PROISOTROPIC AND PROANISOTROPIC PROCESSES OF PEDOTURBATION

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Because pedoturbation processes (soil mixing) occur in all soils in varying degrees during the course of their evolution, mixing processes should be assessed within the larger context of soil genesis. Soils may be viewed as evolving along two pedogenic pathways that operate concurrently: a progressive pathway that includes processes, factors, and conditions that promote ordered, differentiated and/or deep profiles; and a regressive pathway that promotes disordered, simplified, rejuvenated, and/or shallow profiles. Pedoturbative processes that disrupt, blend, destroy, or prevent the formation of horizons, subhorizons, or genetic layers, such that simplified profiles evolve from more ordered ones, are proisotropic and function within the regressive pathway. Pedoturbative processes that form or maintain profiles and maintain or promote increased profile order are proanisotropic and function within the progressive pathway.

Ten forms of pedoturbation are recognized. Hypothetical and real examples of how proisotropic and proanisotropic mixing processes affect soil profiles are presented. The examples demonstrate that both the form of pedoturbation and the texture of the parent material largely determine whether the ensuing morphology of a soil expresses order or disorder. A particular form of pedoturbation in all soils produces a disordered profile in one soil or polypedon, but a more ordered profile in another. This can be true not only for different soils on a landform, but also for the same soil at different times during its evolution. Homogeneous or heterogeneous geologic deposits may be pedogenically organized, or reorganized, via proanisotropic pedoturbation processes that produce a disordered profile in one soil or polypedon, and in certain cases may produce spatially patterned and microlief. Surface stone pavements and armored surfaces, subsurface stone lines and stone zones, and upper profile bioturbations can thus be formed.

Pedoturbation is a synonym of soil mixing (Hole 1961). Mixing processes occur in all soils to various degrees and scales during their evolution. The process is thus, particularly very important processes. The cumulative effects of pedoturbation may be reflected in soils and soil landscapes at two levels: (1) within soils as distinctive morphologic imprints and structures, such as pedonskeleton, krotovinas, stone zones, vennatured horizons, and garment structures, genetic horizons, and broken or interred vegetation patterns, and (2) at ground surface in microrelief and/or distinct spatial patterns, such as animal mounds, stone pavements, patterned ground, and gilgai. Prints and structures range from microscopic to macroscopic; some features are observed only through thin-section microscopy; other features, such as genetic horizons and layers, are clearly visible in road cuts and other exposures.

Hole (1961) originally listed nine processes of pedoturbation (e.g., faunalpedoturbation, or mixing by animals, and floralpedoturbation, or mixing by plants). Wood and Johnson (1978) summarized the nine terms by omitting the syllable pedo (Table 1). Table 1: The term impoturbation is based on observations of mixed or otherwise disturbed soils exposed in the upper walls of some impact crater, for example as at Odessa, Texas. Hole also grouped the various pedogenic factors and processes in a conceptual scheme consisting of two pathways: (a) proanisotropic factors and processes which differentiate soil horizons; and (b) pedopedoturbation factors and processes which disturb soil horizons (as in pedoturbation), or which impede the formation of soil horizons (Hole 1961, p. 377). In our opinion, this theoretical scheme represents a significant advance by providing a different and very useful view of pedogenesis (the "dual pathways" scheme forms the conceptual nucleus of a new soil evolution model whose essentials are outlined below). The placing of pedoturbation in the proanisotropic pathway implies that morphologically simplified or homogenized profiles are a natural consequence of mixing processes. Because pedoturbative processes do not, however, always produce morphologically simplified or disorganized profiles, soil mixing must be assessed within the larger context of soil genesis.

Soil genesis may be viewed as proceeding along two alternating, coacting pathways that are progressive and regressive: the progressive pathway includes processes, factors, and conditions that promote organized, differentiated, and/or deep profiles, whereas the regressive pathway includes processes, factors, and conditions that promote simplified, rejuvenated, and/or shallow profiles (Johnson and Watson-Stegner 1987). Pedoturbation is a common component of both pathways.

The following definitions and concepts are offered as an attempt to refine and extend the original formulations of pedoturbation within a theoretical framework of soil evolution. Pedoturbative processes that form or substantially aid in forming or maintaining horizons, subhorizons, or genetic layers and/or cause an overall change in profile order are proanisotropic and part of the progressive pathway. Pedoturbative processes that disrupt, blend, or destroy horizons, subhorizons, or genetic layers or impede their formation and cause morphologically simplified profiles to evolve from more ordered ones are thus proisotropic and part of the regressive pathway. (In this usage the prefix pro means "tendencies toward.") Thus pedoturbation that promotes a simplified profile from one that was previously more differentiated across a new horizon or genetic layer may form in the process, is by definition proisotropic. On the other hand, if pedoturbation leads to the formation of one or more horizons or genetic layers, but evidence for overall profile simplification is neutral or absent, as is very often the case, the process is assumed to be proanisotrophic. The nomenclature and particulars of these definitions will become apparent to the reader in later sections.

In the next section we demonstrate the validity and usefulness of these concepts, first by presenting some hypothetical examples of soil mixing, following by review of some actual examples. The actual examples are of soils that express surface micromorphology or pitting or whose morphologies have been imprinted or overprinted by various pedoturbative processes. The review of hypothetical and actual examples is not intended to be comprehensive, but to highlight the concepts presented here.
single profile or pedon. To identify the effects of proisotropic pedoturbation, however, it is usually necessary to study the soil or soils in a spatial and, if possible, temporal context, as in topo- and chronosequences of soils and surfaces. In this way, some understanding of past, present, and probable future pedogenetic pathways is gained (Figs. 1 and 2).

Figures 1 and 2 schematically represent several examples of how proisotropic and proanisotropic pedoturbations can function regressive and progressively to promote soil disorder or order. (Unless otherwise specified, or indicated graphically—e.g., Fig. 21-m, the mineral soil in these hypothetical cases is assumed to consist of nongravelly fine fraction material.) The T1 stages of Figs. 1 and 2 depict generalized horizons characteristics as observed in some modern profiles. The T1 stages depict former morphologies of the same soil prior to the passage of an unspecified period during which pedoturbation occurs. In real field settings, however, firm evidence of prepedoturbation (T1) morphologies are often hard to identify, but pedogenic change and overprinting in some soils can sometimes obscure or erase preexistent morphological states). In such cases, deciding whether a modern (T1) profile reflects predominantly proisotropic or proanisotropic pedoturbation becomes, like much of science, a matter of observer interpretation and bias. Also, Hole (1961) noted that a process "...might appear to be distinctly propedisotropic, yet it is simultaneously propadanisotropic ..." depending on the pedogenic context.

**Hypothetical examples of proisotropic pedoturbations**

In Fig. 1 all four profiles show a decrease in profile order and an increase in morphologic simplicity, i.e., fewer horizons or subhorizons at T1 than T1. Pedoturbation is, thus, by definition of the proisotropic kind. The first example (Fig. 1a) shows how a soil with three horizons at T1 (an A/B/C profile) can regress to one with two horizons at T1 (an A/C profile). In deep, non-gravelly soils that are forested, tree uprooting produces such regressed, simplified soils; if uprooting is frequent enough and widespread, a landscape biomorphic forms that is expressed by hummocky microrelief.

The next three examples (Fig. 1b-d) show how soils with four horizons at T1 (A/E/B/C profiles) can regress to soils with three horizons at T1 (A/B/C profiles). In Fig. 1b the A, E, and Bt horizons are mixed together, resulting in an overthickened A horizon and a thinned Bt horizon by T5. Such profile simulations processes have been attributed to faunalization by earthworms (Langmaid 1964).

In Fig. 1c the E horizon at T1 is destroyed by T5 at the expense of an expanding Bt horizon, a process that some investigators have suggested or implied is due to subsoil argillication (Dan and Singer 1973; Muhs 1980, 1982; Soil Survey Staff 1975, p. 377).

Figure 1d is worthy of note, because it shows how different forms of mixing may occur simultaneously in topsoil and subsoil horizons of the same soil by different pedoturbations, one functioning proisotropically, the other proanisotropically. After T1 the A and E horizons are mixed by faunalization to form a single A horizon by T5. Concomitantly the Bt horizon argillitates, but remains unchanged (i.e., is maintained) during T1-T5 which is proanisotropic pedoturbation as defined. For the profile in general, however, pedoturbation is of the proisotropic kind, because an A/E/B/C profile regresses to an A/B/C profile.

**Hypothetical examples of proanisotropic pedoturbations**

Figure 2 shows 13 profiles also at two different stages in their evolutions. In the first seven examples (Fig. 2a-g) mixing processes act in such a way that the number of preexisting horizons is maintained. Thus, even though the A horizon in Fig. 2f expands at the expense of the C, and the Bt horizon in Fig. 2g expands at the expense of the E, the criteria for proanisotropic pedoturbation are met because the horizons are maintained.

Figure 2h shows that the Bt horizon at T1, through subsurface mixing (e.g., argillication), has promoted the development of a new subhorizon (Bt1) at T5.

Figures 2i and 2j show how geologically deposited homogeneous, gravelly materials at T1 are reorganized bimodally via faunalization, to gradually form a biomorphic comprising a lower coarse-clast stone zone and an upper finer-clast, texturally homogeneous layer. (The earth materials at T1 in both examples could have been heterogeneously deposited in two or more layers, and the results at T5 after pedologic reorganization would be similar.) The different textural expressions of the two figures at T1 reflect differences in animal-mixing vectors (invertebrates in Fig. 2i versus small invertebrates in Fig. 2j).

Figure 2k shows how geologically deposited materials, a fine-textured layer above a coarse-}

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**Fig. 1.** Four simplified, hypothetical schemes showing aspects of proisotropic pedoturbations. Each diagram shows how horizons are reduced and profiles simplified during a period T1 to T5. Other permutations are possible.

**Fig. 2.** Several simplified, hypothetical examples of how proanisotropic pedoturbations can occur during a period T1 to T5. Various mixing and organizing permutations are possible, probably more than are shown here.
in some Torrerts and Xererts suggests that they were once more complex soils with argillic horizons (Muhs 1982, 1983, Soil Survey Staff 1975, p. 377). Muhs (1982), for example, presents evidence that 200,000-year-old Xererts on San Clemente Island, California, evolved from argillic B horizons of younger Xererts. According to Muhs, the B horizon gradually thickened via clay illuviation, became vertic because the clay was dominated by expandable species, then eventually engulfed their A horizons. The Xeral stage of the process as described is indicated at T1 in Fig. 1c, and the subsequent Xerert stage to which it evolves is at T1 in Fig. 1a. Other workers have suggested or implied similar explanations for the origin of Vertisols elsewhere (Buol et al. 1980, p. 259; Dan and Singer 1973; Soil Survey Staff 1975, p. 377).

Argilliculation as described above is by definition an example of proisotropic pedoturbation: horizons or soil genetic layers are destroyed, and the profile has regressed to a simpler state. Vertisols meet such conditions when the soil particle sizes are small enough to allow uniform assimilation, mixing, and blending throughout. Conversely, a Vertisol may evolve in parent materials comprising both relatively fine and coarse particles (clays, silts, and sands, as well as pebbles, cobbles, and boulders); then ordering and genetic layering can and probably will occur, as demonstrated later. The result is proisotropic pedoturbation. This points out the importance of parent material particle size in determining whether some soils become ordered or not.

**Faunal Turbation**

Wombat burrowing in mallee country, Australia. Proisotropic pedoturbation may result from the burrowing habits of large vertebrates, for example wombats in the mallee country of Australia. These powerful beasts churn the earth and create warrens that resemble clustered bomb craters, both from the ground and from high altitude (Löffler and Margules 1980). Covering many meters in surface area, the warrens are ridged with burrows that commonly measure 0.5 m or more in diameter. Wombats effectively penetrate not only the soil, but also the dense, thick (20.5 m) underlying calcrite and C horizon material (Fig. 5). The abundance of warrens in the region is truly staggering; some are still active; others are long abandoned and barely perceptible (Fig. 6). In fact, in some parts of the mallee, as at the Brookfield Conservation Park near Blanchetown, South Australia, it is difficult to find any ground or soil that does not show evidence of wombat burrows. Their warren sizes and densities are such that they have even been detected from space by satellite sensors (Löffler and Margules 1980). These animals clearly play a profound role not only in breaking up calcrite and mixing the soil, but also in serving (along with plants) as fragmentation agents in the calcrite brecciation process in Australia (cf. Klappa 1979, 1980).

Because such burrowing occurs throughout the entire profile, including the C horizon, the process is not captured by the examples of Fig. 1, although Fig. 1a comes closest (if the arrows extended into the C horizon, Fig. 1a would display such mixing).

**Processes of Pedoturbation**

**Fig. 6.** Warrens representing many generations of wombats may be seen at Brookfield Conservation Park, South Australia. Coulthor D. N. Johnson (left) stands on an ancient flattened Warren, while behind her is an active craterlike one. Girl (K. Johnson) at right is standing on a Warren that is intermediate in size and is slightly hummocky. The abundant calcrite chunks on the surface in the photo reflect past generations of wombat burrowing.

**Fig. 7.** Proisotropically bioturbated Xererts near Pleito Canyon on the north-facing slopes of the San Emigdio Mountains, Kern County, California. Ground squirrels (Otospermophilus beecheyi) have homogenized the soils on these slopes and are contributing to the widespread mound microrelief that dot the alluvial aprons entering the southern end of the Great Valley of California.

Ground squirrel burrowing, California. In some parts of California, ground squirrels (Otospermophilus beecheyi) are so abundant that they have an enormous effect on soil morphology and create a mima moundlike surface microtopography. Their burrows are about 10 cm in diameter and range up to 12.7 m in length and as much as 0.5 m in depth (Borst 1968). Some profiles are riddled with their burrows in the form of old and new krotovina (Fig. 7). Their
activity destroys incipient subsoil horizons and prevents formation of argillic horizons. Soils that evolve under such intense mixing tend to be either Xerothermic, Entic Haploxerolls, or Xerochrepts (Rendzinas, Regosols, or "minimal" Noncalcic Brown soils), mainly with A/C profiles.

Earth materials excavated by the squirrels form mounds up to several meters in diameter and 0.75 m high. The mounds range in particle size from clay to cobbles up to 15 cm in diameter. Apparently, however, much material is transported below surface, from new to abandoned burrows rather than to the surface (Borst 1968). Mound size is thus misleading as an estimate of the volume of material moved. Using squirrel population estimates and mean burrow volumes, Borst (1968) estimated that the animals are capable of mixing topsoil and subsoil horizons to a depth of 0.75 m in about 360 years.

Clearly, these animals are important, not the dominant, pedogenic agents in such soils. The occurrence of A/C profiles on many Holocene and earlier geomorphic surfaces in California (Keller et al. 1985) probably reflects the prioniprotic pedoturbative action of these and other rodents at such sites. Figure 1a approximates such ground squirrel mixing processes, except that burrowing often extends well into the C horizon.

Earthworm burrowing in fine-textured podzols, New Brunswick, Canada. In the course of a correlation study in New Brunswick described by Langmaid (1964), five soil profiles were described, sampled, and characterized. The sites were carefully chosen for their undisturbed condition and their representative acid podzols (the soils belong to the Mongaut, Caribou, and Bellefleur series). This field work took place in 1958. Three years later, in 1961, the sites were revisited. In the interim earthworms had invaded three of the five sites and had completely changed the organic and mineral horizons. The F, H, Ae(E), and part of the B horizons were destroyed and blended. In addition, changes—some drastic—had occurred in the texture, color, structure, and pH of these profiles.

A site that was not part of the original study was also investigated in 1961 (Langmaid 1964). The soil was an orthic podzol (Glasville series). Near the site was an earthworm colony of recent origin that occupied an area of 27 m². One year later the colony had enlarged to 810 m² and had completely mixed the upper layers of the virgin soil.

Figure 8 depicts the four soils before and after invasion by earthworms. In all four soils the upper horizons were blended to form a distinct, simplified single horizon with a lower boundary that was very abrupt and smooth. From a time perspective, the anisotropically integrity of some soils can thus be very tenuous indeed. Figure 1a approximates the kind of profile modifications caused by such earthworm mixing.

Soils that express prioniprotic pedoturbations

Profile expressions of prioniprotic pedoturbation are often less obvious and more complex than those of prioniprotic pedoturbation. Such mixing processes probably play a far greater role in the evolution of many soil profiles than is acknowledged in most pedogenetic studies. The following five field situations include texturally differentiated profiles that reflect faunalturbation, argilliturbation, and cryoturbation. In one case both faunalturbation and argilliturbation occur simultaneously in different horizons of the same profile.

Faunalturbation

Earthworms and ants burrowing in soils that once had surface manuports and artifacts in England and the United States. Darwin observed that Roman artifacts, such as metal items and building stones, left on the English landscape 2000 years ago are now invariably found within the soil rather than upon it. During research to learn why, which covered many decades and included numerous experiments and observations, Darwin concluded that earthworms, mainly, were responsible (Darwin 1882). The process reflects the habit of earthworms passing soil material taken at depth through their intestinal tract, then depositing it on the surface as small mounds. Since they pass only fine fractions through their gut, any larger object will tend to be displaced downward as fines are cycled surfaceward during succeeding generations of earthworms. Given enough time, large objects will be lowered to levels that approximate the maximum depth of earthworm burrowing, which must vary spatially according to site and environmental conditions.

Darwin noted that the maximum depth of lowering he observed in his study area was approximately half a meter (he assumed surface removals via erosion had offset some of the burial effects of the worms). More recently, Johnson (1983a) determined that earthworms and ants in an urban setting in Illinois had buried plastic in the field by 48 cm in fewer than 23 years and stepping stones 4.7 cm in fewer than 15 years. Aside from site characteristics, rate of lowering obviously would depend on earthworm types and densities, whether their churning action occurs all year or is seasonal (due to climate), the amount of surface removals via erosion, and/or the amount of geogenic surface upbuilding that might have occurred.

Such processes will cause such individual objects as artifacts, manuports, gizzard stones of birds and reptiles, and stones that were geologically deposited, to be lowered to levels dictated by site conditions. If present in adequate numbers, such objects will form surfacial horizons and layers (artifact layers, stone lines, and stone zones: Johnson 1983a; Johnson and Watson-Stegner 1987). A biodemically ordered biomantle thus results that consists of a lower coarse clast zone and an upper fine fraction zone (Fig. 21).

Pocket gopher burrowing in gravelly soils, Lompoc area, California. Near Point Arguello, Lompoc, California, on the Signorelli Ranch is an outcrop of fractured and jointed clastic rock composed of opaline silica. It is part of the Monterey Formation of Miocene age. Because it is relatively resistant to weathering, it forms a steep ridge with a southern, debris-covered slope that rests at a repose angle (Fig. 9). The rock is thinly bedded, and clasts released to the slopes by weathering are commonly tabular in shape, ranging from granules several millimeters in diameter to fist-sized and larger pieces. The clasts mass-waste down the steep slopes and are eventually delivered to a colluvial apron that lies at the base of the ridge. The colluvial apron have been pedogenetically assimilated into a dark, organic-rich gravelly Xeroll (Johnson 1983a,b).<ref>

FIG. 9. Ridge of resistant opaline silica with colluvial apron at its base on Signorelli Ranch near the end of the San Migueto Canyon Road, Lompoc, California (see Fig. 10).

The depth of the pedogenetic apron is unknown, but is observed to be at least 2 m deep in a recent borrow pit. Exposed in the wall of the borrow pit is a conspicuous stone zone consisting of coarse siliceous clasts (> 7 cm in long axis diameter) within a matrix of smaller clasts (< 7 cm) and dark soil (Fig. 10). The stone zone is also visible in road cuts leading to the pit. The tabular coarse clasts that form the stone zone show random orientation, although new clasts migrate down the ridge slope onto the apron with their flat sides generally parallel to the apron surface.

D. L. Johnson, Subsurface stone lines, stone zones, artifact-manuport layers, and biomantles produced by faunalturbation via pocket gophers (Thomomys bottae), unpublished manuscript.
When the site was studied in 1982, the colluvial apron was covered with the mounds of pocket gophers (*Thomomys bottae*). Analysis of 11 mounds revealed that all had clasts less than 7 cm in long axis diameter. Further, the borrow pit wall had fresh, unfilled gopher burrows from the surface to a depth of 2 m, though most burrowing was higher in the profile. (Burrows of *Thomomys* average 6 to 7 cm in diameter.) Particle size and organic-matter analyses of the fine fraction (< 2 mm) from three pedons exposed in the borrow pit wall showed similar depth functions above and through the stone zone (Fig. 11), which are best explained by mixing.

Clearly the gophers have thoroughly homogenized the soil fraction that can be moved through their burrows—particles less than 7 cm in long axis diameter. In this way, as gophers bring smaller clasts and soil to the surface, the coarser clasts that they cannot move upward gradually settle downward and become concentrated as a stone zone. Random orientation of the rocks thus lowered and that make up the stone zone is thought to reflect jostling as the finer materials around them are cycled upward. The result is a clast-dominated, layered profile with a gross morphology that reflects proanisotropic pedoturbation. The process is modeled in Figs. 2j and 12.

**Faunaluration and argillurbation**

Gopher burrowing in manupartment- and artifact-bearing topsoils, and shrinking and swelling of clays in subsoils, Point Conception, California. About 20 km south of Lompoc on the California coast near Point Conception, is the Conception soil, an Argiiboll-Natralliboll formed under a seasonably moist/dry climate. The soil has evolved in late Pleistocene fluvial deposits many meters thick that overlay raised marine platforms (Johnson 1981; Johnson and Rockwell 1982). Archeological materials occur intermittently over this surface, which slopes gently to the south toward beach cliffs. The loamy topsoil has been mixed by pocket gophers (*Thomomys bottae*), as indicated by abundant gopher mounds on the surface and by krotovinas on the side walls of the soil profiles. The loamy, pale, leached E horizon shows signs of seasonal wetness (mottling, gleying). Clay films are relatively thin and few in the upper Bt horizon, but thicken and increase in coverage in the lower Bt. Pedosilicisides and remnants of stress cutans (plasma separations) occur abundantly in the Bt1 horizon—indicating argillurbation in this layer—but are absent from the Bt2 and Bt3 horizons.

For these and other reasons, Johnson (1981b) and Johnson and Rockwell (1982) concluded that gopher burrowing texturally differentiates the upper profile into a biomantle (< 7 cm) whose lower portion contains a stone line. As mentioned, the process is visually and chemically overprinted by seasonally intense lateral leaching processes that differentiate the eluvial E horizon. We interpreted the stones as manupports originally left on the surface by humans that were lowered to their present level in the E horizon by gopher burrowing (Fig. 13). We further concluded that argillurbation occurs in the Bt1 horizon, and that when wetted the Bt1 horizon swells and seals, becoming an aquiclude that inhibits vertical soil water percolation and thereby promotes saturation and intense lateral (downslope) leaching in the underlying E horizon. The complex processes of proanisotropic pedoturbation in this profile are shown in Fig. 2e.

**Argillurbation**

Shrinking and swelling clay soils evolved in parent materials of widely varying particle sizes, Channel Islands and adjacent mainland, California. About 40 km south of Point Conception, across the Santa Barbara Channel, lies San Miguel Island. Pelloxererts on the east end of the island have evolved in marine and eolian sediments that thinly veneer the subjacent, raised, gently sloping marine planation platforms. The soils studied have never been cultivated. They
Fig. 13. Sequential model showing how artifacts and other large surface stones are lowered through the A horizon to the E horizon by pocket gopher burrowing. The dense, clay-rich Bt horizon is not burrowed. Soil and clasts smaller than 7 cm in diameter are recycled to the surface by the rodents. The time frames indicated are suggested on the basis of a previous study (modified from Johnson 1981).

Fig. 14. A Pelloxerert terrain on a raised marine terrace, east-central San Miguel Island, California. A soil pit (0.9 m²) excavated at 15-cm depth intervals revealed that the largest clasts were concentrated in the upper sola. The pile of stones on the left behind the soil pit came from the upper 15 cm, those on the right from the 15-30-cm interval. Stones from the 30-45-cm interval are not shown, but were about the same number as the 15-30-cm interval (see Fig. 15).

Fig. 15. Histogram showing the relative number and size of boulders (>256 mm), cobbles (64-256 mm), and pebbles (4-64 mm) taken from the 0-15, 15-30, and 30-45-cm depth levels of the Pelloxerert shown in Fig. 14 (after Johnson 1972 and Johnson and Hester 1972).

Fig. 16. Hypothetical model showing a subaerially exposed, tectonically raised marine terrace platform (Stage 1) that gains a soil via allochthonously derived silts and clays (Stage 2). At some point, the soil begins argilluribertation (Stage 3) and eventually evolves to a Pelloxerert with a surface stone pavement composed mainly of clast sizes that, once forced upward, are too large to recycle down the cracks (Stage 4) (after Johnson 1972, and Johnson and Hester 1972).

Fig. 17. Model showing more detail of the annual, wet-dry seasonal shrink-swell processes of Stage 4 in Fig. 16.
The principal process involved in promoting patterned ground is repeated freezing and thawing of soil. Saturation of the soil, e.g., Cryaquepts, by melt water and the absence of vegetation (Jahn 1968). On variously textured soils such action causes coarser clasts to be shifted toward freezing surfaces, either upward toward the surface or laterally toward frost cracks, which develop as the ice thermally contracts at low temperatures (below -15°C). In time, originally homogenous or geologically stratified parent material will pedologically reform to patterned ground, as shown in Fig. 21-2m.

**DISCUSSION**

Mixing processes (Table 1) may function either as proasotropically or proasotropically. Proasotrite, for example, may produce a disordered profile (profiles) in one soil or polyleptatively (Fig. 1a), a more ordered profile in another (Fig. 2h), or vice versa. This can be true not only for different soils on a landscape, but also for the same soil at different times during its evolution. For example, in a Natarelli profile with an argillite horizon (Fig. 2g), the E horizon, which contains both silty and argillite, is not a single, but rather a layered sequence of materials. The argillite is typically interbedded with the silty horizon, and the two are separated by a thin argillite layer. This interbedding is characteristic of many Natarelli profiles, and it is thought to be the result of physical processes, such as the movement of water through the soil and the deposition of fine-grained materials on the surface of the soil.

The nature of the parent material is important in determining the morphologic expression of some pedoturbated soils. If, for example, the colluvial apron on the Signorelli Ranch near Lompoc, California, in which Xerolls formed had been composed of fine-textured materials or coarse-skeletal materials, the surface would be more erosive-prone. The surface would be more susceptible to erosion, and the erosional features would be more pronounced. The surface would also be more susceptible to gully erosion, and the gullies would be more likely to develop.

**REFERENCES**


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