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THE EVOLUTION OF LOS VENADOS (SAN LUIS, ARGENTINA) DURING LATE CENOZOIC

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ABSTRACT - *The evolution of Los Venados (San Luis, Argentina) during Late Cenozoic* - Il Quaternario, 4(1a), 1991, pp. 41-48. - After analyzing the different morphological trends present in the range and their relationship with neotectonic structures, the evolution of the landscape is interpreted in relation to fault movements. The main faulting activity has been attributed to Middle Miocene - Pleistocene.

SOMMARIO - *Evoluzione della catena del Los Vanados (San Luis, Argentina) nel Cenozoico superiore* - Il Quaternario, 4(1a), 1991, pp. 41-48. - Sulla base di un esame dei vari motivi morfologici presenti nella catena del Los Vanados, viene esaminato il loro rapporto con le strutture neotettoniche e l'evoluzione del paesaggio viene interpretata in funzione dei movimenti lungo faglia. La principale attività neotettonica appare avvenuta nel periodo Miocene medio-Pleistocene.

Key-words: Morphotectonics, Los Vanados, Argentina
Parole chiave: Morfotettonica, Los Vanados, Argentina

1. INTRODUCTION

The Los Venados Range is located in the Department of La Capital (Province of San Luis, Argentina), five kilometers east of the city of San Luis (Fig. 1). Roads 20 and 146 constitute the main accesses to the range and border its southern and western flanks respectively.

Los Venados, which are tectonically separated from the main block of the San Luis Range, represent the southernmost outcrops of the physiographic unit mentioned above. The range is entirely composed of granitic rocks, sometimes including prominent feldspar phenocrysts (Aquilera, 1981). Intercalations of aplopegmatitic beds are common.

The geology of Los Venados and the San Luis range is similar to that of the Pampean Range system, which is a basement complex that frequently outcrops in northwestern Argentina. Although there are no radiometric data available for these outcrops, the granitic rocks have been interpreted as the result of Paleozoic magmatic cycles (Kilmurray & Dalla Salda, 1977; Criado Roque *et al.*, 1981).

During the Cenozoic, Andean tectonics disrupted and uplifted the range in many blocks by means of recurrent fault movements. Because of the brittle nature of the rocks, the faulting resulted in strong cataclasis. As a consequence of this uplift, continental clastic sediments were deposited toward the outlying hills. At present, they appear at different altimetric levels in the piedmont area, together with loessic material. The morphology of the range is mainly due to the morphogenetic processes of semiarid climates, conditioned by a clear tectonic influence.

Los Venados show significant geomorphological variations. The western area of the range presents sharp watersheds with well-developed V-shaped valleys. On the other hand, the landscape in the eastern sector is characterized by rounded watersheds and relatively lower heights.

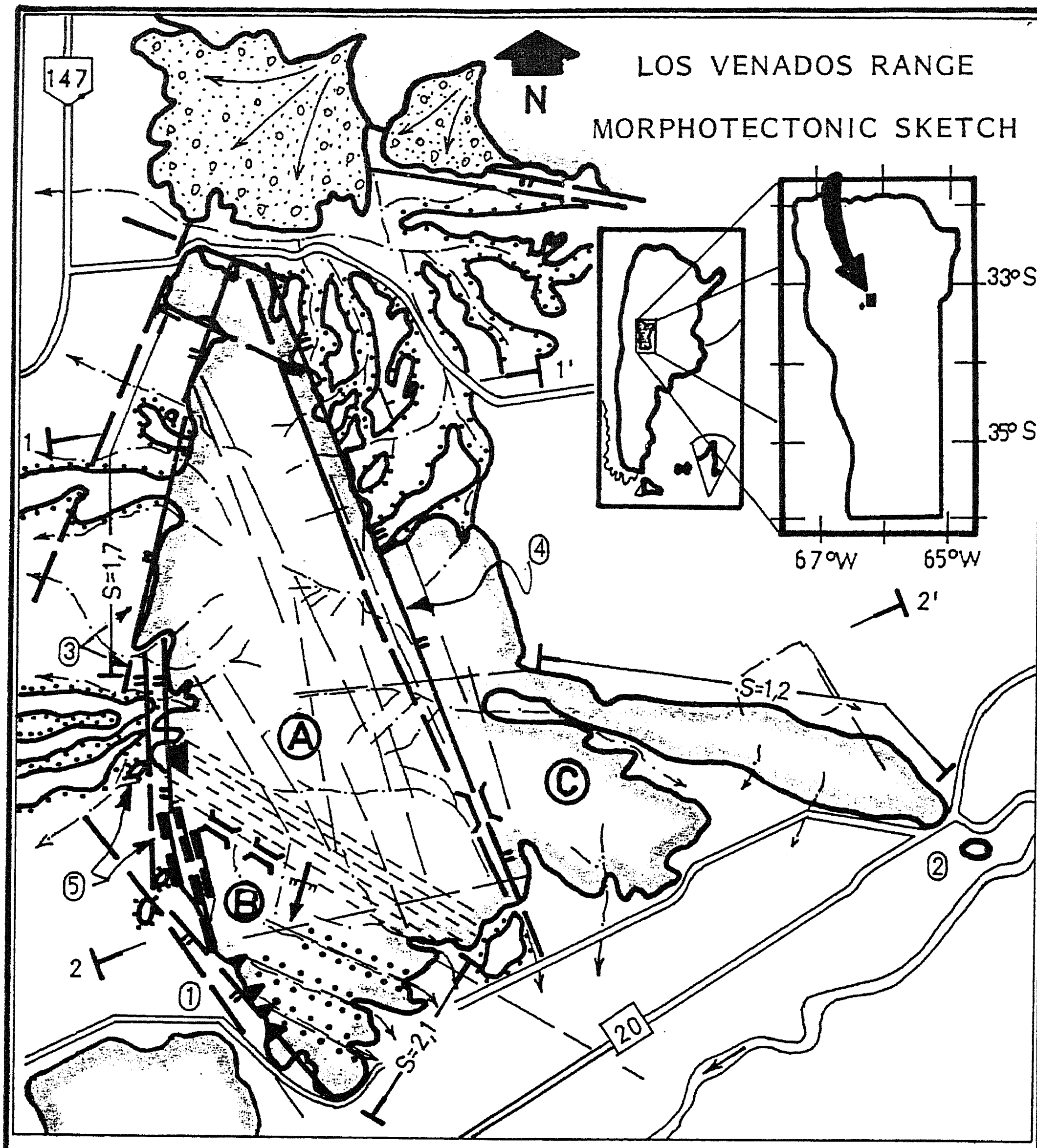
2. THE MORPHOTECTONIC DOMAINS

The boundaries of the different morphological features observed in the range, show direct correspondence with major fault traces (Fig. 2). Considering that the faults related to the Late Tertiary movements produced differential block movements, one may logically postulate that the relationships between the relative uplift descent of blocks with respect to the controlled base level, must have influenced the landforms sculptured by fluvial erosion in the range. According to such a criterion, a Morphotectonic Domain is defined as an area showing uniform morphological features, whose development and relationship with the surrounding areas shows dependence upon tectonic action (Costa & Gardini, 1985). This has proved to be a useful concept for analyzing the recent morphotectonic evolution of the range. For the purposes of this paper, a Morphotectonic Domain shall be considered as an areal morphoneotectonic unit, the analysis of which integrates both structural and morphological data.

Using the definition supplied above, three domains were identified in Los Venados Range (Figs. 1 and 2).

2.1 Domain A

The greatest altimetric heights in the range are found in this domain, the morphology of which is charac-



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: Quaternary materials
: Alluvial fans
: Granitic rocks (Paleozoic ?)
Ⓐ : Morphotectonic Domain
S=1,2 : Sinuosity Index
: Fault scarp
: Hanging valley
: Triangular facet
: Altimetric discontinuity of crests
: Rectilinear valley
: Fault saddle
: Uplifted piedmont planes
: Fault, with downthrown side
: Infered or hidden fault
: Minor faults and lineaments
: Strike and dip of strata
: El Chorrillo Shear Zone
: Drainage
: Road

① Aguada de Pueyrredón, ② San Roque, ③ Western Border Faults, ④ El Portezuelo Fault, ⑤ Low-angle faulting.

Fig. 1 - Morphotectonic sketch of the Venados Range.
Quadro morfotettonico della catena del Los Venados.

terized by symmetric crests and deeply dissected slopes. The planimetry shows sharp and generally sinuous watersheds. V-shaped valleys are a typical feature here and the vertical distances between watersheds and valley bottoms sometimes exceed 150 meters.

Neogene neotectonic fractures are well-exposed and have a strong influence on the sculpturing of the landscape, particularly in the southern area. This fracturing also conditions the drainage network in inverse proportion to the erosive power of streams. Subdendritic and pseudo-pinnate drainage patterns prevail, the latter being dominant in the eastern sector of the domain. This situation is attributable to the eastward dip of a set of penetrative fractures, the similar inclinations of which produce a constant angle of union between the main stream course and tributaries.

Minor morphological variations define more detailed units or subdomains within Domain A (Fig. 2).

Subdomain A1 consists of the northern part of the range, where there are lower heights and fluvial dissection is less intensive. The water parting is gently displaced toward the western slope. Well-preserved scarps

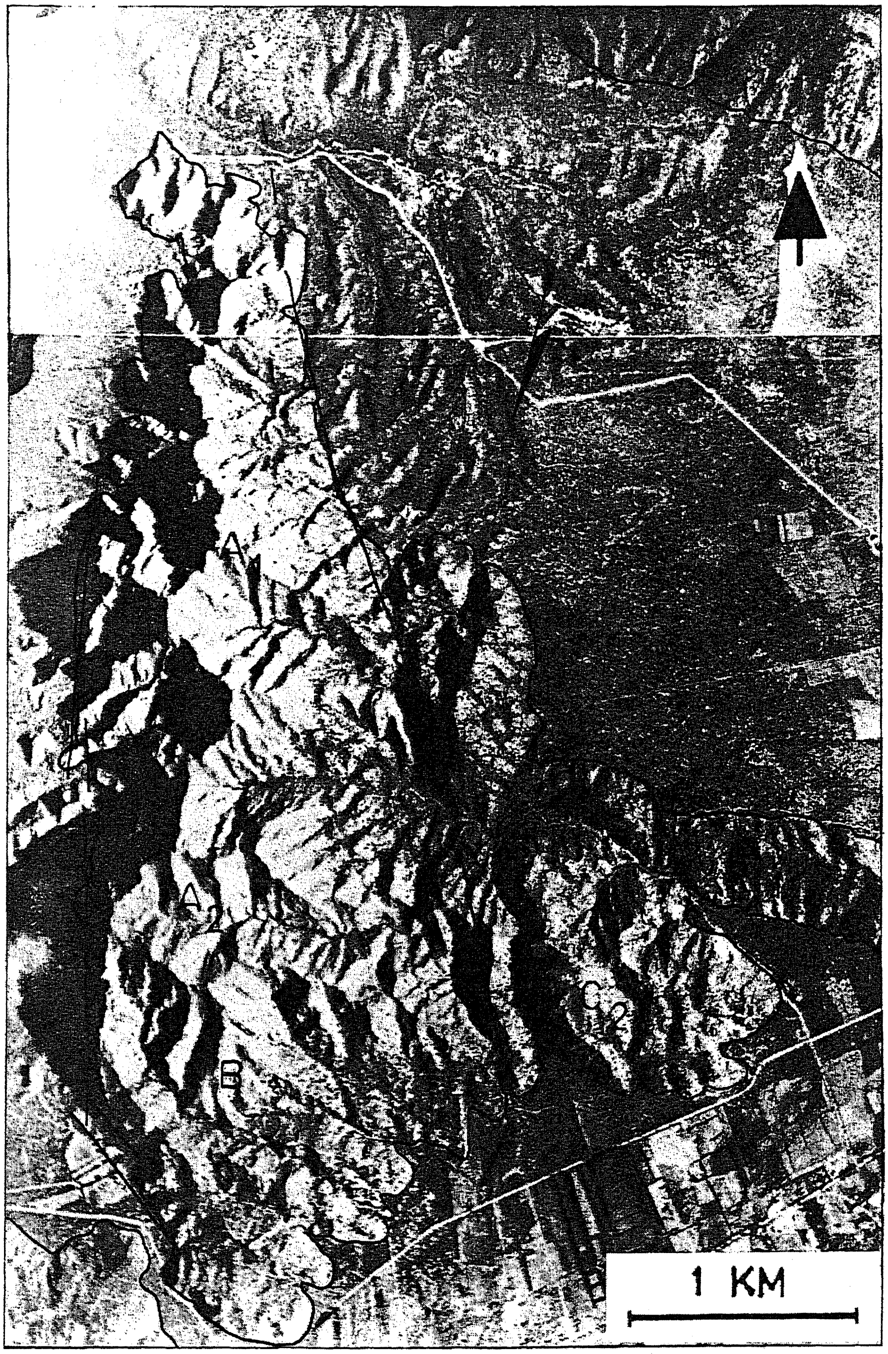

Fig. 2 - Uncontrolled mosaic of the Los Venados Range. (See text for explanation).
Fotomosaico (non controllato) della catena del Los Venados (vedi il testo per le spiegazioni).

and planes with substantial altimetric irregularity are not abundant in the western piedmont.

With regard to the morphotectonic parameters of the western border, there is an average Sinuosity Index (S) of 3.1.

Topographic heights in Subdomain A2 are higher than those in Subdomain A1. The relative relief and intensity of fluvial dissection are also greater in Subdomain A2. The main watershed is displaced toward the western slope, where gradients reach values up to 63%.

Scarps related to secondary fault planes are present in this Subdomain and they correspond to obsequent fault-line scarps. Free face fault surfaces with subvertical dip angles are well-preserved here. In most cases, the planes originated as a result of recent gravitational rock falls, delimited by secondary faults.

The obsequent fault-line scarps have disrupted the longitudinal profiles of some streams, thus generating tectonic hanging valleys.

Surfaces of aggradational genesis are present at different heights in the piedmont area. They contain clastic material with grey-reddish coloring and poorly-sorted sizes.

The average S Index value is 1.26.

2.2 Domain B

Located in the southern sector of the studied area, this Domain is delimited by the El Chorrillo Shear Zone and the Western Border Faults. It is characterized by sharp and upright watersheds, and the valleys coincide with traces of the northwest trend fractures. The sharpness of the crests and the relative relief decrease to the south. Dissection intensity, as well as the heights in Domain B, are moderate with respect to the other domains.

The western border shows straight boundaries. There is a clear influence of the fractures with a northwest trend in Aguada de Pueyrredon, where triangular facets are present (see Fig. 1). The southeast area, on the contrary, shows a well-integrated basement-piedmont junction, with very slight slope angles. The ravines create wide embayments and consequently S Index values are high (*i.e.*, S: 2.2).

2.3 Domain C

This domain shows lower heights and is separated from Domain A by the Portezuelo Fault. The landscape is also characterized by hillsides that are less dissected and crests that are more rounded than those in the other domains. In many ravines, the valleys have flat foors. The latter are not present in Domain A.

The ridges and crests have very smooth topographic surfaces and the granitic rocks are homogeneously denudated. Drainage is poorly developed showing incipient dissection and no continuity in the modern cover. This fact is due to the rapid infiltration of the exiguous and infrequent discharge.

Within the context of the planimetric configuration of this domain, a ridge stands out separated from the range, with a southeast trend. It loses its topographic expression at the San Roque zone. The ridge shows morphological variation with respect the major part of the Domain and thus its distinction as a subdomain (C1) is justifiable. The altimetric values hardly ever exceed 900 meters and fluvial dissection is poorly developed. The watersheds are wider than the valleys. Most of the drainage network is composed of first-order streams, with an average length of 200 meters. The straight border separating the granitic rocks from the more recent fill, suggests that this border has been influenced by fractures, although the latter have not undergone recent movement.

The hills in Subdomain C2 almost reach 1100 meters and the drainage system is more integrated. The drainage system is expressed by subdendritic and nipper-shaped patterns. The former pattern indicates that the influence of the modern fractures is not as strong as in Subdomain C. The contact of Subdomain C2 with Quaternary loessal material shows a festooned contour, similar to that on the southeastern border of Domain B.

3. MAIN NEOTECTONIC STRUCTURES

The modern structures are a result of the Cenozoic uplift of the San Luis Range. In the Los Venados Range, these structures are expressed by subvertical fractures that disrupt the basement rocks in blocks and produce drag folds in the Cenozoic deposits. The density of fractures is great due to the brittleness of the rock. The fractures with a NNW-SSE trend show the highest frequencies and good photogeological expression.

The Portezuelo Fault, the Western Border Faults, and the El Chorrillo Shear Zone shall also be dealt with here because of their morphogenetic significance. The Portezuelo Fault constitutes the contact between Domains A and C (see Figs. 1 and 2). In the northern sector, this fault delimits the basement and fold by dragging the Neogene clastic deposits (Fig. 3). Fault plane attitudes of 350°/85° East have been measured in the field, thus confirming its normal character.

The Western Border Faults have been interpreted as parallel fractures that are associated with the San Luis Fault (defined as a reverse fault, Criado Roqué *et al.*, 1981). The San Luis Fault constitutes the southwestern boundary of the San Luis Range.

A low-angle and eastward dipping shear zone has been detected near the piedmont contact. This not only confirms the reverse nature of the faulting, but also leads us to suspect probable Quaternary faulting activity, due to the good preservation of the faulting products. Moving eastward from the boundary mentioned, the dip of the fault planes are also vertical, with good exposure of the fault surfaces in the Aguada de Pueyrredón area. The unevenness associated with these surfaces does not necessarily demonstrate the real magnitude of fault displacement, but the evidence of boulders bursting and falling through them. Evidently, these fractures constitute the upthrown western front of the range.

The El Chorrillo Shear Zone is a shatter zone of northwestern bearing with a vertical dip and poor exposure of the fault surface. Nevertheless, it shows clear morphological expression. This shear zone includes almost all of Subdomain A2 and separates Domain A from Domain B. The upthrown block is from Domain A.

Beyond the range area, lineaments showing the same trend as the El Chorrillo Shear Zone produce a straight stream alignment in Holocene material.

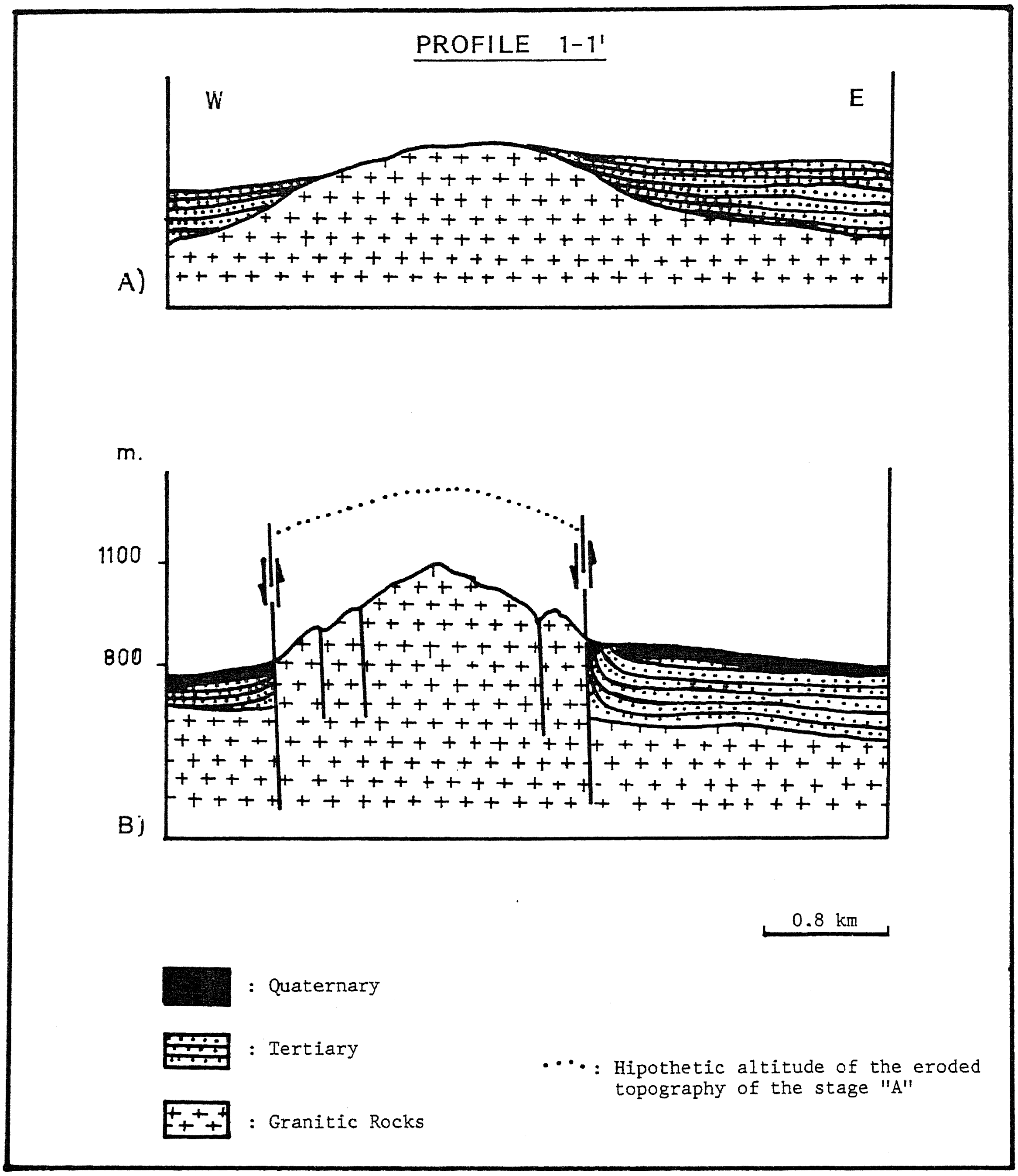

Fig. 3 - Profile 1-1. A) Pre-faulting landscape. B) Post-faulting landscape.
Profilo 1-1. A) Prima della fagliazione; B) Dopo la fagliazione.

4. MORPHOTECTONIC EVOLUTION

It is held that the pre-uplift landscape of the range area was quite similar to the present landscape of Domain C.

Considering that the lithology of the Los Venados Range is homogeneous, the differences in the present geomorphological aspect of the range must have been produced by the greater uplift of the western block as a consequence of the displacement of the El Portezuelo and Western Border Faults (Costa, 1987). In the northern sector, the direction of the movement of the Domain A block is demonstrated by the type of drag in the sedimentary overburden. The stages of evolution are outlined in Fig. 3.

In the southern sector, the direction of the movement of Domain A has been deduced from the sharp contrast in the morphological expressions in Domains A and C. Thus, the greater uplift of the Domain A block, contributed to more rapid dissection in that landscape unit (see Fig. 1). On the other hand, the other domains (particularly Domain C) did not undergo any significant changes in altitudes or in the controlling level of streams. Consequently, remnants of the ancient landscape are still preserved (Fig. 1A). The morphotectonic characteristics of the western border suggest that Subdomain A2 underwent greater uplift or at any rate, more recent activity than Subdomain A1 or Domain B. This fact may emphasize the tectonic significance of the El Chorrillo Shear Zone, even if the scarps and hanging valleys in the western border area show a north-south direction, which does not coincide with the bearing of the shear zone.

It is generally assumed that the landscape of the range prior to the initial phase of regional faulting and uplifting (Oligocene-Miocene?) was quite homogeneous, as shown in Figures 3A and 4A.

Andean tectonic activity disrupted the range by faulting, giving rise to a block mountain structure. Therefore, the geomorphological features of each block had developed differently according to the relationships of each block with the controlling base level.

Assuming that the folded sediments are attributable to the San Roque Formation (Oligocene-Miocene?), the principal tectonic activity must have taken place from the Middle Miocene to the Pleistocene. This is because the Portezuelo Fault does not seem to be affecting the alluvial fan that crops out on the northern side as shown in Fig. 1.

Positive shear movements with a northwest direction were also significant.

5. DISCUSSION

The Los Venados Range shows very direct relationships between the different morphological features and the various movements that the blocks have undergone. This fact is supported by clear evidence in the locations of the principal faults and by the direction of the block movements. It is assumed that this situation highlights the significant modifications in the morphogenetic processes brought about by tectonic disturbances of each block. Therefore, the proposed concept of Morphotectonic Domains that links the relationships between the morphology and faulting activity, could constitute a valid concept in neotectonic surveys of areas affected by modern tectonics and similar morphotectonic settings. It is particularly useful in areas where morphology becomes a valuable aid in the analysis of modern structures due to the lack of modern stratigraphic units.

The Sinuosity Index of a mountain front (S) is a morphotectonic parameter used with the aim of evaluating the degree of tectonic activity of a mountain border (Bull & McFadden, 1977). This index is defined by the ratio: S=Lmf/Ls, where Lmf is the length of the mountain front along the mountain-piedmont junction and Ls is the length of a straight line along the mountain front.

According to Bull and McFadden, the S Index reflects the balance between uplift and erosion. In the case of rapid uplift along the range, the delimiting faults produce a straight border. On the other hand, when uplift slows down or stops, mountain front sinuosity increases over time, together with fault scarp degradation.

As with other parameters, the S values obtained could be tabulated for the purpose of distinguishing sectors with differing degrees of tectonic activity. In this case, the S values in Domains B and C (C2) proved to be higher than that of Subdomain A2. Nevertheless, Subdomain C1, located in a sector with relatively little tectonic activity, yielded S values that were considerably lower in relation to the degree of activity (S=1.2). The straightness of the Subdomain C1 border has not been interpreted as a consequence of recent uplifting, but rather, as a consequence of the very poor sculpturing power of the streams and of the tabular morphology of the ancient landscape (see Fig. 2). At any rate, this situation serves to illustrate the relative nature of this parameter and the caution required in interpreting results.

The morphotectonic evolution of the range has been analyzed keeping in mind the vertical movements which make the development of the various morphological features possible. Such structural patterns are not only documented by the drag folding produced by the Portezuelo Fault, but also by the slickenside striae with subvertical angles present in the surfaces of the main faults. However, many other faults, mainly along the western border, show evidence of horizontal components in their slip. The significance of this point in the structural style of the range has not been fully evaluated yet.

The chronological relationships between the main

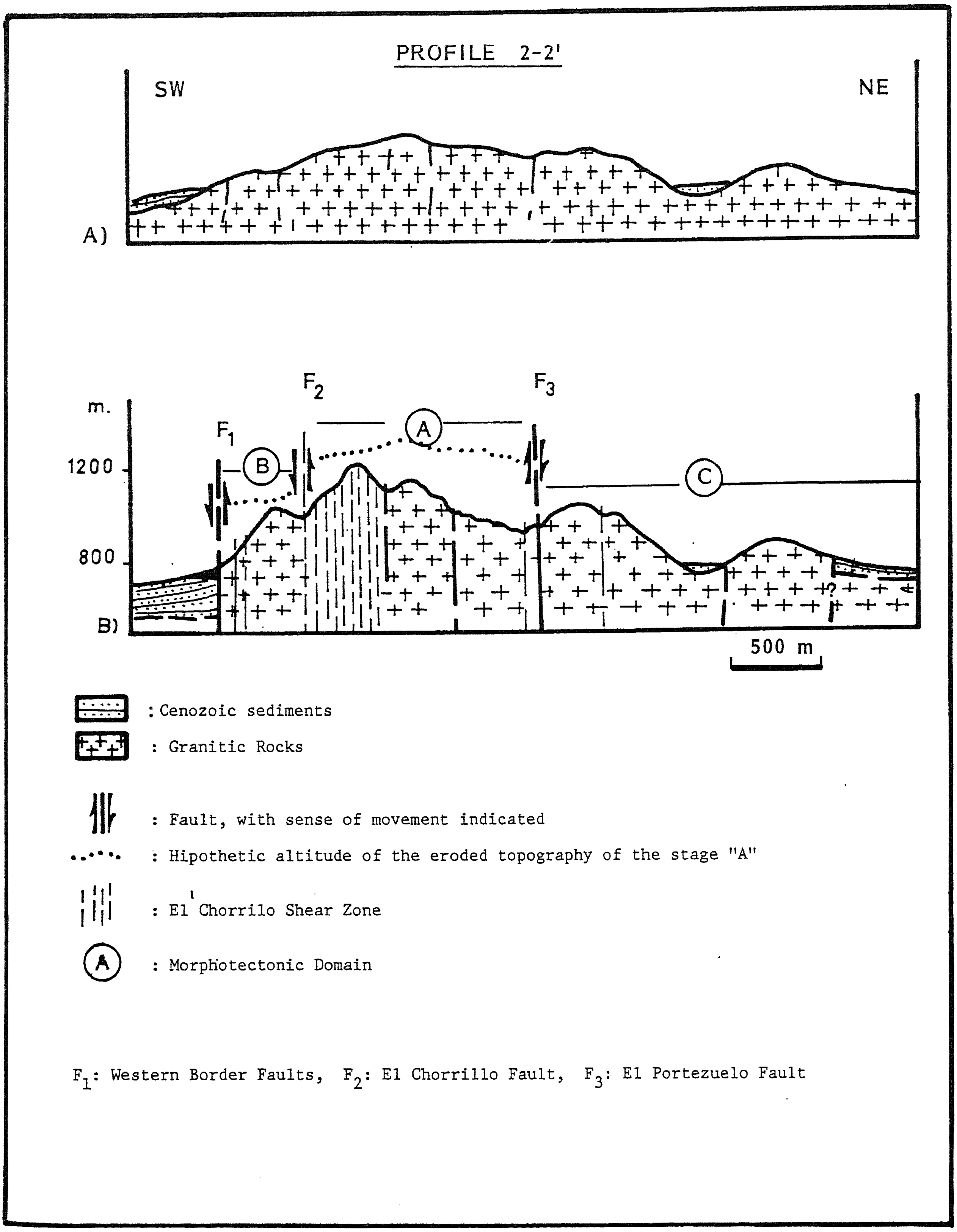

Fig. 4 - Profile 2-2. A) Pre-faulting landscape. B) Post-faulting landscape.
Profilo 2-2. A) Prima della fagliazione; B) Dopo la fagliazione.

faults and the shear zones are still not clear. Beyond the range area, the Western Border and El Portezuelo Faults are buried by recent material, and their interrelationships remain unknown. Sets of fractures showing the same trend as that of El Portezuelo Fault and with expression in the range located northward (see Fig. 2), seem to influence the dissection of modern sediments (shown by the black arrow in Fig. 2). Nevertheless, as no evidence of surficial faulting has been found, these lineaments have been interpreted as transparencies or inherited fractures.

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