piezometers at this time, and they would commence expelling air. They usually started the middle of February and the normal rainfall of 7–10 cm/month was sufficient to continue air emission until April or May. At later dates, water would appear in some of the piezometers, and air could be heard bubbling in these pipes until the water had risen 50 to 75 cm. Other piezometers would still be dry and emitting air. At still later dates, water might enter most of the remaining piezometers; however, some would remain dry during the entire year. The depth of the piezometers appears to have no particular relationship to initiation or duration of air emission. The cessation of air emission coincides with leafing of the trees, presumably because of water removal by evapotranspiration. The largest air pressures develop two or three days following daily rainfalls of 5–7 cm.

The reason for air entrapment during such long periods of time and at relatively high pressures has not been established experimentally. The authors suggest the following tentative explanation which is primarily based on laboratory and field examinations of these soils. The soil at this site has a 20-cm thick silt loam A horizon which is relatively porous and permeable to water due to the extensive tree root system. The upper B horizon is derived from the loess mantle, is silty loam in texture and has weakly developed medium and coarse subangular blocky structure. It extends to about 70 cm at this site and is less permeable than the A horizon. Both the A and upper B horizons have little structural stability under wet conditions. The A horizons of cultivated fields puddle rather easily and exhibit little mechanical strength. The lower B and C horizons are derived from till, extend to 250 or 300 cm, are of clay loam to clay in texture, and exhibit moderate coarse, compound prismatic-blocky structure. Montmorillonite and vermiculite have been identified as major constituents of the clay-sized fraction in all horizons. Because of higher clay contents in the C and lower B horizons, there are probably some shrinkage cracks in this part of the soil profile during periods of moisture stress. Bedrock occurs at 275–300 cm, which is only a few inches below the deeper piezometers. During summer the trees remove large amounts of water, and this results in a large reservoir of soil air. The fall and early winter rainfall first bring the A horizon to approximately field capacity. Further rainfall readily infiltrates the permeable A horizon and slowly wets the lower horizons. Apparently there is some swelling in the upper B horizon following wetting of the expanding-type clay minerals. As a consequence, most of the pores are in the capillary size range. Thus the wetting front advances somewhat uniformly, entraps and compresses the soil air as it moves downward. The underlying paleosol would remain relatively dry for longer periods due to restricted flow in the upper B horizon. The presence of bedrock at nine feet acts as a barrier and aids in compression.

Why this phenomenon has been observed only at this site is not clear. While air emission has not been observed from piezometers at the seven other sites, it is quite probable that small emission rates would not have been noticed. No shallow bedrock was reported for these sites; however,

one might expect the underlying glacial till to serve also as a barrier to air movement. Some of these soils have high clay contents, and the relatively large shrinkage cracks may release the entrapped air before high pressures are developed during initial wetting. Even a cultivated field 100 m away from the Brown County site did not exhibit the phenomenon. In the latter case a possible explanation is that only a small air reservoir was created by low evapotranspiration and that the plow layer had a low infiltration rate.

More extensive information may indeed show that air entrapment is a general occurrence at all field sites, and that the phenomenon described in this report is accentuated by a particularly favorable combination of soil and vegetative factors.

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PRIMARY AND SECONDARY ORIGIN OF “NONEXTRACTABLE” SOIL INORGANIC PHOSPHORUS¹

J. K. SYERS, J. D. H. WILLIAMS, E. H. TYNER,
AND T. W. WALKER²

Abstract

“Nonextractable” soil inorganic phosphorus can have both a primary and a secondary origin. Apatite included within other minerals and phosphorus distributed throughout mineral lattices constitute the primary sources. “Nonextractable” secondary phosphorus accumulates during soil development and is associated with hydrated sesquioxides.

Additional Key Words for Indexing: apatite inclusions, lattice phosphorus, hydrated sesquioxides.

EARLY investigations of the forms of phosphorus in soils showed that frequently a high proportion of total P

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² Formerly Research Fellow, Lincoln College, now Assistant Professor, Univ. of Wisconsin, Madison; formerly Graduate Student, Lincoln College, now Visiting Assistant Professor, Univ. of Wisconsin, Madison; Professor of Soils, Univ. of Illinois; and Professor of Soil Science, Lincoln College, respectively.

Table 1—Relationship between estimates of total P and residual inorganic P using < 250 μ samples

Sample	Total P		ΔP_T^*	Residual inorg. P [†]
	Na ₂ CO ₃ fusion	HClO ₄ digestion		
	ppm			
Hypersthene	2,682	2,573	109	134
Plagioclase feldspar	161	128	33	37
Beach sands 1	326	241	85	80
2	329	238	91	83
3	423	256	167	153
4	571	267	304	290
Graywacke rock 9m	651	603	48	61
sequence 14m	512	459	53	59
18m	624	569	55	58

* Total P by Na₂CO₃ fusion minus total P by HClO₄ digestion.
[†] Determined by inorganic P fractionation.

Table 2—Inorganic P fractions for contrasting samples

Sample horizon	Total P	Acid-extractable Ca-P	Reductant-soluble P	2nd NaOH-P	Residual inorg. P
	ppm				
Franz Josef 1 C	792	753	6	3	10
V A1	764	601	0	7	11
VI A1	650	395	8	7	10
Kiripaka A1	1,615	0	254	101	64
Ruatangata B3	237	0	81	34	45
nodules	83	0	4	27	11
Okaihau B2	445	0	180	57	110
nodules	673	0	374	84	134

could not be extracted by acid or alkali reagents (Dean, 1938; Ghani, 1943; Williams, 1950; Kurtz, 1953). This fraction was usually referred to as one of the following: "nonextractable P," "insoluble P," "inert P," "residual P," or "lattice P." Several workers studied the chemical composition of this fraction and a number of hypotheses were advanced concerning its nature. Recent studies of a wide range of New Zealand soils and parent materials have shown that the fraction referred to as "nonextractable P" in early studies can have both a primary and a secondary origin.

The New Zealand parent materials and soils included the following: rhyolitic pumice ash from which hypersthene and plagioclase feldspar were isolated by magnetic separation and heavy liquid techniques; four beach sands, derived from graywacke and volcanic materials, collected from the West Wellington coast: moderately, weakly, and minimally weathered graywacke sampled from a quarry face at depths of 9m, 14m, and 18m, respectively, below the surface (graywacke rock sequence; samples courtesy of Mr. C. F. Sutherland); a chronosequence of soils developed on comminuted graywacke and mica-schist from the Franz Josef glacier area representing stages I, V, and VI (0, 45, and 55 years of soil development, respectively) (P. R. Stevens, 1963. A chronosequence of soils and vegetation near the Franz Josef glacier. M. Agr. Sci. Thesis. Lincoln College, University of Canterbury, New Zealand); nodules isolated from B horizons of the strongly weathered Ruatangata and Okaihau profiles developed on massive basalt in North Auckland; and the A1 horizon of the moderately weathered Kiripaka basaltic profile, also from North Auckland, which does not contain nodules, included for comparison.

Total P in the samples was estimated in two ways: by fusion with Na₂CO₃ and by digestion with 60% HClO₄

(Syers, Williams, and Walker, 1968). The inorganic phosphorus fractionation procedure and the nomenclature used have been described previously (Williams, Syers, and Walker, 1967). X-ray diffraction patterns were obtained using a G.E. XRD unit and CuK α radiation.

Approximately 5% and 23% of the total P present in hypersthene and plagioclase, respectively, was not determined as acid-extractable Ca-P in the inorganic phosphorus fractionation procedure but was subsequently determined as residual inorganic P (Table 1). A considerably higher proportion of residual inorganic P was obtained with the beach sands. Residual inorganic P values agreed well with the difference between values for total P determined by the two methods.

Petrological analyses of the beach sands, of plagioclase and hypersthene separates following the determination of acid-extractable Ca-P, and of the residues of these samples after HClO₄ digestion, revealed the presence of included apatite. In the case of hypersthene, apatite was included within magnetite and ilmenite inclusions. Electron microprobe studies by Cescas, Tyner, and Syers (1969) confirmed this and revealed that apatite was also present within magnetite-ulvöspinel inclusions in hypersthene and, in addition, that phosphorus was fairly uniformly distributed throughout the lattice of plagioclase feldspar, Fe-Ti rich phases in hypersthene, and constituent minerals of the beach sands.

The residual inorganic P fraction was constant for the three graywacke rock sequence samples (Table 1). The relationship between the magnitude of this fraction and the difference in total P values for each sample was again apparent. Because the beach sands, which were largely graywacke derived, showed the same close relationship between ΔP_T and residual inorganic P as the graywacke rock sequence samples, it is inferred that the latter samples also contained included apatite. Reed (1957) has reported that apatite may occur as inclusions within quartz in New Zealand graywackes.

Reductant-soluble P, 2nd NaOH-P, and residual inorganic P were very low and rather constant in samples from the three stages of the youthful Franz Josef sequence (Table 2), even though acid-extractable Ca-P had declined and secondary forms of phosphorus had accumulated within 55 years of soil development. By contrast, the former three fractions were much higher in the samples from the basaltic profiles, which had no acid-extractable Ca-P. Nodules from the Okaihau profile, composed dominantly of gibbsite and hydrated iron oxides, contained a high proportion of reductant-soluble P, 2nd NaOH-P, and residual inorganic P. The Ruatangata nodules, however, which are dominantly halloysitic with minor amounts of gibbsite, contained a lower proportion of residual inorganic P, even less reductant-soluble P, but a higher proportion of 2nd NaOH-P. High values for the 2nd NaOH-P fraction in the basaltic sequence appear to be related to a high gibbsite content. Relative to the B2 horizon, the nodules from the Okaihau profile were enriched in total P, whereas the Ruatangata nodules were much lower in total P than the horizon in which they were formed. These findings

reflect the greater affinity for phosphate of gibbsite relative to halloysite in natural weathering environments.

On the basis of chemical analyses, Marshall (1935) suggested that "nonextractable" phosphorus could be associated with layer silicate lattices due to proxying of P for Si. Dean (1937) discounted the possibility that "nonextractable" phosphorus consisted of an insoluble titanium phosphate and proposed that this fraction had either an inclusion or a lattice origin. The results obtained in our study indicate, however, that apatite present as inclusions within primary minerals which are resistant to attack by dilute HCl or digestion with HClO_4 can constitute a major source of "nonextractable" primary phosphorus in soils. Similarly, P present within the lattices of primary minerals which are not extensively attacked by acids contributes to the same fraction. Neither the fractionation procedure of Chang and Jackson (1957) nor a subsequent modification (R. C. Glenn, P. H. Hsu, M. L. Jackson, and R. B. Corey, 1959. Flow sheet for soil phosphorus fractionation. Agron. Abstr. p. 9) accounts for phosphorus present in apatite inclusions or that present as an integral part of the silicate structure.

The fact that reductant-soluble P, 2nd NaOH-P, and residual inorganic P constituted a low proportion of total P in the early members of the basaltic maturity sequence and increased with an increase in maturity (Williams and Walker, 1969) indicates a secondary origin for the greater part, if not all, of the phosphorus which appears in these three fractions.

In their studies on Illinois soil development sequence groupings, Bauwin and Tyner (1957) were able to solubilize almost all of the "nonextractable" phosphorus by the use of the dithionite reagent. Chang and Jackson (1958) also found that a citrate-dithionite treatment removed phosphorus from soils previously treated with fluoride, alkali, and acid reagents. The results reported here indicate, however, that the fractionation procedure of Chang and Jackson (1957) would not account for all the inorganic phosphorus from soils in which phosphorus is occluded dominantly, if not solely, within hydrated sesquioxides. It appears that the citrate-dithionite treatment followed by 1N NaOH does not completely extract the inorganic phosphorus from the moderately and strongly weathered basaltic soils and "nonextractable" secondary inorganic phosphorus can only be completely accounted for if residual inorganic P is determined by a drastic treatment, e.g. Na_2CO_3 fusion. Recently, Norrish (1968) has detected small amounts of plumbogummite phosphate minerals in soils but their extractability in the reagents employed in the inorganic phosphorus fractionation procedure is unknown.

Through the use of a recently developed inorganic phosphorus fractionation procedure and the electron microprobe analyzer, it has been shown that the fraction referred to as "nonextractable P" by early workers may have both a primary and a secondary origin.

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BENTONITE STABILIZATION OF SOIL TO RESIST WIND EROSION¹

J. J. C. HSIEH AND R. E. WILDUNG²

Abstract

Preliminary investigations indicate that the addition of bentonite to soil followed by moistening will significantly reduce the susceptibility of the soil to wind erosion after drying. This effect persists after rupture of the aggregates originally formed through bentonite amendment provided the soil is remoistened.

Additional Key Words for Indexing: aggregation, clay amendment.

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²Senior Research Scientists, Ecosystems Department.