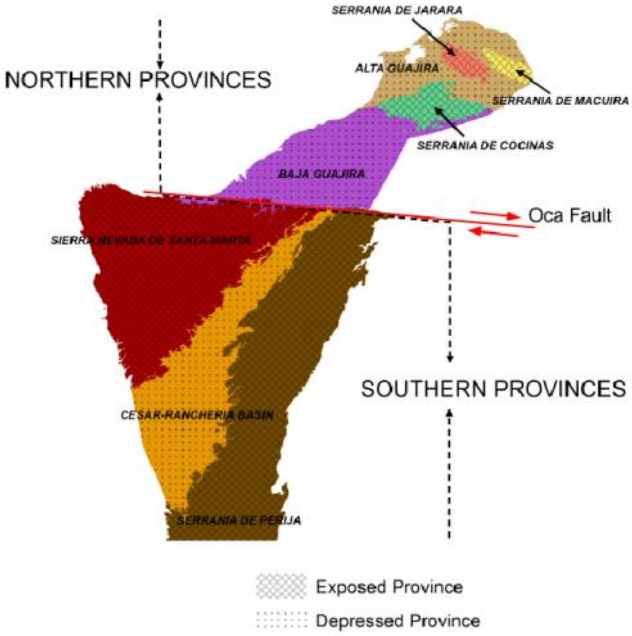

Figure 2. Map of Geological Provinces

Table 1: List of Geological Provinces.

PROVINCE	ABREVIATION	GROUP	TYPE
Alta Guajira	ALTA	Northern Provinces	Depressed
Serranía de Macuira	MAC	Northern Provinces	Exposed
Serranía de Jarara	JAR	Northern Provinces	Exposed
Serranía de Cocinas	COC	Northern Provinces	Exposed
Baja Guajira	BAJA	Northern Provinces	Depressed
Sierra Nevada de Santa Marta	SNSM	Southern Provinces	Exposed
Cesar – Ranchería	CR	Southern Provinces	Depressed
Serranía de Perijá	PER	Southern Provinces	Exposed

METHODS

Three main steps constitute the methodology of the work: data preparation, image interpretation and directional statistics.

Data preparation

Landsat 7 and SRTM, two medium-resolution, free-access datasets were the main sources for lineament interpretation: multispectral information from Landsat data was integrated into a principal component (4th) image while 15m, Band 8 data was used as visible spectrum data source. Three SRTM-derived products (relief, slope, and aspect maps) were prepared (Fig 3).In the northernprovinces, high-resolution World View imagery was used as an additional source data in the visible spectrum.

One of the expressions of lineaments is the shape of the surface. 90m SRTM data was used to prepare the following products for lineament interpretation: eight shaded-relief images each with a different illumination direction, a slope image and an aspect image. Shaded imagery (Fig. 3A) provided a direct way to identify aligned drainages and divides; a complete range of illumination direction allowed for a complete detection of these features. Aligned slope changes in the mountain area were identified with the slope image (Fig. 3B); in the flat regions, aspect image (Fig. 3C) allowed detecting slight changes in slope orientation.

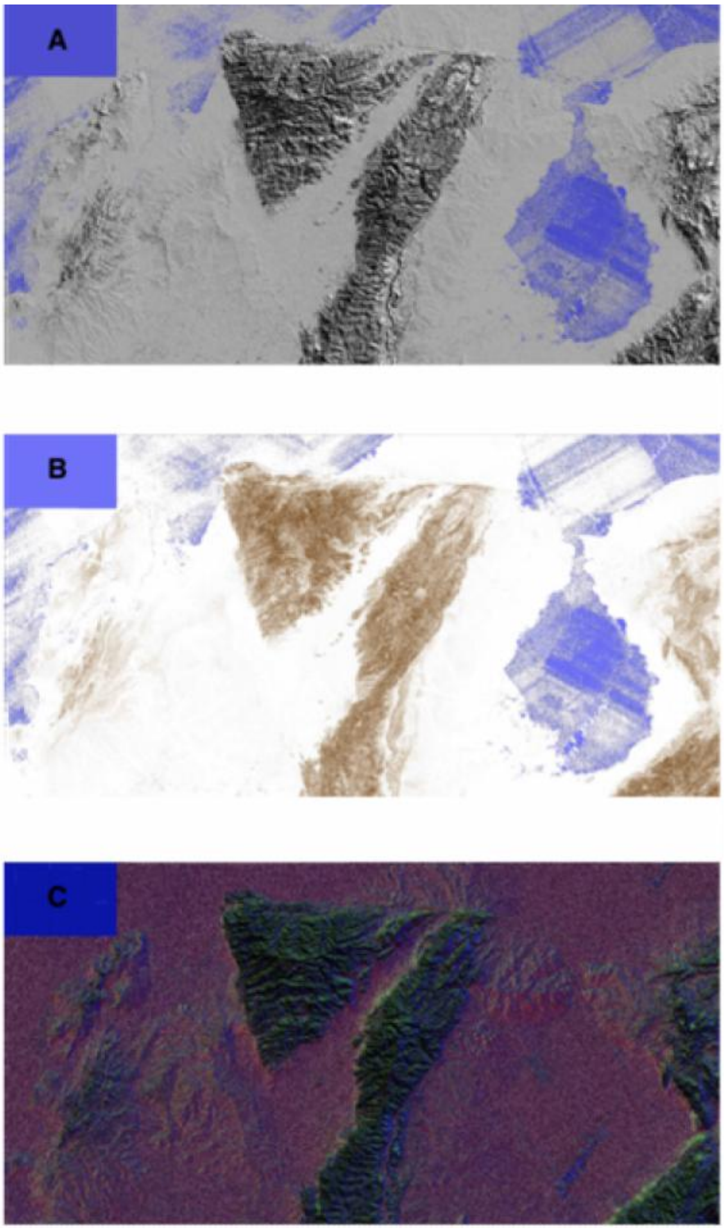

Figure 3. SRTM-derived products in the southern region. A) Example of illuminated SRTM DEM (NW illumination).B) Slope image from the SRTM DEM. C) Aspect image from the SRTM DEM.

Reflected light provide morphological and compositional information from the surface. 15m Landsat 7's band 8 visible light was multi-directionally linearly-enhanced with a Sobel filter. Multispectral information variability was integrated in a 30m Principal Component image where a similar filter was applied. PC4 showed the best potential for linear data interpretation. Landsat data provided information from the whole extent of the work area.

North of the Oca Fault, most of the region is covered with high-resolution WV data. The natural color composition available in Google Earth was used in the interpretation of more detailed lineaments in this area.

Official geological maps (1:100000 – 1:500000) where integrated into a seamless polygon coverage with province, rock age and rock type attributes.

Image interpretation and processing

All source imagery was systematically interpreted following the same rules:

1) Multiple interpretation scales. Each image dataset was progressively examined and interpreted at scales 1:600.000, 1:300.000, and 1:100.000.
2) Low length threshold. Regardless source data, 10 pixels was the minimum length that a linear feature required for collection.
3) Man-made linear features (roads, fences) and those that could be produced by image collection or processing (striping) were avoided in the collection.
4) Because the project is focused on structures, bedding- parallel linear features were avoided as well.

Lineament datasets underwent attribute generation processing in GIS environment (Fig 4).

1) Interpretation scale and source image were added as attributes.
2) Azimuth and length were calculated for all lineaments and stored as additional fields (conforming the “internal attributes” along with source image and interpretation scale).
3) Using linear referencing techniques, geology polygons were used to provide data to lineaments. These are considered the “external attributes” (Fig. 4). Rock age, rock type and province information from surface geology was assigned as attributes to the lineaments (Figs 4 and 5).

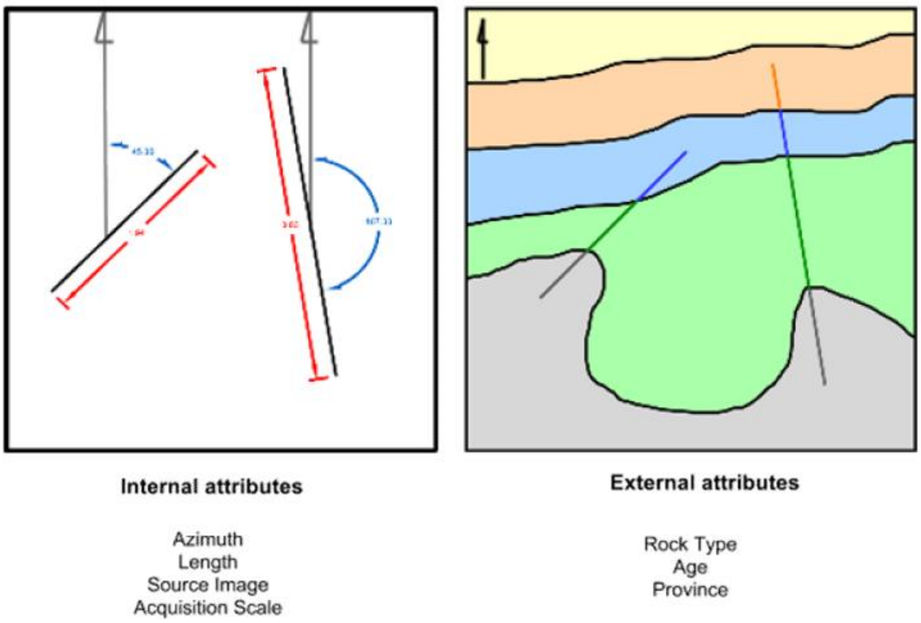

Figure 4. Lineament attributes

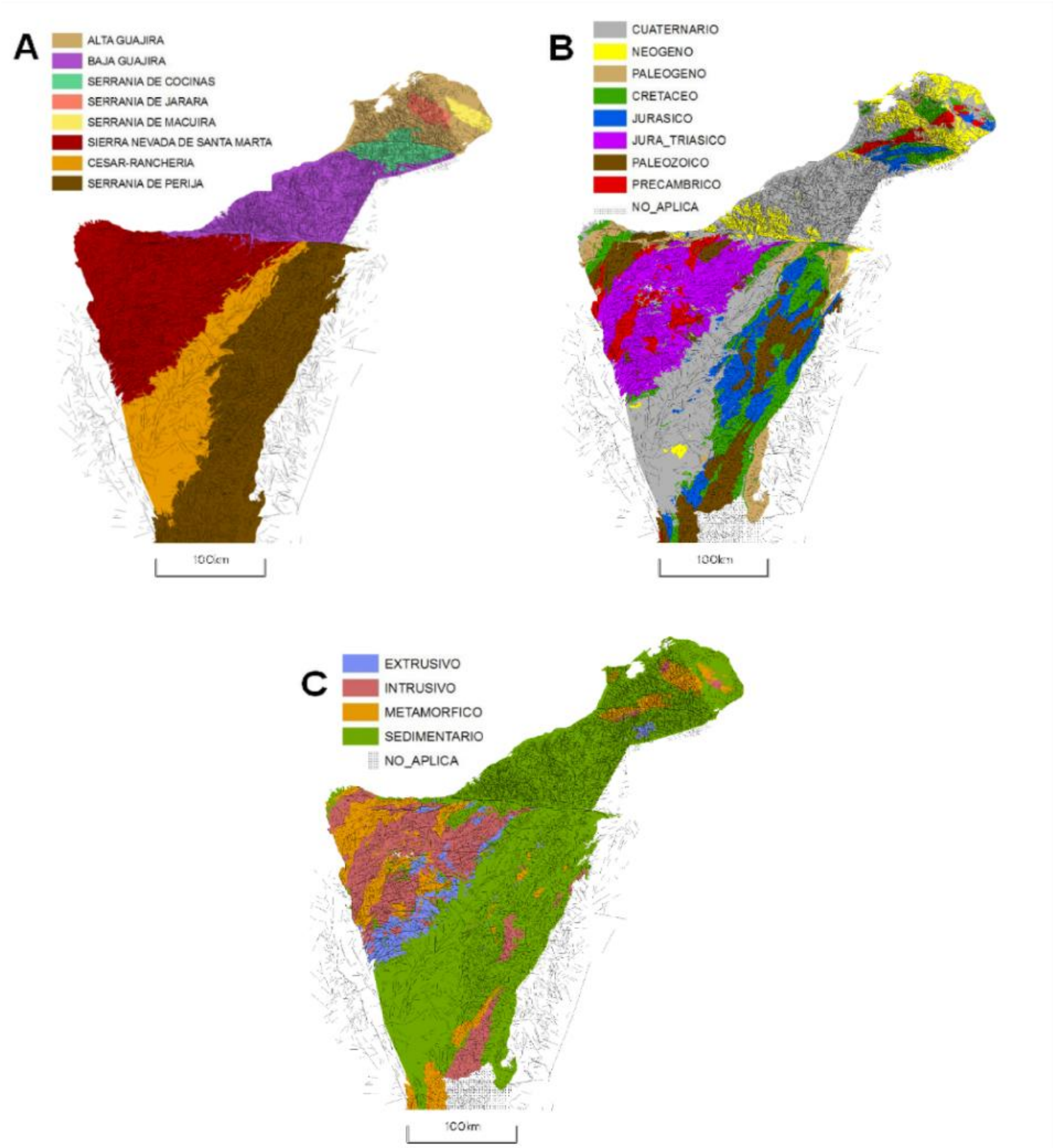

Figure 5. Lineaments with maps of provinces (A), rock age (B) and rock type (C).

Directional statistics

The massive geographic database of lineaments covering 59000km with internal and external attributes provides opportunities for generation of rose diagrams using any combination of attributes as grouping parameters.

Using directional statistics software, exported tables allowed to generate rose diagrams that proved useful in the comparison of the variable effect that each parameter exerts on the overall orientation of lineaments.

Pivot tables were the link between the tables and the software that produced diagrams of all possible combinations of 1, 2 and 3 external attributes.

The following part contains some of the most important findings.

RESULTS

One of the first observations on lineaments is that their appearance changes with province. Figure 6A shows that SNSM has strong tendency towards NEE orientation and long curved lineaments. PER contains a long NE lineament that separates a higher density of medium lineaments in the N from shorter, less dense lineaments in the south. CR, virtually covered by recent sediments, shows the lowest density. A set of short, NW trending lineaments affects all provinces, being denser in the first two.

Rose diagrams (Fig 6B) shows that CR performs an intermediate role between opposite symmetry, bimodal distributions of SNSM and PER with a symmetric bimodal distribution whose peaks are between those of the former two.

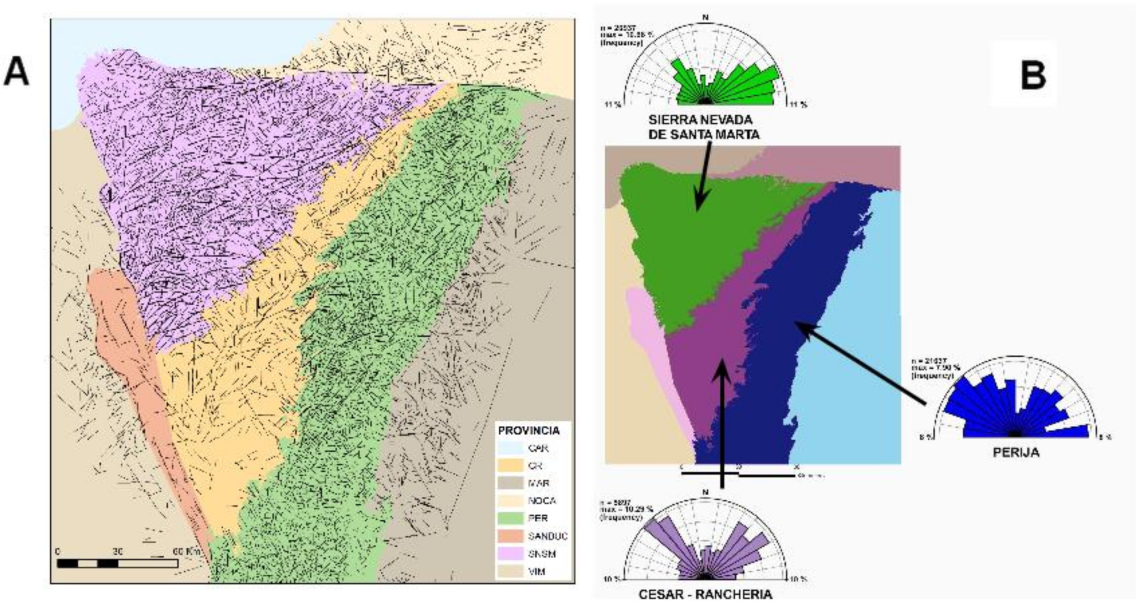

Figure 6. Lineaments in southern provinces (A) and their rose diagrams (B).

In order to establish the spatial variations on lineaments orientation, a square grid of 20km was used to segment them. Rose diagrams were constructed on top of the grid (Fig 7).

E-W lineaments are located mostly on the mountain provinces (SNSM and PER) and N-S lineaments are rare. In PER, E-W lineaments dominate the southern portion, while they are present throughout SNSM.

In SNSM, NW lineaments are more important in central (trending more NNW than NW) and northern areas (NW trend). Similarly, in the central regions NEE is the tendency, while northern areas display more NE orientation.

NW lineaments are more widespread in the northern part of PER with a NWW to NWWW preference in the south. NE lineaments are constrained to the northern half.

NE lineaments dominate CR province with some NW influence in the south and boundary regions.

The integrated lineament attribute table was used to feed directional statistics, so that multiple grouped rose diagrams were produced. Figure 8 contains the results of using external attributes (geology) in grouping all lineaments.

Province demonstrates to be the principal control on lineament orientation. As discussed before, this is clear in the southern provinces, where (regardless rock age and type) all SNSM roses show a NE tendency. Contrastingly, most PER roses show a NW direction; because of its active filling basin character, CR only shows one rose diagram (same as in figure 6B) which is the intermediate between SNSM and PER.

In the northern provinces, the effect of province is less dramatic but it is also the main control on lineament orientation. The depressed provinces show similar roses, but the difference between exposed provinces is more evident, especially in the oldest rocks.

In general, sedimentary rocks present symmetric bimodal distributions and disperse distributions, unimodal distributions are more likely to occur in igneous rocks, and metamorphic rocks are prone to asymmetric bimodal distributions. Less defined distributions tend to occur in sedimentary or Paleozoic rocks.

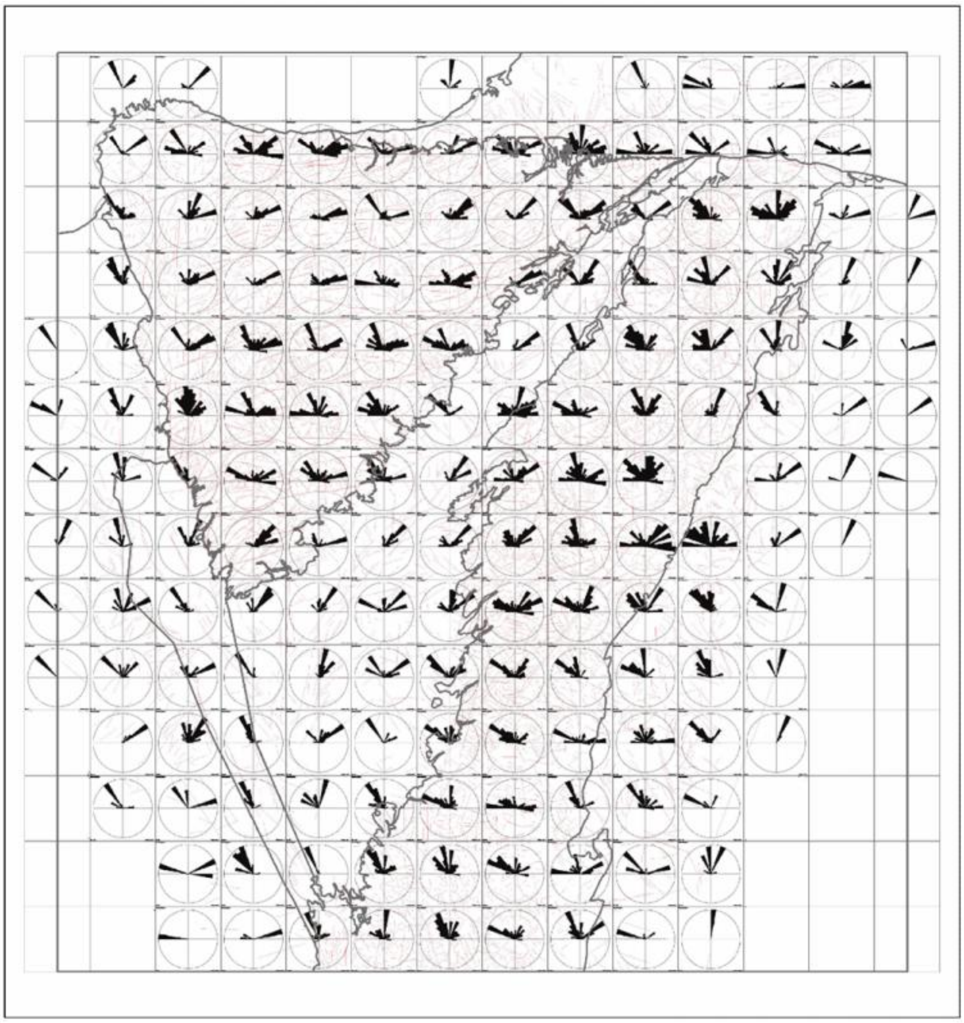

Figure 7. Variation in orientation of lineaments.

Southern provinces sampled with a 20x20km grid. Lineaments in light red.

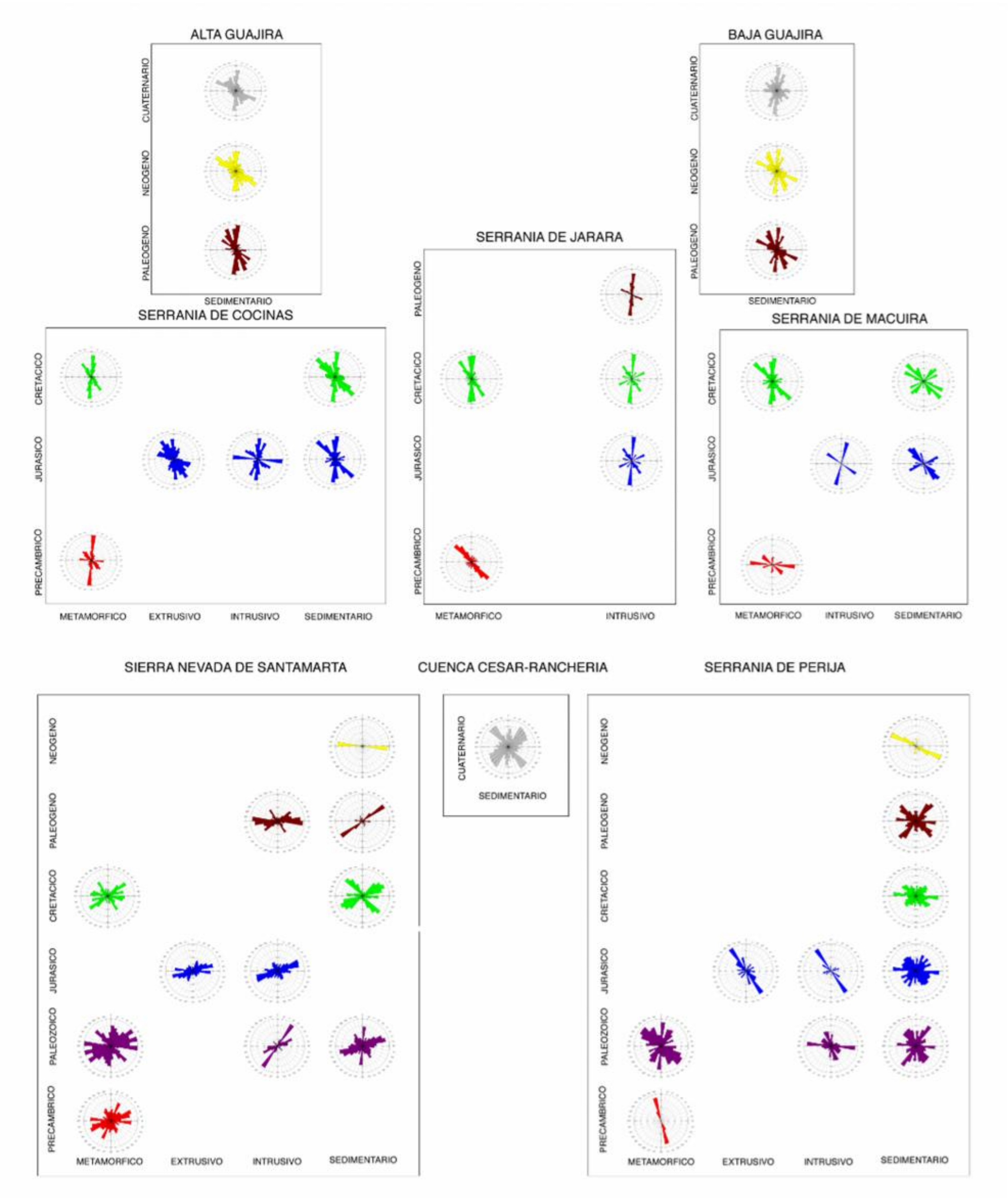

Figure 8. Rose diagrams of lineaments.

Results grouped by province, rock age and rock type.

CONCLUSIONS

The acquisition of a dense network of lineaments with internal (geometric, methodological) and external (geologic) attributes was key in producing a high population for directional statistics and evaluate geologic controls on their orientation. Geological attributes exert control on the orientation of lineaments. Province is the most important, followed by rock age androck type.

Difference in orientations between SNSM and PER supports the idea of separate evolution. Two main theories of tectonic development argue the permanent relative position of these terrains. It is difficult to explain evolution in spatial proximity that produce such disparity.

Because of its interpretative character, lineament maps might depend on the interpreter. It has been shown wide differences in interpretations from similar data sources ([17]). The proposed method of low threshold provides better amount of data for directional statistics and might reduce the interpretation variability. Further research is required in this topic.

The method relies heavily on the interpretation but this time-consuming phase is compensated with semi-automatic linear referencing and directional statistics workflows.

Possible future developments in this line of research include the identification of practical applications of an attributed lineament dataset, developing calibration strategies using field data and the development of a more robust methodology of lineament collection, less dependable on the interpreter.

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REFERENCES

[1] D. W. O'Leary, J. D. Friedman, and H. A. Pohn, 1976. Lineament, Linear, Lineation: Some Proposed New Standards for Old Terms. Geological Society of America Bulletin 87, no.10: 1463.

[2] T. I.H. Rahiman and J. R. Pettinga, 2008. Analysis of Lineaments and Their Relationship to Neogene Fracturing, SE Viti Levu, Fiji. Geological Society of America Bulletin 120, no. 11–12: 1544–1555.

[3] E. S. Papadaki, S. P. Mertikas, and A. Sarris, 2011. Identification of lineaments with possible structural origin using ASTER images and DEM derived products in Western Crete, Greece. *In*: EARSeL eProceedings, vol. 10, no. 1, p. 10.

[4] E. E. Nama, 2004. Technical note: Lineament detection on Mount Cameroon during the 1999 volcanic eruptions using Landsat ETM. International Journal of Remote Sensing, vol. 25, no. 3, pp. 501–510, Feb. 2004.

[5] G. Ujueta, 1992. Lineamientos Rio Ariari, Bogota y Gachala en los departamentos de Cundinamarca y Meta, Colombia.Revista Academia Colombiana de Ciencias, vol. XVIII, no. 70, pp. 345–358.

[6] G. Ujueta, 1994.Modelo de Desplazamiento entre la Cordillera Oriental de Colombia y los Andes de Merida. Revista Academia Colombiana de Ciencias, vol. XIX, no. 72, pp. 95–105.

[7] Shuichi Miyatake, 2002. Regional Lineament Analysis and Alteration Mineral Mapping for Intrusive-related Copper Exploration in the Myanmar Central Volcanic Belt. Presented at the Asian Conference on remote Sensing 2002, Khatmandu, Nepal.

[8] Michael W. Fies, 2004. Lineament analysis South Florida region aquifer storage and recovery regional study. U.S. Army Corps of Engineers, Jul-

2004.http://www.evergladesplan.org/pm/projects/project_docs/pdp_asr_combined/013007_asr_lineament_dtmt.pdf (last date accessed 18 August 2014).

[9] S. Christopher Caran, C. M. Woodruff, Jr., and Eric J. Thompson, 1981. Lineament Analysis and Inference of Geologic Structures - Examples from the Balcones/Ouachita Trend of Texas. Transactions - Gulf Association of Geological Societies, vol. XXXI, no. 1981, pp. 59–69.

[10] Sally N. Shake and J. Gregory McHone, 1987.Topographic Lineaments and their Geologic Significance in Central New England and Adjacent New York.Northeastern Geology, vol. 9, no. 3, pp. 120–128.

[11] Wang, Jinfei, and Philip J. Howarth, 1990. Use of the Hough Transform in Automated Lineament Detection. IEEE Transactions on Geoscience and Remote Sensing 28 (4): 561–66.

[12] A. Karnieli, A. Meissels, Fisher, Leonid, and Arkin, Yaacov, 1996.Automatic Extraction and Evaluation of Geological Linear features from Digital Remote Sensing Data Using a Hough Transform.Photogrammetry Engineering & Remote Sensing, vol. 62, no. 5, pp. 525–531.

[13] Argialas, D. P., and O. D. Mavrantza. 2004. Comparison of Edge Detection and Hough Transform Techniques for the Extraction of Geologic Features. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 34. http://www.cartesia.org/geodoc/isprs2004/comm3/papers/376.pdf (last date accessed 2 Sept 2014)

[14] O. D. Mavrantza and D. P. Argialas, 2006.Object-oriented image analysis for the identification of geologic lineaments.International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 36, no. 4/C42.

[15] Maged Marghany, 2012. Three-Dimensional Lineament Visualization Using Fuzzy B-Spline Algorithm from Multispectral Satellite Data.*In*Remote Sensing - Advanced Techniques and Platforms, Chapter 10,CInTech.

[16] Montes et. al., 2010. Clockwise rotation of the Santa Marta massif and simultaneous Paleogene to Neogene deformation of the Plato-San Jorge and Cesar-Ranchería basins. Journal of South American Earth Sciences, 29: 832-848

[17] Huntington, J.F., y A.P. Raiche, 1978. A Multi-Attribute Method for Comparing Geological Lineament Interpretations. Remote Sensing of Environment 7, n.o 2: 145-61.