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THE TERRACETTE ENIGMA — A REVIEW

Abstract

A review of the available literature suggests that there is no measurement of agreement amongst Geomorphologis as to the origin of Terracettes. Their genesis is considered by some to result from purely physical processes while others advocate their initiation by animal activity. The authors indicated their own methods of research to the problem.

Step-like sequences of sub-parallel ridges known commonly as terracettes are a familiar sight to geomorphologists. Over the last hundred or so years many observers have described these striking slope features, but there has been little agreement as to their genesis; indeed, there has been little concensus regarding their terminology. There is as yet no comprehensive review of the literature concerning these features available in the English language. In the course of their research into this enigmatic phenomenon the authors have been able to bring together a large volume of literature from many scattered sources which refer directly or indirectly to these intriguing slope forms.

In this paper we shall review the current state of knowledge concerning the genesis of terracettes and indicate briefly the authors' own approach to the problem.

The term *terracette* was probably first used by Ødum (1922) in describing (in a morphological sense only) miniature valley-side terraces. However, a wide range of terminology has appeared in the literature some of which is more satisfactory than others. For example, Darwin (1904) described such features as "ledges of earth" and "lines of miniatures cliffs". Jonsson (1905) referred to them as "Rynkeli" — grass slope full of wrinkles and Øyen (1903) as "mill-(ed)-surfaces". Terminologies directly implying genesis are used: the most often cited being cat steps (Kay and Apfel, 1929; Bennett, 1939); sheepwalks (Darwin, 1904; Woodward, 1911); sheep roads or "roadies" (Warming, 1906; and Ostenfeld, 1906); cattle terraces (Bennett, 1939); sentier de vaches (Rempp, Rothe, 1935); pieds de vaches (Meynier, 1951; Derruau, 1958) and sols à gradins (Tricart, 1961). The most

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commonly used term is *terracette*, although none of these terms is entirely satisfactory.

If the terracettes themselves have many descriptive names then there have been even more hypotheses as to their origin. For the sake of convenience we have classified the various views on the mode of formation of terracettes as follows: 1. Solifluction, 2. Gelifluction, 3. Slumping and Rotational slippage, 4. Soil creep, 5. Regolith Control, 6. Vegetation Control, 7. Animal Disturbance.

SOLIFLUCTION

Several authors have attributed the formation of terracettes to various solifluction phenomena. A common theme running through this approach to the problems is that of differential soil horizon movement. In a study of mass movement in the Monaro region of New South Wales COSTIN (1950) concluded that solifluction was the major factor contributing to the formation of terracettes. He considered that the dense development of plant roots near the soil surface restricted solifluction in the A_1 horizon and the faster moving A_2 and B horizons resulted in a gradual backward movement of the ground sward at the base of each bare, depressed, frost-eroded pocket. He used the term *solifluction terracettes* in preference to stock terracettes as, in his opinion, stock were concerned only indirectly in their formation. COSTIN also noted that development of solifluction terracettes often associated with minor slumping on steep, overgrazed slopes of the subalpine tract, was frequently accompanied by large slump movements.

The inception of terracettes by the method proposed by COSTIN is not without its problems however. The scars often seen at the base of terracettes are long, horizontal features normal to the slope and it is difficult to envisage a process whereby frost attacks the soil in such a regular pattern. Further, the authors have observed sequences of terracettes confined to the middle section of slope profiles and again one has to explain the lack of frost-induced erosion on some slope facets.

TIVY (1962) in her detailed study into slope deposits in the Lowther Hills, Southern Uplands of Scotland, concluded that terracettes were a common feature of steeper slopes (+20°) at all altitudes above 2000 feet and may even occur on slopes as little as 10°. Detailed soil profile studies on the treads of numerous terracettes indicated a humic horizon overlying a well-defined, light grey to greyish brown fine silt, A_2 horizon both of which thicken considerably away from the slope. This thickening is attributed by TIVY to contemporaneous solifluction of the more highly saturated H and A_2 horizons.

TIVY concluded that such formed features are miniature turf bound solifluction lobes whose instability is often increased by sheep trampling and particularly by the vegetation cover downslope of them, either by sheep scars or by stream or gully undercutting.

The above two authors, while both generally seeing the formation of terracettes as a solifluction process, differ markedly in their interpretation of the role of the vegetative horizons in being either more or less prone to solifluction than the soil horizons immediately beneath; TIVY favouring faster movement of the upper organic/organo-mineral horizons while COSTIN the lower A_2 and B horizons.

LOTHER (1956) and TRICART (1961) also advocated a solifluction process for the development of terracettes. In a study of the terracettes in le Pays de Herve, France, LOTHER considered that the slopes on which the terracettes are now found have only been meadow land for the last two hundred or so years and he regarded this time as insufficient for terracettes to have formed by trampling under hoof. The latter opinion has subsequently been challenged by other writers, for example GIBBS (1962) and ROBERT (1964) who reported terracette formation within 50 to 80 year periods.

GELIFLUCTION

Here we define gelifluction as solifluction associated with frozen ground. An early paper which recognised the importance of gelifluction processes in the development of terracettes was that by DEMANGEOT (1951) who studied *sols en gradins* (stepped, high altitude, 1700—2400 m, calcareous soils in the central Apennines, Italy) and noticed that the vegetal carpet was carved in strikingly parallel steps. DEMANGEOT supposed that their formation required a special sequence of conditions. First the soil is cracked by solifluction and then the fissures are enlarged by the joint action of frost thaw, aeolian deflation, corrasion and cryoturbation. Finally the grass stripes are tilted over by gently creeping. The steps are more parallel if the material is homogeneous. This latter observation is presumably due to more uniform rate of solifluction in homogeneous materials. It must be pointed out, however, that the soils examined by DEMANGEON were at altitudes from 1700—2400m A.S.L. The severity of conditions required by this theory are not found today in many lowland areas where terracettes occur. If DEMANGEOT's theory is correct such features would have to be fossil and have been initiated under colder conditions. Indeed, GOODIER and BALL (1969) suggest that the formation of terraced slopes in the Rhinog Mountains, North Wales may be attributed to gelifluction and cryoturbation processes in the "Little Ice Age" which occurred between about 1550 and 1750 A.D.

GOODIER and BALL also describe gelifluction phenomena linked spatially with terracette-like forms on the northern rim of the summit plateau of Y Llethr, North Wales. On slopes less than thirty degrees the soil was striped parallel to the slopes but this striped pattern disappeared and became terraced and normal to slopes of greater than thirty degrees. TRICART (1969) too has indicated that terracettes are genetically related to earth hummocks and are a product of gelifluction activity. Terracettes are considered to occur entirely on steep, grassy slopes of at least 20° and as the slope flattens they pan into earth hummocks (REMPP and ROTHE, 1935). The writers themselves have never observed the transitional forms which must have occurred according to TRICART. The terracettes are thought to originate from the slipping of sections of turf under the effects of thaw which penetrates the bare soil outcrop behind each tread more rapidly. It should be pointed out here that not all terracettes have bare risers which would allow rapid penetration of heat.

RUDBERG (1962, 1964) and RAPP and RUDBERG (1964) in a study of mass movement at 700—1700 m in the Norra Storfjäll area, southern Swedish Lappland, observed that terracettes were confined to the drier areas of the lower part of the tundra zone; an observation also made by ØDUM (1922). On rounded spurs without streams and with a thin or absent snow cover in winter and covered by sparse heath vegetation no solifluction lobes were present — only small terracettes, generally with the upper surface more or less without vegetation and without overturned fronts. RUDBERG assumed that a typical terracette environment indicated slow soil movement. The key to the problem, he concluded, might be due to the thinness of the surficial deposits and slow weathering under dry conditions.

SLUMPING AND ROTATIONAL SLIPPAGE

The lines of miniature cliffs on steep, grass-covered slopes observed by DARWIN (1904) in Grisedale, Westmoreland, were considered by him to result from "sliding of the superficial, argillaceous earth, partially held together by roots of the grasses; and in thus sliding had yielded and cracked in horizontal lines transversely to the slope". ØDUM (1922) also reported parallel cracking in the turf associated with rotational slippage of superficial blocks. He, like COSTIN, (1950) noted that where landslips occur terracettes are invariably visible on those parts where no slide occurs. SHARPE (1938) too described four types of landslip terracettes, including that of ØDUM's. He suggested slippage of blocks on a major slip plane, slumping on deep-seated, curved surfaces and gravitational sliding where lithology consists of poorly consolidated material. KAY and APFEL (1929) simirlarly attribute "cat steps" in the loess region in Iowa, U.S.A. to slipping and faulting along the characteristic vertical joint planes of the loess.

Terracettes examined by MEYNIER (1951) at Cap d'Ailly, west of Dieppe, were, he concluded, the result of microtectonic processes; subsidence of the soil being facilitated by frost-cracking followed by thawing. RAGG and BIBBY (1966) also attribute present day frost action as effecting the formation of small slip terraces (terracettes) in southern Scotland.

In discussing terracettes formed in the Devil's Kneading Bowl, Kent, KERNEY, BROWN and CHANDLER (1964) considered they were initiated by small scale slipping before the present grass cover was established and post-dated forest clearance c. 1000 B.C. Terracettes formed on a steep, arcuate slope of a landslip were also attributed to minor movements by FRANKS and JOHNSON (1964). The landslip was pollen-dated as the Late Boreal period (Pollen Zone VI).

Present day formation of terracettes has been studied by BLACK (1969 and 1972) in southwestern Wisconsin, U.S.A. He concluded slumping aided by rotational slippage during wet periods resulted in their earlier form but in a fenced-off site their formation was restricted by installed posts and by invading vegetation.

While the above studies all cite slippage along planes of weakness in fact very few planes have actually been observed in the field to support these hypotheses. Indeed, RAHM (1961 and 1962) at first favoured the formation of terracettes by slumping, arguing that terracettes were too numerous and widespread to be due solely to animals. In his 1962 paper, however, RAHM decided terracettes were a "geomorphic ambiguity" and were probably "cow paths" in most cases in that area of the Columbia Plateau, U.S.A.

SOIL CREEP

Soil creep defined according to TAYLOR and POHLEN (1970) is a slow form of mass movement under the influence of gravity. KOJAN (1967) in his detailed analysis of soil creep rates in California, U.S.A. stated that many of the structural features of "mass creep" were analogous to those found in terracettes. From her studies (1948—1961) of grass-covered slopes in the R. Tchon-Kizilsu Basin, U.S.S.R., IVERONOVA (1964) reported that soil creep occurred on "all grassy banks without exception". IVERONOVA measured different soil horizons and concluded that creep movements were of a discrete nature and were, therefore, different from flow or solifluction processes. Both PISSART (1971) and BLACK (1972) found displacement by creep to be irregular, and measurements lasting twelve years were considered by PISSART (1971) to be necessary in order to obtain significant results.

CLAYTON (1966) suggests that terracettes may be formed by creep while TAYLOR and POHLEN (1970) consider soil creep in its accelerated form to be a necessary condition. Many writers associate soil creep with other factors in terracette formation. For example, DALRYMPLE, BLONG and CONACHER (1968) combined convex form and location on the slope with soil creep. COSTIN (1950) states that soil creep is always associated with solifluction on the alpine and subalpine tracts of Monaro, New Zealand, but in the montane and tableland tracts, where precipitations are lower and temperature higher, soil creep is the dominant process.

As moisture is a necessary factor in solifluction processes it would appear that any general theory for the formation of terracettes must include an experimentation of the role of soil moisture. BLONG (1965) has observed the influence of subsurface water in producing terracettes on a volcanic plateau at Mangawhiriwhiri catchment area, New Zealand. WILLIAMS (1973) considers that "the general explanation of many terracettes will be found in the role of periodically high pore-water pressures associated with fluctuating water tables". This supports the conclusions of BARR and SWANSTON (1970) from their measurements of creep in a steep slope, glacial till soil in southeastern Alaska, where the surficial soil apparently moved as a flow mass with no well-defined shear zones. The tendency for soil movemen t existed throughout the year with the highest rate of movement occurring in the autumn and spring when soil moisture content was highest. However, the high moisture content explains the reduction in the shear strength of the soil but not the general development and morphology of terracettes.

REGOLITH CONTROL

Terracette formation is of a superficial nature thereby distinguishing it from landslides. DARWIN (1904) observed "ledges of earth" were between six to nine inches in depth and above the ledges the earth over the chalk was three to four inches deep. YOUNG (1963) also observed terracettes on slopes between 40° and 33° where the regolith was thin, although the relative thickness of the regolith was not considered by ROBERT (1964) to be a determining factor.

On the other hand, in 1967 a study by CARSON of the slopes in the Exmoor and southern Pennine areas (CARSON and KIRKBY, 1972) the occurrence of terracettes appeared to be very closely linked to the thickness of the soil mantle on the hillslopes; terracettes being rare where the mantle was deep. CARSON concluded that the shallowness of the mantle imparts extra strength to the slope which prevents landslides but still allows small scale instability to occur and to produce terracettes. iIn the thinner mantle the binding effect of the vegetation is relatively greater than in the deeper soils (CARSON, 1969). Whether the lower limiting angle for terracettes s related to the strength of the regolith is not known (Young, 1972). Support for this view may be given by the observations of HUTCHINSON (1967). He noted "undulations" (terracette-like features) occur on London Clay slopes which are close to their angle of ultimate stability against landsliding. Other necessary or favourable conditions of the soil mantle include ØDUM's (1922) "loose earth", SHARPE's (1938) unconsolidated material and FAIRBRIDGE's (1968) poorly consolidated material.

Once formed, however, terracettes are considered by some writers to stabilise the slopes. ØDUM (1922) wrote "terracettes having been formed no new formation, disintegration or downward movement of the earth will take place", GIBBS (1964) also refers to the stability imparted to slopes by terracette formation. Forest "dimples" (hollows left by tree roots) and stock (animal) paths in the Korokoro hill soils and Mabara steepland soils, Wellington, New Zealand, show little evidence of downslope movement since the forest was cleared for farming sixty to eighty years ago.

In the Chambeyron massif at 2800 m above sea level PISSART (1971) confirmed his results (PISSART, 1964) that terracettes stabilise the slopes reaching 43°. Marks made on several terracettes showed hardly any displacement during the period 1963—1970 in spite of the steep slope angle.

If terracettes stabilise the slopes, conditions may have changed so that the features are "fossil" as in the Gelifluction Hypothesis above. One difficulty, therefore, in trying to determine the conditions necessary for the formation of terracettes is that present environmental measurements may be inadequate or irrelevant.

VEGETATION CONTROL

Observations regarding the importance of slope angle and the presence of vegetation have been made by many writers. ØDUM (1922) noted that terracettes occur only on slopes of "steep inclination" and may, therefore, differ from solifluction terraces. Likewise, SAVIGEAR (1952) also observed that terracettes were widespread on slopes of approximately 30°, YOUNG (1961) stated more specifically that terracettes occurred on slopes with continuous soil, vegetation cover and limiting angles between 33° and 36°. An increase in the angle of slope increased the rate of soil movement according to YOUNG (1960). This view is supported by CLARK (1965) who found that slopes steeper than 32° to 33° show increasing sign of instability associated with well-marked terracettes, fractures in the turf cover and a thin soil mantle.

In their "hypothetical, nine-unit landsurface model" DALRYMPLE, BLONG and CONACHER (1968) show that the convex segment (unit 3) near the summit of a slope, with angles never greater than 45°, is commonly characterised by terracettes. Lower down the slope (unit 5) where erosion is most active and angles range from 45° to less than 20° terracettes are also common, although terracettes have been observed by the writers in the middle of slopes where erosion did not appear to be active.

According to DURY (1959) the presence of a root mat is not essential for terracettes can occur on slopes with very little vegetation. However, BAILEY and RICE (1969), PAIN (1971) and KIRKBY (1972) consider the occurrence of soil slopes to be closely related to the rooting habit and density of the vegetation. Indeed, SELBY (1973) wrote "terracettes are very common features in New Zealand even beneath original native forest where they originate through the wasting of debris downslope and its accumulation behind tree roots. These original forms, plus hollows left by roots of fallen trees are inherited in pastures when the forest is cleared".

The vegetation also emphasises the ground pattern. The microtopography formed offers a variety of ecological niches which have been studied by THOMAS (1959), DURING and RADCLIFFE (1962), RADCLIFFE (1968) and RUMBALL and ESLER (1968).

These four studies have been in grazed areas. No explanations have been given for the linear pattern of vegetation in ungrazed areas such as that illustrated by GOODIER and BALL (1969) in the Rhinog Mountains, N. Wales. Whether terracettes may be only a vegetation feature and not related to the regolith has not yet been proven. Although the authors have recently examined sites in northern England where the vegetation root mat has thickened, wedge-like, away from the slope to form a terracette-like feature. It is not known, according to YOUNG (1972) whether the strength of the vegetation is related to the lower limiting angle for terracettes.

BRICE (1958) has related step (terracette) development to slope angle and thickness of the vegetation mat. From his comprehensive field study of stepped, steep, loess-mantled slopes in southern Nebraska, western Iowa and northwestern Missouri, U.S.A. he indicated that breaks in the vegetation cover initiated the formation of terracettes and scarp retreat. Such breaks, however, may have been caused by drought, by overgrazing, by burrowing of rodents, or by the hoofs of grazing animals. He concluded that "steps are poorly developed on heavily sodded slopes because the sod cover reduces the amount of sheetwash and inhibits the initial development of low sod scarps. Steps are not well developed on slopes steeper than about 33 degrees because scarp retreat into such steep slopes is very slow and because slumping along shallow curved surfaces may begin at about this angle of slope. On slopes more gentle than about six degrees, steps are not developed because of the decreasing effectiveness of sheetwash at this angle of slope and because incipient scarps grow very little by retreating into such gentle slopes".

ANIMAL DISTURBANCE

Although DARWIN (1904) attributed terracette formation to wormcasts, many writers suggest that terracettes in certain areas are initiated and developed by animal treading. This view is supported by MEYNIER (1951), GUTHRIE SMITH (1953), GIBBS (1962), BRICE (1958), RAHM (1962), ROBERTS (1964) and MACAR and PISSART (1964). RADCLIFFE (1968) suggests that animal treading has integrated diverse types of soil movement into familiar track contour patterns.

Whether terracette formation processes are abiotic or are related to the trampling of animals or a combination of both has yet to be fully elucidated (CLAYTON, 1966). In 1959 DURY wrote "little or nothing is known of the mechanism of terracettes", a view held by TRICART and CAILLEUX in 1967 who affirmed "terracettes have been little studied, insufficiently explored". BAILEY and RICE (1969) held similar views and suggested that due to their small size and common occurrence terracettes have seldom been analysed in great detail. Why terracettes form in some places but not in others is still not known (CARSON and KIRKBY, 1972). Why the parallel lines of terracettes form such regular patterns is also not known. To the present writers it seems unlikely that the regularity is fortuitous or always attributable to animal treading.

CLASSIFICATION OF TERRACETTES

Different types of terracettes certainly exist. RAGG and BIBBY (1966) distinguish between high-level terracettes which have more sloping and broader treads, forming a honeycomb pattern of small slip features, than the closely spaced, parallel pathway system of terracettes on lower valley sides. The different patterns observed here may be similar to those included in the classification of mass movements in the Alps by LAATSCH and GROTTENTHALER (1972). They record folding and tension cracks in the vegetation cover resulting from surficial creep and sliding induced by rapid thaw in addition to cattle tracks (*Viehtrittwege*).

In the suggested classification by ANDERSON (1972) he distinguished between two basic types of terracettes, namely "normal" and "tear" terracettes. These he further classified according to the angle and width of the riser, the angle along the tread and its unbroken length and the vegetation coverage of the riser. Although one may be tempted by the apparent simplicity of this classification into "normal" and "tear" terracettes, this does not exclude the possibility that a terracette with a so-called "normal" outline may have resulted from one or several different processes within a slope.

Transitions between forms of patterned ground occur as noted in Gelifluction Hypothesis above. The non-sorted terraces (SVENSSON *et al.*, 1967) and non-sorted steps of COSTIN *et al.* (1967) and RAPP and CLARK (1971) may also be genetically related to terracettes. WASHBURN (1970), however, considers there are still too many unknowns to formulate a completely satisfactory genetic classification of patterned ground, although he has tabulated what he considered to be the main processes involved.

METHODS OF APPROACH TO THE TERRACETTE PROBLEM

In this section we shall briefly outline an approach to the problem of terracette development that we are adopting at Salford. Broadly speaking the few geomorphologists who have concerned themselves with the problem have collected three basic types of data:

(a) Observations on the distribution of terracettes and their relationship to slope facet angles and the nature of the soil profile;

(b) The morphology of terracettes and the collection of many detailed measurements for statistical analysis;

(c) Observations of rates of creep on the terracette units.

While the collection of the above types of data is very useful these types of data will not, in our view, provide the information necessary to answer fundamental questions such as why terracettes are formed in some areas and not in others.

Clearly, one type of data missing from the above list is that which defines the nature and role of vegetation in terracette formation. In our studies at Salford we are investigating various methods of measuring the strength of the vegetation cover. This type of information together with the shear strength characteristics of the underlying soil will provide hitherto unavailable information. Work is also in progress to try and define more clearly the nature of the function between a terracette unit and its immediate neighbour. Techniques used in the latter investigation include a quantitative study of movement of soil water within a terracette sequence using water insoluble dyes and thin section analysis of the soil in region of the shear zone.

The authors believe that detailed investigations along the above lines, limited to a few well-chosen sites, will provide strong clues to the mechanism of formation of these often observed but little understood features.

CONCLUSIONS

In reviewing the literature on terracettes it is clear that there are many different types of terracette and many hypotheses explaining them. Their polygenetic nature and consequent confusing terminology has probably hindered sound geomorphic explanations.

Undoubtedly much useful basic information concerned with their distribution and morphology can be gained through detailed mapping of terracette forms and field observations but in itself this type of data is rather limited.

More information is required on the actual strength of the regolith and also on the strength of the vegetation cover before the genesis of these intriguing slope forms can be fully understood.

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