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GEOLOGICAL IMPLICATIONS OF SOIL MECHANICS

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The processes involved in soil development are essentially destructive. They are engendered by contact of the atmosphere with rocks formed in a vastly different environment, and express themselves in the disintegration and/or decomposition of certain rock components. The end products of the destructive process are quartz sand, soluble components and clay minerals. The quartz grains tend to remain behind along the interface of air-rock contact. The salts are removed by infiltrating water under warm-humid climatic conditions, and the clay particles tend to be washed downward and abandoned in smaller interstitial cavities. At the same time organisms ranging from bacteria to nematodes and larger animals carry on their activities below the air-earth interface. Plants rooted below and extending upward into the atmosphere contribute likewise to the system.

Interaction of the components of the soil-forming process results in the gradual separation and rearrangement of atmospheric and earth materials producing recognizably differentiated zones or units designated by letter terminology as A, B and C horizons. Biological, chemical, physical and geological considerations are involved in the complexities of the interactions. Much of the process is less than clearly understood. Long known but generally neglected factors, especially those involving atmospheric mechanics, may furnish additional understanding of soil development and at the same time may contribute to an explanation of some puzzling geological problems.

The process of rock destruction, in Earth Science terminology, is weathering. Disintegration, or mechanical destruction, is said to be predominant under arid or sub-arid conditions (insufficient precipitation to promote extensive solution and illuviation). Decomposition or chemical destruction is considered to be prevalent under humid conditions. Involved is hydrolization and solution of certain components resulting in unit disintegration. For example: ground feldspar in distilled water is subject to leaching and contributes a sufficient number of potassium, sodium or calcium ions, whichever may be present in the feldspar, to produce an alkaline litmus reaction in less than one hour, depending on how finely the rock is ground. Under natural conditions where the active ions have been removed, the remaining portion is "clay (Kaolin)" which has little strength. If the parent material is a granular igneous rock, destruction of the feldspar by decomposition permits disintegration of the remainder. Under humid conditions the leaching process may continue as long as soluble material remains. Under arid or perhaps cold conditions the process may not be carried beyond the initial stages of decomposition.

Moisture and temperature conditions appear to be major factors in determining soil 'types.' It is assumed also that regardless of parent rock composition the end products of weathering are quartz sand and silt, clay and soluble salts. Thus a mature soil developed under warm, humid conditions includes similar A, B and C horizons more or less clearly defined, regardless of parent rock type. The thickness of the horizons is presumably dependent on time as well as climatic conditions. Productivity of a soil may depend more or less on organic activity and content. Nutrient materials in the soil which are available to plants is a measure of fertility, which also is generally assumed to be a product of organic content and activity. Thus Jenny (1950, pp. 43-44) said, "It is often stated that it takes thousands of years to produce one inch of soil." At the same time he suggested the rate might be much higher with respect to "softer rocks, like certain sandstones and shales." Evidently Jenny equated the rate of soil development with the rate of weathering. This assumption is not compatible with the "fertility" profile of a natural soil which lies in the "top soil" or 'A' horizon. Stripping the A horizon under improper farming practices leads to marked reduction in fertility. It appears entirely reasonable, therefore, that fertility is "built" into the soil by organic activity and the accumulation of organic material. Rankama and Sahama (1955, pp. 333-4) suggested that plants tend to accumulate minerals which become concentrated in the topmost layers of forest soils. Likewise (ibid., p. 342) they pointed out the role of bacteria in the process of rock decomposition, which amounts to increasing the quantity of inorganic material dissolved from rocks and their minerals during weathering.

Provided the only source for soil enrichment is carbon dioxide and nitrogen from the air, processed by plants and combined with earth materials made available through organic activity, fertility must finally depend on a positive balance between accumulation in the A horizon and loss through leaching and the physical removal of plant material.

Regardless of other factors, long-term loss is inevitable. Some plant material must blow away or be carried away by animals. Progressively large amounts, depending on humidity and precipitation, are lost by leaching. The Mississippi River

(Fig. 1) annually removes from an area covering 1,265,000 square miles, 136,400,000 tons of dissolved material and 340,500,000 tons in suspension (Emmons, Thiel, Stauffer and Allison 1955, p. 172). The grand total, removed mainly from the surface or near surface A horizon, amounts to almost 477 million tons or 377 tons per square mile per year. Of this quantity about 108 tons is dissolved material. Destruction of forests and prairies in the Mississippi basin may have accelerated erosion. Humphreys and Abbott (1876, p. 148) reported that the river empties 406 million tons of mud in the Gulf of Mexico yearly, a difference of 71 million tons, which may or may not represent a real increase in suspended load since the 1800s. In any event, the dissolved load might concomitantly decrease because solution is mostly attributable to water cycled through the soil to the groundwater body and the rate of infiltration decreases with removal of plant cover. Much of the dissolved material may be supplied from limestone and gypsum deposits (In the lower Mississippi River the sodium-calcium ratio is about 2 Na to 5 Ca) but some is derived directly from the soil, from decaying plant remains and from bacterial activity. The vast quantity of suspended and dissolved material which must be removed from the surface of the land by leaching and erosion is so impressive in magnitude it seems impossible for soil fertility to be increased by organic activity under temperate humid conditions (such as exists over much of the Mississippi drainage basin). Nevertheless, fertile virgin soils are a matter of record and it becomes necessary to find a natural means of supplying mineral resources to replace those lost by erosion and solution.

Two sources of replacement solids are the oceans and deserts of the world. Vast quantities of solids, mainly salts and some organic material, are blown into the air with spray during storms. The water involved falls back into the sea or evaporates in the air leaving the salts as dust particles. These may be carried by the winds and widely dispersed over the continents.

Salt particles serve as condensation nuclei and are washed out of the atmosphere as dissolved material in rain drops. At Perth, Australia, the salt fall out is 3.40 $mg/cm^2/year$ (Eardley et al., 1957, p. 1149). In Iowa it is 0.381 (Goldschmidt 1954, p. 592). In round figures this rate of input would equal about 10 tons per square mile, or a total of about 560,000 tons of salt for the state of Iowa.

If the figure for Iowa is taken as average for the entire Mississippi River drainage basin, covering about 1,243,000 square miles, the total salt fall-out would amount to as much as 12.5 million tons per year.

Besides NaCl, it may be supposed proportionate amounts of all the other substances found in sea water are present in fall-out material. These, without doubt, contribute to soil fertility. Under humid conditions most of the dissolved salts might be expected to be carried away by runoff without having been precipitated. In the desert where the evaporation rate is high, most salts would be deposited and the less readily soluble constituents would remain and contribute to soil enrichment.

In the Mississippi basin the rate of loss of salts is about 108 tons per square mile while the possible increment from the sea is no more than about 10 tons, far less than the needed quantity to counterbalance the loss.

The second source of solid material is the deserts of the world which supply dust. The particles are rock fragments and mineral grains which have escaped extensive leaching. Likewise, a minimum of organic material and activity is involved in the processes which reduced the particles to dust size. Little need be said concerning the potential fertility of desert soils or the fertility of loessal deposits which have been derived from desert areas. Measurements of the quantity of dust transferred yearly into the Mississippi drainage area are not available. Conjectures may be posed on the basis of loess deposits, production of dust storms of the 1890's reported by Udden (1896, p. 655), dust storms of the 1930's reported by Lugn (1935, pp. 165-166) and the immense quantity of material removed yearly by the Mississippi River. By analogy with the salt fall-out and fluvial performance, the amount of dust received yearly in the Mississippi basin must be vastly greater than the amount removed. According to Udden (1896, p. 662) 850,000,000 tons may be held in the atmosphere at one time and transported as far as 1500 miles. Otherwise the development of fertile soils in a land of active leaching should not be possible. Lugn (1935, p. 166) described a single dust storm of March 20, 1935, from which 5 grams of dust per square foot was collected in a pan of water situated on the roof of Morrill Hall. This would amount to 1,536 tons per square mile. Later that spring an additional 800 tons per square mile were added. This total of 2,336 tons per square mile compares very favorably with the average of 270 tons per square mile removed by the Mississippi River. It may not be supposed that the yearly increment can be based on a locally investigated dust storm, and in the absence of comprehensive measurements, it can only be conjectured that a uniform supply of dust is provided yearly from the desert regions of western United States, which amounts to an area equivalent in size to the Mississippi basin, and that this supply of relatively unleached earth material is of primary importance in the de-

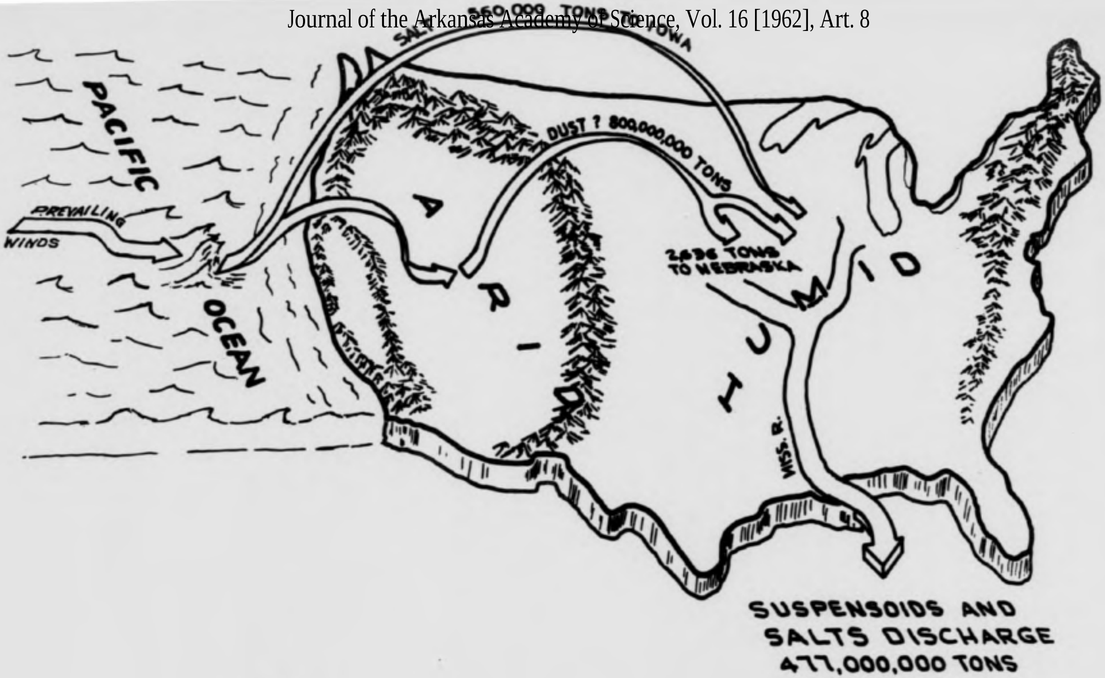

FIG. I

SALT AND SILT SUPPLIED TO THE MISSISSIPPI BASIN BY THE ATMOSPHERE AND THE AMOUNT CARRIED AWAY BY THE MISSISSIPPI RIVER velopment of fertile soils. Thus it may be that the great dust storms of the 1930's were not an unqualified disaster but actually contributed materially to the burgeoning productivity of midwestern soils.

It may be further conjectured that increased precipitation over western deserts with concomitant increase in plant cover would tend to reduce or terminate (for all practical purposes) the supply of dust to midwestern soils. Without the new solids furnished by the wind, leaching would progressively reduce the fertility of the soils in the midwestern area. At the same time the process of soil development would contribute to the segregation of an A horizon composed of maturely weathered quartz sand. Finally, fertility would be reduced beyond the point necessary to the maintenance of continuous plant cover. Without protection, erosional processes would remove the sterile sand layer to the B horizon, where presumably a new cycle might begin in a new soil profile formed or forming on potentially more fertile material. In this way an unlimited supply of quartz sand might be provided to a depositional site under continuously humid conditions.

References

Eardley, A. J. et al. 1957, Hydrology of Lake Bonneville and sediments and soils of its basin: Geol. Soc. America Bull., v. 68, pp. 1141-1202.

Emmons, Thiel, Stauffer and Allison 1955, Geology: McGraw Hill.

Goldschmidt, V. M. 1954, Geochemistry; Oxford at the Clarendon Press.

Humphreys and Abbott 1876, U. S. Army, Corps of Topographic Engineers, Prof. Paper No. 13, Washington.

Jenny, Hans 1941, Factors of Soil Formation: McGraw Hill.

Lugn, A. L. 1935, The Pleistocene Geology of Nebraska, Nebraska Geol. Soc., Bull. 10.

Rankama, Kalervo and Sahama, Th. G. 1950, Geochemistry: University of Chicago Press.

Udden, J. A. 1896, Dust and Sand Storm in the West: Appleton's Popular Science Monthly, v. XLIX.