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# Report for 1956

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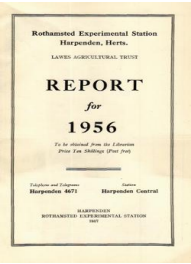
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# Soil Structure

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# SOIL STRUCTURE

By

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## Introduction

The basic problem of soil structure consists in finding out how the individual constituents of soil crumbs, such as sand, clay and organic matter, are bonded together. The nature and number of these bonds will determine the strength of the crumbs. This, in turn, will decide if the surface soil pans under the mechanical action of falling raindrops, whether the soil is free draining and the ease of cultivation. The Physics Department has been particularly interested in the improvement of the structure of clay soils after a period under grass. One of the improvements is known to be an increase in the resistance of the crumbs to breakdown in water, and the problem has been to measure this increase in such a way as to offer some clue as to the mechanism by which it is brought about.

Previous workers have used two main methods. In the first, originated by Tiulin (1928), the dry crumbs were placed on top of a bank of sieves, wetted and the size distribution of the wetted crumbs determined after agitating the sieves under water. The second way, due to Middleton (1931), instead of reducing mechanical breakdown after wetting to a minimum, measures the degree of dispersion produced by a given amount of mechanical action. This is usually done by shaking the crumbs in water in an end-over-end shaker for a fixed time. There are two causes of crumb breakdown in both these methods : the initial breakdown on wetting the air-dry crumbs with water, usually called slaking, and the subsequent mechanical attrition of the crumbs. Slaking is due both to swelling of the clay on wetting, which may in extreme cases lead to dispersion of the clay, and also to the explosive action of entrapped air. The severity of the initial breakdown of the crumbs will clearly depend on the rate of wetting, and this was the first aspect of crumb breakdown which was investigated (Emerson and Grundy, 1954).

## Crumb Breakdown Due to Slaking

Columns of soil about 8 cm. high consisting of 2–5 mm. air-dry crumbs were wetted with distilled water at different rates by means of capillary-tube siphons of different diameter. Check columns were also wetted under vacuum, which would prevent breakdown due to entrapped air. The cohesion of the wet crumbs was determined by measuring the height from which 40 drops of water would cause 0·15 g. out of approximately 1 g. of the wet crumbs to pass through a 1·2-mm.-aperture gauze. This technique was sufficiently gentle to avoid breakdown of the crumbs due to dispersion of the clay, and merely fractured the crumbs along planes of weakness produced during the initial wetting. Samples were taken from two adjoining

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plots on the Rothamsted Farm, containing 30 per cent clay, one under permanent grass and the other permanent arable which receives 14 tons dung/acre annually. The results showed that cohesion decreased sharply with rate of wetting, as expected, the decrease being more pronounced with the arable compared with the grassland crumbs. However, when wet at 0·2 cm./hr. rainfall, which is not often exceeded under the low-intensity rainfall in this part of England, the cohesion of the crumbs was not much lower than those wet under vacuum or extremely slowly. It was concluded, therefore, that slaking is not an important cause of crumb breakdown for this soil with these cropping treatments. This result is not generally valid, and slaking may be very severe with lighter soils. Extrapolating back to zero rate of wetting, the strength of the grassland crumbs was about twice that of the arable crumbs, showing that there must be an additional cohesive force present in the former.

## Swelling of Soil Crumbs

A by-product of the preceding work was to demonstrate that the amount of water held by a soil at low suctions (up to about 200 cm. water) depended both on the rate at which the soil was wetted, because with rapid wetting more water could be accommodated along the planes of failure and, indirectly, on the length of time the soil was wet, because the swelling of the clay was found to take at least 24 hours. This latter point was later investigated in more detail (Emerson, 1955a). A clay crumb which had been dried to the wilting point (pF 4·2) was suspended on one arm of an analytical balance and slowly wetted using a capillary siphon, care being taken to prevent evaporation from the crumb. Although the crumb appeared to be completely wet after the first drop had appeared on the base of the crumb, in fact the crumb continued to increase in weight and was still doing so very slowly when the experiment was discontinued at the end of three months. Approximately 75 per cent of the total water uptake occurred in the initial wetting. Besides modifying the concept of field capacity, these results have an important bearing on the drainage of heavy clay soils when water percolates to the drains through fissures in the subsoil. The fissures will slowly close up during the winter as the clay swells, and since conduction depends on the fourth power of the radius, a small decrease in size will have a considerable effect on permeability. The more the subsoil is dried out during the summer, the more rapid will be the drainage the ensuing winter. One of the better crops for this purpose would be wheat, and the worst treatment a summer fallow. An analysis of Mr. Nicholson's results on the running of the mole drains on the Cambridge University Farm demonstrated this dependence of drain performance on summer cropping very elegantly.

## Wet Strength of Crumbs

The next step was to investigate the second cause of crumb breakdown, i.e. disintegration of the wet crumbs. The two methods mentioned at the beginning determined the resistance of the wet

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crumbs to mechanical action, but it was thought that more controllable results might be obtained by using a " chemical hammer " on the crumbs in the following way. If two negatively charged plates (idealized clay crystals) are immersed in a salt solution there is a repulsive pressure between the plates due to the higher salt concentration between the plates than in the equilibrium solution outside, and this pressure increases as the salt concentration is reduced if the plates are a fixed distance apart. The pressure may be calculated using the simple Gouy theory, provided the plates are far enough apart. Therefore, by bringing crumbs into equilibrium with increasingly dilute salt solutions the weaker the attractive forces between the clay crystals, the greater will be the distance the crystals are forced apart, until eventually the crumbs fail and disperse. Unfortunately in the case of calcium saturated crumbs, which is effectively the English condition, the intrinsic short-range attractive forces between the clay crystals are sufficiently strong for the crumbs to remain stable even when percolated with distilled water. In water the calcium clay in the crumbs is in a metastable state of equilibrium, because if the crumbs are shaken the clay disperses, and a concentration of about 3 m*M*. $CaCl_2$ is needed before the clay will reflocculate. However, it was known that montmorillonite saturated with sodium would swell up spontaneously when brought into equilibrium with decreasing concentrations of sodium chloride (Hofmann and Bilke, 1936) until at a finite concentration of about 15 m*N*. the clay dispersed. This suggested that if the crumbs were first sodium saturated differences in the attractive forces between crumbs would be brought out.

In the initial experiments (Emerson, 1954a) a 1-cm. bed of 1–2 mm. air-dry crumbs was wetted with 500 m*N*. NaCl slowly under suction on a sintered-glass funnel to avoid breakdown due to slaking. After percolating with 500 m*N*. NaCl to displace all other exchangeable cations, successively more dilute salt solutions were percolated through, maintaining a constant hydrostatic head, and the decreases in permeability measured as functions of salt concentration in the leachate. The method was tried first on the Barnfield soil used in the earlier rate-of-wetting experiments. Two plots on Barnfield itself, 80, the unmanured plot, and 2N, receiving 14 tons dung annually, were compared with adjoining permanent grass, i.e., the same mineral constituents but different amounts of organic matter. The crumbs from 80 dispersed completely in 30 m*N*. NaCl, those from 2N in 5 m*N*., whereas the permeability of the grassland crumbs was still appreciable when percolated with distilled water. By contrast, on shaking the sodium-saturated crumbs into suspension it was found that the flocculating concentration of NaCl for the 80 plot was about the same as the dispersion concentration, but in the case of the grassland and 2N plots it was considerably higher, namely 250 m*N*. The organic matter present in the soil could therefore act both as a cementing agent for the flocculated clay in the crumbs and as a peptizer if the clay was brought into suspension.

In attempting to refine the technique it was found that an important part of the measured decrease in permeability was due to blockage of the pores in the sintered-glass funnel by dispersed clay and silt. This difficulty persisted even with coarser funnels, and it

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has only recently been overcome. In the method of test at present, a bed of 1–½-mm. glass spheres has been substituted for the sinter and the crumbs are brought into equilibrium with one concentration of NaCl only, namely 50 m*N*. At this concentration the Barnfield 80 crumbs, the weakest possible crumbs, collapse to form an impermeable bed, but no dispersed clay actually appears in the leachate, whereas the permeability of the corresponding permanent-grass crumbs remains unchanged.

To recapitulate, one of the reasons for developing the sodium method was to distinguish increased crumb stability, due to a slower rate of wetting when the crumbs are immersed in water, and a genuine increase, due to stronger attractive forces between the clay crystals in the crumbs. The former effect can be achieved by coating the crumbs with any substance which increases the contact angle of the crumbs with water.

## Nature of the Organic Clay Complex

To obtain some insight into the way in which the organic matter stabilized the crumbs even after Na-saturation, the stabilization of crumbs and also pure clays by various substances of known chemical composition was investigated, since the organic matter appeared to stabilize the clay specifically (Emerson, 1956a). The first substances investigated were the polymers marketed for stabilizing crumbs, known as soil conditioners. These are of two kinds: the non-ionic polymers and carboxylated polymers. The simplest of the first is polyvinyl alcohol (PVA), repeating unit $-CH_2-CH(OH)-$, but natural substances such as dextrans may also be used. The second may be either of the linear ethylenic type, the simplest being polyacrylic acid (PAA), repeating unit $-CH_2-CH(COOH)-$, or polyuronides, such as sodium alginate or carboxymethyl cellulose. Small quantities of these substances in solution were mixed with Barnfield 80 soil to form a paste, which was then pushed through a 3-mm. sieve and finally dried to form synthetic crumbs. It was found that about 0·5 per cent by weight of polymer would confer maximum stability on the crumbs, i.e., no decrease in permeability occurred after percolating *N*/20-NaCl for 24 hours. The one exception was sodium alginate, which was only effective on soil which had been sodium saturated initially. This was ascribed to precipitation of the alginate as calcium alginate before it could become attached to the clay.

It was found that when crumbs stabilized with PVA and PAA were placed in water, after saturating with sodium, the former remained unaltered, whereas the latter swelled considerably. Flakes of Na-clay, to which small quantities of the two polymers had been added, behaved similarly (Emerson, 1955b). PAA was also effective at much lower concentrations than PVA. In particular for montmorillonite (Wyoming bentonite), 4 per cent PVA but only 0·25 per cent PAA were necessary to form stable Na-gels in water. By X-ray measurement of the dry flakes it was shown that PVA was linked to the planar faces of the crystallites to form an interlamellar complex. Unfortunately in the case of PAA, although an X-ray photograph of the dry flake was the same as an untreated



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flake, this was not sufficient evidence to infer that an interlamellar complex had not been formed, as there may have been insufficient regularly arranged crystals to give an X-ray reflexion. The carboxylated polymers would, of course, be expected to be repelled from the similarly charged planar faces. However, it has been found that crystals stabilized by very small quantities of an inter-lamellar complex forming substance can be distinguished by examination of thin sections of the swollen Na-montmorillonite gel under a polarizing microscope (Emerson, 1956c). In this way it has been possible to prove that the carboxylated polymers are not linked to the basal surfaces but must be linked to the edge faces.

The actual linkage depends on the proof by Schofield and Samson (1954) that the edge faces of kaolinite in addition to possessing a negative charge at high pH, due to dissociation of Si–OH groups, can become positively charged under acid conditions. From the similarity in crystal structure and from flocculation experiments, the edge faces of illite and montmorillonite must behave similarly. It is suggested that the polymers are linked by hydrogen bonds through the carboxyl groups to the oxygen and hydroxyls attached to aluminium atoms exposed at the edge faces, forming so-called peripheral complexes (Emerson, 1955b). Since the strength of the hydrogen bonds will depend on the readiness with which the edge faces and the dissociated carboxyl groups co-ordinate hydrogen ions, the efficiency of the polymers will depend both on the acidity and the pK of the carboxyl groups (Emerson, 1956a).

One important way in which the peripheral complexes may be distinguished from inter-lamellar complexes is that peripheral complexes may be dispersed by leaching with neutral pyrophosphate solution, while the latter are unaffected. The pyrophosphate ions displace the carboxyl groups. As a corollary, stable peripheral complexes could be equally well made with polyphosphates (Oplatka, 1954).

When the strength of crumbs from old grassland was measured after leaching with 0·1*M*-neutral pyrophosphate it was not much reduced, although an appreciable amount of organic matter was extracted (Bremner and Lees, 1955; Emerson, 1956b). It is concluded, therefore, that the fraction of the organic matter responsible for the increased crumb cohesion forms an inter-lamellar complex with the clay. After prolonged leaching with dilute alkali the strength of the grassland crumbs is reduced to that of Barnfield 80 crumbs. This contrasts with the stability of the PVA-stabilized crumbs, which are unaffected by alkali. However, inter-lamellar complexes made with gelatin slowly disperse if the pH is raised above the pK of the amino-groups, and by analogy it is suggested that the organic matter forms a polymeric inter-lamellar complex which depends partly for its strength on attraction between positively charged amino-groups and the negatively charged clay. The substance is thought to be polymeric because dispersion is slow and complexes formed with simple amino-acids disperse immediately the pH is raised sufficiently. If this is correct it could be an important source of nitrogen, which would be only slowly available, since it is known that the breakdown of substances is greatly reduced if sandwiched between clay particles (Ensminger and Gieseking, 1942).

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## Effect of Acidity on Crumb Strength

Reconsidering the first tests made with the sodium technique it was fortunate that the soil chosen, Barnfield, was buffered with free $CaCO_3$, for in acid soils increased stability may result from positive-edge to negative-face attraction. Crumbs taken from an acid arable field, Hoos, have been found to be much more stable than Barnfield 80 and, further, synthetic crumbs from the acid soil to which low-molecular-weight sodium alginate had been added were as unstable as the Barnfield soil (Emerson, 1956a). This makes it impossible at present in using the sodium technique to assess improvement in the wet strength of crumbs due to a ley unless the pH of the arable control is the same. It follows too that if liming improves soil structure it does not do so by increasing the wet strength of the crumbs. A possible way in which liming might be beneficial is if it maintains a sufficiently high concentration of $Ca^{++}$ ions in the drainage water to ensure reflocculation of dispersed clay, provided at the same time the positive edges on the clay are neutralized by organic matter in solution. This is at present under investigation.

Until now it has been implied that if the clay fraction of the crumbs is stable, the crumbs themselves will be stable too. In other words, that clay–clay bonds are weaker than clay–sand bonds. Very little is known about the way clay is bonded to sand, but with our present techniques and knowledge of the forces exerted by clay particles, rapid progress should be possible.

## Field Trials

Three groups of plots were sown in successive years to a variety of grasses and lucerne and with fallow strips as controls and left down for four years. Laboratory tests showed that the wet strength of the crumbs was appreciably increased by the grasses, particularly in the 0–2-inch layer. All the grasses were about equally effective, whereas lucerne had little effect. After ploughing up, heavy fertilizer dressings were given to minimize differences in the nutrient status of the plots, so that any difference in crop yield between the fallow and grass plots could be ascribed to structure. The first two blocks were sown in successive years to spring beans, winter wheat and spring barley. There was an increase in yield with the spring beans after grass, but unfortunately the yields were very low due to aphid attack. The only response with wheat and barley was an appreciable increase in yield of wheat after lucerne. This particular effect accords with results of ley–arable experiments elsewhere on the farm. This year on the third block, after ploughing up, the market-garden crops carrots and beet were sown. Immediately after germination, during prolonged dry weather, there was a spectacular increase in the rate of growth of carrots after grass, compared with the former lucerne and fallow plots. Later weather was particularly favourable for growth, and the final yield of carrots on the grass plots was not much higher. It appears, however, as though response to structure may be obtained from horticultural rather than agricultural crops.

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## References


Bremner, J. M. & Lees, H. (1950). The extraction of organic matter from soil by neutral reagents. *J. agric. Sci.* **40**, 274.

Emerson, W. W. & Grundy, G. M. F. (1954). The effect of rate of wetting on water uptake and cohesion of soil crumbs. *J. agric. Sci.* **44**, 249.

Emerson, W. W. (1954a). The determination of the stability of soil crumbs. *J. Soil Sci.* **5**, 233.

Emerson, W. W. (1954b). The effect of various grasses and lucerne on the cohesion of soil crumbs. *Trans. 5th int. Congr. Soil Sci.* **2**, 65.

Emerson, W. W. (1955a). The rate of water uptake of soil crumbs at low suctions. *J. Soil Sci.* **6**, 147.

Emerson, W. W. (1955b). Complex formation between montmorillonite and high polymers. *Nature, Lond.* **176**, 461.

Emerson, W. W. (1956a). Synthetic soil conditioners. *J. agric. Sci.* **47**, 117.

Emerson, W. W. (1956b). A comparison between the mode of action of organic matter and synthetic polymers in stabilizing soil crumbs. *J. agric. Sci.* **47**, 350.

Emerson, W. W. (1956c). Liquid crystals of montmorillonite. *Nature, Lond.* **178**, 1248.

Ensminger, L. E. & Gieseking, J. E. (1942). Resistance of clay-adsorbed proteins to proteolytic hydrolysis. *Soil Sci.* **53**, 205.

Hofmann, U. & Bilke, W. (1936). On the intercrystalline swelling of montmorillonite. *Kolloidzschr.* **77**, 238.

Middleton, H. E. (1930). Properties of soil which influence soil erosion. *Tech. Bull. U.S. Dep. Agric.* 178.

Oplatka, A. (1954). *Disc. Faraday Soc.* **18**, 219 (quoted by Lifson).

Schofield, R. K. & Samson, H. R. (1954). Flocculation of kaolinite due to the attraction of oppositely charged crystal faces. *Disc. Faraday Soc.* **18**, 135.

Tiulin, A. F. (1928). Questions on soil structure. II. Aggregate analysis as a method for determining soil structure. *Results Invest. Dep. agric. Chem. Perm. agric. exp. Sta.* **2**, 77.