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Accelerated Soil Erosion: A Problem of Man-Land Relationships

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Accelerated soil erosion has posed a latent if not chronic environmental problem ever since agriculture became the dominant mode of subsistence in parts of the Old World, almost 10 millennia ago. Cultivation and the pressures of livestock grazing marked the first serious impact of man on ecosystems, and thus opened a Pandora's Box of complications in regard to the balance of vegetation cover, soil mantle, and runoff. No food-producing culture or environment has been immune to the threat of accelerated soil erosion, and soil-conserving agricultural methods have been applied locally and temporarily since pre-historic times. But by and large, farmers and herders have tended to be ruthless rather than conservative in their exploitation of the environment. Mainly through ignorance, population pressures have usually been countered by over-intensive land use, with a concomitant, self-defeating deterioration of natural resources. However, until the 16th century A.D. the ecological crises provoked by man were of limited area and duration, and essentially confined to parts of Eurasia. Since then the exponential increase of population and an unprecedented global colonization by western society has provided the people and the technology essential to severe environmental deterioration in all but the desert and polar worlds.

As the second half of the 20th century progresses there is a growing awareness of overcrowding, of the false panacea of unrestricted technology, and of the inability of society at large to deal with the processes that threaten the planetary ecosystem. One of the few advantages of the growing current of pessimism is that blind trust in the efficacy of expanding G.N.P.'s is being replaced by a search for new perspectives. Educators are now confronted with students more sympathetic to innovative curricula, less intolerant of cultural diversity, and above all willing to admit to the existence of current problems.

Soil destruction is one such problem, and its solution demands more than the conservation programs of an earlier generation that knew the Dust Bowl years or formed the subject matter of *The Grapes of Wrath.* At issue is an aspect of man-land relationships: a matter of universal education in the value of the precarious soil resource, in the use and abuse of the land, and of the relative suitability of new and traditional technologies. Apart from instilling ecological values at home, where most of the damage may already have been done, there is urgent need to educate subsistence farmers of underdeveloped areas in methods of optimal land use, while preserving those techniques or attitudes that may be most harmonious with local conditions.

SOIL FORMATION AND EROSION

Soil can be defined as a shallow zone of intermixed mineral and organic matter, exhibiting one or more horizons that differ from the underlying regolith in morphology, particle size, chemical composition, and biological characteristics. Soils, in this restricted sense, are common to perhaps 75 percent of Earth's land surface and are lacking only in certain polar, desert, and mountain settings. Even where man has not interfered with ecosystems, soils are subject to some degree of erosion. In fact, the ideal condition is a balance between weathering and erosion (Bunting: 1965, Chapter 6) as expressed by the equation

$$E = W + S$$

where E is erosion by runoff and mass movement,
W is the rate of weathering and soil formation, and
S is soil wash and other colluvium added from upslope.

Under most normal conditions a balance will be maintained, with the thickness of soil profile varying according to the steady-state defined by conditions that reflect climate, vegetation mat, bedrock, gradient and length of slope, as well as degree of human interference.

On undisturbed moderate or steep slopes, "natural" erosion is persistent and requires continuous formation and replacement of soil products. Consequently even without interference, most slope soils are not inherently stable and remain permanently "young" since they are ever composed of fresh products.

A rupture of the ecological balance, produced by deforestation, overgrazing, or cultivation can promote an *active balance* with $E > W + S$, until a new balance is attained or until bare rock is exposed. Strictly speaking, an active balance cannot be maintained indefinitely except in unconsolidated rocks. However, it is useful to employ a broader definition of active balance whereby $E > W + S$ whenever a lithosol or bare rock is present. By this criterion, convex facets or segments of most intermediate-gradient slopes have an active balance. This is also the case wherever backwearing is dominant, as a result of steep initial slopes, continued slope undermining, or climatically-inhibited chemical weathering in very dry or very cold environments.

Where soil profiles deepen through time, $E < W + S$ and a *passive balance* prevails. Soils on convex slopes thicken until increasingly fine texture and greater inherent soil moisture decrease the shear strength of the soil. At that point mass movements and possibly sheetwash promote erosion of any excess soil on increasingly unstable slope segments, until a steady state is reestablished. Consequently a passive balance cannot persist indefinitely, even on concave slopes, except in a very relative way whereby profiles thicken almost imperceptibly over centuries and millennia.

When an *established* soil is suddenly removed faster than it forms, there obviously is a disruption of the normal balance between weathering, soil formation, erosion, and deposition. Lithosols and other "immature" soil profiles may be a permanent feature in steep mountain country, the polar world, or in hyperarid deserts as a result of topography or climate. However, when an existing soil in an intermediate environment begins to show net erosion, there are two possible explanations: (1) a change of climate and macro-environment, affecting the vegetation cover and other aspects of the ecosystem, or (2) human interference. Practically all such *accelerated soil erosion* visible today is the result of man's manifold activities.

SOIL ERODIBILITY

The erodibility of a soil mantle varies considerably according to a variety of environmental parameters, including:

(1) Intensity and duration of precipitation. High-intensity or protracted rains increase amount and proportion of runoff and accelerate overland flow, whereas light rains do not increase soil or slope instability.

(2) Slope angle and length. Steep slopes favor runoff over infiltration and accelerate overland flow, particularly on long slopes that increase water velocity as a function of time and mass, the latter as a result of greater local concentration (Horton: 1945).

(3) Vegetation type. Trees, closed grass cover, or shrubs with contiguous crowns will intercept raindrops, break their impact, and reduce splash erosion. Deforestation, overgrazing, or cultivation reduce or eliminate this vegetation mantle.

(4) Organic mat. The rooting network, sod and leaf or grass litter of an undisturbed vegetation/soil interface increase infiltration, reduce runoff velocities, impede concentrated overland flow, and provide general protection and stabilization for the mineral soil. Plowing and intensive overgrazing destroy this organic mat.

(5) Soil texture. Permeability and porosity strongly affect infiltration rates, which are greatest in sands. Equally important are coherence and structure imparted by texture: clay content favors aggregation, while cohesivity is also high in mixed-grade soils where "binding" clays and silts are well dispersed among the larger sand grains. On the other hand, well sorted silts or sands are highly susceptible to erosion. Plasticity and cohesiveness are also increased by excess lime or colloidal silica, although increased water content decreases shear strength regardless of texture.

(6) Parent material. Subsurface lithologies are important both indirectly as parent materials and directly as a precondition for gross slope stability. In particular, unconsolidated materials are prerequisite for deep gullying, while large-scale mass movements are inhibited by most compact, unweathered rock types.

All in all, erodibility is determined by multivariate factors and is difficult to evaluate. Bryan (1968) has reviewed the various indices that attempt to express erodibility in practical terms, while Wischmeier and Smith (1965) provide a soil-loss equation in relation to rainfall factors, soil erodibility, slope length and gradient, crop/vegetation cover factors, and conservation practices.

Clearly a great deal of regional information is necessary before such an equation can be solved. More recently, Wischmeier *et al.* (1971) have devised nomographs that incorporate only five soil parameters: percent of silt, percent of sand, organic matter content, structure, and permeability.

THE MECHANICS OF SOIL EROSION

Disturbance or elimination of the vegetation mantle by man introduces a new geomorphic agent capable of upsetting an ecosystem within as little as a few years. In basic terms, deforestation or cultivation reduce the proportion of rain water that infiltrates, increase the ratio and rate of surface runoff, permit splash erosion (Hudson: 1971, Chapters 3-4) as well as accelerated erosion by overland flow (Strahler: 1952), or gullying (Ireland *et al.*: 1939), and increase sediment yield (Leopold: 1956; Golley: 1972). Specifically, three degrees of interference can be recognized:

(1) Deforestation or removal of grassy vegetation by lumbering, cultivation, grazing, or burning eliminate raindrop interception and permit splash erosion as well as accelerated soil creep and rill erosion. Experimental work on a small, devegetated watershed in New Hampshire showed that summer discharge increased 40 percent while almost 15 times as much dissolved inorganic material is now removed from the catchment (Likens *et al.*: 1970). Hydrographic observations from 219 rivers in Russia also show that smaller, forested watersheds have significantly less overland flow and runoff, but greater spring and seepage-derived base flow during dry weather (Bochkov: 1970). The accelerated loss of solubles, and particularly soil nutrients, is confirmed by this Russian study as well as by recent French work. For example, calcium and magnesium ions are removed 4 to 5 times more rapidly on cultivated fields in south France and 20 to 25 times more rapidly in Ivory Coast, West Africa (Clauzon and Vaudour: 1971). This chemical erosion reflects the removal of ions, colloids, and clays in solution and suspension, both by surface sheet flow and lateral seepage of percolating waters through the topsoil.

(2) Plowing and severe overgrazing destroy the litter or fermentation horizons that constitute much of the organic mat. This further reduces infiltration capacity, increasing the volume and velocity of surface runoff, and exposes bare soil to alternating rain and drought. The last result in turn accelerates oxidation of organic matter and reduces the variety and number of soil micro-organisms that generate beneficial humus. As a result, soil structure is modified, with heavy soils taking on forms that are less permeable and aerated, and therefore more erodible and less fertile; light soils, on the other hand, lose their aggregation properties and become incohesive. Depletion of organic matter through soil overuse has similar effects on structure. At this stage of disturbance the probability and destructiveness of soil slumping, debris slides, earthflows, or deflation are greatly increased.

(3) Bad cultivation practices enhance the trend already established. Plowing across the contours provides countless ready-made channels for concentrated overland flow after each rainstorm, allowing appreciable sheet erosion on slopes of as little as 2° and rill erosion on slopes of 5°. Planting of open row crops such as corn, cotton, or tobacco will provide bare soil not only during the sowing season and after the harvest, but throughout the growing season with its maximum-intensity rainstorms. Removal of natural vegetation along stream banks and headwaters further invites bank and headwater erosion. Finally, without terracing, cultivation of slopes steeper than 8° is an invitation to disaster.

The individual processes of accelerated erosion are broadly similar to those normally operating on gentle or intermediate slopes through a broad range of environments. The primary difference is that rates of erosion are higher, gentler slopes are affected, and a greater variety of processes can be seen at work in any one area. Apart from the chemical erosion already referred to, the mechanical processes include the following (compare Happ *et al.*, 1940):

(1) *Sheet wash*, the gradual removal of topsoil over wide areas by successive rainstorms. Sheet wash becomes conspicuous when light-colored B or even C-horizons are exposed on convexities and dark, A-horizon topsoil in concavities.

(2) *Rill wash*, the rapid removal of topsoil along plow furrows or natural lines of concentrated drainage. The effectiveness of rill wash is commonly obscured by plowing that erases temporary rills, but that cannot restore lost topsoil.

(3) *Gullying*, the rapid and catastrophic erosion of all soil horizons by deep channels that eat back from permanent drainage lines. Gullies deepen, widen and cut headward after each rainstorm, mainly in unconsolidated parent materials. Headward erosion in silts may be aided by subsurface piping (Figure 1).

(4) *Mass movements*, including soil creep, soil slumping, earth flows and debris slides. Such processes accelerate and intensify the impact of running water on slopes of over 5°, and can lead to catastrophic destruction of hillsides with clayey substrates. Bank slumping and collapse as well as soil fails also aid in the growth of gullies.

(5) *Deflation* or wind erosion, primarily of dry, incohesive soils. Although most common and effective in semiarid and coastal areas, deflation can attack exposed soil in humid lands during periods of drought.

EROSIONAL RATES IN DIFFERENT ENVIRONMENTS

The close relationship between environmental parameters and erodibility presupposes that erosion rates vary from one environment to another.

Fournier (1960, pp. 123ff.) has devised a quasi-empirical formula

$$E \propto p^2/P$$

where E is erosion, p is the mean precipitation of the wettest month, and P is the mean annual precipitation.

This function expresses a simple relationship with seasonal periodicity and ignores the crucial variations of rainfall intensity (Greer: 1971). Applying the

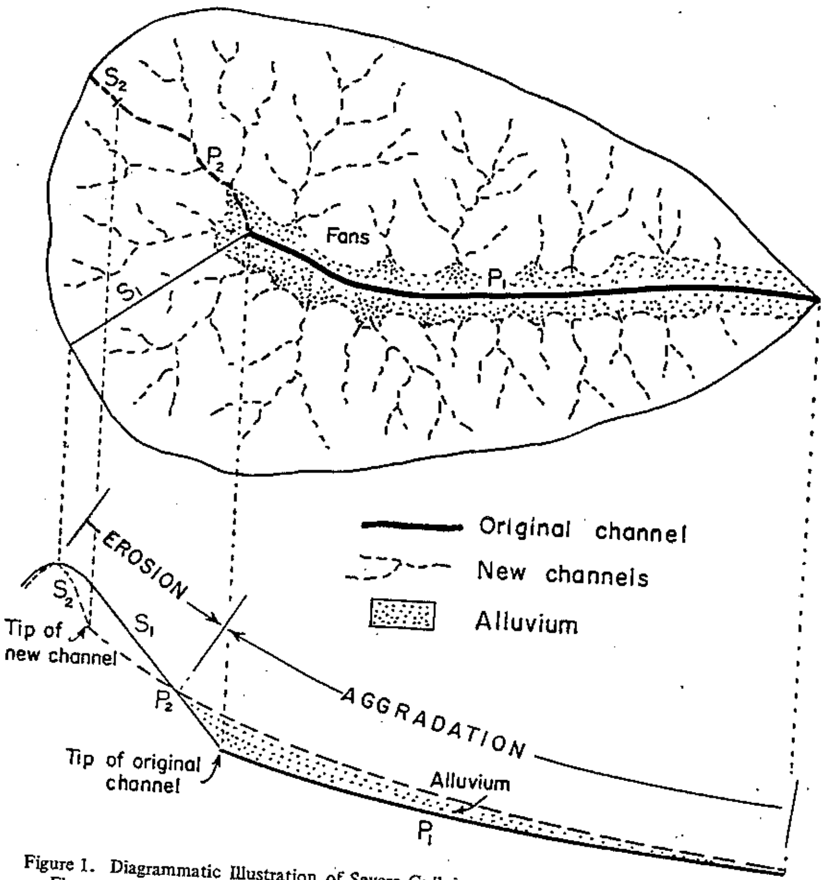

Figure 1. Diagrammatic Illustration of Severe Gullying on Slopes, Alluviation of a Valley Floor, and Increase of Both Channel and Slope Gradients. Reproduced from Strahler: 1956, by permission of the University of Chicago Press.

index to station data from the conventional Koeppen climatic provinces we obtain the following results for p^2/P:

Dcw and *Dd*	(9 stations)	0.77
Dcf	(15 stations)	0.39
Dbf	(17 stations)	0.43
Daf	(16 stations)	0.46
Cbf	(15 stations)	0.73
Caf	(19 stations)	0.81
Caw (monsoonal only)	(12 stations)	2.99
Csb	(14 stations)	0.92
Csa	(31 stations)	0.77
BSkw	(12 stations)	0.36
BShs	(13 stations)	0.76
BWh	(18 stations)	0.55
BShw	(15 stations)	1.29
Aw	(16 stations)	2.95
Am	(15 stations)	4.11
Af	(15 stations)	2.63

The high erosional rates suggested here for tropical and monsoonal climates are given a greater measure of reality by their generalized correspondence with high rainfall intensities. In fact, Hudson (1971, p. 74ff.) estimates the erosive force of tropical rains to be 16 times greater than that of mid-latitude rains, while the removal of soil nutrients from vegetated ground is 5 to 20 times greater in Ivory Coast than in southern France, and the corresponding values for cultivated fields are 30 to 100 times greater (Clauzon and Vaudour: 1971). Similarly, the critical gradient threshold for large-scale erosion from cultivated fields is 8° in western Europe compared with 2° in Rhodesia, reflecting primarily on rainfall intensity and periodicity (Stocking, 1972).

The available quantitative data on regional denudation rates unfortunately are inadequate either to support or question such generalizations. A variety of regional estimates of sediment yield and erosional rates based on river sampling have been offered by Corbel (1964), Fournier (1960, p. 33ff.), Livingstone (1963), Judson and Ritter (1964), Schumm (1965), and Strakov (1967). These are all based on short-term measurements, seldom standardized, fraught with assumptions (Meade, 1969), and in part mutually contradictory. Major difficulties lie in the lack of usable data on bed-load sediments, and in the fact that accelerated soil erosion primarily involves localized erosion and deposition that may show little output beyond small watersheds. The only generalizations that can be drawn at this time are that (1) overall denudation is 2 to 5 times greater in mountain country than on plains, (2) chemical denudation is significantly greater in humid than in dry lands, and (3) the yield of suspended sediment in middle latitudes is greatest in semiarid climates.

In effect, these materials caution against the overemphasis of zonal climates in evaluating problems of regional soil erosion. Once the vegetation has been removed it appears that slope and the nature of the soil itself are primary criteria. Furthermore, in this writer's experience in North America, Europe, and Africa, the constellation of "accelerated" geomorphic processes in operation, as well as the micro-landforms generated, most conspicuously reflect initial slope and lithology.

CULTURAL FACTORS IN ACCELERATED SOIL EROSION

Land use provides variable opportunities for accelerated soil erosion. Some practices are patently exploitative, disrupting ecosystems and maintaining a permanent state of imbalance. Others establish new ecosystems capable of a reasonable steady state. Factors such as technology, subsistence economies, and social attitudes are critical in assessing the following man-soil interactions:

(1) Forest clearance. Patterns of plot clearance or general deforestation vary greatly. On the one hand, slash-and-burn cultivators may clear small woodland plots, killing the larger trees (which are frequently not

removed) and cutting or burning away only the undergrowth and that minimum of mature trees inimical to successful cultivation; some raindrop interception remains and the rooting network commonly continues to stabilize the soil mantle. On the other hand, cultivation based on heavy, wheeled plows generally leads to complete clearance of large plots, with destruction of stumps and roots. Additional deforestation for timber, fuel, or herding opportunities can intensify this denudation by destroying the cover of adjacent steeper slopes or roughlands. Even within these broad types of clearance, attitudes to the maintenance of forest stands and of ornamental or shade trees range from the sublime disinterest of the Near Eastern cultivator to the tree-consciousness of the transalpine peasant.

(2) Soil preparation. The shallow and incomplete soil upturning associated with hoe and digging-stick cultivation may not favor good crop yields, but it does help preserve soil moisture and reduce the depletion of organic matter and biota. Similarly, the scratch-plow commonly preserves the base of the humic A-horizon and does not expose the heavier and more erodible B-horizons to rain splash and the compaction associated with periodic, intensive dehydration. The deep-delving wheeled plough, while favoring more sustained yields—and almost essential on heavy soils—is a potential menace on erodible land. Without fertilization, deep plowing destroys the biota, organic matter, and structure of the A-horizon, ultimately favoring maximum erodibility. Most of the recent and rapid soil destruction in the New World was predicated on deep plowing, and many Western technologists are still attempting to introduce similar implements to tropical nations where the tractor-drawn steel plow can have a catastrophic impact.

(3) Planting techniques. Dissemination of seeds or root cuttings affects erodibility in several ways. Broadcast seeds provide even and relatively dense stands of crops, compared with row planting. As a result grains and alfalfa provide good to excellent ground cover for most of the growing season, while row crops of maize, cotton, and tobacco expose much bare and disturbed ground at all times. By contrast, tropical "mound" planting of seed or root plants leaves most of the ground undisturbed. Crop rotation reduces erodibility, at least in part because legume plantings help restore organic matter and biotic activity. Leaving plots in bare-ground fallow may be advantageous for restoring soil fertility, but the minimum of ground cover invites intensive erosion on sloping land. A quantitative example, derived by Bennett (1939, p. 148) from rates of denudation on an 8° Ohio slope, illustrates some of these differences of cover. The theoretical time necessary to erode 175 mm. of soil is as follows:

forest	173,700 years
grass	28,900 years
rotation (maize-wheat-alfalfa)	100 years
fallow (bare ground)	17 years
maize	16 years

Intercropping is far more favorable than monocultures, by providing longer and more complete ground cover: e.g., alternating rows of vines and fruit trees, interspersed with grains and vegetables in Mediterranean vineyards; almond or olive trees with winter wheat and capers in other Mediterranean areas; yams and rice in southeast Asia; or maize and root crops in Latin America.

(4) Special landscaping. Several cultures inhibit soil erosion by landscaping techniques that may be necessary for hydraulic or slope cultivation. Wet-rice fields on level land or behind water-retaining terrace embankments suffer next to no erosion. Contoured or terraced vineyards commonly occupy slopes too steep or stoney for other cultivation but manage to reduce accelerated soil erosion to an acceptable minimum. Other terraced slopes have traditionally been created through the painstaking efforts of cultivators to collect or preserve slope soils, sometimes in connection with water distribution from elaborate irrigation devices. Many such attempts at cultural landscaping succeed only for a time, and their willful destruction or abandonment can be disastrous, because once breached, terraced or embanked soils erode rapidly and extensively. Other ancient landscaping techniques include such "modern" remedial measures as contour plowing and strip cropping.

(5) Pastoral activities. Although livestock raising does not involve deliberate eradication of the vegetation mantle, its effects are mainly negative. Pasture is often temporarily improved by burning of grassland or open woodland. Trees are browsed by many kinds of livestock, and the cropping of leaves for cattle feed is still practiced in some areas. Overstocking—beyond the carrying-capacity of pasture at its seasonal minimum productivity—is bad with all species. Sheep have the additional trait of grazing down to root level, often destroying beneficial grasses and permanently opening up the ground mat, with only partial recolonization by shrubby vegetation. Goats are notorious for indiscriminate grazing, resulting in destruction of trees and their seedlings. Large aggregations of livestock in fenced plots or through nightly collecting of herds in enclosures also serves to destroy the plant cover, not the least through trampling. In many ways, therefore, pastoralism can promote accelerated soil erosion on a scale that vies with the impact of cultivation. Traditional dairy farming is the notable exception here, and the European version of manured hay crops provides a striking counter-example to tribal herding.

The cultural factors outlined above help explain why the visible evidence for accelerated soil erosion bears little relationship to rainfall intensity, slope, or the innate erodibility of soils. They show that the Eurasian grain-farming tradition is far more destructive than the much-maligned shifting cultivation of the tropics. They single out paddy cultivators, horticulturalists, dairy farmers, and wine growers as successful specialists in the spectrum of rural achievement. And they provide the explanatory key for understanding of accelerated erosion in an historical context.

HISTORICAL PERSPECTIVES: THE OLD WORLD

Agricultural communities were already established in western Asia and along the Greek shores of the Aegean Sea by 8000 B.P. (before present time), in the Hungarian Plain and Italy by 7000 B.P., in central Europe and eastern Spain by about 6400 B.P., and in northwestern France and Britain by about 5300 B.P. (Ammerman and Cavalli-Sforza: 1971; Berger and Protsch: 1973). This gives a *de facto* time depth of 6 to 9 millennia for primary village-farming communities in Europe and its Asiatic borderlands, although it should be noted that C^{14} dates in the time range discussed here are approximately 800-1000 years younger than true calendar years, as corrected by bristlecone pine calibration.

Some degree of deforestation was involved in most of the environments used by early agriculturalists and, as Dimbleby (1972) has pointed out, the removal of the dominant organism—the tree—inevitably altered naturally balanced ecosystems and frequently led to ecological disaster. Yet, early "primitive" agriculture was not inherently destructive and seems to have been surprisingly well-adapted to local environments. Soil preparation was done by hoe or digging stick, plots were small and used for short periods only, and only level lands were cultivated (Butzer: 1971, Chapter 33).

A potential change was first introduced with the ox-drawn scratch plow or *ard* in the 3rd millennium B.C. (Fowler: 1971). The first suggestions of large-scale deforestation and cultivation on unstable slopes, with resulting soil erosion, are recorded within lake sediments of the English Lake District (Mackereth: 1965) and by valley hillwash in Kent (Evans: 1971*b*), both incidents also dating to the 3rd millennium B.C. Yet, despite the evidence of man's increasingly intensive impact on vegetation, there is little evidence for either significant or extensive soil erosion in temperate Europe or the Mediterranean Basin until the end of the Bronze Age, about or shortly after 1000 B.C. (Evans: 1971*b*; Huckriede: 1971; Yassoglou and Nobeli: 1972, p. 174ff.).

The Mediterranean World after 1000 B.C.

Several classical Greek authors were the first to draw attention to deforestation and soil erosion problems, and the commentary of Plato (Critias, 111, D-E), in the 4th century B.C., is the first of its kind:

> In consequence of the successive violent deluges . . . there has been a constant movement of soil away from high elevations; and, owing to the shelving relief of the coast, this soil, instead of laying down alluvium as it does elsewhere, has been perpetually deposited in the deep sea around the periphery of the country or, in other words, lost. . . . All the rich, soft soil has molted away, leaving a country of skin and bones [so that rainfall] is allowed to flow over the denuded surface [directly] into the sea. . . .

Elsewhere Plato attributes this soil erosion to deforestation. His views find some confirmation in the observation of Pausanias, in the 2nd century A.D., who related siltation on the coast of Asia Minor to increased stream sedimentation as a result of soil erosion due to cultivation. Although also affected by relative movements of land and sea, this coastal progradation in Asia Minor began *ca.* 750 B.C., reached its maximum from 300 to 100 B.C., and came to a close by 700 A.D. (Eisma: 1962). Alluviation of a coastal plain was also underway in the northwestern Peloponnese by the 2nd century B.C., reaching its maximum in Roman times and essentially coming to a close in the 3rd century A.D. (Raphael: 1973).

Rediscovery of the Greek and Roman authors, and the antiquarians that began to seek out the ancient Mediterranean world since the late 17th century, created a false impression of the ravages of soil erosion. It has become commonplace to attribute denuded mountain slopes and alluvial lowland soils everywhere to the impact of historical soil erosion (see, for example, Bennett: 1939, p. 24 ff., and Stallings: 1957, p. 2 ff.). This gross exaggeration has unfortunately found its way, by implication, into many general texts, whereas in fact the Mediterranean Basin is no more scarred by soil erosion than is the United States.

Two points deserve elaboration in connection with Mediterranean soil erosion: the true age of the red soil sediments often attributed to historical erosion, and the chronology of documented, historical erosion.

Red Mediterranean soils are today found primarily in piedmont alluvial plains or river floodplains, with little more than discontinuous veneers on uplands or hillsides (Durand: 1959, part 3 and map). Closer examination shows most of the lowland occurrences to be silty or sandy, reworked soil derivatives. Yet even the apparently intact profiles of *terra rossas* (and equivalent red-yellow podsolic soils on non-carbonate parent material) appear to be relict, and no longer developing today. It can be demonstrated geologically that red Mediterranean soils were last formed on a regional scale during the early Upper Pleistocene (before 70,000 B.P.), that such soils are relict and have not developed on freshly exposed sediments during the last 10,000 years, and that related soil mantles were repeatedly and intensively eroded by episodes of natural erosion during Pleistocene times (Butzer: 1963, 1964, 1971, pp. 306 ff., 378 ff.; Fränzle: 1965). For example, below the plain of Palma de Mallorca, Spain, situated at the foot of high, denuded, limestone sierras, there are over 150 m. of interdigitated red soil sediments and fanglomerates. These Mallorquin piedmont deposits span the late Pliocene and most of the Pleistocene, and the only post-Pleistocene wash is limited to isolated 1-1.5 m. channel fills and restricted coastal veneers that interfinger with +1 to 2.5 m. beach deposits, all containing post-Reconquista pottery, i.e., post-dating A.D. 1228. Numerous similar examples could be cited from Mallorca and Catalonia. The implication is that in the case of hills or mountains formed of compact bedrock, the great bulk of the piedmont soil colluvia are of Pleistocene age. By contrast, unconsolidated sediments such as the late Tertiary shales of southern Italy and southeastern Spain gully rapidly (Bennett: 1960) and catastrophic mass movements occur persistently in response to human activities (Kayser: 1961; Franceschetti and Masone: 1968).

As to the chronology of Mediterranean soil erosion, a classic example is provided by the original Olympic site, in the western Peloponnese. The shrine of Olympia was originally built on a non-functional stream confluence fan in the 8th century B.C. A drainage culvert was constructed there about A.D. 130 and an adjacent Byzantine fort was built in the 5th century A.D. The site continued to be used for settlement until *ca.* A.D. 680 (Büdel: 1965). Aggradation of silty hillwash probably began after A.D. 500, when records of catastrophic floods begin. At any rate, all of these structures were buried by 7 m. of colluvium before the first traveller's description in 1776. However, by that time the stream channels had once again cut down 7 m. below the post-680 valley floor, although remaining 2 m. higher than in ancient Greek times (Büdel: 1965).

This denudation of slope soils in post-Roman or Medieval times was not restricted to Olympia but rather was widespread in the Mediterranean Basin: (1) A 4-5 m. sandy alluvial terrace of the Gornalunga River in east-central Sicily dates to Medieval times (Judson: 1963); (2) Some 5-8 m. soil wash and alluvium buried Roman buildings and roads in southern Etruria after A.D. 209 and before 1534, with C^{14} dates suggesting a specific age of A.D. 500-1000 (Judson: 1963;

also Vita-Finzi: 1969, p. 72); (3) 2 m. of soil wash, eroded from Roman vineyards, buried latifundia in Catalonia that were abandoned between 258 and *ca.* A.D. 400 (Butzer: 1964, p. 48 f.).

Vita-Finzi (1969) has collected a variable body of data to show that during late Roman or early Medieval times many of the streams of the Mediterranean Basin were in fact subject to a significant change of geomorphologic equilibrium: vertical cutting of older alluvial fill gave way to alluviation in the lower stream courses. As a result, longitudinal stream profiles were steepened and smoothened, while broad tracts of loamy agricultural soils were created along the valley floors by silt-laden floods. In recent centuries these "post-Classical alluvia" have once again been subject to dissection. Unfortunately these valley alluvia are discussed by Vita-Finzi (1969) with little attention to colluvial deposits and the complex of slope processes; interactions of vegetation mat, soil properties, and denudational forces are neglected at the specific level; and interpretations are not based on sedimentological studies. Finally, changes of land use, gradual or repeated devegetation, and other human influences are discounted or relegated to secondary and local significance by this author. Instead, the "post-Classical fill" is thought to reflect vague climatic factors affecting the whole Mediterranean Basin simultaneously, possibly the "Little Ice Age."

It need not be emphasized that alluviation which had terminated before A.D. 1500 cannot be ascribed to the "Little Ice Age" of the 16th and 17th centuries. More significantly, Vita-Finzi can make no case for strictly synchronous slope denudation and valley alluviation over a possible range of 1000 years. Finally, there have indeed been earlier episodes of soil destruction, as witnessed by the early siltation of the Asia Minor or Peloponnesian coasts or, in the Gornalunga, by the 5-6 m. of alluvial sand and silt washed together after the beginning of Greek colonization in Sicily, but before the digging of burials that date from *ca.* 325 B.C. (Judson: 1963). Consequently, the Mediterranean Basin suggests localized soil erosion problems as early as the mid-first millenium B.C., and far more general soil stripping in the wake of the economic decline of the Roman Empire, with its attendant rural depopulation, barbarian invasions, and land abandonment.

It seems that the onset of "post-Classical" erosion varied over a span of 500 years, between the 3rd and 8th centuries, depending on the history of local land use. Although some sets of climatic anomalies may have aided in the process, a series of pollen studies including the central Spanish sierras (Welten: 1954), the Valencian and Mallorquin coasts (Menéndez-Amor and Florschütz: 1961*a*, 1961*b*), Dalmatia (Beug: 1967*b*), western and northern Greece and Crete (Wright: 1972; Wijmstra: 1969; Rossignol and Pastouret: 1971), Israel (Horowitz: 1971), and Asia Minor (Beug: 1967*a*; Van Zeist *et al.*: 1970) show conclusively that there was no regional climatic oscillation or change during the last 2500 years. In other words, man must assume the primary responsibility. Whether the process of soil erosion was ultimately and inadvertently beneficial to agriculture as claimed by Vita-Finzi (1969, p. 117 ff.) is debatable. To suggest that valley floor alluvia are easier to cultivate and irrigate than hillside soils may be true, but the hillside soils were much more extensive before being reworked into deep but restricted valley fills, and those valley fills that have been described are at best loamy, and many are sandy or gravelly. Fertility would have been quite low on crude mineral soil and slope derivatives.

Soil erosion remains a chronic problem, particularly in overpopulated, marginal environments of the Mediterranean Basin to the present day, e.g., the Apennines and the Atlas Mountains (Kayser: 1961; Aubert and Monjauze: 1946).

Temperate Europe after 1000 B.C.

Soil erosion in temperate Europe, although less conspicuous, was in many areas no less significant than in the Mediterranean world. Evidence to this effect is so far restricted to soils developed in veneers of unconsolidated parent material, such as till and particularly loess.

In central Europe loessic slope soils were first swept into the river valleys at the transition from the Bronze to the Iron Age, *ca.* 750 B.C., and further evidence of accelerated erosion comes from several areas of Halstatt-La Tène (Celtic) settlement in subsequent centuries (Lüttig: 1960; Jäger: 1962; Strautz: 1963; Huckriede: 1971). Older, Bronze Age valley settlements were buried by as much as 1-2 m. of loessic soil wash, and accelerated floodplain sedimentation locally destroyed riverine forests. It remains uncertain whether deforestation and increased runoff played a key role in this process, whether cultivation of precarious intermediate slopes was responsible, or whether abandonment of hillside plots during successive periods of widespread unrest triggered off episodes of disequilibrium. The ancillary role of cool-wet climatic oscillations with the onset of the Subatlantic phase (*ca.* 800-300 B.C.) also remains to be considered.

Celtic and Roman cultivators continued to employ the scratch-plow and concentrated their plots on upland plains and some intermediate-slope hillsides. By the time of the Germanic migrations the uplands of Britain and Gaul had lost much of their topsoil to erosion and the Germanic tribes colonized the mainly unused lowlands, where they were able to till the heavy-textured soils with the heavy, mould-board plow that had been first introduced to northwestern Europe in Roman times. Thus in southern England cultivation shifted to the lowlands, with the old, eroded upland fields partly abandoned to pastoralism (Crawford: 1923; Bowen: 1962; Fowler: 1971). In northern and eastern Gaul, on the other hand, a dichotomy of settlements arose, similar to that of central Europe. Population pressure built up in central Europe during the 13th century, leading to extensive deforestation and cultivation on the rougher uplands. By the time the more marginal of these settlements were abandoned, *ca.* 1350-1450, most of the topsoil had been destroyed and a second wave of loessic soil sediments inundated footslopes and floodplains (Jäger: 1962; Strautz: 1963; Huckriede: 1971). The truncated B-horizons of abandoned fields can still be recognized under the forests of today (Machann and Semmel: 1970), and some German valleys are mantled by 1-8 m. of corresponding "haugh loams."

The third episode of soil erosion in temperate Europe is dated between about 1760 and 1880, a time of renewed rural population pressure, consolidation of fields, shifts to monocultures, resurveying along geometric grids, upland deforestation, and destructive herding in once-protected woodlands. These manifestations are richly documented in the archives and have been described from France (Vogt: 1953, 1971) and Germany (Hard: 1971), with close modern parallels evident for post-1918 Poland (Miszczak: 1960), and comparable trends related to deforestation can be recognized in many uplands of the Mediterranean world. This last major wave of soil erosion was eventually halted by conservation measures such as strip-cropping and reforestation.

The Asiatic Monsoon Lands

Although southern and eastern Asia qualify as ancient agricultural lands, there is as yet little precise information as to the adaptation or innovation of agricultural traits. On the Indian subcontinent there is an embarrassing lack of substantive evidence for domesticated plants or animals until shortly before the appearance of the Harappan civilization (Allchin: 1969). In China there happens to be no isotopic dating or even a developed relative stratigraphy for the Neolithic, so that we can only assume that grain-farming was established there relatively early (Watson: 1969). For Southeast Asia there are tantalizing indications that independent domestication may have begun as early as in the Near East and southeastern Europe (Gorman: 1971), but regional and temporal patterns have not yet begun to be understood.

The difficulty of establishing a datum for early agriculture in the Asiatic monsoon lands underscores the inadequacies of archeological and historical research in land use in such vital areas where population pressures and soil deterioration appear to have been chronic for at least several centuries. Conservatively speaking there is an agricultural time depth of at least 4 or 5 millennia in most of this region, significantly greater in parts. Destructive monocultures such as jute, cotton, and wheat were long favored by the export-oriented economy of the British raj in India. Above all, however, these same lands are characterized by maximum erodibility in climatic terms, and the sediment yields of Indian and southeast Asian rivers are almost phenomenal.

The degree of gullying in India is catastrophic, and no less so than in the unconsolidated volcanic hillsides of Java. Soil stripping has almost denuded the uplands of southern China, while deflation and gullying of the loessic regions of the north is also in an advanced stage (Min Tieh: 1941). It is unfortunate, therefore, that there are no comprehensive surveys of erosion problems today, let alone in historical perspective. Here, even more than in the Mediterranean world and temperate Europe, there is a fruitful field for interdisciplinary research.

HISTORICAL PERSPECTIVES: THE NEW WORLD

Serious soil erosion in the 18th century was essentially limited to the ancient agricultural lands of Eurasia and North Africa. Almost nowhere else did technological levels and population pressures present significant problems of overintensive or abusive land use. However, in the past two centuries soil erosion has become commonplace in the New World as well as in large parts of subsaharan Africa. The obvious exploitation of the earliest European *conquistadores* and frontiersmen was perpetuated with a vengeance by the colonists and settlers. Only, the object of their pillage was neither gold nor slaves nor furs but the land itself. Unlike the Old World peasant who was committed to making a livelihood from his holdings, from one generation to the next, the New World farmer was patently speculative in his land use. When one farm failed it was abandoned and a new start made elsewhere.

The American colonization of the mid-central U.S.A. may be the most flagrant example of land abuse. Farming populations began to cross the Appalachians in the late 1700's and westward colonization only succumbed on the Great Plains amid the 1930's Dust Bowl. Preceded by systematic deforestation to the prairie margins (Schmid: 1974), and following a disastrously conceived geometric grid system (Pattison: 1957) these pioneers in reckless land use at first attempted to farm on all available slopes, plowing up- and downhill. Specialization rapidly followed mixed general farming, and monocultures became dominant with intercropping practically unknown. In about 150 years the agricultural soil resources of the United States have been cut by perhaps a half, and in some areas such as Oklahoma, a single generation sufficed to destroy almost 30 percent of the soil mantle. Such a systematic if unconscious rape of the land has had an impact that rivals or exceeds that of 6 to 10 millennia of cultivation in the Mediterranean world.

Early signs of accelerated soil erosion were apparent in the hilly farmlands of New England by the early 18th century (Stallings: 1957, p. 12 ff.) and remedial measures were already the subject of debate well before the appearance of the major work of George Perkins Marsh (1864). As the cutters slashed westward and the settlers shifted from farm to farm in their wake, ecosystems were thoroughly disrupted. This has been tangibly documented for southwestern Wisconsin by Happ (1944) and particularly by Knox (1972 *a, b*; Knox and Corcoran: 1972), who has resurveyed stream widths first recorded in the Federal Land Survey of 1832-33. Existing forest cover was reduced 80 to 90 percent by the earliest settlers, increasing the frequency and magnitude of flood flows and disrupting the balance between slope, sediment, and discharge. Soils were truncated and the eroded silts and clays systematically distributed over downstream floodplains. This increased sediment yield created alluvial fans at tributary confluences and significantly increased bed-load fractions and channel width. An older, but equally valuable paper by Gottschalk (1945) describes the impact of soil erosion since colonial times on sedimentation in Chesapeake Bay.

A fine historical documentation of accelerated soil erosion has been provided for another region, the upper Georgia piedmont, by Trimble (1969, 1970). Settlement of the bottom lands began there between 1780 and 1805, but erosion first became apparent when sloping lands were cleared and was locally accentuated by the impact of plantation agriculture after the 1840's and 1850's. In contrast to the older cotton plantation areas, major erosion was delayed until the 1880's when forest acreage was significantly decreased and row crops, especially cotton, became dominant. By the 1930's, when the efforts of the U.S. Soil Conservation Service began to take effect, the impact of man on the soil mantle, hydrography, and sedimentation had exceeded that of any natural climatically-induced ruptures of equilibrium experienced in the southeastern U.S.A. during all of Pleistocene times.

The American Southwest has also been ravaged by soil erosion but here, surprisingly, the major culprit has been climate rather than man. A relatively well-known hemi-cycle of gullying and range deterioration has drastically reduced land values for grazing purposes since the 1880's. Ongoing research has shown that rainfall at all seasons was well below normal during the intervals 1872-89 and especially 1895-1904 (Stockton and Fritts: 1971), which resulted in a reduction of soil moisture and a weakening of the grass cover. Coincident with a rapid increase of livestock, a unique combination of climatic and cultural stress produced the results in evidence today (Hastings and Turner: 1965).

The present state of soil erosion in the U.S.A. and the varying degree of success in combating it are described by Bennett (1939), Stallings (1957), and in several regional studies. In much of the eastern United States the state of erosion as of 1934 was documented by field mapping at 1:62,500 and published (state) maps at 1:500,000 (U.S. Department of Agriculture, Soil Erosion Service, *Reconnaissance Erosion Survey*, Washington, 1935). A wealth of historical data was also collected at that time, and various specific studies and a monumental card file of historical references to soil erosion were reposited in the National Archives, Washington (Files of the Section of Climatic and Physiographic Research, Soil Conservation Service, "Thornthwaite Collection," especially Record Groups 114 and 221. S. W. Trimble, personal communication).

Comparable problems are, of course, shared by Canada, especially the Prairie provinces, and by most of Latin America (F.A.O.: 1954), particularly in areas of overpopulation such as central Chile and central Mexico (Cook: 1949), or exploitative monocultures, such as the coffee plantations of Colombia and southern Brazil (Maack: 1956). Similar pictures of agricultural disaster can be given for large tracts of those other two "colonial" lands, Australia and South Africa.

To this overall picture of limited encouragement comes the more recent impact of urban sprawl and associated construction that has introduced an unprecedented level of intensity to disturbance and now threatens to ravage large parts of the United States. Sobering examples have been provided by Wolman (1967) from Baltimore, Vice *et al.* (1969) from Fairfax County, Virginia, and Thompson (1970) from Detroit (see also the chapter of Mrowka in this volume). The need for "urban" geomorphologists begins to be alarmingly obvious!

FUTURE PERSPECTIVES

With the geometric increase of accelerated soil erosion and the exponential increase of world population, the soil resource has become at once both more precarious and more essential. A potential solution depends on the development and application of remedial measures on the one hand, and on social attitudes and capital resources on the other.

Methods of soil conservation, as developed in North America, have been outlined by Bennett (1939) and Stallings (1957), and a refreshingly cosmopolitan approach has recently been presented by Hudson (1971), whose field experience comes primarily from Africa and Britain. Remedial or preventative measures can be summarized only at the certain risk of over-generalization, since directional change within any one complex ecosystem is difficult to predict. The suggestions discussed below are therefore offered with reservation:

(1) The basic options for coping with soil erosion include: (A) On severely eroded surfaces (bad gullying and 75 percent of topsoil removed)—reforestation or reestablishment of a permanent grass cover is commonly recommended. (B) In areas where gullying has begun or is actively underway—construction of check dams or obstructions is essential to attempt gully stabilization, with contour plowing and strip cropping another "must." (C) Where topsoil erosion by sheetwash is significant—contour plowing, strip cropping (e.g., alternating field strips of hay and crops), and avoidance of open row crops are recommended. In general, terracing may be the only solution on steep slopes used for anything but woodland or hay.

(2) The time to initiate conservation measures is *before* accelerated erosion begins. Contour plowing should always be employed if slopes exceed 2°, and on almost level land checkerboard plowing (each adjacent plot with furrows at right angles) helps to retard sheetwash. Plowing as well as construction should avoid the edges of steep bluffs, leaving areas of potential gullying or mass movements along river breaks in permanent grass or woodland. Alternation between open and close-grown crops and even strip cropping are recommended on all slopes of 3 to 5° or more. In areas of potential wind erosion, woodland shelter belts or windbreaks may well be necessary. Finally, soil organic matter and structure must be maintained at reasonably good levels.

(3) In all environments, every form of cultivation or grazing activity will produce *some* accelerated soil erosion. But with careful cultivation or pasturing of limited numbers of suitable livestock, soil erosion can be kept to an acceptable minimum that, given access to fertilizers, will not affect soil productivity over extended periods of time. On the other hand, poor land management can produce catastrophic and often irreversible damage in a remarkably short time.

Beyond this lowest common denominator of conservation guidelines there is a crying need for ecological thinking. One reflection of this problem can be seen in the controversies surrounding shelter-belt construction in southern Russia and on the Great Plains (George *et al.*: 1957). Another case in point is the reforestation of many central European uplands with pine and spruce, in areas where hardwood forests had once been in equilibrium with eutrophic soils; the resulting timber yield has been commercially profitable, but man-made podzolization has rapidly created acidic, low base-saturation soils (Duchaufour: 1956). Perhaps one of the greatest planning mistakes of the 20th century was the "virgin lands" cultivation in Soviet Central Asia, in what seemed to be a grim attempt to emulate, in 1960, the American Dust Bowl calamity of the 1930's. Any program that plans to institute conservation measures or to "improve" existing land use patterns must be carefully scrutinized within overall landscape ecology.

This is particularly important in the tropics, where a third of the world's population is concentrated, and where standard approaches derived from higher latitudes must be considered suspect. What is good for Missouri may well not be appropriate for Malaysia! Most tropical soils have different clay minerals, so that exchange capacities are highly variable and often so low that fertilization methods must be drastically modified. Many tropical soils have a consistency, porosity, and permeability that bears no obvious relationship to texture, depending on variables such as colloidal silica. Above all, crops, crop seasons, plot size, and technology must all be geared to local conditions. Underdeveloped nations may never have the resources to provide the fertilizers necessary for overambitious agricultural schemes once inaugurated, nor to pay for costly conservation measures necessary once the subsistence cultivator is persuaded to turn in his digging stick for a tractor-drawn, steel plow.

The success or failure of conservation methods depends on social attitudes as much as anything. The traditional values of the Eurasiatic peasantry (Wolf: 1966; Tuan: 1968) have, by and large, preserved soil resources indefinitely, regardless of the odds. The family group or restricted community has had to be more or less self-sufficient in dealing with its land, with no higher power to guarantee continued soil productivity and few if any options to find new land.

The resulting ethic of responsibility for the state of the land and its preservation stood the Eurasiatic peasant in good stead but, unfortunately, did not cross the ocean to the Americas, Australia, and South Africa.

Farms are commonly bought and sold in New World areas of recent colonization, and most North American farmers' overriding concern is short-term investment and profit. Whatever success the U.S. Soil Conservation Service has had in checking erosion can be attributed to its educational program in convincing the farmer that erosion means less cash. The United States farmer expects outside assistance to tackle any environmental problem, and environmental hazards have become equated with governmental responsibility (Leopold: 1966, part IV). As a result, conservation is not practiced independently but becomes a matter of politics at the county, state, and even federal level. Erosion once out of hand becomes an expensive problem to check, but the responsibilities that were shirked by the offending farmer ultimately require major capital expenditures, a tax burden to be shared by the nation at large.

Another conservation problem that has yet to be faced is the direct agency of man in creating or modifying landforms. Highways, strip mines (U.S.D.I.: 1971) and, above all, the "creation" of subdivisions continue to upset the ecological balance on a local but intensive scale that makes agricultural soil erosion seem relatively minor. When social attitudes and capital interests fail as effective deterrents, then clearly there must be political activity and legislation. This is both the critical threshhold and focus where all concerned individuals of a depersonalized, industrial society must act in concert.

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