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Mega-terracettes and related ungulate activities in Loess Hills, Iowa, USA

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with 11 figures and 4 tables

Summary. Terracettes are small, quasi-parallel, staircase-like, stepped landforms generally <1 m in tread width and riser height, as long as 300 m, and located transversely along slopes. Numerous theories purport to explain causal mechanisms, including animal disturbance, soil creep, solifluction (gelifluction), slumping and rotational slippage, regolith and vegetation control, subsidence, and anthropogenesis or tectonism. Terracettes in the western Iowa Loess Hills were characterized morphogenetically, with field observations suggesting high association with ungulate activities. A new class of mega-terracette is recognized that characterizes study- area forms orders of magnitude larger than those discussed by others. This addition to the prior terracette morphologies adds to understanding of concepts of equifinality in which terracettes result from multiple processes. These mega-terracettes are related to ungulate activities of geophagy, soil transport from hooves, compaction, smearing, pawing, and wallowing (dust bathing) as well as the effects of variable soil moisture on erosion of the forms.

Key words: terracette landforms, anthropogenesis, zoogeomorphology, polygenesis

1 *Introduction*

Terracettes are a microform occurring on slopes, and may be the most widely dis- tributed micro-relief feature on Earth (Young 1972). Locally, they are small, quasi- parallel, staircase-like, stepped landforms, generally < 1 m in tread width and riser height and as long as 300 m that are located transversely along grassy, loess-mantled slopes. Terracettes occur in almost all parts of the Earth that have regolith-mantled slopes with textures ranging from sand to silt (Rahm 1962), although they are most extensive in humid environments (Fairbridge 1968, Parsons 1988, Verster 1986).

Terracettes are hypothesized to be of varied genesis, and many theories purport to explain causative mechanisms. The microform falls under the quasi-synonymous terms of *convergent*, *polygenetic,* and *equifinal* landforms. Processes creating terracettes are; animal disturbance (Anderson 1972, Butler 1995, Darwin 1890, Higgins 1982, Rahm 1962, Thorn 1978, Trimble 1995), soil creep (Costin 1950), solifluction (Costin 1950), gelifluction (Demangot 1951), slumping and rotational slippage (Odum 1922, Sharpe 1960, Vincent & Clark 1979), regolith control (Dar- win 1890, Carson & Kirkby 1972), vegetation control (Young 1972), subsidence (Brice 1965), anthropogenesis (Wood 1961), and tectonism (Bielecki 2002).

Because of the numerous theories associated with terracettes, multiple names are applied. Some of the most common are *catsteps* (Brice 1958, Dillon 2006, Kay & Apfel 1929, Mutel 1989), *sheep paths, sheep roadies, sheep walks* (Odum 1922, Sharpe 1960), *cowtours* (Trimble 1995) *cattle terraces*, *lynchets* (Wood 1961), *mill surfaces, rynkeli, horizontalrynker, liketrykslinjer* (Odum 1922, Sharpe 1960), *peds de vanche, sols a gradins* (Tricart 1969), and a variety of vernacular terms such as cow paths, deer trails and grazing steps.

Explanations of terracette origins relying on theories of polygenesis are not fully accepted, nor is there a general consensus as to dominant processes responsible for terracette formation. Most literature considers terracette genesis to be of varied, enigmatic origins. Terracettes have been considered a “geomorphic ambiguity” (Rahm 1962), “controversial” (Verster 1985, Vincent & Clark 1976) and “often mentioned but little studied” (Gerrard & Webster 1979). Few prior studies on terracettes exist in the Loess Hills of Iowa.

1.1 *Study area*

The area studied is in the Loess Hills of western Iowa that extend north along the western border of the state to eastern South Dakota and into northwestern Missouri (fig. 1). The bluffs of the Loess Hills are particularly noticeable from the Missouri River floodplain because they were undercut and steepened in some places by the Missouri River during the Late Pleistocene and Holocene. The study area is a 141.6- hectare pasture in Pottawattamie County, IA (fig. 2).

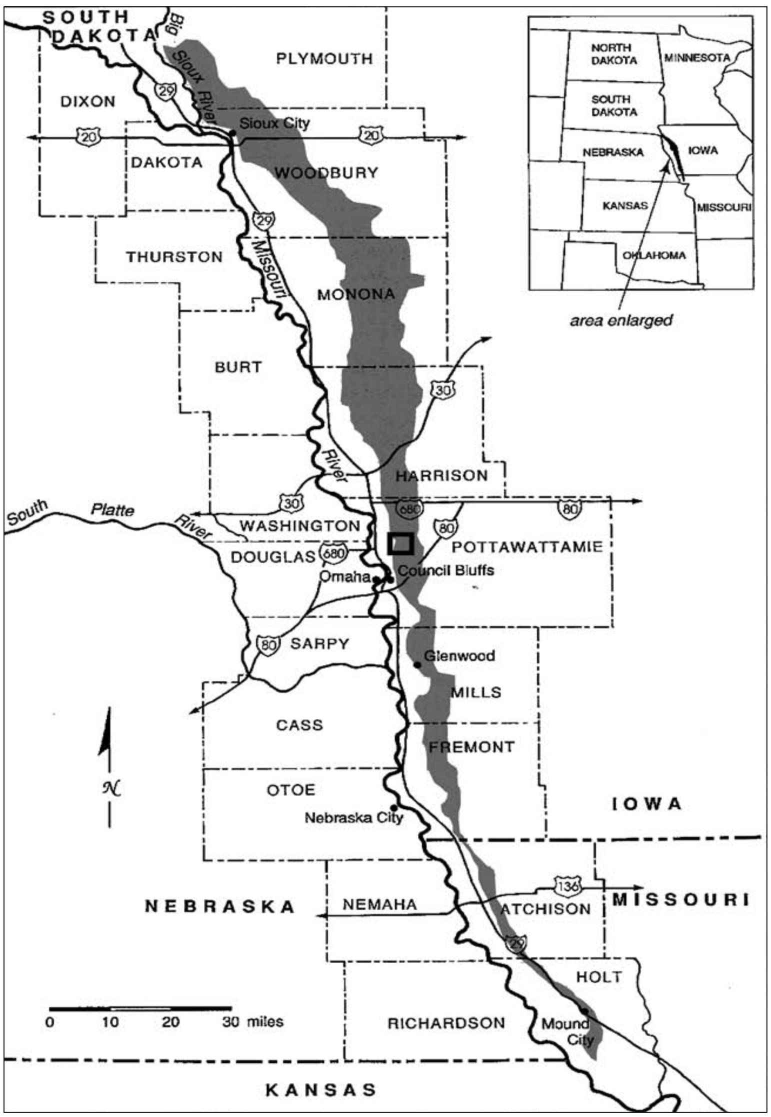

Fig. 1. The Loess Hills of western Iowa. Box indicates generalized study area location (modified from Mutel, 1989, map 1).

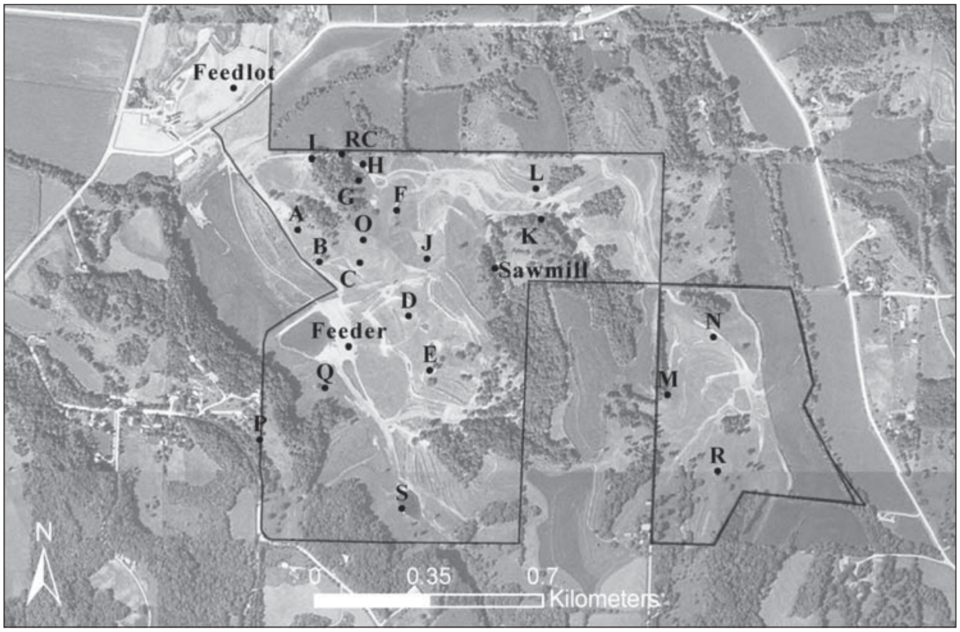

Fig. 2. Annotated aerial photo of study site locations north of Crescent, IA, western Pottawattamie County, IA. (approximately 41° 23’ N., 95° 50’ W.)

1.2 *Geology & soils*

The geology of the Loess Hills is Paleozoic carbonates and shales and Mesozoic sand- stone covered by glacial till of Middle Pleistocene age, and overlain by at least three episodes of loess deposition, the Pleistocene Loveland and Peorian loesses and the Bignell Loess of Altithermal time in the Holocene. The Loess Hills of Iowa are com- posed of, or mantled with, wind-blown silt and clay that is typically permeable and porous, and capable of maintaining high angles of repose. These high angles are readily apparent in vertical bluffs or cliffs associated with the sediment. The qualities that allow loess to form bluffs and cliffs with steep angles of repose are its angular particle structure and their interlocking orientation with adjacent grains. This flocculated structure or card-house matrix results when many particles tend to organize perpendicular to each other, leaving room for air or water to enter. Loess blankets the entire study area to an average depth of about 17.5 m, thinning systematically to the south- east (Ruhe 1969). Soil characteristics and mantle thickness have been used in the past as variables to postulate terracette genesis (Vincent & Clark 1980, Verster 1985). The flocculated structure of loess and the high angles of repose it imparts on study area slopes appear to be important factors in local terracette morphology.

1.3 *Geomorphic evolution*

The sources of the loess in the Loess Hills are mainly deflated glacial outwash from the Missouri River and the arid Sand Hills of western Nebraska. Considerable loess from the Sand Hills was washed down the Niobrara River to the north and the Platte River to the south, and many other smaller tributaries, into the Missouri River and consequently accumulated during floods and periods of outwash on bars and flood- plains. This material was then deflated by prevailing winds and re-deposited in its present locations. Subsequent fluvial and mass-movement modification of loess slopes then occurred to the present day (Ruhe 1969, Bettis 1986). Pre-settlement development and/or modification of terracettes in the Loess Hills most likely occurred through bison, elk, and deer, although little supportive data of this exist (Dillon 2006). Post-settlement human activities in the study area seem to have involved prior land-use processes that can produce or modify terracettes, such as agricultural grazing, direct anthropogenic erosion, and controlled burning of the land that can cause erosion.

2 *Methodology & results*

Methods employed included measuring terracette morphology, recording observa- tions of animal behavior, chemical analyses of study-site soils, landowner interviews, dendrochronology, and the use of a geographical information system (GIS) for analysis of remotely sensed data. A methodological diagram shows these techniques, their resultant data, and the synthesized end-products (fig. 3).

2.1 *Data & instrumentation*

A GIS was used for the mapping as well as for extraction of point data. ArcMap 9.2 from ESRI (Environmental Systems Research Institute) and Light Detection and Ranging (LIDAR) data were used during the production of maps, and for analysis within this study.

Field measurements included different types of instrumentation and data recorded both at the meso-scale (slope scale) and the micro-scale (terracette-component scale). Data were entered on a spreadsheet for statistical analyses. Only instrumentation requiring more complex operation is included in the following discussion.

- Soil penetrometer readings were collected for study site terracette treads and risers as a measure of soil compaction within a range of 0–4.25 kg/cm^2, using the penetration principle to measure unconfined compressive strength in triplicate and averaged according to the Butler et al. (2004) methodology.
- A digital angle-finding instrument was used to collect terracette tread and riser angle data. The instrument's range of measurement was 0–189° with a precision of 0.1°. Boards of various lengths were used for several measurements due to the large size of treads/risers.
- A non-differential global positioning device acquired location data, including latitude/longitude and point elevation data created through waypoint entry and shapefile manipulation.

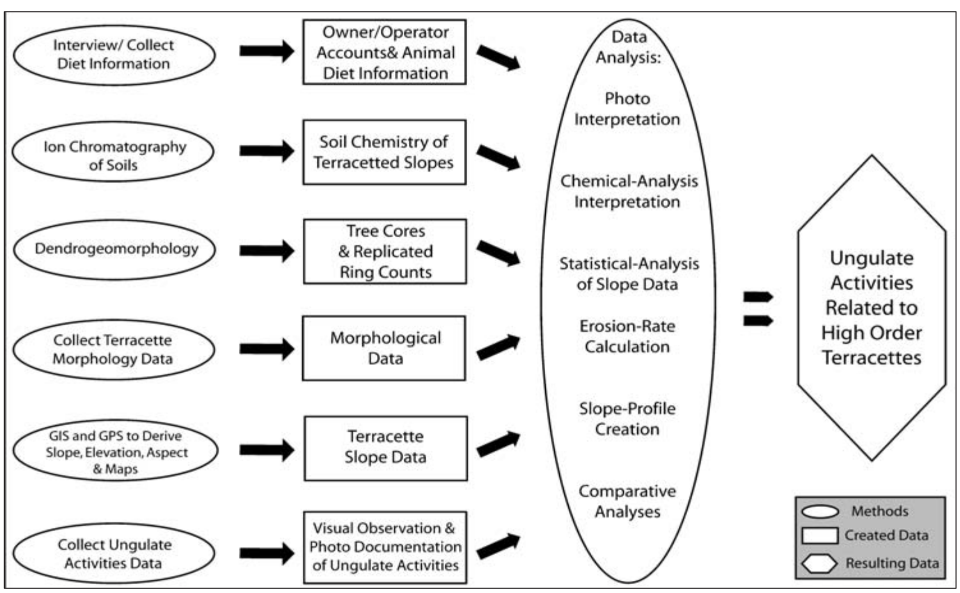

Fig. 3. Methodological diagram for characterizing ungulate activities related to higher order loess terracettes in western Pottawattamie County, Iowa.

Laboratory measurements included dendrogeomorphologic measurements made by taking four cores per tree to ensure replication, gluing the cores to prepared mounts, sanding, burnishing and making multiple ring counts (Shroder 1980), and standard ion chromatography using both anion and cation analysis of sediment samples (Harris 2007, Bruckner 2009).

Fig. 4. Fossorial rodent burrow collapse initiated by ungulate shearing, which enlarged and modified the mega-terracette at site E.

Fig. 5. Wet, flicked soil at site F. Note pawing marks on mega-terracette.

2.2 *Field observations*

Observations of ungulate activity as a primary objective in the study area were documented with photos and notes of visual observations. Records of > 91 trips to the study area spanned approximately 2 years (2006–2008) and ranged from brief excursions to all-day. Summer months afforded maximum faunal and floral measurement, mostly because cattle are pastured in spring and so most cattle-movement information came from spring and summer months. Considerable data were also collected during months cattle were not present. Horses and deer were observed to be active throughout the year. Horses, however, were observed to be less active than cattle any- time of the year.

Fig. 6. Dry, trampled and pulverized soil at site B, with mega-terracette in left background and beginning of exposure of root flare on right. Pulverized, trampled loess is easily subject to deflation and mobilization by sheetwash.

Cattle movements tended to occur most between about 7:00 a. m. to 1:00 p. m., with intermittent rests. As the summer progressed and the cooler, lusher conditions turned warmer and drier, activity became mostly limited to mornings, which was followed by afternoons at the water sources and under shade. June was by far the most active month, and a large amount of relevant activities were logged then. During most of the time in the field, the cattle were grazing, usually in large subgroups of the entire herd. They would sporadically move across terracette study sites and would of- ten break from grazing to rub themselves on the faces and tops of risers, paw the treads/risers, and dust themselves by flicking dirt and by wallowing. Rubbing was often paired with geophagy, and was observed at all sites. Other forms of erosion related to shearing and trampling were also recorded from evidence left at terracette locations (fig. 4). Cattle were also observed moving down slope, transverse to terracettes, which typically caused shearing, sometimes appreciably (fig. 4, near site E). Shearing was witnessed through direct and indirect observations at all study sites.

The effects of soil moisture combined with cattle activities were profound at certain times throughout the study (figs. 5 & 6). This wetting and drying of surface soils followed by trampling allows the small particles to deflate easily.

Erosion caused directly by cattle was observed in areas near the pasture feeders, as well as feedlot fence lines. In both cases, these places were heavily eroded (decimeter+) in a very short time span of approximately 3 months. A hackberry tree (*Celtis occidentalis*) germinated near study site S (fig. 7) that was observed in historic aerial photographs. At present the soil is deeply denuded all around the base of the tree, exposing the roots by about 0.7 m. Since most trees germinate in the humic layer of a developing soil, the age of the tree was determined through standard dendrogeomorphologic analysis, revealing the tree to be 30–40 years in age. The approximate animal-accelerated erosion rates at the site were thus 1.8–2.3 cm yr^{-1}.

Generally speaking, ungulate activities such as geophagy, rubbing, shearing, smearing, flicking, trampling, and grazing were observed at nearly all study sites at various times during the study. Cattle were especially active in comparison to the horses and deer. No regular movements occurred to or from terracette locations and there was no regularity to these activities, excepting grazing times. The sporadic nature of these activities complicates approximation of erosion rates. However, it is clear that the role of ungulates, especially cattle, in terracette development and enlargement is critical, because of the multiple sources of evidence of the kind described above.

Fig. 7. An exhumed hackberry tree (Celtis occidentalis) near site S, showing exposed root flare that is characteristic of significant denudation. This root exposure is clearly the result of animal activities.

2.3 *Morphology*

Sampling morphology of terracettes is foremost in nearly all empirical studies about the form, so it was necessary to closely replicate this method for comparative purposes. Terracette morphology from 19 local sites was compared to the findings of Anderson's (1972) 215-site-study because of some similarities in morphology, although the examples from the study herein are considerably larger (table 1). Ander- son separated his terracettes into two classes, "normal terracettes" (170 sites) and "tear terracettes" (45 sites), the former having "risers generally bare of vegetation", and the latter being "transverse to slope angle with a complete vegetation cover" (Anderson 1972). Average length of study-site terracettes is an entire order of magnitude above Anderson's tear terracette lengths. Tread and riser angles are also different, with Anderson's average riser angles being both above and below the average found in Iowa. Average tread angles of Anderson's tear terracettes were almost double those found for this study, whereas Anderson's normal terracettes were much closer. Average tread width was also a major point of difference with widths being ~ 80–100 cm above Anderson's. Average riser widths (assumed to be a vertical measurement by Anderson, but still called width) were very close between normal terracettes and the study area terracettes, with a marked contrast between local and tear terracettes. Anderson also provided minima/maxima from his study, though sporadically. It is clear from examples, such as tread/riser width maximums and maximum riser angle, that the magnitudes of terracettes in the study area are much different from those in Anderson's (1972) study areas. Unfortunately, Anderson (1972) does not discuss in detail the regolith conditions in which his tear and normal terracettes occurred, only stating that the various study sites were located in "parts of Western Britain ranging from Somerset to the Northwest Highlands" and that "normal terracettes occur . . . on predominantly mineral soils, while tear terracettes are usually found in areas of rough grazing where there is a marked organic horizon". It is likely that soil mantle characteristics, namely angle of repose, play critical roles in control- ling the morphologic parameters of terracettes.

Variable	Mega	Tear	Normal
Tread Angle Average (degrees)	9.4	16.8	10.5
Tread Angle Standard Deviation	5.3	4.6	4.5
Riser Angle Average (degrees)	48.5	68	39.9
Riser Angle Standard Deviation	21.9	13.9	9.5
Tread Width Average (cm)	132.8	36	54.5
Tread Width Standard Deviation	93.7	10.6	10.9
Riser Width Average (cm)	87.6	25.9	90.5
Riser Width Standard Deviation	48	15.6	24.9
Average Length (m)	46.6	1	-
Length Standard Deviation	35.8	-	-
Max Length (m)	164	1	>90
Max Riser Width (cm)	246	90.5	-
Min Riser Width (cm)	17.5	-	25.9
Max Tread Width (cm)	523	54.5	-
Min Tread Width (cm)	28	-	36
Max Tread Angle (degrees)	22.6	-	22
Min Tread Angle (degrees)	1	2	-
Max Riser Angle (degrees)	96.8	-	68
Min Riser Angle (degrees)	1.3	40	-
Sample Size (number of sites)	19	45	170
Material of Development	Loess	-	-

Table 1. Terracette morphology table showing values from Anderson's (1972) study com- pared with mega-terracettes of western Iowa.

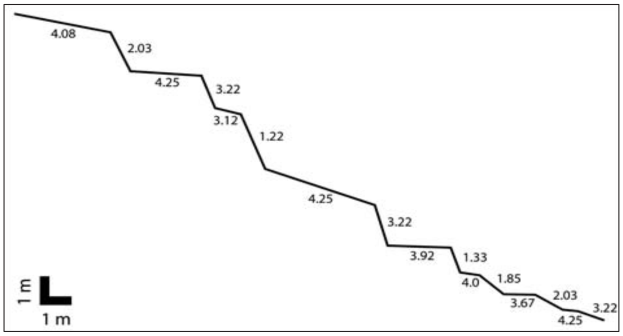

Fig. 8. Site F profile of mega-terracette and compaction data. Tread and riser compaction values are located adjacent to sample tread/risers. Average compaction was 3.94 kg/cm^2 for treads and 2.27 for risers.

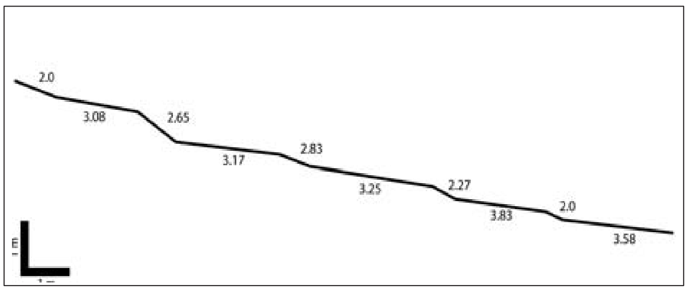

Fig. 9. Site O profile of low-order terracette and compaction data. Tread and riser compaction values are located adjacent to sample tread/risers. Average compaction was 3.38 kg/cm^2 for treads and 2.35 for risers.

Fig. 10. Site A (A) and B (B) terracette photos. Note the variability in terracette magnitudes between newly developing terracettes in the foreground of photo A, and the meter plus terracettes of sites A (adjacent to vehicle) and B. Also note the continuum of vegetation (~ 25 to 100 %) that exists within and between sites.

Study-area terracette profiles were created from 98 tread and riser measurements to achieve a graphical presentation of morphologic data. These profiles were created using tread/riser angles, tread/riser widths, with additional compaction information itemized accordingly. What is most evident from inspection of these profiles is the high magnitude and variability of the forms, especially between sites O, P, and Q, and the remaining sites, excepting the feedlot. Sample stratification was employed and sites O, P, and Q were not considered statistically. This is because of their major differences in morphology (low order) from the rest of the study site terracettes. How- ever, sites O, P, and Q were included in the study to show the contrast or suspected continuum that may exist. These low-magnitude terracette formations were typically 75–100 % sod-covered and had low tread/riser angles. These findings are consistent with what Higgins (1982) termed “grazing steps”, as well as Brice’s (1965) “thickly sodded slopes” that had low scarp heights. Many of the focus sites of this study (high- magnitude sites), as mentioned previously, were at least one order of magnitude above the averages found by Anderson (1972). Additionally, these study sites were dis- similar to Higgins’ (1982) “grazing steps” in that tread and riser angles were extremely high in many cases, a continuum of vegetation occurred on both treads and risers, and the forms were quite variable in size and shape (figs. 8, 9 & 10, table 2, 3).

Table 2. Tread & riser morphologic data for site F.

Site	Tread Angle	Riser Angle	Length	Tread Width	Riser Height	Tread Compaction	Riser Compaction
F	12.20	65.40	44.59	288.00	141.00	4.08	2.03
	3.70	69.50	34.72	211.00	114.00	4.25	3.22
	15.30	68.50	9.37	81.00	194.00	3.12	1.22
	20.10	73.60	59.35	345.00	137.00	4.25	3.22
	1.90	71.50	43.75	189.00	87.00	3.92	1.33
	9.20	40.80	57.75	62.00	94.00	4.00	1.85
	1.00	31.00	27.60	94.00	96.00	3.67	2.03
	6.20	21.50	25.37	45.00	83.00	4.25	3.22
Mean	8.70	55.23	37.81	164.38	118.25	3.94	2.27
	Degrees	Degrees	Meters	Centimeters	Centimeters	Kg/Sq Cm	Kg/Sq Cm

Table 3. Tread & riser morphologic data for site O.

Site	Tread Angle	Riser Angle	Length	Tread Width	Riser Height	Tread Compaction	Riser Compaction
O	5.90	23.40	53.64	230.00	38.00	3.58	2.00
	6.70	25.70	71.63	187.00	53.00	3.83	2.65
	7.60	19.40	60.66	256.00	66.00	3.25	2.83
	6.20	35.10	62.79	217.00	95.00	3.17	2.27
	8.70	18.90	84.12	170.00	92.00	3.08	2.00
Mean	7.02	24.50	66.57	212.00	68.80	3.38	2.35
	Degrees	Degrees	Meters	Centimeters	Centimeters	Kg/Sq Cm	Kg/Sq Cm

Slope concavity was sampled through visual observation. The distribution between convex (11 slopes) and concave (8) slopes was fairly even. However, the con- vex slopes, in general, are the high-magnitude terracette sites. This is believed to be a result of both divergent flow over convex-convex slopes (Parsons 1988), also called “slope noses, or spurs”. Because slope noses are features that bulge out rather than cup inwards as concave slopes, they are more prone to erosion. Additionally, diver- gent flow is more conducive to sheet-wash erosion. This is because once mobilized, soil-laden water is diverted away from the slope nose. Conversely, concave slopes have less concentrated erosion, and sediment mobilization is concentrated by convergent, overland flow.

Aspect values for each study site slope (19 in total) were recorded and analyzed with mixed results. Two aspect directions seem to be preferred in the study area; northwest (4 slopes) and south (4 slopes) (fig. 11). The remaining aspects are rather evenly distributed, each having 3, 2 (mode), or 1 slope of those directions. Correlations between animal behavior and terracette aspects cannot be made based on these findings, in part because there was no apparent relationship in field observations, and because a sample size of 19 is too small for robust statistical analyses. However, cattle tend to organize themselves in ways that provide the most shelter (from sun, wind, rain) which has the potential to influence terracette aspects depending on whether or not they provide such shelter. With this in mind, more aspects in the northwest and south could be explained by their provision of shelter from winter winds (NW) and summer sun (S). Additionally, aspect may be autocorrelated by the existence of more slopes in certain directions.

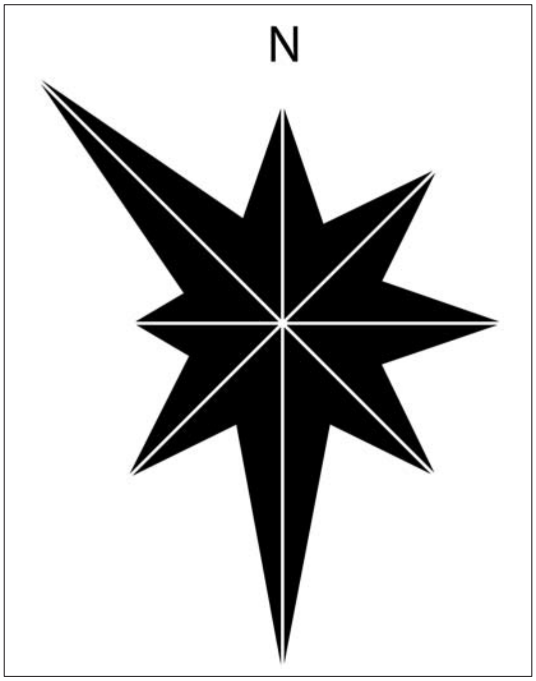

Fig. 11. Rose diagram of study site aspects of mega-terracettes. Note preferential orientation of mega-terracettes to the northwest and south, which may reflect some animal preferences for shelter from winter winds and summer sun, although the sample size is not sufficient to be definitive.

2.4 *Subsurface data*

Soil compaction was sampled at all high-magnitude sites as well as 4 other sites (sites O, P, Q, and feedlot). The results of the compaction tests were predictable because treads at the high-magnitude sites are considerably more compacted than risers, which is understandable because the cattle cannot traverse large, steep risers. Conversely, sites O, P, and Q had tread and riser compaction values that were closer to each other, which could be attributed to the low angles of the risers that allow more movement across them. The feedlot was highly compact with all tread and riser readings reaching the maximum of the soil penetrometer (4.25 kg/cm^2). Constant tram- pling from highly confined cattle, paired with the constant excretion of urine onto the soil, are likely explanations for the high compaction occurring in the feedlot.

Subsurface (trench) data were collected at three terracette locations to investigate possible slip planes (Vincent & Clark 1982), bioturbation, soil-development depths, and subsurface vegetal controls. Trenches were transects of sample terracette treads and risers at site E, site D, and near site N, which would be considered a nor- mal terracette by Anderson (1972). The trench near site N was the only one producing possible relict evidence of bioturbation directly under and parallel with a tread. Trenching at site D allowed inspection of carbonate surrounding a likely relict root-system, however no signs of bioturbation, slip planes, or soil horizons were observed. The trench at site E was less conclusive than the others, containing little usable data. In short, trenching was the most disruptive, least fruitful task conducted at the study area, and so was abandoned for additional sites.

2.5 *Soil chemistry*

Chemical analysis of soils at terracette locations was undertaken to better understand relationships between flora, fauna, and the soils with which they interact. This was particularly relevant where the cattle were observed eating soil (geophagy) from terracette risers, which begged the question to what end they were eating soil. Jones & Hanson (1986) noted that animals are believed to use soils as roughage to aid in digestion. This has been documented by other authors (Healy 1973) wherein diets of cattle were controlled and complemented with clays/sands. It was found, by con- ducting chemical analysis on the cattle feces, that a small percentage increase in mineral nutrients was retained when a small amount of sediment roughage was added to the diet. The second reason for faunal ingestion of soils is to directly supplement their diet with a desired mineral, including but not limited to, salts. Finally, geophagy is believed to act as a detoxifying agent, as described by Butler (1995). Licks have been documented by several authors, such as Heimer (1973), Jones & Hanson (1986), and Butler (1995). Though the minerals procured from different lick sites may change, what is most interesting is that animals will habitually return to a lick, creating a *lick route*, as well as exacerbating the lick exposure. These facts are paramount to under- standing field observations of this study, because geophagy was witnessed at terracette locations nearly every time field reconnaissance was performed.

Understanding reasons for cattle geophagy at terracette locations required chemical analysis with an ion chromatograph of soils collected. Results from chromatograph plots were compared with documented evidence of particularly desired minerals (Jones & Hanson 1986). Ion chromatography of soils revealed higher concentrations of certain ions at many study sites. In general these concentrated ions were nitrate, chloride, sulfate, calcium, and magnesium.

In spite of a lack of comparative data on cattle or from IA, it is possible to postulate potential chemical reasons for cattle consuming soils in the study area. Alka- line salts such as NaCl or KCl are usually considered in describing animal licks. Data from the study area, however, show low ionic concentrations of Na (< 0.8 mg/L) with the exception of the feedlot. Many sample sites contained high concentrations of SO_4, however, Jones & Hanson (1986) have rejected this as a major attraction in most licks. S was rejected on the basis that most of their sites had low concentrations. Jones & Hanson (1986) did allude to the fact that S salts are an important constituent in some licks and were thought to contribute importantly to the S nutrition of some animals. $CaCO_3$ also was discussed as an important mineral to ungulates and it was thought to be of some nutritional significance and physiological importance in geophagy. Mg was also significant in most soil samples for the study herein. Jones & Hanson (1986) hypothesized that Mg is one of the key elements explaining geophagous behavior due to its requirement in a large number of metabolic reactions.

Type	Terracettes		
	Mega	Tear	Normal
Length	1- 164 meters	.25 - 1 meter	1-90 meters
Tread Width	Meter +	Sub-meter	Sub-meter
Riser Height	Meter +	Sub-meter	Sub-meter
Tread Angle	< 10 Degrees	10< X<23 Degrees	
Riser Angle	< 40 Degrees	>40 Degrees	

Table 4. Proposed morphologic scheme that incorporates Anderson's (1972) normal and tear terracettes as well as mega-terracettes occurring in this study.

3 *Conclusions*

The results of this study are consistent with the hypothesis that ungulate activities, such as geophagy, pawing, smearing, shearing, flicking (transport off hooves), hoof compaction and wallowing (dust bathing) are responsible for likely initiation and definite modification of higher order terracettes in the study area. Data acquired herein are temporally short, circumstantial and thus not definitive of terracette causation. However, ungulate activities did appear to maintain terracette treads and risers in a constant state of change. This conclusion is largely based on the preponderance of visual observations of cattle moving across and spending time at terracettes, exacerbating the forms while at the same time setting up conditions, such as trampling and pulverizing soil, so that processes such as sheet-wash or deflation could easily remove the otherwise quasi-stable soil. Geophagous activities, in particular, appear to be a direct attraction for the cattle, horses, and deer to terracette locations. Geophagy was witnessed at nearly all locations, and the notion that ungulates affect terracettes with heightened activities is substantiated by chemical analysis that indicates abundant concentrations of minerals apparently desired by ungulates. Furthermore, higher order terracette slopes have very different morphology than most discussed in cur- rent literature. Sub-aerial characteristics, especially compaction, also suggest the high frequency of terracette use by the cattle. Unfortunately, spatial association is not a proxy for initial genesis, and although ungulate activities may be concentrated at higher order terracette locations, truly definitive explanations of causal processes could not be achieved because of the current lack in historical substantiating data of initial conditions.

In spite of the circumstantial nature of the collected data, ungulate activities seem to be at least partially responsible for local terracette evolution. Based on data acquired during this study, it seems probable that terracettes are polygenetic at least in terms of their development because a host of processes, including ungulate activities, are likely to compound the continued production and modification of these features in various ways. An obvious need exists to quantify ungulate activities in a more systematic and temporally extensive way that answers the questions of initial gene- sis, as well as rates terracette development. This could be achieved using time-lapse photography, or change detection using high-resolution datasets (such as recent LIDAR, and perhaps declassified historical Corona – CIA imagery).

The addition to current classifications of a higher order, or mega-terracette, as proposed as a result of this study seems appropriate given the morphological findings herein (tab. 4). It is suspected that a gradation of terracette magnitudes occurs. Because this is a preliminary study of higher order terracettes in loess in association with ungulate activities, additional spatially and temporally extensive investigations of terracette magnitudes on loesses in the world might be productive.

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