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Micromorphological and chemical examinations of mechanically resistant soil aggregates

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The structure of soil is to a great extent decisive of the course of physical, chemical and biological processes occurring in it, what has been proved by the researches carried out so far [2-4, 7-10, 19, 23]. Soil aggregates are the exponent of the soil structure as, according to micromorphological researches by Beckmann and Geÿger [5], they are characterized by different shapes and kind of pores or limiting edges depending on the conditions of soil formation. According to Kaczyński [10], soil aggregates can be formed in different ways, among others as a result of coagulation of colloids, chemically, biologically or under the influence of surface tension.

In the process of coagulation of colloids participate, among others, cations of calcium and iron [4, 10], particularly important role in the formation of aggregates being played by organic matter [3, 7-12, 15-19, 23]. In the latter group of structure-forming compounds some authors include so far defined compounds of polyuronide and polysaccharide type [8, 15-17] as well as other organic and organomineral substances which are, first of all, real humus compounds. The participation of humus matter in the formation of soil structure has been pointed out by the works of Williams [22], Tiurin [20], Tiulin [19], Kononova [11], Musierowicz [15], Gastoł [9], Tokaj [21] and others.

In one of his papers Baver [4] pointed out that humus is conductive to form larger aggregates, while Zajcev [23] demonstrated that, beside humus, the presence of calcium and clay is decisive of soil granulation. Some authors point to a high ability of humic acids to stick the soil matter [9, 10, 11, 19, 20].

According to Tiurin [20] and Flaig [8] the highest ability to produce soil aggregates is demonstrated by humic acids as well as fulvic acids combined with them and with iron and aluminium sesquioxides. Kononova [11] came to the conclusion that in the formation of aggregates in chernozemic soils of greater importance are humic acids, while in podzolic soils similar action can be performed by fulvic acids.

Several authors [9, 11, 17] point out that the fractional humus composition in soil aggregates varies with different crops, while the works of Ambroz [2] proved differences in the qualitative composition of humus in crumbs of different sizes.

Although the literature concerning the part of humus in the processes of formation of soil structure is rather ample, however it has not been stated unanimously which humus fraction is of decisive importance to clotting of typologically differentiated soils. Moreover, it has not been yet explained if different-size aggregates have the same composition of humus compounds and if their micromorphology is similar.

Therefore, the objective of this work has been to trace the micromorphological changes of different-size aggregates coming from different soil types and to compare the fractions of humus compounds appearing in them.

METHOD

The investigations were carried out on samples taken from the humus horizons of three soil types: brown leached, pseudopodzolic and podzolic, formed out of loess and genetically connected in their evolution cycle. Each sample was separated on sieves into six groups of mechanically resistant aggregates size $>$ 6 mm, 6-3 mm, 3-1 mm, 1-0.5 mm, 0.5-0.25 mm and $<$ 0.25 mm. In each group of aggregates thin soil sections were made by the method of Kubiëna [14] and Altemüller [1] modified by Kowaliński *et al.* [13]. The thin sections were used for micromorphological examinations. The determination of C-total by Tiurin's method, and the analysis of fractional composition of humus compounds by Boratyński and Wilk's [6] method were made in all aggregate groups.

RESULTS

The micromorphological traits of characteristic horizons of the soils are shown in following Figs. 1-9. Micromorphological examinations of different-size aggregates coming from different soil types demonstrated that their forms differ mainly depending on the represented soil type. Among the aggregates separated from podzolic and pseudopodzolic soil no concentrations of iron compounds were found; though the latter were present in aggregates coming from brown leached soil (Fig. 10).

Aggregates of these soils are of grey colour, as during the leaching processes they get deprived of iron hydroxides. They are probably the humus compounds which are the main binder decisive of the formation of aggregates in these soils.

In the aggregates from brown soil there are observed iron compounds

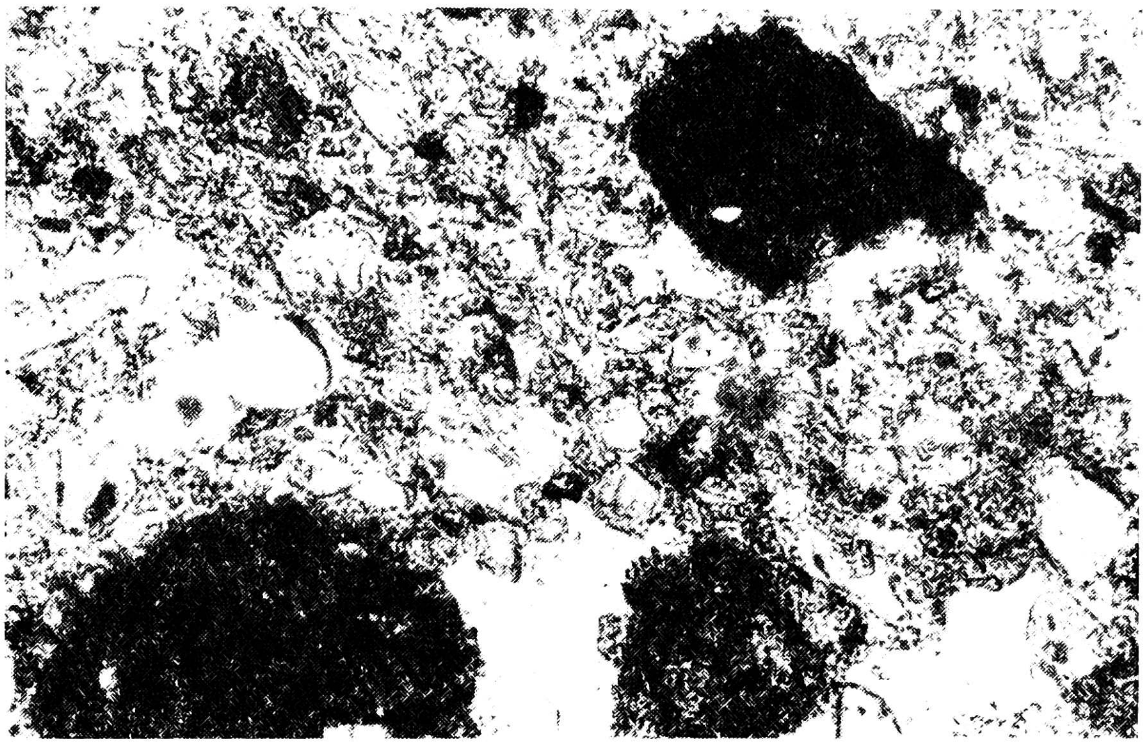

Fig. 1. Brown leached soil. General view of horizon A_1, plain light. Magnif. about 75×.

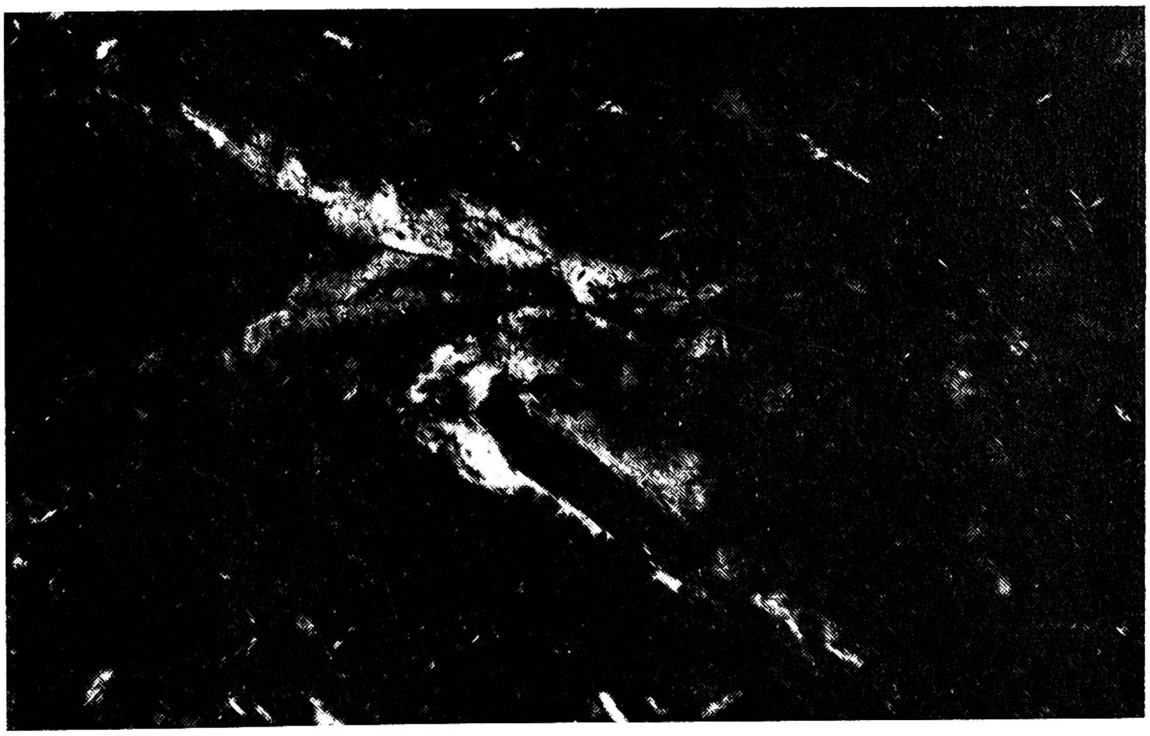

Fig. 2. Brown leached soil. Horizon (B), Vosepic — characteristic accumulation of optically oriented clayey-ferruginous compounds in the pores, crossed polarizers. Magnif. about 75×.

either strongly dispersed, or appearing in form of numerous concentrations or microconcretions (Fig. 11).

Unlike in aggregates of podzolic and pseudopodzolic soils, the amount of organic matter is in them much lower and occurs mainly in the shape of humified and strongly dispersed forms (Fig. 12).

Considering the characteristic traits of aggregates it can be stated that their shape, kind of pores and character of edges were approximate in different soil types. Most often the aggregates were of polygonal shape, with mostly unjagged edges and with frequent inner pores (Fig. 13).

Within every soil type it could be noticed that among smaller aggregates, particularly below 1 mm, there appeared more and more aggregates with jagged edges; besides, there could be found among them more of dark aggregates, containing pronouncedly higher amount of dispersed humus (Fig. 14).

This phenomenon was already pointed to by Kowaliński [12] and Tokaj

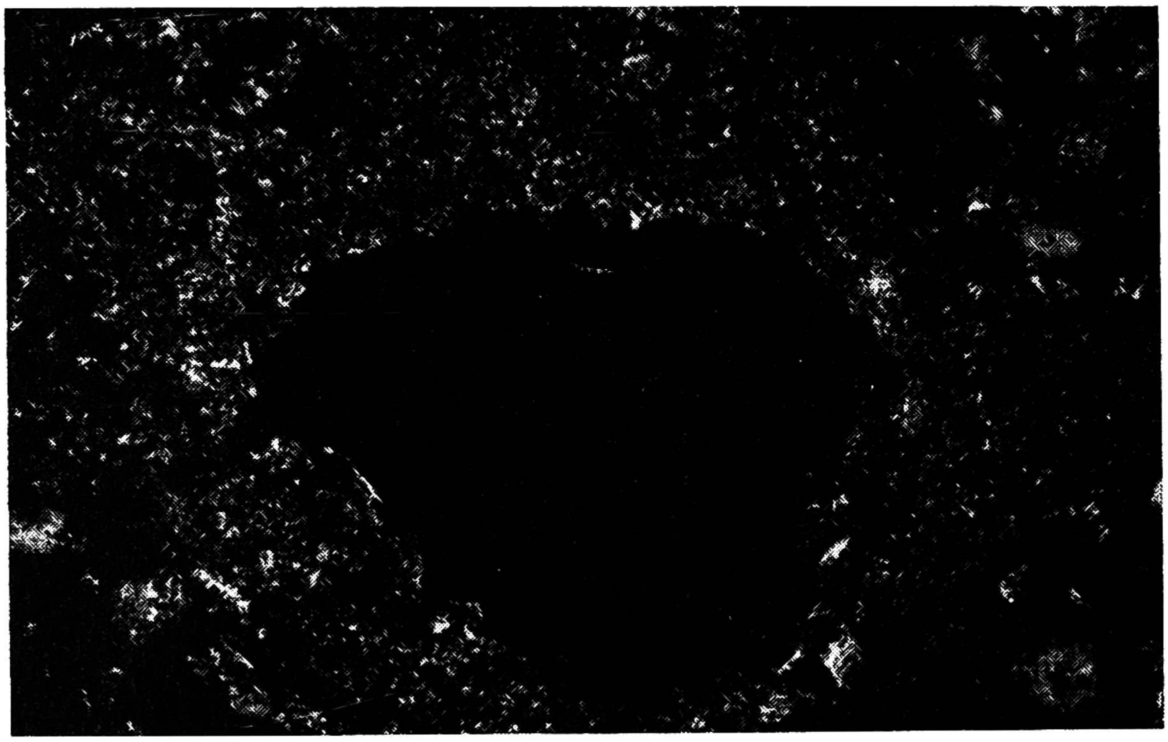

Fig. 3. Brown leached soil. Horizon C. A pore saturated with calcium carbonate, crossed polarizers. Magnif. about 75×.

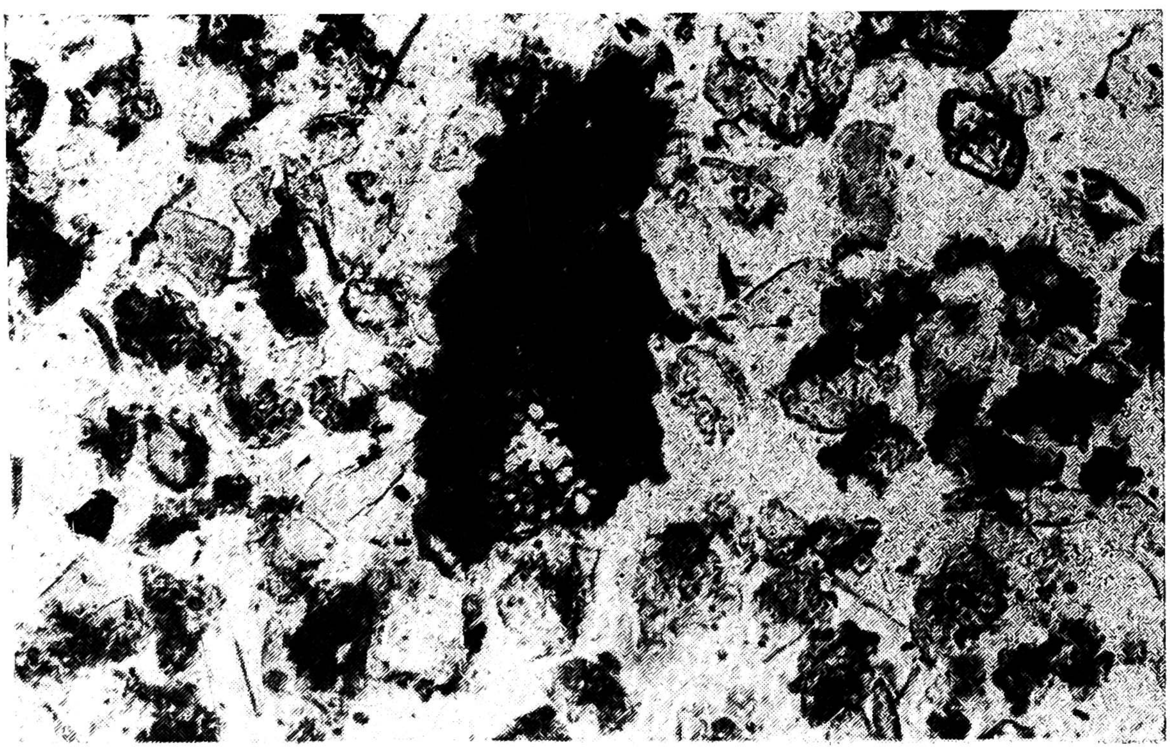

Fig. 4. Pseudopodzolic soil. Horizon A_1. Characteristic forms of humus matter, plain light. Magnif. about 75×.

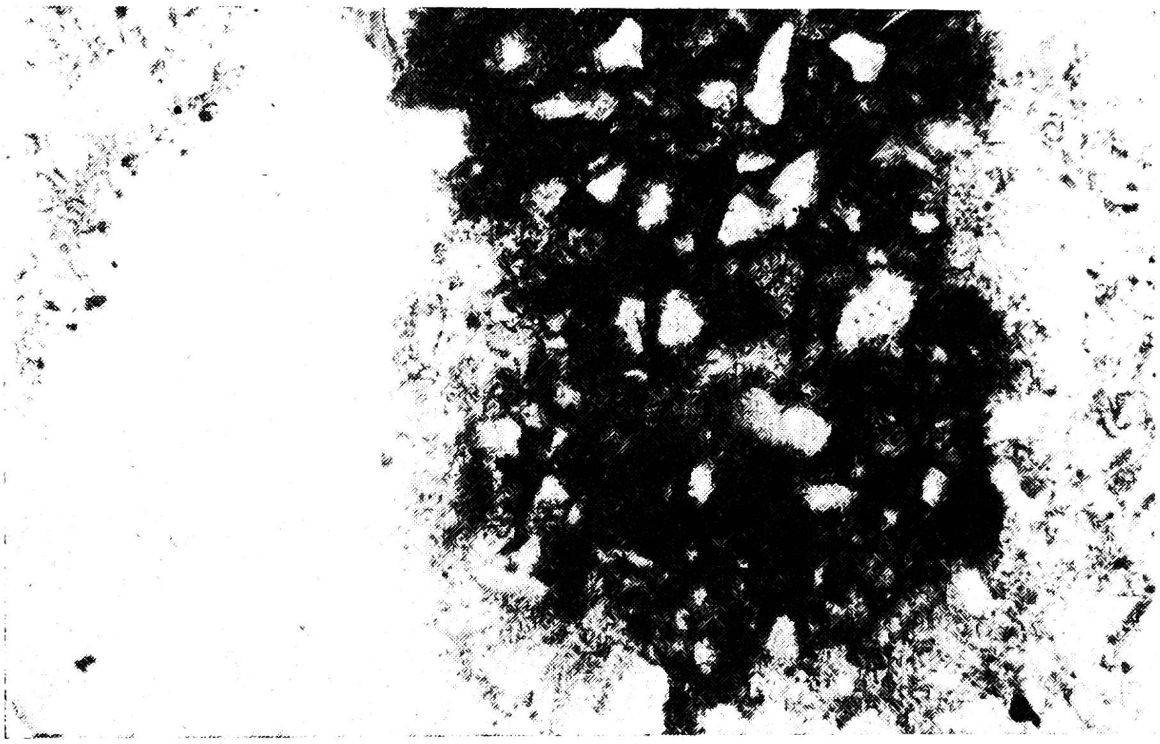

Fig. 5. Pseudopodzolic soil. Horizon A_3. An organomineral concretion and a pore saturated with clayey matter, plain light. Magnif. about 75×.

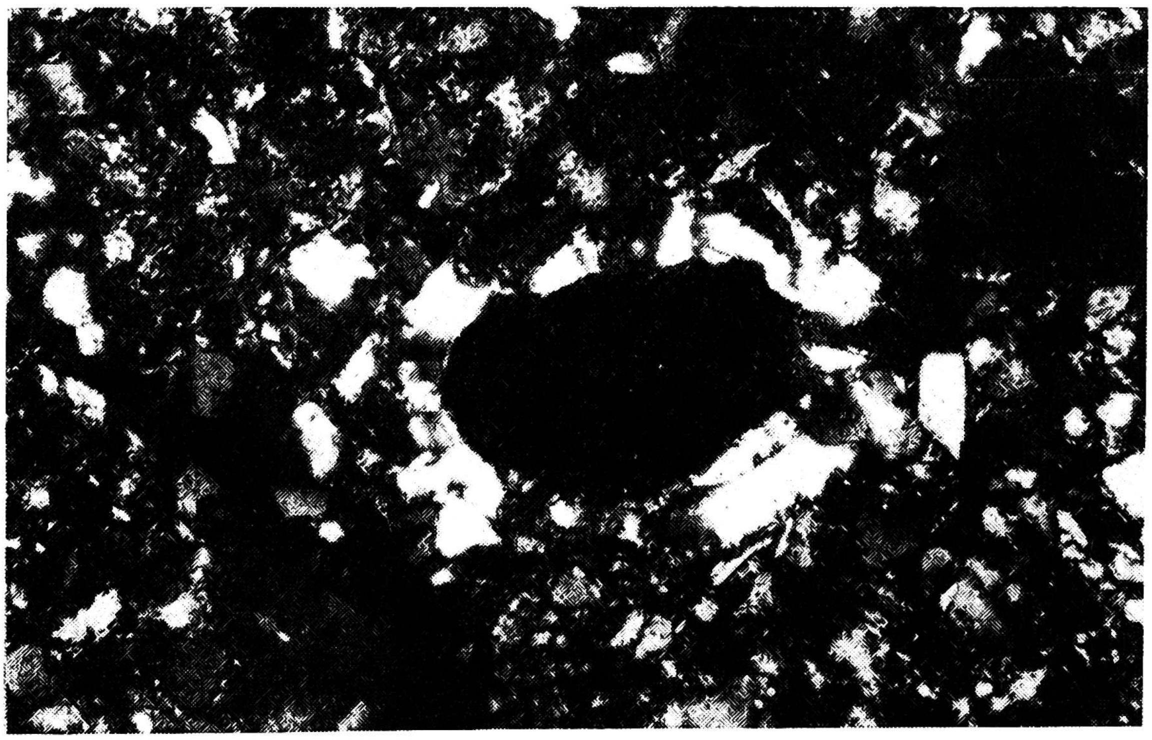

Fig. 6. Pseudopodzolic soil. Horizon B_3. A characteristic pore with walls saturated with optically oriented clayey-ferruginous matter, crossed polarizers. Magnif. about 75×.

[21], who in one of his papers divided soil aggregates into light and dark ones.

Among the separated aggregates most organic compounds were usually observed in the groups of aggregates smaller than 1 mm. In them, beside the increasing lot of humus aggregates, there is often observed more numerous appearing of strongly decomposed organic matter, which still exhibits a distinct cellular structure (Fig. 15).

Organic matter in this form passes through a sieve and collects among smaller-sized aggregates. Because of their small sizes they are difficult to be separated from typically organomineral aggregates; hence, they contribute to a higher content of organic matter among the smaller aggregates.

Our micromorphological observations of the examined aggregates do not fully confirm the conclusions of Baver [4], who says that humus is conducive to formation of larger aggregates. They rather point to a higher lot of darker aggregates, containing more humus and strongly decomposed organic matter among the smaller aggregates.

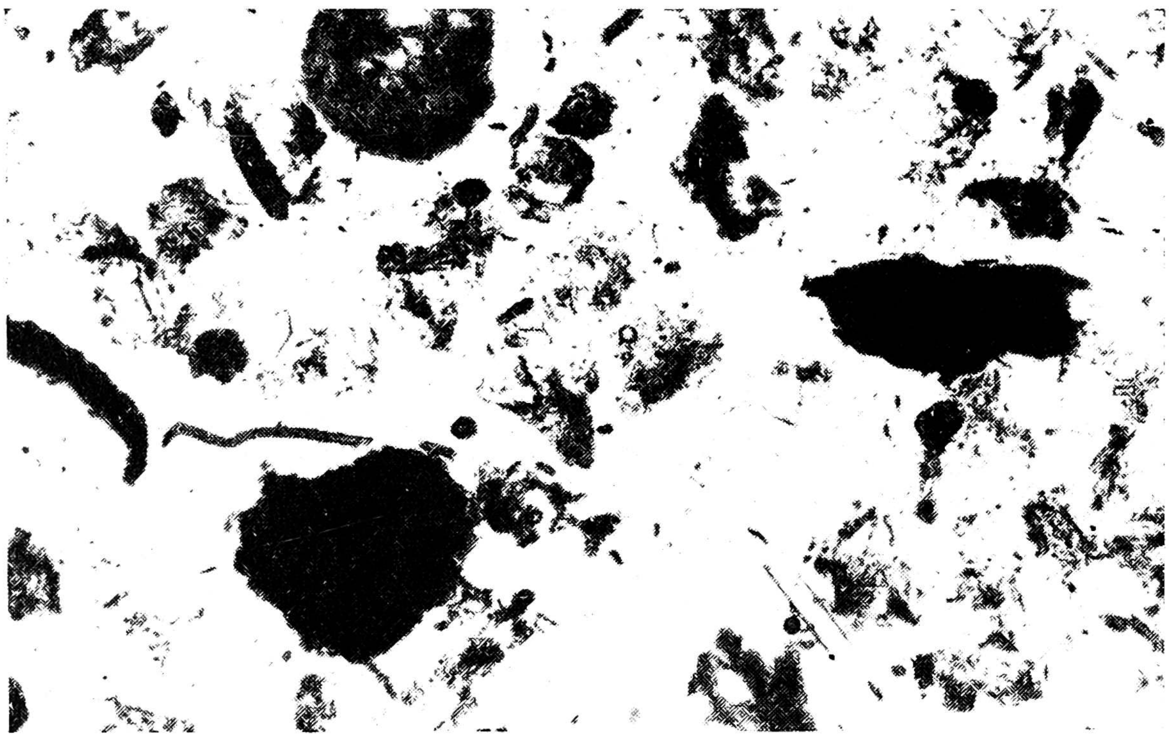

Fig. 7. Podzolic soil. Horizon A_1. Organic matter decomposed to a different degree beside mineral matter, plain light. Magnif. about 75×.

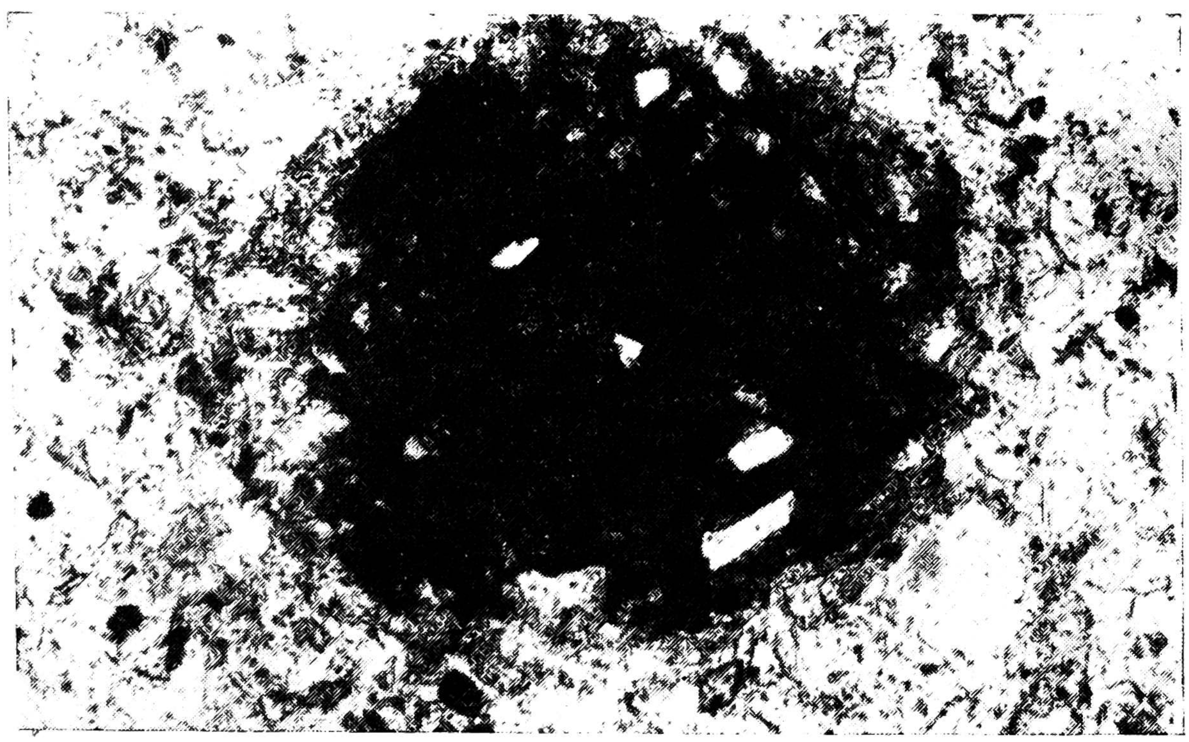

Fig. 8. Podzolic soil. Horizon A_2. Characteristic organomineral concretion containing larger quartz grains, plain light. Magnif. about 75×.

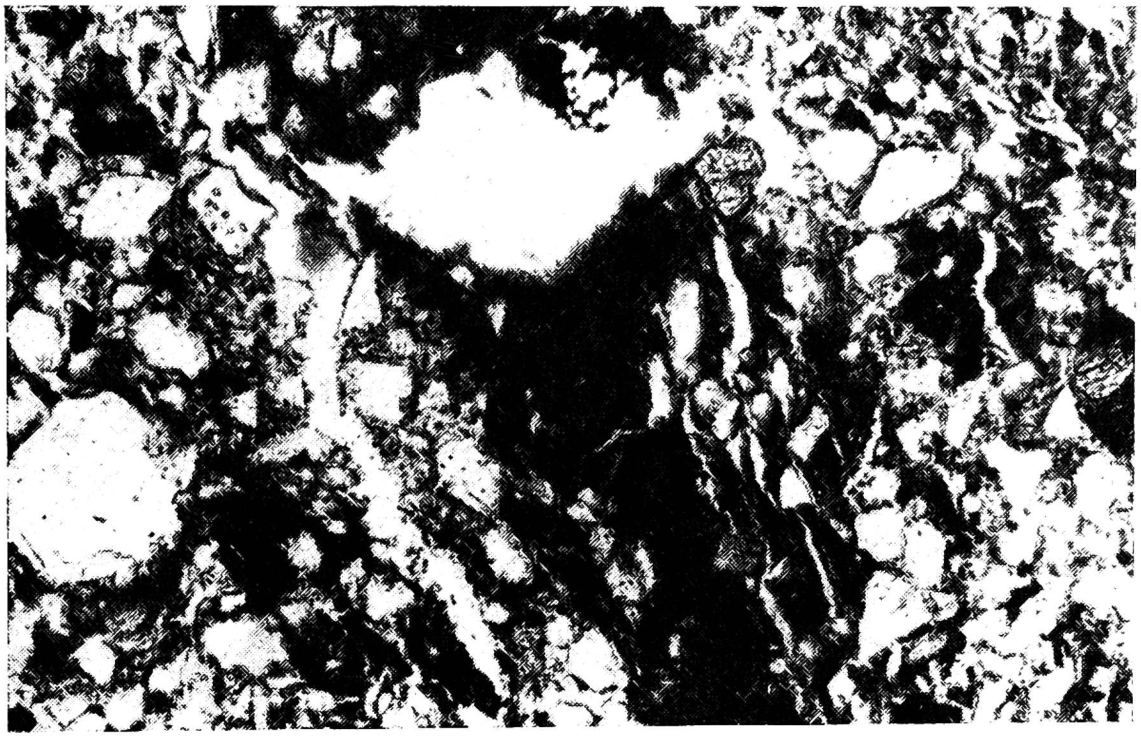

Fig. 9. Podzolic soil. Horizon B_h. Pores filled up amply and impregnated with clayey-humus matter, plain light. Magnif. about 75×.

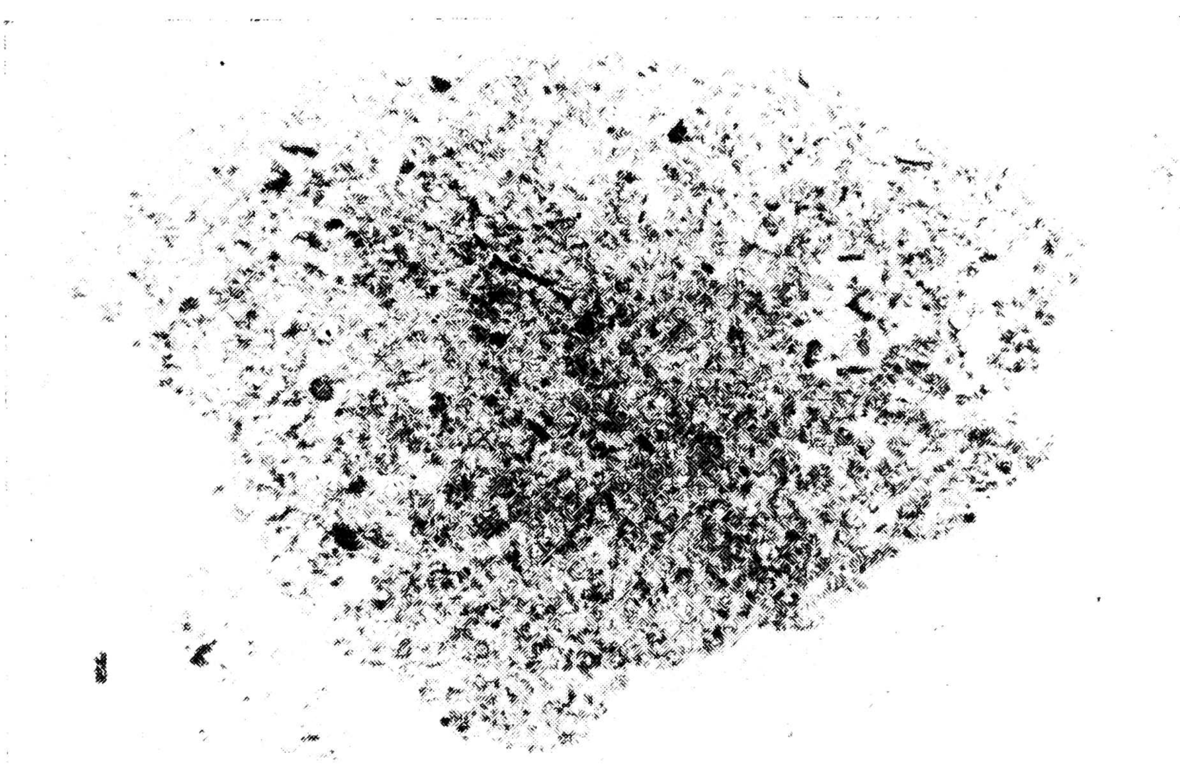

Fig. 10. Podzolic soil. Horizon A_1. A fragment of aggregate 3-6 mm devoid of iron compounds, plain light. Magnif. about 20×.

Basing on the opinion of the author mentioned above, as well as on our micromorphological observations, it may be supposed that the formation of larger or smaller aggregates in the accumulation horizon is decided by the qualitative composition of humus compounds appearing in them. On this assumption we carried out a fractional analysis of humus compounds in different-size aggregates coming from different soil types. The results are shown in Table.

The content of C-total in different-size aggregates of the examined soil types was increasing pronouncedly towards the smaller aggregates, its highest content having been found in aggregates 0.5-0.25 mm. Thus the quantitative determinations of humus content in different-size aggregates have fully confirmed our earlier micromorphological observations, which helped us point out which forms of the organic matter contained in the aggregates are decisive of the increase of C-total in them.

The absolute amount of C of several fractions in the aggregates changes alike the C-total content. Many researches [6, 9, 11, 20] have pointed

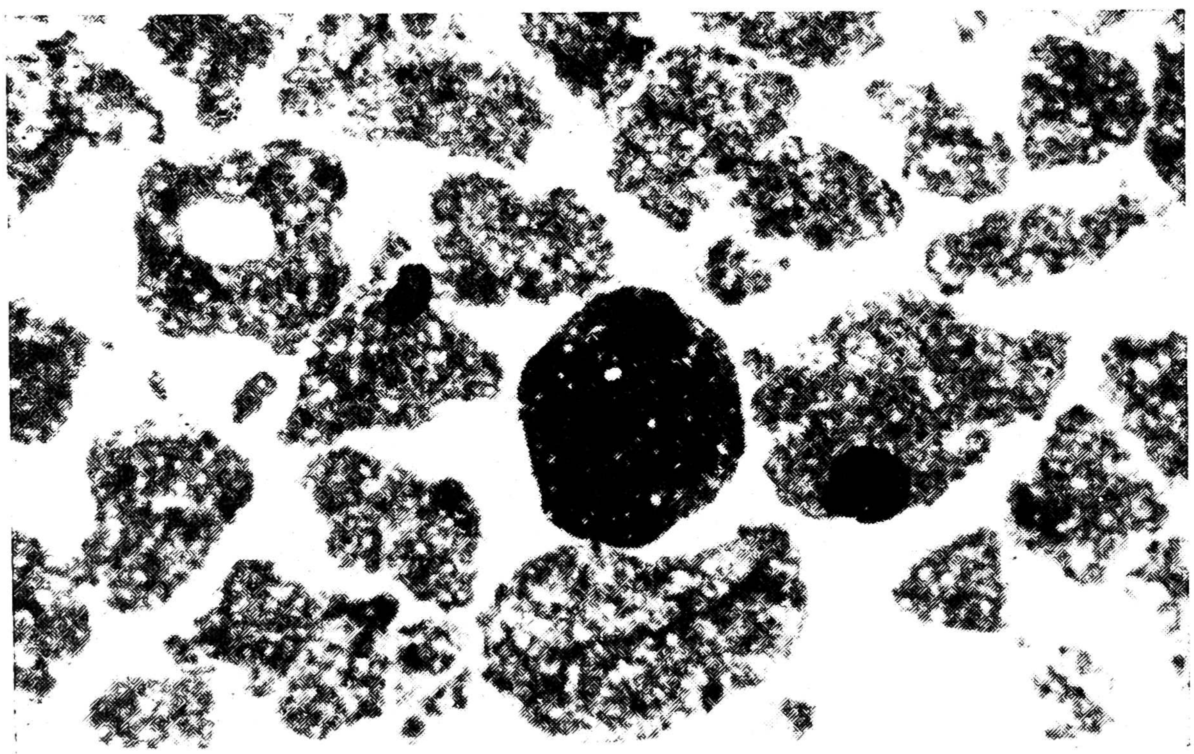

Fig. 11. Brown soil. Horizon A_1. Aggregates 0.5-1 mm with visible accumulations of iron compounds, plain light. Magnif. about 20×.

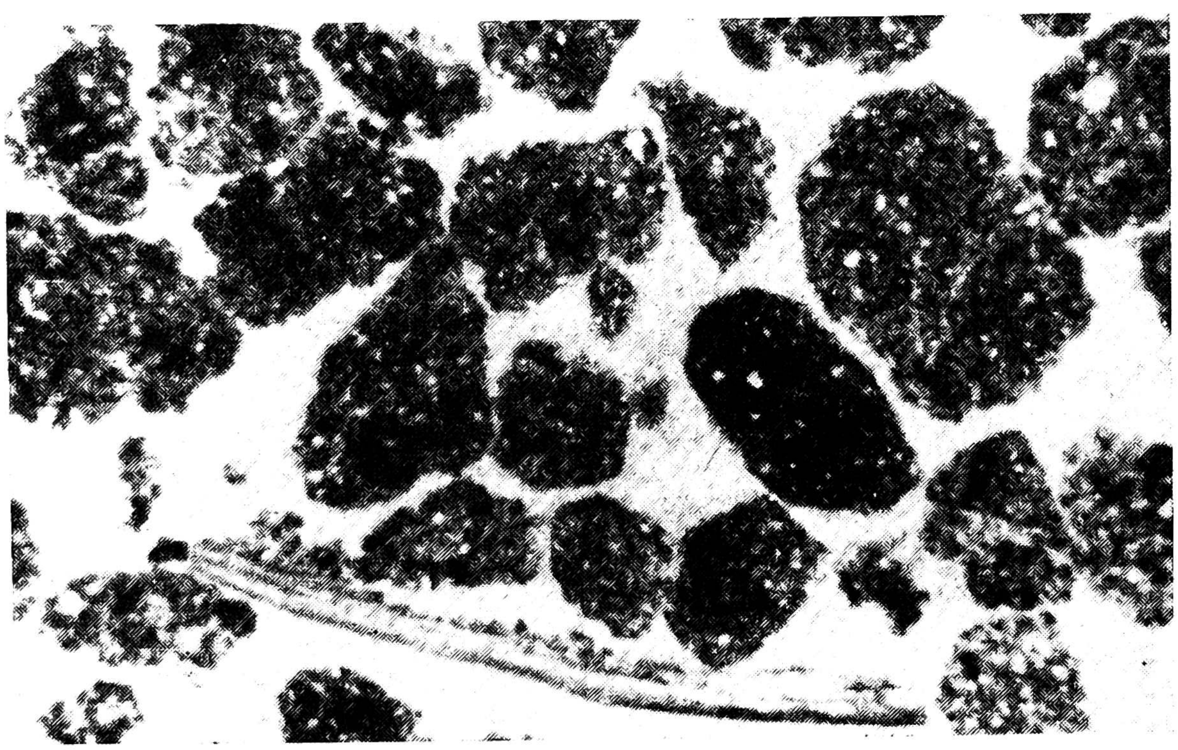

Fig. 12. Brown soil. Horizon A_1. Aggregates sized 0.5-1 mm containing strongly dispersed humus matter, plain light. Magnif. about 20×.

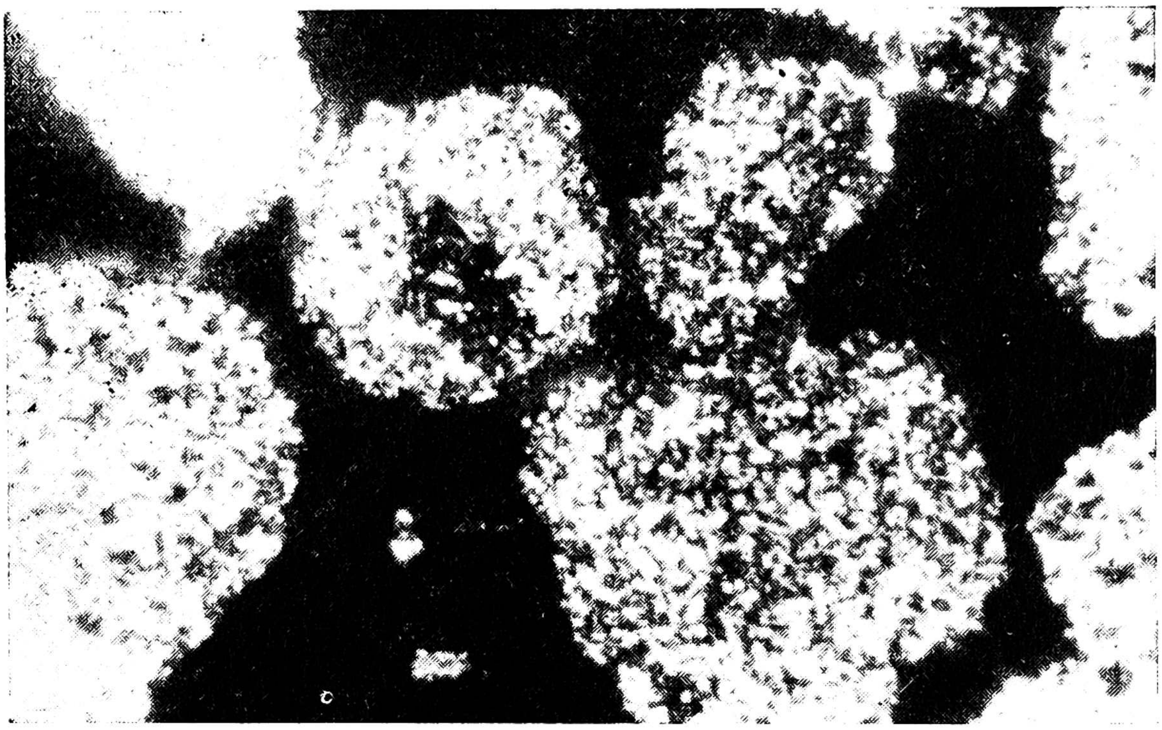

Fig. 13. Brown soil. Horizon A_1. Aggregates sized 1-3 mm with unjagged edges and inner pores, crossed polarizers. Magnif. about 15×.

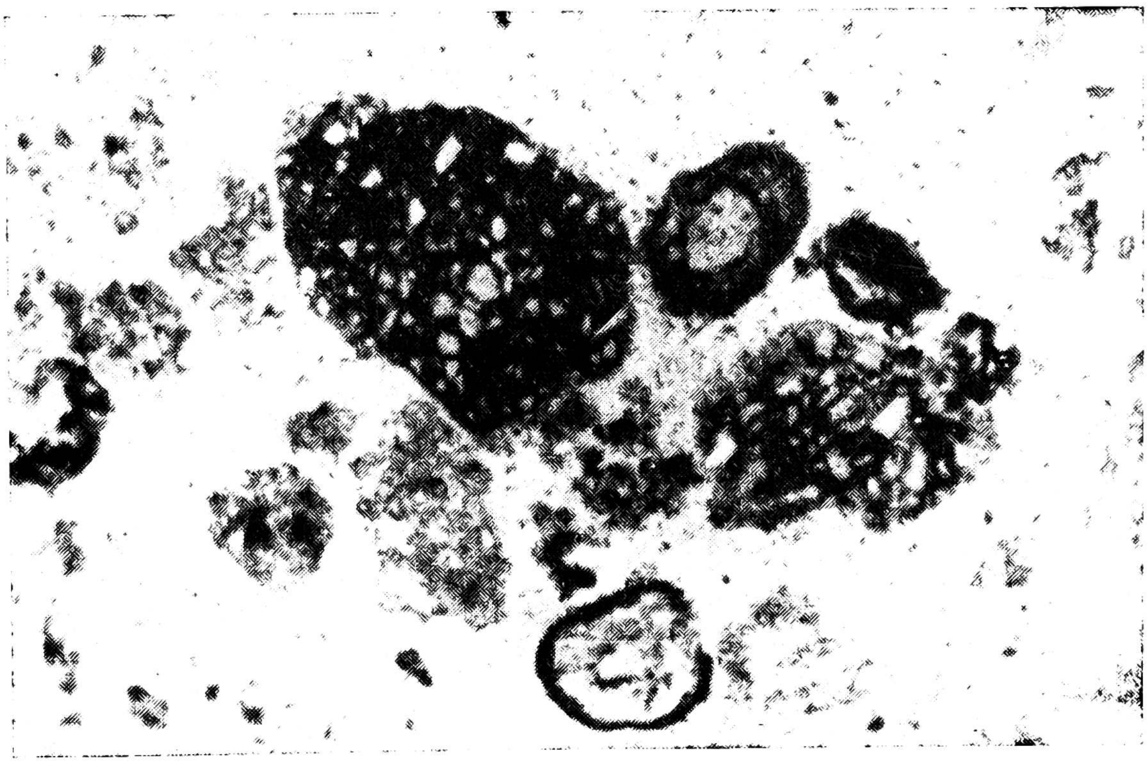

Fig. 14. Podzolic soil. Horizon A_1. Light and dark aggregates, plain light. Magnif. about 40×.

out that when interpreting the fractional composition of humus one should base oneself on the contents of several fractions expressed as C-total per cent. Thus, the data in Table show that the composition of humus compounds changes in several aggregates depending on the soil type considered.

Among the aggregates of the three analysed soil types the highest regularity in the system of several humus fractions is observed in podzol, and the lowest in brown soil.

It is characteristic for podzolic soil that along with decreasing size of its aggregates the contents of some humus fractions change too. This applies mainly to the mobile humus compounds extracted with 0.1n sodium pyrophosphate of pH 7, this fraction increasing pronouncedly in $<$ 0.25 mm microaggregates. Similarly, the contents of humus compounds extracted with 0.1n NaOH increase in smaller aggregates of ⌀ 1 mm. Changes in these fractions are accompanied by similar system of fulvic acids extracted with 0.1n NaOH prior to acid hydrolysis. Aggregates larger than 6 mm are characterized by pronouncedly higher contents of humic acids compared with microaggregates. These changes are best reflected in the ratio of C-humic acids to C-fulvic acids, which assumes the highest values in the largest aggregates and gradually decreases with their decreasing sizes. This phenomenon may be confirmed by the supposition put forward by some investigators pointing to a great importance of organic matter in the formation of various soil aggregates [2, 3, 9, 10, 21]. Our results suggest that the sizes of mechanically resistant aggregates in the podzolic soil under examination are greatly decided by the quality of humus compounds taking part in their formation. Higher content of more mobile humus compounds and fulvic acids, and low content of compounds permanently bound with the mineral matter of soil in smaller aggregates points that in the examined soil the compounds of humic acids type and those very strongly bound with the mineral part of soil are greatly decisive of the formation of larger aggregates.

In the aggregates of pseudopodzolic soil a change in the per cent content of several fractions of humus compounds was observed, too, though in a considerably lower degree. This concerned mainly the mobile

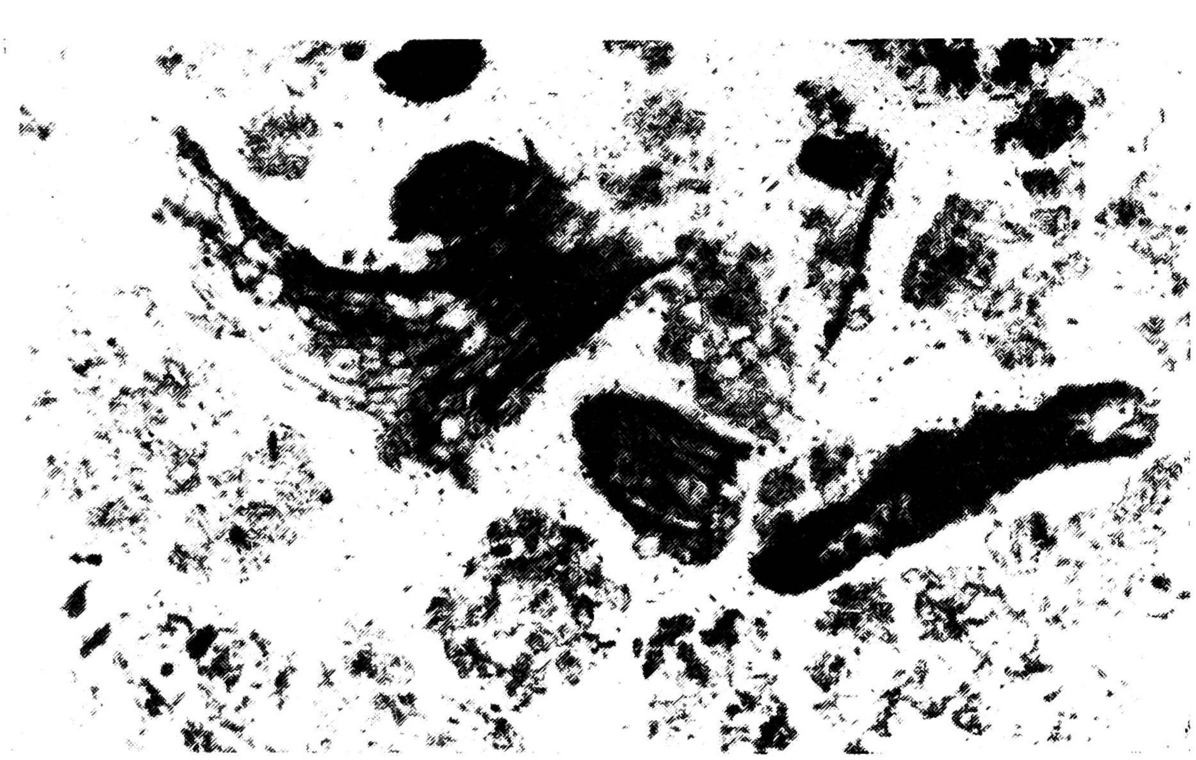

Fig. 15. Podzolic soil. Horizon A_1. High content of non-humified organic matter in aggregates 0.25-0.5 mm, plain light. Magnif. about 40×.

Table. Fractional composition of humus from horizons A_1 (per cent in total C)

Soil use	Soil type	Size of crumbs in mm	C-total in mg 100 g of soil	C bitumens	C-separated with 0.1n $Na_4P_2O_7$	0.1 n NaOH				C separated with 0.5n H_2SO_4	0.1 n NaOH				C in non-hydrolizing residue
						C separated	C of humic acids	C of fulvic acids	$\frac{C_h}{C_f}$		C separated	C of humic acids	C of fulvic acids	$\frac{C_h}{C_f}$	
Soil under spruce forest	Podzolic soil	6	2502/100	6.1	32.8	16.5	9.5	7.0	1.3	1.7	3.6	1.9	1.7	1.1	37.3
		6-3	2461/100	9.5	32.5	16.6	9.3	7.3	1.2	1.5	3.9	1.9	2.0	1.0	36.0
		3-1	2620/100	10.8	33.3	15.5	8.0	7.5	1.1	2.1	3.4	1.6	1.8	0.9	34.5
		1-0.5	3085/100	8.3	34.2	18.3	7.6	10.7	0.7	1.0	3.0	1.5	1.5	1.0	33.6
		0.5-0.25	4140/100	7.4	34.2	19.1	6.8	12.3	0.5	1.0	3.0	1.4	1.6	0.9	33.3
		< 0.25	3250/100	7.2	39.3	17.3	6.8	10.5	0.6	0.9	3.6	1.5	2.1	0.7	32.7
Soil under beech forest	Pseudopodzolic soil	> 6	2260/100	9.4	17.3	16.9	8.4	8.5	1.0	1.5	5.2	3.7	1.5	2.7	49.8
		6-3	2300/100	13.2	17.7	16.2	7.8	8.4	0.9	1.3	5.2	3.5	1.7	2.2	45.7
		3-1	2620/100	15.5	17.7	15.9	7.1	8.8	0.8	1.0	4.6	3.0	1.6	1.9	45.4
		1-0.5	3070/100	13.3	18.9	15.5	7.3	8.2	0.9	0.7	3.2	2.2	1.0	2.2	45.2
		0.5-0.25	3830/100	17.5	18.1	15.6	7.1	8.5	0.8	0.6	2.7	1.8	0.9	2.0	45.4
		< 0.25	2680/100	12.1	20.5	19.5	9.2	10.3	0.9	0.8	3.2	2.4	0.8	3.0	44.4
Cultivated soil	Brown leached soil	> 6	680/100	1.5	17.2	22.5	10.7	11.8	0.9	3.0	7.8	4.7	3.1	1.5	46.9
		6-3	660/100	1.0	18.3	21.5	9.5	12.0	0.8	2.6	7.0	3.9	3.1	1.3	46.2
		3-1	710/100	1.5	17.6	21.3	10.5	10.8	1.0	2.4	6.3	3.9	2.4	1.6	46.0
		1-0.5	740/100	3.3	17.3	20.4	9.6	10.8	0.9	2.4	7.3	5.0	2.3	2.2	44.8
		0.5-0.25	910/100	5.8	17.7	20.8	10.3	10.5	1.0	1.7	5.6	3.5	2.1	1.7	45.1
		< 0.25	710/100	3.6	17.9	22.2	11.4	10.8	1.0	2.5	5.7	3.8	1.9	2.0	42.5

fraction, whose per cent lot slightly increased in the smallest aggregates compared with the larger ones. There was also observed a change in the per cent content of insoluble fraction which, according to many authors, is characterized by most permanent bond with the mineral matter of soil. In aggregates of this soil the contents of fulvic and humic acids do not show any distinct dependences, as it was with podzolic soil.

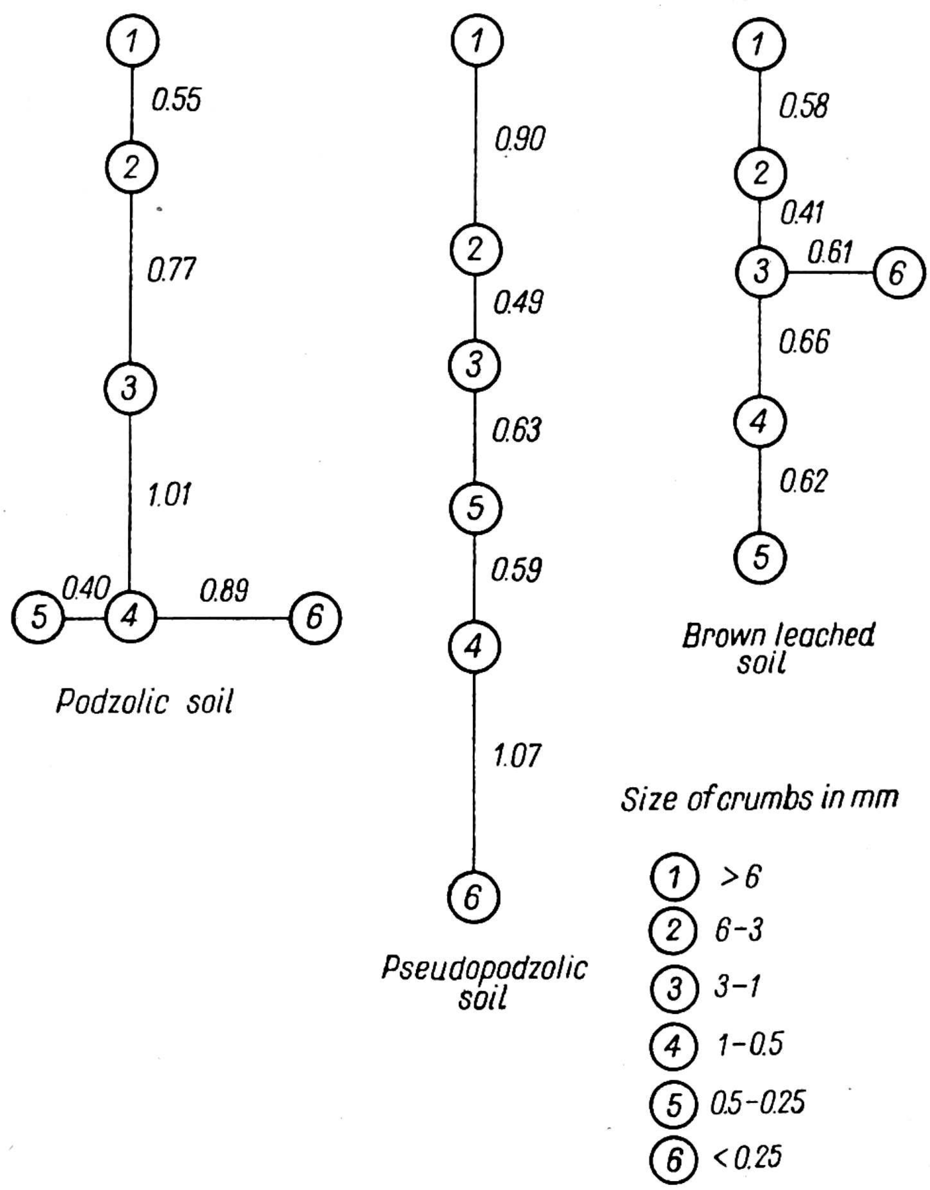

Fig. 16. Dendrite arrangement of crumbs of the examined soils, based on the fractional composition of humus.

The least qualitative changes of humus depending on the size of aggregates were found in brown leached soil. A distinct regularity in the quantitative system was proved for the insoluble fraction representing humus compounds most strongly bound with the mineral matter of soil. The dependence of this fraction is similar to that in aggregates of podzolic and pseudopodzolic soil, what points to its great importance in the formation of larger aggregates.

Our trial of dendrite arrangement of different soil aggregates based on the fractional composition of humus showed that podzolic and pseudopodzolic soil aggregates larger than 1 mm distinctly differ in their fractional composition from those smaller than 1 mm, what is manifested by their mutual position in the dendrite shown in Fig. 16.

In brown soil, where aggregates show less differentiation in the fractional composition, of greater importance in the formation of aggregates are mineral colloids, mainly numerous combinations of different type iron compounds. This has been suggested by many micromorphological examinations, which helped to reveal greater accumulation of iron compounds in several aggregates of brown soil than in those of other soil types under investigation.

The question of quantitative and qualitative lot of these compounds in different-size aggregates of brown type soils should be the subject of further investigations aiming at explaining the importance of mineral colloids in the formation of different-size structural aggregates.

CONCLUSIONS

The investigations have helped to draw following conclusions:

1. Micromorphological character of soil aggregates shows some differentiation depending on their size and on the soil type.
2. The size and shape of aggregates formed in the accumulation horizon of podzolic and pseudopodzolic soils are markedly influenced by the character of humus compounds participating in their formation.
3. Micromorphological observations indicate that the formation of larger aggregates in brown soil is greatly decided by mineral colloids, and mainly by abundant iron compounds occurring there.

SUMMARY

There were carried out some investigations to find the relation between the micromorphological properties of soils on one hand, and the C-total content and the fractional humus composition in various mechanically resistant crumbs of some soil types, on the other.

The tests were carried out with samples from horizon A_1 of three types of soils formed out of loesses, namely brown leached, pseudopodzolic, and podzolic ones, genetically bound in their evolution cycle. Each sample was separated into six groups of mechanically resistant crumbs sized > 6, 6-3, 3-1, 1-0.5, 0.5-0.25, and < 0.25 mm.

In all the examined soils the C-total content was increasing along with decreasing sizes of aggregates, this content being the highest in the group of 0.5-0.25 mm crumbs. In the crumbs of podzolic soil there was observed an apparent dependence of the crumb sizes on the fractional humus composition, as compared to other analyzed soils. Unequal influence of mineral colloids on the formation of soil aggegates also depends on the soil type.

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