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Gravity and the formation of the archaeological record: Main concepts and methodological tools

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Abstract

This contribution aims to discuss how gravity-driven processes affect the archaeological record with the goal of building a broad conceptual and methodological framework for dealing with these contexts. A wide compilation of cases regarding gravity-driven processes is analyzed to recognize relevant environmental factors, the way they affect the properties of the record, and long-term archaeological expectations. Only by understanding the specific mechanisms and processes that occur in each context can an accurate methodological approach be chosen on which to base interpretations. A careful taphonomic study of the spatial distribution, frequency, size, diversity, and orientation of materials comprising the archaeological record is the first step to recognizing formation processes. Actualistic studies provide a framework for discussing the timing and intensity at which processes occur. A detailed geomorphological description is required to interpret sedimentological and micromorphological analysis, which in turn helps understanding of the relative subaerial permanence of the record, its temporal resolution, and preservation potential. Interpreting surface and buried materials requires the understanding of pedogenetic processes. Broad in/off-site spatial sampling strategies definitely yield a more realistic picture about the variety of processes in slope settings.

KEYWORDS
geomorphology, pedology, sedimentology, surface/burial archaeological record, taphonomy

1 | INTRODUCTION

For more than 40 years it has been recognized that underestimating or misunderstanding the role of natural processes can bias the interpretation of human behavior made from the archaeological record. Thus, determining if the data are appropriate for our theoretical goals is a fundamental step in every archaeological agenda (Butzer, 1971, 1982; Davidson & Shackley, 1976; Renfrew, 1976). The present contribution will discuss gravity-driven processes in archaeological settings in order to build a broad conceptual and methodological framework for dealing with the archaeological record affected by them. For this purpose, a wide range of case studies concerning gravity-driven processes that take place on slopes is considered in order to understand relevant environmental factors, the way they affect properties of the archaeological record, and the consequent archaeological expectations related to different processes. Since there are already many useful studies regarding this topic, critical synthesis can create operative models upon which to work.

The importance of understanding gravity-driven processes in archaeological contexts lies in their significant impact on the spatial properties of the archaeological record. In addition, as some of these processes operate on specific particle sizes, densities, or shapes, archaeological assemblages can be differentially affected. It is gravity-driven processes that can control the spatial arrangement, density, and size of the material culture. These archaeological properties, in turn, are indicative of past human behavior since they help the understanding of activity areas, nature, and intensity of human occupation, thus contributing to broader interpretations such as defining mobility systems or biogeographical issues. For instance, the proposed late Pleistocene archaeological artifacts from northeastern Brazil are, for some authors, geofacts introduced by gravity (Aimola, Andrade, Mota, & Parenti, 2014; Böeda et al., 2013; Lahaye et al., 2015). Less controversially, the study of natural and anthropogenic deposits accumulated by gravity-driven processes can also offer indirect data about paleoenvironmental conditions (e.g., Bertran, 2005; Bertran, Hetu, Texier, & Van Steijns, 1997; Bertran, Laurent, Lenoble, Masson, & Vallin, 2010; Lenoble, Bertran, & Lacrampe, 2008; Texier & Meireles, 2003).

The archaeological record on slopes is often associated with a colluvial talus of outcrops (caves, rock shelters or walls), though it can also be located in other accumulation geoforms such as dunes and moraines (Fig. 1). In all cases, gravity is the major factor in two main types of processes: (1) collective or mass

FIGURE 1 (a) Slope of Cerro Cabeza de León; note the abundance of rocks along the hillslope (Tierra del Fuego, Argentina; photo courtesy of K. Borrazzo). (b) Vegetated hillslope of Tres Arroyos Site (Tierra del Fuego, Chile); note the erosion scarps due to soil creeping. (c) Semivegetated hillslope of Cóndor 1 Site; (Santa Cruz, Argentina; photo courtesy of R. Barberena). (d) Soil creeping and slides scars on a moraine slope at Marazzi 2 (Tierra del Fuego, Chile). (e) Slides at Marazzi 2 Site; note that the older slide was dissected by a river. (f) Semivegetated hillslope of La Vieja Cave (Aysén, Chile); note intensive sheep action (circular nonvegetated depressions) and the abundant rock fall. (g) Colluvial fan at the entrance of Baño Nuevo 1 Cave (Aysén, Chile). (h) Hillslope of Cerro Ventana Site with patches of vegetation (Santa Cruz, Argentina, photo courtesy of N. Cirigliano). (i) Vegetated low-angle hillslope of Cerro Sin Nombre (Tierra del Fuego, Argentina). (j) Rocky hillslope of Fell Cave (Santa Cruz, Chile) [Color figure can be viewed at wileyonlinelibrary.com]

movement processes (creeping, landslides, flows, solifluction that comprises frost-creep, and gelifluction); and (2) individual particle processes (rolling, bouncing, falls, and toppling; Hungr, Corominas, & Eberhardt, 2005; Hutchinson, 1988; Nardin, Hein, Gorsline, & Edwards, 1979; Ritter, Kochel, & Miller, 2006; Sharpe, 1938; Summerfield, 1991; Varnes, 1978; Wainwright, Parsons, Powell, & Brazier, 2001; among others).

The occurrence, speed, extent, and frequency of slope processes depend on several interconnected factors and triggers, such as climate (precipitation, humidity, temperature and wind intensity through the year), abundance and type of vegetation, soil development, microtopography, substrate granulometry, mineralogy, drainage condition, slope angle, slope shape (e.g., rectilinear, concave, etc.), availability of solid loose material, human impact (deforestation, overgrazing, soil depletion, etc.), and earthquake occurrence (its frequency and intensity).

From a geoarchaeological perspective, many studies have discussed gravity-driven processes in archaeological contexts (Butzer, 1971; Goldberg & Macphail, 2006; Rubin de Rubin & Da Silva, 2004; Straus, 1995; Waters, 1992; among others). However, less attention has been given to constructing conceptual models to deal with slope archaeological settings in general. The main reason for this is probably the complex interplay among several factors, which restricts a broad model application; even on the same slope, a slight topographic change can give rise to a different pattern in the archaeological assemblage (Bertran et al., 2015).

2 | THE ARCHAEOLOGICAL RECORD AND GRAVITY-DRIVEN PROCESSES

Archaeological sites on slopes could be considered as a particular taphonomic mode (*sensu* Behrensmeyer & Hook, 1992), namely, a set of environmental features that determine specific preservation conditions. For instance, by considering bone and lithic assemblages in cold semiarid contexts (North Isla Grande de Tierra del Fuego, Argentina), Borrazzo and Borrero (2015) defined a cliff taphonomic mode, emphasizing hillslope dynamics. The authors noted that surface lithic assemblages on slopes exhibited low frequencies of small artifacts, while these were frequent in the below-ground samples at the same site (also Borrazzo, 2009, 2010). This pattern was explained due to the high burial potential of small size materials along vegetated slopes. This example draws attention to the importance of considering on-going processes in these contexts, as the type and size of debris give relevant technological information related to the function and the intensity of human occupation.

With some minor exceptions, all cultural material is deposited on the surface and, depending on the environmental conditions, can be buried, unearthed and re-buried many times. Thus, a clear distinction between the buried and surface archaeological records is not completely possible, though processes that occur in one or other context act differently. In the next paragraphs, a synthesis of slope formation processes of the buried and surface archaeological records is presented.

2.1 | Buried archaeological record

The presence of vegetation (grass cover, shrubs or trees) plays a substantial role in particle downslope movement (artifacts and natural clasts) because it increases friction and thus decelerates or inhibits the transport of particles along the hillslope (Bertran & Texier, 1999b; Heydari, 2007), while roots stabilize and fix the matrix. Generally, the presence of vegetation is a consequence of climatic conditions, and both climate and vegetation are important soil formation factors (Birkeland, 1999). Therefore, the presence of vegetation is closely associated with soils. In turn, soil bioactivity, together with the slow or absent movement of surface particles, promotes the sinking of natural and cultural clasts (e.g., Balek, 2002). Interestingly, this process operates at short time intervals (about 1 year) and even in poorly developed soil profiles, as was demonstrated in the actualistic research conducted on vegetated slopes carried out by Martin and Borella (1999) and Massone, Jackson, and Prieto (1993) in Tierra del Fuego (at Cerro Cabeza de León Site and Tres Arroyos Site, respectively; Fig. 1a and b). Similarly, at the Tres Arroyos Site, Martin (2006) analyzed buried human remains placed along the hillslope (10°–18°). She concluded that, after body deposition, a rapid carnivorous action occurred, promoting disarticulation and displacement of skeletal elements. Finally, once stability was reached, a rapid burial took place.

If the archaeological record is buried, a unimodal vertical distributions of artifacts in the lower A/ AC soil horizons (or lower Ab/ ACb horizons) must alert us to consideration of soil biomechanical dynamics. It is well known that due to their depth and abundance of organic matter, these epipedons are the most affected by soil fauna, which sieve out the gravel fraction causing it to sink through soil horizons (Balek, 2002; Canti, 2003; Darwin, 1896; Favier Dubois, 2017; Kutschera & Elliott, 2010; Stein, 1983; Van Nest, 2002). Thus, although high burial rates preserve the archaeological record against subaerial weathering and temporal scattering, soil dynamics may also modify the vertical distribution and create a cumulative palimpsest (Bailey, 2007). This aspect is well illustrated at Marazzi 2 and Cerro Sin Nombre Sites (northern Tierra del Fuego, Chile and Argentina; Fig. 1d, e, and i), where low weathering stages of buried materials were recorded along with unimodal vertical distributions (Fig. 2).

It should be mentioned that the presence of a single mode in the vertical distribution of artifacts can also be derived from a single archaeological level. In this case, a single taphonomic story should be expected, as the record was deposited in a single synchronic episode. Additionally, cryoturbation and argilloturbation (Lenoble et al., 2008; Texier et al., 1998; Waters, 1992), can also sort artifacts by size and affect the vertical distribution and composition of the assemblage. In the latter scenarios, the recognition of expansive clays (smectite clay minerals) and/or frost action features (such as lenticular microstructures) may help to detect argillo/cryoturbation processes. In turn, pH, humidity, rooting, and microbial attack constitute biochemical hazards promoting destruction of buried material (e.g., Borrazzo, 2006, 2010; Gutierrez, 2004; Hedges, 2002; Karkanas, 2010; Lyman, 1994; Shahack-Gross, Bar-Yosef, & Weiner, 1997), thus burial archaeological record is not completely safe.

For the last two decades, a French team has focused on long-term experiments in periglacial environments resulting in the most systematic set of data concerning slope processes in extreme non-vegetated environments affecting the archaeological record (Bertran & Texier, 1995; Bertran & Texier, 1999a, 1999b; Bertran et al., 1997, Bertran, Bordes, Barre, Lenoble, & Mourre, 2006, 2010; Bertran, Lenoble, Todisco, Desrosiers, & Sørensen, 2012, 2015; Lenoble, 2005; Lenoble & Bertran, 2004; Lenoble et al., 2008; Texier et al., 1998). These actualistic studies found that, on slopes in periglacial settings, solifluction can create lobes that move irregularly at 1–10 cm/yr. This slow but constant process buries archaeological material and, after a certain time, mixing must be expected. In addition, a coarsening-upward trend has been observed within 1 year (Bertran et al., 2010; Lenoble et al., 2008; Texier et al., 1998). Experiments recorded that 3.6% of artifacts buried 10 cm deep were "frost-jacked" to the ground surface only 1 year after the beginning of the experiment, while 22.7% of artifacts buried at 5 cm progressively reached the ground surface during five subsequent years (Texier et al., 1998).

As noted in the introduction, downslope particle movement can be caused by transport of particles individually, or by the movement of the entire soil matrix. Soil creeping (Fig. 1d) is characterized by the accumulation of minimal displacements over long time periods, typically a few millimeters or centimeters per year, and affects the whole artifact assemblage (Lenoble et al., 2008). By contrast, fast processes such as earth flows can drastically invert archaeological stratigraphies, as reported in Wadi Ziqlab (northwestern Jordan) where Roman artifacts were buried over 1 m deeper than a Neolithic site only 200 m away, but located beyond the margins of the colluvial slopes (Field & Banning, 1998).

Among mass movement processes, landslides have specific effects on the archaeological record. For the Marazzi 2 Site (Tierra del Fuego, Chile), Morello et al. (2009) describe how rotational slides (Fig. 1e) along a cliff reduce the lateral extension of the site but preserve the vertical spatial relationships among the archaeological material contained in the pedo/sedimentological matrix. In contrast, the Espíritu Santo and Cañadón Alfa 1 Sites, also located along cliffs in northern Tierra de Fuego (Argentina), show a reduction in the distribution of the archaeological material due to falls and topples, which indeed destroyed the spatial relation of the record contained in the matrix (Borrazzo, 2010; Borrazzo & Borrero, 2015).

Finally, it is worth mentioning that gravity-driven process can also contribute to good preservation of the buried archaeological record. Rockfalls from caves or rockshelters can "seal" archaeological deposits, such as in the Kal Anar Rockshelter, where Epipaleolithic deposits were preserved due to a rockfall from the roof (Heydari, 2007). Similar situations of collapsed blocks have been reported at Sitio do Meio, Piauí, Brazil (Aimola et al., 2014) and Cueva del Medio, Última Esperanza, Chile (Martin et al., 2015).

In sum, some archaeological cases indicate that the degree of preservation of the archaeological record buried in slopes, as well as its spatial properties, need to be examined first. As was mentioned, even along slopes the soil biomechanical action may contribute to rapid particle burial (e.g., Canti, 2003), so this is not a guarantee of spatial stability and preservation once within the soil matrix. Relative substrate hardness and animal trampling may accelerate sinking processes (e.g., Borrero, 2007; Nielsen, 1991; Otaola & Tripaldi, 2016). In contrast, in environments that lack soil development, more mixing and subaerial weathering could be expected, depending on the slope angle and biotic factors. Rockfalls or block collapses may offer good preservation conditions of the deposit underneath, whereas mass movement processes can even cause a stratigraphic inversion. On the other hand, both rotational and translational slides can affect the extent and spatial integrity of an archaeological site, although they allow the integrity of the matrix containing the archaeological record to be preserved.

2.2 | Surface archaeological record

Between the deposition of anthropogenic or natural material and their burial, there is a varying probability of downslope movement. Rick's (1976) model proposed that, in slopes with little vegetation, lack of

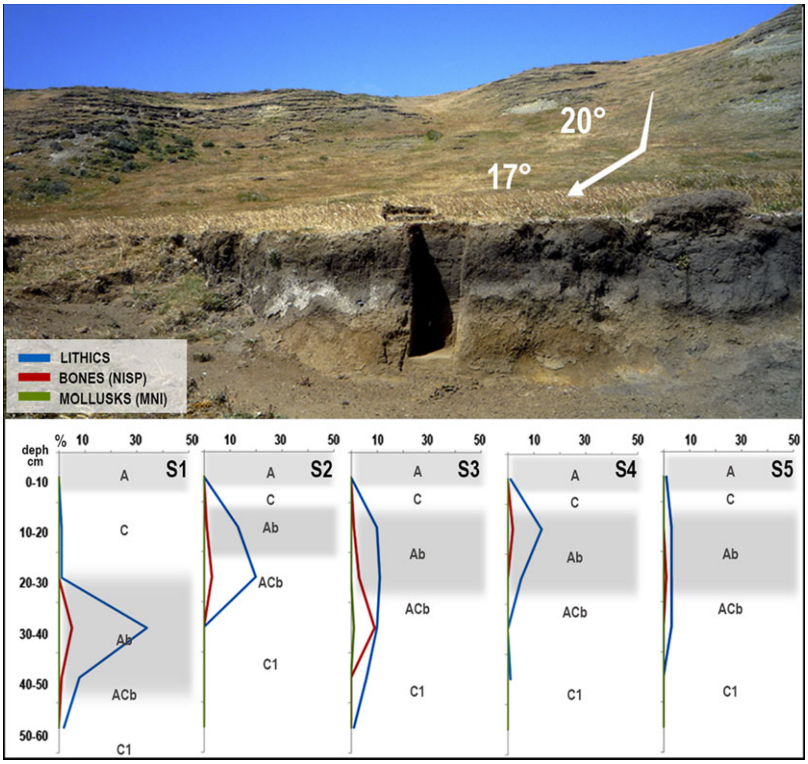

FIGURE 2 Vertical frequency distribution of the archaeological material of Marazzi 2 Site, Sector 2 (S1, S2, S3, S4, and S5 are pits placed at the footslope). Abscissa axis shows the soil horizon (A-C-Ab-ACb-C1) by depth in centimeters. The unimodal pattern is interpreted as a result of the soil biomechanical effect [Color figure can be viewed at wileyonlinelibrary.com]

frost action, and overland flows, denser and heavier artifacts were more likely to move and thus to be found further downslope. However, the processes involved in sorting artifacts along slopes are variable. On the hillslope below Ccurimachay Rockshelter, Perú, Rick found that an inverse relation between artifact weight and slope angle may occur when a slope is steeper than 16°–17°, and particles are heavier than 2–8 g. As well, Hètu and Vandeklac (1989) found that compact and isometric particles reach the footslope more frequently than platy-shaped elements (also see Van Steijn, Bertran, Francou, Hétu, & Texier, 1995). At slope angles higher than 32–35°, rolling is able to occur. At lower slope angles, stones remain close to the impact point on the hillslope. Other processes act to redistribute the debris downslope (debris flows, overland flows, solifluction, creeping), resulting in specific spatial patterns and size distribution. For instance, mass movement generally leads to poor downslope sorting.

Surface transects conducted at the Cóndor 1 Site (Southern Patagonia, Argentina; Fig. 1c) recorded the weight and frequency of lithic artifacts along with the presence of vegetation, natural traps, and slope angle (Barberena, 2008). Major lithic abundance was concentrated at the middle of the hillslope, decreasing downslope, and heavier material occurred at the footslope, independent of the angle (4°–16°) and the presence of natural traps. Despite angles being below the critical thresholds proposed by Rick (1976), this case fits relatively well with that model, so there are other critical variables beyond slope angle. Barberena (2008) drew attention to biotic factors (e.g., animal kicking), as Bertran et al. (2015) did for periglacial context in Southwest France (see below). In contrast with Rick's model, the most abundant material was found in the upper and middle hillslope at the Cerro Cabeza de León Site. Here, the presence of natural traps such as rocks or a denser vegetated cover were the main reason for the observed distribution, independent of slope angles and clast weights (Favier Dubois, 1998; Martin & Borella, 1999). Microtopographic changes over the hillslope may also explain the distribution of the archaeological record, as demonstrated by Oría et al., (2014) on a <10° slope at Amalia 5 Site (Tierra del Fuego, Argentina), where the record was more concentrated in sectors of the hillslope with lower angles (also see Martin, 2006).

An experimental study was carried out at the Cerro Sin Nombre Site (Fig. 1i), quantifying surface natural clasts weathered from the sandstone shelter and distributed down the hillslope at the upper, medium, and lower levels (Fig. 3). Table I summarizes the slope angles of each transect, its grass cover percentages, absolute clasts frequencies, size range distributions, clast orientations with respect to the slope (only registered for elongated clasts) and some additional data concerning estimations of relative frequencies of burial gravel and blocks. Altogether, this survey showed that (1) clast frequencies decrease toward the footslope (namely, there are more clasts near the primary source); (b) there is no order in the size range distributions with respect to the slope angle, nor the hillslope level; (c) there is a weak direct relationship between the abundance of clasts found on the surface and the abundance of buried clasts; and (d) clast orientation is mainly subparallel to the slope, although it does not seem to be conditioned by slope angle or grass cover. Even though these data are preliminary, one could state that since clast movement along this vegetated hillslope (<15°) is low,

TABLE I Results of the four experimental transects (see Fig. 3a, b, and c)

Surface Clasts Along the Slope										Buried Clasts Recorded in Test Pits	
				Abundance According to Size Range							
Experimental Transects (~25 m)		Grass Cover (%)	Absolute Frequency (*n*)	<1 cm^2	1–10 cm^2	<40 cm^2	<100 cm^2	<250 cm^2	Orientation of Elongated Clasts[a]	Gravel Fraction (2–10 mm) Relative Frequency[b] (%)	Presence of Blocks (~70 cm Long)
T1	Upper 10°	90–100	33	–	2	10	6	15	90°–113°–0°–0°	~15	Yes
	Medium 5°	100	4	–	0	4	0	0	23°		
	Low 0°	100	0	–	0	0	0	0	n/r		
T2	Upper 10°	0–20	130	Abundant	114	13	1	2	23°–23°–23°–23°		
	Medium 5°	80–100	45	–	9	21	8	7	0°–90°–0°–45°		
	Low 0°	100	6	–	0	5	0	1	135°–135°–135°		
T3	Upper 10°	30–70	71	Frequent	57	6	7	1	45°–135°–90°–0°113°–23°	~7	No
	Medium 10°	100	20	–	6	8	4	2	113°–68°–90°		
	Low 5°	100	0	–	0	0	0	0	n/r		
T4	Upper 15°	0–90[a]	28	Abundant	18	9	0	1	n/r	~8	No
	Medium 10°	10–90[a]	33	Abundant	16	7	5	5	45°–135°		
	Low 10°	100	13	–	5	5	1	2	45°		

Superficial clast properties were quantified along with contextual information, including estimations of relative frequencies of coarse-buried material.

[a] Each angle comprises a single-clast orientation and 0° (so its opposite direction at 180°) refers to an orientation parallel to the slope (see Fig. 3d).

[b] Estimated by averaging the percentage of the gravel fraction recorded at 10-cm intervals up to a depth of ~70 cm.

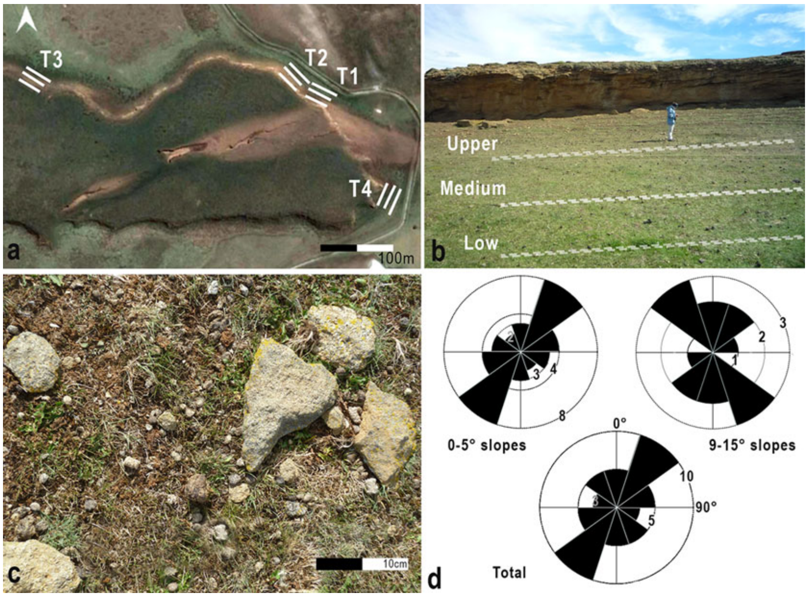

FIGURE 3 Superficial clast quantification at the Cerro Sin Nombre Site. (a) Satellite image of the sandstone outcrop with the location of the four transects carried out on the hillslope. (b) Detail of the upper, medium, and lower levels of each transect. (c) Example of natural clasts recorded on the surface. (d) Orientation rose diagrams corresponding to low (0–5°), high (9–15°), and total (0–15°) angle slopes [Color figure can be viewed at wileyonlinelibrary.com]

one would expect a low horizontal displacement of the archaeological record, as was suggested by a previous taphonomic study (Ozán, Borrero, Borrazzo, & L'Heureux, 2015). The grass cover, the tabular shape of the sandstone and its high weathering rate could reduce the capacity for clast movement and increase the likelihood of sinking. Notably, only 10 archaeological stone artifacts were found on surface, versus the ~900 recovered in the excavations.

Concerning the role of water, a fining downslope pattern of clasts has been proposed as a consequence of overland flows (e.g., Bertran et al., 2012; Fanning & Holdaway, 2001; Schick, 1986), although in contexts with rare vegetation. In western New South Wales (Australia), it was found that even at low gradients (<5°), artifact size and slope angle were significantly related, but in a different way to Rick's model (Fanning & Holdaway, 2001). The authors noted that smaller particles transported by overland flows moved farther downstream than larger particles, and this effect increased with slope angle (see also Nash & Petraglia, 1987; Schick, 1986; Wainwright & Thornes, 1991).

In another experiment, particle size distributions of different Paleolithic experimental debitage were analyzed by Lenoble (2005) and Bertran et al. (2012), determining that a strong sorting would not be expected in anthropogenic discard. On the contrary, overland flow rapidly causes a weak longitudinal grain size gradient, from coarser to finer fractions downslope, with variable thresholds depending on the flow speed, particle size, shape, microtopography, soil saturation, and rain intensity (Fanning & Holdaway, 2001; Lenoble, 2005; Middleton & Southard, 1984; Schick, 1986; Texier et al., 1998). Similarly, in the case of the Cerro Sin Nombre Site described above, histograms of the size range of archaeological artifacts were made to analyze natural biases. Figure 4 presents the Bertran et al. (2012) experimental knapping size range histogram compared with the Cerro Sin Nombre Site and the particle size distribution of lithic assemblages affected by overland flows (Lenoble, 2005). This comparison shows that in the case of Cerro Sin Nombre some hillwash processes could have disturbed the anthropogenic pattern by affecting the smaller size range of the expected knapping pattern. Of course, technological or other human behavior could have also affected the distribution.

Bertran et al. (2015) conducted a 5-year study in periglacial and alpine contexts (French Pyrenees) in order to analyze taphonomic issues concerning bones and flint artifacts within a cave and its immediate exterior. They carefully measured climatic variables and placed experimental material in several subareas within each context, including slopes between 15° and 34°. Lithic displacement outside the cave, down a 22° slope, was between 1 and 3.5 cm/yr, while bones showed a greater displacement of 15.5 cm/yr. Fresh bones were displaced even further, at a rate of over 25 cm/yr, as they were also affected by scavenging (Bertran et al., 2015). Additionally, the authors found that experimental artifacts were also affected by creeping (from 2.1 to 13.6 cm/yr) due to the impact of debris falling as a result of rockwall weathering at the entrance space of the cave. Interestingly, they observed a relationship between the weight of fallen debris and the average artifact movement. Furthermore, Lenoble et al. (2008), by setting an experimental knapping station on a solifluction lobe, demonstrated a downslope translation of the gravity center, resulting in an artifact density decrease.

Finally, shelters and vegetation are strong animal attractors so that trampling, kicking, and fractures may be expected on slopes associated with them (see also Borrero, 1990, 2001, 2003, 2007; Balirán, 2014; Bertran et al., 2015; Fiorillo, 1988; Gifford-Gonzalez, Damrosch, Damrosch, Pryor, & Thunen, 1985; Lenoble & Bertran, 2004; Martin, 2006; Nielsen, 1991; Olsen & Shipman, 1988; Oría et al., 2014, Oría, Salemme, & Vázquez, 2015; Otaola, 2014; Otaola & Tripaldi, 2016). Rapid and significant displacement of bone fragments as a

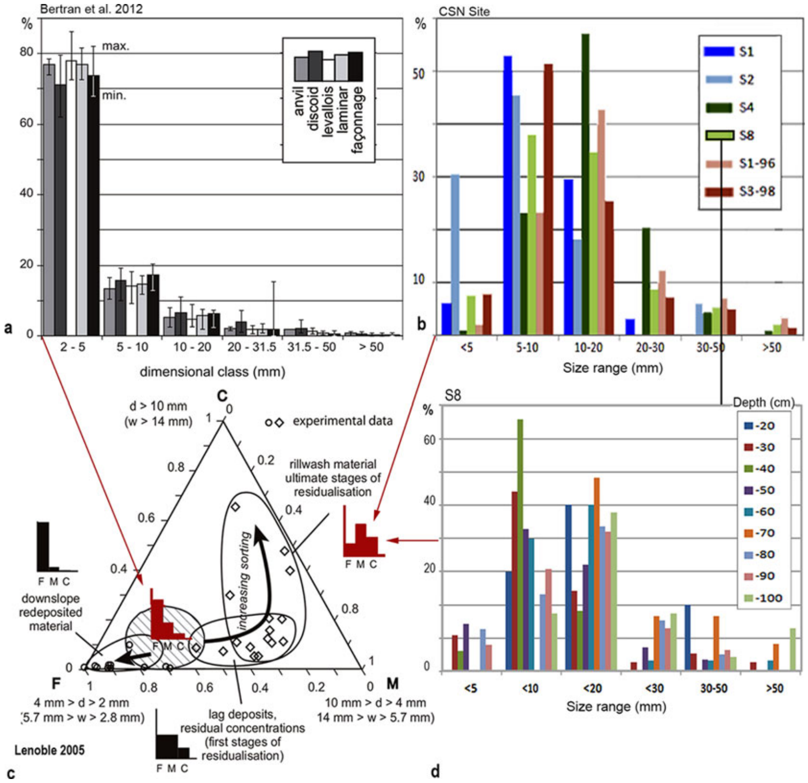

FIGURE 4 (a) Size-range histogram of experimental knapping using different techniques (Bertran et al., 2012). (b) Size-range histograms of buried lithic assemblages of the Cerro Sin Nombre Site, with S_x excavation units. (c) Diagram presenting some lithic assemblages affected by natural process on slopes such as water flow, hillwash, among others (modified from Lenoble, 2005). (d) Size-range histograms of the Unit S8 (Cerro Sin Nombre) considering the frequencies by depth [Color figure can be viewed at wileyonlinelibrary.com]

consequence of scavenging was also recorded in longitudinal studies carried out in Mendoza, Argentina (Otaola & Tripaldi, 2016), and in the cold semiarid steppe of Tierra del Fuego (Martin, 2006; Massone et al., 1993; Fig. 1d). Also in the region of Tierra del Fuego, Borrero (2007) observed also a significant burial rate within a year, due to animal trampling in muddy substrates. Biotic factors are probably more intense in vegetated areas, though they are also present in nonvegetated slopes.

3 | DISCUSSION: PROCESSES, EXPECTATIONS AND METHODOLOGIES

Geological, climatic, and biological factors imprint any hillslope deposit comprising both natural and cultural materials. Their complex interaction does not allow the differentiation of clear boundaries between these factors when analyzing the record. Nonetheless, all these factors comprised processes that impact the archaeological record, modifying its spatial properties and integrity. By critically integrating the information from the study cases discussed above, Table II summarizes the interplay among these processes, including their characteristics, controlling variables, impact on the archaeological record, archaeological expectation, and suitable methodological perspectives for detecting and understanding the type and degree of postdepositional modifications.

Despite the fact that some processes are assumed to act all along the hillslope, they are never absolutely continuous, so one would expect a variety of taphonomic stories, sedimentation rates, temporal resolution, and pedogenetic developments within a single archaeological locality, over areas of tens to a couple hundred meters in diameter (Bertran et al., 2015; Borrazzo, 2010; Favier Dubois, 1998; Martin & Borella, 1999; Ozán et al., 2015; Straus, Akoshima, Petraglia, & Séronie-Vivien, 1988). Thus, an extensive sampling strategy based on a geomorphic inspection of the area will definitely yield a more realistic picture.

Of course, several of the processes presented separately in Table II may occur together, and some may even overlap and obliterate the signature of previous ones (e.g., bioturbation alters eolian beddings). Moreover, exceptional and catastrophic phenomena can rapidly change the situation, for example, the flooding caused by beaver dams in Tierra del Fuego (Borrero, 2007). Hence, the most frequently occurring processes are not necessarily those most represented in the sedimentological, micromorphological, or geochemical records. Once again, the broader the sampling area, the more likely one is to identify the range and diversity of processes that modify the properties of the archaeological record.

Most of the study cases reviewed are based on actualistic research, so there are ample data from which to establish some archaeological expectations of the influence of each process. These long-term expectations are theoretical and assume that the archaeological record was deposited at the upper end of any hillslope. As can be observed in

TABLE II Synthesis of the main biophysical processes that modify the archaeological record on slopes

Formation Processes of the Archaeological Record Placed on Slopes								
	Process	**Spatial Distribution**	**Speed**	**Frequency of Occurrence**	**Controlling Variables**	**Impact on the Archaeological Record and Long-Term Archaeological Expectation**	**Methodological Approach**	**Study Cases**
Geological factors	Creeping	Continuous along the slope	Slow	Continuous	Slope angle, water content, mineralogy, presence of vegetation	Low. On surface record: horizontal migration downslope. Long-term expectation: higher frequencies at the footslope. Palimpsests. Slope parallel orientation	Modern observations and measurements (e.g., longitudinal experimentations), fabric studies. Magnetic properties[a]	Lenoble et al. (2008)
	Rockfalls, topple, bouncing, and rolling	Sectored or associated with cliff fronts, rockshelters, caves, and walls	Rapid/moderate	Discontinuous	Outcrop presence, lithology, vegetation (source of friction), slope angle, microtopography, size, weight, and clast shape	Variable. On burial record: rockfalls can "seal." On surface record: horizontal migration. Long-term expectation: rockfalls may preserve subsurface deposits. On surface record: higher frequencies at the footslope or flatter topography along the hillslope. Sorting (heavier clasts at the footslope). Rounded edges. Palimpsests	Geomorphology, taphonomy, sedimentology, micromorphology	Rick (1976), Favier Dubois (1998), Bertran and Texier (1999a), Martin and Borella (1999), Martin (2006), Heydari (2007), Barberena (2008), Borrazzo (2010), Aimola et al. (2014), Oría et al. (2014, 2015), Borrazzo and Borrero (2015), Martin et al. (2015), Ozán et al. (2015)
	Landslides (rotational and translational)	Sectored along the slope	Slow	Discontinuous	Slope angle, soil structure, abundance of vegetation, mineralogy	Low. On surface and burial record: horizontal displacement. Long-term expectation: reduce the lateral extension of the site but preserve—for a period of time—the vertical spatial relationship among the archaeological materials contained in the pedo/sedimentary sequence	Geomorphology	Morello et al. (2009)

(Continues)

TABLE II (Continued)

Formation Processes of the Archaeological Record Placed on Slopes

	Process	Spatial Distribution	Speed	Frequency of Occurrence	Controlling Variables	Impact on the Archaeological Record and Long-Term Archaeological Expectation	Methodological Approach	Study Cases
	Earth flow and debris flow	Sectored to lobes or channels	Rapid/moderate	Discontinuous, more or less periodic	Slope angle, soil structure (compaction, porosity, lithology, etc.), abundance and type of vegetation. Frequency and intensity of triggers such as rain, earthquakes, anthropogenic activities, etc.	High. On surface and burial record: horizontal migration. Abrasion (destruction). Rotational slumps can preserve the internal relationship between components within single blocks. Long-term expectation: higher frequencies at the footslope. Poor downslope sorting. Higher probabilities of buried record. Palimpsests. Stratigraphic inversion. High degrees of weathering. Orientation parallel to slope	Geomorphology, sedimentology (granulometry, shape, fabric orientations, etc.). Macro and microstratigraphic analysis. Actualistic observations. Taphonomy. Magnetic properties	Field and Banning (1998), Bertran and Texier (1999a)
Climatic factors	Expanding/shrinking cycles due to frost/melting cycles or expansive clays. The latter is also a geological factor[b]	Continuous along the slope. The effect decreases with depth	Slow	Periodic/seasonal	Temperature, humidity, granulometry, mineralogy	Low. On buried record: some vertical upward migration of coarser fraction (frost-jacking). Long-term expectation: sorting (coarsening upward pattern). Palimpsests. Stratigraphic inconsistencies. Isotropic orientation	Sedimentology, micromorphology, mineralogy	Waters (1992:292–300), Texier et al. (1998), Lenoble et al. (2008)
	Overland flow/rillwash/run-off	Continuous along the slope. Sectored in channeled flows	Variable	Periodic/seasonal	Vegetation, microtopography (natural traps), slope angle, liquid/solid precipitation, and soil saturation capacity (granulometry, drainage, etc.)	Variable. On surface record: horizontal migration downslope. Rillwash exposes, transports and mixes buried materials. Physical weathering (destruction). Long-term expectation: sorting (fining downslope pattern). Higher frequencies at the footslope. Palimpsests. Slope parallel orientation of the surface record	Sedimentology, pedology, taphonomy. Magnetic properties	Schick (1986), Nash and Petraglia (1987), Texier et al. (1998) and Bertran and Texier (1999a), Fanning and Holdaway (2001), Lenoble (2005), Bertran et al. (2012), Ozán et al. (2015)

(Continues)

TABLE II (Continued)

Formation Processes of the Archaeological Record Placed on Slopes								
	Process	Spatial Distribution	Speed	Frequency of Occurrence	Controlling Variables	Impact on the Archaeological Record and Long-Term Archaeological Expectation	Methodological Approach	Study Cases
	Solifluction	Sectored to solifluction lobes	Slow/moderate	Seasonal	Temperature, humidity, granulometry, mineralogy	High. On surface record: horizontal migration, dispersion, burial. On buried record: upwards vertical migration (frost-jacking). Long-term expectation: sorting (coarsening upward pattern). Higher frequencies at the footslope. Palimpsests. Orientation parallel to slope	Geomorphology, sedimentology, fabric analysis. Magnetic properties	Texier et al. (1998), Bertran and Texier (1999a); Lenoble et al. (2008), Bertran et al. (2010), Bertran et al. (2015)
	Eolian action^{b}	Windward and leeward hill faces	Slow/moderate	Dependent on the local wind dynamic	Wind intensity, availability of sandy sediments, microtopography (natural traps)	Low. On surface record: concentration of coarser particles. Abrasion (destruction). Burial. Low-term expectation: high degree of weathering. Sorting. Palimpsest (due to deflation and/or migration of very small material)	Sedimentology, taphonomy	Borrazzo (2010, 2013), Oría et al. (2014)
Biological factors	Soil biomechanical action, rooting, bioactivity^{b}	If at least a weak soil profile is developed, continuous along the slope	Rapid	Continuous	Humidity, temperature, low or lack of detrital input. Profile depth	High. On surface record: rapid burial. On buried record: biophysicochemical attack (destruction). Long-term expectation: isotropic orientation of the surface record. Unimodal vertical distributions with peaks in lower A or AC soil horizons. Palimpsests. Variable degrees of weathering. Root marks, carbonates, manganese and iron oxide precipitation	Pedology, vertical quantification of the archaeological record	Stein (1983), Bertran and Texier (1999b), Balek (2002), Van Nest (2002), Canti (2003), Heydari (2007), Borrazzo (2009, 2010), Kutschera and Elliott (2010), Ozán and Tchilinguirián (2015); Favier Dubois (2017); among others

(Continues)

TABLE II (Continued)

Formation Processes of the Archaeological Record Placed on Slopes

	Process	Spatial Distribution	Speed	Frequency of Occurrence	Controlling Variables	Impact on the Archaeological Record and Long-Term Archaeological Expectation	Methodological Approach	Study Cases
	Trampling, kicking (large mammals, >50 kg), pulling, transportation (scavengers such as canids, birds, felines, etc.), and burrowing (fossorial animals such as rodents)[b]	Discontinuous	Rapid	More or less continuous	Zoogeography (latitude), substrate hardness (porosity, granulometry, humidity, lithology, etc.). Presence of shelters or vegetation that attract animals	High. On surface record: fragmentation, burial (trampling), horizontal migration (kicking, pulling), destruction (chewing, digesting). Dispersion. On buried record: vertical migration (by burrowing). Long-term expectation: isotropic orientation. Carnivorous marks on bones. Physicochemical weathering. High fragmentation. Palimpsests	Taphonomy	Gifford-Gonzales et al. (1985), Fiorillo (1988), Olsen and Shipman (1988), Borrero (1990, 2001, 2003, 2007), Nielsen (1991), Massone et al. (1993), Martin and Borella (1999), Lenoble and Bertran (2004), Bertran et al. (2006, 2015), Martin (2006), Balirán (2014), Otaola (2014), Bertran et al. (2015), Oría et al. (2015); Otaola and Tripaldi (2016); among others

[a] Magnetic properties may be a useful tool if there are indirect combustion signals such as charcoal or burnt bones.
[b] Processes that also occur without slope.

Table II, most of the expectations concern the existence of palimpsests and higher frequencies of the archaeological material at the footslope. Sedimentological, micromorphological, and taphonomic evaluation may reduce equifinality. In the next paragraphs, the main methodological approaches to recording processes and their impact are detailed.

3.1 | The archaeological record: Taphonomy

A careful examination of the macro- and microscopic archaeological record constitutes a fundamental step to alert one to preservational biases (Bertran et al., 2012; Borrazzo, 2010; Paddayya & Petraglia, 1993; Fig. 5a and b). In a sloping site, low artifact diversity, high sorting, a strong axis orientation, high and/or different weathering stages recorded at the same depth (e.g. Fig. 5a), and/or unimodal vertical distributions are some of the properties that should call attention to postdepositional modifications. Additionally, comparison (frequency, size, spatial distribution, orientation, degree of weathering, etc.) between natural gravel and artifacts offers insights into depositional agents and, therefore, reworking processes of the archaeological record (e.g., Bertran et al., 2012; Borrazzo, 2009; Ozán, et al. 2015; cf. Lahaye et al., 2015).

The distinction between surface and buried archaeological records has to be treated with caution. Here, taphonomy is one constructive way to discuss the relative subaerial permanence of any particle. In other words, as all of the buried record was on the surface at some time in the past, only the study of specific properties can tell us how long it was on the surface, and then, how appropriate is the distinction between surface and buried assemblages (Borrazzo, 2010, 2013; Borrazzo & Borrero, 2015). Even though lithic and bone assemblages must be considered separately, some relevant indicators of subaerial/burial permanence are weathering degrees, root marks, carnivore/ rodent marks, cracks, presence of lichens, abrasion (degree of roundness), exfoliation, chemical precipitations (carbonates, iron and manganese oxides, etc.), varnishes, horizontal and vertical dispersion of the assemblage, disarticulation, and degree of fragmentation (e.g., Behrensmeyer, 1978; Binford, 1981; Blumenschine, 1989; Borrazzo, 2006, 2009, 2010; Borrero, 1990; Gifford, 1981; Hiscock, 1985; Lyman, 1994). A considerable number of investigations have also been published concerning microtaphonomical issues, such as recrystallization processes, mineral neoformations, dissolution rates, histological preservation, microfissures, among other features (e.g., Berna, Matthews, & Stephen, 2004; Estévez, Villagran, Balbo, & Hardy, 2014; Hedges, 2002; Hedges & Milliard, 1995; Karkanas, 2010; Stiner, Kuhn, Weiner, & Bar-Yosef, 1995; Villagrán et al., 2011).

3.2 | Geomorphology and sedimentology

Along with taphonomy, geomorphology and sedimentology also contribute to understanding the dynamics of deposition and erosion. A detailed geomorphological description carried out at the appropriate spatial scale, that is, consistent with the extent of the archaeological site, is recommended prior to sampling and subsequent sedimentological and micromorphological analysis. Landforms provide context for individual deposits.

Among sedimentological approaches, granulometric studies are central to determining the transport capacity (sorting) of natural agents, as well as whether particle size distributions within the archaeological record are biased by natural processes. In a primary archaeological context, one should not expect agreement between the particle size histograms of the archaeological artifacts and the sedimentary matrix that contains them. However, in some cases of significant transport, the size composition of an archaeological assemblage can be different from that of the host sediment. To monitor this possibility, the sampling strategy should cover a broader area, beyond the archaeological site "boundaries," and take into account the diverse associated landforms. To analyze artifact transportation, special attention should be given to the record itself (e.g., rounded edges, abrasion, etc.). If thin sections are available, type of minerals, particle shape, and orientation can also be described, offering useful information about erosive unconformities, sediment sources, and syn/postdepositional processes (Fig. 5c and d). The study of clast orientation with respect to the slope constitutes a complementary tool toward the understanding of single or collective slope processes. Although clast orientation is not unequivocal—for example, isotropic orientations of vegetated slopes may obliterate evidences of other processes—abundant research points out that processes such as creeping, solifluction, mudslides, debris flows, and dry grain flows leave slope-parallel preferred orientations, and rockfall and runoff movements leave planar to plurimodal orientations (Bertran & Texier, 1995; Bertran et al., 1997; Bertran et al., 2015; Lenoble & Bertran, 2004; Texier et al., 1998).

3.3 | Soil studies

Both surface and buried archaeological material placed on soils need to be interpreted in the light of pedogenetic processes (Holliday, Ferring, & Goldberg, 1993). Macro- and microscopic observations of profiles give information about biochemical processes (e.g., bioactivity intensity, pH, REDOX, etc.) that could bias the integrity of the archaeological record, whereas the degree of soil development also offers a relative time frame for the human occupation palimpsests (Bailey, 2007). The more developed the soil, the longer the time span of upper horizons, so the more likely there is to be mixture of the temporal record (see above and Fig. 2).

As an example, buried archaeological material within an A horizon (e.g., up to ∼30- to 40-cm deep) was probably deposited on a surface and reached its current position by trampling and/or biomechanical action. As the grass cover (the top of a soil) is time-transgressive and contributes to geomorphological stability, the archaeological material contained in A-AC horizons is likely a palimpsest. Moreover, due to the fact that in hillslopes the particle kinetic energy is higher, palimpsests found in upper soil horizons are probably not only "cumulative," but also "spatial" (*sensu* Bailey, 2007). Taphonomy at different scales of resolution and "taxon-dates" are the best way to confirm the degree of chronological and "behavioral" mixture (Binford, 1981; Grayson, 1987).

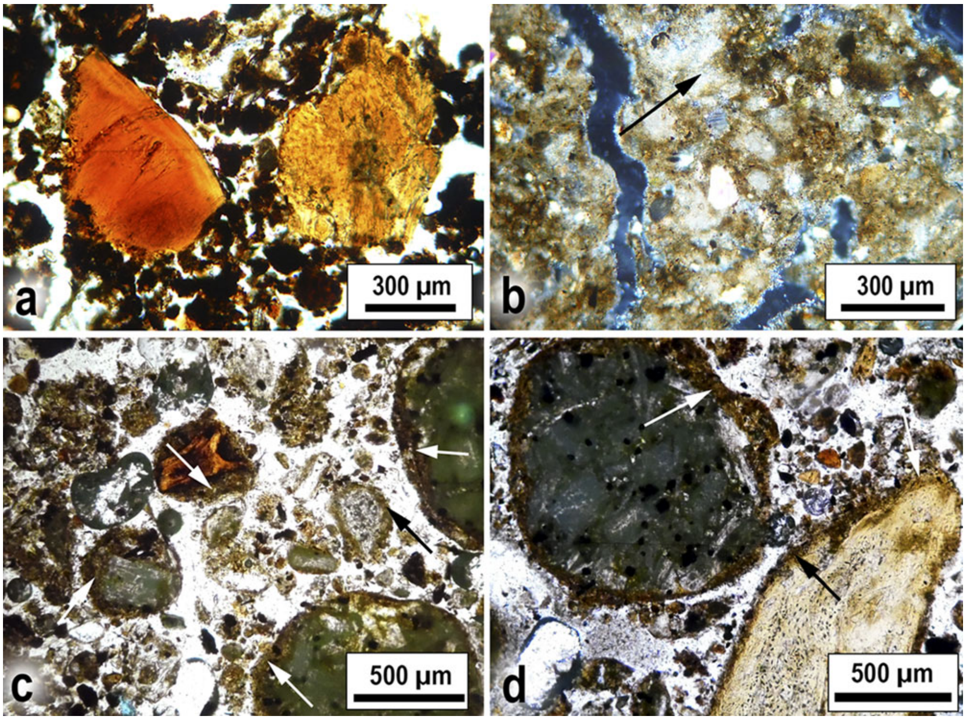

FIGURE 5 (a) Microphotographs show two bone fragments probably deposited at different times as shown by their different weathering stages (Cerro Sin Nombre Site, plane polarized light, S4 18–30 cm). (b) Calcitic ash embedded in the groundmass and interpreted as a nonreworked deposit (Marazzi 2 Site: cross-polarized light; P1 63–75 cm). (c, d) Arrows point a "ring" (coating) of highly humified organic matter around minerals, rocks, and bone fragments interpreted as a consequence of particle rolling promoted by gravity (Cueva de la Vieja Site, plane polarized light, 32–44 cm) [Color figure can be viewed at wileyonlinelibrary.com]

On the other hand, archaeological material contained within a C horizon could have been deposited (1) before pedogenesis (as C horizons are the parent material of soils), or be a consequence of (2) vertical migration due to burrowing, cryo/argilloturbation, rooting, etc. Other scenarios should be evaluated by soil micromorphology in order to better understand soil processes and macro- and microtaphonomy (see above). Finally, the archaeological record found in B horizons was likely deposited during the soil-forming processes of "aggradational soils" (Birkeland, 1999) or reached that depth by vertical migration, such as with C horizons. Thus, taking these mechanisms into consideration and if the dates of pedogenetic processes are known, one can establish a relative temporal framework for the archaeological record contained within a soil profile (Holliday et al., 1993; Ozán & Tchilinguirian, 2015).

Analysis of magnetic properties within soils and parent material can also contribute to discussions concerning postdepositional slope effects (Dalan & Banerjee, 1998). For instance, at the Marazzi 2 Site (Tierra del Fuego, Argentina), a buried archaeological record near a moraine slope was thought to be reworked by gravity-driven processes. However, a detailed stratigraphic study of magnetic properties at the foot of the moraine showed an increase in soil magnetic susceptibility caused by combustion (Ozán & Orgeira, 2015). In areas with a lack of natural fires, if sediments were thermally modified by human populations (therefore showing a high magnetic susceptibility signal), then the archaeological material within the matrix under investigation must be a primary deposit.

4 | CONCLUSION

Although gravity-driven processes occur on all slopes, other processes that are not gravity-dependent must also be taken into account to arrive at an accurate and holistic interpretation of the archaeological record in these sedimentary contexts. A complex interaction between climatic, geologic, and biological processes takes place along hillslopes making the establishment of sharp slope classification criteria difficult. *A priori*, the archaeological record must be considered as modified by environmental factors and research designs built toward understanding those modifications. Each process affects the archaeological record in a singular way, though the existence of palimpsests seems to be a common postdepositional result of all the processes that take place on slopes. Surveying should extend beyond the apparent limits of the archaeological site. A detailed geomorphological description together with sedimentological studies, macro/microscopic soil evaluations, and a taphonomic treatment of the archaeological record are definitely the appropriate complementary approaches for a more nuanced archaeological interpretation at any spatial scale.

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