Erodibility of Forest Soils -- A Factor in Erosion Hazard Assessment

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ABSTRACT

Surface erosion is a function of two opposing forces--driving force and resisting force. Analysis of surface erosion hazards at a site should consider the resource at risk, the duration of hazard, and the site characteristics. Soil erodibility is an important site characteristic determining resisting force. To evaluate erodibility, soil samples were collected from 36 cutblocks in Redwood National Park, California. Soil series represented were Masterson, Orick, Sites, Atwell, Hugo, and Melbourne. Samples were analyzed for size distribution and indexes of erodibility. Atwell, the least oxidized soil, had significantly higher erosion indexes than Sites, the most oxidized.

INTRODUCTION

Surface erosion is a major contributor of sediment to Redwood Creek and other disturbed streams in the north coastal region of California. Logging has generally accelerated surface erosion much more than mass movement in the Redwood Creek basin (Janda and others 1975). With better understanding of the processes of surface erosion, erodible soils can be more easily identified, rehabilitation sites can be selected, and appropriate methods of erosion control can be prescribed.

Surface erosion is a function of two opposing forces--driving force and resisting force. The resisting force is the result of conditions that protect soil particles from being detached; the driving force is the kinetic energy of rainfall and runoff.

The processes of surface erosion can be quantified for inclusion in the following factor of safety (FS) equation:

$$FS = \frac{\text{Resisting force}}{\text{Driving force}}$$

Surface erosion occurs when $FS \leq 1$.

Undisturbed forest soil has a strong resisting force because the mineral soil is overlain by a protective layer of litter; the driving force is weak because the soil has abundant macropores, infiltration rates are high, and overland flow is limited. Consequently, surface erosion tends to be low in undisturbed

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forests. It has been reported to be surprisingly common, however, in the Redwood Creek basin (Janda and others 1975).

Logging activities such as roadbuilding and tractor yarding expose soil and can lower the factor of safety by altering the resisting and driving forces. Disturbance by tractors may remove the litter layer, destroy soil structure, and bring the less aggregated subsoil to the surface. As a result, the soil has less ability to resist erosion by raindrops or runoff. Disturbance may also compact soil and thereby decrease infiltration and percolation rates, causing more overland flow or a greater driving force down the slope. The extreme case occurs with inboard road ditches that concentrate runoff.

Most of the research in predicting surface erosion has been conducted on agricultural land that is in sharp contrast to forest land. Farm land commonly has disturbed, unprotected soil readily available for transport, and erosion occurs in proportion to the driving force, the variable energy of the runoff. Because forest lands of the Pacific Northwest are characterized by steep slopes, runoff tends to be high in energy and has the capacity to transport much more material than is available. As a result, the resisting force, as the variable supply of detachable soil, is of greater importance.

Studies of bedload transport and suspended sediment in steep mountain streams (Nanson 1974, Paustian and Beschta 1979) have documented that the sediment loads are more closely related to the available supply (resisting force) than to flow conditions (driving force). Investigation of a stream in the Oregon Coast Range showed that following disturbance by logging an armor layer of gravel and cobbles forms and controls the release of the underlying fine sediment (Milhous and Klingeman 1973). A paired watershed study of two north coast streams (North and South Forks, Caspar Creek) found that while logging and roadbuilding had little or no effect on peak flows (driving force), suspended sediment production increased substantially (Ziemer 1981, Rice and others 1979). These studies show that after disturbance the resisting force decreases; a period of recovery follows, during which the channels are rearmored.

Although previous work has focused on perennial streams, field observations suggest that related processes occur in rills and gullies. Site disturbance exposes soil, allowing rills and gullies to form; as erosion continues, coarse fragments left behind accumulate in these small channels and armor the underlying soil against further downcutting. The size of the material needed for armoring depends on the driving force. For example, cobbles may be necessary in stream channels, pebbles in gullies, and granules in rills. Organic debris can also provide the armor for forest drainages.

The surface erosion potential at a site must be evaluated before any rehabilitation steps are taken. Ideally the erosion potential is determined before disturbance occurs, so that measures can be taken to mitigate effects. The following considerations apply to either course of action.

Resource at risk--An important factor in determining the value of rehabilitation is assessment of what is being protected. It may be the fisheries resource, site productivity or simply esthetic value. On the north coast, the fisheries resource is of great importance, and the sediment delivery ratio is thus a major component of the assessment. For example, erosion sites that release sediment directly to channels with spawning gravels would likely rate high as candidates for rehabilitation.

Duration of erosion--Another consideration is whether the erosion problem is short or long term. Short-term erosion hazards occur where disturbance is followed in 2 or 3 years by revegetation or an erosion pavement. This sequence is common on skid roads and main haul roads. Long-term erosion problems occur where the slopes are steep and vegetation or erosion pavements cannot get established. Long-term erosion may be found in landslide scars, road cuts, landings, and failed stream crossings.

Site characteristics--A variety of site variables can influence soil erosion, including topography, vegetative cover, climate, and soil erodibility.

We evaluated one of these site variables--soil erodibility in Redwood National Park. The sites selected included skid roads and other tractor-disturbed areas on recent clearcuts.

EVALUATION OF SOIL ERODIBILITY - REDWOOD NATIONAL PARK

Soil types--In Redwood National Park, several forest soils are associated with different lithologies and weathering stages. On the west slope, underlain by the Redwood Creek Schist, the Masterson Soil Series weathers to Orick and eventually to Sites. On the east side, underlain by the Franciscan Formation, Hugo soil predominates, and weathers to Melbourne and then to Sites. Atwell soil is present on the east side in association with fault gouge material. Masterson and Hugo are inceptisols, Atwell is an alfisol, and Orick, Melbourne, and Sites are classified as ultisols.

Sample collection--Soil samples were collected from Redwood National Park in April 1981. Atwell soils were collected from an area classified as "highly erosive unit confined to southeast corner of the Park ..." on a disturbance map of Redwood Park (National Park Service 1980). The other samples were selected from cutblocks mapped as "recent tractor-yarded units with minimal regrowth; prominent drainage disturbance." The dominant soil type was determined for each of these mapped units from soil-vegetation maps (DeLapp, et al. 1961a, 1961b; Alexander et al. 1960, 1961). Six cutblocks were randomly selected for each of the six soil series. Soil series on each site was verified by examination of relatively undisturbed pedons. Three subsamples were then randomly selected from exposed soil surfaces at each of the 36 sampling sites. The samples may have included soil from any of the horizons, subsoil, slash, or debris. The three subsamples were thoroughly mixed to form a composite sample for each site.

Size distribution--The composite samples were wet-sieved to obtain the fractions at 5.6 mm, 2-5.6 mm and 2 mm. The results (Fig. 1) indicate that Masterson, Hugo, and Atwell soils have the most coarse fragments: more than 35 percent by weight. However, Tukey's test for multiple comparison (Guenther 1964) showed that the only significant differences were between Masterson as compared to Orick and Sites, and Atwell as compared to Orick. The coarse fragments are important in evaluating erosion because they may contribute to erosion pavement formation.

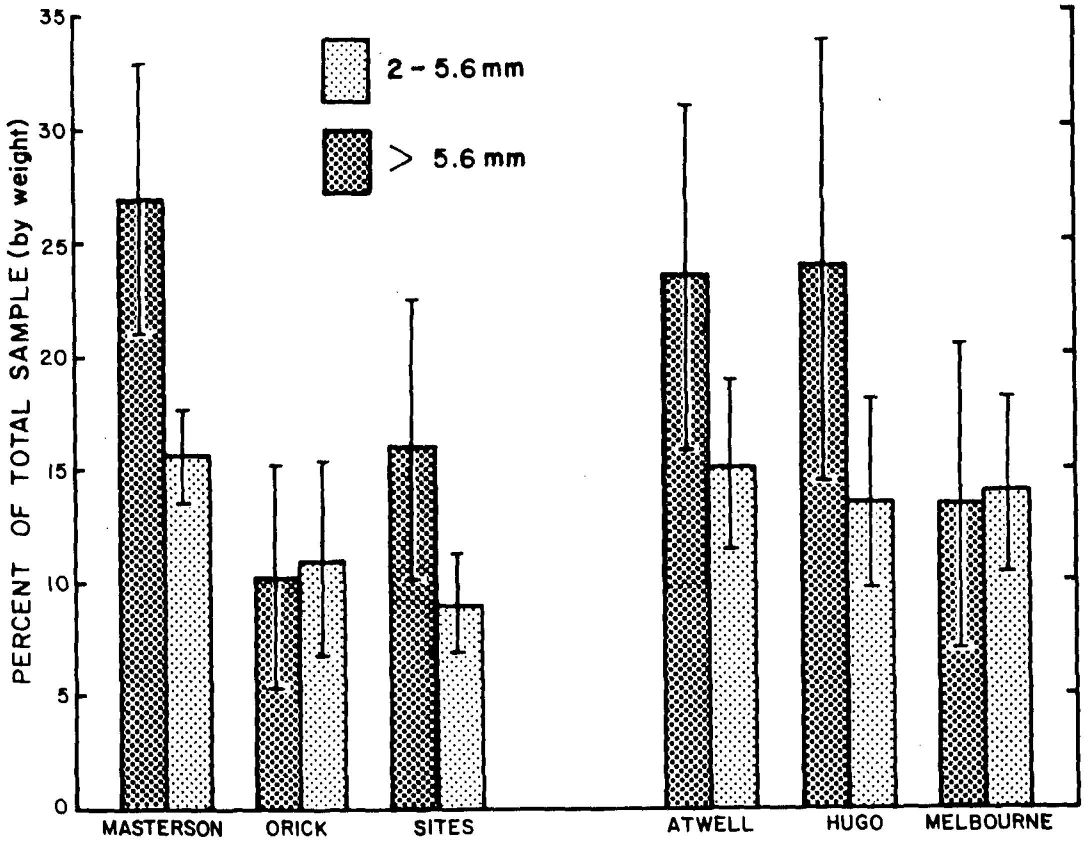

Fig. 1. Percentages of coarse fragments in the composite samples from the six soil series. The columns indicate means and the lines show standard deviations.

The fine grained fractions of soils on both sides of the basin (Fig. 2) show that the soils have substantial amounts of clay. Sites and Orick are classified as clays and the others are clay loams. Tukey's test (Guenther 1964) showed that Sites had significantly more clay than Masterson, Atwell, or Hugo.

Color--The dry composite samples have the following colors according to the Munsell color chart:

Masterson--Light gray to brown. 2.5 Y 7/2, 10 YR 5/4, 10 YR 6.5/4, 10 YR 6.5/3, 10 YR 6/3, 10 YR 5/3.
Orick--Pale yellow to very pale brown. 2.5 Y 7.5/4, 7.5 YR 7/6, 7.5 YR 6.5/6, 7.5 YR 6/6, 7.5 YR 5/6, 10 YR 7/4.
Sites--Reddish-yellow to yellowish-red. 7.5 YR 5/7, 7.5 YR 5/6, 7.5 YR 6/6 (X2), 5 YR 6/7, 5 YR 4.5/6.
Atwell--Light brownish-gray to gray. N 5/0 (X4), 2.5 Y 6/2 (X2).
Hugo--Light gray to pale brown. 10 YR 7.5/2, 10 YR 7/4, 10 YR 7/3 (X2), 10 YR 6/4, 10 YR 6.3.
Melbourne--Yellow to light yellowish-brown. 10 YR 7/6, 10 YR 7.5/3.5, 10 YR 7/4 (X2), 10 YR 6/4 (X2).

The samples tend to range from gray for Atwell, the least developed soil, to a yellowish red for Sites, the most developed.

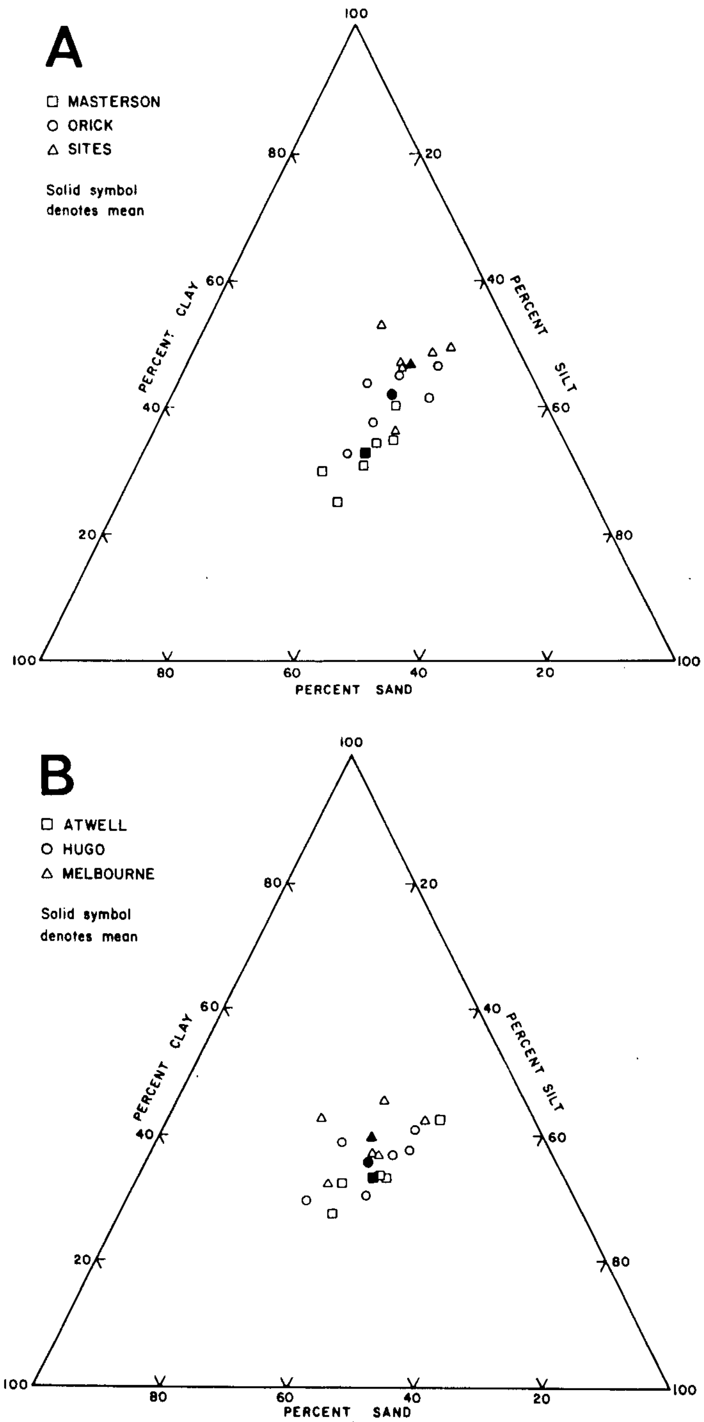

Fig. 2. Particle size distribution of composite samples with mean of the soil series. (A) Soils on west side of Redwood Creek (B) Soils on east side of Redwood Creek.

Erodibility indexes--Some simple laboratory analyses have been designed to evaluate soil erodibility. Middleton (1930) devised the "dispersion ratio" whereby the percent of silt plus clay dispersed by distilled water is divided by the total percent of silt plus clay. Anderson (1951) found that a regression equation using dispersion ratio and percent cover had a correlation coefficient of 0.89 with suspended sediment discharge of Coast Range drainages in southern California. Anderson (1954) later examined soils and sediment discharge from western Oregon watersheds and found that the surface aggregation ratio was an improvement over the dispersion ratio. The surface aggregation ratio is the surface area of sand and coarser particles (> 0.05 mm) divided by the aggregated silt plus clay.

The composite samples were tested for their dispersion ratios and surface aggregation ratios. Our procedures were similar to those described in the

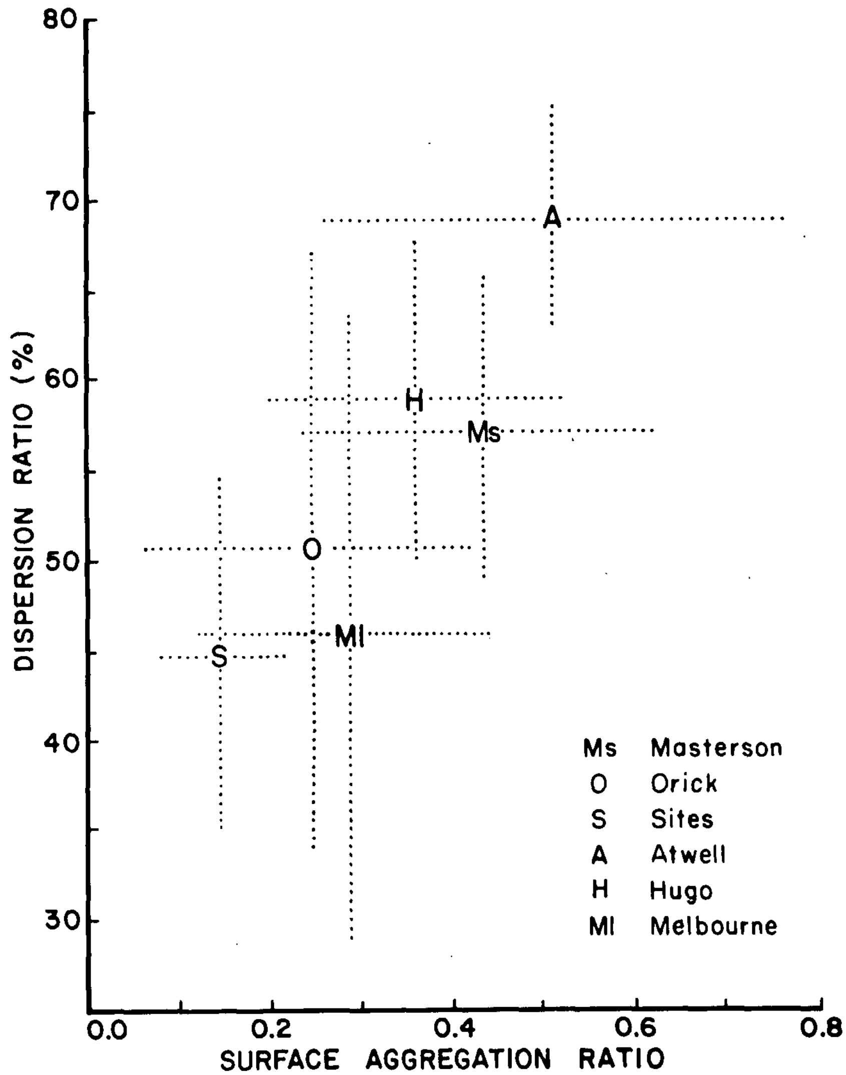

Fig. 3. The surface aggregation ratios and dispersion ratios of the composite soil samples. Letters denote the means and dotted lines indicate the standard deviations.

publications cited above except that the dispersion ratio was determined by hydrometer and the surface aggregation ratio was determined with a 5.6 mm sieve instead of a 5 mm sieve.

The results of these tests (Fig. 3) indicate that there is considerable variation in erodibility in any soil type and consequently there may not have been enough samples to show that some soils are statistically different from others. However, Tukey's test showed that the only significant difference in surface aggregation ratio was between Atwell and Sites. The most apparent difference between these two soils is their range of oxidation. Atwell primarily contains reduced iron whereas Sites is dominated by oxidized ferric hydroxide ($FE(OH)_3$). Orick and Melbourne are difficult to differentiate and are more oxidized than Hugo and Masterson. Although Atwell is classified as being more mature than Hugo and Masterson, the Atwell samples were generally collected from the poorly weathered subsoil that is exposed on the Copper Creek drainage in the southeast portion of the Park.

The most widely used erosion index is the universal soil loss equation. The soil factor (K) in this equation is derived from a combination of 24 variables (Wischmeier and Mannering 1969). Since K is too difficult to determine under most circumstances, simpler methods have been devised. For example, the Pacific Southwest Region (R-5) of the Forest Service has prepared a guide (R5-2500-14) which approximates the soil factor by evaluating soil detachability, infiltration, permeability, and depth. Soil detachability is measured by the response when water is applied to an aggregate with a squirt bottle (with a modification for coarse fragments). This technique is intended to give some idea of the amount of water-stable aggregates in soil.

Detachability was measured on air-dried composite samples according to the R-5 method. The results show no correlation ($r^2 = 0.0087$) with the surface aggregation ratio. These findings indicate that the detachability index needs further critical evaluation to determine whether it is of value in erodibility predictions.

The relative erodibilities of soils as measured by two erosion indices and as determined through observations by the soil-vegetation survey (DeLapp et al. 1961a, 1961b; Alexander et al. 1960, 1961) are compared in Table 1. The most erodible soil is given a value of 1.0 in these indexes.

Table 1 - Relative erodibility indexes

Soil series	Mean percent slope	Detachability index (R-5)	Surface aggregation ratio (Anderson)	Soil-vegetation survey
Atwell	39	0.8	1.00	Moderate to high
Masterson	39	.9	.84	Moderate to high
Hugo	35	1.0	.71	Moderate to high
Melbourne	30	0.9	.55	Moderate to high
Orick	33	1.0	.47	Moderate
Sites	23	0.9	.28	Slight to moderate

Relation to slope--Determination that a site is highly erodible cannot be made from data on relative soil erodibility only. Slope, disturbance, and other conditions must be considered in the hazard evaluation. In Redwood National Park, soil erodibility is not independent of slope (Table 1). The older, less erodible soils are on the gentler slopes. In contrast, Atwell and Masterson are on the steeper slopes and because of their poor physical properties, are associated with slumping and sliding.

Causes of erodibility differences--The dominant conclusion from the data is that the young Atwell soil is more erodible than the strongly developed oxidized Sites (Fig. 3). Weathering produces iron oxides that improve a soil's physical properties by promoting aggregation and higher porosities (Arca and Weed 1966, Lutz 1936). Sites also has a higher percentage of clay, a trait associated with lower erosion rates (Buoyoucos 1935). The cohesive clay resists detachment of the soil particles.

The type of clay may also contribute to differences in erosion rates. Clay mineralogies were determined by x-ray diffraction on random samples from four of the soil series. The Hugo and Masterson were similar and contained vermiculite, intergradient chlorite-vermiculite, and chlorite. Atwell was dominated by authigenic chlorite but contained mica as well. The x-ray analysis verified the existence of chlorite in Sites but could not determine if kaolinite was also present. There is some agreement between these findings and a study by Winzler and Kelly (1975). However, we found vermiculite to be more common than they reported. The number of samples we tested was insufficient for statistical reliability.

The relation between clay mineralogy and soil erodibility has not been documented, although Singer and others (1978) studied the erodibility of some California soils and found that the smectite clays were more erodible than vermiculite. Both the most and least erodible soils of Redwood Park had chlorite as a primary constituent. The major difference between the clays we identified is their cation exchange capacity (CEC). Vermiculite has a CEC of 100 to 150 meg/100αg of dry soil compared to 10 to 40 for chlorite and 3 to 15 for kaolinite (Birkeland 1974). Vermiculite has a much greater negative charge and therefore more potential for dispersion. However, this negative charge is offset by the clay's exchangeable cations. The type of exchangeable cations can also influence erodibility (Wallis and Stevan 1961) but their determination was outside the scope of this study.

IMPLICATIONS FOR MANAGEMENT

Rehabilitation should either decrease the driving force or increase the resisting force. The change may be accomplished by common methods, such as mulching, revegetation, or creating an erosion pavement. Natural erosion pavements can occur on any of the Redwood Park soils provided the gradient is not too steep. Erosion pavements are most likely on the young skeletal soils where they are also most needed.

This study suggests that rehabilitation efforts should be concentrated in areas with highly erodible soils such as Atwell. The Atwell soils are commonly underlain by fault gouge or melange and are associated with seeps and slumps. It is difficult and expensive to retard slumping but revegetation will at least decrease the active surface erosion of Atwell soils, as in the Copper Creek drainage.

The goal of earth science specialists should be to identify highly erosive sites before logging so that mitigation measures can be taken and the need for rehabilitation avoided. The best method at this time is field observation of disturbed sites on terrain similar to the area proposed for logging. This will define the important variables better than any rigid scheme. There are several disadvantages to this approach, however, the most important being that it depends on subjective evaluation. The demand is for an objective, quantitative approach that can be widely used and will hold up in court if necessary. Several erosion hazard rating schemes are available but none have a high success rate. They can be helpful as guidelines but should not be followed dogmatically.

Although mapping of soil series is based on such factors as bedrock, vegetation, and slope, rather than soil characteristics these maps can provide some help in predicting soil erodibility. However, this study suggests that even with more samples there probably would be no significant difference in erodibility between the Orick and Melbourne or the Hugo and Masterson. In field observations, Popenoe[2] has found no practical differences and thinks these soils should be grouped. On the other hand, Hugo and Masterson have skeletal and nonskeletal phases and that differentiation would be helpful for soil management.

The trend in soil mapping is toward less reliance on bedrock as a basis for classification. Therefore soil mapping of National Park lands today would group some soils and more closely reflect soil erodibility. Specific sites could be evaluated by quantification of coarse fragments, free iron oxide and organic matter. Soil color reflects free iron oxide content. We are now conducting a study to determine if color is a useful prediction tool that has as good a correlation with erodibility as the surface aggregation ratio.

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2 Personal communication, J. Popenoe, Soil Scientist, Redwood National Park, Orick, Calif. 1981.

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