STRUCTURAL DEFORMATIONAL PHASES AT THE NORTHERNER BORDER OF THE PLATE BOUNDARY BETWEEN THE NORTH AMERICAN AND CARIBEAN PLATES

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ABSTRACT

The work was aimed at determining structural characteristic and updating the geological map of San Antonio del Sur area, located in Oriente province, Cuba. As result, this study contains new structural data collected from the field observation. The tectono-stratigraphical column for the area was worked out and the geological map was updated. It has also allowed for a better synthesis on the tectonic evolution of the area.

The following evolutional stage and deformational phases were stablished:

First: Cretaceous period marked by the volcanic island arc. At that time the volcano-sedimentary rocks were formed and later deformed in the Campanian to early Maastrichtian with first deformation phase (D1). Consist of very close (F1) macro folds, which are almost isoclinal.

Second: Late Maastrichtian. The cretaceous volcanic rocks were thrusted by ophiolite complex. According to the observation, the sense of thrusting from SE to NW. The second deformation phase (D2) consist of folds from micro to meso fold (F2) with vergence towards NNW.

Third: Middle to Late Eocene. The deformation and generation of the thrust movement from SW toward the NE gave rise to the third deformation phase (D3). This deformation almost perpendicular form superimposed folds above the D1 and D2. Open folds characterize the F3 folds, with fold axis oriented to the NNW (350º).

Fourth: Oligocene – Miocene to Recent. Transpressional-transtensional tectonic movement became active along the Oriente fault; the sinistral sense of the movement generated the fourth, predominately brittle, deformational phase (D4). It is characterized by gently dipping fold (F4) with fold axis oriented to the NW.

Introduction

The study area is about 20x30 km, and lies in the north of San Antonio del Sur village, in Oriente province, in the eastern part of Cuba. The geographic coordinates is given by Latitude: 19°59’26. 4’’ N; Longitude: 74°55’20. 3’’W and Latitude: 20°15’33. 9’’ N; Longitude: 74°43’39. 0’’ W. The area is about 55 km East of Guantanamo City. The Eastern part of Cuba, where the study area is located, is identified as the Neotectonic East province of Cuba.

As in all Cuban archipelago, the geological composition and structure of the area consists of two main structural levels: the foldbelt and the neoautochton (Iturralde-Vinent, 1994). The foldbelt is composed of deformed and metamorphosed continental and oceanic units. It represent more than 60% of the whole area, as Ophiolite, Puriales complex, El Cobre formation, Charco Redondo formation, San Ignacio formation and San Luis formation. The neoautochthon is composed of latest Eocene to recent slightly deformed sediments, which have not been displaced since deposition. It represents the other 40% of the area. It contains different units such as Cilindro Formation, Maquey formation, Yateras formation, Rio Maya formation and Recent deposits which can be differentiated by genesis as elluvial, colluvial, prolluvial, alluvial and marine deposits.

The study area is placed at the northern border of the plate boundary between the North American and Caribbean plates, which is highly affected by transpressional sinistral movement of the Oriente fault. The structural studies in the area are limited, and the influence that particular geotectonic situation has on the area is still unknown. In the last few years several studies involving the geology in the eastern part of Cuba were carried out. Previous works were mostly based on field observation and aerial photo interpretation. Geology and tectonic structures of the area, however, have been studied using a conventional mapping approach with full consideration to using remotely sensed data and data integration using GIS.

Data input and Methodology

During the Preparatory Stage, several image processing techniques were used in order to improve the data and visualization of the geological and structural features. Lineaments were traced by on-screen digitizing on the edge-enhanced remote sensing data and products obtained from DTM, were integrated to form the lineament map based on satellite image and topographic features interpretation. Lineament analysis was performed by means of rose diagrams and fracture maps. Structural field data were analyzed using rose diagrams, stereographic projections and maps.

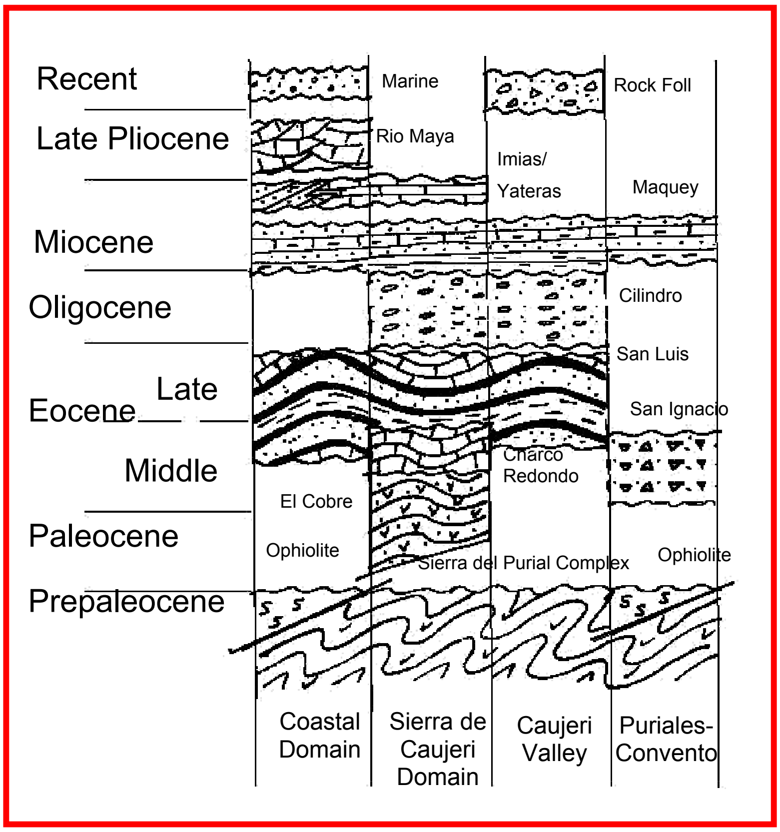
Structural analysis of different deformation phases by means of folds, faults and shear zones, was carried out to develop ideas about the tectonic evolution of the area.

In order to give a detailed description of the geology and the structure of the area, geological and structural fieldwork observation, updated geological map and three schematic profiles traced along the area in different directions were considered. These were: W-E across the Caujeri Valley, the second NNW-SSE across the Caujeri Valley and the third along the highly deformed metavolcanite of Sierra de Puriales Complex.

Data Analysis Results and Interpretation

Based on the analysis of the structural data taken during the study, the area was subdivided into four structural domain based on the different development they had in the past. For domain subdivision structural-stratigraphic, tectonic and evolutionary criteria were used. The structural domains are Puriales-Convento, Sierra de Caujeri, Caujeri Valley and Coastal Valley.

The **Puriales-Convento** is the most complex structural domain due to the influence of the important tectonic event: the thrusting of Ophiolite complex. It also represents the oldest tectono-stratigraphic units of foldbelt in the area. Consequently this domain had recorded all geological history. However, in this area after the metavolcanites and ophiolites, only the tectonic breccia of San Ignacio and some areas with Maquey formation were developed. This suggests that the block of the Puriales-Convento emerged almost throughout the geological time. It appears strongly deformed and faulted. From the thin section, the foliation is defined by the preferred orientation of pyroxene fragment, feldspar and calcite subhedrial crystals (in the marble). It formed frequently synquinematic porphyroclast with σ and ϕ types. The ϕ type has tails but no stair steeping. The σ type has wide mantles near the porphyroclast with two planar faces and two curved faces that define the asymmetry. They were found indicating the inverse movement.

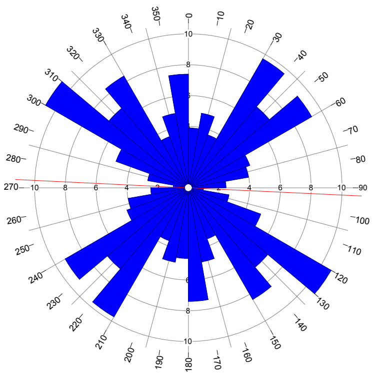


Tectonic-stratigraphic column for the study area subdivided by different structural domain

According to the subdivision, the **Sierra de Caujeri** domain contains the allocthonous sequence of El Cobre coming from the Paleogene island arc and tectonically emplaced later. This domain from on the other hand is characterized by all the formations present in the area but Quaternary. This suggests that the area was exposed to continuous transgression and regression the first one in the Latest Eocene to Oligocene, and the second in the Lower Miocene to Late Miocene. Fault system almost parallel to each other are developed in this domain with main direction towards NE-SW and very few to NW-SE, the dip direction of the bedding plane of the Miocene Formations generally appear dipping gently toward the S or SE. Oscillatory vertical movements characterize the shape of the horst-graben block feature that is easily seen from the Caujeri Valley.

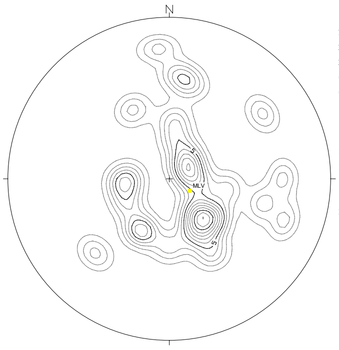
Negative relief characterizes the **Caujeri Valley.** It is a tectonic depression. In this block the Miocene deposits were eroded due the intensification of erosional processes. Later the accumulation of the Quaternary colluvial, prolluvial, alluvial and deluvial deposits started. Now intensive erosional processes are occurring in this area. In spite of being covered by sediment, some of the fault products of the neotectonic movement can be traced inside the valley and they conserved the NE minor direction. The alluvial sediments in the valley are dipping horizontally but in some place already very gentle dipping to the North with 5º. This fact, the displacement of the riverbed from the original place, and the others suggest the uplift of the valley bottom. The uplift is not uniform. Instead the bottom of the valley slopes gently to the North.

The **Coastal Valley** structural domain limited by the main Riedel (NE-SW) sinistral shear zone is characterized by tectonic control of relief. There are all sedimentary deposits, which suggests this area to be exposed to continuous transgression and regression, the first one in the Latest Eocene to Oligocene, the second in the Lower Miocene to Late Miocene and the last one that started at Pliocene to Recent.

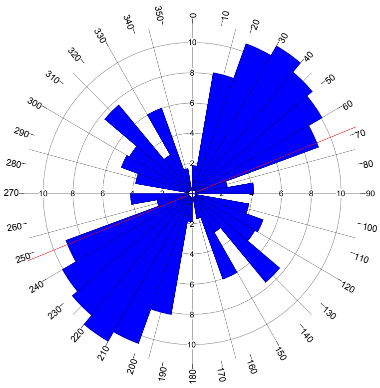


Calculation Method .... Length
Class Interval .... 10 Degrees
Length Filtering ...... Deactivated
Azimuth Filtering ..... Deactivated
Data Type .... Bidirectional
Population 317
Maximum Percentage .... 10.7 Percent
Mean Percentage .... 5.5 Percent
Standard Deviation .... 2.68 Percent
Vector Mean .... 92.73 Degrees
Confidence Interval ... 6.46 Degrees
R-mag 0.61

Puriales-Convento Domain

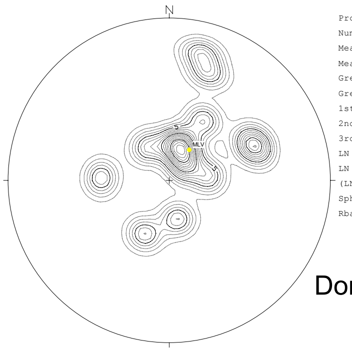


Projection .... Schmidt (Equal Area)
Number of Sample Points 29
Mean Lineation Azimuth 120.5
Mean Lineation Plunge 78
Great Circle Azimuth 359.1
Great Circle Plunge 79.7
1st Eigenvalue 0.674
2nd Eigenvalue 0.185
3rd Eigenvalue 0.14
LN (E1 / E2) 1.291
LN (E2 / E3) 0.277
(LN(E1/E2)] / (LN(E2/E3)) .. 4.654
Spherical variance 0.199
Rbar 0.801



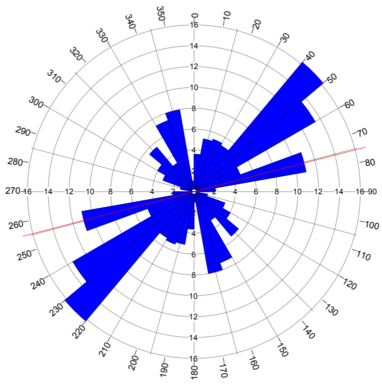
Calculation Method .... Length
Class Interval .... 10 Degrees
Length Filtering ...... Deactivated
Azimuth Filtering ..... Deactivated
Data Type .... Bidirectional
Population 124
Maximum Percentage .... 11.3 Percent
Mean Percentage .... 6.2 Percent
Standard Deviation .... 3.3 Percent
Vector Mean .... 68.06 Degrees
Confidence Interval ... 8.29 Degrees
R-mag 0.71

Sierra de caujeri Domain



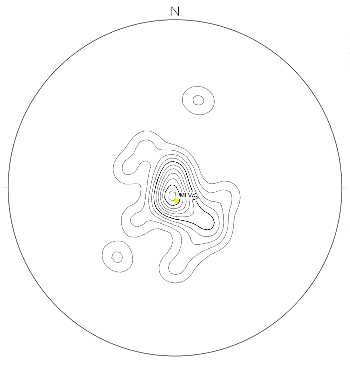
Projection .... Schmidt (Equal Area)
Number of Sample Points 14
Mean Lineation Azimuth 33.3
Mean Lineation Plunge 71.4
Great Circle Azimuth 215.1
Great Circle Plunge 89.4
1st Eigenvalue 0.752
2nd Eigenvalue 0.178
3rd Eigenvalue 0.071
LN (E1 / E2) 1.443
LN (E2 / E3) 0.921
(LN(E1/E2)] / (LN(E2/E3)) .. 1.566
Spherical variance 0.1432
Rbar 0.8568

Sierra de Caujeri Domain (Northern part)



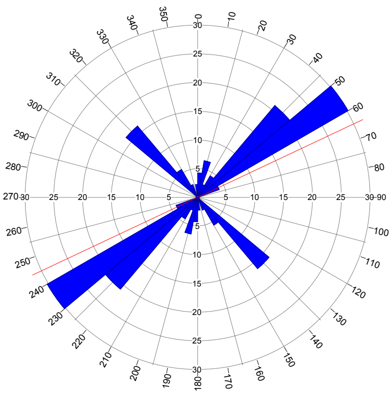
Calculation Method .... Length
Class Interval .... 10 Degrees
Length Filtering ...... Deactivated
Azimuth Filtering ..... Deactivated
Data Type .... Bidirectional
Population 47
Maximum Percentage .... 16.2 Percent
Mean Percentage .... 5.9 Percent
Standard Deviation .... 4.12 Percent
Vector Mean .... 75.44 Degrees
Confidence Interval ... 14.74 Degrees
R-mag 0.67

Valley Domain



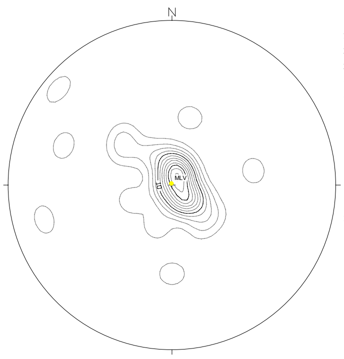
Projection .... Schmidt (Equal Area)
Number of Sample Points 22
Mean Lineation Azimuth 173.8
Mean Lineation Plunge 83.7
Great Circle Azimuth 357
Great Circle Plunge 89.8
1st Eigenvalue 0.865
2nd Eigenvalue 0.087
3rd Eigenvalue 0.048
LN (E1 / E2) 2.295
LN (E2 / E3) 0.602
(LN(E1/E2)] / (LN(E2/E3)) .. 3.814
Spherical variance 0.0742
Rbar 0.9258

Sierra de Caujeri Domain



Calculation Method .... Length
Class Interval .... 10 Degrees
Length Filtering ...... Deactivated
Azimuth Filtering ..... Deactivated
Data Type .... Bidirectional
Population 67
Maximum Percentage .... 30.2 Percent
Mean Percentage .... 6.7 Percent
Standard Deviation .... 8.67 Percent
Vector Mean .... 64.73 Degrees
Confidence Interval ... 11.28 Degrees
R-mag 0.71

Coastal Domain



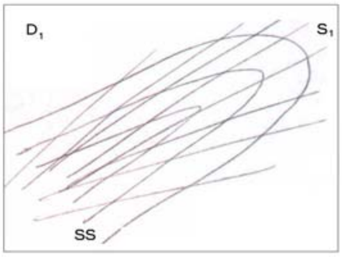
Projection .... Schmidt (Equal Area)
Number of Sample Points 30
Mean Lineation Azimuth 339.6
Mean Lineation Plunge 89.1
Great Circle Azimuth 297.9
Great Circle Plunge 89.4
1st Eigenvalue 0.811
2nd Eigenvalue 0.128
3rd Eigenvalue 0.061
LN (E1 / E2) 1.85
LN (E2 / E3) 0.741
(LN(E1/E2)] / (LN(E2/E3)) .. 2.496
Spherical variance 0.1196
Rbar 0.8804

Rose diagrams of main fractures and stereo-contour diagram of bedding for differents structural domain

In this domain it is possible to find highly deformed San Luis deposits. Several extension fault systems control the mass movement of the landslides. The presence of at least three terrace levels in the coastal hills illustrates that neotectonic vertical movements are developed and push the recent sediments above sea level more than 200m.

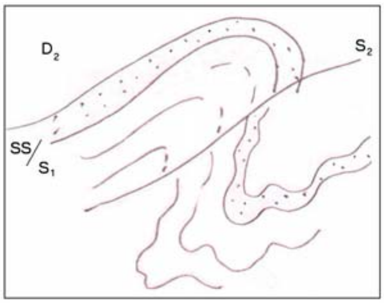
Four principal deformation phases are developed

D1: Ductile deformation regime, which affected all the Cretaceous Volcanic Sedimentary Sequences,



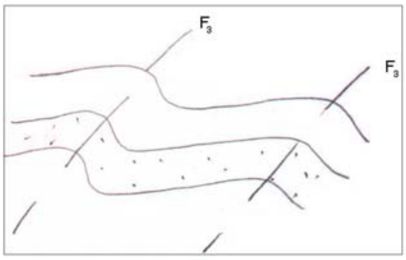
consists of very close (F1) macro folds that are almost isoclinal. Parallel to the bedding plane SS, S1 schistosity cleavage was generated. This deformation is difficult to see in the field as only cleavage remains. It developed a low-grade metamorphism (green schist facies).

D2: Ductile-Brittle deformation regime. Ophiolite thrusting event defines D2 deformation. This strongly



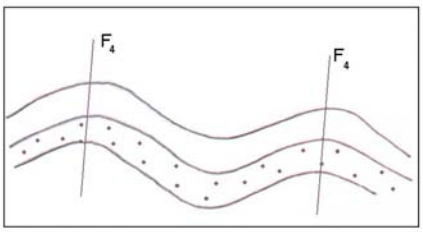
affects the ophiolite and metavolcanite near to the tectonic contact, with folds ranging from micro to meso fold (F2) and verging towards the NNW with fold axis oriented to the NE (75°). Far from the contact the deformation are represented by fracture foliation (S2) plane. The F2 are characterized by fracture and shear axial plane. Other fracture and fault systems are related with this deformation phase, and transcurrent or Tear fault associated with the thrusting event with NW orientation.

D3: Ductile-Brittle deformation regime. The D3 probably defined by emplacement of the piggyback

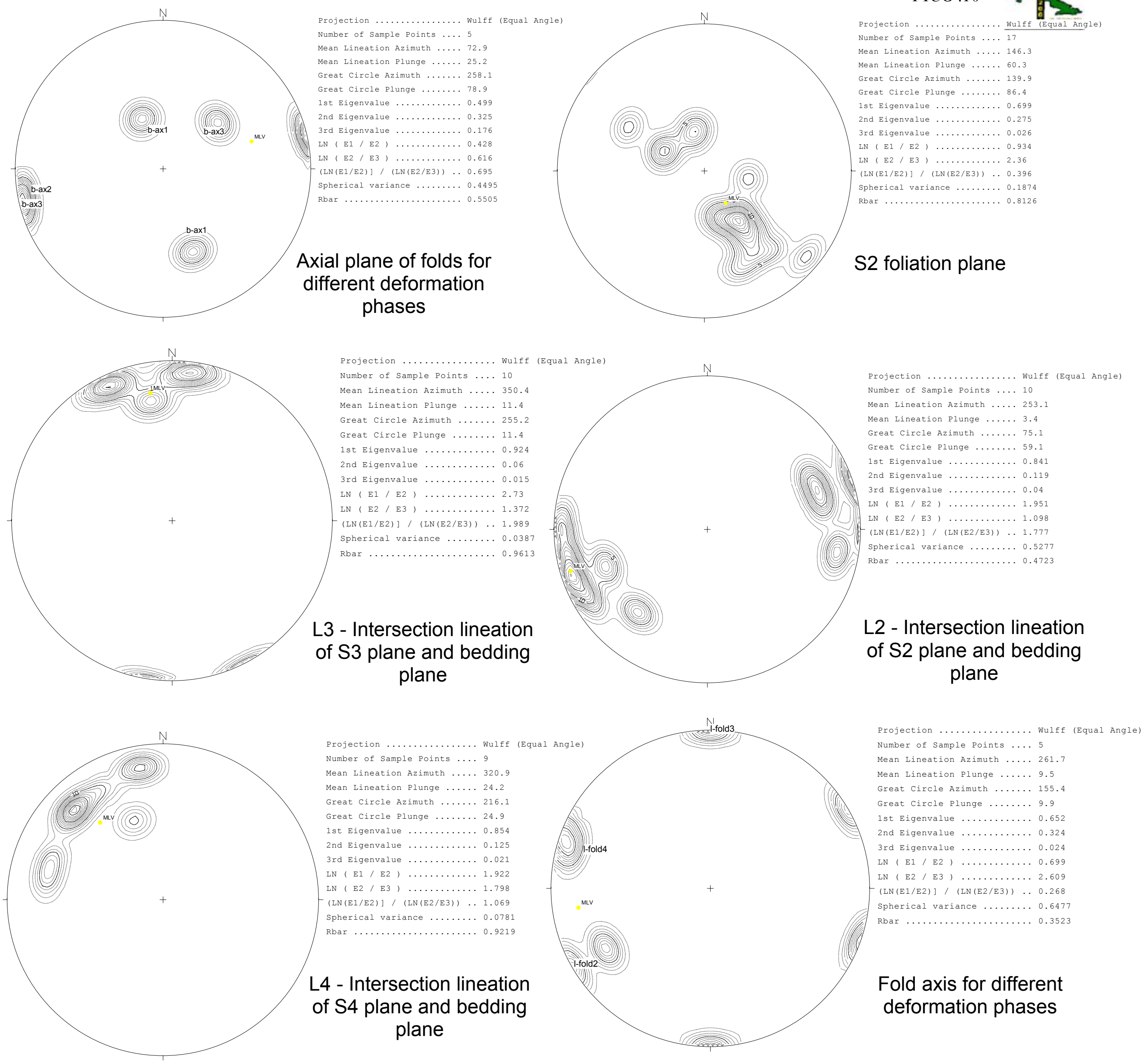


Paleogene basin that affects metavolcanites, ophiolite complexes and Paleogene formation like Charco Redondo, El Cobre and San Luis. This deformation almost perpendicular form superimposed folds above the D1 and D2, and development of the egg box pattern. The F3 folds characterized by open folds with fold axis oriented to the NNW (350º). Sinistral Shear zone is evident with direction toward 220º

D4: Brittle-Ductile deformation regime: It is related with the transpressional sinistral movement along the



Oriente fault. It affects all the geological units, including the recent. Controls the neotectonic activity of the whole area. It is characterized by gently dipping fold (F4) with fold axis oriented to the NW, several systems of fault, dextral and sinistral (Riedel system) strike-slip faults, extensional conjugated fault and joints. The vertical oscillatory movement in the area, with develop block systems of horst and graben structures, several terraces level in the coastal hills, inverted relief in the



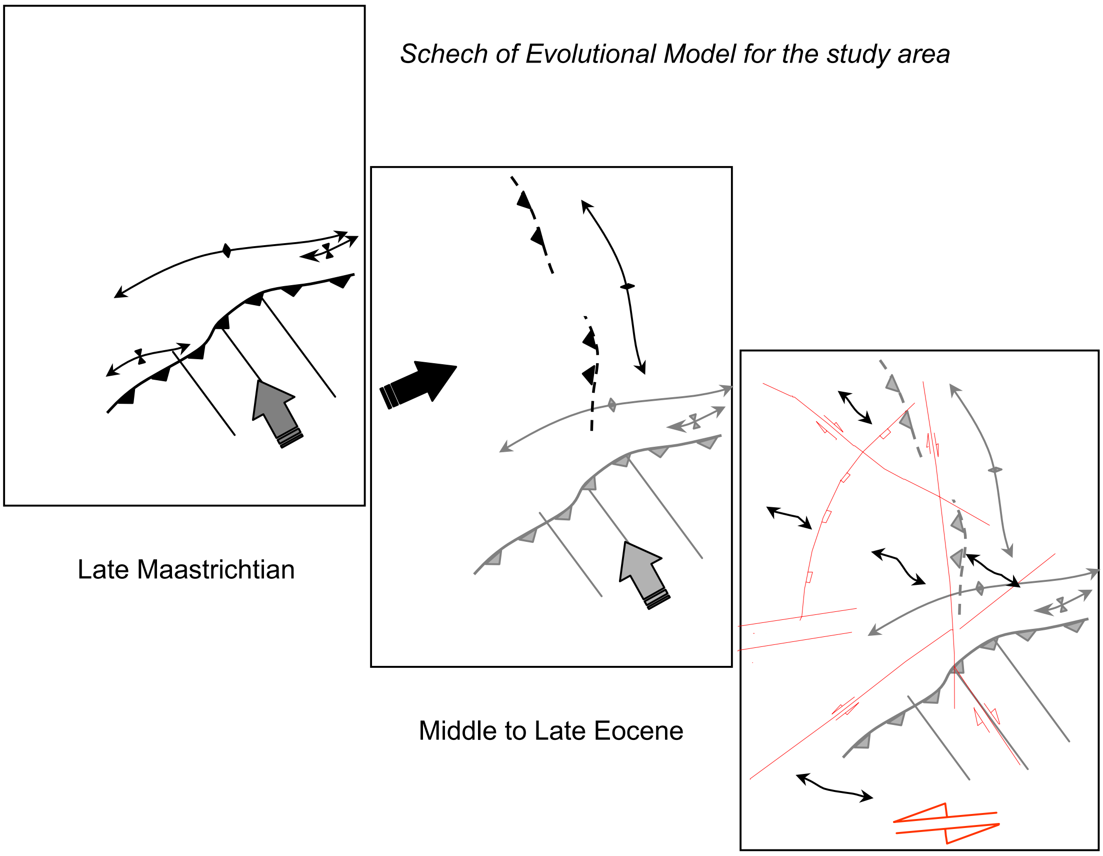
Contour Stereoplot for structural features on the Puriales Complex

valley, and several system of multiple landslides in the whole area are also related with this deformation phase.

Principal fault system

According with the detail level of the work, the main lineament systems recognized during interpretation of aerial photograph, satellite images and digital elevation model show NE-SW, NW-SE, NNE-SSW, NW-SSE and some E-W orientations

Schech of Evolutional Model for the study area



Late Maastrichtian

Middle to Late Eocene

Oligocene-Miocene to Recent

These fault systems are very well fixed with the regional strain ellipse, associated with a strike-slipe fault system or Reidel model of brittle deformation. Its are active in the area from the late Oligocene-Miocene to Recent, due to the aperture of the Cayman Ride that started the sinistral transpressional-transtensional movement along the Oriente regional fault. Its are the responsible for the neotectonic reactivation of several old faults and the configurations of the actual relief.

Tectonic Evolution

The evolution of the region started during the Cretaceous period, with the beginning of the volcanic island arc. At that time the volcano-sedimentary rocks of the Puriales complex were formed. In the Campanian, the Cretaceous volcanic arc became extinct. In the Campanian to early Maastrichtian these rocks were deformed and S1 foliation cleavage appears. Close isoclinal folds were also developed. The cretaceous volcanic rocks were thrusted by ophiolite complex. According to the observation, was late Maastrichtian age movement and the sense of thrusting can be described coming from the SE (160º) to NW, and it is evident because the occurrence of deformation phase with NW limb of folds steeper than the SE limb. Several strike-slip or tear faults that control the unequal movement of the thrusting body were generated, as well as inverse shear zone towards 320º.

The metamorphism was dated before Late Maastrichtian (Millan 1985). However the presence of epidote growth along the crenulation cleavage suggest that they are synkinematic with the second deformation phase. The metamorphism also could be linked with the thrusting event.

In the Paleocene to early Middle Eocene new volcanic arc evolved, volcanic sequences like El Cobre Formation were developed. Due the orogenic movement in the Middle to Late Eocene a piggyback basin was developed at the top of the Cretaceous foldbelt. Sequences such as San Luis were very well developed and slightly deformed. Unit from the paleogene arc, such as El Cobre Formation was thrusted over the sediments of the basin. However this thrusting can be seen only in some parts of the basin. The generation of the thrust movement from SW (230º) toward the NE develops superimposed deformation at almost 70 degree from the fold axis orientation of the previous one. Thrusting plane, shear zone and fault system oriented to the NE in the some places were also detected. These facts suggest the clockwise rotation of the maximal compressive stress, which finally lie in the NE direction.

In the late Late Eocene to Miocene transpressional-transtensional tectonic movement became active along the Oriente fault. The sinistral sense of the movement generated a predominately brittle deformation phase with several sinistral and dextral strike slip faults. Very gentle folds with fold axis dipping towards the NW deformed the previous folded planes but almost in the same direction. Several normal folds were also generated by the system with NNE-SSW direction. As a result of strike slip movement, some other deformations appeared, but their distribution is locally, restricted to the boundaries between blocks.

Conclusions and Recomendations

Based on fieldwork observation some conclusions that were drawn on structural characteristics of the study area are listed below.

- In the study area several folds and fault systems were recognized and the whole area is characterized into four deformational phases: D1, D2, D3, D4.
- Analysis of data collected in the field such as axial plane, fold axis, shear zone and the study of the contour diagram related with the second deformation phase suggest the ophiolite complex to be thrusting the metavolcanic complex with orientation of the main force toward the NW. The folds are asymmetrically inclined, wich the northern fold limb (330º) shorter and steeper than the south one.
- The accommodation of the Paleogene volcanic arc, and thrusting of some part of them over the piggyback sediments basin was generated by main forces oriented close to the NE (according to their relation with the previous deformation, which was superimposed almost perpendicular to each other). The volcanic rocks appear strongly fractured and their contacts are always tectonics, with predominantly tectonic breccia, and shear zone in the bottom plane of the formation.
- By means of the analysis of oriented thin section it was possible to establish deformation crenulation cleavage with orientation NW and NE.
- The ages of the four evolutional stages for the San Antonio del Sur area are the following: Campanian-early Maastrichtian, Late Maastrichtian, Middle to Late Eocene and Oigocene-Miocene.

- It will be very useful to carry out more detail microstructural and microtectonic study in the area, in order to compare the deformation phases within the Ophiolite and Metavolcanite.
- It is necessary to carry out studies, which take in consideration the metamorphic grade of the Metavolcanic and Ophiollite complex, in order to clarify the relation of the metamorphism with the thrusting event and different deformation phases.

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Structural interpretation for the area