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Notes

Quaternary landscape evolution and human occupation in northwestern Argentina

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Abstract: Our study area is located in northwestern Argentina. It is a semiarid valley in which developed agricultural pre-Columbian settlements were located. The objectives of our research were to establish the geomorphological characteristics of the area, its relative chronological development, and the relationships between geomorphological development and pre-Columbian settlements.

Pre-Quaternary lithologies are represented by a metamorphic basement that is commonly exposed on slopes and belongs to the Precambrian and Cambrian periods. Tertiary sediments from several formations are exposed over an extensive surface forming cuesta relief landforms. Quaternary landscape units were classified according to their genesis into structural–denudational landforms (denudational slopes and structural scarps), denudational landforms (covered glacis), fluvio-alluvial landforms (alluvial fans, fluvial fans, and fluvial terraces) and aeolian forms (stabilized dunes).

Archaeological sites belonging to the Formative (500 BC–AD 1000) and Regional Development (AD 1000–1500) periods were identified. The main archaeological sites are located on the surfaces of debris-flow deposits and some covered glacis. They are characterized by the presence of residential units together with agricultural structures (terraces and irrigation channels). The earlier settlements (Formative period) are restricted to alluvial fan landforms (debris-flow deposits), where present hydrological supply is lower than in the rest of the study area. Later settlements (Regional Development period) are juxtaposed with earlier settlements in the south of the area, where present hydrological supply is higher owing to larger river catchments and moisture-laden winds from the SE.

This research was carried out on the western hillsides and piedmont of the Calchaquíes Summits (Santa María Valley, Tucumán Province, northwestern Argentina). The study area's limits are the Amaicha River to the south (in Tucumán province), the Campo La Hoyada to the north (in Salta Province), the watershed over the Calchaquíes Summits to the east, and the Santa María River to the west (Fig. 1).

The Santa María Valley is a deep depression with a planar floor oriented north–south. It extends between the Quilmes Range to the west and the Calchaquíes Summits and Aconquija Ranges to the east. Water flows from south to north, in the opposite direction to the normal regional inclination. The altitude at the bottom of the valley varies between 1900 and 1600 m above sea level (Strecker 1987).

The regional climate is desert-type, with an average annual temperature of 18 °C, and average annual precipitation of less than 250 mm (most falling during the summer season) (Perea 1994). Precipitation varies according to hillside orientation, and because moisture-laden winds regularly come from the east and the SE, our study area is the drier sector of the valley. Wind action produces desiccation and hardening of exposed surfaces, and also the movement of fine particles from the surface, which constitute the material for the dune fields of the region.

Antecedents

Geological antecedents

The geology of the Santa María Valley consists of medium- and high-grade metamorphic basement rocks, overlain discordantly by Early Tertiary layers (Salta Group) of fluvial sedimentary rocks. Over them, also discordant, lie Miocene and Pliocene (Santa María Group) fluvial and lacustrine sediments (González *et al.* 2000).

Quaternary deposits are of either fluvial or torrential origin, with coarse sand textures close to the summits and sandy clay textures in the centre of the valley (González *et al.* 2000). According to Ruiz Huidobro (1972), during the Quaternary, fluvial cycles determined the formation of piedmont

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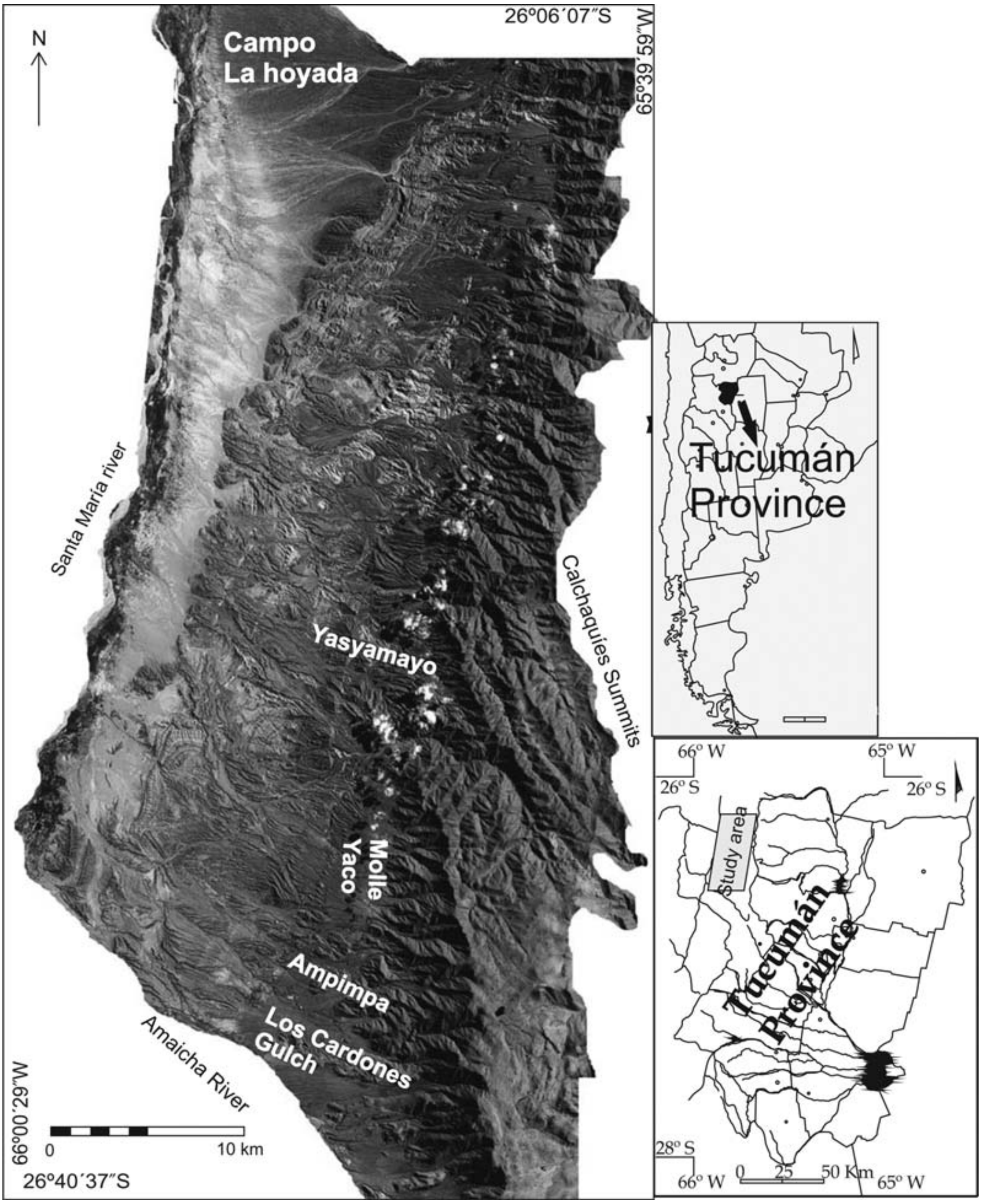

Fig. 1. Study area location.

levels over older pediments. Strecker (1987) established the presence of five pediment levels formed by fanglomerates. He also observed the large extent of old coalescent alluvial fans, both landforms being of Early Pleistocene age. The Holocene is represented by debris-flow deposits covering the piedmonts of the Aconquija Ranges and the Calchaquíes Summits, with fanglomerates, sands and fluvial silts in the centre of the valley. Petrocalcic horizons and dunes are associated with arid periods (Sayago *et al.* 1998). The Middle Holocene period had wetter conditions at a regional level, and is linked to the generation of thick clastic sequences associated with alluvial fans or debris flows produced by increased glacial and periglacial activity in summit areas (Sayago *et al.* 1998).

At a regional level, from the palaeoenvironmental point of view, the Pleistocene period is characterized by the presence of loess–palaeosol sequences representative of environmental conditions changing between cold–dry phases (periods of loessic deposition) and warm–wet phases (with pedological development) (Sayago *et al.* 1998).

In the Tucumán plain and piedmont, Early and Middle Holocene environments are represented by oscillating dry and wet sequences (Sayago *et al.* 1998). The oldest palaeosol in the plain has been dated to 6290 ± 120 BP (^{14}C years). Its characteristics suggest that the climate was wetter than at present (Sayago *et al.* 1998).

Contemporaneously, in the northwestern area of the Southern Sub-Andean Ranges, the climate was semiarid with wetter phases. Humidity increased progressively through the Late Holocene. The transition from Middle to Late Holocene coincided with a loessic deposition cycle and the development of soils. In the western Chaco plain a palaeosol was dated to 3780 ± 40 BP (^{14}C years) (Sayago *et al.* 1998). In the Tafí Valley, close to Santa María Valley, a sequence of alternating dry and wet periods was identified. A palaeosol reflecting wet conditions was dated to 2480 ± 110 BP (^{14}C years) (Sampietro Vattuone 2002). This period was contemporary with the development of Formative Tafí pre-Columbian settlements, and lasted until 875 ± 20 BP (^{14}C years), when pollen (Garralla 1999) and pedological (Sampietro Vattuone 2002) evidence shows that a drier period was established. During that phase Tafí culture collapsed. After that a slight environmental recovery was inferred from pedological evidence.

In the Santa María Valley, Strecker (1987) found sand layers enriched with organic matter on the western side of the Santa María River. They were dated to 2190 ± 530 BP (^{14}C years) and 1470 ± 50 BP (^{14}C years). They may correspond to a period with wetter climatic conditions. Other layers located above showed that after 1100 ± 70 BP (^{14}C years) drier conditions were established (Strecker 1987) (Fig. 2).

Archaeological antecedents

The Santa María Valley has many archaeological remains from the pre-Columbian period, which we use to outline the following cultural sequence, based on González & Pérez (1972). We consider that although this is not the most recent cultural framework proposed (see Olivera 2001) it is the most satisfactory at a regional level.

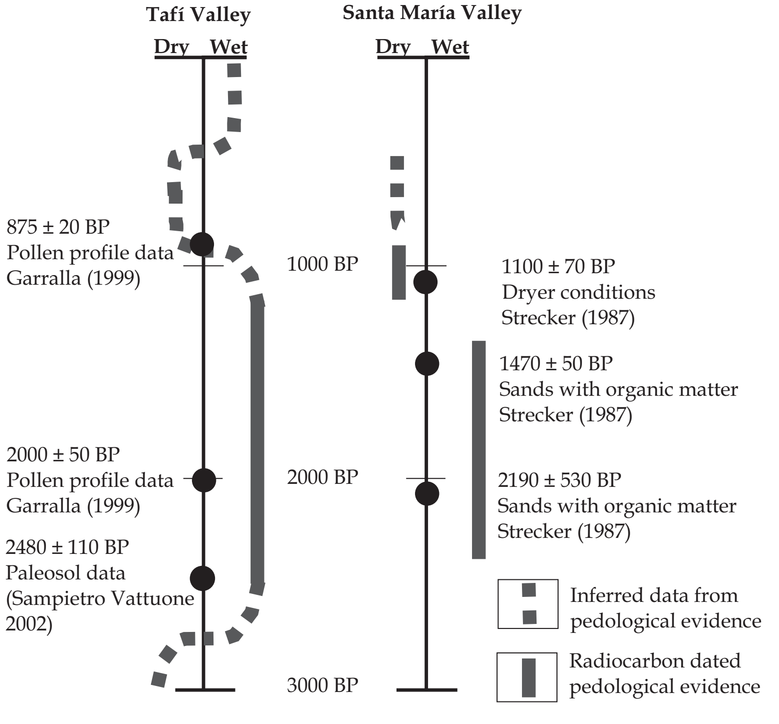

Fig. 2. Palaeoenvironmental data from the Santa María and Tafí valleys.

Two main cultural phases can be distinguished: (1) pre-ceramics, characterized by the presence of hunter–gatherer populations covering the time period from the arrival of the first humans in the region to 2500 BP; (2) the ceramic period (2500–500 BP) characterized by the appearance of ceramics, agriculture and sedentary settlements (González & Pérez 1972).

Within the pre-ceramic stage it is possible to distinguish the Palaeoindian period (? to 7000 BP), which is poorly represented in the regional archaeological record and is characterized by the presence of hunters of large mammals; and the Archaic (7000–2500 BP), with specialized hunter–gatherers with high mobility and an excellent use of natural resource diversity (González & Pérez 1972).

The Pre-Columbian ceramic period can be divided into three well-differentiated periods: (1) the Formative period (500 BC–AD 1000), during which sedentary settlements were established and agricultural practices started, together with ceramic manufacture and camelid domestication; (2) the Regional Development period (AD 1000–1500), during which populations grew, defensive structures were built and agricultural systems improved (especially in terms of irrigation structures); (3) the Inca period (AD 1400–1500), during which the Inca Imperium expanded over wide areas of northwestern Argentina, generating changes in the power system (González & Pérez 1972).

The study area comprises several archaeological settlements representative of the cultural stages mentioned above, especially the Formative and the Regional Development periods.

Settlements belonging to the pre-ceramic period were observed in the Amaicha River basin and adjacent areas, in the south of our study area (Cigliano 1961, 1968; Hocsman *et al.* 2003; Somonte 2007). Archaeological material appeared in open-air workshops, without stratification or associated buildings. Therefore the exact chronology is difficult to establish.

Earlier ceramic sites, belonging to the Formative period, were identified in the southern sector of the study area. Buildings from this period are still visible on the surface, although they are fragmentary and obscured by later structures (Sosa 1996–97, 1999; Aschero & Ribotta 2007; Somonte 2007). The typical settlement pattern consists of circular rooms, similar to those described by Sampietro Vattuone (2002) in the Tafí Valley. Walls are built of stones without mortar or foundations. The rooms are dispersed over terraced agricultural fields. Radiocarbon dates obtained for them are 900 ± 70 BP (accelerating mass spectrometry (AMS), UGA 8359), 1180 ± 40 BP (AMS, UGA 8360) and 1130 ± 40 BP (AMS, UGA 8361) (Aschero & Ribotta 2007).

Sosa (1996–97) used the visual interpretation of aerial photographs from the east side of Santa María Valley, especially the Amaicha del Valle and its surroundings, to identify Formative archaeological settlements. He identified the presence of six occupational settings located along the Amaicha River.

Later settlements, located around Los Cardones gulch, belong to the Regional Development period. Radiocarbon dates obtained for these settlements are 460 ± 60 BP (LP 1484), 570 ± 60 BP (LP 1573) and 930 ± 70 BP (LP 1495) (Rivolta 2007). The settlement pattern can be characterized as a semi-urban village; the areas where slopes are more pronounced have terraced structures. Potsherds are of the Santa María bicolour and crude types (Rivolta 2005). Downhill from this archaeological site, next to Los Zazos, Formative potsherds were collected (ciénaga, vaquerías and tafí types); they were associated with circular structures and agricultural terraces (Rivolta 2005). The materials and structures showed the superimposition of settlements from the two periods in this sector (Rivolta 2005). Related to this point, Sampietro (1992) commented on the presence of architectural and ceramic features belonging to the Formative and Regional Development periods juxtaposed in the area of the present-day Ampimpa settlements (Fig. 3).

Methods

We started by making geomorphological interpretations from 1:50 000 aerial photographs taken by Spartam Air Service in 1971 (there are no more recent photographs available). Thematic cartography of the area involved the production of a lithogeomorphological map, containing the morphogenetic units in chronological order (Fig. 4), and an archaeological map, to represent the location of archaeological sites in landscape context (Fig. 5). At this scale it was impossible to draw an accurate archaeological map, so we decided to delimit archaeological areas instead.

The geomorphological interpretation was performed following the approach proposed by the International Institute for Geo-Information Science and Earth Observation (ITC, Netherlands) (Van Zuidam 1976). This approach takes into consideration the genetic factors that make it possible to characterize each landform unit, together with lithology and topography.

We considered the determination of geomorphological units to be especially important because: (1) their genesis and temporal evolution is homogeneous over the entire landform surface; (2) they have spatial homogeneity owing to the recurrence of endogenous morphogenetic elements such as lithology, sedimentary composition,

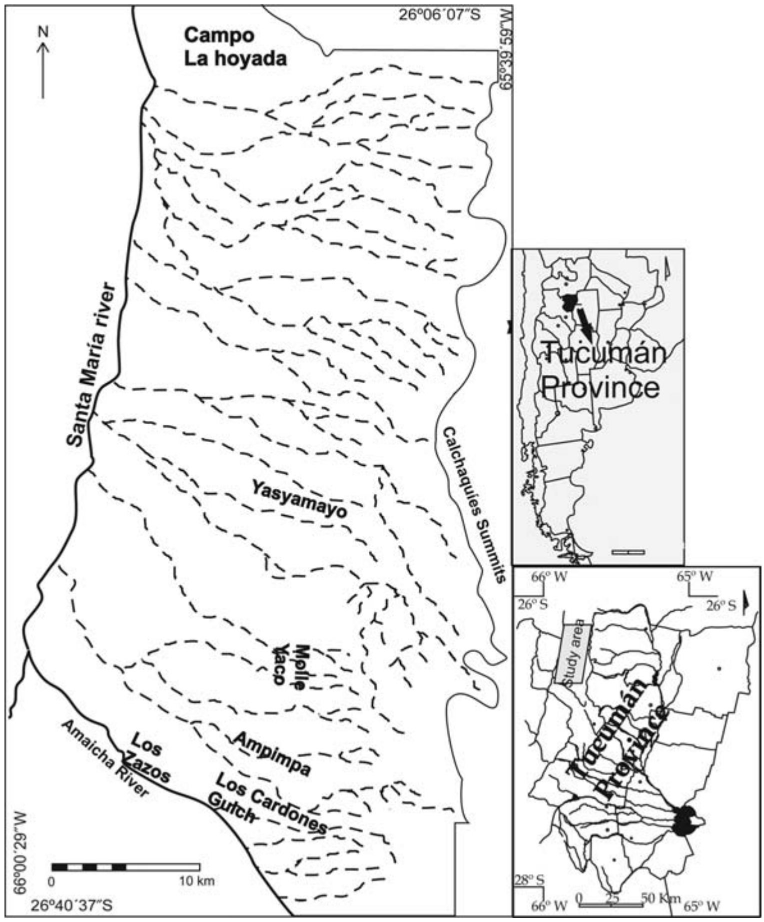

Fig. 3. Simplified topographic map with archaeological settings.

stratigraphy, etc.; (3) as these factors (endogenous morphogenetic elements) are common to the whole landscape unit, they permit the extrapolation of palaeopedological, palaeoclimatic, lithostratigraphic and geochronological features to the entire landform unit; (4) they make it easier to have a dynamic and integrated vision of the area's palaeoecological evolution through the analysis of the evolutionary schemes of each unit (Sayago & Collantes 1991). From an archaeological perspective all of these features allow us to make a better correlation between settlement characteristics and their possible relationships to natural resource exploitation (Sampietro Vattuone 2002).

Thematic maps were ground-truthed by field survey, and a geographic information system (GIS) was constructed using ILWIS 3.4 software (Integrated Land and Water Information System). Subsequently, we performed systematic field research in the areas where archaeological sites were identified. Over these landforms we surface-collected potsherds (there was no other diagnostic material available on the surface) and surveyed archaeological evidence along one longitudinal transect across each landscape unit. We dug 13 archaeological test pits (1 m $\times$ 1 m) in agricultural sectors. As structure features are different according to the cultural period, these features were compared across the various surveyed areas. Although they were very scarce, surface-collected potsherds were classified by comparison with pre-existing typologies, using qualitative and diagnostic criteria following the 1st National Convention on Anthropology (Anon. 1966), to establish the agricultural periods represented.

Results and discussion

The lithogeomorphological characterization of each landform was based on its genetic characteristics

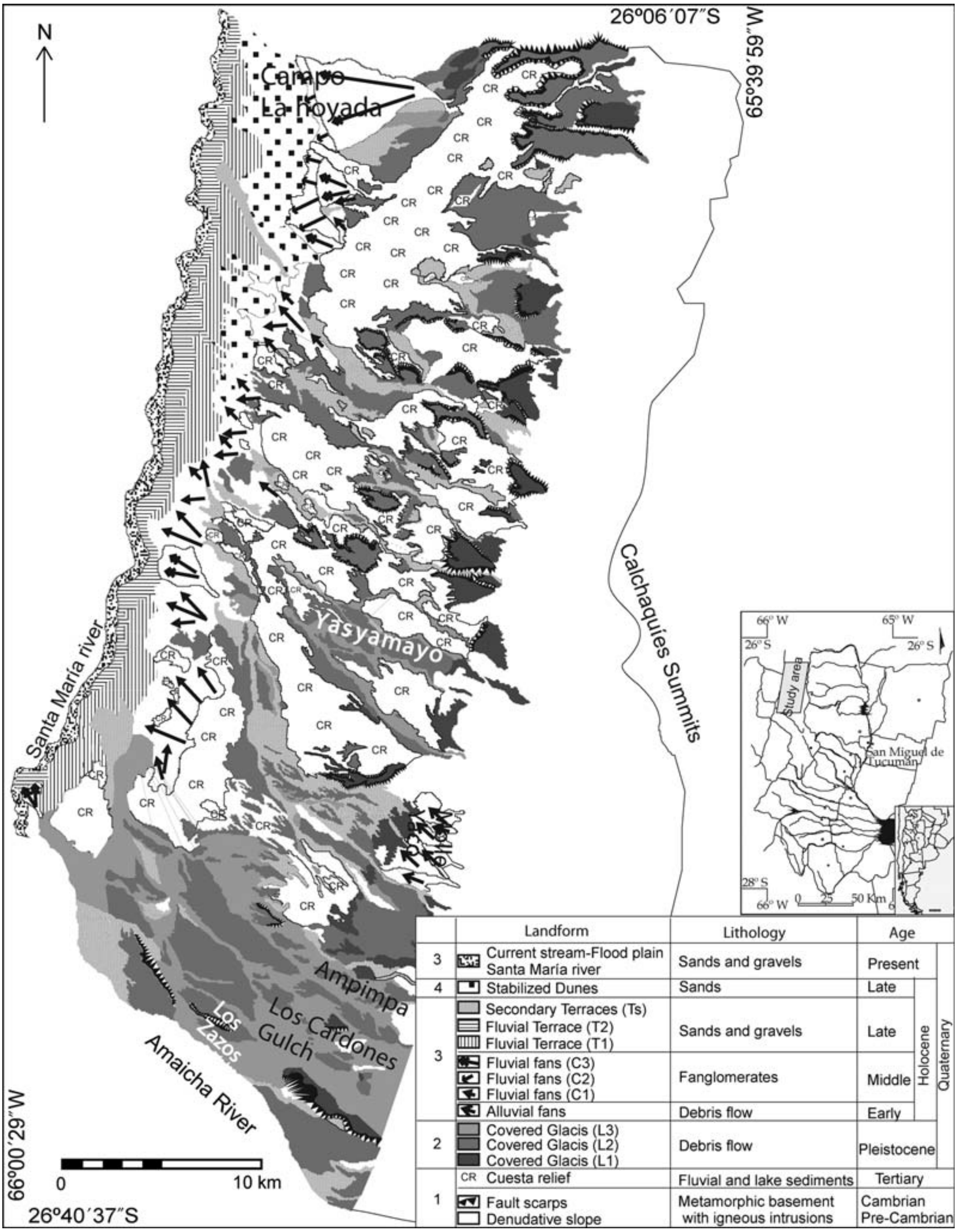

Fig. 4. Geomorphological map of the study area. Landform units classified by their origins: 1, structural–denudational; 2, denudational; 3, fluvio-alluvial; 4, aeolian.

and its lithology. From the morphogenetic point of view we were able to distinguish landforms with structural–denudational, denudational, fluvio-alluvial and aeolian origins (Fig. 4).

Archaeological settlements were identified by photo-interpretation and field survey. Pedestrian surveys allowed us to surface-collect potsherds but the scarcity of such material made it impossible to

Fig. 5. Small structures set into the side of highland fertile valleys (called 'vegas'). Calchaquí summits, denudational slopes geomorphological unit.

undertake ceramic seriation. Nevertheless, it was possible to use these fragments as diagnostic materials by comparison with previous typologies from the region.

The landforms of structural–denudational origin are relief forms developed by the action of seismic movements that generate scarps of various sizes. These have then been affected by denudational processes, giving superficial morphologies that vary according to lithology, climate and tectonics (Neder & Busnelli 2003). In the study area we have identified (1) denudational slopes, (2) erosion scarps, and (3) cuesta relief landforms. Denudational slopes (on the western side of the Calchaquíes Summits), developed over igneous–metamorphic basement rock. They extend from the watershed of the Calchaquíes Summits to the upper limit of the piedmont. These slopes are very steep, with slopes around 45%, and have extant fault scarps. The drainage network is sub-dendritic, and in some sectors subparallel. The fluvial regime is seasonally torrential. It was impossible to establish the presence of archaeological sites by photo-interpretation, although it is highly probable that this area was used for camelid grazing and hunting. By ground survey it was possible to find small structures set into the side of highland fertile valleys (called 'vegas') (Fig. 6). Erosion scarps are present in the apical and middle sector of the piedmont, developed around the earliest levels of covered glacis (Covered Glacis L1). Scarps are indicative of tectonic activity and were generated by degradation processes. Cuesta relief landforms developed in the piedmont over Tertiary formations; they have gentle to moderate slopes (15–45%).

Glacis landform units are of denudational origin, forming as a result of mass movement processes. The changes in their relief reflect the morphogenetic action of rapid climate change alternating with stable periods (Van Zuidam 1976). As a result, it is possible to observe smooth surfaces that required a long time to form. As they are climate and time dependent, their incorporation in the Quaternary stratigraphic record, as chronological and palaeoenvironmental indicators, is very important. Birot (1960), studying the dominant geomorphological processes of arid regions, proposed the use of the term 'covered glacis' for those surfaces that are covered by a thin layer of detrital deposits.

On the western slope of the Calchaquíes Summits it is possible to distinguish three levels of covered glacis of Pleistocene age, starting at the limit between hillside and piedmont and extending downhill to the west. They are formed by mass movements of rock fragments weathered from slopes and the igneous–metamorphic basement of the hillsides, and can be lithologically defined as texturally coarse debris-flow deposits. The fragments are in a dominantly clastic sandy matrix. The three levels correspond to separate accumulation cycles that also show differences in topography and altitude.

The first, and highest, level of covered glacis (Covered Glacis L1) corresponds to the oldest level. It is found at the limit between hillside and piedmont, and has been strongly incised by subsequent morphodynamic processes. In some cases it still has its original triangular shape, principally in the central and northern parts of the study area. Photo-interpretation showed that there are no archaeological structures visible on this level of covered glacis. The next covered glacis level (Covered Glacis L2) is the most extensive in the study area, extending from the apical to middle piedmont and covering Tertiary deposits. This glacis level presents a large quantity of archaeological structures, especially in the central and southern sector of the study area. Circular and quadrangular structures are present. Both are dispersed among agricultural terraces in several areas. Although it was not possible to see by photo-interpretation at the scale we worked at, one semi-urban settlement has been described in the southern sector of the area, at Los Cardones gulch, by Rivolta (2000). Photo-interpreted features (such as changes in the texture of the surface by the accumulation of sand with specific patterns or the growth of vegetation around the collapsed walls) allowed us to infer the juxtaposition of buildings from the Formative and Regional Development periods. Pedestrian surveys and collection of archaeological potsherds corroborated this observation. Formative potsherds are represented by the ceramic types Ciénaga incised, polished grey, a few fragments of Aguada, and polished light red. Regional Development period potsherds are represented by the types bicolour Santa Maria, tricolour Santa Maria, crude coarse

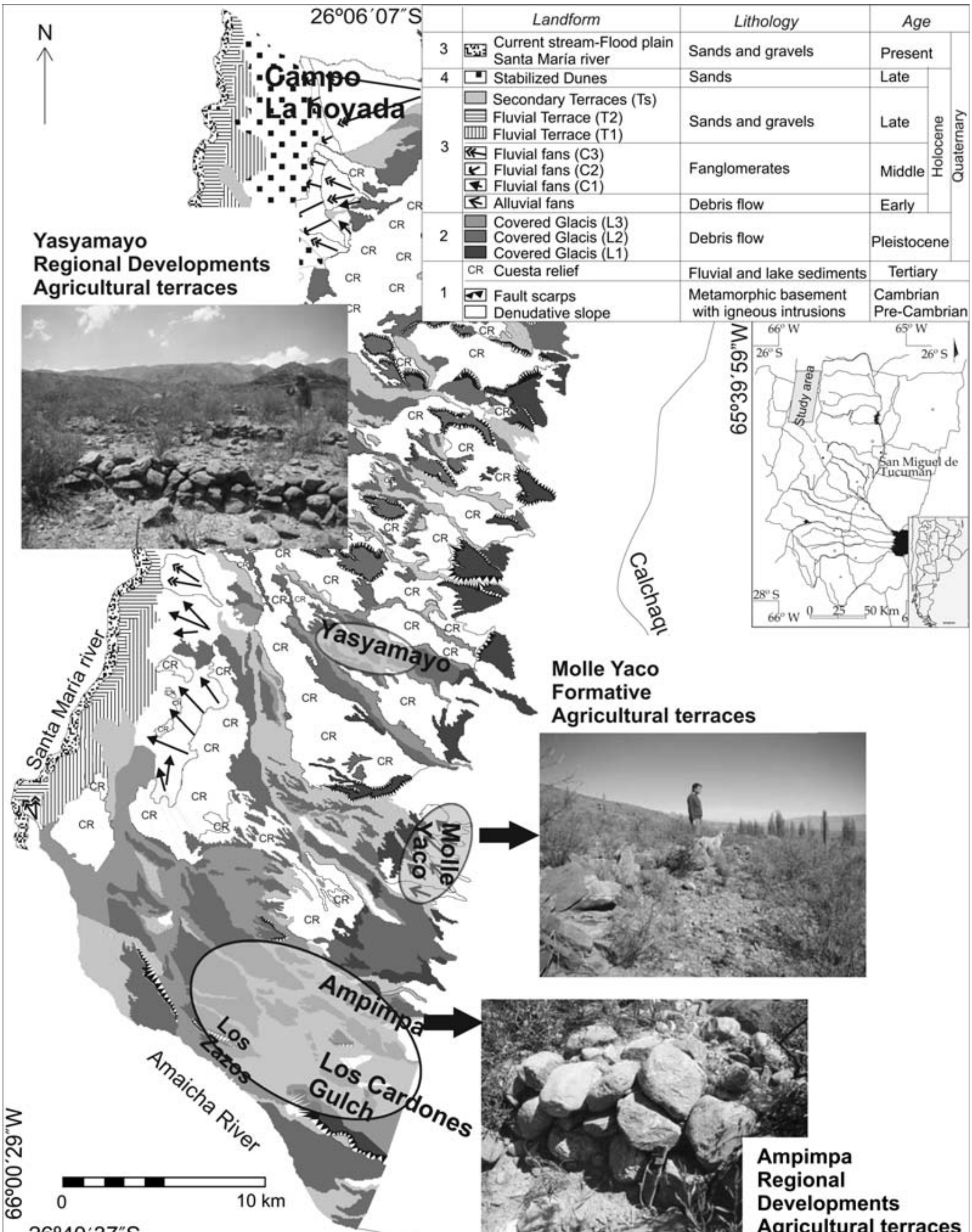

Fig. 6. Archaeological areas related to geomorphological landforms. Landform units classified by their origins: 1, structural–denudational; 2, denudational; 3, fluvio-alluvial; 4, aeolian.

red, and unpolished grey. Finally, the third covered glacis level (Covered Glacis L3) is chronologically the youngest and is located in the lower piedmont. It is composed of texturally finer (silty sand) materials. It is more extensive in the south of our study area. Archaeological settlements are scarce and are located next to those on Covered Glacis L2.

After the development of the covered glacis levels, landforms of fluvio-alluvial origin were formed. The earliest landforms of this type in our study area are alluvial fans (Early Holocene), followed by fluvial fans (Middle and Late Holocene) and fluvial terraces (Late Holocene). Three variables affect the development of alluvial and fluvial fans: topography, lithology and climate. Topography influences the contribution of sediments, because on very steep slopes mass movement processes generate dense flows with the materials generated by weathering. When slopes are gentler, fluvial activity dominates. Lithology conditions the type and size of rocks broken by weathering (Gutiérrez Elorza 2001). Climate is the third factor that regulates fan development. Water determines weathering processes, the transportation of materials and plant growth. In semiarid environments, large volumes of clastic sediments, which form alluvial fans, are transported by running water during storms, owing to the short duration and high intensity of precipitation.

In the study area we were able to distinguish, in chronological order, first, alluvial fans restricted to the SE sector of the area, formed by debris-flow deposits transported from the hillside downstream by currents and deposited in the apical piedmont. They are texturally finer than those that formed covered glacis. They were formed under wetter conditions than at present. In these areas it was possible to identify residential structures, mainly of circular shape, dispersed among agricultural terraces. Surface-collected potsherds have Formative characteristics as described above. After that, three cycles of fluvial fans were identified. The oldest fluvial fans (C1) were formed of transported Tertiary sediments. They are coalescent and much dissected by subsequent erosive processes. They are located in the central and southern sectors of the area and between the distal piedmont and the bottom of the valley. The next fluvial fans (C2) are restricted to the northern sector of the area; as relicts of large fans buried by subsequent deposits (C3), they appear only in the distal sectors of C3. The final fluvial fans (C3) correspond to later fans of wide extent, and are restricted to the same sector as the previous ones. Their drainage network has a radial pattern. In no case was it possible to distinguish archaeological structural features, and no potsherds were surface-collected.

The accumulation landforms described above are the result of fluvial processes, which depend on the volume of precipitation, the amount of sediments available, and the transport capacity of each stream belonging to the Santa María river basin. These rivers have a torrential seasonal regime. During the winter the river beds are dry, whereas in the summer season they transport large amounts of sediments to the lower sectors, where the sediments are deposited. These landforms have a strong relationship with past and present climatic conditions. Thus we were able to distinguish fluvial terraces (T1 and T2), secondary fluvial terraces (ST), and the present river bed and flood plain of the Santa María River, all belonging to the Late Holocene. Fluvial terrace T1 is developed on the right side of the Santa María River. It is more extensive in the middle and northern sectors of the study area, and in the south its development is more restricted. The next terrace level is fluvial terrace T2. It is younger than T1, and shows the same tendencies as the previous terrace, owing to decreasing river surface runoff and shrinking of the present river bed. Secondary terraces (ST) are located in the apical and middle piedmont, and were developed by the tributary streams of the Santa María River. They are smaller in the northern and central parts of the study area than in the south. All of them are of elongated form.

Finally, we were able to distinguish landforms of aeolian origin, represented by stabilized dunes that are located in the northern section of the study area, among the present-day fluvial fans and fluvial terrace level 1 (T1). They are composed of fine sediments, with some vegetation growth over them, and are currently being incised by intermittent streams. At the bottom of the valley, close to the Santa María River, there are mobile dunes composed of very fine materials generated by the dominant dry winds. Their shapes are elongated, with a north–south orientation, and they are not visible on the aerial photographs. There is no evidence of archaeological occupation in this sector.

Conclusions

Geomorphological analysis allowed us to identify three levels of covered glacis developed over Tertiary deposits. These could correspond to the five levels of pediments proposed by Strecker (1987) through the south of our study area over the Aconquija Ranges, with the difference in numbers being due to the intensive neotectonic processes that affected the southern part of Strecker's study area. These covered glacis levels are located in different topographic positions, reflecting changes in climatic conditions during their formation. They were formed during the Pleistocene period by currents of high erosive power that eroded existing deposits, generating thick accumulations downstream.

During the Early Holocene, alluvial fans were formed by more fluid currents that formed debris-flow deposits. After that, during the Middle and Late Holocene, fluvial fans were formed, in several cycles, reflecting periods of torrential water availability.

During the Middle and Late Holocene, streams from the Calchaquíes Summits hillsides formed the secondary terraces of the Santa María River tributaries, excavating old deposits and forming several cycles of fluvial fans. During the Late Holocene fluvial terraces were developed on the Santa María River. Finally, dunes were formed then stabilized.

Against this background, it is possible to identify archaeological sites with different superficial characteristics, composed of residential and agricultural structures. Residential units appear dispersed on agricultural fields, and have different shapes (quadrangular and circular), allowing us to differentiate two occupational periods, Formative (500 BC–AD 1000) and Regional Development (AD 1000–1400). The only semi-urban settlement identified was that already cited by Rivolta (2005). Archaeological surveys showed that alluvial fans are the only landscape unit with only Formative period structures. The other geomorphological units with archaeological remains (slopes and covered glacis (L2)) had structures from the Formative and Regional Development periods juxtaposed. The construction characteristics of the agricultural terrace walls vary. Agricultural structures from the Formative period, which are associated with circular rooms and early ceramic types, are made with boulders without mortar, whereas the structures from the Regional Development period, associated with rectangular structures and Santa Maria potsherds, are made with flagstones and mud.

We relate this differential distribution of archaeological settlements to the general process of aridization that the area was affected by during the Quaternary period. According to the geomorphological evidence, water availability diminished through time. The sequence of landscape unit evolution, together with the sizes of such units, and the decreasing transport energy of the entire system through time support this interpretation. In general terms, the mass movement processes that accumulated the original material of the covered glacis required the action of transport agents of low fluidity and high competence, generating solifluxion processes over the materials crushed during glacial periods in the high mountains. Those materials are characteristic of fluvio-glacial depositional environments (Sayago & Collantes 1991). After that, torrential environments dominated, first forming alluvial fans in a very restricted area and then fluvial fans. Alluvial fans are formed by texturally coarse debris flows, which represent greater transport energy than the later landforms. Finally, fluvial terraces are restricted to present-day rivers, especially in the valley bottom where water flow is higher, and are of limited extent compared with the previously described landforms.

From the archaeological point of view, it is possible to observe a differential distribution of settlements by period. Alluvial fans, formed in the smallest river basins, were occupied only during the Formative period, whereas in the south and north of this area, where river basins are larger, Formative settlements are juxtaposed with Regional Development period structures. This could be related to the differences in water availability that have already been established in the Tafí Valley, close to Santa María Valley, by Sampietro Vattuone (2002). The climatic and geomorphological evidence thus combines to suggest that during Formative times the climate was wetter and occupation of the smaller river basins (as well as the larger ones) was possible. By the Regional Development period, the drier climate caused people to restrict their settlements to the larger river valleys, as only there was there an adequate supply of water. Even today, water availability is better in these areas, reinforcing this argument.

Although this is a first approach to the subject in this region, we believe that the results of our work demonstrate that the integrated interpretation of archaeological features and landscape evolution systems is a profitable approach to understanding human occupation evolution through time.

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