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Rock art and social networks among hunter gatherers of north-central Chile

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ABSTRACT

This paper discusses the relationships between rock art and the production of social networks among hunter-gatherers from the Late Holocene in central-northern Chile. Despite the low visual integrity of the paintings under study, the use of D-Stretch software allowed us to digitally improve the images, and conduct formal and quantitative analyses at different levels of variability. The comparison between two areas of the region showed two systems of visual communication that structure themselves along divergent principles. Such results point to the existence of two different social network systems due to social complexity processes and the increasing spatial demands of the communities living in the area. The very existence of rock art is interpreted in the light of these historical processes. The results we present help expanding the discussion on rock art and social networks considering the multiscalar nature of the networks as well as by weighing the role of history and environment in such a process.

1. Introduction and theoretical background

In this paper we discuss the process of constitution and the characteristics of social networks between hunter-gatherer groups of Central north Chile (30° Lat. S) during the Late Holocene, through the study of the variability of rock art paintings. The Late Holocene saw important transformations in the way of life of the hunter-gatherer communities, evidenced in the archaeological record, due to the demographic increase, conflict, and intensification in the exploitation of the environment. These new trends have been interpreted in association to processes of social complexity, territoriality, and to a reorganisation of social relations characteristics of hunter-gatherer populations, if compared to previous times (Schiappacasse and Niemeyer, 1964, 1965–1966; Ampuero and Hidalgo, 1975; Castillo, 1986; Quevedo, 1998; Castelleti et al., 2012; Méndez and Jackson, 2006).

As in other parts of the world, paintings in our region are extremely deteriorated, which made it difficult to record them with the naked eye and therefore to analyze them. For this reason, we took digital photographs of the motifs and painted blocks and then digitally enhanced them using the Decorrelation Stretch plug-in (D-Stretch) to Image J software, which is widely used in rock art studies (Gunn et al., 2011; Ritter et al., 2011; Brady and Gunn, 2012; Caldwell and Botzojorns, 2014, among others). This software enabled us to recover a rich corpus of motifs from across the region, which was then formally and quantitatively analyzed, in order to identify differences in regional distribution, on multiple levels. These differences are discussed in light of social network dynamics and the formation of territorial systems.

Social networks are a central element in the constitution and social reproduction of hunter-gatherer communities. (Jochim, 1976; Conkey, 1980; Kelly, 1995; Whallon, 2006, 2011; Hamilton et al., 2007; Apicella et al., 2012; Aubry et al., 2012). Through them, different family units dwelling in a particular landscape create bonds of cooperation, communication, integration, and segregation, in what Whallon (2011) has defined as safety nets, crucial for the social endurance. The constitution and characteristics of these networks are closely related to the social organization and to the territorial systems of these groups (Braun and Plog, 1982; Kelly, 1995; Whallon, 2006; Hamilton et al., 2007; Apicella et al., 2012; Aubry et al., 2012). On the one hand, they allow the union of different mobile units through solidarity and cooperation bonds, surpassing the family unity (cohesive power), and on the other, they allow the creation of barriers to exchange and communication with other social groups (disruptive power) (Hamilton et al., 2007). Thus, to comprehend the characteristics and nature of these networks would allow us to move forward in the understanding of the territorial and cooperation dynamics of these groups

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(Wobst, 1977; Jochim, 1976; Scheinsohn, 2011; Mc Donald and Veth, 2011; Aubry et al., 2012).

Due to their relevance of in social and economic reproduction, one would expect that these networks would have been unfolded in every landscape inhabited by the hunter-gatherer groups, but with different degrees of connectivity (Braun and Plog, 1982). Regarding this, it has been proposed the existence of a close relationship between connectivity of these networks and the environmental uncertainty of the landscapes (Gamble, 1982; Whallon, 2006, 2011; Scheinsohn, 2011). Particularly, the previously referenced authors have argued that the higher the environmental risk, networks would be more open, favouring cooperation and associativity between the different mobile unites. Nevertheless, and as has been pointed out by Braun and Plog (1982, see also David and Cole, 1990), even though the environment is a relevant factor, historic dynamics and ways of social organization of the hunter-gatherer groups are also significant elements to understand the structuration of the social networks. This consideration makes it possible to acknowledge the variability and the particular historic trajectories displayed around the construction of social networks between these groups in similar or homogenous environments.

A central element in the constitution of these networks is the flow of information (Wobst, 1977; Gamble, 1982; Whallon, 2006, 2011), especially social information as it allows both the perpetuation of the mobile group, and the construction and reproduction of bonds with other mobile units (Whallon, 2006, 2011; Hamilton et al., 2007; Funk, 2011; Ichikawa et al., 2011; Hill, 2011). Acquisition and control of social information is so relevant that information mobility has been identified as a specific type of movement deployed by these groups in order to secure their reproduction (Whallon, 2006).

Material culture is central in the information flows and in the construction of networks, making it possible to storage and to circulate information (Wobst, 1977; Gamble, 1982; Braun and Plog, 1982; Whallon, 2006, 2011). Visual attributes of objects have been the explored the most to understand and characterize social networks of hunter-gatherer groups, analyzing them from their distribution and circulation within wide regions. In this context, it has been observed how through the production and use of different objects, different social networks have been created and maintained. For example, Whallon (2006, 2011), has suggested that the exchange and circulation of objects within a short distance are usually associated to utilitarian objects, whereas in larger distance contacts are reinforced by symbolic items, possibly due to their higher social significance. Also regarding the circulation of objects, Gamble (1982) has suggested that in spaces where social networks are open, and social alliances operate over extensive areas with shared territories, visual information systems should be homogeneous because they function as a resource that promotes intergroup cohesion on a broad scale. In contrast, in regions with closed social networks and rigid territorial dynamics, the visual information should reflect the presence of different groups, each with its own system. The difference in the constitution of networks through the particular elements of material culture used and produced is related to the multi-level character of these networks, which can cover from gender groups to family units (Hamilton et al., 2007; Whallon, 2011; Lovis and Donahue, 2011).

Although the above shows how information flow and the constitution of networks occur at different scales (Braun and Plog, 1982; Hamilton et al., 2007; Fitzhugh et al., 2011; Ichikawa et al., 2011; Whallon, 2011), visual/symbolic elements seem to work as resources for the construction of affiliations in a wider spatial, intergroup scale, related to their symbolic nature and their association to ritual dynamics linked to social tradition (Gamble, 1982; Whallon, 2011; Zvelebil, 2011).

Following this idea, we consider rock art as related to the flow of information and to the construction of networks in a wide spatial scale, related to territory and space. In fact, as different scholars have acknowledged (Tilley, 1994; Bradley, 1997; Nash, 2000; Chippindale and Nash, 2004), the immobility of rock art deeply anchors its flows of information, audiences, and its very nature, to the landscape in which human groups lived their lives. Through its distribution and presence, landscapes are semanticized and made part of the human action (Tilley, 1994; Bradley, 1997). Thanks to this, its scale of action and connectivity surpasses the limits of the mobile family unit, favouring the articulation of a series of other units dispersed in, and occupying a particular landscape.

This idea is supported by the work of different scholars, who have used spatial and visual variability of rock art as an indicator to evaluate the flow of visual information, the nature of social networks, and the territorial dynamics of hunter-gatherer groups (e.g. Mc Donald and Veth, 2011; Veth et al., 2011; Scheinsohn, 2011; Gallardo et al., 2012; Bernardini, 2005; Quinlan and Woody, 2003). These studies have mainly relied upon Gamble's proposals (1982, see also Scheinsohn, 2011), suggesting a large-scale model for homogeneity in rock art associated with extensive and open macroregional networks of interaction, and a smaller-scale model for spatial heterogeneity in rock art that is associated with territorial circumscription and closed networks. In most of these approaches environmental elements have been highlighted in the configuration of the networks (David and Cole, 1990; Mc Donald and Veth, 2006, 2011, 2012, 2013; Scheinsohn, 2011), although some researchers have questioned the necessary relation established between environmental characteristics, rock art and the nature of social networks (David and Cole, 1990; Smith, 1992). Methodologically, these works have been focused on the discussion of the networks based on the formal variability of the representations, but without integrating it into a wider argument associated to the multi-level character of these networks. In contrast, our approach involves multiple levels of analysis based on the basic propositions by Wobst (1977), Gamble (1982) and Whallon (2011), who affirm that, above and beyond formal differences in visual information systems, it is the rules guiding the codification of key information that are most relevant for differentiating such systems, and therefore for evaluating whether or not the record is homogeneous or heterogeneous at the regional level. These systems, including rock art, follow a set of basic rules to codify information that is then decoded by individuals who know the rules (Wobst, 1977; Gamble, 1982; Whallon, 2011). We believe that these should be expressed through: (i) the use of a finite set of minimal units; (ii) some rules for combining these minimal units to produce the repertoire of motifs; and (iii) some compositional principles that relate the motifs on the panels to one another, expressed as combinations of specific motifs or symmetrical patterns (Sauvet, 1988; Groupe U, 1993; Troncoso, 2005; Basile and Ratto, 2011). This last aspect refers to more structural aspects that define those visual information systems (Wobst, 1977; Washburn, 1999; Nash and Children, 2008; González, 2011). Also; given that the space is a key variable in creating these kinds of visual information systems, the frequency with which rock art is distributed within the space is an indicator of the intensity with which these visual information systems were deployed in the landscape, which in turn should be related to the need for and importance of deploying these communication networks in the region.

Using these different analytical variables enable a discussion on the constitution of the networks and their multi-level character within the landscape occupied by the Late Holocene hunter-gatherers in Central-north Chile.

2. Background

Chile's semi-arid north, and particularly the sub-region lying between 30° and 32° Lat. S, has one of the country's most extensively surveyed collections of rock art. The region has a semi-arid climate and watercourses that flow down from the Andes Mountains to the Pacific Ocean. The middle and upper reaches (between 400 and 2000 m.a.s.l.) comprise narrow fertile river valleys bordered on the north and south by high mountain peaks. In the lower reaches, the river valleys are broader and delimited by expansive plains that stretch down to the nearby coast. The shift in landscape and topography occurs around 300 m.a.s.l.

Two types of rock art have been recorded here—engravings and paintings. While the former are concentrated in the inland and foothills sectors between 30° and 32° Lat. S, the latter have been identified in both coastal and inland locations, but are concentrated around 30° Lat. S., which coincides with the Elqui and Limarí river valleys (Fig. 1).

Given the poor state of conservation and low visibility of rock paintings, few studies have focused on them; investigators do agree, however, that they were produced by hunter-gatherers of the Late Holocene (Ampuero, 1966; Ampuero and Rivera, 1971a; Iribarren, 1973; Troncoso et al., 2008) and they are the earliest expression of rock art in the regional history. Chronologically, they have been situated between ca. 3500 and ca. 1500 B.P. Different lines of evidence support this chronology: on the one hand, there are direct absolute dates of black paintings made with charcoal (Troncoso et al., in press, Table 1); on the other, direct dates of soot under the paintings are in the range of the Mid Holocene, suggesting that the paintings are later than this (Troncoso et al., in press).

Even more, all of the sites with paintings are located in association with residential camps of the Late Holocene hunter-gatherers (Troncoso et al., 2014). Also, pigments are recurrent in stratigraphic contexts of these sites, while being scarce in earlier and later occupations. As can be seen in Table 1, direct dates of rock art paintings are contemporary to the dates obtained in stratigraphic contexts of settlements with rock art painting and pigments in stratigraphy. For example, dates for Tamaya site were obtained from mortar with red pigments in a stratigraphic layer, and in the surroundings of the site there are rock paintings of the same color and same chemical composition (hematite). These dates are within the same range as those for Covacha Pintada.

Finally, another line of evidence concerns reviewing other decorated material. In particular, bone tools from contexts dated between 4000 and 2000 B.P. show decorations and patterns of symmetry similar to some motifs in rock paintings (among others Punta Teatinos see Table 1, see Fig. 2) (Schiappacasse and Niemeyer, 1965–1966; Quevedo, 1998). Neither the symmetry nor the designs are replicated at earlier or later dates on any material support, and again, this is coherent with the absolute dates of the paintings.

The production of rock art by these hunter-gatherer groups is associated with increasing social complexity, which begins to emerge around 4000 B.P. and consolidates around 3000 B.P. During this time, these groups developed a residential mobility system that included more intense and recurrent occupations of the region than in the Middle Holocene (Ampuero and Hidalgo, 1975; Méndez and Jackson, 2006).

The pressure exerted by these developments would have led some groups to make territorial claims on particular spaces (Méndez and Jackson, 2006). This phenomenon has been studied primarily in the coastal lowlands, where such territorial claims are associated with the delimitation of spaces by means of huge shell middens (Méndez and Jackson, 2006) and with the existence of large, aggregate social units based around extensive cemeteries with up to 200 graves (Quevedo, 1998; Iribarren, 1956). Such large-scale burial sites are not found in the highlands, which instead contain isolated graves in settlements and rockshelters (Ampuero and Rivera, 1971b).

While this process was occurring, plant resources were becoming increasingly important and hunting less so in the economies of these populations, as witnessed by the spread of grinding instruments and the decrease and lower frequency of projectile points (Schiappacasse and Niemeyer, 1964; Ampuero and Hidalgo, 1975; Quevedo, 1998). This situation gradually limited the mobility of these hunter-gatherer communities (Schiappacasse and Niemeyer, 1964; Ampuero and Hidalgo, 1975; Méndez and Jackson, 2006), which around 2000 B.P. also incorporated pottery into their material repertoire (Castillo, 1986; Troncoso and Pavlovic, 2013; Méndez et al., 2009) while still maintaining a way of life with limited mobility and an economy based on the use of plant resources (Méndez et al., 2009; Pavlovic, 2004). There is also stratigraphic continuity between occupations previous to and subsequent to the incorporation of pottery during this time period. All of this is coherent with the timeframe of rock painting production, which disappears and is replaced by rock engraving around 1400–1200 B.P. (Troncoso et al., 2008), in concert with a broader change in these groups' settlement pattern and material culture.

The nature of the social networks and territorial systems that functioned in this context of complexification (Méndez and Jackson, 2006) is unknown. Some authors propose a territorial model in which the coastal lowlands and the highlands each had their own closed social network that developed independently (Llagostera, 1989). While the former groups were oriented to the maritime environment and shared some attributes with social groups living along the coast and in coastal valleys (Llagostera, 1989), those in the highlands relied upon inland resources and maintained social networks with other mountain-based groups. Other authors, in contrast, propose an open social network based upon a model of ecological complementarity in which groups migrated seasonally from the coast to the highlands and back, exploiting the different ecological strata (Ampuero and Rivera, 1971b; Ampuero and Hidalgo, 1975). In discussing the open or closed nature of these networks, however, none of these proposals have analyzed cultural material such as visual information systems.

3. Material and method

In the Limarí River basin a total of 115 km^2 was surveyed, 54 km^2 in the lowlands and 61 km^2 in the inland zone (Fig. 1). The surveys were carried out using a random stratified sample based on quadrants and were oriented to identifying rock art sites as well as the regional distribution of the zone's different human occupations. The sites thus identified were combined with additional ones discovered by other researchers (e.g. Ampuero, 1966; Ampuero and Rivera, 1971a; Iribarren, 1973), enabling us to survey a total of 24 sites showing evidence of rock paintings. The sites are distributed among in the coastal lowlands (Lower Limarí) and in the highlands (Upper Limarí) (Table 2 and Fig. 1).

Given the poor visual condition of the paintings, they were recorded in two consecutive stages. In the field, geo-spatial data was collected from the sites and from each of the painted blocks. A set of photographs was taken of each rock with a Nikon D-80 10.1 MP digital camera and 18–135 mm lens. The photographs were taken in natural light from different angles to obtain the best results.

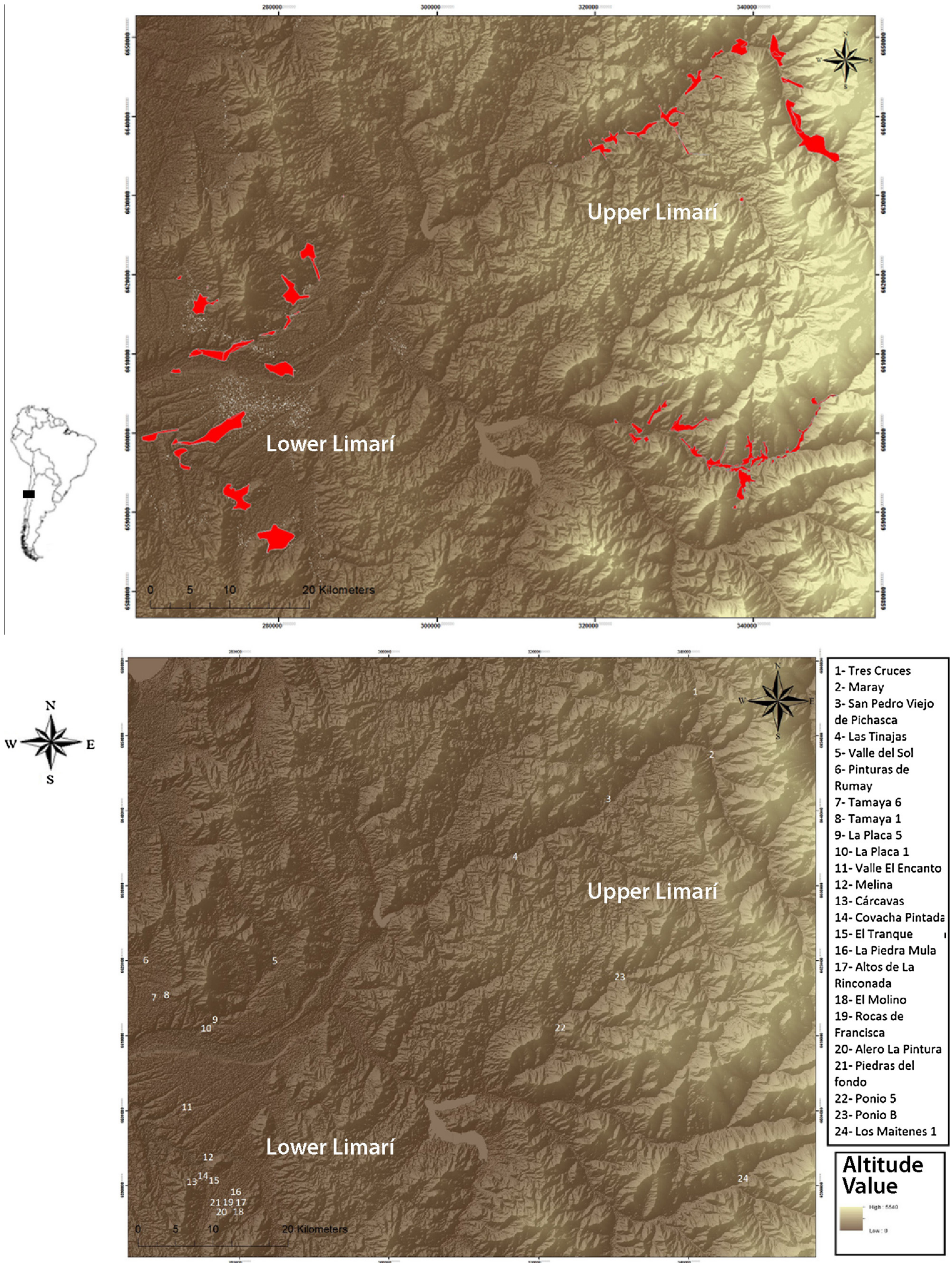

Fig. 1. Map of the area of study indicating areas prospected and sites discussed.

Table 1
Direct dating of rock art paintings and statigraphical deposits associated to rock art paintings and/or pigments. Dates calibrated using OxCal 4.2 (Bronk Ramsey, 2009) and the ShCal13 curve (Hogg et al., 2013).

	Sector	Site	Provenience	Material	Code	^{14}C years BP	2σ Cal AC–DC	13C/12C ratio %	Source
Direct dating of rock art painting	Lower Limarí (coastal lowlands)	Covacha Pintada	Black painting	Charcoal	UGAMS 17274	3290 ± 42	Cal. B.C.E. 1623–1431	−24.5	Troncoso et al. (in press)
		La Placa 5	Black painting	Charcoal	UGAMS 17738	1890 ± 30	Cal C.E. 80–240	−25.0	Troncoso et al. (in press)
	Upper Limarí (highlands)	Cabrito Laguna	Black painting	Charcoal	UGAMS 23983	3200 ± 40	Cal. B.C.E. 1521–1297	−24.4	FONDECYT 1150776
Archaeological sites with rock art paintings, and/or pigments in stratigraphy	Lower Limarí (coastal lowlands)	Valle El Encanto	PL3: 10–20 cm	Camelid bone	UGAMS 9353	3680 ± 25	Cal. B.C.E. 2127–1892	No available	FONDECYT 1110125
			PL1: 90 cm	Charcoal	AA 95189	2579 ± 36	Cal. B.C.E. 799–514	−22.6	FONDECYT 1110125
			PL3: 70 cm	Charcoal	UGAMS 05013	2000 ± 25	Cal. B.C.E. 36–129C.E.	−22.8	FONDECYT 1110125
			MP1: 35 cm	Charcoal	UGAMS 05014	1890 ± 25	Cal. C.E. 86–248	−23.7	FONDECYT 1110125
		Tamaya 1	U1: 40 cm	Camelid bone	UGAMS 11772	3290 ± 25	Cal. B.C.E. 1608–1432	−19.7	FONDECYT 1110125
			U1: Feature 1	Camelid bone	UGAMS 9352	3200 ± 25	Cal. B.C.E. 1497–1320	−17	FONDECYT 1110125
		Melina 1	U2: 35 cm	Camelid bone	UGAMS 11771	1680 ± 25	Cal. C.E. 325–537	−22.7	FONDECYT 1110125
		Punta Teatinos	Tomb 146	Human Bone	Beta 4514	3320 ± 70	Cal. B.C.E. 1756–1438	No available	Schiappacasse and Niemeyer (1986)
			Tomb 40	Human Bone	Beta 4515	3000 ± 70	Cal. B.C.E. 1414–1040	No available	Schiappacasse and Niemeyer (1986)
			Tomb 178	Human Bone	Beta 4516	1920 ± 60	Cal. B.C.E. 43–C.E. 232	No available	Schiappacasse and Niemeyer (1986) and Quevedo (1998)
	Upper Limarí (highlands)	San Pedro Viejo de Pichasca	E1D1: 30 cm	Charcoal	I5957	2375 ± 95	Cal. B.C.E. 767–202	No available	Ampuero and Rivera (1971b)
			Mammalian mandible painted in red	Mammal bone	UGAMS 22817	2150 ± 25	Cal. B.C.E. 337–58	−7.5	FONDECYT 1150776
		Alero Cachaco	U1: Layer B, 25 cm	Camelid bone	D-AMS 015319	2809 ± 25	Cal. B.C.E. 998–834	−19.6	FONDECYT 1150776
Archaeological site with pigments in stratigraphy, but no rock art	Upper Limarí (highlands)	Alero El Puerto	Unit 1, layer B, 70 cm	Camelid bone	UGAMS 13129	3630 ± 25	Cal. B.C.E. 2026–1780	−23.7	FONDECYT 1110125
			Unit 2, layer C, 59 cm	Camelid bone	UGAMS 22813	4060 ± 25	Cal. B.C.E. 2620–2469	−9.9	FONDECYT 1150776
			Unit 2, layer B, 24 cm	Camelid bone	UGAMS 22814	2940 ± 25	Cal. B.C.E. 1210–996	−12.7	FONDECYT 1150776

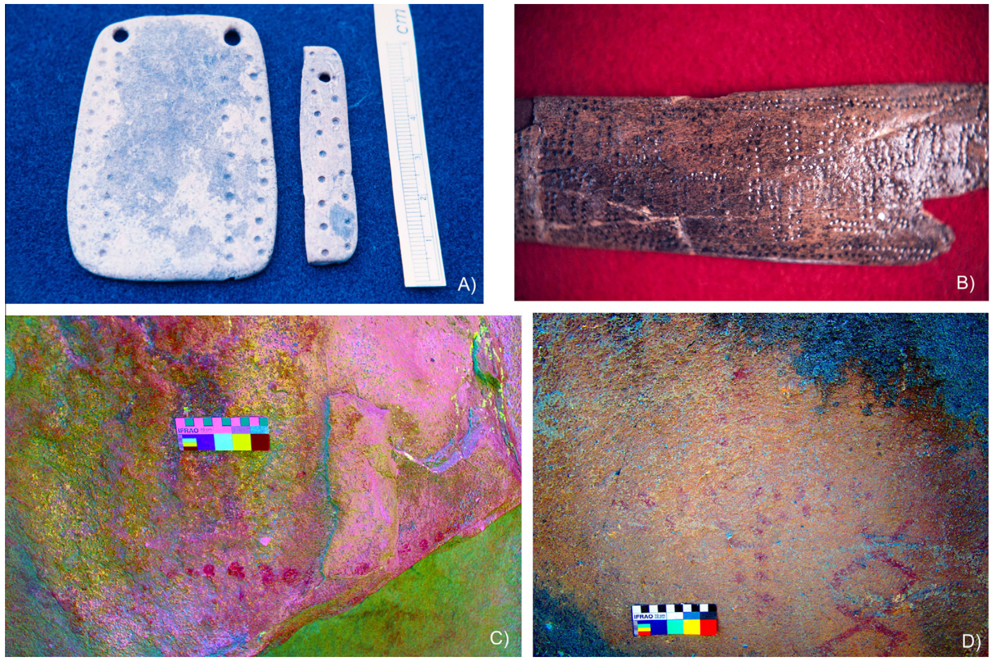

Fig. 2. Similar motifs on bone instruments (a and b) at Punta Teatinos (Late Archaic cemetery) and rock art (c and d). Images of bone instruments were scanned from photographs of Hans Niemeyer Archivo at Museo Nacional de Historia Natural (Santiago). Paintings were digitally enhanced using D-Stretch, C = channel CRGB Intensity 15; D = channel LDS Intensity 15.

Table 2
Characteristics of the sample studied.

Sector	Site	Total blocks	Total blocks analyzed	Total paintings (analyzable designs and non-analyzable designs)	Minimum number of non-analyzable designs	Total designs analyzed
LowerLimarí (coastal lowlands)	Alero La Pintura	1	1	1	0	1
	Altos de La Rinconada	1	1	7	0	7
	Cárcavas	1	1	1	0	1
	Covacha Pintada	2	1	11	1	10
	El Tranque	1	1	2	1	1
	La Placa 1	3	3	9	1	8
	La Placa 5	1	1	2	1	1
	Melina	2	1	4	3	1
	Pinturas de Rumay	3	2	19	3	16
	Valle del sol	1	1	2	0	2
	Valle El Encanto	11	9	64	25	39
	El Molino	2	0	2	2	0
	La Piedra Mula	1	0	1	1	0
	Rocas de Francisca	3	0	1	1	0
	Piedras del fondo	1	0	1	1	0
	Tamaya 1	1	0	1	1	0
	Tamaya 6	1	0	2	2	0
	Total	36	22	130	43	87
UpperLimarí (highlands)	San Pedro Viejo de Pichasca	1	1	71	15	56
	Los Maitenes 1	1	1	8	1	7
	Ponio B	1	1	13	9	4
	Las Tinajas	1	0	1	0	1
	Tres Cruces (Iribarren)	2	1	1	1	0
	Maray	1	5	1	0	1
	Ponio 5	1	0	1	1	0
	Total	7	5	96	27	69
Totals		43	27	226	70	156

In the lab, the photographs were analyzed with the Decorrelation Stretch (DStretch) application developed for ImageJ by J. Harman. This application enhanced the contrast among weak colors on the digital images, improving the outlines of colors not perceived by the human eye by producing a false color image created by a decorrelation algorhythm. DStretch operates with a variety of decorrelation matrices and color spaces (YDS, LAB, RGB, LAX, etc.), some of which were specially created for rock art (Gutiérrez et al., 2009). This approach made some imperceptible designs visible, overcoming the limitations of the human eye to perceive images with very low contrast (Harman, 2008). This program is being used increasingly in the study of rock paintings in different parts of the world because of its ability to highlight and improve differences between colors in a digital image (e.g. Acevedo and

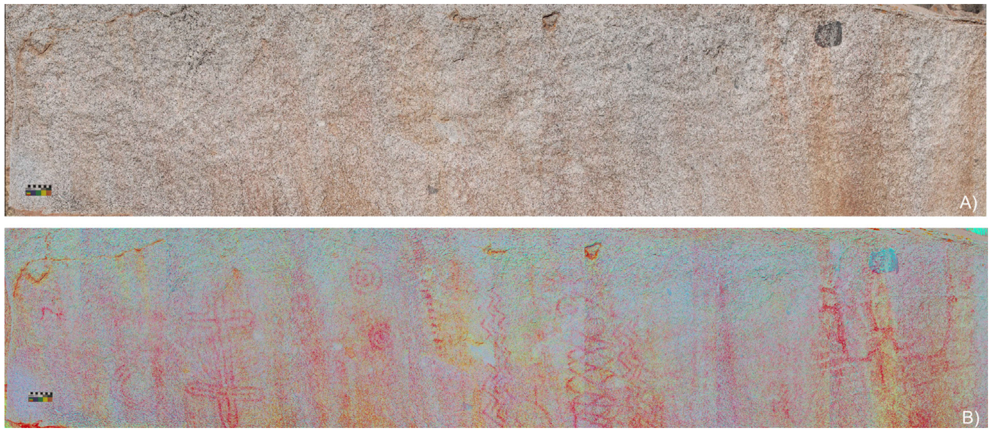

Fig. 3. Digital enhancement of a rock art panel using D-Stretch, channel LRE Intensity 15. (A) Before, (B) after D-Stretch.

Franco, 2012; Caldwell and Botzojorns, 2014; Gunn et al., 2011). The image enhancement was conducted following standardized D-Stretch color spaces, thereby allowing other investigators to replicate the procedure (Brady and Gunn, 2012) (Fig. 3).

Despite the software's potential, for paintings that are very deteriorated it is not possible to recover entire motifs, but only paint "blotches." Because of this, once the photos were enhanced, only those images in which shapes could be deciphered were analyzed, and all un-analyzable "blotches" were set aside (Table 2).

It is worth underlining here that the use of digital technologies has become more common in recording and surveying rock art (e.g. Cerrillo-Cuenca et al., 2013; Bednarik and Seshadri, 1995; Gunn et al., 2010). Nevertheless, as some authors point out (Brady, 2006; Brady and Gunn, 2012; Gutiérrez et al., 2009), the use of these new technologies has focused more on methodological issues such as recording and preserving information, and few studies have sought to integrate the results obtained into discussions of prehistoric issues (e.g. Ritter et al., 2011; Gunn et al., 2011; Caldwell and Botzojorns, 2014; Brady, 2006).

The images were analyzed on three different levels. The first involved the formal and syntactical analysis of the designs, and to achieve this, the images were divided into two categories: figurative and non-figurative designs. The former were described on the basis of their visual similarity to elements of the real world (e.g. hands, camelids), while the latter were analyzed according to their geometric features and type of decoration, if any. We understood decoration to include any figures added to the primary geometric design, and the ones we identified came in a variety of forms (lines, dots, etc.). This classification allowed us to evaluate how the designs were constructed and to identify comparable attributes.

Regarding the identification of formal syntax, simple designs were separated from complex ones. A complex design was defined as a motif composed of several complementary figures that cannot be separated from each other. In contrast, a simple design was understood as one or more figures that are individually separable.

Based on the two aspects mentioned, the images were divided into sets with the same attributes. These descriptive types (Francis, 2001) thus grouped together rock motifs with a consistent, repetitive pattern of attributes.

For the second level of analysis, composition (Gallardo, 2009), we considered the symmetrical movement of the designs and their parts, following the proposals offered by Washburn (1999) and González (2011), as well as the color of the pigments used.

The third level examined the spatial dimension, and for this we considered the distribution and frequency of designs in the area. For this level, the ratio of block frequency to designs was quantified for each area surveyed to describe the intensity of rock art production in the space.

All results were compared in order to evaluate the variability of the paintings from the Lower and Upper Limarí. The comparative analysis focused on non-figurative designs, as these were the only kind found in both sectors. Chi-square hypothesis testing was undertaken to determine whether there was a statistically significant relationship between the particular behavior of each of the variables analyzed and the sector from which the sample was taken (Shennan, 1992; Barceló, 2007). A diversity analysis was also conducted to evaluate the richness and homogeneity of the non-figurative design typologies using the Shannon-Weaver index, to offset the impact of the sample size (Jones and Leonard, 1989; Lanata, 1996). In general terms, the *richness* (H) reveals the number of different categories, in this case the number of design types recorded, measuring the degree of differentiation of the samples (Lower–Upper Limarí), considering their relative sizes. For its part, *homogeneity* (J) considers the distribution of designs among the different types, determining whether they are equally abundant or occur in unequal frequencies. By comparing the sets identified, this type of index applied to rock art (Basile and Ratto, 2009; Ratto and Basile, 2013) enables a discussion of the structure of the motif repertoires deployed in both sectors.

4. Results

Digital enhancement of the photographs led us to identify a total of 156 analyzable designs, which we divided into 150 non-figurative and 6 figurative ones, distributed among a total of 16 sites and 27 blocks. All of the figurative motifs were from highland locations (Upper Limarí). Among the non-figurative motifs, 63 (42%) were from the same sector and 87 (58%) were from coastal lowland sites (Lower Limarí) (Table 3).

4.1. Figurative designs (N = 6)

The figurative designs are concentrated in two sites. In San Pedro Viejo de Pichasca there are two red hands, possibly left ones, that are not part of any composition. At Los Maitenes 1, four images were recorded that fall into the category of framed designs (Cabello, 2011) (Fig. 4) and correspond to faces with headdresses. All are circular in shape except for one that is rectangular, and most are monochromatic red, although one circular frame is bichromatic red and black.

Table 3
Variability and complexity in the rock art of the Lower and Upper Limarí river valley.

Dimension 1: formal attributes of non-figurative designs		Lower Limarí (coastal lowlands)	Upper Limarí (highlands)	Total
Form	Syntax			
Line	Isolated lines	20	19	39
	Linear designs with appendages	13	12	25
	Complex linear designs	22	16	38
	Linear designs forming enclosed areas	3	6	9
Circle	Undecorated	5	3	8
	With interior decoration	10	1	11
	With appendages	2	1	3
	With interior decoration and appendages	2	1	3
Square	With interior decoration	3	1	4
	With interior decoration and appendages	1	2	3
Diamond	Juxtaposed	2	0	2
Trapezoid	Undecorated	1	0	1
Points	Undecorated	3	1	4
Total		87	63	150
Dimension 2: types of decorative designs				
Form	Type			
Line	Inscribed cross	5	0	5
	Strait in translation	6	7	13
	Meandering	16	2	18
Circle	Circles with appendages	2	2	4
	Circles with interior decoration	9	1	10
	Circles with juxtaposition	3	0	3
	Simple circles	4	1	5
Square	Squares with interior decoration	4	2	6
Diamond	Juxtaposed diamonds	2	0	2
Trapezoid	Trapezoid	1	0	1
Undefined designs		35	48	83
Total		87	63	150
Dimension 3: symmetrical patterns				
Present/absent	Type of symmetry			
Absent	Absent	33	47	80
Present	Translation	35	14	49
	Specular reflection (mirror image)	19	2	21
Total		87	63	150
Dimension 4: color				
Monochromatic		85	55	140
Bichromatic		2	6	8
Polychromatic		0	2	2
Total		87	63	150

4.2. Non-figurative designs (N = 150)

4.2.1. Shape and syntax (Dimension 1)

Lines are the basic resources used to construct non-figurative designs, followed distantly by circles and squares, then diamond and trapezoid patterns (Table 3). The minimal units are similar for both spaces, and while they display different frequencies (lines make up 81.4% of such coastal lowland designs vs. 66.7% of highland ones, while circles comprise 9.5% and 21.8%, respectively), their differences are not statistically significant ($X^2 = 7.48$; df = 5; $p = 0.187$ or $p > 0.005$).

Lines tend to be single lines going in different directions ($N = 39$). A few lines have appendices on their sides, or are composed of two or more separate lines, or are lines joining together that cover an area of the panel without making any identifiable closed design. Although these different configurations of lines appear differently in the two spaces, the differences are not statistically significant ($X^2 = 1.791$; df = 3; $p = 0.617$).

Circles, which are most frequently found in coastal lowland paintings, also contain mainly interior decorations. Appendices that are independent of those decorations are rare (Table 3). In regard to this aspect, no statistically significant differences can be observed between the two different spaces ($X^2 = 3.569$; df = 4; $p = 0.468$).

The number of squares recorded is very low for both spaces ($N = 5$), and those that do exist have decorations, although it is notable that the squares found at coastal lowland sites are all decorated. In both areas, interior lines are used as decoration (Table 3). No differences were observed in the distribution of appendices.

Lastly, the study found trapezoids ($N = 1$) and dots ($N = 4$), though only in the Lower Limarí, except for one dot motif that was found at San Pedro Viejo de Pichasca (Upper Limarí).

4.2.2. Typology and complexity (Dimension 2)

The designs underwent formal-syntactical analysis of their minimal units and combinations in order to compare the variation of

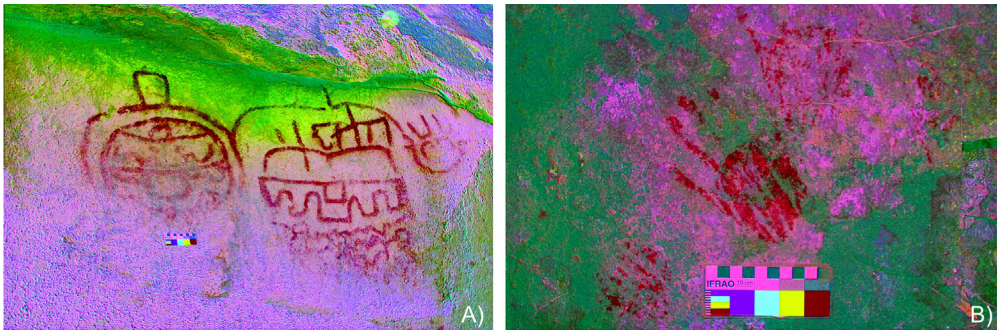

Fig. 4. Figurative designs: (a) framed designs at Los Maitenes 1 (D-Stretch channel CRGB-Intensity 15), (b) Hand at San Pedro Viejo de Pichasca (D-Stretch channel CRGB-Intensity 15).

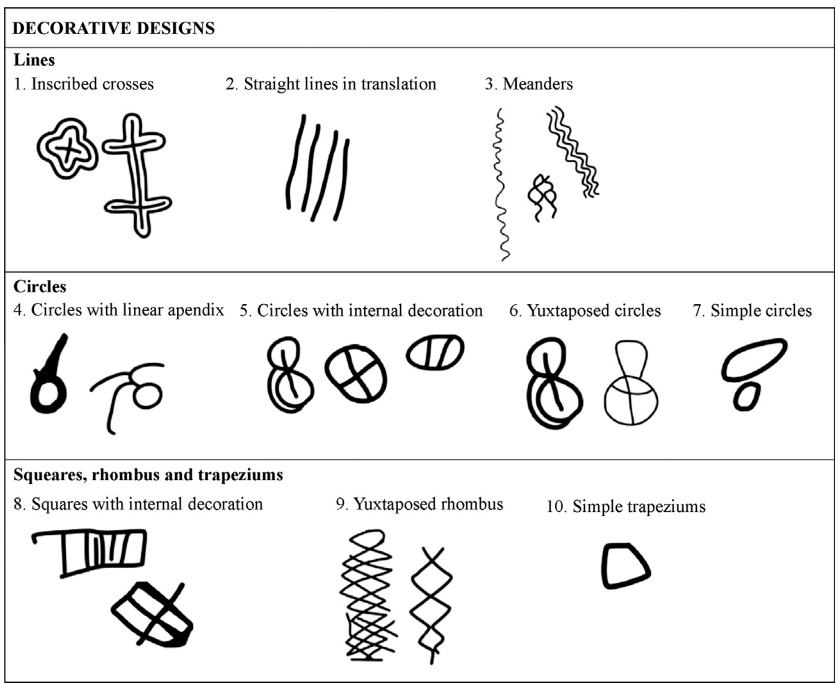

Fig. 5. Typology of the motifs.

the representations found in each space. Eleven descriptive types were defined based on their formal attributes, including one 'undefined' category (Fig. 5). The undefined designs tended to be highly heterogeneous and very complex, which prevented them from being included in any of the categories with standard attributes (Fig. 6). They were not assigned to this category because they were in a poor state of conservation; indeed, they were in good condition and could be effectively described.

As can be observed in Table 3, while in both spaces the undefined group predominates, in the highlands it is followed by the category 'strait lines in translation' (46.7%) and meandering lines and squares with interior decoration (13.3% each), while in the coastal lowlands the meandering lines follow first (30.8%), then circles with interior decoration (17.3%) and strait lines in translation (11.5%) (Table 4). At this level of analysis the differences observed among the types of designs identified in the two spaces are statistically significant ($X^2 = 29.791$, df = 10, $p = 0.001$).

For its part, the diversity analysis conducted tells us that the typology of the designs is different in each sector. While the Lower Limarí designs are very homogeneous and extremely rich, the Upper Limarí designs are moderately homogeneous and rich. In terms of richness, this means that more sets of designs were documented in the coastal lowlands than in the highlands. In terms of homogeneity, the types of designs are similarly represented in the lowlands, meaning that none are noticeably more frequent than the others, while in the Upper Limarí the "undefined designs" category is notably more frequent than the others. The low correlation (r Pearson = 0.350) between the number of designs and types recorded in each sector suggests that there are designs that circulate in one sector and not in the other (see Fig. 7).

Analyzing the way in which sets of motifs are combined in the blocks of each sector, we observe 18 combinations among the 11 types identified. To reveal the variability in motif combinations, we generated a binary number that expresses the presence or absence of each type of motif identified for each of the blocks documented (Table 5). While there are blocks that present combinations of unique types and others that present a mixture of up to seven types of designs, the most frequent combination in both sectors involves one or two types of designs.

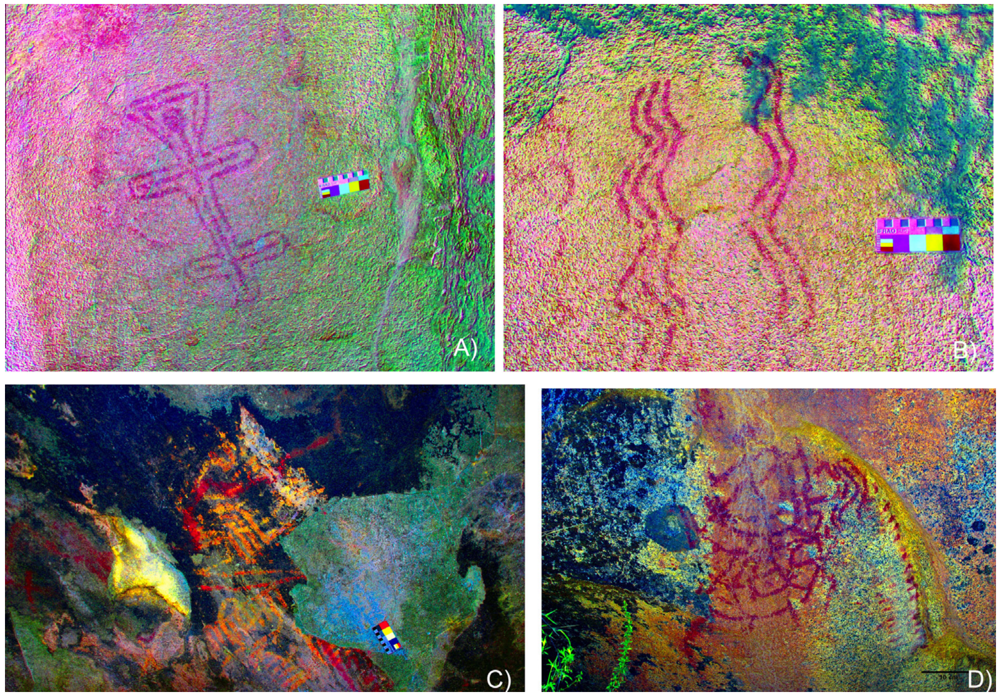

Fig. 6. Types of motifs: (a and b) simple, (c and d) complex unclassifiable designs. Paintings were digitally enhanced using D-Stretch, A = channel CRGB Intensity 15; B = channel RGB Intensity 15; C = channel LDS Intensity 15; D = channel LRE Intensity 15.

Table 4
Combinations of decorative design types recorded per block.

Types of decorative designs											Combinations
1 Inscribed cross	2 Lines in translation	3 Meandering	4 Circle with appendage	5 Circle with interior decoration	6 Circle with juxtaposition	7 Simple circle	8 Square with interior decoration	9 Juxtaposed diamonds	10 Trapezoid	11 Undefined designs	
0	0	0	0	0	0	0	0	0	0	1	00000000001
1	1	1	0	0	1	0	0	0	0	1	11100100001
0	0	0	0	0	0	0	1	0	0	0	00000001000
0	1	0	0	1	0	0	1	0	0	1	01001001001
0	0	0	1	0	0	0	0	0	0	0	00010000000
1	0	1	0	0	0	0	0	1	0	1	10100000101
1	0	0	0	0	0	0	0	0	0	1	10000000001
0	0	0	0	0	0	1	0	0	0	1	00000010001
0	0	1	0	0	0	0	0	0	0	1	00100000001
0	1	0	0	0	0	0	1	0	0	0	01000001000
0	0	0	0	0	1	0	0	0	0	1	00000100001
0	1	1	0	0	1	0	0	0	0	1	01100100001
1	1	1	0	1	0	0	0	1	1	1	11101000111
0	0	1	0	0	0	0	0	0	0	0	00100000000
1	0	1	0	0	0	0	0	0	0	0	10100000000
0	1	1	0	1	0	1	1	0	0	1	01101011001
0	0	0	1	0	0	0	0	0	0	1	00010000001
0	1	1	0	0	0	0	0	0	0	1	01100000001

Nevertheless, except for combinations consisting exclusively of undefined designs (00000000001), the combinations found on the blocks of the Upper Limarí are not replicated in the Lower Limarí (Table 6).

Lastly, the complexity of the designs varies little, with simple designs predominating in both cases (93.1% and 90.5%, respectively).

4.2.3. Composition (Dimensions 3 and 4)

The use of symmetry as a resource in the creation of non-figurative designs was observed in 46% of the sample. In regard to the kinds of symmetry employed in each sector, we observed that they share the same operational repertoire. Translation and specular reflection were used (Table 3), in both cases applied to circles and lines (Fig. 8). However, there are statistically significant differences ($X^2 = 21.933$; df = 2; $p = 0.000$) on two levels. First, in regard to frequency, this compositional resource recurs most in the Lower Limarí (60.9%/24.5%). Furthermore, in regard to the frequency of these kinds of symmetry, the use of specular reflection is much more recurrent in this space than in the Upper Limarí, where it is much less frequent.

In regard to color, monochromatic paintings predominate (139:150), with bichromatic (6%) and polychromatic (1.3%) paintings occurring only rarely. Among monochromatic paintings the

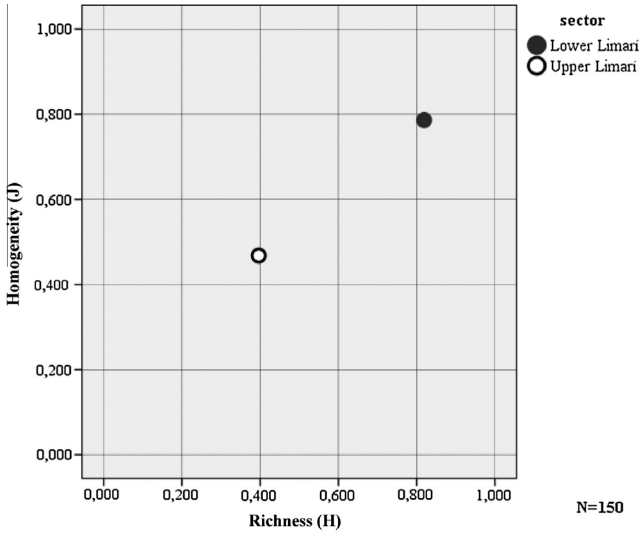

Fig. 7. Diversity of decorative design types for the two sectors analyzed.

Table 5
Combinations of decorative types recorded per block and by sector of origin.

Number of decorative design types combined	Combined decorative design types per block	Sector		Total
		Lower Limarí (coastal lowlands)	Upper Limarí (highlands)	
1	00000000001	7	2	9
1	00000001000	1	0	1
1	00010000000	1	0	1
1	00100000000	1	0	1
2	00000010001	1	0	1
2	00000100001	1	0	1
2	00010000001	0	1	1
2	00100000001	2	0	2
2	01000001000	1	0	1
2	10000000001	1	0	1
2	10100000000	1	0	1
3	01100000001	0	1	1
4	01001001001	1	0	1
4	01100100001	1	0	1
4	10100000101	1	0	1
5	11100100001	1	0	1
6	01101011001	0	1	1
7	11101000111	1	0	1
Total		22	5	27

color red predominates (119:150), followed by yellow (17:150) and black (3:150).

At the regional level, we found that monochromatic paintings were the norm, with polychromatic ones only observed in the Upper Limarí, where they combine red, yellow and green. Among monochromatic paintings, red is the only color found in the coastal lowland sector, while in the highlands we also found yellow (31.5%) and black (5.6%) monochromatic paintings. Bichromatic paintings are more abundant in the highlands, and in all cases combine red and yellow ($n = 7$), while in the coastal lowlands red and black is the only 2-color combination found ($n = 2$). This difference in how frequently each color was used is statistically significant ($X^2 = 6.762$; df = 2; $p = 0.034$) (Table 3).

4.3. Spatial dynamics of rock art

The spatial distribution frequencies of the rock art assemblages found in the two spaces are different, with the Lower Limarí showing a higher spatial recurrence (Table 6, Fig. 9). We believe this difference is relevant, and not investigative bias, as the size of the areas surveyed and the method used to select them are similar. Also similar are the availability of rocks suitable for painting and their state of conservation.

The higher density of paintings in the Upper Limarí is the result of the high frequency observed in San Pedro Viejo de Pichasca (56:69). This concentration of paintings in a single site and on one support is exceptional; indeed, it is not found at any other site in the Lower Limarí, where the density of motifs per block and per site have similar maximum concentrations of up to 15 designs per block, though the most common frequency in both sectors is up to five motifs per support (Fig. 10).

5. Discussion

The use of the DStretch plug-in allowed us to recover a rich corpus of rock paintings in the Limarí River basin that were in such poor condition that they could barely be seen by the naked eye, which had hindered the detailed study of this material record. Unfortunately, the poor state of conservation of some of these paintings made them unrecoverable even by digital means, producing only blotches of paint that could not be formally analyzed. Still, we hope to be able to analyze these paintings in the future as new and more advanced software becomes available.

Nevertheless, the number of motifs recovered is significant enough to enable a discussion of the dynamic of this visual information system and its relation to prehistoric social networks and territorial systems. In both the coastal lowlands and highlands, the same minimal units were employed in the construction of non-figurative designs, which is to be expected given the limited repertoire of geometric elements that could be represented in this fashion. This also led to the recurrence of certain kinds of motifs in both sectors. However, the frequency, diversity and combination of descriptive types at the level of individual blocks displays significant differences between the two spaces, which were reinforced in our evaluation of the types and frequency of symmetry and the colors and color combinations employed. What these compositional differences mean is that motifs that share space on one rock art panel in the zone do not occur together in others, and viceversa, which leads to differences in the visual syntax of each.

The separateness of these two spaces is reinforced by the unequal distribution of figurative motifs, which, though rare, are found exclusively in the Upper Limarí. This compositional

Table 6
Quantification and comparison of the distribution of rock paintings in the Upper and Lower Limarí.

	Lower Limarí (coastal lowlands)	Upper Limarí (highlands)
Area surveyed	54 km^2	61 km^2
Sites	17	7
Blocks	36	7
Density of sites (km^2)	0.31 sites × km^2	0.11 sites × km^2
N blocks with paintings	0.66 blocks × km^2	0.13 blocks × km^2
N paintings	2.38 paintings × km^2	3.65 paintings × km^2

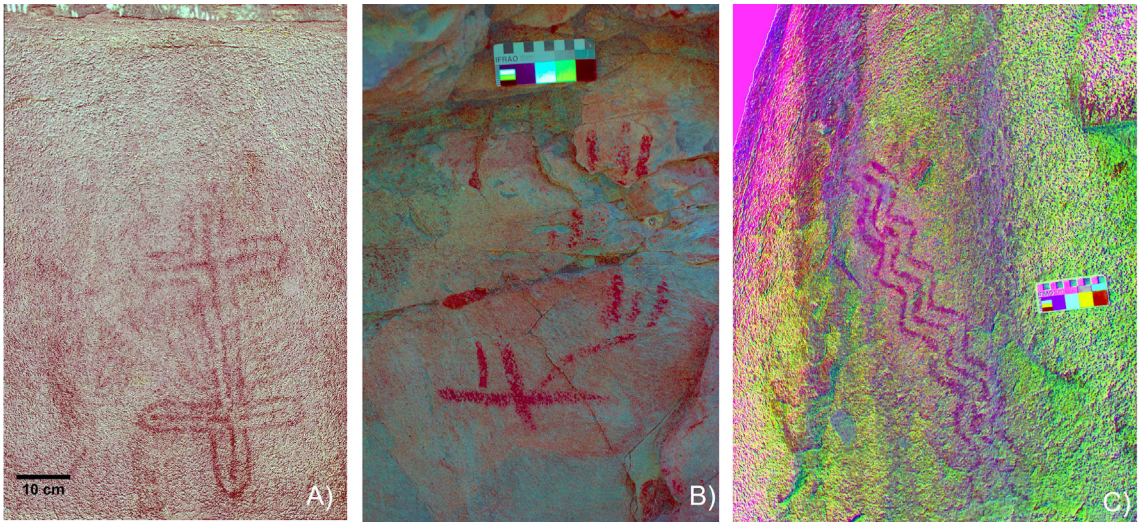

Fig. 8. Patterns of symmetry: (a) specular reflection, (b and c) translation. Paintings were digitally enhanced using D-Stretch, A = channel LRE Intensity 15; B = channel LRE Intensity 15; C = channel CRGB Intensity 15.

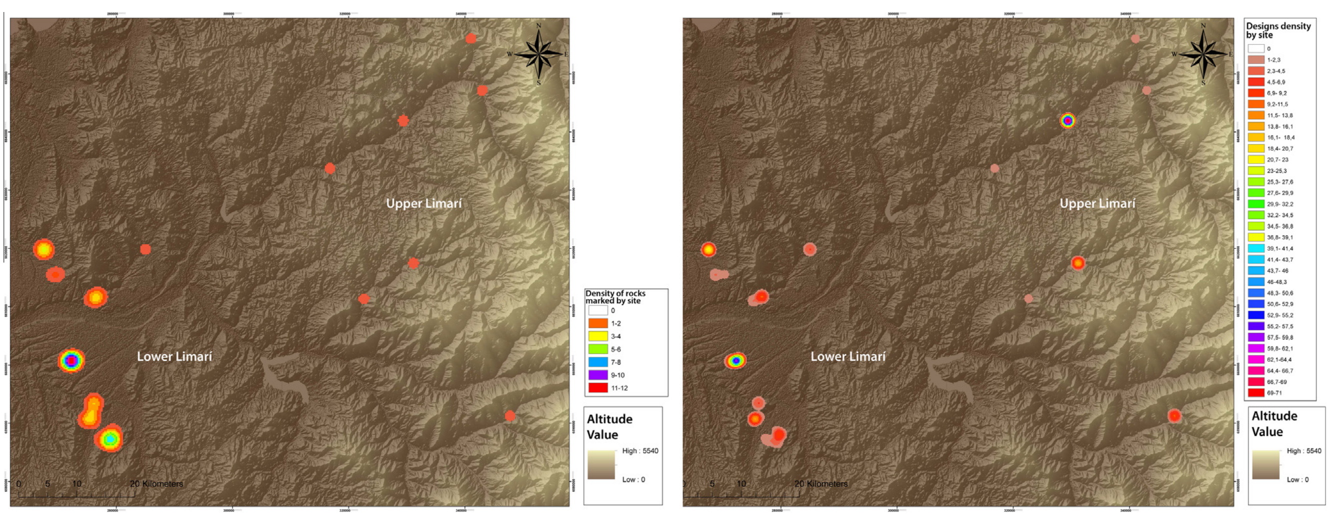

Fig. 9. Density of rock art in the region: (a) density of rocks marked in each site, (b) density of motifs in each site.

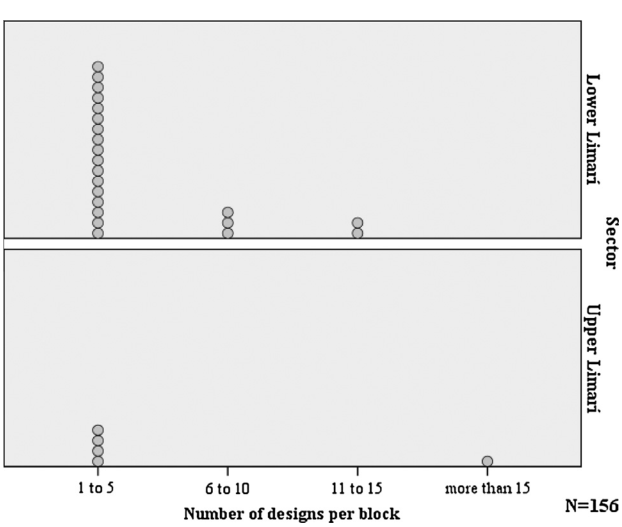

Fig. 10. Quantity of motifs recorded on each block by sector (Lower and Upper Limarí).

variability in the rock art found in these two separate spaces indicates that different norms governed the construction of this visual information, as Gamble (1982) and Wobst (1977) have suggested. This notion is supported by semiotics, with Sampson (1985) proposing that in semasiographic semiotic systems—those in which it is not possible to translate or read a text unit by unit, as in the case of rock art—the production of information and meaning relies on both composition and redundancy, meaning that different compositions imply different communication systems.

In this way, hunter-gatherer communities constructed through the spatial and visual dynamic of rock art of the region, two spatially segregated visual information systems that operated differently among coastal lowlands and inland hunter-gatherer groups in the region. This is in tune with the nature of rock art, which as a ritual and symbolic element of these communities would have acted at a macro-spatial level, as a interfamily affiliation group (Gamble, 1982; Whallon, 2006; Whallon and Lovis, 2011; Zvelebil, 2011; Aubry et al., 2012). Nevertheless, we do not identify in either of these sector what could be defined as cultural markers or emblems for each network (*sensu* Scheinsohn, 2011; Bernardini, 2005). Even though this is not necessary, (see Mc

Donald and Veth, 2006, 2013), we think that the functioning of the information flow and reproduction of these network rests rather on their spatial dynamics. Rock art paintings are always associated to residential camps of the hunter-gatherer groups. This enables the audience to be the whole mobile unit, allowing, in one way or another, a flow of information that includes the social group as a whole. Albeit the control of this information within the mobile group can be varied (Kelly, 1995; Whallon, 2011; Funk, 2011; Lovis and Donahue, 2011), its location makes it possible for every member of the group to see and relate with the paintings, their motifs, and compositions, something that is not always the case in hunter-gatherer contexts (i.e. Whitley, 2000; Mc Call, 2010). Therefore, with this spatial practice, the bonds and links between groups sharing this system of visual information is reinforced through the inhabiting of the residential spaces. These groups are part of these networks, creating dynamics of territoriality and rooting of the human groups with their occupied spaces (Whallon, 2011; Zvelebil, 2011).

This process of segmentation would have its origins in the Middle Holocene, in a context in which human occupations were increasing and the dynamics of social interaction were transforming. Researchers investigating this time period have proposed a model of seasonal mobility, with groups moving between the coast and the mountains as a way of offsetting the environmental stress associated with low population density and an arid climate (Jackson, 2002). This situation would change in the Late Holocene when the number of occupations in the region increased, along with the population, especially in the coastal lowlands, and groups began to claim certain spaces and/or territories as their own (Méndez and Jackson, 2006; Ampuero and Hidalgo, 1975; Quevedo, 1998). Two separate social networks also formed at this time, one in the coastal lowlands that covered both the coastline and coastal valleys, and the other in the highlands (Llagostera, 1989). This proposition is supported by the separation of the two visual information systems that, following the proposals of other authors (Gamble, 1982; David and Cole, 1990; Mc Donald and Veth, 2006, 2011, 2012, 2013) would have fostered different dynamics in each zone, in terms of interactions and alliances, without becoming an integrated system for the entire Limarí River valley.

As occured in other spaces, the spatial reduction of the dynamics of social interaction and territorial claims are intimately linked to the fragmentation of these visual information systems. However, in our case it appears that the transformation from a long distance interaction system for a low-density population to one involving a short distance, larger population and territorial claims is also responsible for the appearance of rock art in the region, as it formalized informational assemblages on the landscape that enabled the storage, circulation and mobilization of information within the social group, without the need for mutual presence. The social demands that emerged from these changes—the more intense use of the region, the population increase and claims over spaces—meant that social networks among communities in this space had to be strengthened, and rock art was one of the material resources deployed to serve this purpose. Nevertheless, these situations are linked to a complex panorama, as although there is a shared practice with a spatial logic similar in both sectors (produce rock art paintings in habitation spaces), their visual and compositional principles separate them, making them particular to each of these areas.

As we have mentioned, different scholars have suggested the existence of close relations between environmental conditions and the constitution of these networks, especially Gamble (1982), who proposed a direct relationship between closed networks and fertile environments, something that has been evidenced in this region, where the paleoenvironmental record does not show big changes with today's environment (Maldonado and Villagran, 2002). Nevertheless, and following other proposals (Braun and Plog, 1982; David and Cole, 1990), we consider historic contexts to be a more relevant aspect to understand the way in which these visual information systems worked. In our case, the pressures resulting from the more recurrent use of the space, the population increase and territorial claims led to the need to construct systems of social interaction that operated over short distances and were reinforced through the use of visual information systems such as rock art. The need to reinforce and accentuate social units through visual information appears to have been more frequent and intense in the coastal lowlands than in the highlands, as the former displays rock paintings that are more spatially concentrated.

The relationship between the appearance of rock art and the intensification of social interaction is supported by two additional facts. First, it is during this time that *piedras tacitas* (grinding hollows) first appear in the region. While these stones have been interpreted as implements used to crush plants (Schiappacasse and Niemeyer, 1964), like rock art they are also an unmovable material object associated with occupational spaces and as such, like all material culture, they codify some kind of information (Wobst, 1977). For this reason, in other spaces they have also been interpreted as forms of rock art (Bednarik, 2008; Taçon et al., 1997). *Piedras tacitas* are common in the coastal lowland area studied ($N = 183$) and are absent in the highlands.

Additionally, the region's most complex and extensive cemeteries have been found in the coastal lowlands, suggesting that this sector had a higher population density (Quevedo, 1998) than the highlands, where isolated burials in residential sites are the norm.

In this scenario, the very intense production of rock art points to a need to strengthen alliances and networks in the coastal lowlands in an area with large population centers that also experienced intergroup conflict. Indeed, recent bioanthropological studies of samples from some lowland cemeteries suggest an increase in violence and social conflicts among coastal hunter-gatherer groups during the Late Holocene that have been related to the high population density and to territorial claims made by those communities (Quevedo, 1998; Fuentes et al., 2010).

6. Conclusions

As Braun and Plog have suggested (1982, see also Aubry et al., 2012), in every landscape occupied by hunter-gatherer groups, social networks are unfolded at different levels of connectivity. This is related to the relevance that these networks have in the social and economic reproduction of these groups, mainly through the flow of information that allows the creation of cohesions and disruptions within the supra-family units (Jochim, 1976; Conkey, 1980; Hamilton et al., 2007; Apicella et al., 2012; Whallon, 2006). Our study case is not the exception. The digital enhancement of the images allowed us to carry out an integral analysis over a set of images that was dispersed due to their low visibility and bad preservation state. This helped us to see how spatial and visual attributes of the paintings acted in different levels, to conform different social networks in the region. On the one hand, in a wide scale, and from the repetition of a spatial practice, painting integrate hunter-gatherer groups of the region within a whole that shares basic principles associated to the production of rock art and the need of marking space. In fact, regardless of the differences in the composition of the representations, in both spaces a same location pattern is replicated (associated to residential camps), a preference for non figurative designs, and the use of the same colours and symmetry patterns. In one way or another, this created a shared horizon for these communities, integrating the whole region through a same practice, and a similar process of semantization of space. The appearance and distribution of paintings in a regional scale is associated with the processes of territorialisation and demarcation of space by the hunter-gatherer groups. All this is the result of historic dynamics of the region, associated to a demographic increase, higher levels of conflict, and to spatial demands over the landscape by the hunter-gatherer groups.

On the other hand, the analysis also allowed us, at a lower scale, to identify that it is through the compositions themselves and the ways in which flows of information are constructed, that rock art created two closed social networks: one in the coastal lowlands, and another one for the highlands in a context where groups were territorially separated. Through this segregations, these two regions mark and construct their differences as divergent social units with closed territorialities, despite the production of a shared social landscape. Finally, in one of these territories—the coastal lowland space—rock art production and the flows of information were intensified in order to reinforce interaction, the flow of information and alliances in a space intensively occupied, and where the pressures for the use of space were greater than in the highlands, requiring more recurrence and recursiveness of the flows of information (Fitzhugh et al., 2011).

In this way, networks constructed through rock art worked at different scales and with different dynamics within this territory. This is coherent with the social complexity associated to the flows of information in hunter-gatherer groups, as well as with the existence of different mechanisms to circulate different types of information, in different quantities, frequencies, and qualities, in different spatial scales (Whallon and Lovis, 2011). This requires to acknowledge that social processes operate on different scales within historic dynamics of communities, something that is particularly true in the case of rock art and other materials associated to mobilization of social information, and that are fundamental for the social reproduction of human communities (Whallon, 2006; Hamilton et al., 2007; Funk, 2011; Apicella et al., 2012).

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