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Gabriela LARA[1], Laura PERUCCA[1, 2*] & Martin ROTHIS [1,2]

MORPHOMETRIC, GEOMORPHOLOGIC AND FLOOD HAZARD ANALYSIS OF AN ARID MOUNTAIN RIVER BASIN, CENTRAL PRE-ANDES OF ARGENTINA. SOUTHWESTERN SOUTH AMERICA

Abstract: Lara G., Perucca L. & Rothis M., *Morphometric, geomorphologic and flood hazard analysis of an arid mountain river basin, central pre-Andes of Argentina. southwestern South America.* (IT ISSN 0391-9838, 2018).

A geomorphologic and morphometric analysis was performed in order to determine the characteristics of the de La Ciénaga river basin, an arid mountain river basin located in the southwest of San Juan Province (31°45´S, 68°50´W), Central Pre-Andes, Argentina. The drainage networks were derived from shuttle radar topographic mission (SRTM) data, satellite imageries (Landsat TM and Spot image) and field works. The paper also addresses a preliminary evaluation of the flood hazard responsible for severe damage to farming and infrastructure in the downstream region. The study basin area covers almost 700 km^2, comprising five sub-basins, ranging from 111.96 to 159.30 km^2. The asymmetrical morphology of the basin, neotectonic features and the diversity of alluvial deposits found along the de La Ciénaga river basin show that it is in an active tectonic environment with strong lithological and structural controls and a marked tilting. One common feature to all analyzed sub--basins is their elongated shape, which allows a rapid concentration of water that intensifies the power of the flash floods. The drainage network in the different sub-basins has, in general, two predominant patterns; one is parallel to sub-parallel to the headers and foothill areas; and the other, in the piedmont zone, is divergent. Zonda valley, located downstream of the basin, is affected by flash floods coming from the mountainous area.

Key Words: La Ciénaga river basin, morphometry, flash flood, Precordillera, Argentina.

[1] *Gabinete de Neotectónica y Geomorfología. INGEO. Facultad de Ciencias Exactas, Físicas y Naturales. Instituto de Geología - Universidad Nacional de San Juan. Avenida Ignacio de La Roza y Meglioli 5400 - provincia de San Juan.*

[2] *CIGEOBIO-CONICET. Facultad de Ciencias Exactas, Físicas y Naturales. Instituto de Geología - Universidad Nacional de San Juan. Avenida Ignacio de La Roza y Meglioli 5400 - provincia de San Juan.*

* *Corresponding author: L. Perucca lperucca@unsj-cuim.edu.ar*

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INTRODUCTION

A flash flood is a very fast flow that occurs generally in arid environments. It can be generated instantly during or shortly after torrential rains on steep hill slopes with exposed rocks and lack or scarcity of vegetation (Lin, 1999; Wheather, 2002). Due to their almost instantaneous occurrence, together with their high capacity of transport, flash floods are one of the most significant weather-related hazards in many parts of the world (Gaume & *alii*, 2009). Morphometric analyses were generally used for basin characterization (Miller, 1953; Gardiner, 1975; Costa, 1987; Nag, 1998; Moussa, 2003; Sreedevi & *alii*, 2004; 2013; Esper Angillieri, 2008; 2012; Perucca and Esper Angillieri, 2011). Geomorphologic and morphometric studies of a basin are basic tools to estimate and predict its behavior under conditions of heavy rainfall, and to calculate the potential flash floods hazard to downstream settlements.

The drainage pattern of de La Ciénaga basin area is the result of the combination of climatic, tectonic, lithological, geomorphological, soil and vegetation factors. The stream pattern responds not only to present conditions, but inherits past modeling conditions. Differences in the drainage system are due to the combination of these factors and to the prevalence of one of them.

Drainage network characteristics in the de La Ciénaga river vary according to the sector being analyzed, responding primarily to geological and geomorphological controls.

In this study the morphology of the La Cienaga river basin is studied with special focus on morphometric parameters of the drainage system. We used DEM data, satellite imagery and fieldwork to quantify basin parameters. The results are discussed in the context of flood hazard in the downstream settlements. In addition, we present a regional geomorphologic map that illustrates the landforms and geomorphic processes observed in this portion of San Juan province, Argentina. The results can provide a basis for urbanism, land use planning and hazard management.

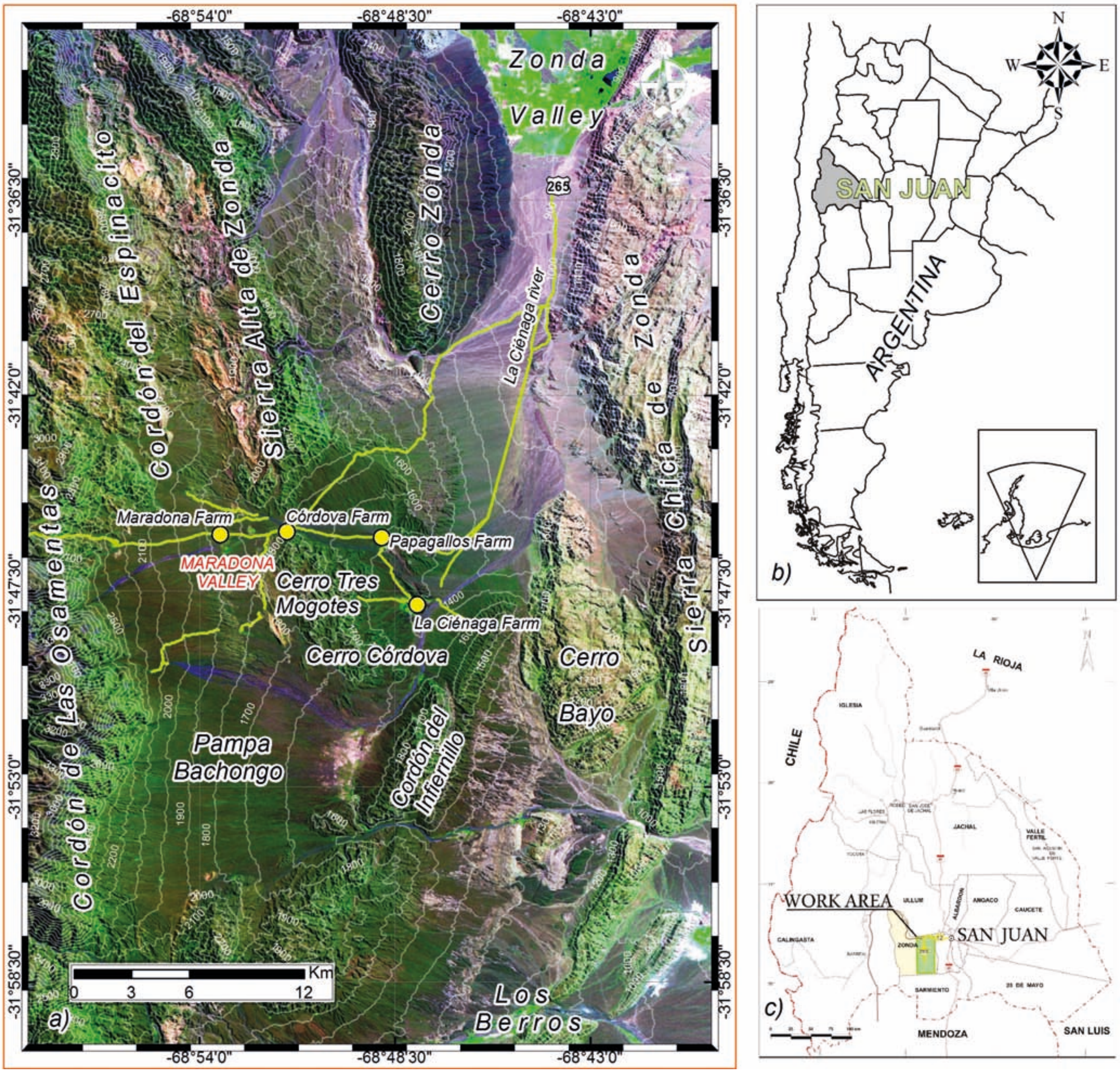

FIG. 1 - a) Satellite image of the study area. b) Map showing the relative location of San Juan province in Argentina. c) Location of the studty area.

Most of the small farms in the area located in south of the province of San Juan, Argentina, e.g. Puesto La Ciénaga, Córdova and Papagallos (fig. 1a,b,c) are situated in the river basin of La Cienága. These farms and those located downstream in the Zonda Valley have suffered flash floods during each summer with severe material damage.

The latest destructive event took place on January 25, 2007 (fig. 2a) when as a result of heavy rainfall (100 mm/h), a sizeable flash flood affected the Zonda valley, damaging the road that connects the farming communities and several farming and buildings (fig. 2b,c,d,e,f). Besides, many people were evacuated and a total of 30 ha were flooded (Source: Hydraulic Department).

STUDY AREA

The de La Ciénaga river basin covers an area of 663.81 km^2 in the southern Department of Zonda, Province of San Juan, about 50 km southwest of the capital city (fig. 1b,c).

San Juan province supports an arid and semiarid climate; the total annual rainfall average is very small, about 93.3 mm/year. Winter temperatures are generally mild, ranging between 1.0 and 18.0 °C, whereas summers are hot and very dry, with temperatures between 19.0 and 35.0 °C (Source: Hydraulic Department). Maximum rainfalls are usually coincidental with the highest summer temperatures.

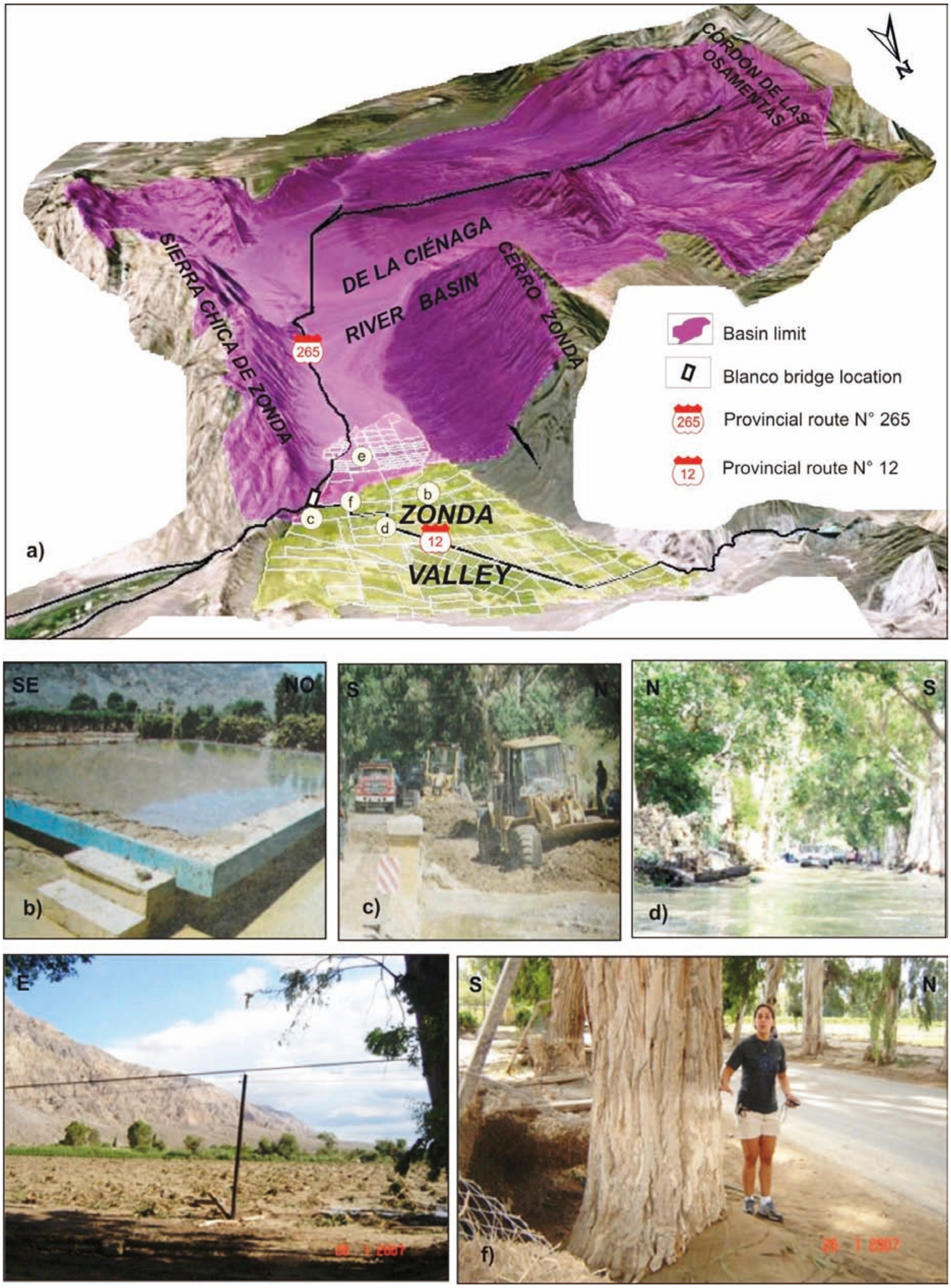

FIG. 2 - a) Google Earth DEM of De La Ciénaga River Basin with the location of photographs showing damages occurred during the flash flood event, b) swimming pool filled by mud, c) Damages in provincial route N° 12, next to Blanco bridge, d) The route N° 12 was completely filled with mud, interrupting traffic for a few hours, e) View to the south, cultures of grapevine destroyed by the flash flood. f) High water mark of the 2007 flood on a tree (Photos obtained on January 26, 2007 by Perucca).

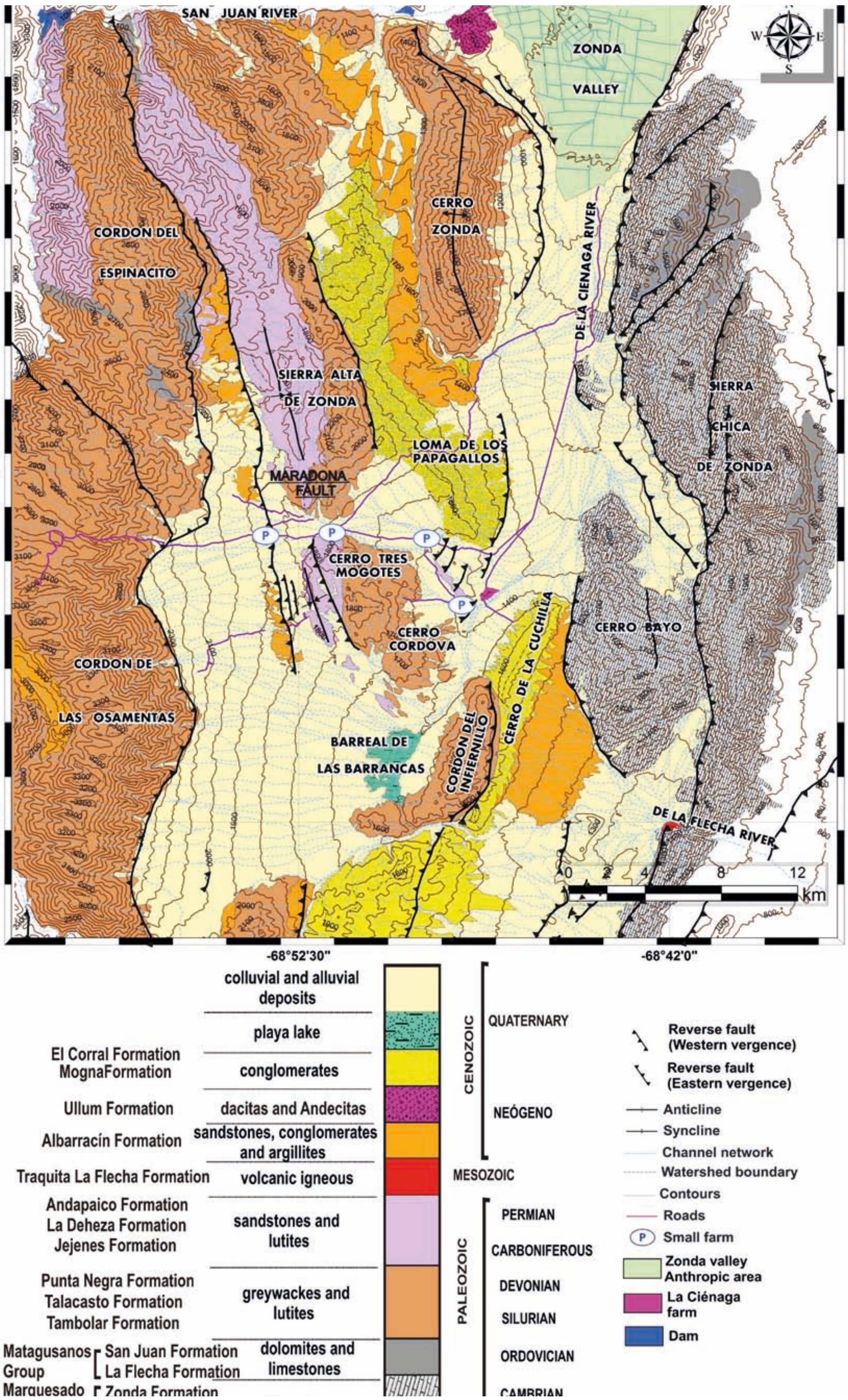

FIG. 3 - Geological map of the study area.

Mountain ranges located east and west of the valleys have an important influence on their climatic conditions and the great distance to the ocean increases aridity. Mountains trend N-S, favoring the entrance of winds coming from the southeast, that cause falling temperatures. However, in these conditions, Poblete & Minetti (1989) individualized "semiarid-isles" characterized by higher precipitation within a markedly desert domain. For example, in the western sector of the work area, near the Cordón de Las Osamentas ranges, higher moisture can be found, with an incipient soil development and markedly different vegetation when compared with the eastern sector.

Rainfall in this area reaches up to 290 mm/year, while a few kilometers further east (Tulum Valley) barely reaches 100 mm annually.

GEOLOGICAL SETTING

The study area supports a wide range of geologic units (fig. 3). The stratigraphy, from oldest to recent is: (1) Cambrian-Ordovician sedimentary rocks, mainly consisting of limestone, dolomite and lutite, (2) a package of greywacke and lutite, of marine origin and Silurian-Devonian age, (3) a continental Carboniferous sandstone and lutite, (4) Neogene sedimentary rocks (conglomerates and argillites), (5) Quaternary colluvial-alluvial consolidated deposits, (6) unconsolidated modern deposits, consisting of sand, silt and clay, restricted to narrow river channels and valleys. It is located in the transition zone between the Eastern Precordillera and Central Precordillera; both are characterized by several elongated mountainous ranges with a regional north-south trend, following the division proposed by Heim (1952), Baldis & Chebli (1969) and Ortiz & Zambrano (1981), among others.

The Central Precordillera has been described by several authors (Allmendinger & *alii*, 1990; Von Gosen, 1992; Jordan & *alii*, 1993; Cristallini & Ramos, 2000) as a typical thin-skinned thrust-and-fold belt, with Neogene crustal shortening dipping west, and imbricated structures rooting down towards a 10-15 km deep main decollement (Allmendinger & *alii*, 1990).

The outcropping structures on Eastern Precordillera generally are large asymmetric anticlines, with their axes running sub-parallel to the mountain ranges. The axial planes of these structures dip sharply to the east, and most of their western flanks are vertical, overturned or have been eliminated by high-angle reverse faults sub-parallel to the structural axes. The longest of these faults corresponds to the western limit of the Eastern Precordillera, highlighting the sinusoidal shape of Eastern Precordillera in the Sierra Chica de Zonda region. It is because these characteristics that Zapata & Allmendinger (1996), Jordan & *alii* (2001) and Siame & *alii* (2006) place the Sierra Chica de Zonda within the Sierras Pampeanas domain.

MATERIALS AND METHODS

Both the morphometric-geomorphic characterization and basin delineation were made using topographic data, fieldwork and digital satellite imagery (Landsat 7). The La Ciénaga river basin was delineated based on the water divide line concept. The basin was divided into five sub-basins, which were on-screen digitalized using GIS technology. Sub-basin margins were also defined by the surface divide, according to their lithological, structural and slope characteristics, and author's criteria. The ordering of the La Ciénaga river basin was made based on Strahler (1964). The main channel length (Mcl) and Basin length (L) were calculated according to Schumm (1956). Elevations were obtained using a digital elevation model obtained from the radar shuttle topographical mission, 90 m spatial resolution (USGS, 2014).

The morphometric parameters of the basin and sub-basins were quantitative calculated using GIS technology.

TABLE 1 - List of derived parameters, equations and references.

Derived parameter	Equation	References
Basin relief	$Hr = H - h$	(Hadley & Schumm, 1961)
Compactness index	$Kc = 0{,}28(P / A)$	(Gravelius, 1914)
Circularity index	$Rc = 4\pi A / P2$	(Miller, 1953)
Elongation ratio	$Re = (4A/\pi) / L$	(Schumm, 1956)
Form factor	$Ff = A / L2$	(Horton, 1932)
Form index	$If = 1/Ff$	(Strahler, 1964)
Lemniscata Índex	$Le = \pi L22/4Au$	(Chorley & *alli*, 1957)
Relief ratio	$Rh = Hr/L$	(Schumm, 1956)
Melton ratio	$MR = Hr/A^{1/2}$	(Melton, 1957)
Sinuosity Index	$S = Lcp/L$	(Schumm, 1977)
Asymmetry Factor	$FA = 100 (A_r / A_t)$	(Hare & Gardner, 1985)

These morphometric parameters were divided into basic and derived parameters. Basic parameters are area (A), perimeter (P), length (L), mean width (W), river network (Rn), maximum and minimum heights (H, h), total channel length (Tcl), stream order (Nn) and main channel length (Mcl). Derived parameters like circularity index (Rc), elongation ratio (Re), relief ratio (Rr), sinuosity index (S), asymmetry factor (AF) among others, were calculated using the equations in Tables 1 and 2.

We determined flash flood hazard employing the compiled historical record from local newspapers, technical reports and oral histories. The return period (T) and probability of occurrence (P) were calculated according to Weibull (1939, 1951). The results were summarized in Table 3.

For the geomorphological map, all recognized landforms through the analysis of satellite images, DEMs and fieldwork were mapped manually on screen in a GIS environment (in vector format) and later were verified by fieldwork. Geologic sheets published by the Servicio Geológico Minero Argentino (Argentine Mining Geologic Service) on a 1:250,000 scale were used to determine the lithology.

GEOMORPHOLOGY

The study area is an intermountain tectonic depression bordered by the mountain ranges of Central Precordillera on the west and Eastern Precordillera on the east. Based mainly on the relief, slope, lithology, dominant processes among others, the following geomorphological units were distinguished (fig. 4a), a) Mountainous unit (Upper and Lower mountains), b) Piedmont unit, and c) Valley floor unit.

The Upper mountains correspond to a prominent fault elevated relief, which stands out over the surrounding areas and trends N-S with gentle inflections: To the east, the

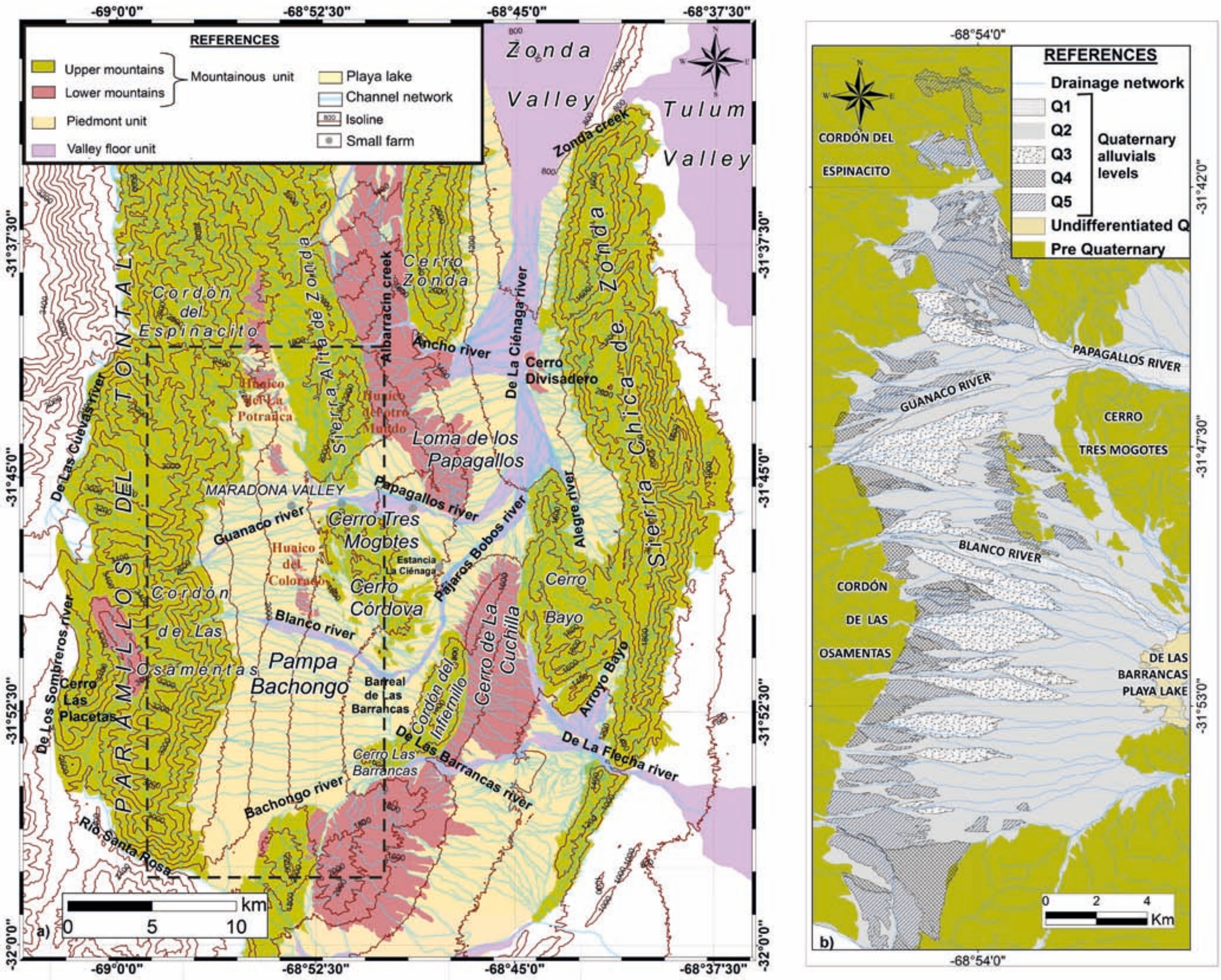

FIG. 4 - a) Geomorphological map of the de La Ciénaga basin area, b) Detail of the geomorphological map showing the alluvial levels (Q1, Q2, Q3, Q4 and Q5) in the cordón de Las Osamentas piedmont.

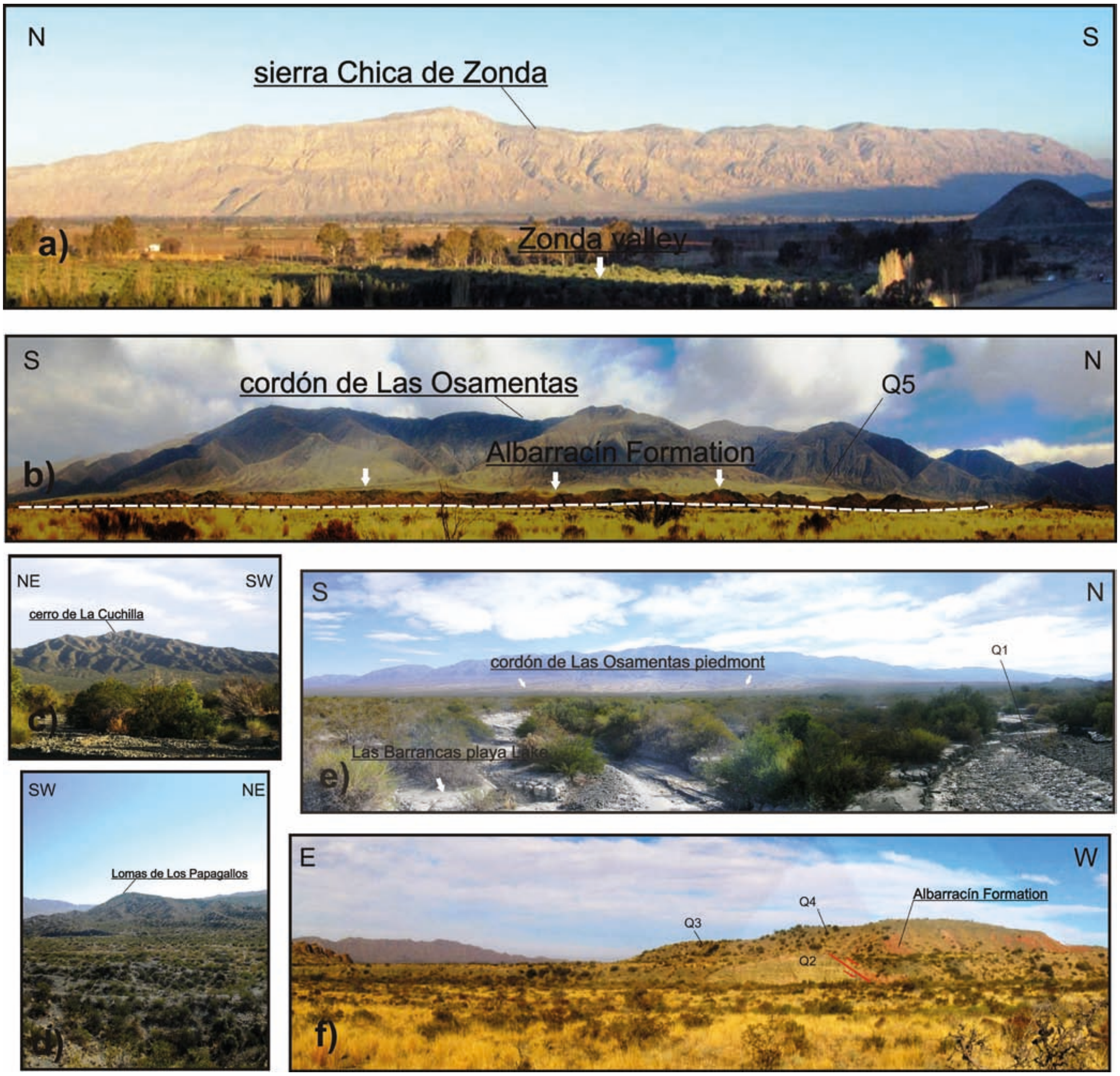

FIG. 5 - a) View to east of the of the Sierra Chica de Zonda , b) View to west of the of the cordón de Las Osamentas, c) Cerro de La Cuchilla d) Loma de Los Papagallos, e) Pleistocene-Holocene channel deposit of the de Las Barrancas Playa Lake f) View to the east, where three alluvial levels affected by Quaternary faults can be recognized.

unit is represented by the Sierra Chica de Zonda and the Cerro Bayo; to the north by the Cerro Zonda and Sierra Alta de Zonda; and to the west by a series of mountain ranges like cordón de Las Osamentas and cordón del Espinacito (fig. 4a, b).

The limestone outcrops located in the east of the study area (Sierra Chica de Zonda and Cerro Bayo) have steep slopes resulting in a relief of rough surfaces and an asymmetric profile, with gentle slopes on the western flank and eastern steep slopes (fig. 3). This is the result of the Zonda regional fault affecting the western flank of these mountain ranges. The highest peaks can be found in the Sierra Chica de Zonda with an altitude of 2,213 m asl (fig. 5a).

The mountain ranges developing in the western sector are characterized by Devonian rocks (psammites) affected by west-dipping thrusts. The mountain heights increase from east to west, being the highest the cordón de Las Osamentas, with an altitude of 3,557 m asl (fig. 5b). On the other hand, these high reliefs are continuously countered by erosion due to torrential precipitation, wind and extreme temperatures favouring crioclastism and slides.

The Lower mountains correspond to those less prominent positive reliefs: like the high mountains, these hills trend N-S with minor inflections. They mainly occur in the central portion of the study area, between the cordón the Las Osamentas and the Sierra Chica de Zonda mountain ranges (fig. 4a). The main hills are the Lomas de Papagallos, Loma de Las Cuchillas and other N-S low hills (fig. 5b, c, d). They have a Quaternary alluvial cover over Miocene rocks. This positive relief often exhibits asymmetrical transverse profiles with a steeper flank located in the front of the strata. Their maximum altitudes range between 1,100 and 1,300 m asl. Where Miocene sediments with softer sedimentary rocks and clay rich soils outcrop, a bad land environment with lack of vegetation and rare stream networks is found. They have been extensively barren, battered and eroded by water and are called "*Huayquerías*" by the local settlers.

The Piedmont unit corresponds to the intermountain areas located between the mountain morphostructural units and lowlands or Valley floor unit. It extends from the mountain fronts to the local erosion base levels, flood plains or playa lakes (fig. 4a). The Central Precordillera piedmont has a remarkable width when compared to the eastern Precordillera western piedmont (fig. 4a, b) and local base level is displaced to the east at an altitude of about 1,000 m asl.

Several accumulation landforms, such as large alluvial fans or alluvial cones are located in the cordon de Las Osamentas piedmont (Lara, 2015). They were identified from Q5 the oldest level to Q1 the youngest according to their relative position, degree of desert varnish on cobbles and river incision (fig. 4b and 5b, f). These alluvial covers exhibit a clear predominance of sandstone clasts of Silurian–Devonian age, resulting from the erosion of the surrounding mountains and are affected by Quaternary faulting (fig. 5f).

The youngest fan generation Q1 has adjusted to the present floodplain and is interpreted as the result of the currently ongoing degradation of the quaternary slopes. These active areas are frequently flooded with modern flash floods, having a poor development of the drainage pattern.

The Playa lake Las Barrancas, locally called "Barreal Las Barrancas", is located at the distal portion of the southern piedmont, where fine grained material is deposited (figs. 3, 4b and 5e).

The Valley floor unit corresponds to the main floodplain rivers or the area. These alluvial systems contain both active channels and adjacent floodplains and terraces (fig. 4a). Floods is considered the crucial agent of geomorphic change in these channels and valley floors.

DE LA CIÉNAGA RIVER BASIN DESCRIPTION AND RESULTS

The de La Ciénaga river basin is elongated in a SW direction, with a stream order of eight and an area (A) of 663.81 km^2 (fig. 6). The main course is the de La Ciénaga River, ephemeral in almost its entire length, with a main channel length (Mcl) of 52.5 km. Its northern boundary is formed by the Sierra Alta de Zonda and the Cerro Zonda. The western boundary is formed by the cordón del Espinacito and the cordón de Las Osamentas, to the south, is formed by the water divide crossing west to east in the Pampa de Bachongo and the broken line joining the summits of cordón del Infiernillo, Cerro de La Cuchilla and Cerro Bayo and the eastern boundary is the Sierra Chica de Zonda (fig. 7). The results of the morphometric analysis of this mountain river basin is given in Table 2. The elongation ratio (Re) value of the study area shows that the basin assumes an elongated shape (Re 0.5~0.7).

The form factor value of the basin is 0.354 which also represents an elongated basin and indicates that the basin will have a flatter peak of flow for longer duration.

The index of compactness of the entire basin of the La Ciénaga River is 1.49, so we can consider that the basin is roughly oval.

The de La Ciénaga River Basin, with a factor (Rc) of 0.38 can be considered of little circularity intensifying flooding.

The Sinuosity index (S), which takes values very close to 1, reveals a rectilinear to braided mainstream type in their headwaters and lower section, where the prevailing deposits are alluvial type, indicating high flow strength, facilitated by steep gradients. The relief ratio (Rh) can be positively correlated with the rate of sediment loss from a basin. The low value of 0.06 for the entire basin and the values obtained for their sub-basins suggest low erosive power and moderate to gentler slopes. Melton's ratio (MR) is in all basins, lower than 0.3, indicating that these basins are more susceptible to flows with low mass content.

The value of the form factor of the basin is quite low, which equally implies a strong tendency to elongation, and low probability of experiencing frequent flooding, because its shape does not allow expose all its surface to the range of action of a given storm. However, these statements are relative, as it depends on the size or extent of the storm and the duration and intensity of it. Nevertheless, the probability that hydrograms of floods with pronounced peaks of short duration occurrence is high, due to the characteristics of the relief.

Another characteristic feature of the de La Ciénaga River basin is its marked asymmetry, with a very large area on the right margin in contrast to the much smaller area on the left one. The Asymmetry Factor (AF) is obtained in order to determine if there is any tectonic tilt in the area due to tectonically active fault zones (Hare & Gardner 1985, Keller & Pinter 2002).

For a stream network, that developed and continues to flow in a stable tectonic setting and uniform lithology, asymmetry factor should be equal to about 50, whereas active setting would give a deviation from normal value either < 50 or > 50 (Keller & Pinter, 2002). AF is close to 50 if there is no or little tilting orthogonal to the direction of the main stream.The AF value for this basin is 18.97, indicating a strong asymmetry and tectonic tilt from the west (Central Precordillera), due to influences of the Cordón de Las Osamentas Fault and the Maradona fault system in the area (fig. 3). The main channel de La Ciénaga River has shifted towards the downstream right side of the drainage basin, that is, towards the east.

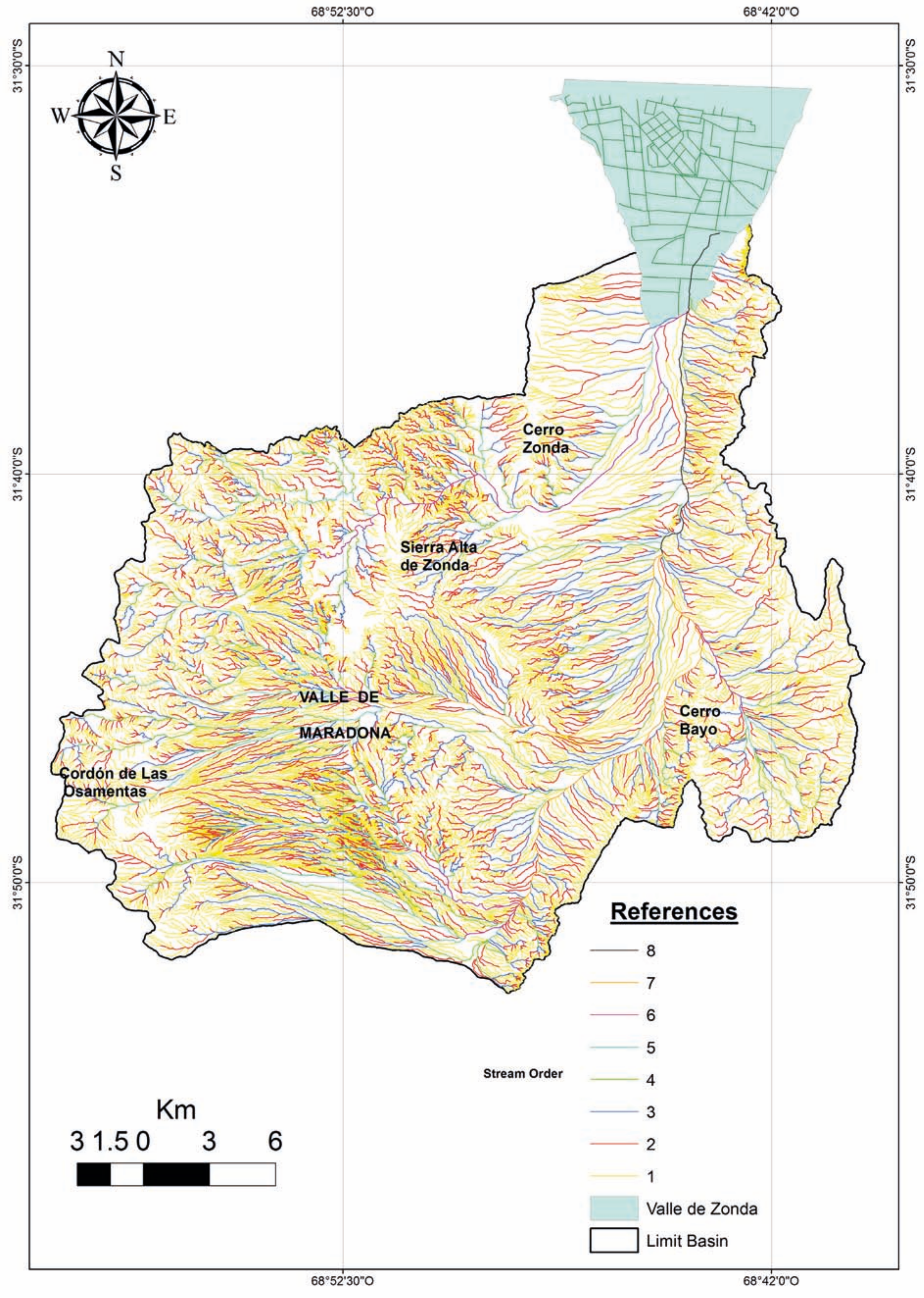

FIG. 6 - Drainage pattern of de La Ciénaga River basin with stream orders.

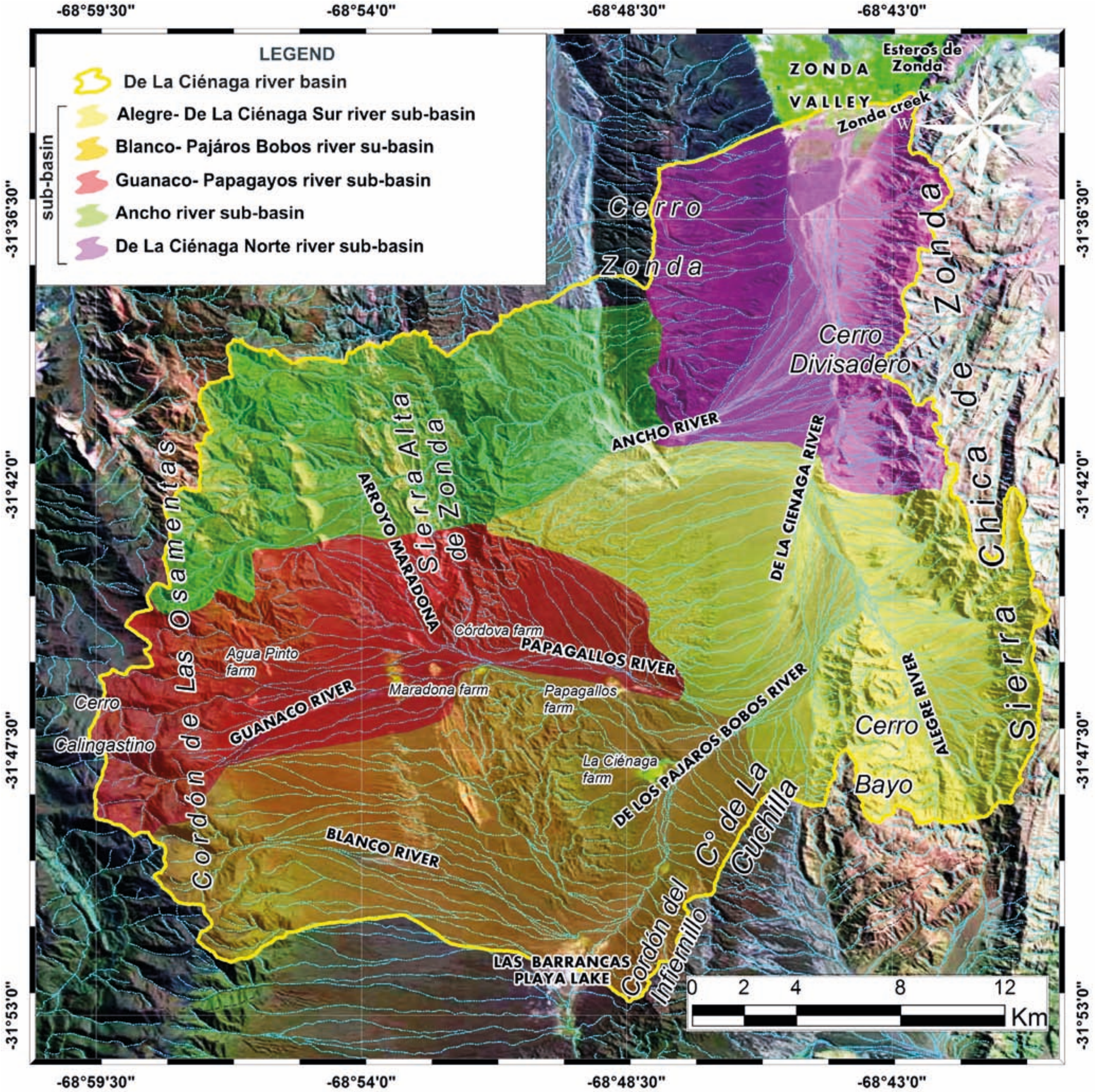

FIG. 7 - Main sub-basins location.

In this work, the basin was divided into five sub-basins according to their lithological, structural and slope characteristics (fig. 7).

Sub-basins Blanco-Pájaros Bobos River, Guanaco-Papagallos River and Ancho River are located in the western portion of the main basin (fig. 7) in the Cordón de Las Osamentas and Cordón del Espinacito. They have headwaters with a dendritic pattern, due to the relative uniformity of the substrate and the similar erosion resistance of the outcropping sedimentary rocks. The basins shape is elongated in the W-E direction. Once leaving the mountain front, the drainage pattern becomes divergent, typical of alluvial fans, with its middle section showing anomalies related to the Maradona Quaternary fault trace (fig. 3) (Lara, 2015).

The stream pattern is basically determined by the field gradient, mainly to the East. However, when rivers meet the central portion of the piedmont, elevated by the Maradona fault system, tributaries of 1st-3rd order have a strong structural and lithological control with confluence angles of 90° and a broom-shaped river pattern (Lara, 2015).

TABLE 2: Morphometric parameters of de La Ciénaga river basin and sub-basins.

a) Basic parameters

	Total Basin	Sub-basin				
		Ancho	*Guanaco-Papagallos.*	*Blanco-Pájaros Bobos*	*Alegre-Ciénaga Sur*	*Ciénaga Norte*
$A\ (Km^2)$	663.81	112.95	118.05	158.76	159.30	111.96
$P\ (Km)$	147.00	58	59	59	70	64
$L_2 (Km)$	43.3	22	20	24	24	23
$W\ (Km)$	15.33	5.13	5.90	6.61	6.63	4.86
$H(m)$	3450	3029	3450	3432	2036	2088
$h(m)$	780	2121	2416	1267	1064	780

b) Morphometric parameters

Parameters	Total Basin	Sub-basin				
		Ancho	*Guanaco-Papagallos*	*Blanco- Pájaros Bobos*	*Alegre-Ciénaga Sur*	*Ciénaga Norte*
$S=Mcl/L$	1.15					
$MR=Hr/A^{0,5}$	0.10	0.08	0.09	0.17	0.07	0.12
$Kc= 0,28(P/A^{1/2})$	1.497	1.529	1.521	1.511	1.553	1.693
$Rc = 4\pi A/P^2$	0.386	0.421	0.426	0.573	0.408	0.343
$Re = (4A/\pi) / L$	0.67	0.653	0.751	0.842	0.845	0.619
$Ff = A/ L^2$	0.354	0.233	0.295	0.275	0.276	0.211
$If=1/Ff$	2.82	4.28	3.38	3.62	3.61	4.72
$Le= \pi L22/4Au$	2.21	3.36	2.65	2.84	2.83	3.70
$Hr= H-h$	2.670	908	1.034	2.165	972	1308
$Rh= Hr/L$	0.06	0.04	0.05	0.09	0.04	0.05

FIG. 8 - a) Google Earth image showing the lower portion of the La Cienaga River basin with b) the retaining dam, c) and d) several precarious defenses location.

Sub-basin Alegre-Ciénaga Sur River is located in the southeast portion (fig. 7) of the study area. The sub-basin shape is elongated in the NW direction, although its eastern end is much wider than the western one. This sub-basin has also many anomalies in the drainage pattern, mainly due to a marked structural control. For example, channels of 4th order trend W-E, then deviating 90° from South to North.

On the other hand, sub-basins and tributaries from Sierra Chica de Zonda are short and have a parallel pattern, characteristic of the steep slopes resulting from the uprising of the range caused by the regional fault affecting its western flank. Due to the strong structural control by fractures and faults affecting the Cerro Bayo, located in the south portion of the basin, this area has a rectangular drainage design.

Ciénaga Norte sub-basin is located on the upper right margin of the basin. It has an elongated in the N-S direction. The river pattern is sub-dendritic, being lithology, slope and structure the main controls. The basin has a marked asymmetry, with a smaller area to the south margin with respect to the north one. Confluence angles near 90° are predominant on the central portion, mainly due to structural controls (faults, strata and joints). The eastern margin has a dense dendritic pattern and the western margin has a divergent pattern, characteristic of alluvial fans, where the controlling factor is the topographic slope.

TABLE 3: Archive data, Rainfall intensity (mm/h), 1977 to 1987. La Ciénaga Station (División Hidrología-Departamento Hidráulica San Juan).

Year	*Precipitation*	*Intensity*	*n*	*T*	*P*	*P*	*P(o) [%]*	*P(o)[%]*
	[mm]	*[mm/h]*			*[%]*		*10*	*20*
1980	50	-	1	13.0	7.69	0.077	55.09	79.83
1977	48	21.3	2	6.5	15.38	0.154	81.19	96.46
1981	46	-	3	4.3	23.08	0.231	92.75	99.47
1984	40.5	3.4	4	3.3	30.77	0.308	97.47	99.94
1982	36	12	5	2.6	38.46	0.385	99.22	99.99
1983	30.5	2.3	6	2.2	46.15	0.462	99.80	100.00
1987	28.0	18.7	7	1.9	53.85	0.538	99.96	100.00
1979	26	-	8	1.6	61.54	0.615	99.99	100.00
1976	23	7.3	9	1.4	69.23	0.692	100.00	100.00
1978	20.5	30,7	10	1.3	76.92	0.769	100.00	100.00
1985	18.0	1.4	11	1.2	84.62	0.846	100.00	100.00
1986	15.0	3.3	12	1.1	92.31	0.923	100.00	100.00

DISCUSSION AND CONCLUSION

The morphometric characteristics of the de La Ciénaga River basin show that mostly lower-order streams dominate this elongated basin. The river network is of order eight, and the regional pattern of the basin is sub-dendritic.

According to generated results, the basin is tectonically influenced by the Cordón de Las Osamentas fault and Maradona fault system. It shows an asymmetry factor which is in well correspondence with the N-S oriented thrust faults and tectonically uplifted areas. The distinct value of basin asymmetry (i.e., AF =18.97), is associated with high relative uplift rates and recent tectonic activity in this area.

Torrential rains in summer caused severe damage to localities downstream of the de la Ciénaga basin in the past. We showed that the basin morphology provides conditions for rapid concentration of water and fast delivery and generation of high runoff peaks.

Melton's ruggedness number (MRN) suggests high susceptibility to flash flooding, with low amounts of sediment transported. Torrential rains in summer like the 2007 January storm, cause severe damage to the locality of Zonda due to its geomorphologic and infrastructure conditions (figure 2a, b, c, d, e, f).

To conclude, morphometric analysis provides a basis for estimating subsequent peak flood flows for different return periods and rain duration, as a direct function of its morphometric parameters. It also provides important elements to the hydraulic and hydrologic design of structures to contain flood and sediment, as well as for floods and landslides analysis, evaluation and susceptibility zoning by floods.

Besides, one of the main causes of the destructive impact of flash floods in this mountainous basin area is produced by strong reduction of the main river channel downstream, close to the populated areas. Channel reduction to < 20m is the result of an artificial dam and precarious canalizations of the lower section of the river to prevent flooding of crops located further downstream (fig. 8a-d).

This decrease in the channel section leads to accelerated flow velocities, greater erosive power and increase of flow heights and subsequent flooding along its route (fig. 8a, b).

The maximum rainfall intensity recorded in the La Ciénaga station between 1977 and 1987 was 192.7 mm on January 21, 1979.

In addition, rainfall data recorded by one of the stations located at the headwaters of the basin show, for a rainstorm of 50 mm as occurred in summer, 1980, a recurrence interval of 13 years, with a probability of 7.69% that a storm with these characteristics occurs in any year and a probability of 50% of occurrence in 10 years. On the other hand, for a heavy rainstorm with intensity of 21.3 mm/h as was recorded in 1979, the interval of recurrence is 6.5 years, with a probability of 15.38% that such torrential rain take place in any year and a probability of 81% that occur in 10 years and 96% in 20 years (Table 3).

The present work constitutes a first approach to the identification and analysis of the geomorphologic features and processes in this portion of the Precordillera of San Juan, Argentina. These studies are also essential tools for an adequate land-use planning in mountainous areas.

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